Test Impacts and Availability of Water Pursuant to Applications Pending Under Order 1169

Presentation to the Office of the Nevada State Engineer

U.S. Fish and Wildlife Service
Bureau of Land Management
National Park Service

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Contents

Summary of Analyses and Conclusions from the Order 1169 Pumping Study/Test

Summary of Analyses

In 2002, the Nevada State Engineer issued Order 1169, which stated that all pending and new water right applications in the carbonate-rock aquifer in Coyote Spring Valley (Basin 210), Black Mountains Area (Basin 215), Garnet Valley (Basin 216), Hidden Valley (Basin 217), the Muddy River Springs Area, a.k.a. Upper Moapa Valley (Basin 219), and Lower Moapa Valley (Basin 220) would be held in abeyance pending further study (NSE, 2002a). California Wash (Basin 218) was later added to the list through Ruling 5115 (NSE, 2002b). The applications were held in abeyance because the State Engineer believed he needed more information on the effects of groundwater pumping from the carbonate-rock aquifer before making a determination on pending water right applications in the listed basins. The order called for a study covering a "*5-year minimum period of time during which at least 50% of the water rights then currently permitted in the Coyote Spring Valley groundwater basin are pumped for at least two consecutive years.*"

The study/pumping test was delayed due to permitting issues and officially started several years later on November 15, 2010. Carbonate pumping in Coyote Spring Valley (CSV), which began in 2006 and averaged about 2,000 acre-feet per year (afy) from 2006 to 2009, more than doubled to 5,400 afy during the pumping test from November 15, 2010 to December 31, 2012. Groundwater pumping in adjacent basins remained relatively constant during the period of the pumping test. The volume of pumping in CSV during the test was approximately one-third of the groundwater rights currently permitted in the basin. The State Engineer declared in an amendment to Order 1169 (NSE, 2012e) that the test was completed on December 31, 2012, saying he believed that sufficient information had been obtained from the test and related monitoring to make a determination on the pending water right applications. However, while the pumping test ended, the pumping in CSV has continued, to date, at approximately the same rate as during the test. In the amended Order, the State Engineer invited study participants to file a report interpreting the monitoring results and the information from the Order 1169 test.

The U.S. Fish and Wildlife Service, National Park Service, and Bureau of Land Management have prepared this report in response to the State Engineer's request for information related to the pumping test. The report uses the monitoring data collected within the Study Area (**Figure S-1**) to address the three questions posed by the Nevada State Engineer in Order 1169A (NSE, 2012e):

- What information was obtained from the pumping study/test?
- What were the impacts of pumping under the pumping test?
- What is the availability of water pursuant to the pending applications?

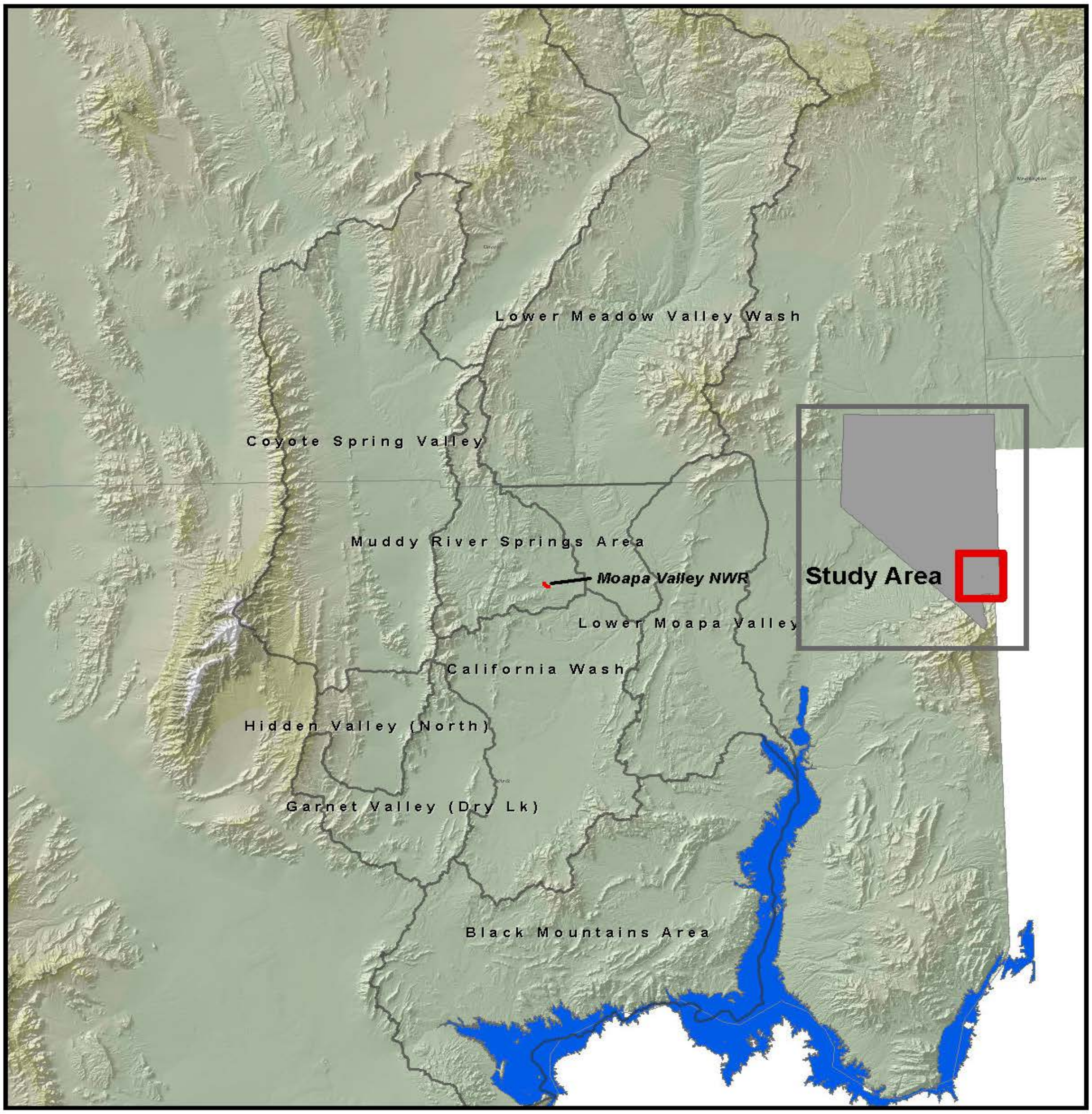

Figure S-1. The Study Area is defined as the area in which hydrologic data (groundwater level, production, and spring/stream discharge measurements/estimates) were collected as part of the 2-year pumping test/study conducted in response to Order 1169, specifically: Coyote Spring Valley (Basin 210), the Muddy River Springs Area (Basin 219), Hidden Valley (Basin 217), Garnet Valley (Basin 216), the Black Mountains Area (Basin 215), California Wash (Basin 218), Lower Moapa Valley (Basin 220), and Lower Meadow Valley Wash (Basin 205).

In this report, we analyze groundwater level, pumping, spring/stream discharge, and climatic data collected before and during the Order 1169 pumping test to address these three questions. In Section 1, we present a detailed evaluation of the impacts of pumping on groundwater levels and spring discharge. In Section 2, we present results from a numerical groundwater model that was used to evaluate impacts at future times and under varying pumping scenarios. We also use the model to evaluate the recovery of the system following curtailment of pumping. In Section 3, we address the central question of availability, given what was learned from the pumping test and previous water budget and perennial yield information. In Section 4 of the report, we briefly discuss the potential implications of decreased spring/stream discharge on groundwater-dependent resources, such as Moapa dace and the Moapa Valley National Wildlife Refuge (NWR). In the last section, we summarize our findings and conclusions.

Summary of Conclusions

What information was obtained from the pumping test?

Groundwater level, pumping, and spring/stream discharge data collected before and during the Order 1169 pumping test are sufficient to:

- Document the immediate effects of the test pumping, including pumping approximately one-third of existing permitted groundwater rights in CSV, on groundwater levels and spring/stream flows in the Study Area.
- Delineate a portion of the carbonate-rock aquifer, a subset of the Order 1169 Study Area, in which pumping results in roughly equal drawdown throughout the area in a relatively short period of time.
- Develop a conceptual model of the delineated portion of the carbonate-rock aquifer with significant implications for the impacts of carbonate pumping anywhere within the area on spring and stream flows and phreatophytic vegetation in the MRSA and California Wash.
- Estimate the extent to which pumping was captured from groundwater storage (a lowering of groundwater levels) as opposed to spring/stream discharge as of the end of the test, and consequently the degree to which the full impacts of the test on spring/stream flows and phreatophytic vegetation have been realized to date.
- Determine the availability of water pursuant to applications pending under Order 1169.

What were the impacts of pumping under the pumping test?

Based on our analyses of groundwater level data from the pumping test, we have delineated a portion of the carbonate-rock aquifer, consisting of five hydrologic basins within the Study Area, in which carbonate pumping results in drawdown of nearly uniform magnitude everywhere within the five basin area within a period of months. The delineated area encompasses almost 700,000 acres, or 1,100 square miles, and includes the following hydrographic basins: CSV, the MRSA, Hidden and Garnet valleys, and

California Wash. Drawdown during the pumping test ranged from 1.9 to 2.5 ft throughout this portion of the carbonate-rock aquifer, with over half of the drawdown attributable to MX-5 pumping in CSV. The observed declines in groundwater levels are unprecedented in the record.

The near uniformity and large areal extent of drawdown indicates a high degree of hydrologic connectivity throughout the five basins and suggests that carbonate pumping anywhere within these five basins will affect groundwater levels throughout the delineated area. We hypothesize that this portion of the carbonate-rock aquifer acts as a high-transmissivity (high-diffusivity) reservoir with fixed inflows. The potential for pumping to induce additional groundwater inflow into this portion of the carbonate-rock aquifer system is very limited. As a consequence, carbonate pumping would eventually capture the only major forms of natural groundwater discharge in the area – spring/stream discharge and ET in the MRSA and California Wash.

The drawdown observed, to date, has resulted in a small capture of spring discharge, and possibly ET, in the MRSA and California Wash. Almost all the springs and flow monitoring sites in the MRSA showed some level of decline during the pumping test. The degree to which spring discharges were impacted is a function of the land surface elevation of the springs, with the higher elevation springs showing the greater relative declines in discharge. The discharge at Pederson Spring, the highest elevation spring in the MRSA, declined about 63% during the pumping test. If the current rate of carbonate pumping and drawdown continues, this spring will be dry in another 1.5 years. The discharge at Pederson East Spring, the second highest elevation spring in the MRSA, declined about 45% during the test and will be dry in another 2.5 to 3 years, if the current rate of pumping and drawdown continues. Flows at Warm Spring West flume declined about 9% during the test. Relative changes in flows at other lower elevation springs and flow sites during the pumping test were -6% at Iverson Flume, -4% at both Jones Spring and Baldwin Spring, and +19% per year at Muddy Springs. The flow increase at Muddy Springs may be partially due to upstream effects from the July 2010 fire in the MRSA.

We estimate that 80 to 90% of groundwater withdrawn during the pumping test was captured from groundwater storage, with only a small fraction captured from natural groundwater discharge. We interpret this to mean that the system has not yet reached equilibrium with respect to the increased carbonate pumping imposed during the test. The potential for drawdown to induce more inflow into the area is very low because the increase in hydraulic gradient will be 1% or less. Therefore, all pumping from the carbonate-rock aquifer in this area must eventually capture the only forms of natural groundwater discharge in the area before a new state of equilibrium can be established. Consequently, we expect the longer-term impacts from the current level of pumping on spring discharge and ET rates in the MRSA and California Wash to be much greater as the system transitions from capture of groundwater storage to capture of groundwater discharge.

Although the pumping test has been completed, SNWA has chosen so far to continue the pumping at MX-5 in CSV at approximately the same rate, presumably to augment water supply for Las Vegas. It is not known how much longer this pumping will continue. Numerical pumping simulations performed by Tetra Tech (2012b) show that pumping in the carbonate-rock aquifer at the rates imposed during the test (or greater) can be expected to result in substantial additional declines in groundwater levels and spring and stream flows beyond those observed as of the end of the test. The results of the 'post-audit' simulation of the second year of the test suggest that the Tetra Tech Version 1.0 Model used to perform these pumping simulations (Tetra Tech, 2012a) underestimates the amount of drawdown created by pumping and the impacts to spring discharges, and overestimates the timeframes in which the projected impacts will occur, but the areal extent of drawdown is simulated accurately.

The recovery simulation, in which MX-5 pumping was simulated as being stopped as of the end of the test, suggests that recovery of water levels from the effects of MX-5 pumping would take years, and that in the MRSA, recovery from the MX-5 test pumping would be approximately 70% complete after 15 years. Longer periods or greater volumes of pumping will result in even slower recovery. This has some serious implications for the effectiveness of management strategies aimed at reducing or curtailing pumping in order to protect spring flows, biological resources, and downstream water rights.

While the pumping test yielded much information, there are some things that are still uncertain. The level of pumping in CSV during the test was only one-third of the annual volume allocated in CSV under existing water right permits, although the Order required that 50% of the existing permitted rights be pumped. Therefore, the impacts of pumping half or all of the permitted allocation in this basin were not evaluated. The effectiveness of pumping reductions or curtailment was simulated with the modeling but was not directly evaluated during the test. If the higher elevation springs stop flowing completely, it is not known how fast or how effectively the system will respond to adjustments in pumping and whether biological resources may be adversely affected in the process.

What is the availability of water pursuant to the pending applications?

Our review of earlier water budget and perennial yield information for CSV, as presented in Order 1169 (NSE, 2002a), leads to the conclusion that there is no water available for appropriation within the five-basin area delineated through our groundwater analyses (CSV, the MRSA, Hidden and Garnet valleys, and California Wash). The water budget information and pumping test results suggest that all available water in CSV is appropriated and our additional analysis of information in recent rulings suggests that the basin may currently be over-appropriated. Additionally, the groundwater modeling simulation results, which examined progressively greater pumping of pending water rights in these five basins, provide supporting evidence to the wide-ranging effects that can be expected in these five basins with increased pumping.

An average of 5,400 afy of groundwater was withdrawn in CSV over the period of the test. This is only one-third of the 16,300 afy of existing permitted rights to groundwater already appropriated in CSV. The pumping test provides evidence that even this reduced volume of groundwater pumping cannot be developed long-term without adverse impacts to springs, endangered fish, Federal trust resources, and downstream senior water rights. Consequently, we conclude that no additional groundwater is available for appropriation to satisfy the pending water right applications that are currently being held in abeyance for this portion of the carbonate-rock aquifer.

Section 1 - Impacts of Pumping under the Order 1169 Pumping Test

Impacts to Groundwater

In this section of the report, we analyze the impact of the Order 1169 pumping test on groundwater levels throughout the Study Area. Interpretations presented in this section focus largely on the analysis of groundwater level observations and production from the carbonate-rock aquifer.

Data Sources

Groundwater level and production data used in these analyses, including the source, frequency, period of record, monitoring agency or organization, and location and physical characteristics of wells utilized in these analyses are summarized in **Table A.1 (Appendix A)**. **Figure 1.1** shows the locations of these monitoring and production wells within the Study Area. Data interpreted in this section can be found on a data exchange Web site maintained by the Nevada State Engineer for the Order 1169 pumping test as of the time of this report (NDWR 2012).

Monthly precipitation data from Nevada Climate Division 4 (Extreme Southern Nevada) are used to represent precipitation in the Study Area. Nevada Climate Division 4 includes CSV and the MRSA (see appended data file: NV Climate Divisional 3_4 and PRISM pcp data 1985-2012.xlsx for maps). Mayer and Congdon (2008) found that 24-month moving average precipitation data from this division correlated best with carbonate water levels in the MRSA. Climate division data through 2012 are available at http://www.wrcc.dri.edu/spi/divplot2map.html. For comparison, we also examined monthly precipitation data from Nevada Climate Division 3 (South Central Nevada), which is north of the CSV-MRSA area, and monthly PRISM precipitation data, compiled for the area of the Moapa Valley NWR and for the entire White River Flow System. PRISM data are available at http://prism.oregonstate.edu/.

Summary of Analytical Methods

For the purposes of these analyses, we assume the pumping test started on September 15, 2010 and ended on December 31, 2012. The official start date of the test was November 15, 2010. However, significant pumping was initiated at carbonate production well MX-5 in CSV on September 15, 2010. While MX-5 pumping was discharged to Pahranagat Wash from September 15 through October 29, 2010, we see no evidence that this affected carbonate water levels in the area in any major way **(Figure A.2-1)**. Lastly, we informally refer to the test as a “2-year pumping test” in this section even though the test length actually exceeded two years by several months.

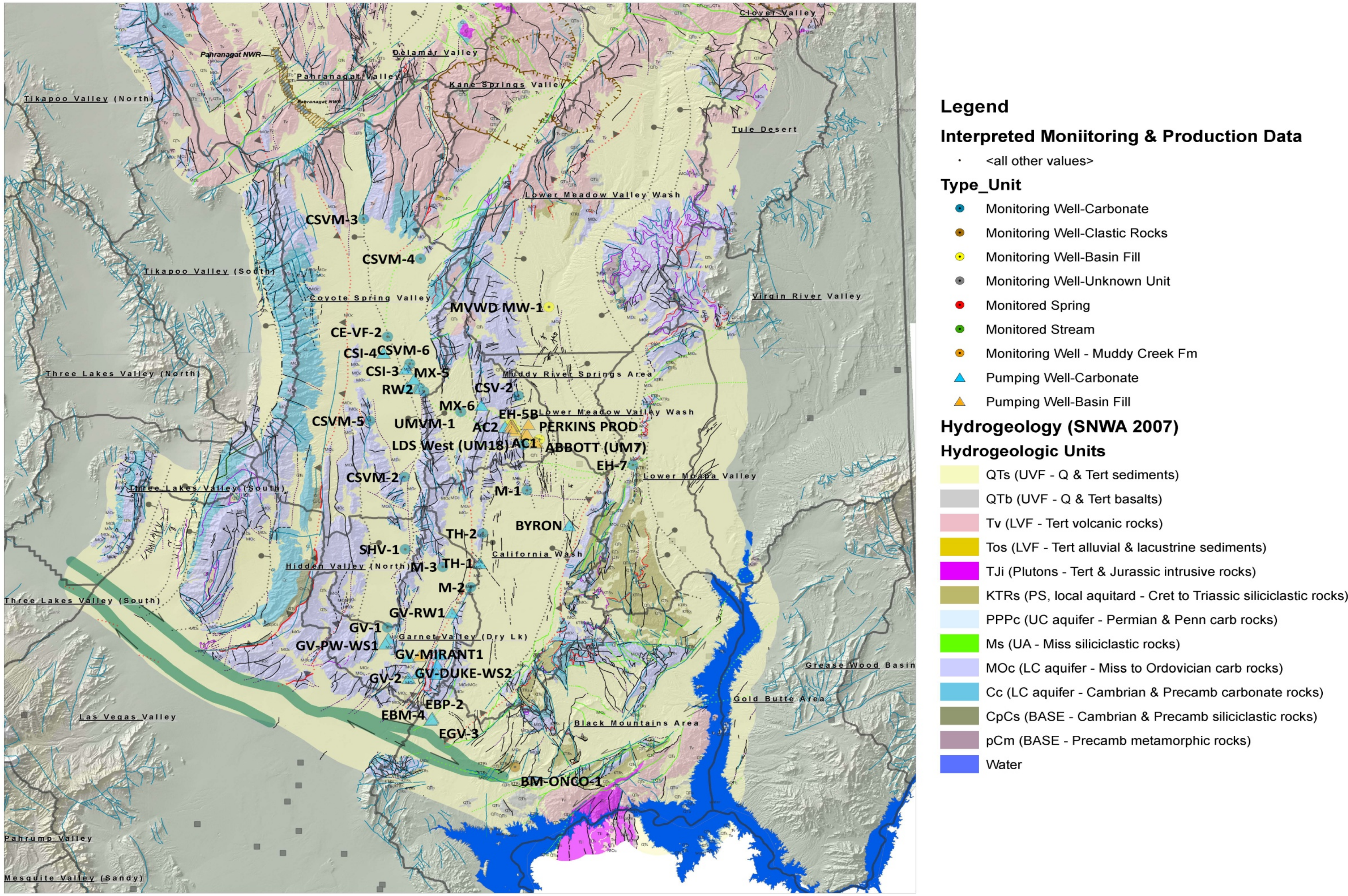

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Figure 1.1. Map showing the locations of monitoring and production wells utilized in analyses presented in this report (on a base map of surficial hydrogeology prepared by SNWA 2007a)

We computed water year (Oct-Sept) precipitation from 1987 to 2012 from the four sources of monthly precipitation referenced in the Data Sources section above: NV Climate Division 3 and 4 and PRISM data for two separate geographic areas. Water year was used rather than calendar year so as not to split the winter precipitation season arbitrarily. We primarily utilize NV Climate Division 4 data in subsequent analyses since it encompasses CSV and the MRSA, but also examine the other sources of precipitation data to emphasize the consistency in wet and dry years throughout the region.

Our evaluation of groundwater level and production data includes several different forms of analysis to evaluate the effects of the Order 1169 pumping test:

- time series hydrographs of groundwater levels, drawdown, and pumping for carbonate monitoring and production wells throughout the Study Area;
- multiple linear regression with time and terms that account for seasonality to determine the drawdown rate in EH-4 during the period of the pumping test.
- multiple linear regression of the average annual water level in EH-4 from 1987 to 2012 with water year precipitation and annual carbonate pumping in CSV and the MRSA.
- distance-drawdown hydrographs along two transects through the Study Area;
- SeriesSEE analyses of groundwater level data collected during and prior to the pumping test in a range of monitoring wells throughout the Study Area, accounting for all major pumping in the area;
- development of a conceptual model leading to identification of a portion of the carbonate-rock aquifer in which pumping causes water level declines of roughly equal magnitude throughout this part of the aquifer, depletion of the Muddy River Springs, and capture of other forms of natural discharge in the MRSA and California Wash; and
- an assessment of the extent to which the test pumping was captured from groundwater storage, as opposed to natural discharge (spring and stream discharge and evapotranspiration), as of the end of the test.

For the time series hydrographs and distance-drawdown hydrographs, drawdown was estimated as the change in groundwater elevation from the beginning to the end of the pumping test (9/15/2010 to 12/13/2012, the last date of available water level data for sites with periodic measurements). Because the SeriesSEE analyses interpret changes in groundwater levels during the test that are, in part, due to pumping that predated the test, this analysis evaluates drawdown over a longer period, 1/1/2008 to 12/13/2012.

No corrections have been made for changes in groundwater levels due to earth tides and fluctuations in barometric pressure in any of these analyses. We believe that these corrections, had they been made in estimating drawdown, would be on the order of a few tenths of a foot, the magnitude of corrections made to carbonate water levels in California Wash during a previous study (Waddell and Roemer, 2006). 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[1]. Additional information concerning methods employed to analyze groundwater level and production data are provided later in this section.

Results and Discussion

Table 1.1 summarizes average production rates and volumes from major production wells listed in **Table A.1** over the 2-year test period, pumping which influenced groundwater level and spring/stream discharge data collected during the test. The appended data file (Order_1169_Monthly_Pumpage data.xls) summarizes the historical carbonate and basin-fill pumping data from five basins in the Study Area (CSV, the MRSA, Garnet Valley, California Wash, and the Black Mountains Area) from 1987 to 2012. Basin-fill pumping in the MRSA has been ongoing for decades and has been relatively constant, averaging about 5,000 afy since 1987. Significant carbonate pumping first began in the Study Area in 1992 in the MRSA, averaging about 1,000 afy from 1992 to 1997. Carbonate pumping in the MRSA more than doubled in 1998, when pumping at the Arrow Canyon well began, and has averaged about 2,300 afy from 1998 to 2012. Carbonate pumping in CSV essentially began in 2006, averaging about 2,000 afy, and increased to more than 5,000 afy in 2010 with the start of the pumping test. There was 7,500 afy of combined carbonate pumping from CSV and the MRSA during the period of the pumping test, with 5,400 afy, or 70%, of this occurring in CSV. The 5,400 afy in CSV represents only about one-third of the total annual pumping rate currently appropriated through existing water right permits in CSV. Carbonate pumping in Garnet Valley has been ongoing since at least 2000, but at a fairly small rate. It averaged about 800 afy from 2000-2005 and about 1,200 afy from 2006-2012 and did not change substantially during or just before the pumping test. Carbonate pumping in California Wash has been very small, about 20 afy from 2009 to 2012, with no pumping prior to that. The total carbonate pumping during the test in CSV, the MRSA, Hidden and Garnet valleys, and California Wash was about 8,540 afy or 19,900 af in total.

The appended data file for precipitation data (NV Climate Divisional 3_4 and PRISM pcp data 1985-2012.xlsx) shows water year precipitation in both NV Climate Divisions as well as PRISM data for the area of the Moapa Valley NWR and the area of the White River Flow System. Data for all areas and sources are consistent in terms of wet and dry years (see the correlation matrix in the appended data file). All four data sources indicate that there was above average precipitation in water year 2011, which begins October 2010 and coincides with the start of the pumping test. Consequently, the first year of the pumping test was conducted during fairly wet conditions. We only present NV Climate Division 4 (Extreme Southern Nevada) precipitation data for the remainder of the report.

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[1] The HRT identified CSVM-3 as a potential reference well, however, our SeriesSEE analyses presented later in this section suggest that changes in groundwater levels in CSVM-3 since 2008 include the effects of MX-5 pumping, superimposed on the more pronounced effects of a reduction in pumping at carbonate production well CSI-3 in CSV, rather than a long-term (regional) trend.

Table 1.1. Average production rates from major (utility- and industrial-scale) production wells within the Order 1169 Study Area during the test (9/15/2010 to 12/31/2012).

Basin Name	Wells	Average Production Rate 9/15/10 - 12/31/12 (afy)	Total Volume of Pumping 9/15/10 - 12/31/12 (af)
CSV	**MX-5**	4,072	9,332
CSV	**MX-5, CSI-1, CSI-2, CSI-3, CSI-4**	5,383	12,325
Total MRSA (carbonate)	**MX-6, Arrow Canyon-1, Arrow Canyon-2**	2,094	4,800
Total CSV and MRSA (carbonate)		**7,477**	**17,125**
Central Garnet Valley	**GV-Migrant 1, GV-Duke-WS1 and -WS2, GV-PW-WS1, GV-RW1**	637	1,459
Southern Garnet Valley	**Chem-Lime Old, Chem-Lime New, Republic Wells 1, 2, 5, and 6**	558	1,278
Total Garnet Valley		**1,194**	**2,737**
California Wash	**TH-1, ECP-1, ECP-2, ECP-3**	23	52
Total CSV, MRSA (carbonate), Garnet, & CA Wash		**8,539**	**19,914**
Black Mountains Area	**All NV Cogen Carbonate Wells**	1,463	3,353
Total MRSA (basin-fill)	**All Nevada Energy Basin-Fill Wells**	3,649	8,363

Time Series Hydrographs of Groundwater Levels and Drawdown in the Carbonate-Rock Aquifer

Water level hydrographs are presented for carbonate monitoring wells EH-4, EH-5b, CSV-2, UMVM-1, CSVM-1, MX-4, and CSVM-6 in CSV and the MRSA (**Figures 1.2, 1.3, and A.2-2 to A.2-8**). We focus first on EH-4 and EH-5b, two carbonate monitoring wells located in the MRSA (**Figure 1.1**) that have some of the longest records of any of the carbonate monitoring wells in the Study Area. The water level records at these two wells reflect an annual seasonal cycle, long-term declines related primarily to the carbonate-rock aquifer pumping (**Figure 1.2**), and wet year responses in 1992, 1993, 2005, and, to a lesser degree, 1998 and 2011 (**Figure 1.3**). In contrast to the obvious wet year responses, there is no indication that dry years cause a comparable response in water levels. For example, the declining trend in water levels from 1998 to 2004 seems unaffected by water year 2002, which was extremely dry. Mayer and Congdon (2008) showed statistically that carbonate water level response to precipitation was asymmetric, with the groundwater system being much more responsive to wet years than dry years.

The seasonal cycle observed in the early part of the records of carbonate monitoring wells EH-4 and EH-5b (**Figure 1.2**) is likely related to evapotranspiration (ET) and/or basin-fill pumping, both of which are seasonal. Basin-fill pumping in the MRSA from 1987 to 1997 was fairly constant and averaged about 4,000 afy. There was very little carbonate pumping during this period. There was a slight decline in water levels in both EH-4 and EH-5b from 1987 to 1992 which may have been a response to basin-fill pumping. The increase in water levels in 1992 and 1993 was likely a response to wet years. Water levels were fairly stable from 1994 to 1997.

Increased carbonate pumping at the Arrow Canyon well in the MRSA, beginning in 1998, increased the seasonal variation and caused water levels in EH-4 and EH-5b to decline considerably from 1998 to 2004 (**Figure 1.2**). The Arrow Canyon pumping is also mainly seasonal and greatest in the summer. There is little evidence in the precipitation record that suggests the multi-year decline was a response to climate (**Figure 1.3**), as is discussed further in the multiple regression analysis below. The 1998 to 2004 declines were interrupted by the extreme wet year in 2005 but resumed again from 2006 to 2010. Increased carbonate pumping with the initiation of the pumping test in late 2010 caused the declines to accelerate significantly. The steepest decline in carbonate water levels occurred during the pumping test, specifically following the initiation of MX-5 pumping from the carbonate-rock aquifer in southern CSV at an annual-mean rate of 4,072 afy (**Table 1.1**). The annual rate of drawdown in EH-4 during the pumping test was 0.92 ft per year based on a multiple linear regression with time and seasonal effects (see appended data file: Order 1169 EH4 Data_NDWR_Dec 2012.xlsx).

The lowest carbonate water levels in the 25 years of record for both EH-4 and EH-5b occurred in December 2012, at the end of the pumping test. These unprecedented declines in carbonate water levels were accompanied by unprecedented declines in the discharge of the two highest-elevation warm springs in the Muddy River Springs Area, Pederson and Pederson East springs, as well as declines in the discharge at the Warm Springs West gage in the Moapa Valley National Wildlife Refuge (Moapa Valley NWR) (**Figures 1.4 and 1.5**). Impacts to spring discharges are analyzed and discussed further below.

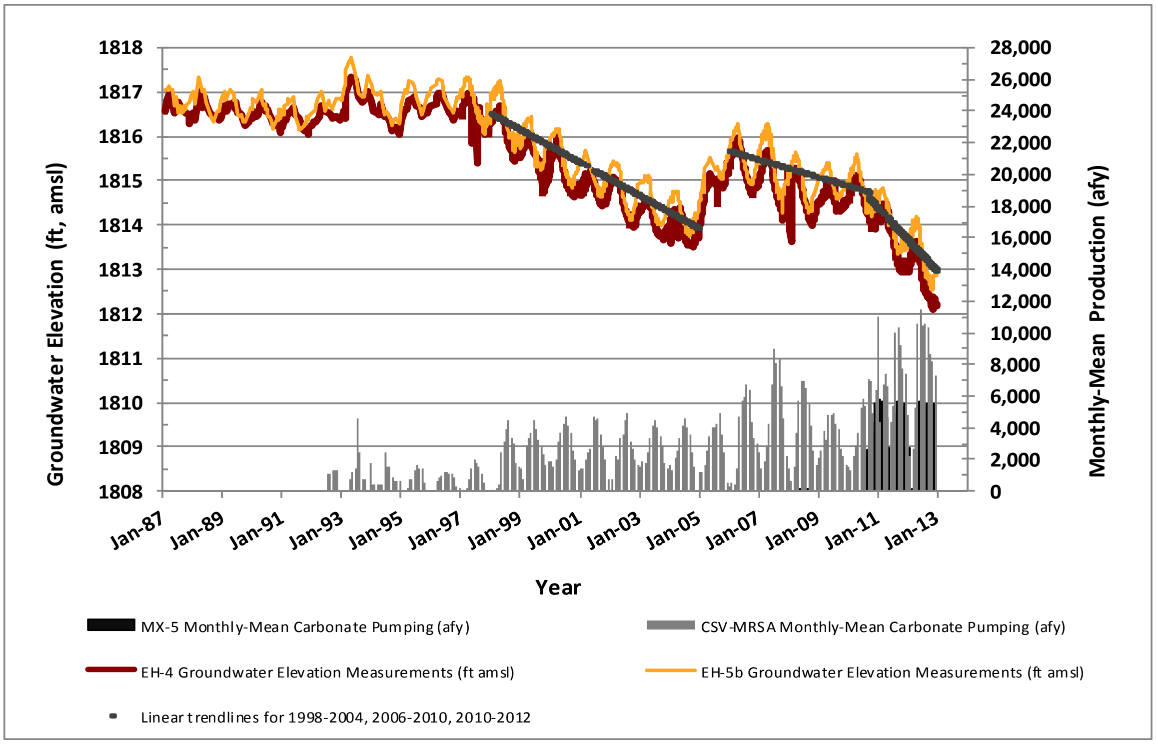

Figure 1.2. Groundwater elevations in carbonate monitoring wells EH-4 and EH-5b in the MRSA and monthly-mean production rates in the carbonate-rock aquifer at production well MX-5 and in the combined CSV and MRSA area from 1987 to 2012. Linear trendlines are shown for 1998-2004, 2006-2010, and 2010-2012.

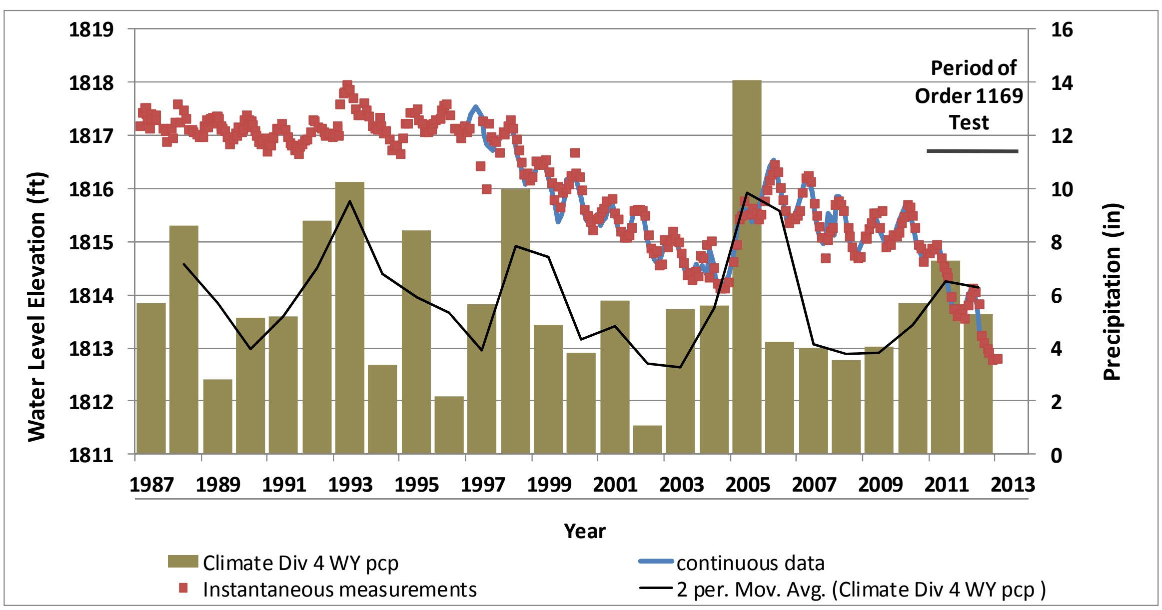

Figure 1.3. Groundwater elevations in carbonate monitoring well EH-4 in the MRSA and Nevada Climate Division 4 water year precipitation (centered on April of each water year) for the period 1987 to 2012. The black line shows the 2-year moving average of precipitation.

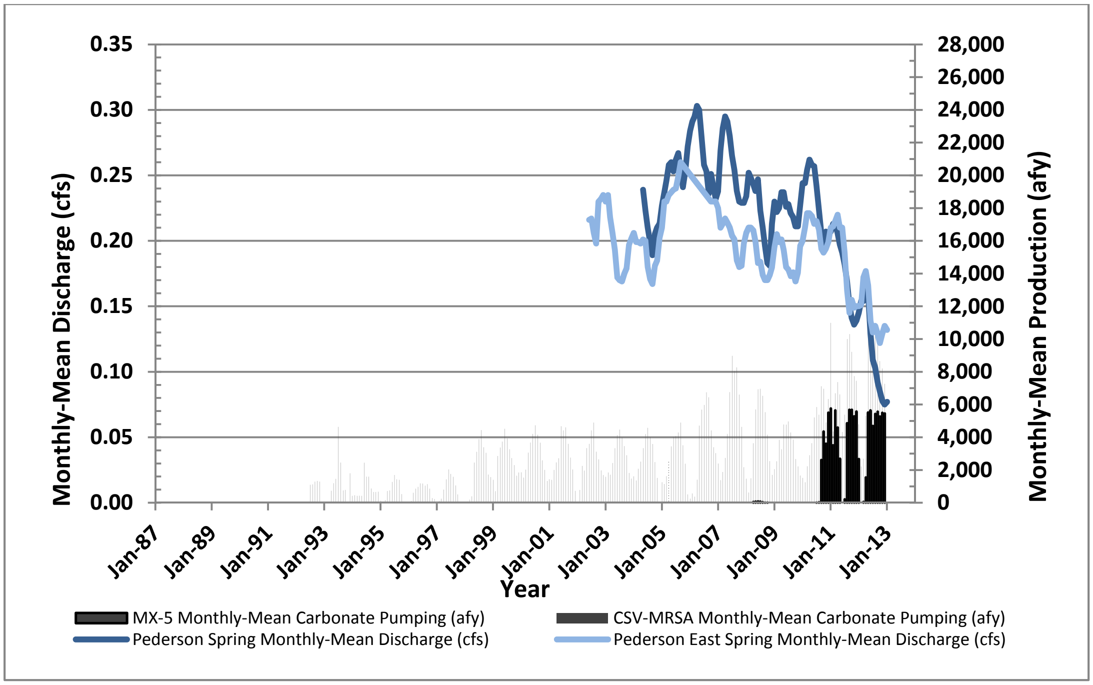

Figure 1.4. Monthly-mean discharge of Pederson and Pederson East springs in the MRSA (Moapa Valley National Wildlife Refuge), January 2004 to January 2013 and June 2002 to January 2013, respectively, and monthly-mean production rates in the carbonate-rock aquifer at production well MX-5 and in the combined CSV and MRSA area from 1992 to 2012.

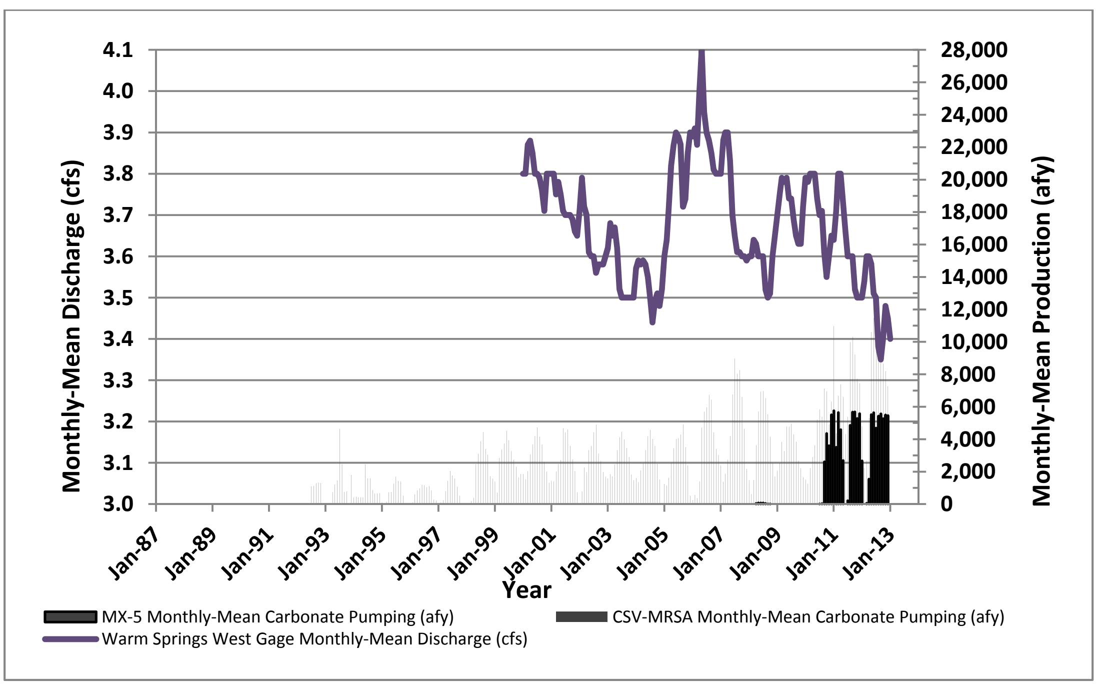

Figure 1.5. Monthly-mean discharge at the Warm Springs West gage on Pederson stream in the MRSA (Moapa Valley National Wildlife Refuge), January 2000 to January 2013, and monthly-mean production rates in the carbonate-rock aquifer at production well MX-5 and in the combined CSV and MRSA area from 1992 to 2012.

Regression analysis demonstrates the influence of precipitation and carbonate pumping on carbonate water levels in the MRSA. A multiple linear regression with three explanatory variables: the square transform of 2-year moving average Climate Division 4 WY precipitation; annual carbonate pumping in the MRSA; and annual carbonate pumping in the CSV, explains 83% of the variance in average annual carbonate water levels in EH-4 from 1987 to 2012 (adjusted r^2=0.834, **Figure 1.6**). The regression coefficients are positive for precipitation (indicating increases in water levels with greater precipitation) and negative for the two carbonate pumping terms (indicating decreases in water levels with greater pumping). The value of the regression coefficient was slightly more negative for carbonate pumping in the MRSA than in CSV, which may indicate a slightly higher sensitivity of EH-4 water levels to carbonate pumping in the MRSA. Mayer and Congdon (2008) explored the influence of precipitation and pumping in greater detail.

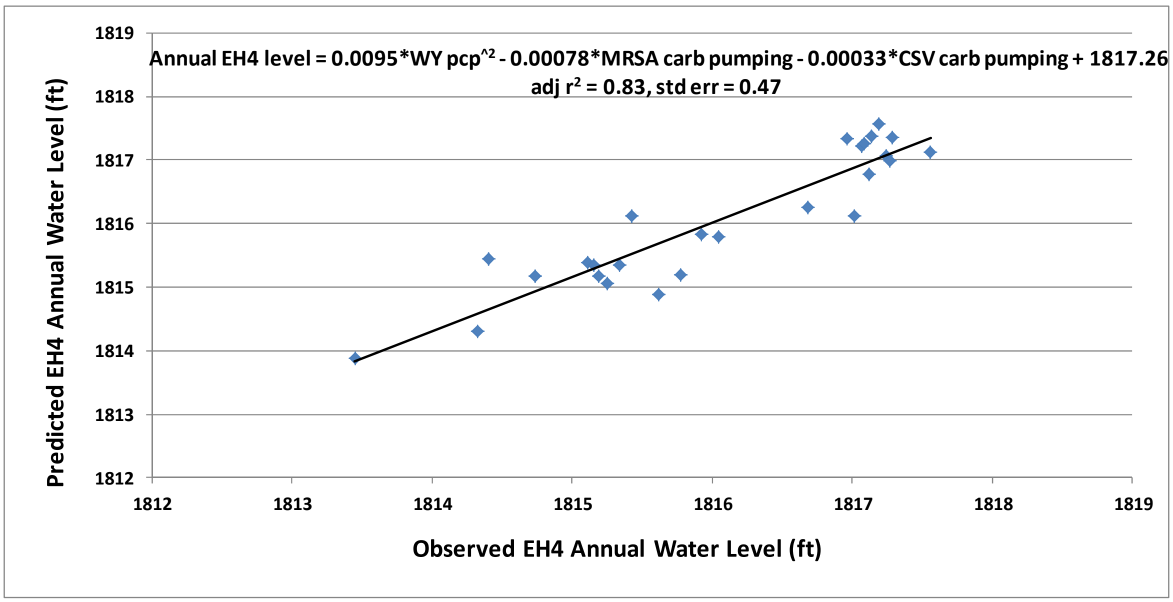

Figure 1.6. Predicted and observed annual average carbonate water levels in EH-4 for the period 1987 to 2012. The three explanatory variables are described in the text. Units are inches for precipitation, and acre-feet/year for pumping. The multiple regression explains 83% of the variance in annual water levels in EH-4.

While all three explanatory variables were statistically significant, the two carbonate pumping terms are much more important than the precipitation term in explaining variance in annual carbonate water levels. Without the precipitation term, the two carbonate pumping terms still explain 80% of the variance in annual EH-4 water levels. However, using the precipitation term only, without terms for carbonate pumping in the regression, explains only 3% of the variance and the precipitation term is not even statistically significant in the regression (p=0.34). This strongly suggests that the long-term declines in water levels observed in EH-4 and EH-5b, which comprise most of the variance being explained in the regression, were caused by carbonate pumping rather than climate. Annual alluvial pumping in the MRSA was not a significant explanatory variable in the multiple linear regression.

Based on these observations (primarily the response to MX-5 pumping), we conclude that saturated carbonate rocks of southern CSV and the MRSA are part of a single carbonate-rock aquifer system and the warm springs of the MRSA discharge from this aquifer. That is, the warm springs, already known to discharge from the carbonate-rock aquifer based on their temperature and chemistry (Eakin, 1966), and the aquifer, are one hydrologic system. Consequently, the warm springs can be impacted by drawdown induced by pumping in the carbonate-rock aquifer in CSV and the MRSA.

Water level hydrographs for carbonate monitoring wells M-3, M-2, and GV-1 in Garnet Valley, and TH-2 and M-1 in California Wash, along with carbonate pumping in those same basins are presented in **Figure 1.7**. Groundwater records for carbonate monitoring wells in CSV, Garnet Valley and California Wash (**Figures 1.7 and A.1-2 to A.1-9**) are generally shorter than those for EH-4 and EH-5b (**Figure 1.2**), but for the overlapping periods all the hydrographs are similar. Groundwater levels in all of the monitoring wells declined from 2001 to 2004 (where data are available), increased in response to the extreme wet year in 2005, resumed their decline from 2006 to 2010, and began to decline much more rapidly with the initiation of the pumping test in late 2010. We acknowledge that none of these records have been corrected for the effects of barometric pressure fluctuations and earth tides. However, these corrections, had they been made, would be on the order of tenths of feet, an order of magnitude less than the trends observed in the carbonate wells. Therefore, the overall trends cannot be due to these other factors.

The effects of MX-5 pumping in southern CSV appear to be present in groundwater level hydrographs for carbonate monitoring wells in Garnet Valley and California Wash (**Figure 1.7**). Specifically, combined pumping in carbonate production wells in Garnet Valley, the Black Mountains Area, and California Wash has been relatively stable since 2006; yet groundwater levels in carbonate monitoring wells in Garnet Valley and California Wash dropped to unprecedented levels following the introduction of MX-5 pumping in southern CSV in 2010 (**Figure 1.7**). Moreover, groundwater level hydrographs for carbonate monitoring wells in Garnet Valley and California Wash closely resemble those for wells in CSV and the MRSA that clearly include the signature of MX-5 pumping (**Figures 1.2, 1.7, A.1-2 to A.1-4, A.1-8, and A.1-9**). This suggests, at a minimum, that carbonate pumping in CSV produces drawdown in the carbonate-rock aquifer in Garnet Valley and California Wash, as well as the MRSA (the source of the Muddy River Springs and Muddy River).

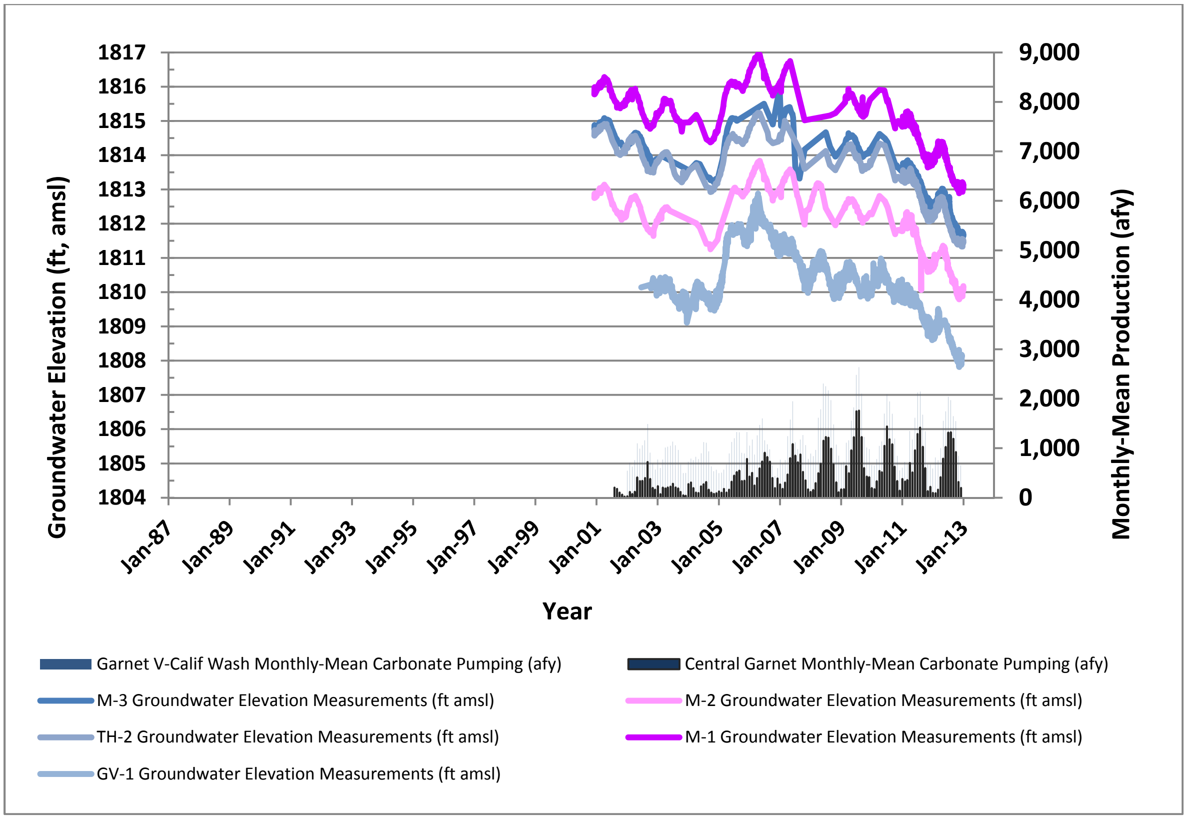

Figure 1.7. Groundwater elevations in carbonate monitoring wells M-3, M-2, and GV-1 in Garnet Valley and TH-2 and M-1 in California Wash and monthly-mean production rates from the carbonate-rock aquifer in central Garnet Valley (GV-MIGRANT 1, GV-DUKE-WS1, GV-DUKE-WS2, GV-PW-WS1, and GV-RW1) and Garnet Valley and California Wash as a whole from 2001 to 2012.

There appears to be a groundwater divide in the carbonate-rock aquifer at the southern end of CSV based on water level elevations in carbonate monitoring well CSVM-2 which are consistently higher than those in nearby carbonate monitoring wells CSVM-1, to the north, and SHV-1, to the south in Hidden Valley. We interpret this to be due to the development of local cones of depression in the CSV-MRSA area and Garnet Valley in response to long-term pumping in the MRSA and Garnet Valley, respectively. We note, however, that the presence of this groundwater divide does not preclude the propagation of drawdown due to pumping in CSV and (or) the MRSA into Hidden and Garnet valleys or California Wash, or vice versa, through the carbonate-rock aquifer.

Hydrographs showing drawdown in carbonate monitoring wells of CSV and the MRSA during the pumping test and monthly-mean production in the carbonate-rock aquifer at production well MX-5 and in the combined CSV and MRSA area are presented in **Figures 1.8 to 1.10**. Hydrographs showing drawdown in carbonate monitoring wells of Hidden and Garnet valleys and California Wash during the pumping test and combined monthly-mean production in the carbonate-rock aquifer at MX-5, in the combined CSV and MRSA area, central Garnet Valley (the Apex area), and Garnet Valley and California Wash are presented in **Figures A.3-1 to A.3-4**. The timing and magnitude of increases and decreases in drawdown in carbonate monitoring wells of CSV, the MRSA, Garnet Valley, and California Wash are similar and coincide with periods of pumping and shutdowns at MX-5 in CSV (subject to time lags on the order of months). Additionally, total drawdown in the carbonate-rock aquifer in the four basins as of the end of the test was similar in magnitude, ranging from 1.9 to 2.5 feet. Again, this suggests that carbonate pumping in CSV produces drawdown in the carbonate-rock aquifer in Garnet Valley and California Wash, as well as the MRSA, and that the entire area is hydrologically-connected.

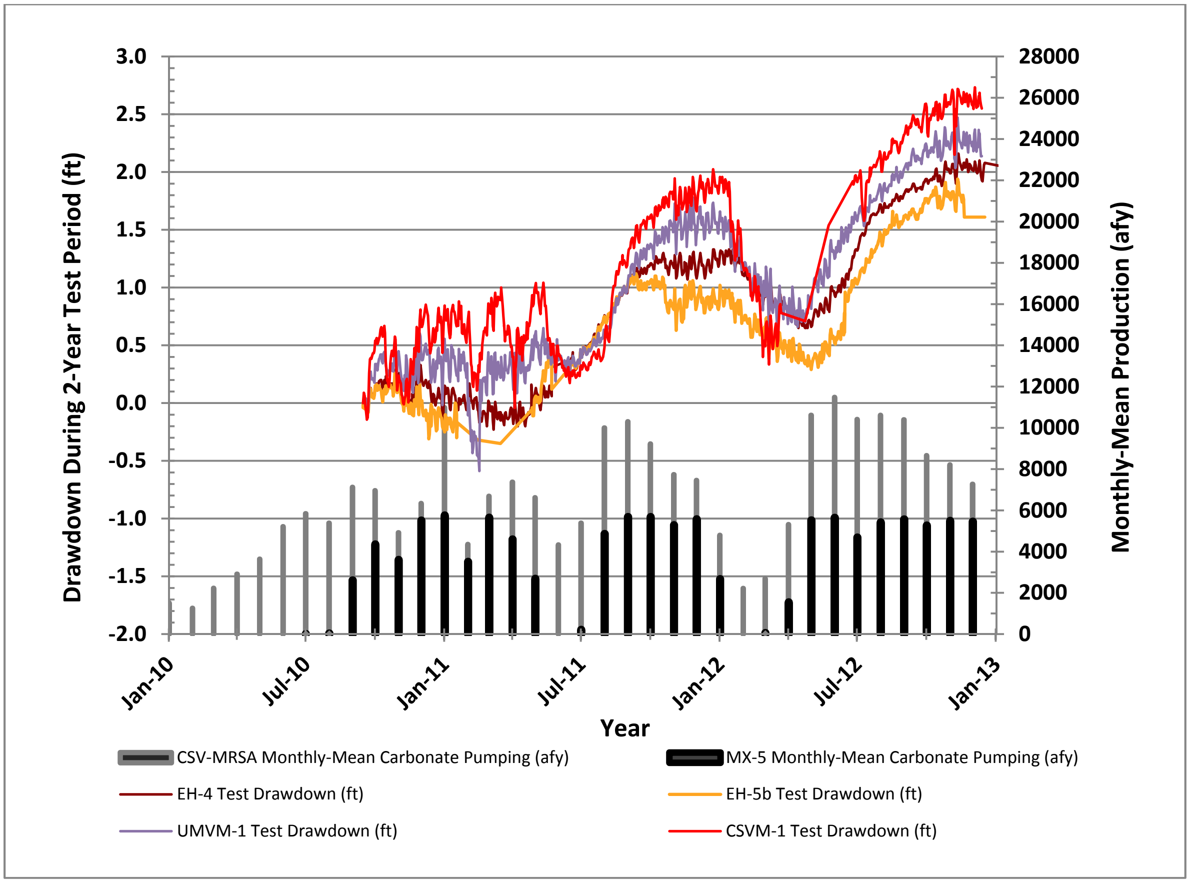

Figure 1.8. Drawdown in carbonate monitoring wells CSVM-1 in CSV and UMVM-1, EH-5b, and EH-4 in the MRSA, versus monthly-mean production rates in the carbonate-rock aquifer at production well MX-5 and in the combined CSV and MRSA area, from September 15, 2010, to December 31, 2012, i.e., during the 2-year pumping test.

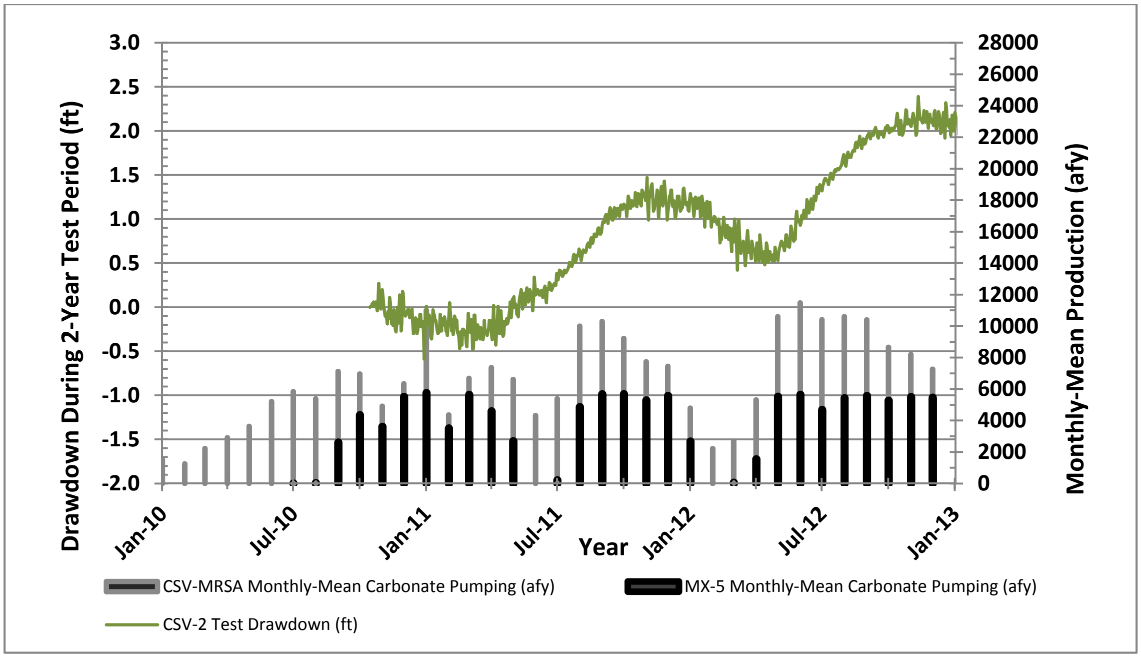

Figure 1.9. Drawdown in carbonate monitoring well CSV-2 in the MRSA versus monthly-mean production rates in the carbonate-rock aquifer at production well MX-5 and in the combined CSV and MRSA area, from September 15, 2010, to December 31, 2012, i.e., during the 2-year pumping test.

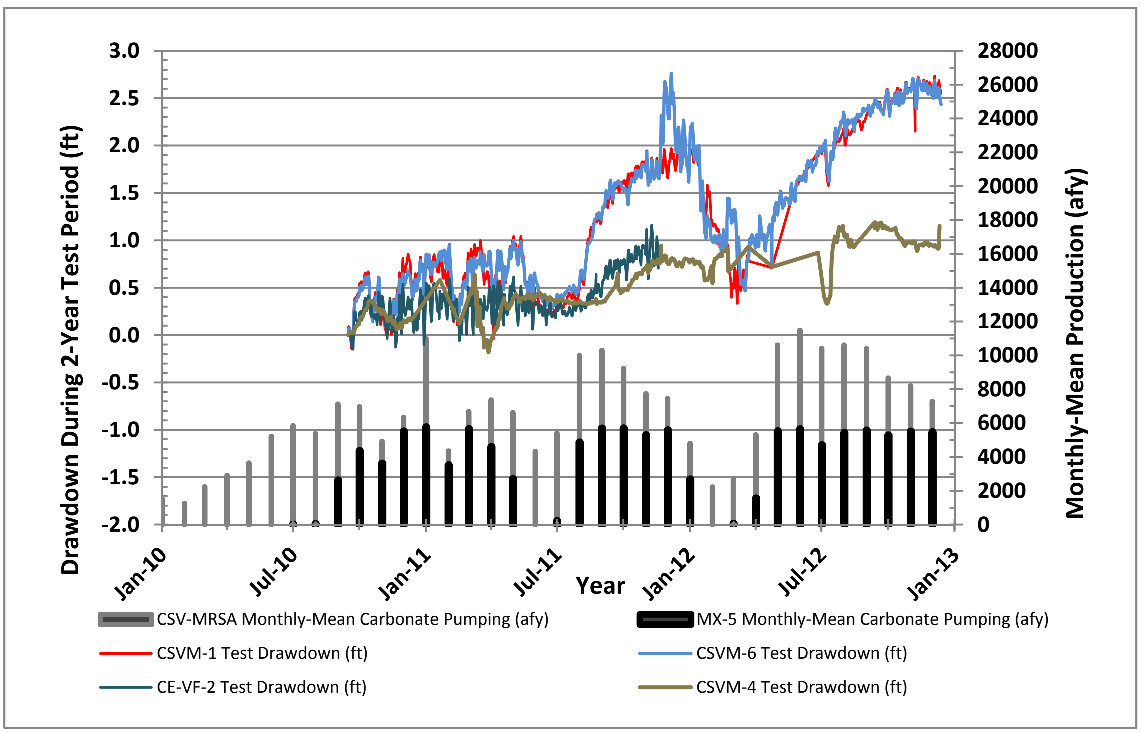

Figure 1.10. Drawdown in carbonate monitoring wells CSVM-1, CSVM-6, CE-VF-2, and CSVM-4 in CSV, versus monthly-mean production rates in the carbonate-rock aquifer at production well MX-5 and in the combined CSV and MRSA area, from September 15, 2010, to December 31, 2012, i.e., during the 2-year pumping test.

Distance-Drawdown Hydrographs in the Carbonate-Rock Aquifer

Drawdown as a function of distance along two transects through the Study Area, CSV to the MRSA and CSV to California Wash through Hidden and Garnet valleys, respectively, is presented in **Figures 1.11** and **1.12** for the following times during the test:

- 10/29/2010, the end of the first MX-5 pumping period (after 1.5 months of MX-5 pumping);
- 5/15/2011, the end of the second MX-5 pumping period (after a 1-month shut-down and an additional 5.5 months of MX-5 pumping);
- 7/10/2011, the end of a ~2 month recovery period from MX-5 pumping;
- 1/14/2012, the end of the third MX-5 pumping period (after an additional ~5 months of MX-5 pumping);
- 4/22/2012, the end of a ~3.5 month recovery period from MX-5 pumping; and
- 12/13/2012[2], the end of the fourth MX-5 pumping period and end of the test (after an additional ~7.5 months of continuous MX-5 pumping).

The transect from CSV to the MRSA represents a zone of known high transmissivity within the carbonate-rock aquifer[3], consequently a likely path for the propagation of drawdown originating in CSV. The transect from CSV to California Wash through Hidden and Garnet valleys is likewise a physically plausible path for the propagation of drawdown originating in CSV given the apparent presence of a MX-5 pumping signature in water level hydrographs for carbonate monitoring wells in Garnet Valley and the results of SeriesSEE analyses presented later in this report.

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[2] 12/13/2012 was the date of the last groundwater level measurement in a large number wells monitored as part of the Order 1169 test.

[3] Based on the calibration of flow models to date.

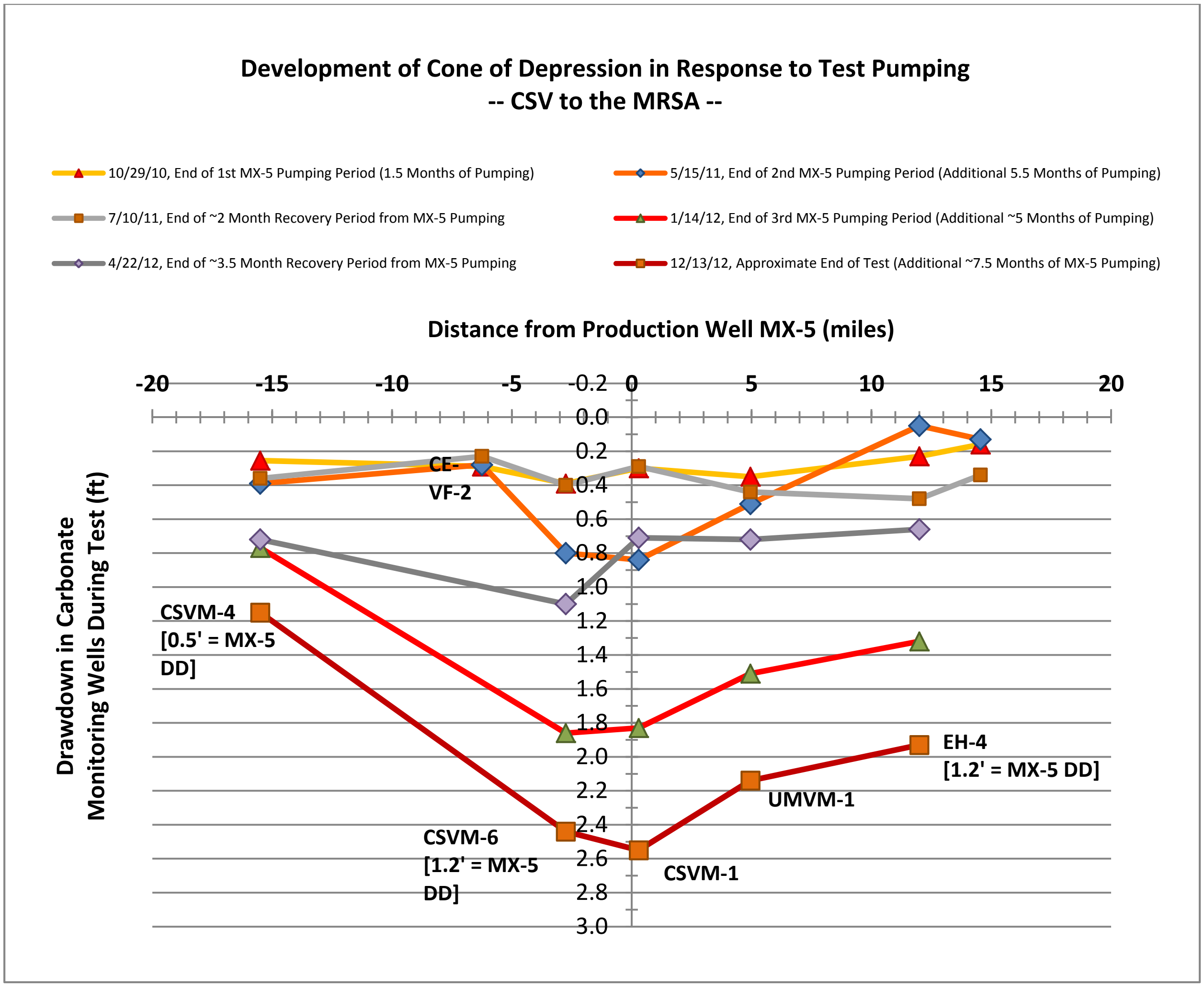

Figure 1.11. Distance-drawdown hydrographs along a transect from northern CSV to the MRSA at a series of times during the 2-year test period.

The shapes of the distance-drawdown hydrographs presented in **Figures 1.11** and **1.12** indicate that drawdown in the carbonate-rock aquifer was at a maximum at the location of production well MX-5 in southern CSV throughout the 2-year test, except for periods of recovery following intermittent shut-downs of MX-5. During periods of recovery from MX-5 pumping, the greatest rebound in groundwater levels occurred in the area of MX-5, as expected. The introduction of MX-5 pumping at an average rate of 4,070 afy during the test represented a significant stress on the carbonate-rock aquifer system. The rate of MX-5 pumping during the test exceeded the combined rate of pumping at all other carbonate production wells in the CSV-MRSA area (3,405 afy) and significantly exceeded the combined rate of carbonate pumping in Garnet Valley and California Wash (1,220 afy). Consequently, drawdown was at a maximum at the location of MX-5 during all phases of the test in which MX-5 was pumping.

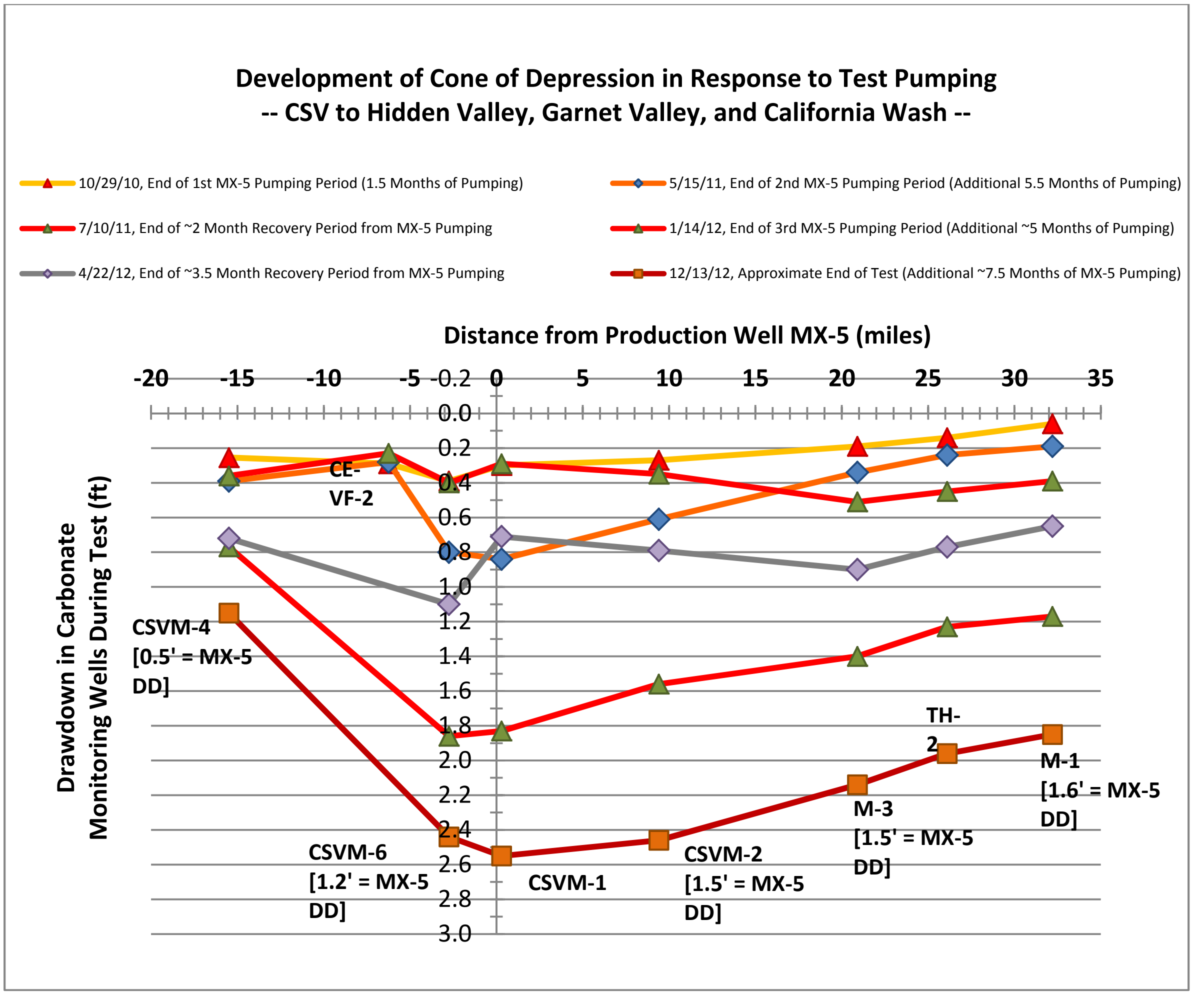

Figure 1.12. Distance-drawdown hydrographs along a transect from northern CSV to California Wash through Hidden and Garnet valleys at a series of times during the 2-year test period.

As of mid-May 2011, following 7 months of MX-5 pumping and a 1-month recovery period, drawdown due to the test pumping extended over a distance of at least 7 miles in the carbonate-rock aquifer from central CSV (well CSVM-6) to western MRSA (well UMVM-1) and at least 22 miles from central CSV (CSVM-6) to northern Garnet Valley (well M-3). As of mid-January 2012, following 13 months of MX-5 pumping in 3 periods and 3 months of recovery in 2 rest periods, drawdown in the carbonate-rock aquifer extended over a distance of about 27 miles from the northern end of CSV (well CSVM-4) to the Muddy River Springs (well EH-4) and 47 miles from northern CSV (CSVM-4) to California Wash (wells TH-2 and M-1) through Hidden and Garnet valleys.

The cone of depression that developed in the carbonate-rock aquifer between CSV and the MRSA following initiation of the test is shallow, relatively flat, and areally extensive (**Figure 1.11**). This is consistent with the known high transmissivity and hydraulic diffusivity of this portion of the regional carbonate-rock aquifer based on documented low hydraulic gradients under pre-test conditions, as well as the calibration of two groundwater flow models (the CCRP Model by SNWA and Tetra Tech Model Version 1.0 developed for the DOI agencies). Distance-drawdown hydrographs for carbonate monitoring wells in CSV, Garnet Valley, and California Wash (**Figure 1.12**) are likewise flat, or flatter. We interpret this to be the result of Garnet Valley pumping superimposed on the effects of carbonate pumping in CSV and the MRSA.

The effects of earth tides and fluctuations in barometric pressure on water levels in the carbonate-rock aquifer should be roughly equal throughout the Study Area at any given time. Consequently, the shapes of the distance-drawdown hydrographs presented in **Figures 1.11** and **1.12**, which represent conditions in the carbonate-rock aquifer at particular times, should be unaffected by the absence of these corrections. Likewise, longer-term (regional) changes in carbonate water levels should be similar throughout the area given the high transmissivity and diffusivity of this portion of the carbonate-rock aquifer, subject to minimal differences in timing. Consequently, the shapes of the distance-drawdown hydrographs should be minimally affected by the absence of a correction for long-term regional trends.

Isolation of Drawdown from MX-5 Pumping using SeriesSEE Analysis

Drawdown observed in the carbonate-rock aquifer and other hydrogeologic units during the test was the result of pumping at a large number of production wells, including the 39 utility- and industrial-scale (major) production wells listed in **Table A.1**. For illustrative purposes, these production wells have been grouped into four major pumping centers in **Figure 1.13**: Q_CSI, Q_EAST, Q_SOUTH, and Q_MX-5. Average annual pumping from all major production wells in the Study Area ranged between 9,500 to 14,000 afy (**Figure 1.14**) over the last 10 years. Monthly pumping from major pumping centers in the area varies seasonally and typically fluctuates between 6,400 and 19,300 afy. Q_EAST, located east-southeast of well MX-5 in the MRSA (**Figure 1.13**), is the primary pumping center in the Study Area. Pumping in the MRSA ranges seasonally from 4,800 to 12,900 afy. Monthly-mean pumping at well MX-5 in CSV was 4,070 afy during the test and ranged between 0 and 5,800 afy from September 2010 to August 2012.

We have employed SeriesSEE analysis (the method of Halford et al. 2012) to isolate, i.e., differentiate, drawdown induced by pumping at carbonate production well MX-5 from drawdown induced by pumping at other major production wells (carbonate and basin fill) that were operating in the Study Area during the test. Specifically, we have used SeriesSEE analysis to estimate the magnitude of drawdown induced by MX-5 pumping as of 12/13/2012[4] at a range of locations within the Study Area *as a means of identifying the high-connectivity portion of the carbonate-rock aquifer that includes the MRSA*.

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[4] 12/13/2012 was the date of the last groundwater level measurement in a large of number wells monitored as part of the Order 1169 test.

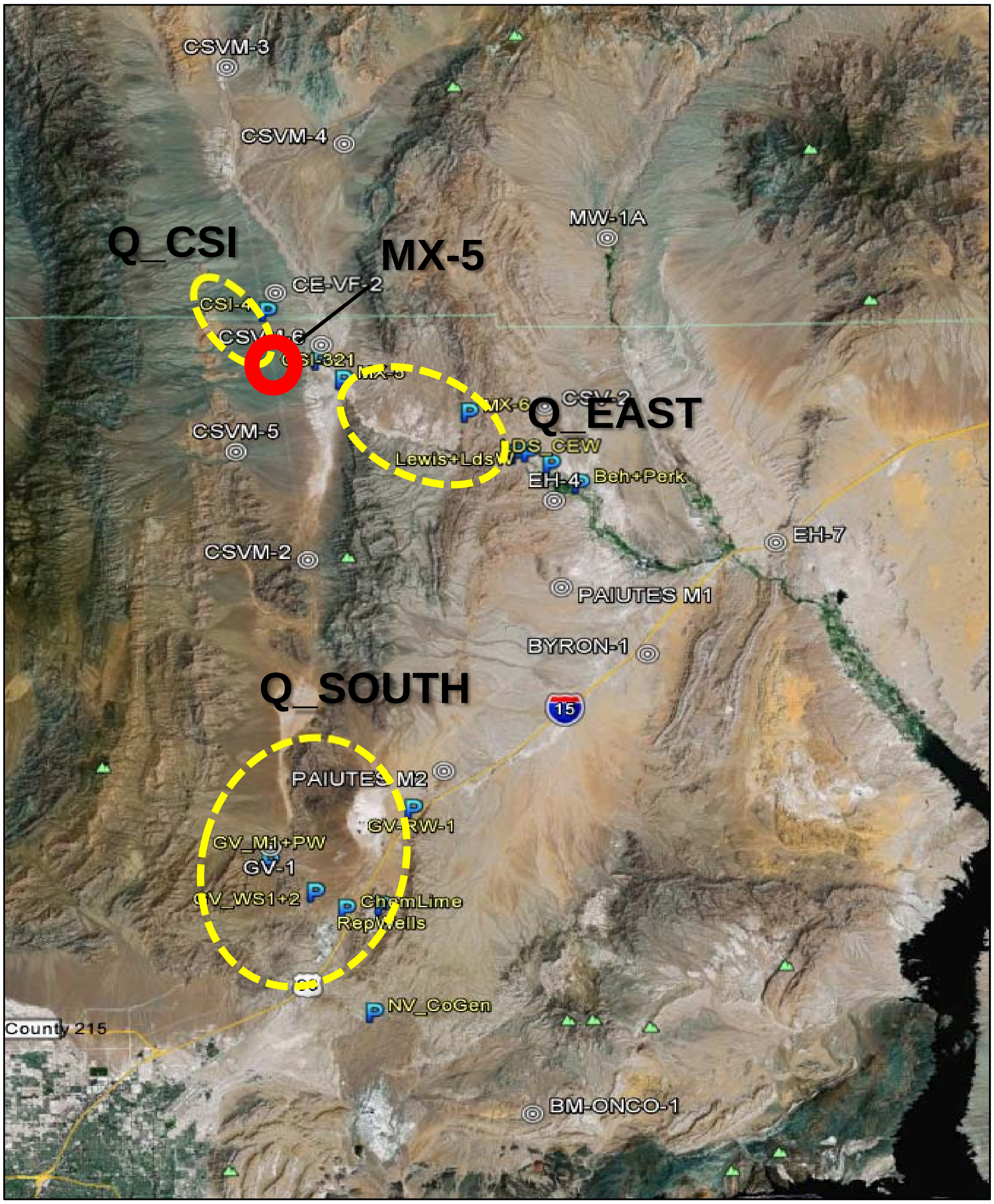

Figure 1.13. Major pumping centers within the Study Area.

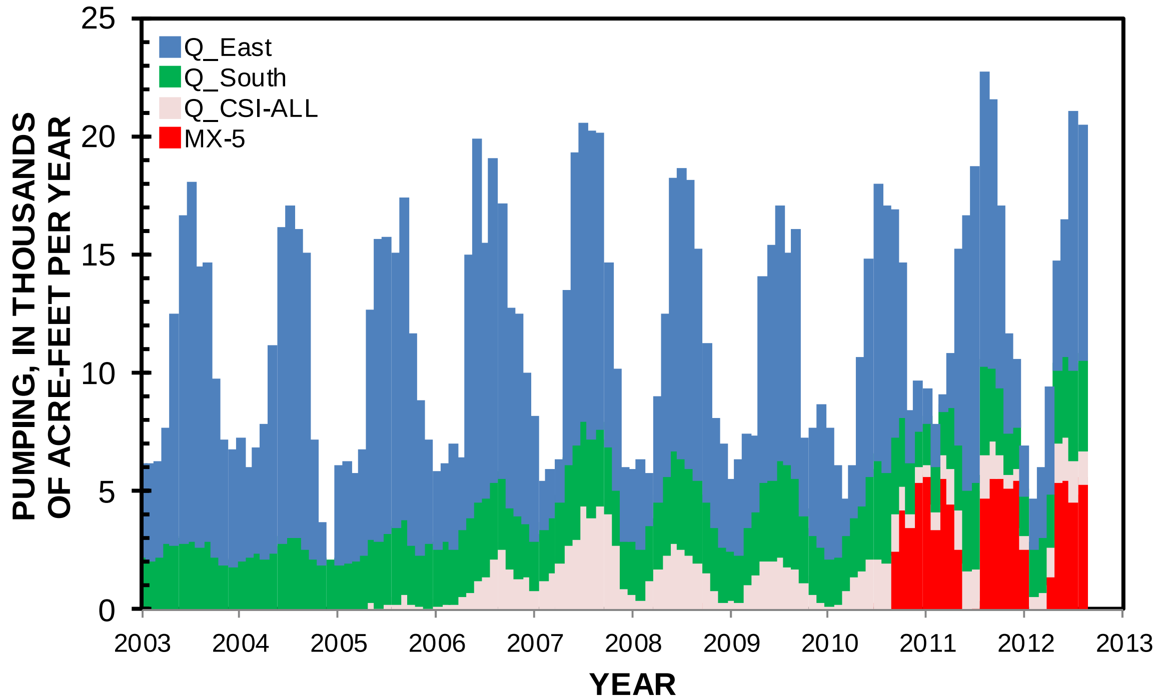

Figure 1.14. Monthly pumping from Q_East, Q_South, Q_CSI, and MX-5 for the period 2003 to August 2012.

In particular, we have modeled groundwater level data collected in 14 monitoring wells in the MRSA, CSV, Garnet Valley, the Black Mountains Area, California Wash, Lower Moapa Valley, and Lower Meadow Valley Wash using SeriesSEE (Halford at al., 2012) to estimate the magnitude of drawdown induced by MX-5 pumping as of the end of the test (12/13/2012). Drawdown induced by pumping at all 39 major production wells listed in **Table A.1** was simulated analytically using Theis transforms, where step-wise pumping records of discharge are transformed into water-level changes using multiple superimposed Theis solutions. Theis transforms can approximate drawdowns, as well as the measurement resolution of transducers, even in complex hydrogeologic systems (Garcia et al., 2013). Groundwater-level fluctuations from environmental stresses such as barometric changes, earth tides, and regional trends in groundwater levels were not modeled.

Pumping at the 39 major production wells listed in **Table A.1** was simulated from 1/1/2008 to 12/13/2012, grouped into the 13 pumping centers shown in **Figure 1.15** (each depicted with a 'P'). Groundwater level data for this same period was interpreted for the following monitoring wells[5]:

- CSVM-3 (carbonate monitoring well at the north end of CSV);
- CSVM-4 (carbonate monitoring well in northern CSV, immediately south of Kane Springs Valley on the southeast side of the Kane Springs Wash Fault);
- CE-VF-2 (carbonate monitoring well in north-central CSV);
- CSVM-6 (carbonate monitoring well in central CSV);

[5] Simulated production rates were monthly-mean values. The frequency of modeled groundwater level measurements varied according to what is available; in some cases modeled groundwater level data were intermittent tape-downs, in other cases they were daily-mean values from continuous transducer records.

- CSVM-5 (carbonate monitoring well in an elevated portion of southern CSV);
- CSV-2 (carbonate monitoring well in the MRSA, north of the Arrow Canyon wells);
- EH-4 (carbonate monitoring well in the MRSA ,close to Pederson and Pederson East springs of the Muddy River Springs);
- M-2 (carbonate monitoring well in northern Garnet Valley);
- GV-1 (carbonate monitoring well in southern Garnet Valley close to central Garnet Valley/Apex area pumping);
- BM-ONCO-1 (monitoring well completed in clastic rocks in the Black Mountains Area south of central Garnet Valley/Apex area pumping)
- M-1 (carbonate monitoring well in northern California Wash, close to the MRSA);
- Byron-1 (carbonate monitoring well in southern California Wash);
- EH-7 (monitoring well completed in younger carbonate rocks of Lower Moapa Valley); and
- MW-1A (basin-fill monitoring well in Lower Meadow Valley Wash).

Our SeriesSEE analyses span the period 1/1/2008 to 12/13/2012 because groundwater level measurements collected during the test (9/15/2010 to 12/13/2012) were, in part, due to pumping that predated the test. The 14 monitoring sites listed above represent a combination of locations that were judged *a priori* to be located within and outside the high-connectivity portion of the carbonate-rock aquifer based on an inspection of available groundwater level hydrographs. All but two of the monitoring wells, MW-1A in Lower Meadow Valley Wash and EH-7 in Lower Moapa Valley, are completed in the carbonate-rock aquifer. Well MW-1A is a shallow well completed in basin fill; EH-7 is completed in carbonate rocks that are younger than the Paleozoic carbonate rocks comprising the regional carbonate-rock aquifer.

Our estimates of MX-5 induced drawdown in the 14 monitoring wells as of 12/13/2012 are summarized in **Figure 1.15**. The results of these analyses are provided in graphical form in **Appendix A.4-4** (rates of MX-5 pumping and total pumping within the Study Area provided as points of reference). In particular, no drawdown due to MX-5 pumping was identified in the records of:

- carbonate monitoring well CSVM-5 in an elevated portion of southern CSV (an area of possible low permeability accounting for the slow rise in groundwater levels in this well over that last several years);

- clastic monitoring well BM-ONCO-1 in the northern Black Mountains Area (south of the central Garnet Valley/Apex production wells);

- carbonate monitoring well Byron-1 in northwestern California Wash; or

- basin-fill monitoring well MW-1A in Lower Meadow Valley Wash.

Moreover, no MX-5 induced drawdown appears to be present in the record of monitoring well EH-7 in Lower Moapa Valley (completed in carbonate rocks that are not part of the regional aquifer). However, the magnitude of MX-5 induced drawdown was substantial and nearly equal in most of the carbonate monitoring wells analyzed in the floor of CSV, the MRSA, Garnet Valley, and California Wash as of December 2012 (1.1. to 1.6 ft of a total 1.9 to 2.5 ft of observed water level change). Carbonate monitoring wells CSVM-4 and CSVM-3 in northern CSV were an exception to this otherwise remarkably uniform response as of the end of the test. Smaller components of MX-5 induced drawdown were estimated in CSVM-4 and CSVM-3 (about 0.5 and 0.1 ft, respectively).

We conclude that pumping at MX-5 in the carbonate-rock aquifer created drawdown of approximately equal magnitude throughout CSV (at least the floor of the valley), the MRSA, Hidden and Garnet valleys, and California Wash as of the end of the 2-year test. Given this result and the connectivity of this portion of the carbonate-rock aquifer based on low hydraulic gradients under pre-test conditions and the calibration of two groundwater flow models, we likewise conclude that carbonate pumping at other locations within this area has also created (and will create) drawdown of nearly equal magnitude throughout the identified area. Using the results of these SeriesSEE analyses, we have delineated a portion of the carbonate-rock aquifer in which pumping causes water level declines of nearly equal magnitude throughout this part of the aquifer (**Figure 1.16**), including the source of the Muddy River Springs and majority source of the Muddy River. We note that these conclusions are consistent with the distribution of total drawdown documented in carbonate monitoring wells as of the end of the 2-year test (**Figure 1.17**).

We note that this differentiation of pumping signals includes differentiating drawdown induced by MX-5 pumping in CSV from drawdown induced by pumping at the Arrow Canyon and basin fill wells in the MRSA, the CSI production wells in CSV, and production wells in Garnet Valley, the Black Mountains Area, and California Wash (the other major production wells listed in **Table A.1**). See **Appendix A.4** for a discussion of the extent to which drawdown due to pumping at locations other than MX-5 has been isolated as part of these analyses.

Due to the limited availability of observation wells in east-central to southern California Wash and the portion of the Black Mountains Area that lies between southern California Wash and the Overton Arm of Lake Mead, it was not possible to evaluate the potential for a hydraulic connection between the delineated area (including California Wash) and Rogers and Blue Point springs.

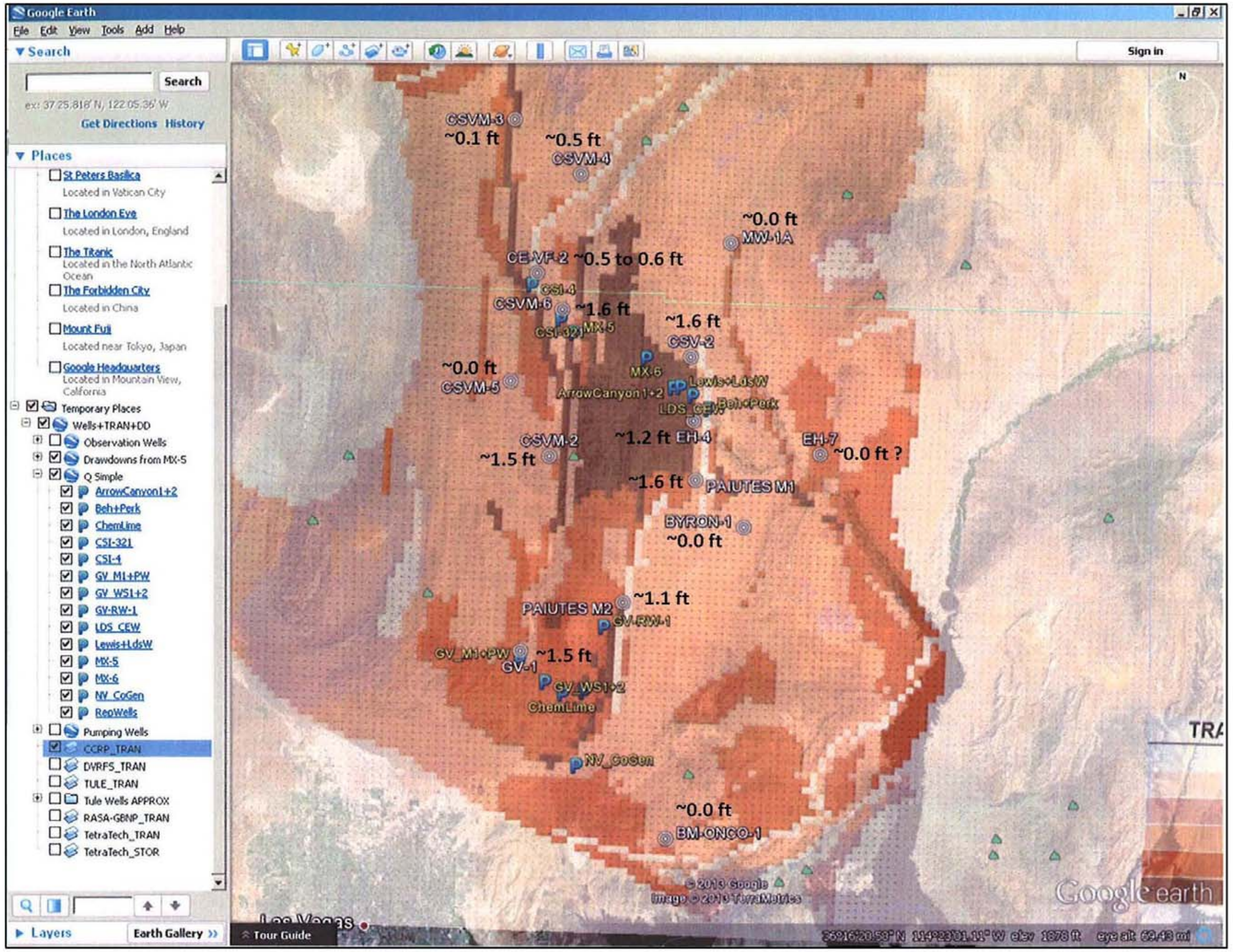

Figure 1.15 MX-5 pumping-induced drawdown (ft) in monitoring wells within the Order 1169 Study Area based on preliminary SeriesSEE analyses performed using the method of Halford et al. (2012); base map is total transmissivity calibrated using the Central Carbonate-Rock Province (CCRP) Model developed by SNWA for the Clark, Lincoln, and White Pine Counties Groundwater Development Project.

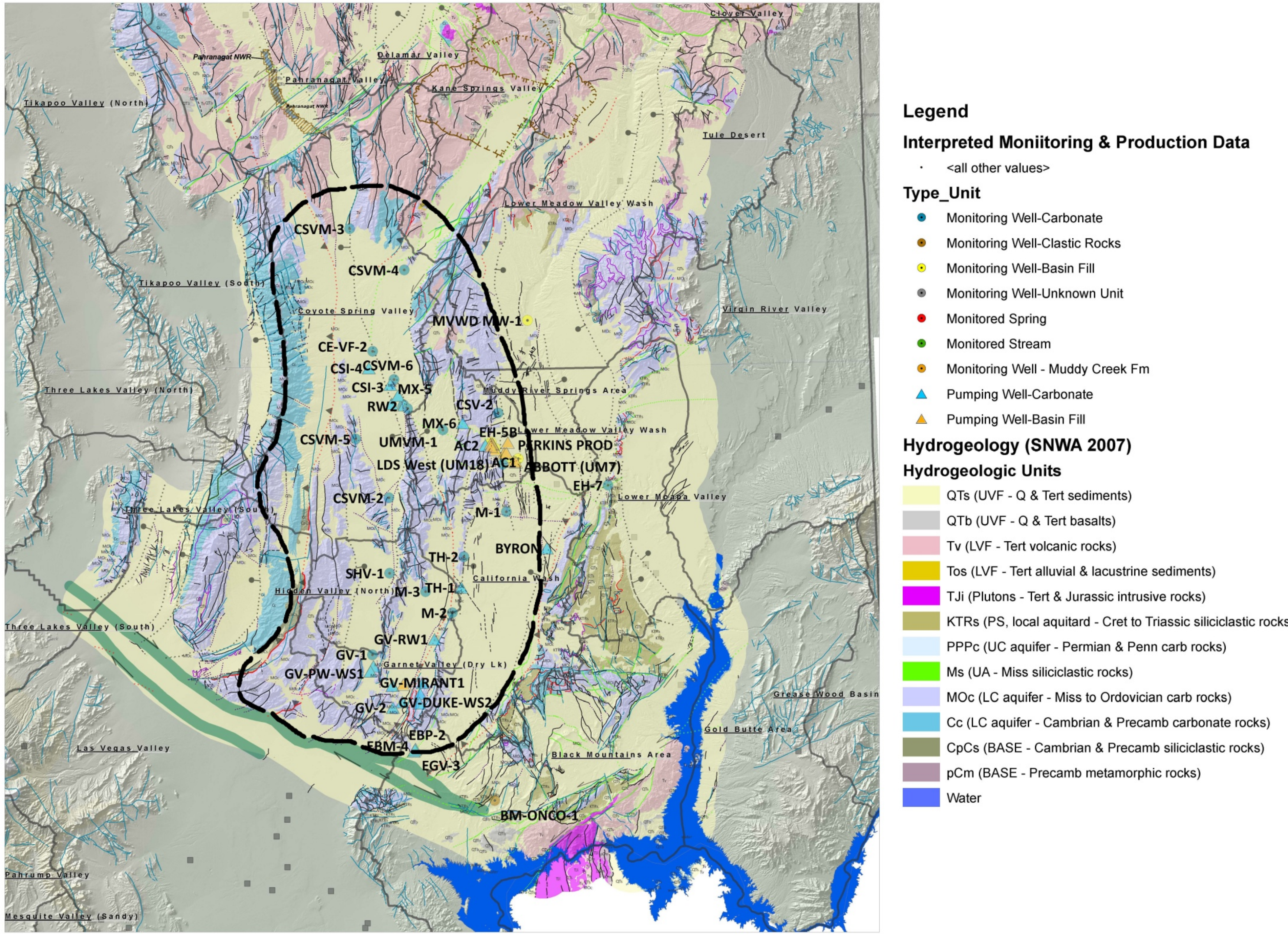

Figure 1.16. Map showing the approximate location of the portion of the carbonate-rock aquifer in which pumping results in water level declines of roughly equal magnitude everywhere else in this part of the aquifer and depletion of the Muddy River Springs. (Delineated area based on SeriesSEE analyses and generalized geologic considerations. Base is SNWA (2007a) Hydrogeologic Units.)

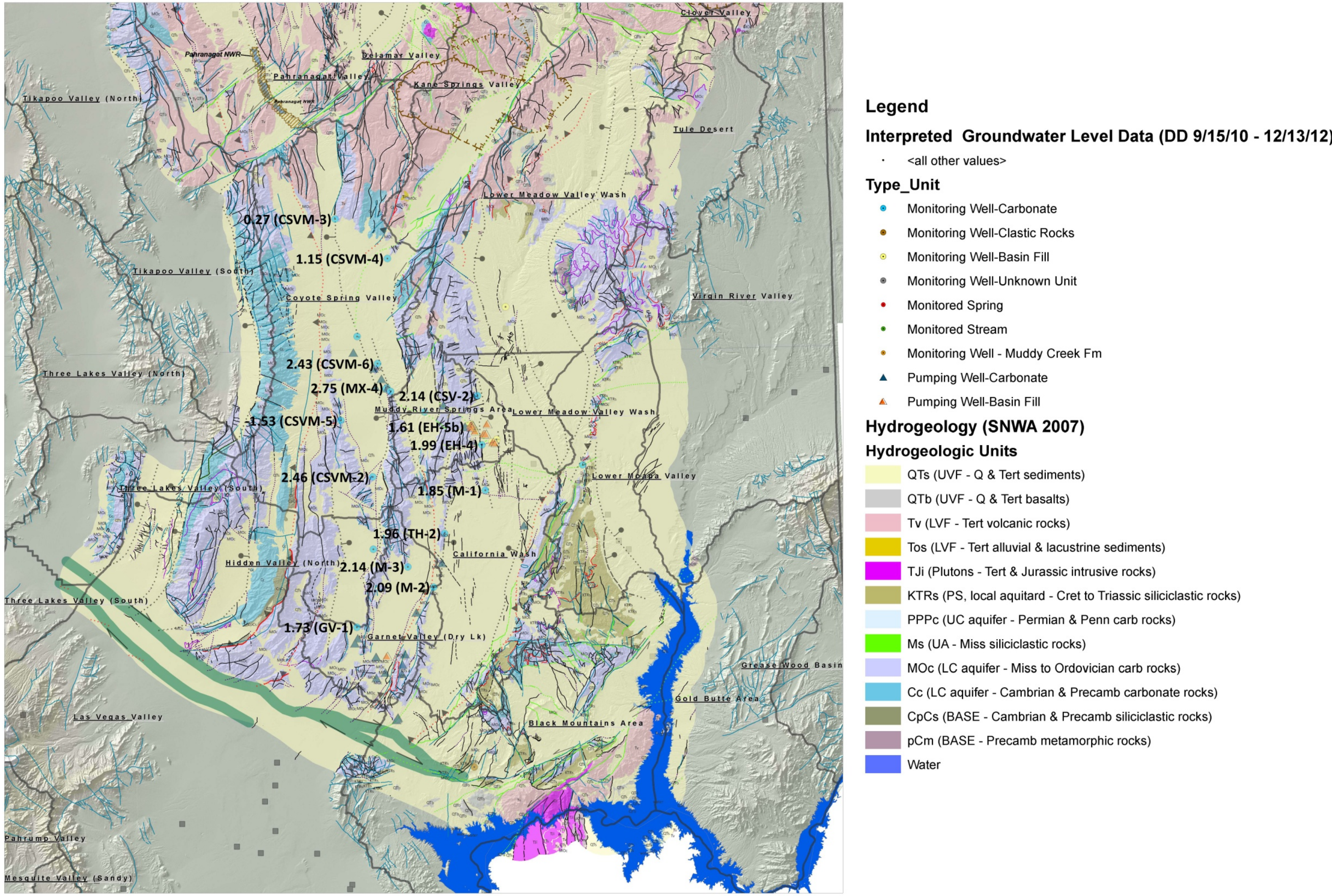

Figure 1.17. Total drawdown in the carbonate-rock aquifer due to all carbonate pumping during the Order 1169 test, September 15, 2010 to December 31, 2012; base is SNWA (2007) Hydrogeologic Units.

Conceptual Model of the Portion of the Carbonate-Rock Aquifer System Affecting the Muddy River Springs

We hypothesize that the response to MX-5 pumping observed during the Order 1169 pumping test was due to two factors:

1. a high degree of connectivity within the portion of the regional carbonate-rock aquifer underlying CSV, the MRSA, Hidden and Garnet valleys, and California Wash (the delineated area); and

2. relatively constant groundwater inflows to this portion of the carbonate-rock aquifer.

Based on the results of our SeriesSEE analyses and a range of other observations discussed in previous sections, a high degree of connectivity exists within the portion of the carbonate-rock aquifer underlying the delineated five-basin area (as discussed in the previous section). We additionally propose that groundwater inflows to this portion of the carbonate-rock aquifer are primarily limited to CSV and that these inflows are relatively constant.

Specifically, the magnitude of the head drop from Pahranagat Valley into CSV (or Delamar Valley to CSV) is on the order of 1,000 ft. As a result, no amount of pumping-induced drawdown in CSV or the other four basins can measurably increase the hydraulic gradient and the groundwater inflow across the northern boundaries of CSV into the delineated area. Interbasin groundwater flow into the portion of the carbonate-rock delineated in **Figure 1.16** is for all practical purposes constant, regardless of the magnitude of drawdown induced in CSV and the other basins by pumping.

Likewise, groundwater inflow to CSV and the other basins in the form of precipitation recharge is not only limited, but relatively constant from year to year compared to the overall water budget of this portion of the carbonate-rock aquifer. Consequently, the portion of the carbonate-rock aquifer delineated in **Figure 1.16** is effectively a high-transmissivity carbonate-rock reservoir with fixed inflows. Pumping anywhere in this portion of the carbonate-rock aquifer effectively lowers groundwater levels everywhere within 'the reservoir' by almost equal amounts in relatively short periods of time (consistent with the results of our SeriesSEE analyses and a range of other observations during the test).

Additionally, groundwater pumping must eventually be balanced by increased inflows, decreased natural outflows, or a combination thereof (Bredehoeft, 2007). Since groundwater inflows to this portion of the carbonate-rock aquifer are for all practical purposes constant, all pumping from the 'reservoir' must eventually be captured from natural discharge at a rate approaching 100 percent of the rate of pumping. Natural discharge within the delineated area, in turn, is limited to the Muddy River Springs, and the Muddy River and ET associated with phreatophytic vegetation in the MRSA and California Wash (DeMeo et al., 2008). Consequently, all pumping from this portion of the carbonate-rock aquifer must eventually be captured from the springs, river, and (or) ET in the MRSA and California Wash. Any carbonate pumping in excess of the current rate of natural discharge in the MRSA and California Wash will potentially result in capture from Rogers and Blue Point springs over longer periods of time and/or long-term declines in carbonate water levels throughout the five basins.

Capture of natural discharge in the MRSA has already occurred to some extent as a result of the Order 1169 pumping. We have documented a total reduction in spring discharge of about 1200 af during the pumping test (described in detail in the following section on impacts to springs). Unprecedented declines in carbonate water levels during the test were also accompanied by unprecedented declines in the discharge of the two highest-elevation warm springs in the MRSA, Pederson and Pederson East springs, as well as lesser reductions in discharge at the Warm Springs West gage (**Figures 1.4** and **1.5**) and several lower elevation warm springs in the MRSA (Jones, Baldwin, and the Plummer Unit springs).

Assessment of Pumping Captured from Groundwater Storage during the 2-Year Test

We estimate that a large portion of MX-5 pumping and some portion of the other carbonate pumping which occurred during the Order 1169 pumping test was likely captured from groundwater storage as of the end of the 2-year test, with only a fraction captured to date from natural discharge. The high-transmissivity carbonate-rock reservoir delineated in **Figure 1.16** is approximately 690,000 acres in area[6]. Based on SeriesSEE analyses, an average 1.4 ft of drawdown was induced in this portion of the carbonate-rock aquifer as of the end of the test in response to the withdrawal of 9,300 af from MX-5 (9/15/2010 to 12/13/2012). If the average storage coefficient for this portion of the carbonate-rock aquifer is 0.01, then the majority of groundwater pumped from MX-5 during the 2-year test was captured from groundwater storage. Likewise, carbonate water levels declined an average of 2.0 ft in the delineated area over the 2-year test period in response to the withdrawal of 19,900 ac-ft from all carbonate production wells. Again, if the average storage coefficient for this portion of the carbonate-rock aquifer is as great as 0.014, then the majority of carbonate pumping was captured from groundwater storage, rather than natural discharge, during the test.

We note that the magnitude of the storage coefficients implied by these simple volumetric calculations, approximately 0.01, is plausible based on estimates of storage coefficients for the carbonate-rock aquifer at other locations. Specifically, no storage coefficient estimates are available for this portion of the carbonate-rock aquifer based on the interpretation of pumping (aquifer) tests. No storage coefficient was estimated from a multi-well pumping test performed in carbonate well Arrow Canyon 1 in the MRSA in the 1990's (Buqo, 1994; after Belcher et al., 2001); and no storage coefficients could be estimated from 1986 single-well pumping tests conducted in carbonate wells CSV-2 in the MRSA or CE-VF-2 in CSV (USGS, 2013). However, an unconfined storage coefficient of 0.020 has been estimated from a multi-well pumping test in carbonate well 184W101 in Spring Valley (USGS, 2013); and a confined storage coefficient of 2.0E-04 to 9.0E-03 was estimated by the Southern Nevada Water Authority (SNWA 2009) from a multi-well pumping test in well 184W105 in Spring Valley.

Based on the available storage coefficient estimates for carbonate rocks elsewhere in Nevada, we conclude that the storage coefficient implied by our volumetric calculations for the delineated portion of the carbonate-rock aquifer, which data suggest is confined in some locations and unconfined in others,

[6] Specifically, 693,100 acres is roughly the area delineated in Figure 1.16 less the most northerly portion of CSV where MX-5 induced drawdown as of the end of the 2-year test was less than the 1.1 to 1.6 ft estimated at nearly all other locations in the identified area.

is plausible and that the bulk of carbonate pumping during the test was captured from groundwater storage. As such, only a fraction of the pumping was captured from natural discharge as of the end of the test. We expect the full impacts of the Order 1169 pumping test, most of which have not yet been realized, to include capture of spring and stream discharge, followed by ET, in the MRSA and California Wash in an amount that approaches the rate of MX-5 pumping imposed during the test. Moreover, about three-quarters of drawdown observed in the carbonate-rock aquifer within the five identified basins was attributable to MX-5 pumping as of the end of the test based on SeriesSEE analyses. We interpret this to mean that the remaining quarter or more of drawdown was attributable to other pumping. That is, the carbonate-rock aquifer system, specifically the portion underlying the delineated area, had not reached equilibrium with respect to pumping at one or more production wells predating MX-5 as of the end of the test. As a consequence, we expect the full impacts of the test to include the capture of an additional increment of natural discharge associated with continued pumping at some number of existing carbonate production wells (wells predating MX-5) within the Study Area.

Limitations of the Test and Unresolved Questions

The only significant limitation of the Order 1169 pumping test was that two years was not sufficient to observe the transition from the capture of pumping from groundwater storage to the capture of pumping from natural discharge. As a result, the full impacts of the level of pumping during the test on spring and stream discharges were not observed during the 2-year test.

The time required to transition from a state where pumped water is supplied from groundwater storage (reductions in groundwater levels) to the capture of spring/stream discharge and evapotranspiration is unknown. The time for this transition to occur may be so long that by the time a critical reduction in spring flow is identified (e.g., based on a reduction in flow at the Warm Springs West gage), the ensuing recovery in groundwater levels may not occur fast enough to protect spring discharge and biological resources in the MRSA.

Additionally, available information is not sufficient to evaluate the potential for a hydraulic connection between the delineated high-transmissivity portion of the carbonate-rock aquifer (CSV, the MRSA, Hidden and Garnet Valleys, and California Wash) and Rogers and Blue Point springs; nor is it sufficient to determine whether MX-5 induced drawdown in California Wash propagated through the MRSA, through Hidden and Garnet valleys, or both.

Conclusions for Impacts to Groundwater

Based on our SeriesSEE analyses, we have delineated a portion of the carbonate-rock aquifer underlying CSV, the MRSA, Hidden and Garnet valleys, and California Wash, a subset of the overall Order 1169 Study Area, in which pumping causes water level declines of nearly equal magnitude throughout this part of the aquifer over relatively short periods of time (i.e., the 2-year test period or less). The results of our SeriesSEE analyses confirm that the 'signature' seen in groundwater level hydrographs for carbonate monitoring wells in these five basins was indeed due to MX-5 pumping. The area delineated using

SeriesSEE analyses is also consistent with distance-drawdown hydrographs for the carbonate-rock aquifer constructed using data collected during the test.

Based on this result and considerations related to the nature of groundwater inflows to CSV, we hypothesize that this portion of the carbonate-rock aquifer acts as a high-transmissivity (high-diffusivity) 'reservoir' with fixed inflows. As a consequence, pumping anywhere in this portion of the carbonate-rock aquifer effectively lowers groundwater levels everywhere in 'the reservoir' by nearly equal amounts (consistent with the results of our SeriesSEE analyses and a range of other observations). As an additional consequence, all pumping from the 'reservoir' must eventually be captured from the Muddy River Springs, Muddy River, and (or) ET associated with phreatophytic vegetation in the MRSA and California Wash, the only forms of natural discharge in the delineated five-basin area, at a rate that approaches 100 percent of the rate of pumping. Any carbonate pumping in the area that exceeds the current rate of natural discharge in the MRSA and California Wash will potentially result in capture from Rogers and Blue Point springs over longer periods of time and (or) long-term declines in groundwater levels.

We estimate that the bulk of MX-5 pumping, as well as some portion of other carbonate pumping that occurred during the test, was likely captured from groundwater storage (a lowering of groundwater levels) based on volumetric calculations, which suggests that only a fraction of the water pumped was captured from natural discharge as of the end of the test. This is confirmed by our estimate of the decline in spring flows that occurred during the test in the MRSA (discussed in detail later in this section) which represents a fraction of the average rate of MX-5 pumping.

If pumping in the carbonate-rock aquifer continues in the delineated area at the rate it occurred during the test, we expect additional declines in spring and stream flows to occur in the MRSA and California Wash in an amount that approaches the average rate of MX-5 pumping, plus an additional increment of capture associated with the continuation of other carbonate pumping in the area. Increasing the rate of carbonate pumping in the delineated area over the level that occurred during the test will result in further capture of spring and stream flows and (or) ET in the MRSA and California Wash in an amount that approaches 100 percent of the increase in the rate of pumping.

Finally, we note that the impacts of the Order 1169 pumping test, both observed and anticipated, are the result of pumping approximately one-third of the 16,300 afy currently permitted in CSV[7] and that the applications pending under Order 1169 potentially represent a substantial increase in those rights. This suggests that water is not available for the pending applications in CSV, in part or whole, or for applications pending in the MRSA, Hidden or Garnet valleys, or California Wash under the Order, as discussed in the Availability section of this report.

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[7] The annual-mean rate of pumping in CSV during the test, 5,378 afy, divided by the currently permitted rights in CSV, 16,300 afy.

Impacts to Springs

This portion of the report presents our interpretation of the impacts of the Order 1169 pumping test on springs and discharge in the MRSA. We begin by describing the theoretical relationship between groundwater levels in the carbonate rock aquifer and regional spring discharge. We hypothesize that changes in spring discharge will be proportional to the changes in hydraulic head differential at each individual spring and that the higher elevation springs with the smallest hydraulic head will be the most sensitive to the drawdown observed during the pumping test. To validate this hypothesis, we examine the observed changes in discharge at several springs and flow monitoring sites in the system in relation to spring water surface elevation, groundwater level decline, and the estimated changes in hydraulic head differential at the springs. We also discuss other factors affecting groundwater levels and spring discharge during the pumping test including precipitation, fire effects, and land use changes in the area.

Theoretical Groundwater Level/Spring Discharge Relationships

It is well established that spring discharge in the MRSA emanates from the regional carbonate-rock aquifer (Eakin 1966; Prudic et al., 1993; Thomas et al., 1996). The regional carbonate-rock aquifer is confined and the potentiometric surface of the aquifer is greater than the land surface elevation of the springs. This hydraulic head differential causes groundwater in the carbonate rock aquifer to rise to the land surface, along fissures and fractures that occur in the area, and flow as spring discharge. We assume that the flow at any spring is governed by Darcy's Law, which states that flow through a porous medium is proportional to the hydraulic head differential or hydraulic gradient (Fetter, 1994). The greater the difference between the water surface elevation at the spring and the hydraulic head of the aquifer, the greater the spring discharge, other factors being constant.

The high transmissivity of the carbonate rock aquifer in the CSV-MSRA corridor creates a consistent and fairly uniform potentiometric surface beneath the landscape with little variation in hydraulic head in the aquifer. The difference in land surface elevations between MX-4 in CSV and the springs in MRSA, some 15 miles to the east, is about 350-450 feet, but the difference in the potentiometric surface of the regional aquifer between carbonate monitoring wells MX-4 in CSV and EH-4 in MRSA is only about 5-6 feet. The high transmissivity and associated low hydraulic gradient results in a fairly uniform potentiometric surface elevation across the MRSA. However, the elevations of springpools in the area vary by more than 70 feet (Beck et al., 2006). This potentially leads to a large range of hydraulic head differential between the individual springs in the MRSA. Higher elevation springs have a much smaller hydraulic head differential than lower elevation springs. This concept is illustrated in **Figure 1.18**.

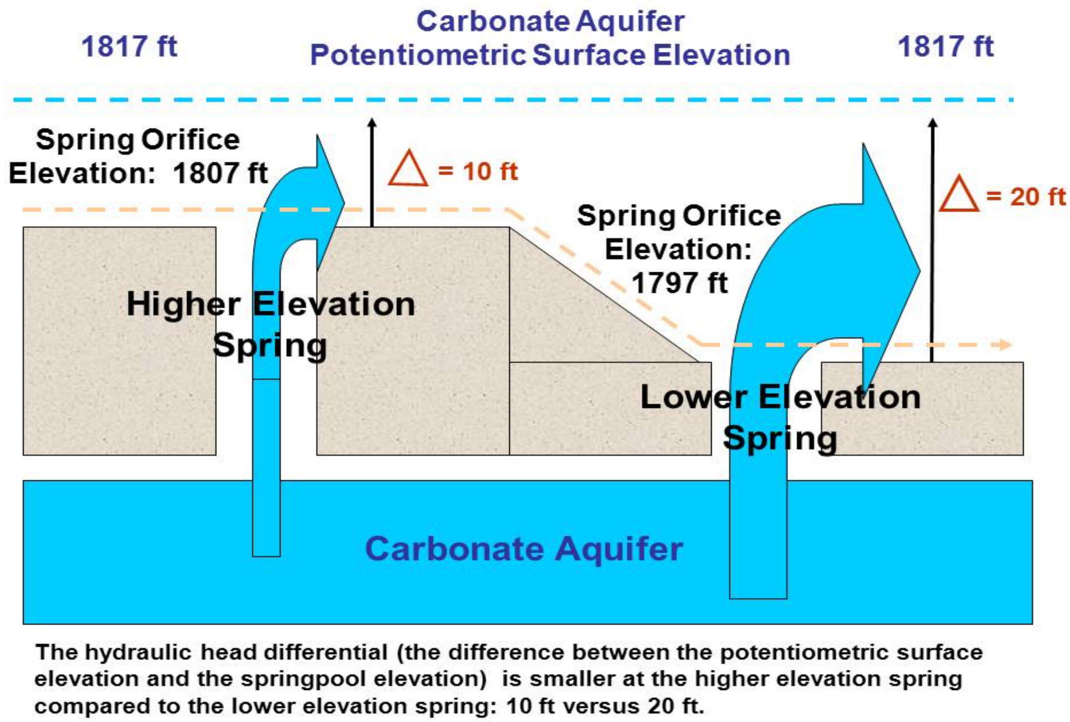


Figure 1.18. Theoretical head differential at springs of *different* elevation, assuming a uniform potentiometric surface in the regional carbonate-rock aquifer.

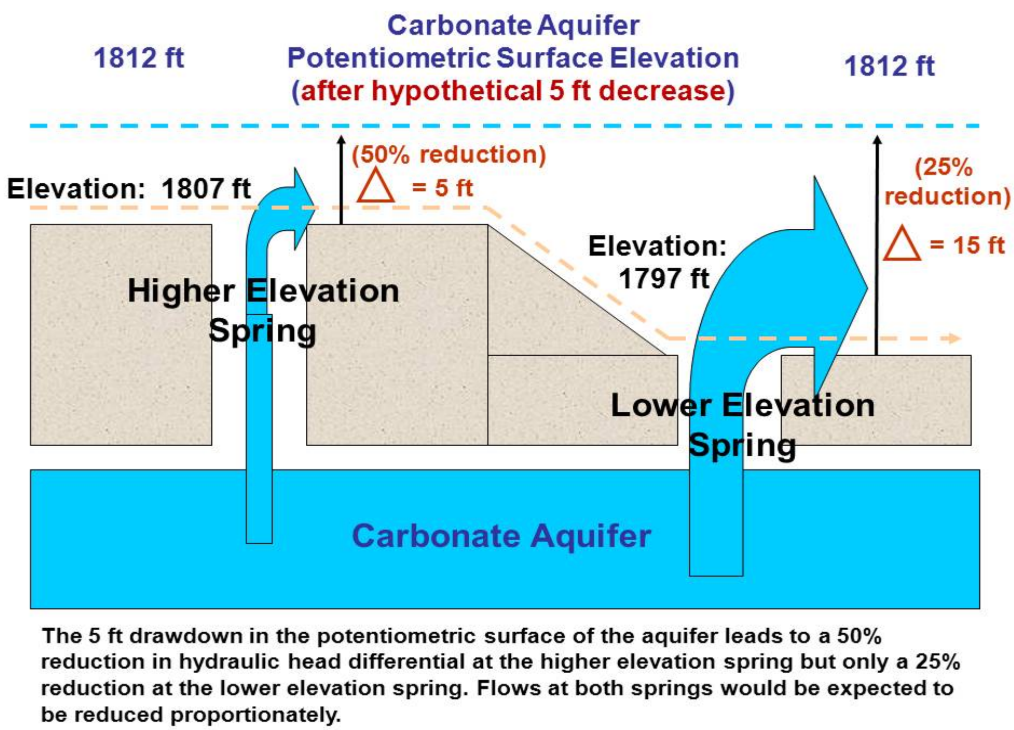


Figure 1.19. Theoretical effects of a uniform drawdown on head differential and spring discharge at higher and lower elevation springs.

Groundwater pumping leads to the development of a drawdown cone around the pumping center. As the drawdown cone extends to the springs, the hydraulic head differential at the springs will be reduced. Darcy's Law states that a reduction in the hydraulic head differential will result in a proportional decrease in flow rate, all other factors being constant. If, for example, a lowering of the potentiometric surface leads to a 25% decrease in the hydraulic head differential at a spring, one would expect a similar percentage reduction in flow at that spring. It follows that the springs in the system with the smallest hydraulic head differential, i.e., the highest elevation springs, will be relatively more sensitive to a uniform decline in the potentiometric surface of the carbonate rock aquifer resulting from groundwater pumping. This concept is illustrated in **Figure 1.19**.

Data Sources and Data Quality

The data we used in our analyses, including the source, type, and frequency of the data; period of record and site history; monitoring agency or organization; quality of the data; and location and physical characteristics of the site will be discussed in this section. **Figure 1.20** shows the location of all the monitoring sites described here. For surface water monitoring sites, we found it convenient to distinguish between spring monitoring sites (those sites located directly at the springpool outflows) and flow monitoring sites (those sites located some distance downstream of the springpools). All data presented here, along with the graphical and statistical analyses, are appended as data files to this report.

There are two carbonate monitoring wells in the MRSA near the Refuge: EH-4 and EH-5b (**Figures 1.1 and 1.20**). Both wells are monitored by Nevada Energy and have periodic measurements since 1986, with continuous data available since 1997. The water level elevations and trends at both monitoring wells are very similar and highly correlated (see **Figure 1.2** and the appended data file: Order 1169 EH4 Data_NDWR_Dec 2012.xlsx, for a comparison of the two wells). Because the data from EH-4 are less erratic and more complete, and the well is physically located closer to the Refuge, we use EH-4 data here and assume that the water level in EH-4 is representative of the elevation of the potentiometric surface in the regional carbonate-rock aquifer in the MRSA. There is some uncertainty associated with this assumption; the hydraulic head at the springs themselves may differ from that represented by water levels at EH-4. The springs are physically located some distance from EH-4 and the aquifer depth at which the springs are sourced may not correspond with the depth of the well opening at EH-4. Nevertheless, the EH-4 data were used to develop relationships between carbonate water levels and discharge at various sites in the MRSA.

We also used periodic measurements of shallow groundwater levels from October 2009 through December 2012 in nine monitoring wells located in the MRSA. These data are collected and reported by the Southern Nevada Water Authority (SNWA).

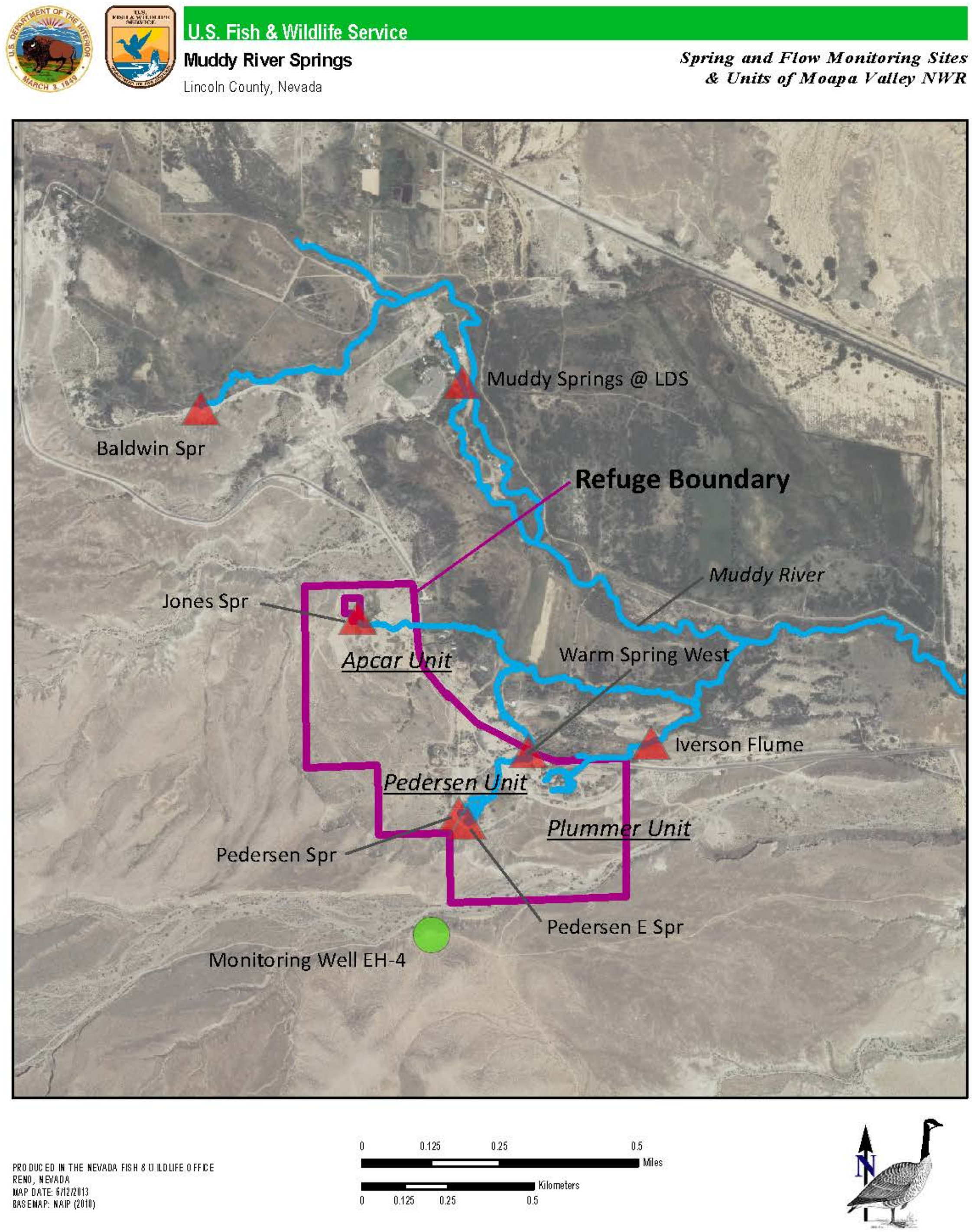


Figure 1.20. Map showing the locations of spring and flow monitoring sites; the boundary and three units of the Moapa Valley NWR; as well as the EH-4 carbonate monitoring well, all discussed in this section of the report.

The Moapa Valley NWR consists of three units: the Pedersen[8] Unit, the Plummer Unit, and the Apcar Unit (**Figure 1.20**). The springs on the Pedersen Unit are the highest elevation springs in the MRSA. Given the expected sensitivity of the higher elevation springs and the importance of the Warm Springs West, we mainly focus our analyses on this area. There are three continuously monitored USGS sites on the Pedersen Unit: Pederson Spring (USGS Site No. 09415910), Pederson East Spring (USGS Site No. 09415908), and Warm Springs West (USGS Site No. 09415920). Pederson Spring and Pederson East Spring are two spring monitoring sites that measure the outflows from the springpools. Both springs have historically averaged about 0.2 cfs until recently. Warm Springs West is a flow monitoring site that measures the combined discharge from diffuse groundwater seepage and five major spring groups located about 0.1-0.2 miles upstream on the Pedersen Unit of the Refuge.

Pederson Spring (USGS Site No. 09415910) has been monitored continuously by the USGS with a v-notch weir since 1986, with data gaps from 1994 to 1996 and 2003 to 2004. The v-notch weir readings are converted to flow using an independent rating developed by the USGS for the site. Finalized flow data are available through February 21, 2013 at this site. The early record is variable and may have been affected by poor check measurements, diversions from the springpool, a major fire at the site in 1994, leakage under the weir, and other factors. In April 2004, the old v-notch weir was replaced with a new v-notch weir because of leakage around the old weir. Ratings for the new weir were adapted by USGS in October 2004 and again in April 2010. The gap in the record from February 2003 to April 2004 is due to questions about leakage and accuracy of the old weir during this period. The relationship of spring discharge to EH-4 water levels is significantly different ($p=0.0000$) for the old weir and the new weir, in terms of slope and intercept (see appended data file: USGS 09415910_Pederson Sprs nr Moapa_all data_1985-2013.xlsx). This suggests that measurements from the two periods may not be comparable. For this reason, we only use the record from the new weir since 2004 when considering the relationship of Pederson springflow to EH-4 water levels.

Pedersen East Spring (USGS Site No. 09415908) has been monitored continuously since 2002 with a v-notch weir. The v-notch weir readings are converted to flow using an independent rating developed by the USGS for the site. New ratings were adapted by USGS in October 2002 and again in April 2010. Finalized flow data are available through February 21, 2013 at this site. Pedersen East Spring is the highest elevation spring in the Pedersen East Spring group but there are several other springs in the spring group that are comparable in flow. The combined flow of the Pederson East Spring group, which includes Pederson East spring, has been measured periodically with a current meter by the USGS, as discussed below.

Warm Springs West (USGS Site No. 09415920) has been monitored continuously with a flume since 1985. Flume readings are converted to discharge using the theoretical stage-discharge relationship of the flume. Finalized flow data are available through February 20, 2013 at this site. Unmetered irrigation diversions on the Refuge upstream of the site during the first half of the record resulted in

[8] There are two different spellings of this name: Pedersen with an "e" at the end is the correct spelling of the landowner's last name. Pederson with an "o" at the end is an incorrect spelling of the landowner's name, but was adopted by the USGS for the spring and stream names. We will use both spellings here, in context.

measurements that were quite variable throughout the period. The variability in flows was greatly reduced once these diversions were discontinued after 1999 (**Figure 1.21**). For this reason, we only use the measurement record after 1999 when considering the relationship of Warm Springs West discharge to EH-4 water levels.

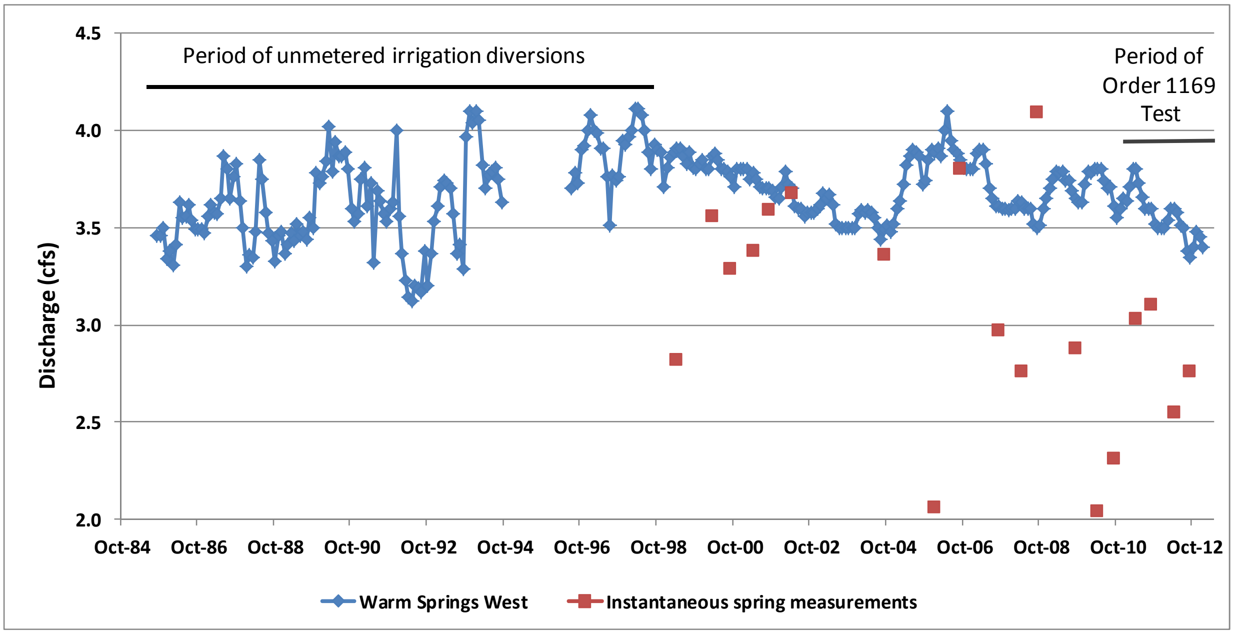


Figure 1.21. Monthly flows at the Warm Springs West gage (USGS No. 09415920) from 1985 to 2012 and the sum of instantaneous measurements collected upstream of the gage by USGS at M-11, M-12, M-13, M-19, and Pederson Spring twice a year from 1999 to 2012.

The Warm Springs West gage captures the discharge produced from Pederson and Pederson East Springs, in addition to several other smaller springs and diffuse groundwater seepage occurring upstream of the gage. The majority of flow at the gage is produced by four major spring groups (M-11, M-12, M-13, and M-19) that are larger and downstream of the Pederson and Pederson East springs. The USGS has been collecting synoptic measurements of spring discharge at these spring groups with a current meter or SonTek FlowTracker about twice a year (usually spring and fall) since 1999. The sum of the instantaneous measurements from these sites and the concurrent flow from Pederson Spring on the same date (which is not captured by any of the synoptic measurements), is shown in **Figure 1.21**. The outflow channels at these four spring groups (M-11, M-12, M-13, and M-19) are small, shallow, and narrow and are difficult to measure, resulting in much more variability than the v-notch weir or flume measurements.

The sum of these periodic measurements (**Figure 1.21**), which include all spring discharge contributing to the Warm Springs West gage, is usually less than the flow measured at the Warm Springs West gage located about 0.1 miles downstream. The remaining flow at the gage is assumed to come from diffuse groundwater seepage into the channel, upstream of the gage. Reportedly, USGS and FWS biologists have observed cool-water inputs in the lower part of the stream, just upstream of the Warm Springs West gage, while snorkeling during fish surveys.

Other USGS sites examined and discussed in this report include three USGS flow monitoring sites: the Warm Springs confluence at Iverson flume (USGS Site No. 09415927), the Muddy Springs at LDS Farm nr Moapa (USGS Site No. 09415900) and the Muddy River nr Moapa (USGS Site No. 09416000). The Iverson flume is located off the Refuge, about 0.25 miles downstream of the Plummer Unit springs, and therefore measures a combination of carbonate springflow, rainfall runoff, and diffuse groundwater seepage emanating upstream of the gage. From October 2001 through October 2008, the Iverson Flume gage measured the combined outflows of the Pedersen and Plummer Units of the Refuge. However, in October 2008, the outflow from the Pedersen Unit, downstream of Warm Springs West, was disconnected from the Plummer outflow stream and restored to a historical stream channel. The post-restoration average flow at the Iverson Flume gage is about half of the pre-restoration average since the Pederson outflow stream is no longer captured in the measurements. We only use the measurement record during the pumping test when considering the relationship of Iverson flume discharge to EH-4 water levels. Finalized flow data are available through September 2012.

In addition to the springs on the Plummer Unit, there is at least one large spring downstream of the Refuge boundary that contributes flow to the Iverson Flume gage. The USGS has collected periodic measurements of the outflow from the Plummer Unit at the Refuge boundary (USGS Warm Spring East, Site No. 364236114424301), upstream of this spring and the Iverson Flume gage. The nine measurements from 2008 through 2012 range from 2.13 cfs to 2.79 cfs and average 2.53 cfs, a little over half the post-restoration flow measured at the Iverson Flume gage since 2008. So the contribution from the large downstream spring and any other spring discharge and shallow groundwater seepage in the reach between the Refuge and the gage is considerable.

The Muddy Springs at LDS Farm nr Moapa (USGS Site No. 09415900) measures the spring discharge from the largest and lowest elevation spring in the MRSA. The spring, which had been used to maintain two swimming pools on the LDS property, has a continuous record of flow from 1985 to the present. According to the USGS site description, the site is located 0.1 miles downstream of the LDS pools and measurements at the site are affected by irrigation and recreation diversions for the pools upstream. The two large pools and the recreational facility have not been operated since they burned in the July 2010 fire, just prior to the pumping test. Finalized flow data are available through September 2012 for this site.

The Muddy River near Moapa site (USGS Site No. 09416000) measures the discharge in the Muddy River, just downstream of the MRSA. This site also has a continuous record of flow from 1985 to the present. The site measures a combination of carbonate spring discharge, shallow groundwater discharge, irrigation return flow, and rainfall runoff. We did attempt to relate discharge at the Muddy River site to carbonate water levels in EH-4 due to the influence of these other factors. Finalized flow data are available through September 2012 for this site.

We also consider data from two other spring monitoring sites in the MRSA: the daily total natural spring discharge at Jones Spring and Baldwin Spring, collected and reported by MVWD for the period August 2010 to December 2012 and available on the NDWR Order 1169 webpage http://water.nv.gov/mapping/order1169/. Both sites are located very close to the carbonate spring source and therefore, will primarily measure spring discharge from the regional carbonate springs only. The time series plot of discharge at both of these sites shows some questionable measurements during short periods of the pumping test (see appended data file: MVWD_data_Baldwin_Jones_daily_monthly 2010-2012.xlsx). We assumed there were problems with these values and we excluded data from these periods in developing the relationships between discharge and carbonate water levels during the pumping test at these sites. There was little difference in regression slopes with and without the excluded data. The appended datafile for these sites provides comparisons of the regression results.

Methods

For this section of the report, we consider monthly data for the period of the Order 1169 pumping test, which is considered to be from October 2010 to December 2012, the first and last complete months of the test. We focus on the period of the pumping test primarily but look at longer periods as well, depending on the site and the availability of data.

For the spring and flow monitoring sites, we conducted graphical and statistical analyses. We examined the relationship between discharge and climate graphically. We examined the relationship between discharge and pumping statistically, by correlating monthly discharge with monthly carbonate water levels in EH-4 for the period of the pumping test and for longer periods, where data are available. We calculated the slope and r^2 values for these relationships and estimate the maximum, minimum, and change in discharge observed during the pumping test. Because there is variability in the actual field discharge measurements, we used the regression equations from the discharge/EH-4 water level relationship to estimate discharge at a given carbonate water level.

For each site, we estimated the maximum, minimum, and change in the hydraulic head differential during the pumping test by computing the difference between the water surface elevation at the spring(s) contributing to the site and the carbonate water levels observed in EH-4 during the test. We then compared our estimates of the relative changes in hydraulic head differential during the pumping test, expressed as a percent, with the relative changes in discharge observed at each site, also expressed as a percent. Our assumption, as discussed above, is that relative changes in head differential and discharge should be approximately equal. Using the drawdown rate that we determined for EH-4 during the pumping test and the discharge/water level relationships, we estimate when discharges at key spring and flow monitoring sites will reach certain points of interest, assuming the level of pumping, drawdown, and decline in flow continue at the rate observed during the test. Lastly, we finish this part of the report with a discussion of some of the other factors that may have affected water levels and discharges during the period of the pumping test.

Results and Discussion

Pedersen Unit

Figures 1.22 and **1.23** show spring discharge at the three continuous surface water monitoring sites on the Pedersen Unit of the Refuge, along with water year precipitation in NV Climate Division 4. Springflow measurements are more variable than groundwater level measurements. Note that the discharge scale for the Warm Springs West gauge only extends from 3.0 to 4.2, while that for the Pederson gauges extend from 0.0 to 0.35. Thus the variability in the Pederson flows are proportionally larger than those for Warm Springs West. The seasonal cycles and trends in flows since 2000 generally mirror the carbonate water levels, decreasing from 2000 through 2004 due to increased carbonate pumping, increasing in 2005-2006 in response to the 2005 wet year, and declining overall during the 2-year pumping test. As with the groundwater levels, the lowest spring flows in the record at all of these sites occur during 2012, near the end of the pumping test despite the wet year in 2011. However, as can be seen on the figures, not all the spring measurement sites show the same degree of response to groundwater level declines, mainly because of differences in spring elevations, as discussed above. Next, we examine those individual responses in more detail, by considering relationships between discharge and carbonate water levels in EH-4.

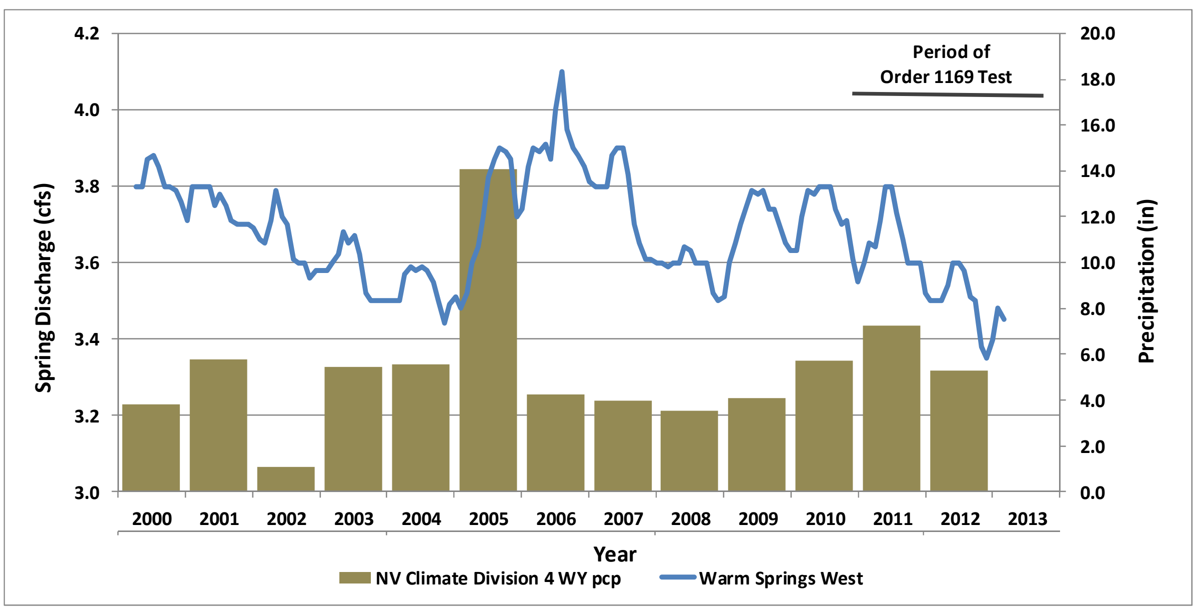


Figure 1.22. Monthly flows at the USGS Warm Springs West gage (USGS No. 09415920) and Nevada Climate Division 4 water year precipitation (centered on April of each water year) for the period Jan 2000 to Dec 2012.

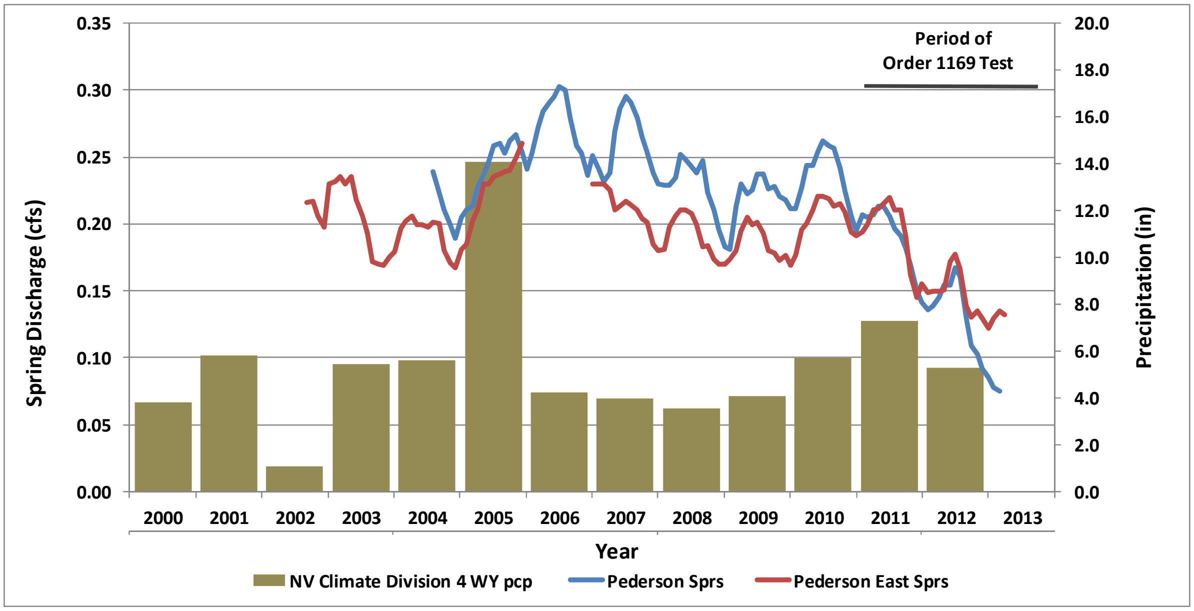


Figure 1.23. Monthly flows at the USGS Pederson Spring gage (USGS No. 09415910), Pederson East Spring gage (USGS No. 09415908), and Nevada Climate Division 4 water year precipitation (centered on April of each water year) for the period Jan 2000 to Dec 2012.

The first spring considered is the Pederson Spring, the highest elevation spring in the area (the gage datum or zero point of flow is 1810.99 ft). During the pumping test, the flows at Pederson Spring declined from a maximum of 0.22 cfs to 0.08 cfs (a 0.14 cfs or 63% reduction total from the maximum flow observed during the pumping test, **Figure 1.24**). The correlation between spring discharge and water level for EH-4 is very high (r^2 = 0.98 during the pumping test and r^2 = 0.93 for the entire 2004-2012 record). The slope of the discharge-water level relationship over the pumping test equates to -0.062 cfs (-28%) per unit foot of drawdown in the carbonate-rock aquifer. This means that for every one foot decline in the EH-4 water level, Pederson Spring loses about 0.06 cfs of discharge (about 28% relative to the maximum discharge observed during the pumping test). The next question we address is: “Is this reasonable and close to what we expect for this site?”

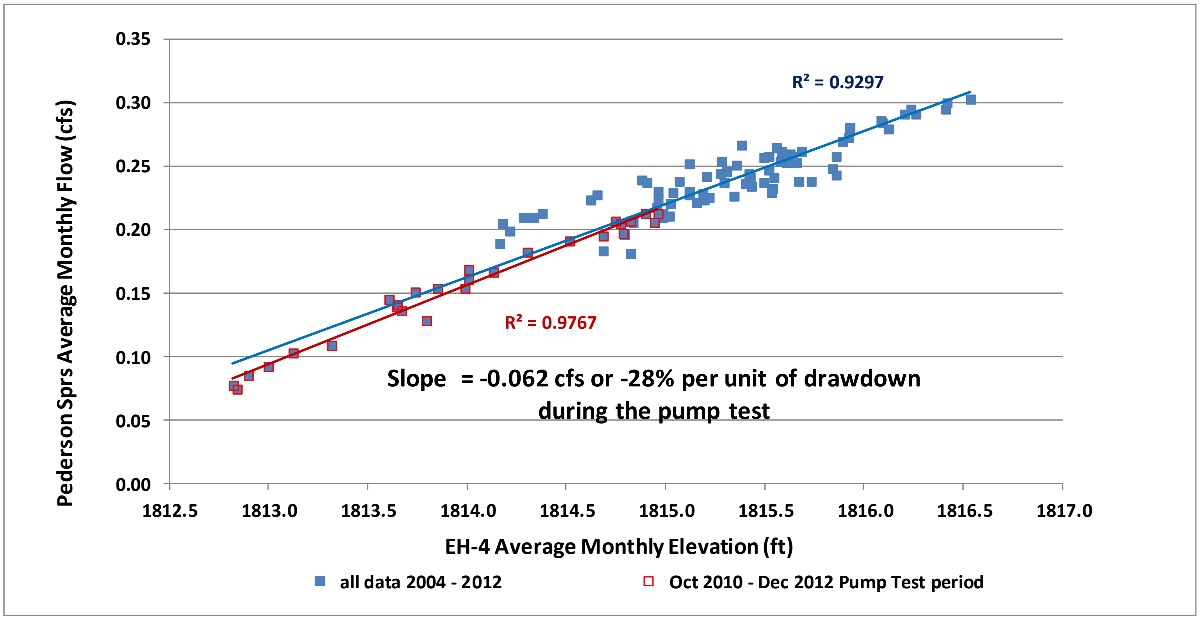


Figure 1.24. Monthly flows at Pederson Spring versus monthly carbonate water level elevations in EH-4 for the period May 2004 to Dec 2012.

The maximum and minimum monthly EH-4 carbonate water level elevations observed from October 2010 to December 2012 were 1815 ft and 1812.8 ft, respectively. At the maximum groundwater level elevation, Pederson Spring, with a water surface elevation of 1811 ft, had a hydraulic head differential of 4.0 ft (the "head differential" being estimated as the difference between EH-4 water level elevation and the spring water surface elevation). At the minimum EH-4 water level elevation observed during the pumping test, 1812.8 ft, the "head differential" is only 1.8 ft. Based on these two estimates, there is a predicted 25% decrease in hydraulic head differential per unit foot of drawdown, or a total reduction in head differential of 55% (assuming the maximum head of 4.0 ft represents 100%). Under the assumption that flow is proportionate to head, we should expect a similar percentage decline in flow. As shown above, there was a 28% decrease in flow per unit foot of drawdown or about 63% over the 2.2 foot range of carbonate water levels observed during the pumping test. The observed decline is very close to the independent estimate. The spring appears to be behaving in response to the decline in carbonate water levels and head differential as expected.

The x-intercept of the discharge/water level regression for the period of the pumping test is 1811.5 ft (**Figure 1.24**). This is the predicted carbonate water level elevation at which the spring discharge goes to zero (the spring dries up), based on the relationship between spring discharge and EH-4 levels. It differs from the estimated spring water surface elevation, perhaps because of the errors associated with the assumption that the water level in EH-4 represents the hydraulic head at the springs. Anyway, if the current rate of drawdown in EH-4 (0.92 ft/year) continues, the spring will stop flowing in about 1.5 years.

Next, we consider Pederson East Spring, which is the second highest elevation spring in the area, with a gage datum or zero point of flow of 1807.7 ft. During the pumping test, the flows at Pederson East Spring ranged from 0.22 cfs to 0.12 cfs (a 0.10 cfs or 45% reduction in total discharge, **Figure 1.25**). The correlation between spring discharge and EH-4 water level for Pederson East Spring is high during the pumping test but poorer for the entire period of record (r^2 = 0.92 during the pumping test and r^2 = 0.59 for the entire record). The reason for the poorer correlation over the entire record is not clear but it may indicate some changes or problems in the earlier flow record at the site. The slope of the relationship over the pumping test equates to -0.043 cfs (-21%) per unit foot of drawdown in the carbonate-rock aquifer. This means that for every one foot decline observed in the EH-4 water level, Pederson East Spring loses about 0.04 cfs (or about 21% per unit foot of drawdown). This is less than Pederson Spring, as expected, since Pederson East Spring is slightly lower in elevation and has a greater hydraulic head differential, and therefore, should be less sensitive to drawdown (see **Figure 1.19**).

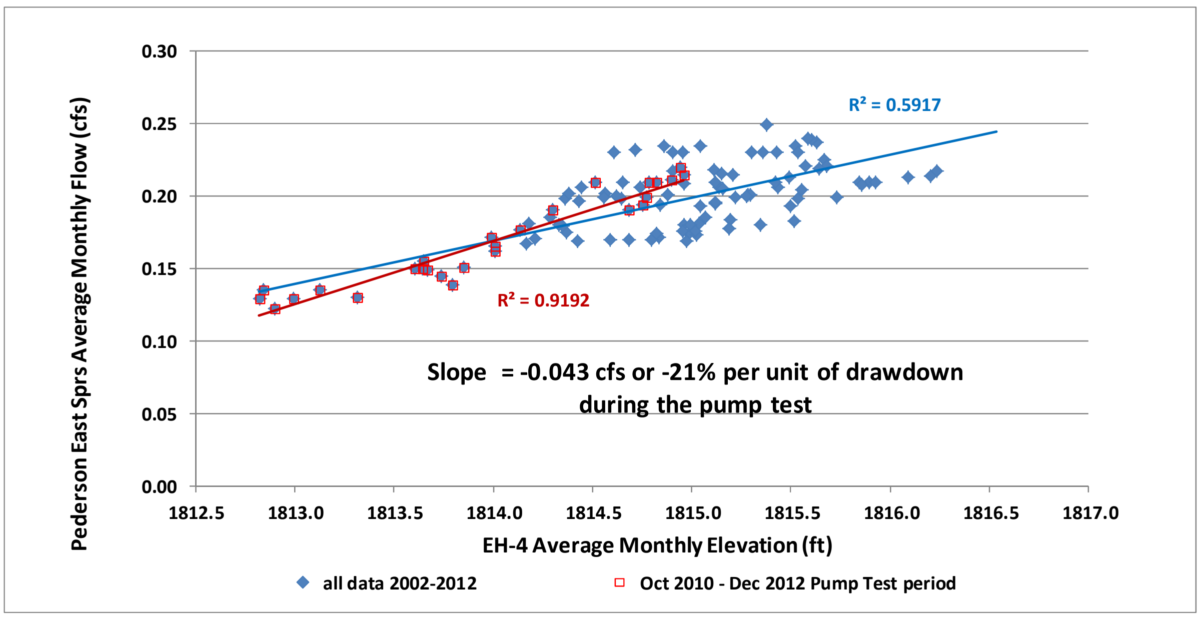


Figure 1.25. Average monthly flows at Pederson East Spring versus carbonate water level elevations in EH-4 for the period June 2002 to Dec 2012.

At 1815 ft., the maximum EH-4 carbonate water level elevation observed during the pumping test, Pederson East Spring has a hydraulic head differential of 7.3 ft (based on a water surface elevation of 1807.7 ft). At 1812.8 ft., the minimum EH-4 elevation observed, the "head differential" is 5.1 ft, which represents a 30% reduction in head from the maximum EH-4 water level elevation during the test. For every unit foot of drawdown, we expect about a 14% decrease in hydraulic head differential and flow. As shown above, the observed decline in flow was greater than this, about 21% per unit of drawdown or about 45% over the range of carbonate water levels. Nevertheless, the estimated and observed reductions are less than at Pederson Spring, and the Pederson East Spring discharge appears to be less sensitive to drawdown, as expected.

The x-intercept of the regression for the period of the pumping test is 1810.1 ft (**Figure 1.25**). This is the predicted carbonate water level elevation at which the spring discharge will go to zero. As with Pederson Spring, the elevation of the x-intercept of the regression differs from the water surface elevation of the spring, perhaps because of errors associated with the assumption that EH-4 exactly represents the hydraulic head at the spring. If the current rate of drawdown in EH-4 (0.92 ft/year) continues, the spring will stop flowing in about 2.5 to 3 years.

The relationship of Warm Springs West flow to carbonate water levels in EH-4 is shown in **Figure 1.26**. The correlation between discharge and water level for Warm Springs West is fairly high during the pumping test and for the entire period of record (r^2 = 0.79 during the pumping test and r^2 = 0.70 for the entire record). We may expect a poorer correlation between discharge and carbonate water levels at this site compared to the other two spring sites because the site is downstream of the major springs and may be responsive to shallow basin-fill aquifer water levels and rainfall runoff, as well as carbonate-rock aquifer water levels.

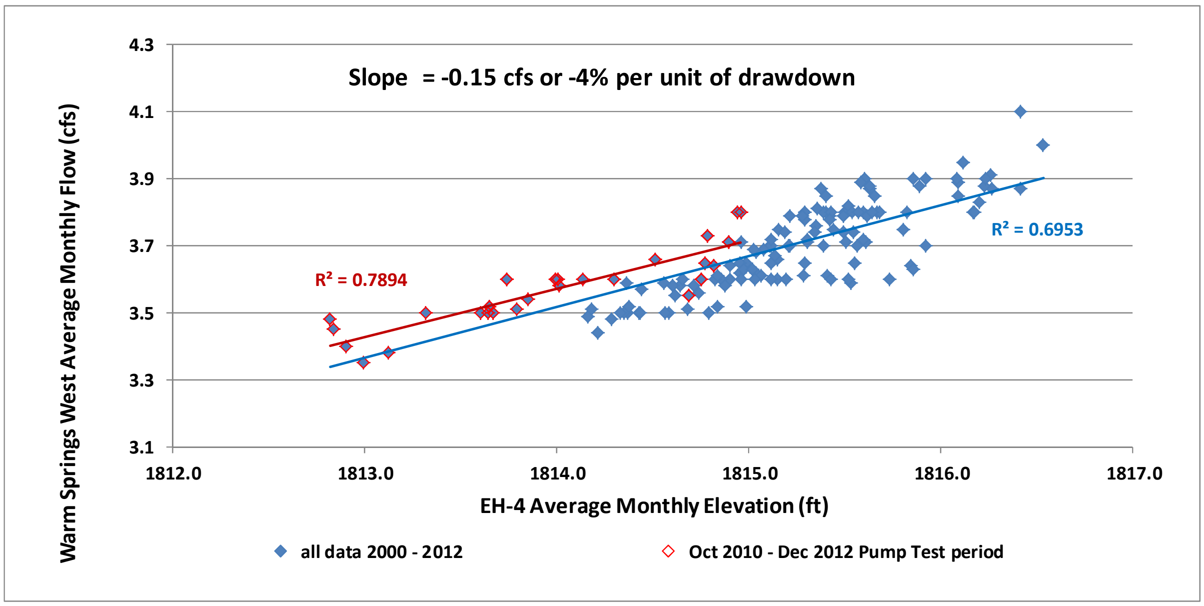


Figure 1.26. Average monthly flows at Warm Springs West versus carbonate water level elevations in EH-4 for the period Jan 2000 to Dec 2012.

During the pumping test, Warm Springs West declined from an average flow of 3.72 cfs, at a carbonate water level elevation of 1815.0 ft, to an average flow of 3.40 cfs, at a water level elevation of 1812.8 ft. The total decline equates to about 0.32 cfs (9%) or about a 4% decrease from the pre-test flow rate per unit foot of drawdown. The total decline, 0.32 cfs, is 0.09 cfs greater than the sum of the declines (0.13+0.10=0.23 cfs) observed in the Pederson and Pederson East Springs, located upstream of the gage. Note that there appears to be little or no decline in flow during the first year of the pumping test at the Warm Springs West gage; most of the decline is observed in the second year (see **Figure 1.22**). We believe that higher precipitation during the first year of the pumping test may have increased shallow groundwater seepage upstream of the gage and countered some of the effects of pumping.

Next, we compare the observed decline with the estimates of the expected decline at the Warm Springs West gage, given the range of carbonate water levels at EH-4 observed during the pumping test. Since the Warm Springs West gage measures the combined discharge from a number of individual springs, estimating the hydraulic head differential at the site is more involved. The majority of flow at the Warm Springs West gage is accounted for with measurements at Pederson Spring and the four major spring groups measured by the USGS twice a year: Spring 19, Spring 13, Spring 12, and Spring 11. (The discharge at Pederson East Spring is included in the measurement at Spring 19). Beck et al. (2006) provides information on the approximate elevation of these different spring groups. Using these approximate elevations, we estimated the reduction in head differential at each spring group and applied this reduction to the average flow, available from the periodic measurements from each of the spring groups (M-19, M-11, M-12, M-13).

The approximate elevations, average flows, estimated head differentials, and estimated reductions in head for each spring or spring group are shown in **Table 1.2**. Because the periodic flow measurements at the spring groups are so variable, we used the measurements from September 2007 to September 2010 (a period when EH-4 elevations averaged 1815.2 ft, see **Figure 1.2** and **1.3**) to calculate the average flow at each of the four spring groups prior to the start of the pumping test. The total discharge at all four measurement sites, along with flows at Pederson Spring, averaged 2.88 cfs for this period (these measurements are plotted **Figure 1.21**). The average of the daily flows at the Warm Springs West gage on concurrent dates for the same period is 3.65 cfs. Approximately 80% of the flow at the Warm Springs West gage is accounted for with the spring measurements during the 2007 to 2010 period.

Using the maximum and minimum carbonate water levels observed at EH-4 during the pumping test, (1815 ft to 1812.8 ft), the proportional reductions in head differential at the five spring groups are 55% at Pederson Spring and 9% to 17% at the other four spring groups. Multiplying the estimated proportional reduction in head differential by the average flow from 2007-2010 at each of the five spring groups shows that the contribution of the springs should have been reduced in total by about 0.5 cfs during the pumping test. Applying a similar reduction in flow at the Warm Springs West gage means the flow during the pumping test should have declined by about 0.5 cfs or 14% in total. The observed decline during the pumping test was slightly less than this, about 0.32 cfs or about 9% in total. Nevertheless, the relative decline at Warms Springs West is considerably less than at Pederson and Pederson East Springs, as expected based on the lower elevations of the other springs.

Plummer Unit, Apcar Unit, and other MRSA Sites

Next, we examine the observed and/or expected reductions in discharge at springs on the Plummer and Apcar Units and elsewhere in the MRSA, given the changes in carbonate water levels observed during the pumping test. Springs in all of these areas are lower in elevation than the springs on the Pederson Unit, so they are expected to be less sensitive to declines in carbonate water levels.

Table 1.2. Periodic measurements and characteristics for the major spring groups on the Pedersen Unit.

Spring or spring group	Water surface elev (ft)	Estimated head differential (ft) at EH-4 = 1815 ft	Average flow (cfs) 2007-2010	Estimated reduction during pumping test (%)	Estimated flow in Dec 2012
Pederson Spring	1811.0	4	0.23	55%	0.10
M-19 (this site includes the discharge from Pederson East Spring)	1802.0	13	0.86	17%	0.71
M-13	1799.5	15.5	0.69	14%	0.59
M-12	1798.5	16.5	0.31	13%	0.27
M-11	1791.5	23.5	0.79	9%	0.72
Total of all springs			2.88		2.40
Warm Springs West (average on same dates)			3.65		*3.17**

This is the estimated flow, applying the reduction that should have been observed at the Warm Springs West gage during the pumping test. As shown above in* ***Figure 1.28**, the flow at Warm Springs West during the pumping test ranged from 3.72 cfs at 1815 ft to 3.40 cfs at 1812.8 ft.*

Monthly flows at the USGS Iverson gage along with water year precipitation in NV Climate Division 4 are shown in **Figure 1.27** for the period October 2008 to December 2012, the period following the restoration of the Pederson channel. Flows were fairly stable during the first part of the pumping test but decreased slightly during the last part of the pumping test. The timing of the decline is similar to Warm Springs West and the flows at this site may have been influenced by the 2011 wet year as well.

The variability and increase in flows observed in 2008-09 may be a response to the restoration itself. The Plummer stream bank at the site of the old Pederson confluence was reconstructed and "shored up" as part of the restoration. There was likely a temporary increase in channel losses along this section of the channel after the restoration. As the reconstructed stream bank became saturated and sealed itself, channel losses would have declined, resulting in an increase in flows measured downstream at the Iverson flume. We have observed a similar response (a period of high initial channel losses followed by recovering flows) with stream restoration work at Ash Meadows NWR. Since this increase is believed to be an artifact of the restoration work, we didn't attempt to correlate discharge with carbonate water levels prior to the pumping test.

The relationship of Iverson Flume flows to carbonate water levels in EH-4 during the pumping test is shown in **Figure 1.28**. The relationship is poor (r^2=0.42) but this is not surprising since the site is located a considerable distance from the springs (about 0.25 miles downstream) and measurements may be responsive to shallow basin-fill aquifer water levels and rainfall runoff, as well as carbonate-rock aquifer water levels. Discharge measurements at the Iverson Flume gage ranged from an average of 4.64 cfs to 4.38 cfs during the pumping test (finalized data are available only through Sept 2012). This is a decline of 0.13 cfs (2.7%) per unit foot of drawdown and 0.25 cfs (5%) over the first two years of the pumping test. Extrapolating this rate of decline through December 2012 gives a total decrease in discharge of 0.28 cfs or 6% during the pumping test.

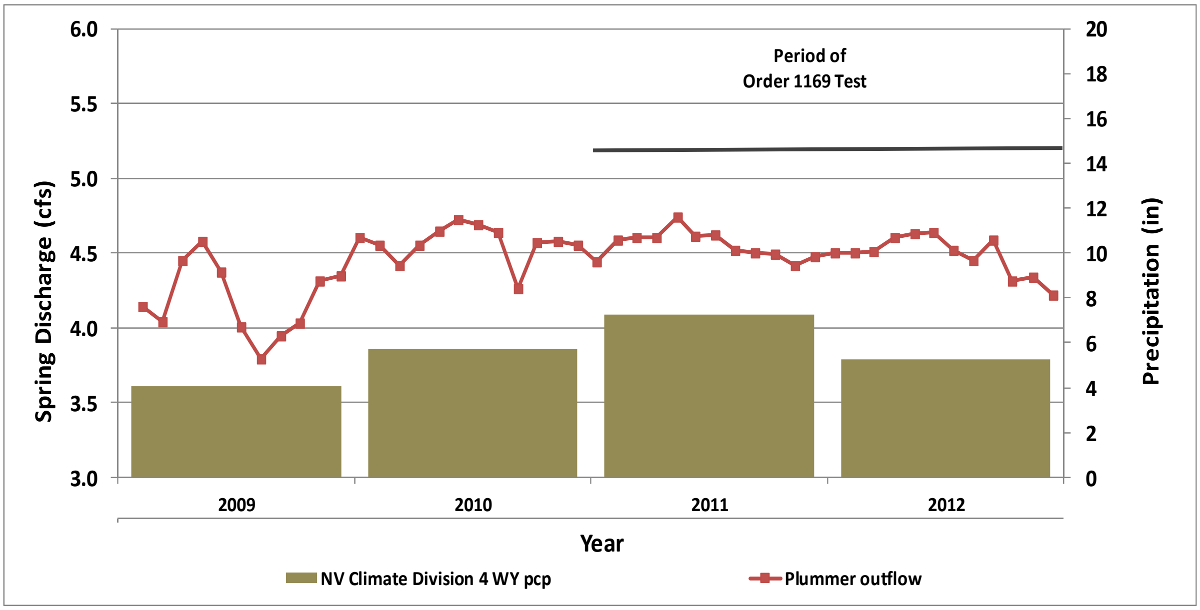


Figure 1.27. Monthly flows at the USGS Iverson Flume gage (USGS No. 09415927) for the period Oct 2008 to Sept 2012 and Nevada Climate Division 4 water year precipitation (centered on April of each water year) for the same period.

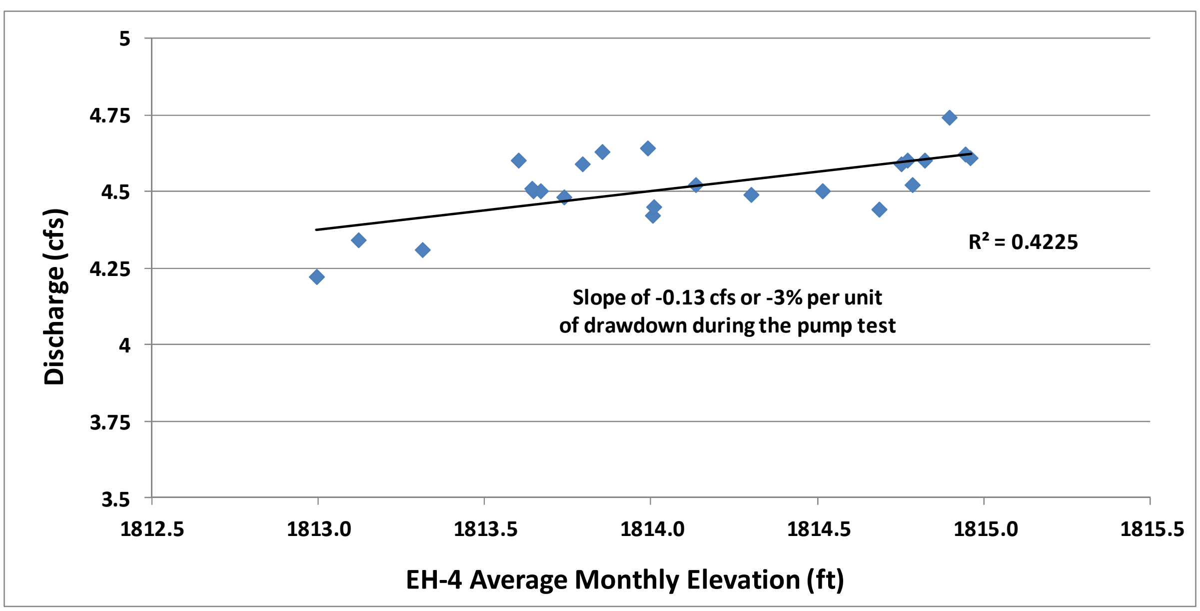


Figure 1.28. Average monthly flows at the Iverson Flume versus carbonate water level elevations in EH-4 for the period Oct 2010 to Sept 2012.

The springs contributing to the Plummer stream outflow are much lower in elevation than those on the Pederson Unit. Beck et al. (2006) give the elevations of USGS sites M-15, M-16, and M-20 (all measuring springs on the Plummer Unit) as 1749.2, 1757.2, and 1749.8 ft, respectively. This means there was 58 to 66 ft of head differential or more at these springs at the start of the pumping test. The spring(s) downstream of the Refuge are even lower in elevation and less sensitive to drawdown, but they contribute close to half of the discharge measured at the Iverson Flume gage. Applying the 2.2 ft decline of carbonate water levels observed during the pumping test indicates the head differential at the Plummer Unit springs was reduced by 3% to 4%. The observed decline of 6% for the pumping test is slightly greater than what is estimated for the Plummer Unit, although the discharge/water level relationship is poor and the regression slope estimate has a large uncertainty in it.

The time series plots of daily total natural discharge at Jones and Baldwin Springs for the period of the pumping test is shown in the appended data file for these two sites. The relationship of the monthly total natural discharge at both springs to monthly carbonate water levels in EH-4 is shown in **Figure 1.29**. At Jones Spring, the correlation is very high during the pumping test (r^2 = 0.90). For the period of the pumping test, Jones Spring declined from an average flow of 1.61 cfs, at a carbonate water level elevation of 1815.0 ft, to an average flow of 1.55 cfs, at a water level elevation of 1812.8 ft. This is a decline of 0.027 cfs (1.7%) per unit foot of drawdown or about 0.06 cfs (4%) in total.

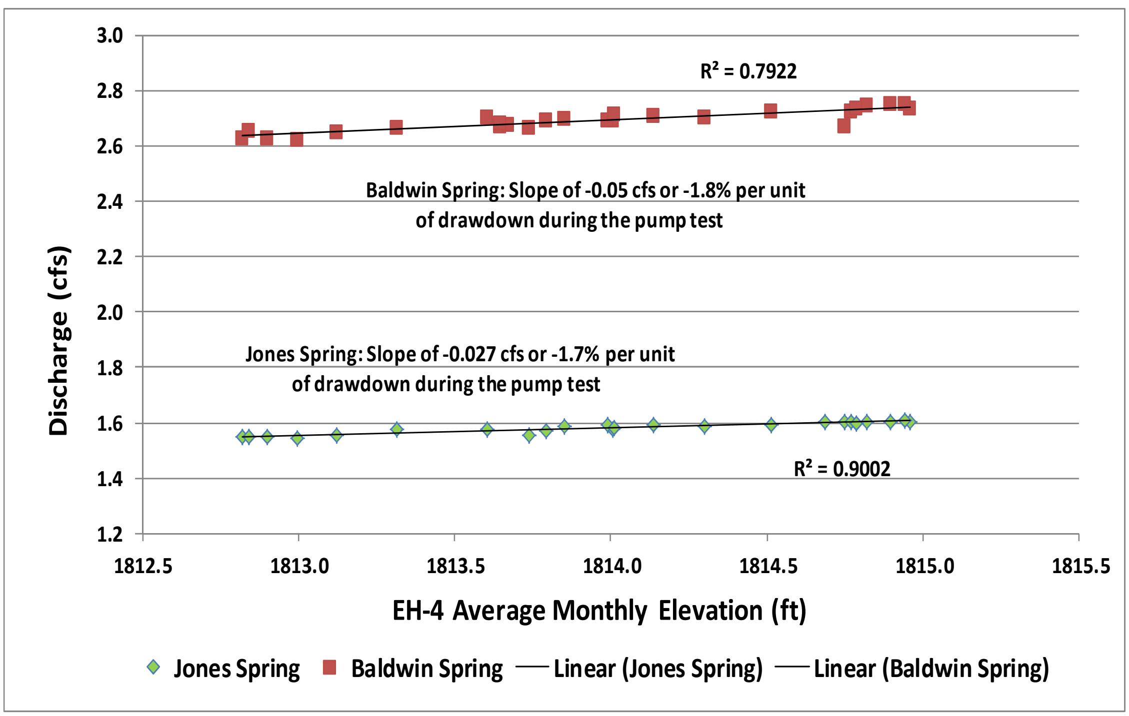


Figure 1.29. Average monthly flows at the Jones Spring and Baldwin Spring versus carbonate water level elevations in EH-4 for the period Oct 2010 to Dec 2012 (excluding Oct-Dec 2011 at Jones Spring and Oct 2010 at Baldwin Spring as discussed in Data Sources and Data Quality).

Beck et al. (2006) gives the elevation of a benchmark located 140 ft northwest of the Jones Spring pumphouse as 1775.72 ft. The actual spring elevation is unknown but assuming the springhead is the same elevation, the estimated hydraulic head differential is 39 feet at the spring at the start of the pumping test. A 2.2 ft drawdown in carbonate water levels represents a 6% decrease in the total head differential at the spring. Based on this, we would expect a 6% decrease in flow during the pumping test. The observed decline in flow of 4% during the pumping test is slightly less than this.
At Baldwin Spring, the correlation between total natural discharge and carbonate water levels in EH-4 is fairly high for the period of the pumping test (r^2 = 0.79, **Figure 1.29**). During the pumping test, Baldwin Springs discharge declined from an average flow of 2.74 cfs, at a carbonate water level elevation of 1815.0 ft, to an average flow of 2.63 cfs, at a water level elevation of 1812.8 ft. This is a decline of 0.05 cfs (1.8%) per unit of drawdown or about 0.11 cfs or 4% in total.

The elevation of a benchmark 100 feet east of the pumphouse at Baldwin Spring is 1775.68 ft (Beck et al., 2006). This is almost equal to the benchmark elevation for Jones Spring above. As with Jones Spring, the actual spring elevation is unknown, but assuming the springhead is the same elevation, then the elevation and head differential is the same as Jones Spring. The 2.2 ft decrease in carbonate water levels observed at EH-4 during the pumping test should result in a predicted decrease of 0.16 cfs (6%) in total. The observed decline of 4% total is slightly less than this (**Figure 1.29**). It is interesting to note that relative declines in flow observed at Jones Spring and Baldwin Spring are equal, although the absolute flows are almost double at Baldwin Spring. Based on the hypothesized relationship discussed above, the relative declines are expected to be equal, given the similarity in spring elevations.

The time series plot of discharge at the Muddy Springs at LDS Farm gage and the Muddy River nr Moapa gage are presented in **Figure 1.30** for January 2000 to September 2012, along with water year precipitation in NV Climate Division 4. Muddy Springs is the largest and lowest elevation spring in the MRSA, with an average flow of 7.6 cfs since 2000 and a water surface elevation of 1745.34 ft (Beck et al. 2006). With an estimated hydraulic head differential of 70 ft, this spring is expected to be the least sensitive to drawdown of any of the springs in the MRSA. Reportedly, according to the USGS, the site is not responsive to precipitation, unlike other flow monitoring sites in the area. This can be seen in the time series plot in the appended data file (USGS 09415900_Muddy Sprs at LDS Farm nr Moapa NV_all data_1985-2012.xlsx), which shows a lack of any clear wet year response, including 2005.

Muddy Spring flows are inversely correlated with carbonate water levels in EH-4 (r^2 = 0.45) during the pumping test, increasing with decreasing carbonate water levels, in contrast to all the other sites (see appended data file). This means there is a slight increase in flow during the pumping test. The correlation is very poor and the residuals with time show a major positive deviation in the second year of the pumping test, indicating a step change in the relationship due to some other factor. The most likely factor is the fact that the two large pools were drained and the recreational facility was essentially abandoned sometime after the fire that occurred in July 2010.

Flows at the Muddy River nr Moapa site show lots of variability and also a slight increasing trend in recent years (**Figure 1.30**). As discussed below, this site is likely responding to several factors including wetter than normal precipitation in 2011, fire effects, and land use changes and restoration activities in the MRSA. We did not attempt to correlate Muddy River flows to carbonate water levels.

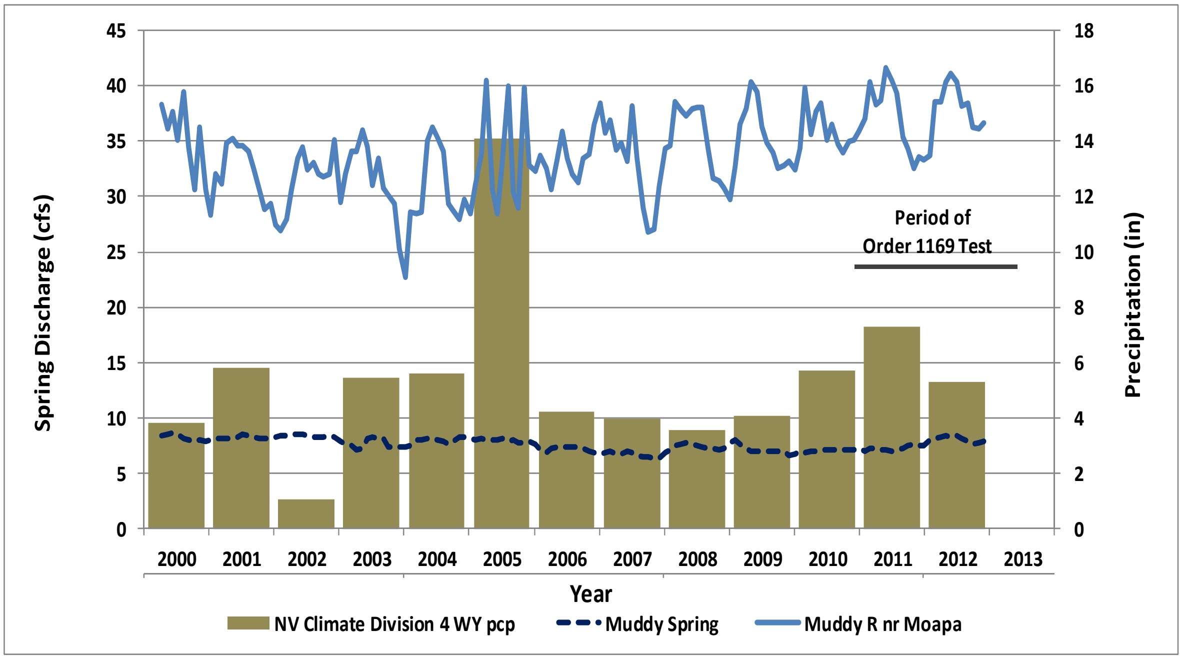


Figure 1.30. Monthly flows at the USGS Muddy Springs at LDS Farm nr Moapa (USGS Site No. 09415900) and the Muddy River near Moapa (USGS Site No. 09416000) for the period Jan 2000 to Sept 2012 and Nevada Climate Division 4 water year precipitation (centered on April of each water year) for the same period.

Other Factors Affecting Spring Discharge and Water Levels

Carbonate water levels and spring discharge in the MRSA are responding to several factors simultaneously and some of these factors cause opposing responses. The major factors that affect water levels and spring discharge in the area are precipitation and carbonate pumping (see the multiple regression presented earlier and Mayer and Congdon, 2008). The influence of precipitation and the wet year in water year 2011, which started in October 2010 at the same time as the pumping test, likely mitigated some of the response to pumping at Warm Springs West gage and the Iverson Flume gage (**Figure 1.22** and **1.27**). Neither flow gage appears to show declines in response to pumping until the 2nd year of the pumping test. The wet year may also be related to recent increases observed at Muddy Springs and the Muddy River gages, although other factors are likely involved as well.

One other factor could be the fire on July 1, 2010 in the MRSA that burned 600 acres, adjacent to the Refuge (**Figure 1.31**). The fire, which occurred just three months prior to the start of the pumping test, destroyed vegetation and resulted in a reduction in ET and an instantaneous increase in shallow water levels in the area of the burn (Christi Emery, SNWA, personal comm. related to a poster presented at the Nevada Water Resources Association 2013 annual conference). Huntington et al. (2013), in Figures 11, 13, and 14, present ET and precipitation in the MRSA from calendar years 2001 to 2012. While precipitation in CY 2005 and CY 2010 were about equal, ET in CY 2010 was much less than in CY 2005, likely because the fire burned much of the vegetation in the area. Figures 11 and 13 indicate that ET stayed low in CY 2011 and CY 2012, after the fire, as well. Precipitation and groundwater discharge that was not lost to ET probably made its way to the river, resulting in higher streamflows in the river. The burned area also included the pool and recreational facility upstream of the Muddy Springs gage, which may be partly responsible for the increase in flows observed at that site.

Figure 1.31. Aerial photo of burned area in the MRSA from the fire that occurred on July 1, 2010, just prior to the pumping test. The extent of the burned area is estimated to be about 600 acres. The view is looking to the southeast.

The ongoing removal of palm trees and tamarisk and the retirement of irrigated lands in the area over the last several years are also important land use changes that are contributing factors. All of these factors are expected to reduce ET and increase shallow water levels and flows in the MRSA. A recent report by DRI (Huntington et al., 2013) estimated that ET in the MRSA has declined about 600 to 900 af over the period 2001-2012. Three of the four SNWA monitoring wells located near the Refuge (Lower Pederson MW1, Stone Cabin MW2, and Francis Taylor) show increasing shallow aquifer levels during the period of the pumping test (see appended file: SNWA shallow monitoring wells_MRSA_periodic meas 2009-2012.xlsx). Because the shallow basin-fill aquifer likely contributes to flow at all the flow monitoring sites (sites located downstream of springs, including the Warm Springs West gage, the Iverson Flume gage, the Muddy Springs gage, and the Muddy River gage), the discharge at these gages may have been affected as well. We propose that while carbonate water levels and spring discharge were decreasing in response to increased carbonate pumping during the pumping test, some of these other factors may have contributed to increases in flows.

Conclusions for Impacts to Springs

Table 1.3 summarizes the results from the analyses. Pederson Spring, Pederson East Spring, Apcar Spring, and Baldwin Spring are all spring monitoring sites that are located at the outflows of springs and only measure regional spring discharge. These spring monitoring sites show the highest correlations with carbonate water levels in EH-4. All four sites showed declines during the pumping test and the relative declines were proportional to the estimated reduction in hydraulic head differential at each spring. Pederson and Pederson East Springs, the highest elevation springs, showed observed declines of 62% and 45%, respectively, during the pumping test. These springs are the most sensitive to groundwater pumping because they have the smallest hydraulic head differential. The Apcar and Baldwin springs, approximately equal in elevation and both lower than Pederson or Pederson East springs, showed observed declines of 4% during the pumping test. Predicted declines in flow, based on changes in head differential, are similar to the observed declines in flow at each spring (see **Table 1.3**). The system is responding to pumping impacts and drawdown as hypothesized (see **Figures 1.18 and 1.19**).

Other flow monitoring sites (sites located some distance from spring sources), such as Warm Springs West and the Iverson flume, were not as highly correlated with carbonate water levels in EH-4. Nevertheless, these sites still showed declines during the pumping test and the declines were approximately proportionate to the expected reductions in head differentials at the springs contributing to the sites. Warms Springs West and the Iverson gage declined about 9% and 6%, respectively, during the pumping test.

Two other flow monitoring sites, the Muddy Springs at LDS Farm and the Muddy River nr Moapa, showed increases in flow during the pumping test. The Muddy Springs is the lowest elevation spring in the MRSA and is therefore least affected by drawdown. Increasing flows at this site during the pumping test may be a result of upstream effects from the fire that led to changes in the operation of the pool and recreational facility. Other factors may have contributed to flow increases at both of these sites as well including 1) the high precipitation during the first year of the pumping test; 2) the fire and loss of vegetation in July 2010 just prior to the pumping test; and 3) the ongoing removal of tamarisk and palm trees and the retirement of irrigation lands in the area. These factors may have ameliorated or obscured some of the pumping impacts at these gages.

The total sum of the reductions in discharge during the period of the pumping test is 0.77 cfs or about 1250 af. This is about 13% of the total MX-5 pumping in CSV during the test and only about 6% of the total volume of carbonate pumping (19,914 af) during the test in CSV, MRSA, Garnet Valley, Hidden Valley and California Wash. As carbonate pumping continues, carbonate water levels will decrease further and the volume of groundwater discharge captured through reduced springflow and ET will increase until the system reaches a new equilibrium and the pumping rate equals the captured discharge rate (Bredehoeft, 2007; Bredehoeft and Durbin, 2009).

With respect to spring discharge impacts, if the current rate of pumping, drawdown, and decline in discharge observed during the test continues in the near-term, Pederson Spring, the highest elevation and most sensitive spring in the MRSA, will reach zero discharge in about 1.5 years. Pederson East Spring, the second most sensitive spring, will reach zero discharge in about 2.5 to 3 years. We note again that the annual carbonate pumping rate in CSV during the test was only about one-third of the total appropriated volume in that basin.

Table 1.3. Summary of Results for Impacts to Spring Discharge

Site name	Type of site	Site elevation (mean sea level)	Correlation with EH-4 carbonate water levels (r^2) during the pumping test	Relative changes in observed discharge during the pumping test (% per foot of drawdown)	Total change predicted during the pumping test (cfs) (based on estimated head changes)	Total change observed during the pumping test (cfs) (based in observed changes in flow)
Pederson Spr	Spring Monitoring	1811	0.98	-28%	0.12	0.13
Pederson East Spr	Spring Monitoring	1807.7	0.92	-20%	0.07	0.10
Warm Springs West (includes Ped Spr and Ped East Springs)	Flow Monitoring	1792 to 1811	0.79	-4%	0.50	0.32
Jones Spr	Spring Monitoring	1776	0.90	-2%	0.06	0.06
Baldwin Spr	Spring Monitoring	1776	0.79	-2%	0.11	0.11
Iverson Flume	Flow Monitoring	1749 to 1757	0.42	-3%	0.16	0.28
Muddy Springs	Flow Monitoring	1745	0.45	+7%		
Total Reduction in Discharge					0.83	0.77*

**Sum of Warm Springs West, Iverson Flume, Jones, Baldwin (the Warm Springs West gage includes Pederson and Pederson East Springs). The sum of predicted changes in flow at these four gages is very close to the observed sum, but that is mainly because of compensating errors at the two flow monitoring gages: Warm Springs West and Iverson Flume. We didn't predict changes in flow at Muddy Springs due to the influence of other factors at that gage.*

Section 2 – Modeling of Groundwater Pursuant to the Pending Applications

Modeling Simulations of Pumping Impacts to Groundwater and Springs

In this section of the report, we use a numerical groundwater flow model developed by Tetra-Tech (2012a) to evaluate the impacts to groundwater levels and springs discharge from various pumping scenarios. We also use the model to simulate the recovery of the system if the MX-5 pumping had ceased after the pumping test was completed in December 2012.

Tetra Tech Groundwater Flow Model

On behalf of three Department of the Interior bureaus (the US Fish and Wildlife Service, National Park Service, and Bureau of Land Management), Tetra Tech (2012a) prepared a three-dimensional model of groundwater flow of part of the Colorado River Flow System. This model is intended to provide information on the long-term effects of existing and future groundwater use on the groundwater system, which includes resources that are the responsibility of these three bureaus.

The model domain includes all basins in which groundwater right applications are pending under Order 1169. The model simulates groundwater flow in the regional carbonate-rock aquifer system that is the source of the Muddy River Springs, Muddy River, and likely contributes to warm springs of Lake Mead National Recreation Area. Tetra Tech Model Version 1.0 (described in detail in Tetra Tech 2012a) is a three dimensional, 18-layer groundwater flow model developed using MODFLOW-2000, a widely used finite difference groundwater flow code developed by the U.S. Geological Survey, calibrated over the following time frames:

- Transient groundwater level and spring and stream discharge measurements, 1949 to 1987, representing a 39-year period of basin-fill pumping in the MRSA. Initial conditions were established by running the model to steady state under pre-pumping conditions.

- Transient groundwater level and spring and stream discharge measurements, October 2008 to December 2011, including the first year of the 2-year Order 1169 pumping test. Calibration focused on CSV and the MRSA.

Simulations of the Potential Effects of Pumping the Pending Applications

A series of pumping simulations were performed using the Tetra Tech Model Version 1.0 to estimate the effects of pumping various subsets of existing rights and pending applications within the model domain, including pending applications held in abeyance under Order 1169 (Tetra Tech 2012b). These pumping scenarios included:

- Scenario 1 – Current locations and rates of pumping;
- Scenario 2 – All existing groundwater rights, pumped and unpumped;
- Scenario 3 – All existing groundwater rights, plus all large[9] pending applications filed through 1989
- Scenario 4 – All existing groundwater rights, plus all large pending applications filed through 1994;
- Scenario 5 – All existing groundwater rights, plus all large pending applications filed through 1999;
- Scenario 6 – All existing groundwater rights, plus all large pending applications filed through 2004; and
- Scenario 7 – All existing groundwater rights, plus all large pending applications filed through 2009.

Tetra Tech (2012b) includes a series of figures showing time-series of simulated groundwater levels and spring/stream discharges and contour maps of simulated drawdown for each of the above pumping scenarios. Contour maps provided in Tetra Tech (2012b) depict simulated drawdown of the water table at a series of elapsed times since the end of 2011 (end of the last calibration run). Time axes for simulated time-series hydrographs depict time elapsed since the end of 2011. The discussion presented below will focus on the simulation results for Scenarios 1, 2 and 3 as they pertain to CSV and the MRSA.

Figure 2.1 (Figure 3.1-2a of TetraTech 2012b) shows the simulated spring discharge in the MRSA for Scenario 1, which evaluates the long-term pumping impacts resulting from a continuation of the current locations and rates of pumping. The model predicts that the discharge from the springs will decline as the existing pumping captures flow from the springs. Discharge from the Pederson spring is predicted to cease after nearly 500 years, but is nearly dry after 200 years. If all existing permitted water rights (used and unused) were pumped (Scenario 2), the model-predicted declines are more significant (**Figure 2.2**, or Figure 3.2.2a from Tetra Tech 2012b), with the Pederson and Cardy Lamb springs predicted to cease flowing in 30 and 60 years, respectively. Finally, **Figure 2.3** (Figure 3.3-2a of Tetra Tech 2012b) shows the simulated spring discharge in the MRSA for Scenario 3, which evaluates the long-term impacts resulting from pumping all existing permitted water rights (used and unused) and all large pending applications in the area filed through 1989, including SNWA's pending water rights in CSV. Under this simulation, the model predicted declines are more significant than under Scenario 2, indicating that the discharge from all of the major springs in the MRSA will cease flowing within 10 years (Pederson Spring) to 150 years (Muddy and Plummer springs). Declines in flow from the springs will affect the flow in the Muddy River downstream from the springs, and impact downstream water users. The following section compares the modeled and observed effects of the Order 1169 pumping using a longer dataset than available for calibrating the model. This analysis found that the model under-simulates the effects of the pumping. Thus, springs will dry up quicker than estimated by the model.

[9] 'Large' pending groundwater right applications refers to applications for 1,000 or more acre-feet per year (Tetra Tech, 2012b).

Post-Audit of Second Year of the Order 1169 Test

A post-audit analysis of the Tetra Tech model (Tetra Tech 2013) was performed, using data collected during 2012, the last year of the test. Calibration of the model was based in part on the observed responses to pumping of the carbonate-rock aquifer in Coyote Spring Valley (CSV) over the first part of the Order 1169 test, during the period September 2010 through December 2011. Data are now available on the effects of pumping in CSV through December 2012. The first part of this section is designed to determine how well the modeling results agree with the water-level drawdown and spring discharge data collected in 2012. The model was not re-calibrated to the more recent information. The results can be used to estimate whether the model over predicts or under predicts the effects of pumping in CSV. The conclusions of this evaluation should only be applied to the effects of pumping in CSV, and not from other Hydrographic Areas.

The post-audit simulation was performed with the long-term model described in Tetra Tech (2012a), modified to include an additional 12 months of pumping to cover the period January 1, 2012 through December 31, 2012. Details are provided in Tetra Tech (2013). In addition, the model simulation time was extended an additional 15 years (2013 to 2027) to evaluate the time required for the groundwater system to recover from the effects of Order 1169 pumping. These changes and the results are discussed later in this section. Briefly, the Multinode Well package dataset in the model was modified by incorporating the reported monthly pumping volumes into additional monthly stress period records. If reported values were not available for a well during 2012, the average of the monthly pumping for the previous three-year period was used for the applicable month in 2012, under the assumption that water needs in 2012 were similar to those in recent years. Other data sets were extended as well, and the changes are described in Tetra Tech (2013).

Figure 2.4 (Figure 2-3 of Tetra Tech 2013) shows the simulated and observed water-level changes, for selected wells. The addition of another year of MX-5 pumping to the simulation, and the comparison of simulated and observed drawdown, makes it evident that the model under-simulates the amount of drawdown that is being caused by pumping of the carbonate-rock aquifer. Tetra Tech (2012a, p. 45) had noted that the model does not simulate short-term (seasonal) variability in some areas where it is observed, and suggested that adjustment of carbonate transmissivity and storage parameters may improve the model fit to observed changes in water levels. Additionally, it was unclear, based on simulating pumping through 2011, whether the model under-simulated the amount of drawdown (i.e., calculated less drawdown than occurred) caused by pumping at MX-5. The current results clearly indicate that the model under-simulates the amount, and probably the extent and timing, of drawdown. For example, at CSVM-6 (located about 3 miles north of MX-5), the simulated drawdown is approximately 0.6 feet, while the observed is up to 2.4 feet. At CSVM-2 and CSV-3, approximately eight to ten miles south of MX-5, the measured drawdowns were up to 2 feet, but the simulated values are less than 0.5 feet. In California Wash, the observed drawdown was also about 2 feet (Paiute M-1 and Paiute M-3) but the simulated drawdown is 0.3 feet or less.

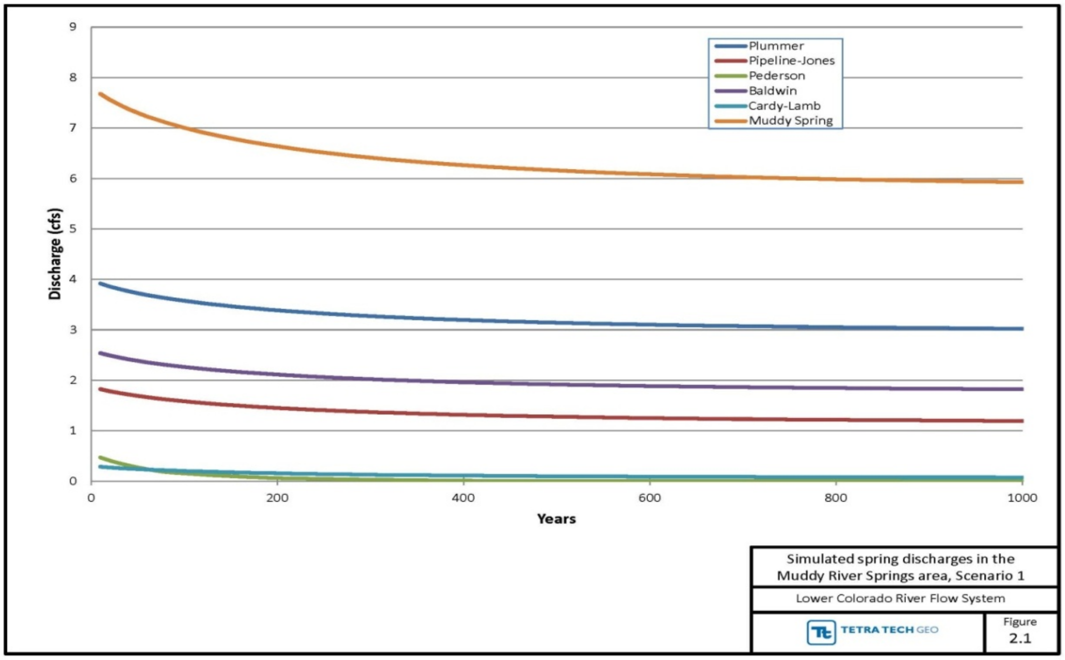


Figure 2.1. Simulated spring discharges in the Muddy River Springs area, Scenario 1.

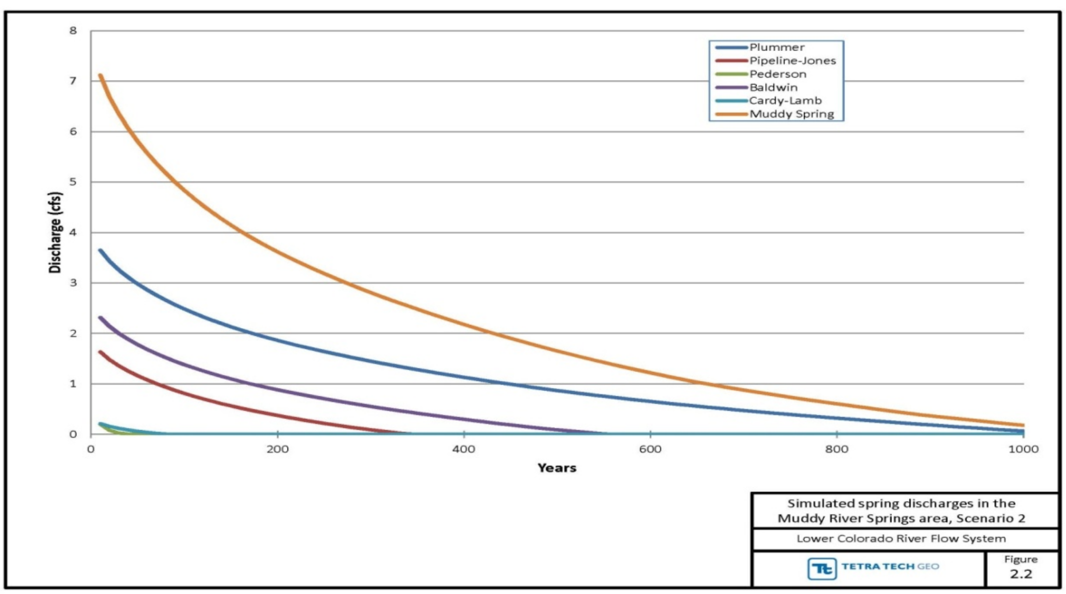


Figure 2.2. Simulated spring discharges in the Muddy River Springs area, Scenario 2.

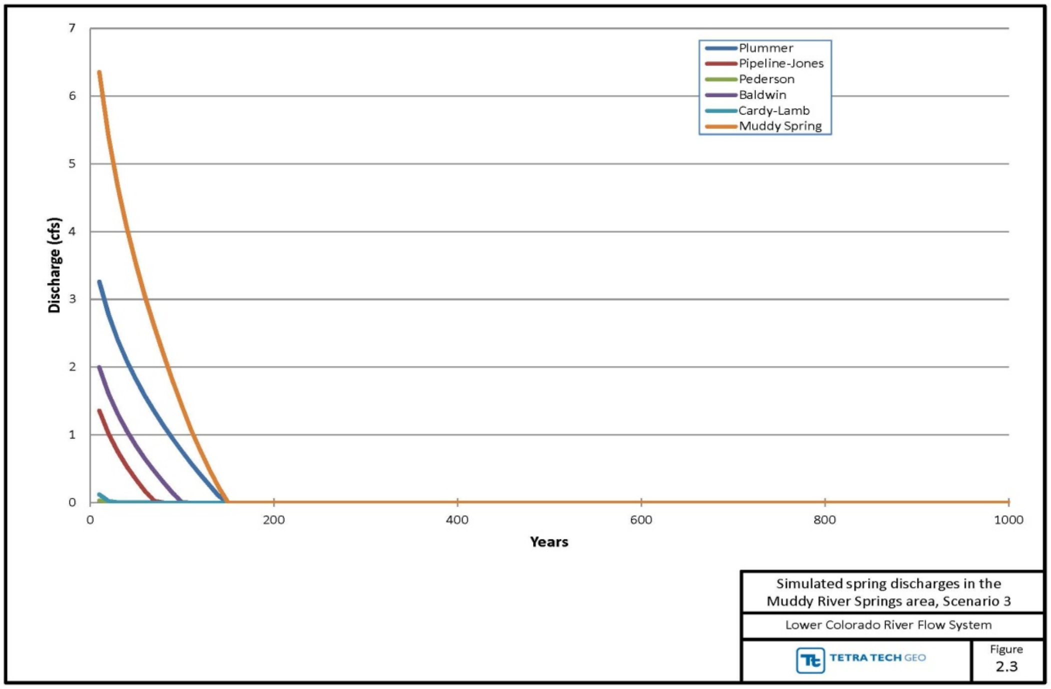


Figure 2.3. Simulated spring discharges in the Muddy River Springs area, Scenario 3.

Figure 2.5 (Figure 2-4 of Tetra Tech 2013) shows the observed and simulated discharge rates from the springs. In general, the model simulates very little change in the discharges, while there are small observed declines in the measured values during the test period. The increases in observed discharge at Muddy Spring are believed to have been caused by anthropogenic changes near the spring and/or the 2010 fire which occurred in the immediate area. The limited simulated impact on the discharge is caused, in part, by the under-simulation of drawdown.

Maps of the simulated drawdown caused by pumping of MX-5 were developed by first simulating the effects of all existing pumping (including MX-5), then simulating the effects of all existing pumping except MX-5, and subtracting the simulated water levels of the second run from those of the first run. The result is a dataset with the simulated drawdown caused by pumping of MX-5. This approach was used to eliminate possible effects that might be caused by non-linear boundary conditions, and isolates the effects of MX-5 pumping.

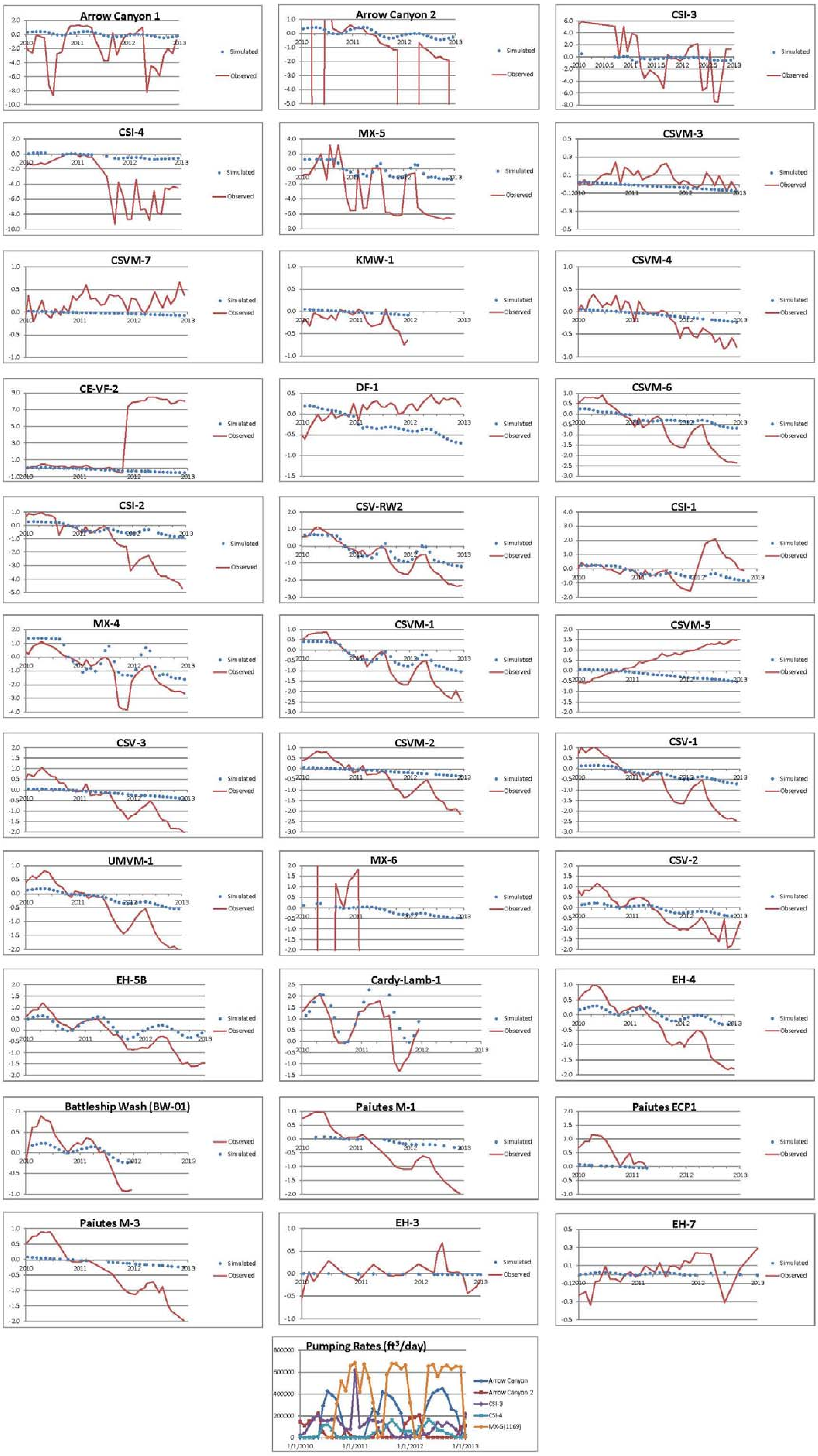


Figure 2.4. Comparison of simulated and observed drawdown in selected wells, 2010 - 2012.

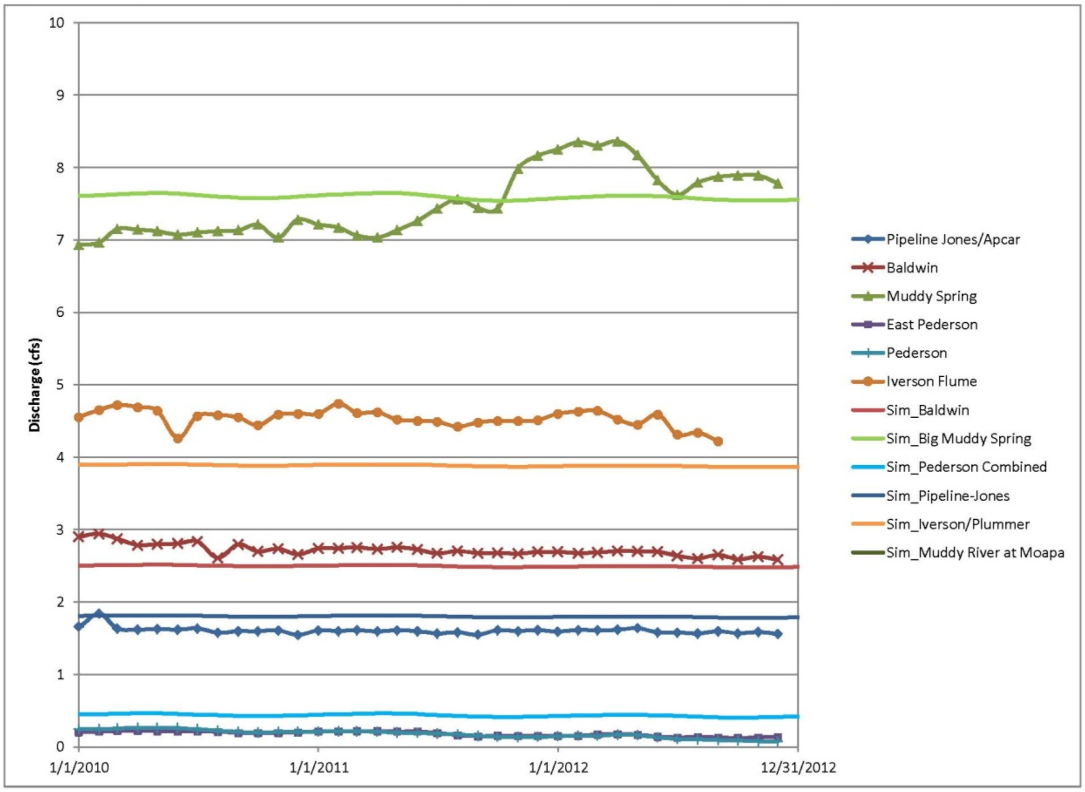


Figure 2.5. Comparison of observed and simulated spring discharge, Muddy River Springs Area, 2010 - 2012.

Figure 2.6 (Figure 2-5 of Tetra Tech 2013) shows the simulated drawdown in model layer 5 caused by MX-5 pumping as part of the Order 1169 test at three different times. The leftmost panel shows the simulated effects at the end of December 2011, while the central panel shows the simulated effects of an additional year of pumping. The rightmost panel is discussed further below under the recovery discussion. Layer 5 is the model layer with the greatest drawdown at the location of MX-5. **Figure 2.7** (Figure 2-6 of Tetra Tech 2013) is a similar set of maps, for model layer 11. This layer has the greatest extent of drawdown.

In the time interval between the end of 2011 and the end of 2012, pumping continued from MX-5, and the extent of simulated drawdown increased in all directions. The amount of drawdown near MX-5 also increases, in both layer 5 and 11. The area of drawdown has begun to extend more in a north-south direction, reflecting the geology. To the north, the area of simulated drawdown greater than 0.1 feet has reached Kane Spring Valley. To the south, it has reached the central part of Garnet Valley and nearly all of Hidden Valley.

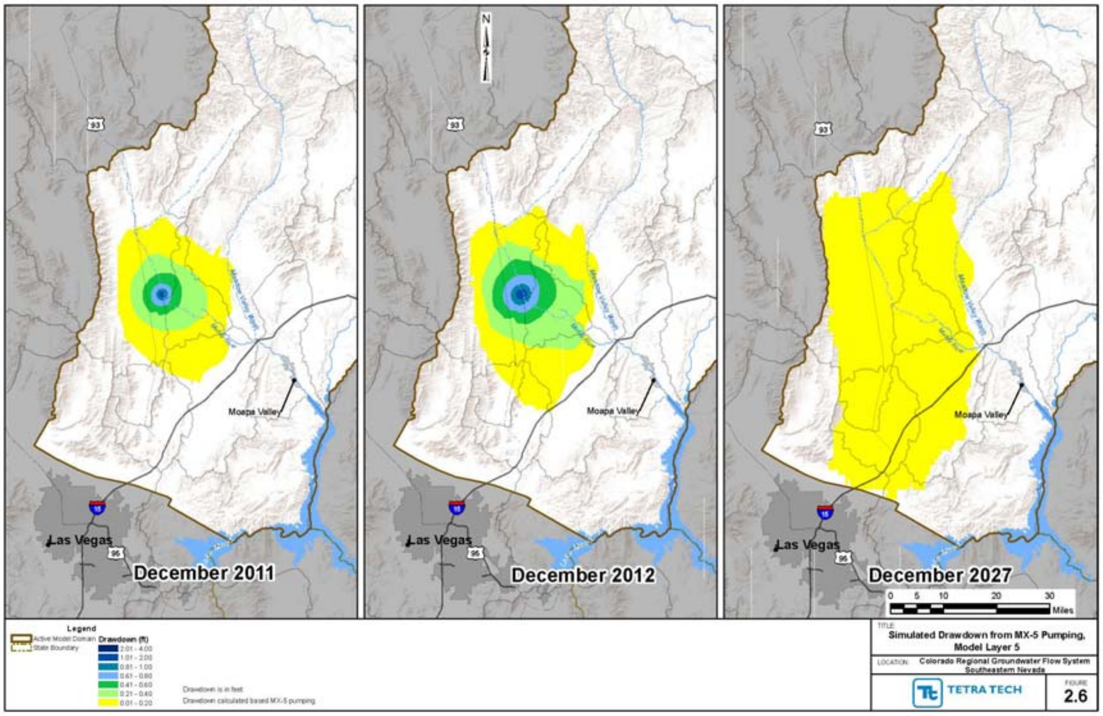


Figure 2.6. Simulated drawdown from MX-5 pumping, Model layer 5.

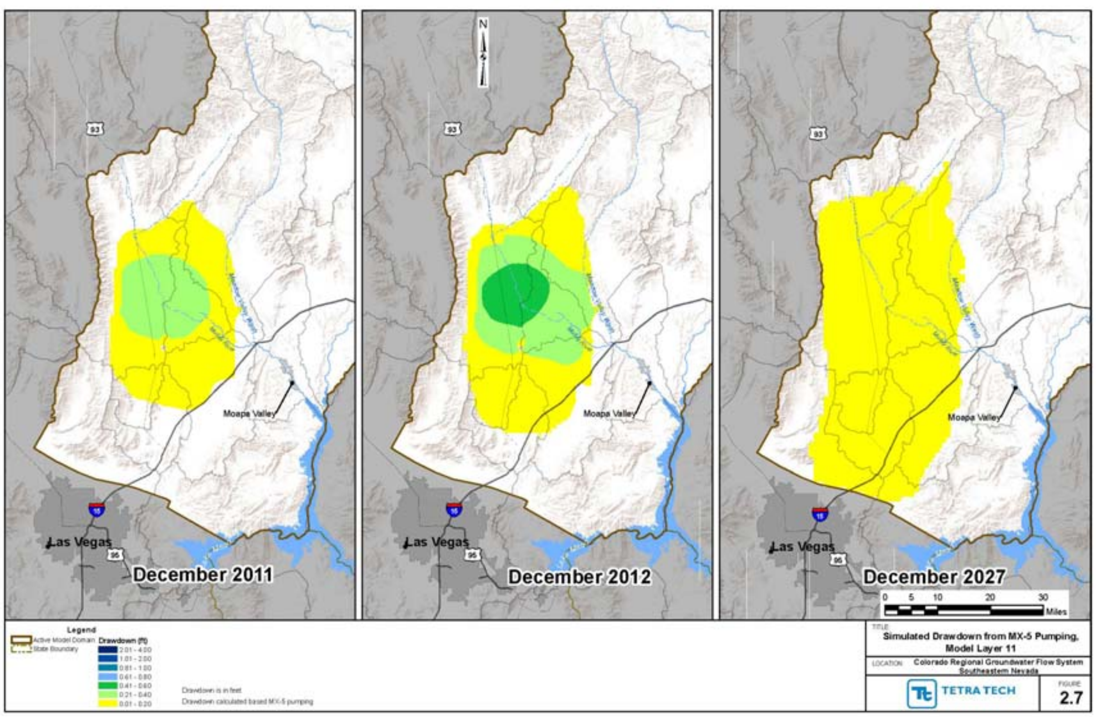


Figure 2.7. Simulated drawdown from MX-5 pumping, Model layer 11.

As noted above, the model under-simulates the drawdown caused by the Order 1169 pumping of MX-5 through the end of 2012. Thus, the amount of drawdown depicted on these maps is less than has been observed. Similarly, the simulated effect of this pumping on the discharge from springs in the Muddy River Springs area is too small. These results indicate that additional calibration of the model using the more recent data would be beneficial. In the interim, the predictive results presented in Tetra Tech (2012b) that pertain to pumping from the carbonate rocks in Coyote Spring Valley should be viewed as conservative. Specifically, the carbonate water levels that drive the discharge from the springs in the Muddy River Springs area will decline more quickly than simulated, and the flows from the springs and in the Muddy River will decline more quickly.

The model was also used to evaluate what is likely to happen if pumping in CSV were to be reduced. One management option for protecting the stream and spring environments in the Muddy River Springs area would be to reduce or curtail pumping rates if water levels declined to a threshold value. However, it is unknown whether a reduction in the pumping rate would cause an "immediate" recovery of water levels and spring flow throughout the Muddy River Springs area, or if drawdown and water-discharge would continue to decline for some time, and by how much. The second part of this section evaluates the likely effects, using cessation of pumping in MX-5 at the end of the Order 1169 test as the imposed change in pumping stress.

The model was run using monthly stress periods for a 15-year period (2013 to 2027), in which no pumping was assumed to occur from MX-5, but other pumping was assumed to occur at the average of the rates reported for 2010, 2011 and 2012.

Simulated drawdown at several wells is shown on **Figure 2.8** (Figure 3-1 in Tetra Tech 2013). The water levels show the effects of MX-5 pumping superimposed on a general downward trend. The effect of stopping MX-5 pumping is very evident in wells close to MX-5 (MX-4, CSV-RW2, CSVM-1, UMVW-1, MX-6) and easily discernible in more distant wells (DF-1, CSVM-6, CSVM-5, CSV-3, CSVM-2, CSV-1). The effect is also present (as observable changes in slope) in the simulated responses of Arrow Canyon, Arrow Canyon 2, KMW-1, CSVM-4, CE-VF-2, CSI-2, CSI-1, CSV-2, EH-5B, EH-4, BW-01, Paiutes M-1 and Paiutes M-3.

The time required for recovery is a function of the distance from MX-5 and the criterion used to define when recovery is complete. **Figure 2.9a** through **2.9d** (Figures 3-2a, 3-2c, 3-2d and 3-2h in Tetra Tech 2013) show the simulated drawdown and recovery responses as a result of starting and stopping MX-5 pumping. For example, at MX-4 (**Figure 2.9a**), about 75% of the drawdown is recovered very quickly, but after 15 years, the recovery is about 90% complete. At MX-6 (**Figure 2.9b**), the simulated recovery is about 75% complete after 15 years. At EH-4 (**Figure 2.9c**), located near Pederson Spring in the MRSA, the maximum drawdown is simulated as occurring several months after cessation of MX-5 pumping, and the recovery is about 70% complete after 15 years. In areas that are much further away, recovery is simulated as not beginning until after 15 years since pumping ceased at MX-5. Although the simulated drawdown at CSVM-3 (**Figure 2.9d**) is only 0.03 feet after the 28 months of MX-5 pumping and 15 years of recovery, the drawdown is continuing to increase.

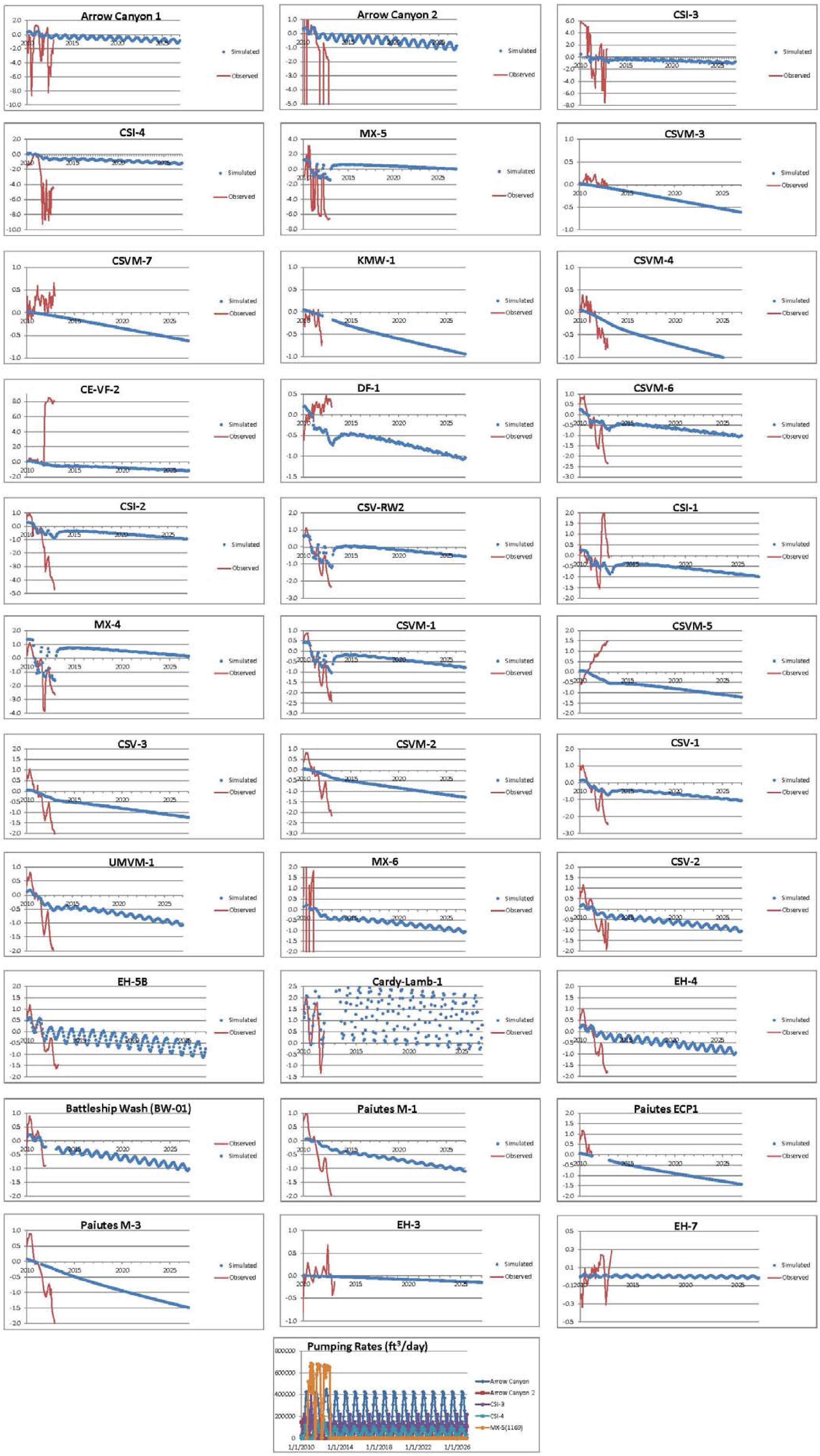
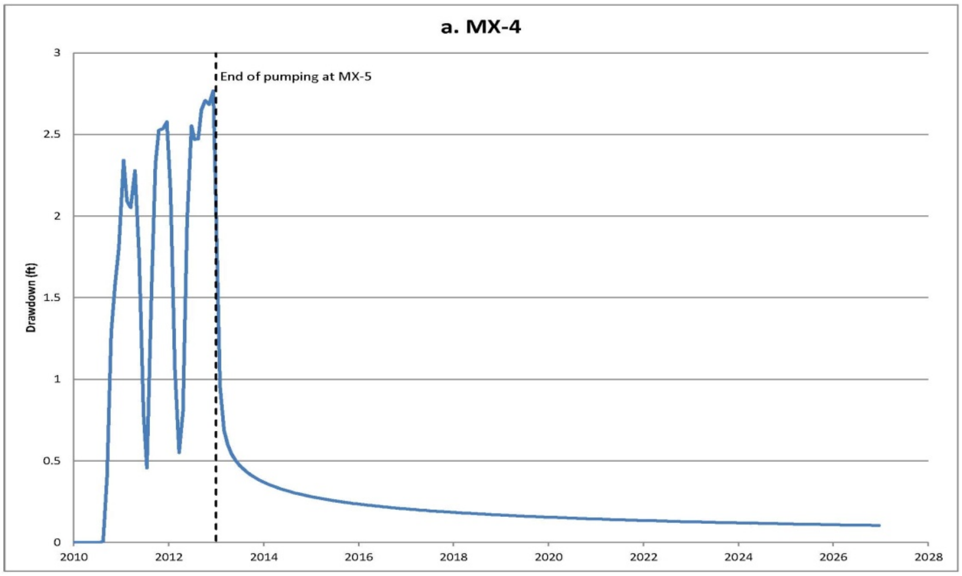
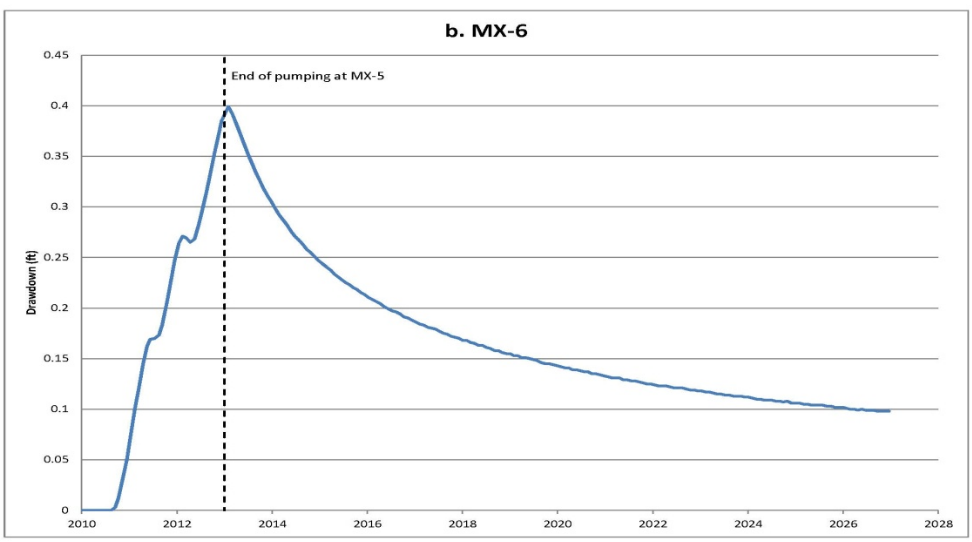
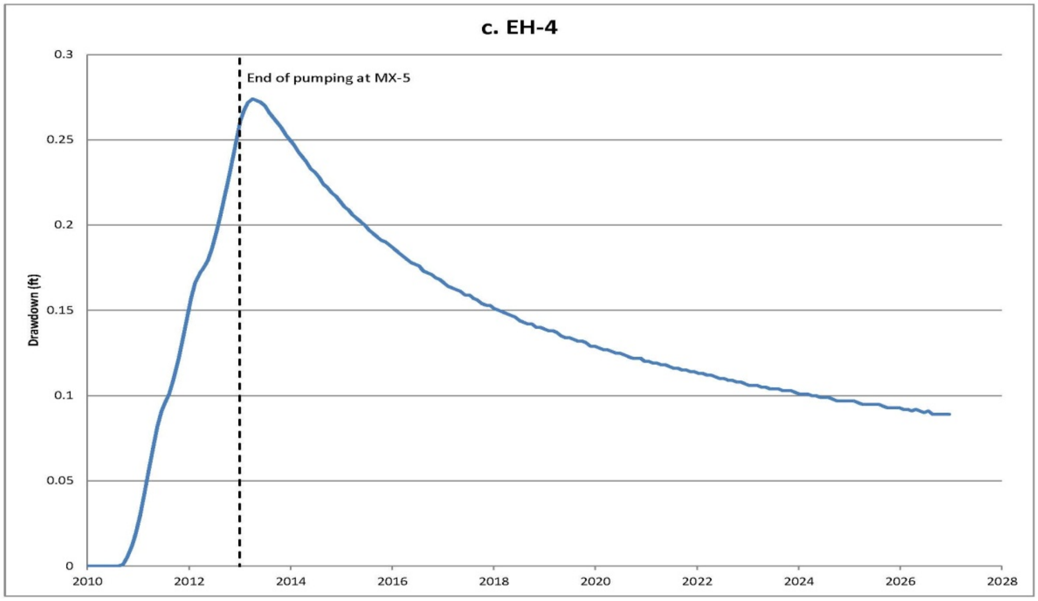


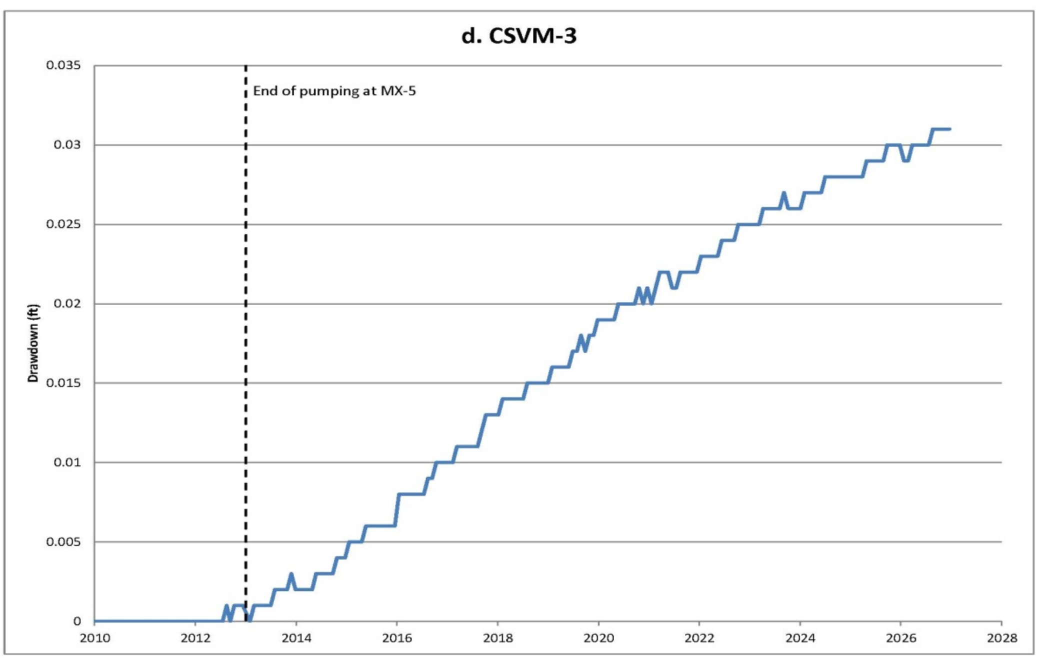
Figure 2.8. Simulation of water levels in selected wells, 2010 - 2012.

Figure 2.9. Simulated drawdown and recovery caused by pumping of MX-5 at selected wells.






c. EH-4
End of pumping at MX-5
Drawdown (ft)
0.3
0.25
0.2
0.15
0.1
0.05
0
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028


d. CSVM-3
End of pumping at MX-5
Drawdown (ft)
0.035
0.03
0.025
0.02
0.015
0.01
0.005
0
2010
2012
2014
2016
2018
2020
2022
2024
2026
2028

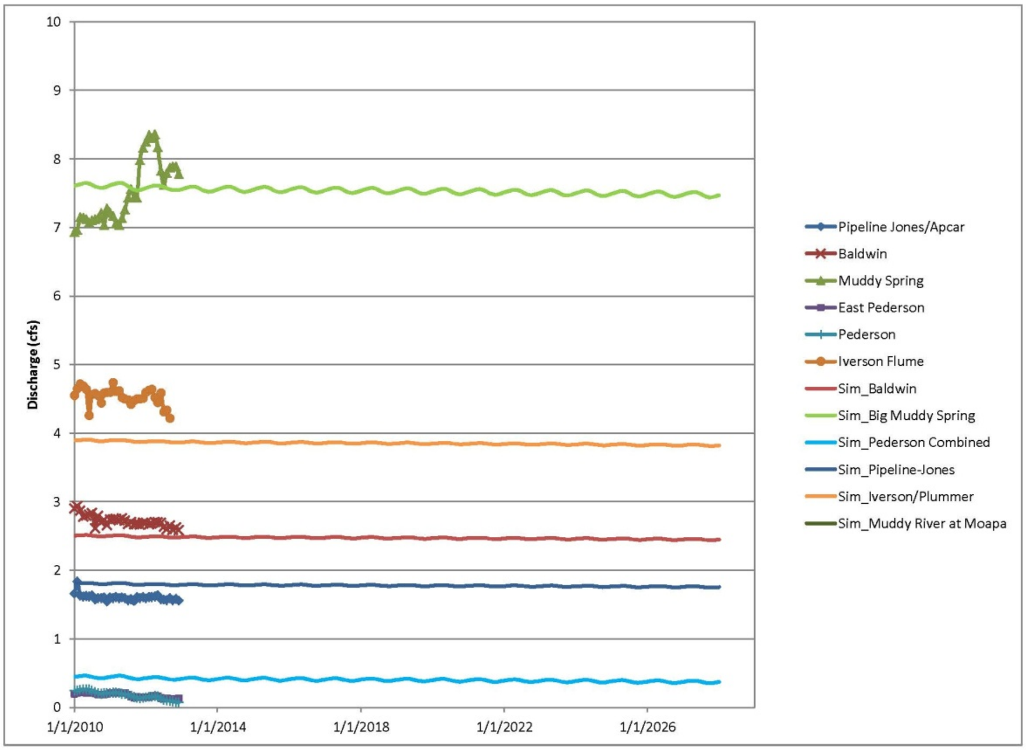


Figure 2.10. Simulated spring discharge rates, Muddy River Springs Area, 2010 - 2027.

Because the model simulates that the effects from the pumping are both smaller than and less widespread than observed, the model also would be expected to predict that changes in water levels occur slower than observed. Thus, the recovery would also be expected to occur quicker than predicted by the model.

Since there was no easily observable decrease in the simulated spring discharge, no easily observable increase in simulated spring flow should occur after MX-5 pumping is stopped. However, a plot of simulated discharge (**Figure 2.10**) shows a minor decrease in flow. For example, the decline simulated for Baldwin Spring is less than 2% of the flow in 2010.

The rightmost panel in **Figures 2.6** and **2.7** shows the simulated drawdown after 15 years of recovery. Recovery near MX-5 is nearly complete (recovery was about 90% at MX-4). However, the area with at least 0.01 feet of drawdown continued to increase, and has reached the western and southern model boundaries in layer 11. While the simulated drawdown in these areas is small, the simulation demonstrates that although drawdown has nearly recovered near the pumping well, impacts in other areas may be continuing to increase a decade or more after pumping has stopped. Although the model under-predicts the amount of drawdown, the area that was simulated as being affected by pumping of MX-5 is quite similar in extent to that determined from the SeriesSEE evaluation of the data. This becomes apparent in the results from the 15-year recovery period, whereas the SeriesSEE evaluation found that the effects were evident at the end of the Order 1169 test.

There are two significant conclusions from the recovery simulation:

1. Except in the immediate vicinity of MX-5, recovery from the effects of the 28-month pumping of MX-5 will take longer than 28 months, and may take substantially longer to occur depending on the location. Near the Muddy River Springs, approximately one-third of the simulated drawdown remains after 15 years of recovery.
2. The model predicts that the drawdown in Coyote Spring Valley and the Muddy River Springs area caused by MX-5 pumping is superimposed on a slower decline of water levels that is likely largely caused by pumping of carbonate-rock aquifer water from Arrow Canyon and Arrow Canyon 2. However, in the recovery simulation, carbonate pumping from wells in Garnet and the western part of the Black Mountains Hydrographic Area was also included in the recovery simulation and may be responsible for part of the slower observed decline in simulated water levels in the vicinity of MX-5.

Conclusions from Post-Audit Simulation

Results of the post-audit simulation indicate that the model under-simulates the amount (i.e., calculates less effect) of drawdown and reduction of spring discharge than has actually occurred as a result of MX-5 pumping. The observed drawdown is more widespread, and of greater magnitude, than simulated. The model simulates that the discharge from springs is not affected to a measureable amount, but the real effects are measureable. Thus, predictions that have been made with the model that evaluate the effects of pumping in Coyote Spring Valley should be considered to be conservative. The impacts from pumping would be larger and more widespread than simulated.

This evaluation also indicates that simulated recovery of water levels and springflow from the 28-month Order 1169 pump test will occur over years, and in the Muddy River Springs area, that recovery will be approximately 70% complete after 15 years. In areas that are “distant” from MX-5, drawdown may still be increasing 15 years after pumping of MX-5 is stopped. If pumping at MX-5 were to occur for longer than 28 months, the rate of recovery can be expected to be slower.

Conclusions from Modeling on the Availability of Groundwater Pursuant to the Pending Applications

The model simulation results presented in Tetra Tech (2012b) had indicated that continuation of the current pumping (including MX-5) into the future would cause slow decreases in discharge from springs in the Muddy River Springs Area, but that if all existing water rights (used and unused) and pending water rights in CSV (including SNWA’s pending water rights applications) were fully pumped, there would be major impacts on spring discharge (and the dependent flow in the Muddy River) within 10 to 150 years. However, the post-audit of the model clearly indicates that the model under-simulates the effects of pumping from the carbonate-rock aquifer. The timeframes predicted by the model for causing impacts to the springs are much too long. The evaluation of the spring flow data presented in Section 1 of this report indicates that if pumping from MX-5 were continued at the recent rates, Pederson Spring would dry up in years, not decades. Thus, the long-term modeling predictions presented in Tetra Tech

(2012b) should be considered to be very conservative. Changes will occur more quickly than presented in that report.

The modeling simulation results provide additional evidence that it is unlikely that the carbonate-rock aquifer can support increases in the pumping rates, without having significant impacts on spring discharge rates. Further, the recovery simulation indicates that the pumping will impact water levels, and thus spring discharge rates, for extended periods of time. Continued monitoring of water levels and spring discharge rates is needed, even if groundwater production does not occur at rates greater than the pre-Order 1169 test rates.

Section 3 - Pumping Test Results and Groundwater Availability

In this section of the report, we review the water budget and perennial yield information for the five-basin area identified in our groundwater analysis. We also summarize portions of recent rulings by the State Engineer related to the concept of perennial yield, especially as it applies to hydrologically-connected basins.

In determining the amount of water available for appropriation, the State Engineer is required to determine that there is unappropriated water available at the proposed source of supply, that the proposed use not conflict with existing water rights, and that the proposed use not prove detrimental to the public interest. The most important information from the pumping test, relevant to these three considerations, has to do with the comparison of the volume of water that was pumped during the pumping test with the volume of water currently appropriated in CSV. The pumping test removed an average of 5,400 afy in CSV over the two-year period of the test. This is only one-third of the 16,300 afy of groundwater that is already appropriated through existing water right permits in CSV (see Order 1169) (NSE, 2002a). The monitoring results from the pumping test clearly show that it is not possible to pump even this reduced volume of groundwater from CSV, at least in the area of MX-5 and the CSI wells, without affecting spring discharge in the MRSA. Furthermore, the results indicate carbonate pumping at any location within the five hydrologically-connected basins in this area (southern CSV, MRSA, Hidden Valley, Garnet Valley, and California Wash) will lower groundwater levels uniformly throughout these basins within relatively short time periods and will eventually capture spring discharge in the MRSA.

Our analyses of spring impacts suggests that if the pumping and drawdown were to continue at the current rate for another 1.5 to 3 years, upper elevation springs will dry up. The pumping test provides evidence that pumping of 5,400 afy of groundwater could be challenging over the long-term without creating adverse impacts to springs, Federal resources dependent on them, and downstream water rights. With respect to the question of whether groundwater is available for appropriation or not, our analysis as presented in this report suggests the answer is no.

Water Budget Analysis

The approach the State Engineer has used in determining water availability for appropriation is to evaluate the water budget information for a basin. The evaluation of water budgets in hydrographic basins in Nevada can be difficult because several components, including recharge from precipitation and interbasin groundwater flow, cannot be directly observed. Usually there are ranges of estimates for these components that are inferred from supporting hydrologic, geologic, and geochemical data. Several competing water budgets for CSV were presented in testimony and evidence at the 2001 protest hearings on the pending water right applications. A more recent water budget modeling effort (SNWA, 2007b) revisited the water budget for CSV but the range of estimates remains essentially unchanged. The information from the 2001 protest hearings, as summarized in Order 1169 (NSE, 2002a, pp 5-6), indicates that there is a maximum of 50,000 afy of groundwater inflow into CSV and a maximum of 53,000 afy of groundwater that flows out of the basin. The extra 3,000 afy of groundwater outflow is the estimate of net recharge from local precipitation in CSV. Of the 53,000 afy of subsurface outflow from CSV, 37,000 afy flows southeast and discharges at the MRSA as spring discharge and ET. This discharge in the MRSA is already fully appropriated through the 1920 decree, as identified in Order 1169 (NSE, 2002a), and therefore not available for appropriation. According to the January 21, 1920, Order of Determination and the March 11, 1920, Further and Supplemental Order of Determination of the Nevada State Engineer, there is no water available for appropriation in the Muddy River, its headwaters, sources of supply, and tributaries (Muddy Valley Irrigation Company, 1938).

That leaves a maximum of 16,000 afy of additional subsurface outflow that may bypass the MRSA and may be available for appropriation. More recently, the State Engineer has questioned and rejected the existence of 8,600 afy of outflow from CSV to Hidden Valley as proposed by SNWA (see Ruling 6167, pp 65-67) (NSE, 2012d), which appears to reduce the estimates of CSV outflow and available water in the basin further. The 16,300 afy of existing water right permits in CSV, as identified in Order 1169, equals or exceeds even the highest estimates of the remaining subsurface outflow from CSV, as acknowledged in Order 1169 (NSE, 2002a, p 6). From a water budget perspective, it appears there is no groundwater available for appropriation in CSV and our interpretation of the pumping test results does not suggest otherwise.

Order 1169 also states that "an unknown quantity of water may be available from storage but it is not known if any of this water could be pumped without unreasonable and irreversible impacts" (NSE, 2002a, p 5). The pumping test provided some information relevant to this issue too. To date, almost all of the water pumped has been removed from storage. Although the pumped volume during the test represents only a small portion (one-third) of the total existing water right permits in CSV, impacts to springs in the MRSA have been observed already, particularly those at the highest elevations. Those impacts are expected to increase if the current rate of pumping continues, as more of the natural spring discharge is captured by pumping in CSV and elsewhere. These effects will only be magnified if more of the existing water rights in CSV are put to beneficial use, which makes mitigating these impacts challenging. Based on the results of the pumping test, it does not seem possible to remove groundwater from storage without reducing carbonate water levels and impacting springflows. With respect to the question of whether groundwater is available for appropriation or not, our analysis as presented in this report suggests the answer is no.

Perennial Yield Analysis

The State Engineer has relied on the concept of perennial yield to assess whether there is unappropriated water available in a basin. Perennial yield is defined as the maximum amount of groundwater that can be salvaged each year over the long term without depleting the groundwater reservoir. Perennial yield is ultimately limited to the maximum amount of natural discharge that can be "salvaged for beneficial use." In a number of rulings, the State Engineer states that the perennial yield cannot be greater than, and in some cases may be less than, the natural recharge of a basin, which is defined as the combination of subsurface inflow and the fraction of local precipitation that contributes to groundwater.

The "salvaged" water referred to above has historically been viewed as the volume of groundwater that is discharged as ET through phreatophytes. "Salvaging" that water means that this groundwater is captured through pumping before it is discharged as ET through plants. In CSV, as in several other basins in the area, there is no phreatophyte vegetation and no groundwater ET to "salvage" (DeMeo et al. 2008). All groundwater in CSV is predominantly discharged as interbasin subsurface outflow to the MRSA and possibly in lesser amounts to other downstream basins as well. The perennial yield of basins like CSV, where there is no ET, is limited to the some portion of the interbasin outflow.

In applying the perennial yield concept to hydrologically-connected basins, the State Engineer has acknowledged that he has to manage basins comprehensively rather than individually. If the interbasin flow into or out of a basin is already appropriated in an upstream or downstream basin, that water is not available for appropriation in the individual basin. The State Engineer notes this in several rulings, including Ruling 5986 (NSE, 2009) on the Tule Desert Hydrographic Basin, which states:

> "The amount of subsurface discharge that can be captured is highly variable and uncertain. Perennial yields for these basins have historically been set at one-half of the subsurface discharge. However, when conditions are such that there is subsurface flow through several basins, there is a potential for double accounting and over appropriating the resource if the perennial yield of each basin is equal to one half of the subsurface outflow, and basin subsurface inflows are not adjusted accordingly. Therefore, allowances and adjustments are required to the perennial yields of basins in these flow systems so that over appropriation does not occur."

In Ruling 6167 (NSE, 2012d) on the Delamar Valley hydrographic basin, the State Engineer states:

> "It is also well known that regional groundwater flow systems hydrologically connect many of these basins and make management on the hydrologic basin-scale complex, and often dependent on prior management/appropriation decisions. In these cases, the State Engineer must determine from which basin the groundwater should be counted as available. If the interbasin flow is appropriated in one basin, it is not available for appropriation in an adjacent basin."

In other words, the same water cannot be "double-counted" or "double-appropriated." As demonstrated with the water budget analysis above, there are 53,300 afy of existing water right permits for the subsurface outflow from CSV, 16,300 afy in CSV and 37,000 afy downgradient in the MRSA. This volume of appropriated water is equal to even the most optimistic estimates of subsurface outflow from CSV. In addition, because the area is hydrologically-connected, we believe that the existing water rights in all five basins must be considered in any appropriation decision.

While considering the hydrologic connectivity of basins, the State Engineer also must consider the time scale of any potential impacts. In Ruling 6167 (NSE, 2012d) again, he states:

> "At the same time, it is important to consider the time frames and geologic uncertainties involved. Withdrawals upgradient may or may not affect downgradient users within a reasonable time frame. The State Engineer has found that if no measureable impacts to existing

> rights occur within hundreds of years, then the statutory requirement of not conflicting with existing rights is satisfied. "

Our analyses of impacts to spring discharge from the pumping test show that measureable impacts from the existing level of pumping are observed on the scale of months to years rather than hundreds of years.

Finally, with respect to the perennial yield of CSV, it has to be noted that some portion of the interbasin inflow to CSV from two tributary basins adjacent to CSV (Delamar, Kane Springs) has been appropriated already, but not developed. Ruling 5712 (NSE, 2007) appropriated 1,000 afy in Kane Springs Valley and Ruling 6167 (NSE, 2012d) appropriated 6,100 afy in Delamar Valley. Both of these appropriations will eventually reduce the interbasin inflow to CSV if and when they are developed. The State Engineer has recognized that prior appropriation of upgradient interbasin flow is an issue that must be considered (see Rulings 5465, 5621, and 6144-6167) (NSE, 2005; NSE, 2006; NSE, 2012a; NSE, 2012b; NSE, 2012c; NSE, 2012d). With respect to Dry Lake and Delamar Valley basins, Ruling 6167 (NSE, 2012d) states:

> "By discounting any subsurface inflow from up-gradient basins that is already appropriated, systematic double counting can be eliminated. These controls on the regional flow system allow groundwater to be available in every basin for beneficial use."

It seems prudent to follow the same approach here and discount the subsurface inflow already appropriated. This means the amount of groundwater already allocated in CSV may even be greater than the actual available water, given the constraints with existing appropriations upgradient and downgradient of CSV. There is no information from recent studies or from our interpretation of the pumping test results to suggest that there is additional groundwater available in the basin. The fact that the pumping to date in CSV represents only one-third of the existing water rights permitted in CSV and that our analysis of spring impacts suggests that even this small level of pumping could lead to unreasonable and possibly irreversible impacts in the next few years confirms what is indicated by the analyses of water budgets and perennial yield – there is no additional groundwater available for appropriation.

Section 4 - Public Interest Considerations and Federal Groundwater-Dependent Resources

This section of the report provides an overview of public interest considerations related to the availability of groundwater for appropriation pursuant to the applications held in abeyance by Order 1169. We focus our discussion on the potential impacts of decreased spring discharge and groundwater levels on resources that the U.S. Fish and Wildlife Service (Service or USFWS), NPS, and BLM hold in trust for the public. As stated earlier, the State Engineer is required to establish that a proposed groundwater use will not prove detrimental to the public interest when determining the amount of groundwater available for appropriation. The State Engineer has considered the protection of threatened and endangered species as well as sensitive species and related environmental values when determining whether water is available for appropriation.[10]

In Nevada, all surface water and groundwater (NRS 533.025), as well as non-domesticated wildlife in its natural habitat (NRS 501.100), is considered a public resource. The State is trustee of these resources, managing them for the benefit of the citizens of Nevada and the United States. Several species that occur in the MRSA are protected under State of Nevada statute, including but not limited to the Moapa dace (*Moapa coriacea*), which is classified as endangered (NAC 503.065.2); the Moapa speckled dace (*Rhinichthys osculus moapae*) and the Muddy River population of the Virgin River chub (*Gila seminuda*), which are both classified as sensitive fishes (NAC 503.067); and many species of migratory birds, including the southwestern willow flycatcher (*Empidonax traillii extimus*), which is classified by the State of Nevada as endangered (NAC 503.050). Some of these species are also federally protected under the Endangered Species Act (ESA) of 1973, as amended (16 U.S.C. 1531 *et seq*.).

Below, we focus our discussion on two resources in the MRSA managed by the Service, which are also of interest to the State of Nevada and the other federal agencies: the Moapa Valley National Wildlife Refuge (NWR; Refuge), including the fish and wildlife found there; and the Moapa dace, which is an endangered fish that has been federally protected since March 11, 1967 (USFWS, 1967). This is followed by a discussion of NPS and BLM water and groundwater-dependent resources. The existence and/or biotic integrity of these resources depend on thermal spring discharge from the carbonate-rock aquifer in the MRSA.

USFWS Moapa Valley National Wildlife Refuge

Moapa Valley NWR was established on September 10, 1979, to secure and protect habitat for the endangered Moapa dace. The purpose or mission of Moapa Valley NWR is derived from the Endangered Species Act of 1973, as amended: "...to conserve (A) fish or wildlife which are listed as endangered species or threatened species...or (B) plants..." (16 USC Sec. 1534) (USFWS, 2009). The Refuge and its resources are held in trust for the public and managed by the Service. Moapa Valley NWR comprises

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[10] See Ruling 3784 (February 14, 1994) (Lahontan cutthroat trout), Ruling 4683 (November 24, 1998) (Cui-ui and Lahontan cutthroat trout) and Ruling 6164 (March 22, 2012) (wildlife, wetlands and fisheries).

multiple, adjacent but visually distinct units – the Plummer Unit, the Pedersen Unit, and the Apcar Unit (see **Figure 1.20**) – purchased by the Service from various, willing sellers from 1979 to 2006.

Moapa Valley NWR is managed for two primary goals (USFWS, 2009):

Goal 1. Protect and restore, when possible, healthy populations of endemic and special status species, such as the endangered Moapa dace, within the Muddy River headwaters.

Goal 2. Provide local communities and others with opportunities to enjoy and learn about the resources of Moapa Valley NWR and participate in its restoration.

Most of Moapa Valley NWR was previously held by private landowners and used as several resorts with swimming pools and other developed features. These alterations have been removed and the habitat improved since 1979, with significant efforts and funding from the Southern Nevada Public Land Management Act (SNPLMA) focused on restoration at the Refuge from 2004 through 2012. Public use facilities were added in 2008 on the Plummer unit of the Refuge and opened to the public in 2009. Opportunities for the public at the Refuge include wildlife observation, photography, hiking, environmental education and outreach programs, and volunteer events. Visitors primarily come from the local communities of Moapa, Overton and Logandale, as well as Mesquite and Las Vegas (including some tourists). These efforts have occurred in support of the aforementioned goals to protect and restore habitat for endemic and special status species, as well as provide opportunities for visitors.

In support of the purpose of Moapa Valley NWR to secure and protect habitat for the endangered Moapa dace, the Service has two water rights that have been certificated by the Nevada State Engineer. One of these is a non-consumptive right for 3.5 cfs of spring flow as measured at the Warm Springs West flume for the maintenance of habitat of the Moapa dace and other wildlife purposes (Permit No. 56668, Certificate No. 15097 issued subject to the terms of Permit No. 56668). The other is for approximately 0.25 cfs from a well (Permit No. 27216, Certificate No. 12758 issued subject to the terms of Permit No. 22738, Certificate No. 8331). Surface water from the springs on Moapa Valley NWR also supports adjudicated rights downstream from the Refuge. Use of these surface water rights downstream does not generally affect the Refuge. In November 2008, the Service also applied for non-consumptive, in-stream flow rights to be used for wildlife on the Apcar and Plummer spring systems. These water right applications are being held in abeyance until the completion of the pumping test under Order 1169.

Moapa Valley NWR contains part of the unique system of thermal springs in the MRSA, including the springs and uppermost streams of Plummer, Pederson, and Apcar/Jones. These springs and streams provide aquatic and riparian habitats that support sensitive birds, amphibians, bats, and other fish in addition to the Moapa dace, including the endemic Moapa White River springfish (*Crenichthys baileyi moapae*) and the State protected Moapa speckled dace. The MRSA provides habitat for a unique assemblage of aquatic species including ten native thermophiles dependent upon the warm springs and streams for survival. Besides the dace and springfish, the system supports four endemic invertebrates found nowhere else in the world – the Moapa naucorid (*Limnocoris moapaensis*), Moapa riffle beetle (*Microcylloepus moapus*), Moapa pebblesnail (*Pyrgulopsis avernalis*), and Moapa Warm Springs riffle beetle (*Stenelmis moapa*). The upland areas on Moapa Valley NWR support a variety of birds, small mammals and reptiles, including the threatened Mojave desert tortoise (*Gopherus agassizii*).

The species and resources that depend on the aquatic and riparian habitats in the MRSA do not recognize and stay within the boundaries of the Moapa Valley NWR. Other adjacent and nearby lands also contain springs, streams, and wetlands that provide important protection for the resources in the MRSA that are held in trust for the public. Specifically, the Warm Springs Natural Area provides habitat that is critical to protect the ten native aquatic species, and numerous birds, amphibians, bats and reptiles observed in the MRSA. The aquatic and riparian habitats on these lands sustain 28 Nevada State sensitive or federally listed species, including important tributary streams and the main-stem river for the endangered Moapa dace, nesting habitat for the endangered southwestern willow flycatcher, and habitat for Nevada's largest breeding population of vermilion flycatcher (*Pyrocephalus rubinus*) (SNWA, 2011). The Warm Springs Natural Area was acquired with public federal funds by the Southern Nevada Water Authority to "develop a natural area" that "will provide controlled public access to enjoy the abundant natural resources, will include interpretation of the resources and Threatened and Endangered species located on the site, and will include measures to preserve and protect those resources" (SNWA, 2011). Further downstream on the main-stem Muddy River, additional aquatic and riparian species depend on the water and associated habitat that occurs along public lands managed by the Bureau of Land Management, State of Nevada (Overton Wildlife Management Area), and National Park Service.

The Moapa Dace and its Vulnerability to Environmental Stressors

The endangered Moapa dace is endemic to the headwaters of the Muddy River system where it is estimated to have occupied 25 springs and about 16 km (10 mi) of stream habitat in the early 20th century (Ono et al., 1983). Currently, the dace population is constrained to three thermal spring complexes and their respective springbrooks (Pederson, Plummer, and Apcar/Jones), including their confluence upstream of the Muddy River, an area that is roughly 20% of its historic distribution. The majority of the dace population is found on the Moapa Valley NWR and the Southern Nevada Water Authority's Warm Springs Natural Area. Habitat alterations, the introduction of nonnative fishes, and water withdrawals over the last century have restricted the dace's distribution within the Muddy River system and resulted in severe population declines.

The status of the species has fluctuated over the last 20 years, with a couple of significant population increases and decreases during this period. Snorkel surveys conducted each February (1994 to present) throughout the upper Muddy River system show that Moapa dace counts have ranged from a high of 3,825 individuals in February 1994 to a low of approximately 460 individuals in February of 2008 and 2009, prior to onset of the Order 1169 pumping test. One significant decline is attributed to the invasion of nonnative blue tilapia (*Oreochromis aurea*) where the dace population decreased from 3,825 individuals in 1994 to 1,565 individuals in 1997. Between 1999 and 2007, surveys yielded between 900 and 1,300 individuals. In 2008, the dace population again experienced a drastic decline in numbers, falling to its lowest known level of 459 individuals (a 60% decline from the previous year). The cause of this population crash remains unknown. From 2009 through early 2012, dace numbers slowly increased. Most recently (February 2013), surveyors counted 1,226 fish, an 88% increase over February 2012 survey results. We attribute this latest population increase to recent habitat restoration activities on the Moapa Valley NWR and the Warm Springs Natural Area, including removal of nonnative palm trees from stream channels, planting of native vegetation, improving stream velocities, and channel reconfiguration. Specifically, the lower Pederson Springbrook was re-routed closer to its historical alignment with a new channel created in October 2008. This reach has generally supported increasing numbers of Moapa dace since its creation and the largest number of dace of any reach in recent surveys (August 2012 and February 2013). Most of the upper and lower reaches of the Apcar/Jones Springbrook have also been restored and the dace population has increased in this area as well.

While the status of the Moapa dace has improved over the last couple of years presumably due to habitat restoration, the Service continues to be concerned about long-term persistence of the species. The different life stages of the Moapa dace are dependent upon thermal springs, springbrooks, and the main-stem Muddy River for survival (Scoppettone et al., 1992), but the availability of these habitat types continues to be limited by system alterations and the presence of nonnative fish. For example, the largest spring in the MRSA remains unavailable to the dace for spawning and use by early life stages due to recreational development (swimming pools, chlorination, and water diversion), and the North Fork, South Fork, Muddy Creek, and the Muddy River main-stem do not currently support Moapa dace. The dace's restricted range and small population size makes it vulnerable to extirpation from existing threats (e.g., nonnative fishes, water withdrawals), catastrophic events, or stochastic variation in demographic rates or in the environment. For example, wildfire in the MRSA is a continuing threat that could be catastrophic to the Moapa dace. In 1994, a fire nearly wiped out the dace population. A more recent (July 2010) fire, while burning about 600 acres including occupied dace habitat, did not spread to the Moapa Valley NWR where 75% of the dace population sought refuge. Thus, maintaining or increasing available spring and springbrook habitat on the refuge and adjacent areas– which in part can be achieved by ensuring adequate flows– will likely reduce extinction risk and increase the dace's ability to recover quickly from disturbances (i.e., increase its resiliency).

For these reasons, the Moapa dace remains highly vulnerable to habitat changes such as those that could result from reductions in spring discharge due to groundwater pumping in the MRSA or adjacent hydrographic basins. Reductions in springflow could affect essential dace habitat features, such as substrate composition and water depth, velocity, and temperature (Hatten et al., 2013). Life history attributes and behavior (e.g., ability to effectively drift feed, fish size and thus fecundity) could also be affected by reduced water volumes and velocities resulting from diminished springflow, and interactions between native and nonnative fishes (e.g., predation and competition) could be exacerbated as habitat diversity and complexity is reduced due to decreased flows. In particular, the dace is vulnerable to habitat changes in spawning areas because of its reliance on thermal spring discharge to create conditions conducive to successful reproduction (stable water temperatures between 30 and 32 ^{o}C, such as that found near and downstream of spring heads) and survival of early life stages (larvae are found exclusively in the upper reaches of these spring-fed tributaries) (Scoppettone et al., 1992).

As just described, the entire Moapa dace population is currently found within the Pederson, Plummer, and Apcar/Jones springbrooks, and the springs that contribute flow to these streams provide important habitat for spawning and early life stages. Therefore, maintaining adequate spring and streamflow in these springbrooks is extremely important to survival of the Moapa dace. The hydrologic analysis presented in this report demonstrates that the springs in the MRSA do not show the same degree of response to groundwater level declines, mainly because of differences in spring elevation. Pederson and Pederson East springs are at a higher elevation than the other MRSA springs and appear to be the most sensitive to declines in carbonate water levels from groundwater pumping. If the current rate of drawdown continues in carbonate monitoring well EH-4, these two higher-elevation springs will cease to flow in 1.5 to 3 years. This does not mean that streamflow in Pederson Springbrook will cease within this timeframe because 4 other major spring groups that are at lower elevation and are less sensitive to groundwater level declines (referred to in this report as spring groups M-11, M-12, M-13, and M-19) contribute a large proportion of total flow to this springbrook. During the Order 1169 pumping test, average monthly flow at Warm Springs West gage on Pederson Springbrook (which measures the combined discharge from Pederson Spring and the other 4 major spring groups) declined by 9 percent. Spring and streamflow reductions during this period were less for Plummer and Apcar/Jones, as expected due to the lower elevation of the springs contributing flow to these springbrooks. We estimated a 6% flow reduction at the Iverson Flume on Plummer Springbrook (with a slightly lower reduction in flow [3-4%] for the contributing springs) and a 4% decline in flow at Jones Spring (which feeds the Apcar stream) during the pumping test.

Based on this, we now address the question “What are the potential impacts to Moapa dace habitat and the dace population if additional groundwater is appropriated in the MRSA and adjacent hydrographic basins?” To answer this, we looked to a recent study conducted by Hatten et al. (2013), in which the authors developed a set of habitat models for the dace and conducted hydraulic simulations with a two-dimensional hydrodynamic model to estimate the extent of dace habitat over a range of flows (plus or minus 30% of base flow, in 10% increments). Using results from this study, we first considered potential impacts to dace habitat based on observed or estimated impacts to spring and streamflow during the Order 1169 pumping test. Because only one-third of the total appropriated volume in CSV was pumped during the Order 1169 pumping test, we anticipate greater impacts to dace habitat if appropriated rights are fully developed and/or additional groundwater is allocated and developed.

The habitat-flow simulations conducted by Hatten et al. (2013) consistently showed that reduced springflows produced less Moapa dace habitat in the Pederson, Plummer, and Apcar springbrooks. Additionally, the simulations showed that Plummer Springbrook appears to be the most sensitive to reductions in flow (i.e., greatest potential habitat loss for any given flow reduction), followed by Pederson and then Apcar. Based on Hatten et al. (2013), a 9% decline in flow in the Pederson

Springbrook (such as observed during the pumping test) would result in a small (<5%) reduction in dace habitat. Similarly, Apcar/Jones springbrook is predicted to have a <5% reduction in habitat from baseline conditions if flows decline by amounts observed at Jones Spring during the pumping test. On the other hand, Moapa dace habitat within Plummer Springbrook appears to be very sensitive to flow reductions. While a 6% reduction in base flow in this stream (the estimated decrease during the pumping test) was not specifically modeled by Hatten et al. (2013), their study predicted a rather large (20%) reduction in dace habitat within this stream in response to a 10% decrease in base flow. We assume a somewhat lower amount of habitat loss for a 6% decrease in flow, but a greater impact if all existing permitted groundwater rights in CSV are developed (as this would represent three times the amount of pumping that occurred under the pumping test). Given the species' limited distribution, habitat losses of this amount could prove significant. We note that the above estimates of habitat loss for all three springbrooks do not take into account the potential offsetting of pumping impacts with recent habitat restoration activities or other conservation measures.

We assume that a reduction in habitat, if it were to occur, would be followed by a decline in Moapa dace numbers since population size of many endangered species is thought to be limited by the amount of suitable habitat available to them (Williams et al., 2002). Over the last five years, the majority (up to 90%) of the dace population counted during fish surveys in the MRSA has been in the Pederson and Plummer springbrooks. Thus, habitat loss within these streams is expected to adversely affect the overall dace population. Additionally, dace only spawn in the Pederson, Plummer, and Apcar/Jones spring systems, while no dace are found in the other two major spring systems (Baldwin and Muddy Spring). Reduction and/or cessation of thermal spring discharge within the three occupied springbrooks, particularly Pederson and Plummer, would reduce the amount of spawning habitat (i.e., waters at the appropriate temperature for spawning), thereby affecting the dace's ability to successfully reproduce and reducing fecundity and overall population numbers. This could have negative implications for survival and/or recovery of the species.

To conclude, we remain concerned about the Moapa dace's ability to persist long-term despite recent population growth. Its numbers are still lower than historic estimates (Scoppettone et al., 1992; USFWS survey data); it is restricted to a small geographic area that is but a fraction of its historic range; it has very specific habitat requirements, particularly for spawning and early life stages, which makes it vulnerable to changes in the environment; and it is exposed to numerous stressors with limited opportunities to move away from the ensuing effects, such as habitat degradation. These are characteristics that make a species highly vulnerable to extinction (Williams et al., 2005; Burkhead 2012). Moapa dace numbers increased during the pumping test period, but we attribute this to recent habitat restoration in the MRSA, which appears likely to have offset impacts to habitat caused by pumping-induced flow reductions, although this has not been substantiated. However, we caution that restoration of physical habitat (e.g., reconfiguration of stream channels, removal of nonnative plants, and planting of native vegetation) will only go so far towards maintaining or improving the dace's status if the anthropogenic stressors that lead to habitat degradation are not also addressed (Hilderbrand et al., 2005; Christian-Smith and Merenlender, 2010). These fish depend on thermal spring discharge to create and maintain important habitat characteristics, and this species is thought to be more sensitive to flow reduction than some other fish species inhabiting the Muddy River system (Hatten et al., 2013). If additional groundwater is appropriated in CSV, the MRSA, and adjacent areas, spring discharge and streamflow could be lowered to the point that physical habitat restoration will not be an effective or possible mitigation option.

Aquatic species such as the Moapa dace have evolved life history strategies primarily in response to the natural flow regime of the systems they inhabit (see Bunn and Arthington, 2002). Altering this flow regime could affect crucial drivers of dace population dynamics, such as the resources needed for spawning, juvenile growth, recruitment, feeding, and other behaviors. Given the dace's sensitivity to flow reduction, and the potential consequences of habitat loss for a species with an extremely limited distribution, we recommend that no additional water be appropriated in CSV and adjacent hydrographic basins.

NPS and BLM Groundwater-Dependent Resources

Several important warm springs are located in the Overton Arm area of Lake Mead National Recreation Area (Lake Mead NRA), which is administered by the NPS. These springs include Rogers, Blue Point, Corral, and Scirpus springs, and other smaller, unnamed springs. Discharge from these springs provides water for riparian vegetation and wildlife habitat, and sustains a recreational amenity enjoyed by many park visitors.

The United States has federal reserved water rights for all of the springs within Lake Mead NRA. The United States also has a state appropriative water right to Rogers Spring (Certificate No. 4476).

The relict leopard frog (*Lithobates onca ;* formerly classified as *Rana onca*), previously believed extinct, has been found at Rogers, Corral, and Blue Point Springs. In 2002, the species was petitioned for listing as endangered under the ESA. The Service subsequently found that listing is warranted, but development of a proposed listing regulation is precluded by other higher priority listings. It remains on the Service's candidate species list. Although not an endangered or threatened species, a herd of approximately 150 of Nevada's official state animal – the desert bighorn sheep - also use these springs in the northern part of Lake Mead NRA.

The likely source of the water discharging from these springs is the regional carbonate-rock aquifer system. Therefore, the withdrawal of groundwater from this aquifer system upgradient of these springs would most likely affect their rates of discharge. Although the Order 1169 pumping test period was too short to be able to identify the effects of upgradient groundwater withdrawals on these springs, geologic, hydrologic, and hydro-geochemical evidence indicates that these springs likely are vulnerable to depletion of discharge from longer-term and/or cumulative carbonate pumping in the five hydrologically connected basins discussed in earlier sections of this report.

The BLM also has several trust resources in the area as well. Both the Moapa dace and the Moapa speckled dace occur in parts of the Muddy River that are managed by the BLM Southern Nevada District Office. Both species are BLM Special Status Species, a category that includes 1) species listed or proposed for listing under the ESA and 2) BLM-designated Sensitive Species - species requiring special management consideration to promote their conservation and reduce the likelihood and need for future listing under the ESA. Sensitive species are designated by the BLM State Director. Many of the species protected by the Service and the State of Nevada are on BLM's State Sensitive Species List. This list includes the Moapa Warm Springs riffle beetle, the Moapa pebblesnail, and the Moapa Valley pryg (*Pyrgulopsis carinifera*), some of which are referred to in this report by the Service.

Further, the BLM is a member of the Biological Action Committee for the Muddy River working to conserve and recover the rare aquatic species listed in this report. As part of these efforts, BLM used SNPLMA funding to design and construct three fish barriers on the Muddy River to prevent the upstream migration of nonnative species from the Virgin River. The barriers also segmented the river into sections that can be treated in order to remove the nonnatives. The fish barrier design includes the ability to remove the center sections and allow for connectivity after the each segment is clear of nonnative fish. The approximate cost for the construction of the barriers was $600,000. BLM has also contributed additional funding for the removal of nonnative fish species. In addition, the BLM has partnered with the Service and the Walton Foundation to conduct restoration projects on the Muddy River to benefit the southwestern willow flycatcher by increasing potential foraging habitat, which is also groundwater dependent.

Conclusions from Public Interest Considerations

Our view continues to be that groundwater should be developed in a manner that will avoid impacts to groundwater-dependent public resources to the extent possible; or, if such impacts cannot be avoided, to minimize those impacts to groundwater-dependent resources, including the natural resources and public facilities at the Moapa Valley NWR, Lake Mead NRA, and on other lands, as well as the endangered Moapa dace and other federally or State-protected and sensitive species that inhabit (some exclusively) these areas. Appropriating additional groundwater within CSV, the MRSA, and adjacent hydrographic basins (Hidden and Garnet valleys and California Wash) would likely prove detrimental to the public interest given that these resources and lands rely on thermal spring discharge from the carbonate-rock aquifer.

Section 5 - Overall Report Conclusions

In 2002, the Nevada State Engineer issued Order 1169, which stated that all pending and new water right applications in the carbonate-rock aquifer in Coyote Spring Valley (Basin 210), Black Mountains Area (Basin 215), Garnet Valley (Basin 216), Hidden Valley (Basin 217), the Muddy River Springs Area, a.k.a. Upper Moapa Valley (Basin 219), and Lower Moapa Valley (Basin 220) would be held in abeyance pending further study (NSE, 2002a). California Wash (Basin 218) was later added to the list through Ruling 5115 (NSE, 2002b). The applications were held in abeyance so that the State Engineer could collect more information on the effects of groundwater pumping from the carbonate-rock aquifer prior to making a determination on pending water right applications in the listed basins. The order called for a study covering a "*5-year minimum period of time during which at least 50% of the water rights then currently permitted in the Coyote Springs Valley groundwater basin are pumped for at least two consecutive years.*"

The Order 1169 Study officially started on November 15, 2010 and was finished on December 31, 2012. Carbonate pumping in CSV, which averaged about 2,000 afy from 2006 to 2009, more than doubled to 5,400 afy during the pumping test. Groundwater pumping in adjacent basins remained relatively unchanged from previous years during the period of the pumping test. The volume of pumping in CSV during the test was approximately one-third of the groundwater rights currently permitted in that basin.

The U.S. Fish and Wildlife Service, National Park Service, and Bureau of Land Management prepared this report in response to the State Engineer's request for information related to the pumping test. The report addresses the three questions posed by the Nevada State Engineer in Order 1169A (NSE, 2012e):

- What information was obtained from the pumping study/test?
- What were the impacts of pumping under the pumping test?
- What is the availability of water pursuant to the pending applications?

The main findings of this report are:

- The effects of pumping MX-5 are readily apparent in water-level data from the carbonate-rock aquifer over a 1,100 square mile area that is hydrologically-connected and encompasses five hydrographic basins: Coyote Spring Valley, the Muddy River Springs Area, Hidden Valley, Garnet Valley, and California Wash. There is no scientific justification for managing groundwater production from the carbonate-rock aquifer separately in these five hydrographic basins.
- The results indicate carbonate pumping at any location within the five hydrologically-connected basins in this area (southern CSV, MRSA, Hidden Valley, Garnet Valley, and California Wash) will lower groundwater levels nearly uniformly throughout these basins within relatively short time periods and will eventually capture from the Muddy River Springs, Muddy River, and (or) ET associated with phreatophytic vegetation in the MRSA and California Wash, the only forms of natural discharge in this area, at a rate that approaches 100 percent of the pumping.

- An evaluation of the discharge from springs in the Muddy River Springs area indicates that pumping of MX-5 has caused observable reduction in the discharge from the higher elevation springs, and that the observed capture of the spring discharge was 10 to 20% of the rate at which MX-5 was pumped. Thus, during the duration of the Order 1169 test, most of the water was being produced from storage (i.e., from the release of water caused by the reduction in water levels). Drawdown in the carbonate-rock aquifer was continuing to increase at the time the test was officially ended (December 31, 2012), and therefore the capture of discharge at the springs was also continuing to increase. If pumping of MX-5 continues at the same rate as during the test, discharge from the Pederson spring would likely cease in about 1.5 years and discharge from Pederson East spring would likely cease in about 2.5 to 3 years. Continued pumping would cause other springs to decline or dry up as well until the declines in spring discharge and ET equal the volume of pumping.
- The model developed by Tetra Tech in 2012 underestimates the magnitude of groundwater-level changes and the amount of time for them to be developed, but matches well the area that will be affected by pumping from the carbonate-rock aquifer. Thus, the predicted effects of pumping from the carbonate-rock aquifer are very conservative, and the springs will be impacted considerably sooner than the model predicts, under the pumping scenarios simulated.
- Our analysis of water budgets and perennial yield information suggests that there is no available water in CSV or any of the other four hydrologic basins discussed above. The fact that the pumping in CSV during the test was only one-third of the existing water rights permitted in CSV and that our analysis of spring impacts suggests that even this small level of pumping could lead to unreasonable and possibly irreversible impacts confirms this finding.
- The ecosystem around the Muddy River Springs area is dependent on the discharge from the springs. The Moapa dace is dependent on the higher temperature discharges. Additionally, the flow in the Muddy River is dependent on the discharge from the carbonate-rock aquifer. Pumping of the carbonate-rock aquifer will reduce the streamflow and impact downstream water rights holders. The Muddy River is fully adjudicated. Therefore, there is no water available for water right applications pending under Order 1169 within the five basins described above.

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