MISSOURI HEIGHTS GROUNDWATER MONITORING PROGRAM

Basalt Water Conservancy District
Colorado Water Conservation Board

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April 3, 2014
Updated April 15, 2014

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

APPENDICIES

1.0 INTRODUCTION AND PURPOSE

Beginning in 2008, the Basalt Water Conservancy District (District), together with the Colorado Water Conservation Board (CWCB), sponsored Phase II of a groundwater investigation of the Missouri Heights region, a broad plateau located in the Roaring Fork River basin approximately 5 miles northeast of Carbondale, Colorado. The investigation was designed to evaluate the effect, if any, that increased residential development and changing land use patterns have had on the water levels of the local aquifers. The Phase II study involved the establishment of continuous groundwater recorders, development of a new, regional weather station, quantification of land use changes, and review of the region's general water balance. This report documents the study methods, assumptions, results and conclusions regarding groundwater development in the Missouri Heights region.

1.1 BACKGROUND INFORMATION

The District was created in 1964 under the authority of the Colorado Water Conservancy District Act. Its purpose is to conserve, develop, and stabilize water supplies for the benefit of its constituents located within portions of Garfield, Eagle, and Pitkin counties. The District is located within the Fryingpan and Roaring Fork River basins generally extending from Aspen to Glenwood Springs, Colorado. **Figure 1** shows the extent and location of the District's division boundary.

The District owns substantial domestic, municipal, and agricultural direct flow water rights, and maintains several reservoir storage contracts with the U.S. Bureau of Reclamation (BOR) for the release of water form Ruedi and Green Mountain reservoirs. These water supplies provide the basis for a comprehensive water supply plan that currently serves thousands of domestic, agricultural, and commercial water users within the District's service area. Under the plan, water users within certain regions of the District can secure a contract that utilizes District water resources to provide the basis for a dependable legal water supply. During periods when the basin is under an administrative call, the District provides augmentation supplies to the river for benefit of its contractees. These supplies allow the contractees to continue to divert water at their individual well, spring, or surface diversion when they otherwise would have been curtailed by the water right call. The

District maintains over 500 water service contracts serving thousands of residents within its service area.

1.1.1 Missouri Heights, a Region of Concern

The District's water supply program includes a region known as Missouri Heights. This region is located on a broad mesa above the Roaring Fork River, approximately 5 miles northeast of Carbondale, Colorado. The mesa encompasses an area of approximately 24 square miles (15,280 acres) and is characterized by rolling topography perched approximately 600 feet above the valley floor. It is geographically located between the Roaring Fork River and Cattle Creek and spans both Garfield and Eagle counties. The area has an average elevation of 7,360 feet with a range from approximately 9,950 feet on Basalt Mountain down to 6,320 feet near the Roaring Fork River. The Missouri Heights region (Study Area) is shown on **Figure 2**.

Historically, Missouri Heights was occupied by a small number of ranches that used irrigation water to raise hay, pasture grass, and cattle. Sources of irrigation water supply primarily included imported surface diversions from nearby Cattle Creek via several agricultural ditches. Some of the ditches imported water directly to the irrigated fields while others stored a portion of their supply in the Spring Park Reservoir for subsequent release in the late growing season. In recent decades, some of these ranches have been sold and split into smaller parcels and subsequently developed into subdivisions, small ranchettes, and individual homesteads. This new, domestic demand has been met by reallocating historic water supply sources and developing new wells, thereby increasing groundwater withdrawals.

The District's water supply program has helped, in part, facilitate the development of groundwater wells in this region. Several subdivisions and individual residents have obtained water service contracts with the District. These wells deplete the Missouri Heights aquifer; however, augmentation releases provided by the District do not provide direct, physical recharge to the aquifer. Rather, the augmentation supplies are released from out-of-basin reservoirs such as the BOR's Ruedi Reservoir located on the Fryingpan River. The lack of direct augmentation supply to the Missouri Heights region has raised concern that the District's water service program in the area could cause a regional decline in local aquifers.

In response to this concern, the District implemented Phase I of the Missouri Heights Groundwater Monitoring Program in 1982. The monitoring program monitors seven sites including three groundwater wells and four springs. A monthly, instantaneous measurement is taken at each of the seven sites. This frequency of data collection provided the basis for a reconnaissance level assessment of fluctuations in groundwater levels and their relationship to climate trends, increased development, and changing land use patterns. The lack of local climatic data and the infrequent monitoring, however, prevented the District from drawing detailed conclusions about Missouri Heights groundwater behavior. Therefore, the District and the CWCB contracted Resource Engineering, Inc. (RESOURCE) to initiate a Phase II study (Study) of the groundwater to better understand the Missouri Heights aquifer.

Section 2.0 of this report provides the reader with a brief summary of the District's Phase I monitoring program. **Sections 3.0 through 5.0** provides the results of the Phase II investigation. **Section 6.0** provides a comparison of the findings between Phase I and Phase II. **Section 7.0** provides recommendations from the Study.

2.0 PHASE I SITE INFORMATION AND CONCLUSIONS

The District's Phase I monitoring program included seven monitoring sites: three wells and four springs located throughout Missouri Heights as shown on **Figure 3**. The Panorama Ranch and the Kings Row wells serve subdivisions consisting of multiple single-family dwellings. The Fender Well serves one individual lot. The four springs: Blue Spring, Blue Irrigation Spring, Cerise Spring, and Crawford Spring all surface at the southern edge of the Study Area where the Missouri Heights mesa descends to the Roaring Fork River. Additional information for each Phase I well and spring are presented below.

2.1 PHASE I SITE INFORMATION

2.1.1 Phase I Study Wells

The three wells participating in the Phase I study include: the Panorama Ranch Well, the Kings Row Well, and the Fender Well. The Panorama Ranch Well is located in the NE1/4 of Section 17, Township 7 South, Range 87 West, of the 6^{th} P.M. and provides a portion of the water supply to the Panorama Ranch subdivision, which consists of 53 single-family residential homes. The well permit limits the maximum pumping rate to 35 gallons per minute (gpm) with an annual amount of up to 48 acre-feet (AF) of allowable withdrawal from the aquifer. The Panorama Ranch Well was drilled to a depth of 480 feet in 1978. Information contained in the well permit application indicates that the well was drilled in the Pleistocene basalt formation which primarily consists of moderately well-sorted to well-sorted, stratified, interbedded sand, pebbly sand, and sandy gravel to poorly stratified, clayey, silty sand, boulder sand, and silty sand.

The original Kings Row Well is located in the SE1/4 of Section 21, Township 7 South, Range 87 West, of the 6^{th} P.M. The well was constructed in July 1973 to a depth of 325 feet. At the time of the well construction, the static water level was at 300 feet from the Top of Casing (TOC) and the well produced 26 gpm during a 24-hour pumping test. Basalt rock was found to a depth of 325 feet. The Kings Row Well was replaced in October 2002 in close proximity to the original well location, but at a depth of 360 feet. At the time of the replacement well construction, the static water level was at 270 feet from TOC and the well produced 20 gpm during a 2-hour pumping test. Volcanic cinders were encountered in the replacement well between 0 and 110 feet, volcanic flows between 100 and 330 feet, and volcanic clays between 330 and 375 feet.

The original Fender Well is located in the NE1/4 of Section 34, Township 7 South, Range 87 West, of the 6^{th} P.M. The well was drilled in June 1965 to a depth of 260 feet. At the time of the well construction, the static water level was 220 feet from TOC and the well produced 10 gpm during a 1-hour pumping test. Volcanic soil types were encountered between 0 and 260 feet. The Fender Well was replaced in June 2012 and drilled to a depth of 365 feet. At the time of the replacement well construction, the static water level was at 245 feet from TOC and the well produced 10 gpm during a 2-hour pumping test. Volcanic material was encountered between 0 and 365 feet. Even though the Fender Well was redrilled in 2012, the original Fender Well is still monitored by the District.

2.1.2 Phase I Study Springs

The four springs that have been monitored as part of the Phase I study include: the Blue Spring, the Blue Irrigation Spring, the Cerise Spring, and the Crawford Spring. The location of each spring is shown on **Figure 3**.

The Blue Spring is located at the southwest corner of the Study Area in Section 25, Township 7 South, Range 88 West, of the 6^{th} P.M. at an approximate elevation of 6,351 feet. The spring has a water right that was appropriated in 1896 for 0.067 cubic feet per second (cfs) and is decreed for domestic and livestock use under Case No. W-0923.

The Blue Irrigation Spring (aka Blue Spring Well) is located at the southwest corner of the Study Area in Section 30, Township 7 South, Range 87 West, of the 6^{th} P.M. at an approximate elevation of 6,356 feet. A water right for this spring was appropriated in 1935 for 0.1760 cfs and was decreed for domestic, municipal, irrigation, and livestock use in 1982 under Case No. 82CW44. Case No. 86CW79 subsequently transferred the water right to the Blue Spring Well.

The Cerise Spring (aka North Spring) is located at the southern edge of the Study Area in Section 33, Township 7 South, Range 87 West, of the 6^{th} P.M. at approximate elevation of 6,485 feet. The water right for this spring was appropriated in 1926 for 0.50 cfs and decreed for irrigation and other beneficial uses in 1958 under Civil Action 4613.

The Crawford Spring (aka Arlian Spring and Pipeline) is located at the southeasterly edge of the Study Area in Section 34, Township 7 South, Range 87 West, of the 6^{th} P.M. at approximate elevation of 6,728 feet. The water right for this spring was appropriated in 1952 for 0.06 cfs and decreed for stock water and domestic uses in 1958 under Civil Action 4613.

2.2 PHASE I RESULTS AND CONCLUSIONS

In 2006, RESOURCE evaluated the information collected from the seven Phase I study sites and concluded the following:

1) The import of agricultural water from Cattle Creek plays a significant role in maintaining the Missouri Heights aquifer. Ditch diversions from Cattle Creek through the Park, Mountain Meadow, and Needham ditches import approximately 12,264 AF of water annually. This amount accounts for approximately 36% of the water that enters the Missouri Heights hydrologic system. Precipitation accounts for the remaining 64%, with approximately 21,387 AF of water coming from snowpack and rainfall.

2) Groundwater levels appear to vary with natural climatic fluctuations. Variations in the regional groundwater table are strongly correlated to dry and wet periods. The regional groundwater table takes approximately one year to respond to climatic fluctuations. For example, groundwater levels will increase approximately one year after an exceptionally wet year.

3) Water levels in the regional Missouri Heights aquifer have not shown a distinct downward trend in response to steady development. However, development involving drying up land may have an impact on the aquifer water levels. The irrigated acreage on Missouri Heights decreased by approximately 16% between 1993 and 2000. As a result, the diversions through the Park, Mountain Meadow and Needham ditches may be decreasing and importing less water to Missouri Heights. The water level in the aquifer may be showing a slight decrease due to the lower diversions.

The conclusions derived from the Phase I study were limited based on the data and sampling methodology and prevented drawing more specific conclusions about the Missouri Heights groundwater behavior. Specifically, the monthly sampling frequency overlooked short term fluctuations and the behavior at the spring sites were highly erratic and could only be used as a proxy for groundwater levels. In addition, climatic data had to be estimated from regional weather station data. To address the limitations of the Phase I study and provide a more detailed understanding of the influences of development on the Missouri Heights aquifer, Phase II of the study was implemented. The following section provides descriptions of existing resource conditions located within the Phase II Study Area.

3.0 PHASE II EXISTING CONDITIONS AND TRENDS

Phase II of the monitoring program was designed to supplement the Phase I study by providing a more detailed review of the influence of development trends and water uses on the Missouri Heights regional aquifer. The Study focused on the recent 2009 through 2013 time period (Study Period). The Study was designed to evaluate how development practices and changes in water use within the Missouri Heights region are influencing water levels in the aquifer. In order to accomplish this, the Study involved installing pressure transducers that continuously monitor the water level in six wells located throughout the Study Area. In addition, a weather station was established to monitor precipitation and temperature within Missouri Heights.

RESOURCE developed a description of the Study Area and sub watersheds based upon review of available land and water resources information. Soils, geology, climate data, and hydrologic information were available from the Colorado Division of Water Resources (DWR), U.S. Forest Service (USFS), Bureau of Land Management (BLM), Natural Resources Conservation Service (NRCS), U.S. Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA). Irrigated areas were identified using aerial photography from the National Agriculture Imagery Program (NAIP) and DWR mapping available through the State's Colorado Decision Support System (CDSS) database. RESOURCE also utilized Geographic Information System (GIS) tools to help quantify various resources within the Study Area. Through these Study procedures, RESOURCE developed a general understanding of the Study Area's hydrologic system, geology, and soils.

The following subsections summarize existing land and water resources contained within the Study Area including: surface and groundwater hydrology, climatic conditions, the import of agricultural water, and water quality.

3.1 MISSOURI HEIGHTS HYDROLOGIC SYSTEM

The Missouri Heights hydrologic system receives recharge from precipitation and the import of irrigation water from nearby Cattle Creek. A portion of the precipitation and irrigation return flows quickly return to the stream system as surface water flows. The balance, infiltrates into the ground and percolates through the soil, eventually reaching the zone of saturation (water table). The rate of water movement through the groundwater system is relatively slow depending upon the underlying geology and hydraulic gradient. As the groundwater moves down gradient, a portion of the water will eventually surface at lower elevations as seeps or springs.

Due to the aerial extent of the Study Area, even small rates of recharge represent significant volumes of inflow to groundwater. Much of the annual recharge arrives in the spring from melting snowpack. This source, combined with the advent of the irrigation season, provide a significant amount of recharge in a relatively short period of time. As a result, the top of the saturated zone (water table) will fluctuate annually in response to these sources. This type of fluctuation is expected and will occur independent of groundwater withdrawals by individual wells. However, this water balance can be upset if the groundwater being pumped and the groundwater that is lost through seeps and springs is greater than the amount of recharge from precipitation and irrigation return flows. Significant withdrawals in excess of the available recharge sources will cause water levels in the Missouri Heights aquifer to decline. Conversely, if the amount of precipitation and irrigation return flows exceed the amount of water leaving the aquifer, the water levels in the aquifer will rise.

3.2 GEOLOGY

In general, the Missouri Heights geology is comprised of basalt flows and associated tuff, breccia, and conglomerate of late volcanic biomodal suite.[1] Areas of alluvium and colluvium containing pebbles, sands, and clays can also be found. On the south side of the Missouri Heights mesa, there is a sequence of evaporitic rock. A surficial geologic map of Missouri Heights can be found on **Figure 4**. Additional detail is contained in geologic maps of the Carbondale and Leon Quads that are located in **Appendix A** of this report.

The subsurface geology of Missouri Heights consists of multiple flows of basalt, basaltic andesiate and basaltic trachyandesite originating from Basalt Mountain. Petrographically, most flows are olivine basalt and porphyritic. The flows are from the Quaternary and Tertiary time period. Stratigraphically, the Eagle Valley Evaporite (Pee) underlays the Basalt (Tb) and alluvial materials (Qc, Qtm, Qls, QTcd, Qac, Qcs) as shown in the maps contained in **Appendix A**.

The Eagle Valley Evaporite contains beds of soluble salts such as gypsum and halite interbedded with mudstone, fine-grained sandstone, and black shale. The introduction of groundwater into these salt beds resulted in the slow but steady solution and removal of this formation over time. As these salts were removed by erosion, the overlaying rocks

[1] U.S. Geological Survey, 2008.

settled, collapsed and deformed, resulting in higher infiltration rates and water bearing capacity of the volcanic rock material.

As described above, the geology of the Study Area is relatively complex and generally consisting of deposits of alluvium, basalt, and evaporates. The distribution of these deposits are highly variable. As such, the groundwater hydrology is highly variable. Certain wells drilled into angular basalt rocks may respond quickly to surface water input from snowmelt and irrigation diversions. Alternatively, wells developed in geologic formations containing volcanic ash and other fines could exhibit a delayed response to sources of surface water recharge.

3.3 SOILS

The surface layers of soil on the eastern edge (approximately 25%) of the Study Area are comprised of stoney loam and loam soils.[2] This soil type has medium available water capacity depending on the location and generally allows water to infiltrate moderately slow into the soil. The parent material is derived from basalt and/or colluvium derived from basalt.

Approximately 20% of the Study Area is currently dedicated to farmland. Farmland areas typically consist of loam and clay loam soils. Slopes in these areas are generally from 2% to 6%, but can be as high as 12%. The parent material is alluvium and/or eolian deposits. The soils are well drained and have a high available water capacity.

The remaining area is composed of variable soils composed of gravelly sandy loam, stoney sandy loam, and loam clay. The alluvium is derived from sandstone, shale, and basalt. Slopes in these areas usually range from 6% to 12%, but can be as high as 65%. The available water capacity can vary from low to high.

3.4 CLIMATE DATA

The relationship between regional climatic trends and groundwater levels was investigated as part of the Study. According to the USGS “consideration of climate can be a key, but

[2] NRCS Aspen-Gypsum Area, Eagle and Garfield Counties, Holy Cross Area, Colorado Soil Data.

underemphasized, factor in ensuring the sustainability and proper management of ground-water resources."[3] For the purposes of this Study, RESOURCE analyzed the climatic precipitation trends to determine if the 2009 to 2013 Phase II Study period represented average, dry, or wet conditions. The analyzed data is divided into water years from November 1st to October 31st.

To identify existing and long-term climatic trends within the Study Area, local weather data was gathered from regional weather stations around the Roaring Fork Valley. For this Study, weather data from 1980 to 2013 from the Aspen 1 SW NOAA (Aspen) weather station and from the Glenwood Springs NOAA (GWS) weather station were utilized. Missing or incomplete data from the GWS weather station was supplemented with data from the Weather Underground South Glenwood Springs weather station. The two Glenwood Springs weather stations are located approximately 0.3 miles apart from one another. Weather data prior to 1980 was not used in the analysis, as the Aspen weather station was relocated in 1980 to its current location, which has a different aspect and elevation than the original site.

In addition to the Aspen and GWS weather stations, local weather data was utilized from August 2008 through 2013 from the BWCD weather station that was installed as part of the Phase II Study. The BWCD weather station was installed by RESOURCE personnel in July 2008 and is located on land owned by the Aspen Mesa Homeowners Association. This weather station is equipped with a Campbell Scientific CR800 Measurement Control System, TR525 Tipping Bucket Rain Gage with CS705 Precipitation Adapter and a Model 107 Temperature Probe. The rain gage continuously monitors precipitation and records total precipitation every 15 minutes. The temperature probe monitors the temperature in degrees Fahrenheit (°F) and records data every 15 minutes. The BWCD weather station is located at an elevation of approximately 7,230 feet, which is near the 7,360 feet average elevation of the Study Area. Therefore, RESOURCE considers the BWCD weather station data representative of overall conditions throughout the Study Area. The location of all the weather stations used to investigate long-term climatic trends can be found on **Figure 5**.

[3] U.S. Geological Survey, 1999

3.4.1 Precipitation Data

Long-term precipitation patterns occurring within the Study Area were calculated by estimating the precipitation at the BWCD weather station prior to 2009 using a regression analysis involving nearby weather data. A regression analysis was completed to compare the precipitation data recorded at the BWCD station from 2009 to 2013, the precipitation data from the Aspen and the GWS weather stations recorded over this same period. The success of a regression analysis can be described through calculation of an R^2 value. The R^2 value defines the relative predictive power or accuracy of the analysis and is a descriptive measure between 0 and 1; where 1 indicates a strong relationship between two sets of data, and 0 indicates no relationship between data sets.

With the exception of the data collected from the GWS weather station during 2010, the regression analysis indicates that there exists a moderate to strong relationship between both the Aspen and GWS weather stations to the BWCD weather station. In other words, the data collected at the Aspen and GWS weather stations can be used to approximate long term precipitation patterns across the Study Area. A mathematical function was developed from the relationship to estimate annual precipitation at the BWCD weather station prior to August 2008 by using available weather data from the Aspen, GWS, and BWCD weather stations from August 2008 through 2013. The relationship between the Aspen and the BWCD weather stations produced an R^2 value of 0.80. While the comparison between the GWS and the BWCD weather stations resulted in a R^2 value of 0.95.

RESOURCE refined the estimates for long-term precipitation at the BWCD weather station by using a weighted average based on distance between the Aspen and BWCD weather stations and the GWS and BWCD weather stations (39% Aspen and 61% Glenwood). This regression analysis resulted in an R^2 value of 0.99. The results from all the precipitation regression analysis can be found in **Appendix B.**

Using the relationship between Aspen, GWS, and BWCD weather stations, precipitation was calculated for Missouri Heights from 1980 to 2013. As shown on **Figure 6**, the 1980 to 2008 projected total annual precipitation average was 15.66 inches, compared to the 2009 to 2013 average of 15.14 inches measured at the weather station. This indicates that the 2009 to 2013 Study Period was slightly drier than the long-term average, experiencing approximately 0.5 inches of less annual rain than during the 1980 to 2008 period.

Analysis of the data shows that over a 32-year period from 1981 to 2013, the Study Area experienced alternating wet and dry cycles. These precipitation cycles are shown on **Figure 7** and include three wet cycles and three dry cycles. The beginning of the Phase II Study Period in 2008 started in a wet cycle; however, this wet cycle ended with the 2012 drought year.

3.5 IMPORTED AGRICULTURAL WATER

Agricultural irrigation has historically been a predominant land use within the Missouri Heights region. Thousands of acre feet of water are diverted from nearby Cattle Creek annually and imported into the Study Area. Water diversions to Missouri Heights primarily occur from five ditches: Park Ditch, C and M Ditch, Needham Ditch, Monarch Ditch, and the Mountain Meadows Ditch (aka Spring Park Reservoir). The location of each ditch and their associated irrigated regions are shown on **Figure 8**. The Phase I groundwater investigation concluded that these diversions play a significant role in maintaining the Missouri Heights aquifer. The significance of the import of agricultural water into the Study Area was further examined in the Phase II Study.

3.5.1 Irrigated Area Analysis

To quantify the extent of imported water into the Study Area, RESOURCE completed an analysis of historic irrigated acreage and associated stream diversions originating from Cattle Creek. RESOURCE obtained irrigated acreage data including irrigated acreage polygons from DWR's CDSS database. The irrigated acreage polygons were overlaid onto recent NAIP aerial photography and updated to reflect any changes that occurred between 2005, when the DWR updated their irrigated area polygons, and the start of the study in Water Year 2009.

Irrigated areas were subsequently divided into areas that were located inside and outside of the Study Area. The irrigated fields located inside and outside of the Study Area were then used to proportion ditch diversions that were tributary to the Missouri Heights Study Area. For example, the Park Ditch diverted 2,879 AF of water annually from 1994 to 2008 and irrigated approximately 500 acres. However, only 133 of the 500 acres (27%) are tributary to the Missouri Heights Study Area. Therefore, only 766 AF (27% of the total 2,879 AF) was estimated to be delivered from Cattle Creek into the Study Area. Irrigated areas within the Study Area are shown on **Figure 8** and the *pro-rata* share of the diversion records for each major ditch can be found in **Appendix C.**

The volume of water diverted from Cattle Creek was calculated for the 1994 to 2008 and 2009 to 2013 periods. Diversion record data after 1994 was chosen, as the DWR considers these records more reliable than record data from previous years. As shown on **Figure 8**, the average annual estimated amount of water diverted from Cattle Creek to Missouri Heights, for the 1994 to 2008 and 2009 to 2013 periods are 9,057 AF and 6,063 AF respectively. This estimate represents an approximate 30% drop in ditch diversions between the two time periods. RESOURCE believes that the drop in ditch diversions is likely due to a reduction in available streamflows associated with recent dry years. However, based upon conversations with the DWR, lower ditch diversions may also be attributed to improved record keeping.

3.6 GROUNDWATER LEVEL TRENDS

The Study Area was divided into four watersheds: West, Central, East, and Spring Park Reservoir. Pressure transducers were installed in two wells in the West, Central, and East watersheds to monitor the groundwater levels (six wells total). The Study Wells were located geographically in the upper and lower regions of the West, Central, and East watersheds. Pressure transducers were not installed in wells located within the Spring Park Reservoir Watershed due to a lack of response from area well owners.

The pressure transducers installed in each of the six Study wells continuously recorded the local groundwater level during the Study Period at 1-hour intervals. The distance from the TOC to the water level was manually measured using an electric well sounder and was set as a datum for each Study well. The six well locations are shown on **Figure 3** and technical data for each well is summarized in **Table 1**.

The water level data collected from the pressure transducers was graphed on **Figures 9, 10, and 11** to show trends in groundwater level movement throughout the Study Period.

The water level data was displayed utilizing a methodology used by the USGS.[4] Average daily groundwater levels were calculated based upon hourly recorded measurements at each well. The daily values were plotted for each study year providing ability to identify and compare rising and falling groundwater levels and dates when groundwater levels reached their highest and lowest elevations. The groundwater hydrographs and annual highest water level and technical information for each Study well is further described below.

3.6.1 West Watershed, Upper Well – Hart Well

The Hart Well is located in the upper portion of the West Watershed in the southwest quarter of Section 13, Township 7 South, Range 88 West, of the 6th P.M. According to the well information obtained from the DWR, the Hart Well was drilled in September 1968 to a depth of approximately 190 feet. There is no available pump installation report; however, the static water level at the beginning of the Study Period was 64 feet. The well is located within irrigated fields under the Park Ditch. According to the geologic map (**Figure 4**), the well is located in areas with alluvial deposits consisting of pebbly silty sand, sandy silt, and clayey silt. The well serves a single family home with no irrigation.

The recorded groundwater levels within the Hart Well are shown on **Figure 9.** Generally, the water level fluctuates annually; water elevations begin to rise each year in May or June and continue to increase into the fall. The highest annual water elevation occurs in November or December. The Hart Well reached its highest level of 6702.3 feet in September 2011 and its lowest level of 6688.0 feet in December 2008 and November 2012. This represents a maximum high water level change of 14.3 feet over the Study Period. A summary of the annual high groundwater elevations over the Study Period for the Hart Well is provided in **Table 2**.

3.6.2 West Watershed, Lower Well – Cerise Well

The Cerise Well is used for livestock watering and is located in the lower portion of the West Watershed in the southwest quarter of Section 24, Township 7 South, Range 88 West, of the 6th P.M. According to the driller's well construction report filed with the DWR,

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[4] U.S. Geological Survey, 2011.

the Cerise Well was drilled in October 2001 to a depth of 170 feet. At the time of well construction, static water level was at 118 feet from TOC and the well produced 10 gpm during a 2-hour pumping test. Volcanic materials were encountered between 0 and 170 feet. The well is located within an irrigated area that is served by the C and M Ditch.

The recorded groundwater levels in the Cerise Well are shown on **Figure 9.** Similar to the Hart Well, the water levels rise and fall annually. Water levels in the Cerise Well typically rise quickly during May and June, reaching its annual peak elevations in late June or July. The Cerise Well reached its highest level of 6654.6 feet in June 2009 and its lowest level of 6638.2 feet in June 2012. This represents a maximum change of 16.4 feet over the Study Period. A summary of the annual high groundwater elevations over the Study Period for the Cerise Well is provided in **Table 2**.

3.6.3 Central Watershed, Upper Well – Mitchell Well

The Mitchell Well is located in the upper portion of the Central Watershed in the southeast corner of Section 16, Township 7 South, Range 87 West, of the 6th P.M. The Mitchell Well, according to the well construction report, was drilled in April 2000 to a depth of 663 feet. At the time of well construction, the static water level was at 510 feet from TOC and the well produced 10 gpm during a 2-hour pumping test. Volcanic, rocks, and clays were encountered between 0 and 320 feet with volcanics between 320 and 663 feet. The well serves a single family home and irrigates a fire protection buffer around the home. There are no irrigated fields in the vicinity of the Mitchell Well.

The recorded data indicates that the water level within the Mitchell Well fluctuates seasonally as shown on **Figure 10**. In general, the water level begins to rise in May or June and continues to increase into the fall. The highest water elevations usually occur in September or October. When comparing the high annual water levels in the Mitchell Well during the Study Period, the highest water level reached was 7049.9 feet in October 2011 and the lowest level was 7042.1 feet in September 2013. This represents a maximum change of 7.8 feet over the Study Period. A summary of the annual high groundwater elevations over the Study Period for the Mitchell Well is provided in **Table 2**.

3.6.4 Central Watershed, Lower Well – Bright Well

The Bright Well is located in the lower portion of the Central Watershed in the southwest quarter of Section 20, Township 7 South, Range 97 West, of the 6th P.M. According to the well construction report, the Bright Well was drilled in September 1995 to a depth of 200 feet. At the time of well construction, static water level was at 123 feet from TOC, and the well produced 15 gpm during a 2-hour pumping test. Volcanics, flows, and cinders were encountered between 0 and 120 feet and eagle valley formation and tan sandstones between 120 and 200 feet. The pump installation report states that the pump intake depth was set at 190 feet from TOC. The well is located near fields irrigated by the Mountain Meadow Ditch. The well serves a single family home and irrigates approximately 5,000 square feet of land.

The water level at the Bright Well does not fluctuate seasonally. The water level at the well remains relatively constant throughout the year. It appears that the well is located topographically in a bowl, which limits the height that the water level can reach every year. The only major change in the water level, is during the irrigation season when pumping temporarily lowers the water level measured in the well. This trend is shown graphically on **Figure 10**. In comparing the high annual water levels during the Study Period, the Bright Well reached its highest level of 6799.3 feet in September 2011 and its lowest level of 6796.9 feet in October 2013. This is a maximum change of only 2.4 feet. A summary of the annual high groundwater elevations over the Study Period for the Bright Well is provided in **Table 2**. RESOURCE also discovered that there was a change in ownership in 2013, which may have resulted in a change of irrigation use.

3.6.5 East Watershed, Upper Well – Pietsch Well

The Pietsch Well is located in the upper portion of the East Watershed in the northeast quarter of Section 21, Township 7 South, Range 87 West, of the 6th P.M. The well construction report states that the well was drilled in November 1994 to a depth of 300 feet. At the time of well construction, static water level was at 228 feet from TOC and the well produced 15 gpm during a 2 hour pumping test. Volcanic flows, rocks, and cinders were encountered between 0 and 300 feet. The pump intake was set at a depth of 280 feet from TOC, according to the pump installation report. The well is located in the upper parts of the Central Watershed away from irrigated fields. The well serves a single family home and is used for landscape irrigation of approximately 0.75 acres.

The water level at the Pietsch Well fluctuates seasonally as shown on **Figure 11**. The water levels in the well begin to rise during May and June, reaching peak elevations in late July and August. In comparing the high annual water levels during the Study Period, the Pietsch Well reached its highest level of 7055.4 in July 2011 and its lowest level of 7047.9 feet in July 2012. This represents a maximum change of 7.5 feet. A summary of the annual high groundwater elevations over the Study Period for the Pietsch Well is provided in **Table 2**.

3.6.6 East Watershed, Lower Well – Elmore Well

The Elmore Well is located in the lower portion of the East Watershed in the northwest quarter of Section 28, Township 7 South, Range 87 West, of the 6^{th} P.M. According to the well completion report, the Elmore Well was drilled in December 1995 to a depth of 220 feet. At the time of well construction, static water level was at 123 feet from TOC and the well produced 10 gpm during a 2-hour pumping test. Volcanic flows, ash, and clays were encountered between 0 to 220 feet. According to the pump installation report, the pump intake depth was set at 210 feet from TOC. The well is located away from irrigated fields. The well serves a single family home and is used for landscape irrigation of approximately 0.3 acres.

The water level at the Elmore Well fluctuates seasonally as shown on **Figure 11.** The water level in the well begins to slowly rise in October and November until it reaches peak elevation, usually in April or May. In comparing the high annual water levels during the Study Period, the Elmore Well reached its highest level of 6879.1 feet in April 2012 and its lowest level of 6869.6 feet in August 2013. This represents a maximum change of 9.5 feet. A summary of the annual high groundwater elevations over the Study Period for the Elmore Well is provided in **Table 2**.

3.7 WATER QUALITY

The Phase II Study included the collection and analysis of groundwater samples taken at three of the wells at the beginning and end of the Study Period. The purpose of the data collection was to provide a baseline description of the groundwater quality over a wide, aerial extent of the Study Area and to identify changes in the water quality, if any, that may have occurred. The selected wells for the water quality samples included the Hart, Pietsch, and Elmore wells.

The water quality associated with the Hart, Pietsch, and Elmore wells is acceptable for domestic use, meeting the basic EPA primary and secondary drinking water standards. The water can be characterized as "hard" with each well containing moderate concentrations of calcium, magnesium, and sodium. Alkalinity varied from 200 to 240 mg/l with pH consistently at 8.3 or 8.4. Total Dissolved Solids ranged from 300 to 350 mg/l and each well reported low concentrations of nitrogen. Perhaps the most surprising finding was the consistency of the groundwater quality of the three wells. The Hart Well is located in the West Watershed while the Elmore and Pietsch wells are located several miles east, both within the East Watershed.

Water quality results for each well are summarized in **Tables 3, 4, and 5**. The water quality lab analysis was conducted by ACZ Laboratories and excerpts from the reports can be found in **Appendix D.**

3.8 DEVELOPMENT TRENDS

To investigate how development has impacted the Missouri Heights aquifer, RESOURCE studied depletions to the aquifer associated with in-house use and irrigation. RESOURCE also identified wells that were replaced or redrilled during the study period to determine if there was a correlation between replacement wells and groundwater elevations.

3.8.1 In-House and Irrigation Depletions

One of the goals of the Phase II Study was to assess the potential impact of continued residential development within the Study Area on the local groundwater elevations. To help quantify the potential impact to the water resources, RESOURCE calculated the total annual water demand and depletions associated with existing development. The amount of in-house and irrigation water use was estimated for a typical residence and extrapolated to the total number of housing units on Missouri Heights.

The location and number of existing residential units was estimated from parcel data obtained from the Garfield County and Eagle County assessor websites and 2013 NAIP aerial photography. As of January 2014, there are approximately 620 parcels on Missouri Heights that have a residence or building built upon it. Using standard engineering assumptions, RESOURCE assumed that each residence diverts on average 350 gallons of water per day and of this amount, 15% is consumed. The balance of the water is returned to the ground as treated effluent through septic tank and leach field systems. Therefore, up to 243 AF of water is diverted annually for residential in-house uses of which approximately 36 AF is consumed and not available to the groundwater system.

For purpose of estimating water demands associated with residential landscape irrigation, each residence was assumed to irrigate 10,000 square feet of lawn. The area of irrigation was estimated by looking at augmentation plans for existing subdivisions located within the Study Area[5]. Irrigation consumptive use (CU) was estimated using the Modified Blaney-Criddle methodology outlined in SCS TR-21 for bluegrass. The irrigation water demand for landscape bluegrass was calculated to be 2.0 feet. Therefore, for 142 acres of irrigation (10,000 square feet x 620 parcels), the irrigation depletion is approximately 285 AF (142 acres x 2.0 feet). A copy of the Modified Blaney-Criddle calculation can be found in **Appendix E.** The total amount of groundwater depletions from in-house and irrigation use is estimated to currently be 321 AF (36 AF + 285 AF).

3.8.2 Irrigation Practices Impact on Wells

Much of the developable land in Missouri Heights exists within historic ranches where the land is generally more suitable for home construction. As stated previously, some of these historic ranches have been sold and split into smaller parcels and subsequently developed into subdivisions, small ranchettes, and individual homesteads. Often, these new developments dry up irrigated lands or utilize more efficient means of irrigation for common areas (i.e., open space), specifically, the conversion of flood irrigation to sprinkler irrigation. As part of this Study, RESOURCE analyzes the effects of converting from flood to sprinkler irrigation in **Section 4.3.2**.

[5] The subdivisions include Kings Row and Sterling Ranch.

4.0 PHASE II ANALYSES AND RESULTS

This section analyzes the conditions and trends that were established in **Section 3.0**.

4.1 GROUNDWATER INFLUENCES FROM PRECIPITATION AND IMPORTED IRRIGATION WATER

The groundwater hydrographs shown on **Figures 9 through 11** display seasonal and annual variations in groundwater depth occurring throughout the Study Period. As discussed in **Section 3.0**, similar cyclic patterns were evident in observed annual precipitation and water imported from Cattle Creek. This section examines the relationship between these variables in an effort to determine the importance of their contribution in sustaining the local aquifers. Specifically, groundwater hydrographs of the six wells were overlain with the previously described trends in precipitation and agricultural diversions that were recorded over the Study.

Of the six Study wells, three are located in proximity to irrigated fields and three are located away from irrigated areas. The Hart, Cerise, and Bright wells are all located within or near agricultural fields that receive irrigation water from Cattle Creek. The Mitchell, Pietsch, and Elmore wells are all located some distance from irrigated areas. The Mitchell Well is located approximately 0.75 miles from the nearest irrigated field while the Elmore and Pietsch wells are both located approximately 0.3 miles from the nearest irrigated fields. The location of each well and their proximity to irrigated fields is shown on **Figure 8**.

4.1.1 Hart Well

The groundwater hydrograph developed for the Hart Well generally exhibits significant variations in groundwater levels throughout the year. Water levels rise and fall (fluctuate) 10 to 30 feet seasonally with lowest levels occurring early spring and highest levels occurring in the fall or early winter. The Hart Well is located within an irrigated region that receives Cattle Creek imports via the Park Ditch. Accordingly, it was logical to compare the groundwater trends to both precipitation and diversion imports. **Figure 12** displays the seasonal groundwater trends with annual precipitation amounts and irrigation diversions representative of this area. Visually, it appears that the groundwater reacts to both precipitation and diversion amounts. In years with higher than average precipitation and irrigation imports, groundwater levels rise. In contrast, in years with low precipitation and agricultural diversions, groundwater levels appear to drop. In an effort to determine which variable has the most influence on the local aquifer, RESOURCE examined precipitation and diversions trends individually.

Precipitation. Groundwater infiltration and aquifer recharge associated with precipitation can be a slow process that occurs over several months or even years. In order to analyze the potential lag between precipitation and groundwater response, RESOURCE conducted a regression analysis that examined the relationship between the annual average height of the water level observed in Hart Well each year compared to that same year's annual precipitation. A total of three analyses were completed; the first analysis assumed that there was no lag between the annual precipitation and observed annual average groundwater levels. In other words, the annual average water elevations recorded in 2009 were compared to 2009 precipitation, the 2010 annual average water elevations were compared to the 2010 precipitation, etc. The second and third analyses assumed that the precipitation took either six or twelve months to reach the aquifer. This was accomplished by artificially delaying precipitation schedules by these time periods.

The described regression analyses did not establish a strong relationship between annual precipitation and annual average groundwater elevations within the Hart Well. Each of the assumed lag periods produced R^2 values ranging from 0.54 to 0.60.

Irrigation Diversions. The lack of a strong relationship between groundwater levels and precipitation suggests that the large seasonal variation in the aquifer is influenced by other variables, in this case, the import of significant volumes of water for irrigation. To evaluate the impact of this water on area groundwater levels, the observed groundwater elevations were compared to the adjusted diversion records for the Park Ditch. For this analysis, RESOURCE selected two representative years for its analysis: 2009 and 2012. These two years were selected as diversions slightly exceeded historic averages in 2009 and diversions were lower than the historic average in 2012.

A review of the diversion records maintained by the DWR over the Study Period indicates that the groundwater level reacted quickly once the Park Ditch diversions commenced. This relationship is shown graphically on **Figure 13**. In 2009, water elevations within the well begin to rise almost on the same day that water is delivered into the region. Even in the 2012 drought year when diversion imports were only 2/3 of what occurred in 2009, the groundwater level at the Hart Well responded almost immediately to irrigation diversions. RESOURCE also observed that in 2012, the groundwater level first stabilized a few weeks after Park Ditch diversion and then the water level began to rise. However, in general, the rise in the groundwater level in 2012 was not as pronounced in 2009.

In summary, groundwater elevations within the Hart Well respond to both precipitation and irrigation return flows; however, due to the proximity of the well to irrigated fields, the rise and fall of the annual groundwater hydrograph is more closely tied to the amount of water imported from Cattle Creek.

4.1.2 Cerise Well

The groundwater hydrograph developed for the Cerise Well is similar to the Hart Well, as the water levels generally exhibited significant variations throughout the year. Water levels rise and fall 10 to 17 feet seasonally with lowest levels occurring in early spring and highest levels occurring in mid-summer. Like the Hart Well, the Cerise Well is located within an irrigated region that receives Cattle Creek imports. The source of supply for the fields in vicinity to this well is the C and M Ditch. Accordingly, RESOURCE again compared the groundwater trends to both precipitation and diversion imports.

Figure 14 displays the seasonal groundwater trends with annual precipitation amounts and irrigation diversions representative of this area. Visually, it appears that the groundwater reacts to both precipitation and diversion amounts. That is, in years with higher than normal precipitation and irrigation imports, groundwater levels rise. In contrast, in years with low precipitation and agricultural diversions, groundwater appears to drop. In an effort to determine which variable has the most influence on the local aquifer, RESOURCE examined precipitation and diversion trends individually.

Precipitation. RESOURCE conducted a similar regression analysis to that described above for the Hart Well. The analysis examined the relationship between the annual average height of the water level observed in Cerise Well each year compared to that same year's annual precipitation. A total of three analyses were completed; the first analysis assumed that there was no lag between annual precipitation and observed annual average groundwater levels. The second and third analyses assumed that the precipitation took either six or twelve months to reach the aquifer. This was accomplished by artificially delaying precipitation schedules by these time periods.

Similar to the results described for the Hart Well, the Cerise Well regression analyses did not establish a strong relationship between annual precipitation and annual average groundwater elevations. Each of the assumed lag periods produced R^2 values ranging from 0.45 to 0.70.

Irrigation Diversions. The lack of a strong relationship between groundwater levels and precipitation suggests that the large seasonal variation in the aquifer is influenced by other variables, in this case, the import of significant volumes of water for irrigation. To evaluate the impact of this water on area groundwater levels, the observed groundwater elevations were compared to the adjusted diversion records for the C and M Ditch. The analysis utilized the same two representative years for study: 2009 and 2012.

The diversion records maintained by the DWR over the Study Period indicates that in 2009, groundwater levels in the Cerise Well began to respond approximately 2 weeks after C and M Ditch diversions commenced. In contrast, due to limited diversions in 2012 (ditch was shut off on June 30) the water levels in the Cerise Well did not recharge and continued to decline throughout the summer. C and M Ditch diversions were insufficient to provide water to the pasture grass, maintain the soil moisture, and recharge the aquifer. This relationship is shown graphically on **Figure 15**.

In summary, groundwater elevations within the Cerise Well respond to both precipitation and irrigation return flows; however, due to the proximity of the well to irrigated fields, the rise and fall of the annual groundwater hydrograph is more closely tied to the amount of water imported from Cattle Creek.

The groundwater hydrograph indicates that the Cerise Well experienced a larger drop in the groundwater level than the Hart Well following the 2012 drought year. The larger drop in the groundwater level appears to be attributed to a combination of extremely low diversions from the C and M Ditch and below average precipitation in 2012. In 2012, the C and M Ditch diverted 345 AF, compared to the 5-year average of 827 AF. Precipitation in 2012 was 12.14 inches as compared to the 5-year average of 15.14 inches. Due to the lack of water delivery from the C and M Ditch for flood irrigation and below average precipitation, the aquifer did not rebound as observed in previous years. Conversely, the Hart Well groundwater level experienced some rebound in 2012. Although the region was experiencing a drought year, the Park Ditch was able to import a total volume of irrigation water equivalent to its 5-year average (605 AF in 2012, 5-year average = 616 AF). Due to below average precipitation, the rebound in the Hart Well was not as high as in previous years.

4.1.3 Mitchell Well

The groundwater hydrograph developed for the Mitchell Well generally exhibits moderate fluctuations in groundwater levels throughout the year as shown on **Figure 16**. During the Study Period, water levels fluctuated approximately 4 to 7 feet seasonally, with lowest levels occurring during the summer. The Mitchell Well is located in the upper parts of the Central Watershed approximately 0.75 miles away from irrigated areas.

Due to the distance between the Mitchell Well and irrigated fields, it is probable that the groundwater levels are influenced by annual precipitation, not irrigation return flows. To verify this, RESOURCE reviewed surface and groundwater elevations within the area to determine the hydraulic gradient of the aquifer and elevation differences between the various Study Wells.

The TOC of the Mitchell Well is located at an elevation of approximately 7,540 feet. The well was constructed relatively deep with the bottom of the well located 663 feet below the surface (Elevation of 6,877 feet). The closest irrigated fields to the well are located northeast of the Bright Well and receive irrigation supply from the Mountain Meadow Ditch. The water elevation in the Bright Well, which remained fairly constant throughout the Study Period, was recorded at 6,795 feet in December 2013. December was selected because it was the first month that most of the Study wells had complete monthly data and aquifer fluctuations are minimized by eliminating irrigation pumping. Thus, the maximum water elevation associated with the closest irrigated fields is 82 feet lower in elevation than the bottom of the Mitchell Well. Due to this down gradient position of the nearest irrigated fields and associated water level, it is unlikely that the Mitchell Well is being recharged from nearby irrigated fields. The elevations of the six Study wells and recorded groundwater depths from December 2013 are summarized in **Table 6**.

Precipitation. With the elimination of irrigation return flows as a source of recharge for the Mitchell Well aquifer, RESOURCE examined the influence of precipitation on local groundwater levels. A similar regression analysis to that described above for the Hart and Cerise wells was used. The analysis examined the relationship between the annual average height of the groundwater levels observed in the Mitchell Well each year compared to that same year's annual precipitation. A total of three analyses were completed; the first analysis assumed that there was no lag between annual precipitation and observed annual average groundwater levels. The second and third analyses assumed that the precipitation took either six or 12 months to reach the aquifer. This was accomplished by artificially delaying precipitation schedules by these time periods.

The regression analyses for the Mitchell Well established a strong relationship between annual average groundwater elevations and precipitation, lagged by 12 months. The calculated R^2 value describing the relationship is 0.97. This strong relationship indicates that the Mitchell Well is influenced by precipitation from the prior year. **Figure 16** displays the seasonal groundwater trends with annual precipitation amounts.

4.1.4 Bright Well

The groundwater hydrograph developed for the Bright Well is shown on **Figure 17.** The observed peak water levels remained relatively constant throughout the Study Period. However, groundwater levels immediately drop when the well is used for irrigation. It also shows that the aquifer recovers quickly when the pump is turned off. The steep drawdown and the rapid recovery observed immediately after irrigation may indicate that the pump is oversized or the well screen is partially plugged.

The Bright Well is located adjacent to irrigated fields supplied by the Mountain Meadow Ditch and Spring Park Reservoir releases. Initially, it was believed that the groundwater levels would behave similar to the Hart and Cerise wells, which were also located adjacent to irrigated fields. However, in this instance, the groundwater levels recover to approximately the same elevation each year regardless of annual precipitation or irrigation water imports. As mentioned previously, the Bright Well is located in a topographic bowl, as the well is surrounded by slightly higher elevations on the north, east, and south sides and lower elevations on the west side. At this location within the Study Area, it appears that the groundwater level reaches a maximum height and does not increase above this level, even with increased precipitation and irrigation diversions.

4.1.5 Pietsch Well

Similar to the Mitchell Well, the groundwater hydrograph developed for the Pietsch Well generally exhibits moderate fluctuations in groundwater levels throughout the year. During the Study Period, water levels fluctuated approximately 5 to 11 feet seasonally with lowest levels occurring during the late summer or early fall. The Pietsch Well is located in the upper parts of the East Watershed. Due to the distance between the Pietsch Well and irrigated fields, it is probable that the groundwater levels are influenced by annual precipitation and not irrigation return flows. To verify this, RESOURCE again reviewed surface and groundwater elevations associated with the well for the purpose of determining the hydraulic gradient of the aquifer and comparing it to nearby wells and irrigated fields in the East Watershed.

The TOC of the Pietsch Well is located at an elevation of approximately 7,280 feet. The well was constructed to a depth of 300 feet (Elevation of 6,980 feet). The closest irrigated fields to the well are located approximately 0.3 miles south of the well and receive irrigation supply from the Mountain Meadow Ditch and Spring Park Reservoir releases. Groundwater elevations recorded in the two Study wells located closest to the irrigated fields, the Bright Well and the Elmore Well, were 6,795 feet and 6,867 feet respectively **(Table 6)**. These groundwater elevations are over 100 feet lower in elevation than the bottom of the Pietsch Well. Due to this down gradient position of the nearest irrigated fields and associated water level, it is unlikely that the Pietsch Well is being recharged from nearby irrigated fields.

Precipitation. RESOURCE conducted a similar regression analysis to that described above for the Hart, Cerise, and Mitchell wells. The analysis examined the relationship between the annual average height of the groundwater level observed in the Pietsch Well each year and the same year's annual precipitation. The same three analyses as described earlier were completed for the Pietsch Well. The first analysis assumed that there was no lag between annual precipitation and observed annual average groundwater levels. The second and third analyses assumed that the precipitation took either six or twelve months to reach the aquifer. This was accomplished by artificially delaying precipitation schedules by these time periods.

The regression analyses for the Pietsch Well established a moderate to strong relationship between annual precipitation and annual average groundwater elevations with 0 to 6 month lag and R^2 values of 0.74 and 0.75. These moderate to strong R^2 values are significantly higher than those calculated for the Hart and Cerise wells and indicate that the Pietsch Well is primarily influenced by precipitation. **Figure 18** displays the seasonal groundwater trends with annual precipitation amounts.

4.1.6 Elmore Well

Similar to the Mitchell and Pietsch wells, the groundwater hydrograph developed for the Elmore Well generally exhibits moderate fluctuations in groundwater levels throughout the year. During the Study Period, water levels fluctuated approximately 3 to 8 feet seasonally with lowest levels occurring during the summer. The Elmore Well is located in the lower regions of the East Watershed approximately 0.30 miles away from irrigated areas served by the Mountain Meadow Ditch.

RESOURCE again compared the groundwater trends to both precipitation and diversion imports. **Figure 19** displays the seasonal groundwater trends with annual precipitation amounts and irrigation diversions representative of this area. Visually, it appears that the groundwater reacts to precipitation only. However, in an effort to determine which variable has the most influence on the local aquifer, RESOURCE first examined precipitation trends.

Precipitation. RESOURCE conducted a similar regression analysis described above for the Elmore Well. The analysis examined the relationship between the annual average height of the groundwater level observed in the Elmore Well each year compared to that same year's annual precipitation. A total of three analyses were completed; the first analysis assumed that there was no lag between annual precipitation and observed annual average groundwater levels. The second and third analyses assumed that the precipitation took either six or 12 months to reach the aquifer. This was accomplished by artificially delaying precipitation schedules by these time periods.

The well regression analyses for the Elmore Well established a strong relationship between annual precipitation and annual average groundwater elevations with a 12 month lag as the R^2 value is 0.98. This strong relationship indicates that the Elmore Well is influenced by precipitation.

4.2 WATER QUALITY DATA

Water samples analyzed from the Hart, Pietsch, and Elmore wells indicates the water quality is acceptable for domestic use as it meets the basic EPA primary and secondary drinking water standards. In addition, the water quality measured at the beginning and end of the Study Period remained fairly consistent. The water from each well is characterized as "hard" as they contain moderate concentrations of calcium, magnesium, and sodium.

The 2008 data collected from the Pietsch Well was inadvertently collected from a location after household water softening treatment as reflected from the low concentrations of calcium, magnesium, potassium, and hardness. The sampling location for the Pietsch Well was moved in 2013 in order to describe the groundwater quality conditions prior to treatment.

In summary, the water found in the three wells have acceptable quality and suitable for household use. In comparing the 2008 data to the 2013 data collected at the Hart, Pietsch, and Elmore wells, the water quality data remained consistent and showed no evidence of an increasing or decreasing trend.

4.3 DEVELOPMENT TRENDS

In addition to examining potential water quality trends, the impact due to potential development on Missouri Heights was also examined.

4.3.1 In-House and Irrigation Depletions

Section 3.8.1 in-house domestic and irrigation depletions associated with residences at Missouri Heights was estimated at 321 AF. To estimate future depletions, RESOURCE conservatively assumed that the region's population triples over the next 50 years. Therefore, annual depletions would be approximately 963 AF or 1,000 AF. These future depletions represent approximately 1/6 (1,000 AF / 6,063 AF) of the average annual import of irrigation water from Cattle Creek over the Study Period (See **Section 3.5.1**). This suggests that even with substantial future development, recharge of the groundwater from imported irrigation water and precipitation should exceed development depletions. However, the impact of future development on local water supplies will likely be more pronounced if irrigated lands are removed from production. This action could result in the reduction of water imported from Cattle Creek and the associated loss of groundwater recharge attributed to irrigation return flows. The effects of change in irrigation practices on the aquifer are discussed in the following subsection.

4.3.2 Irrigation Practices Impact on Wells

New development within Missouri Heights often reduces the amount of historically irrigated land and utilize more efficient means of irrigation for common areas. Specifically, changes in irrigation practices from flood to sprinkler irrigation are to improve irrigation efficiencies. To investigate this, RESOURCE first queried the DWRs database to examine areas where wells were recently redrilled. Based upon the review of the DWR's database, RESOURCE discovered that nine wells were reconstructed during the Study Period. The locations of the nine replacement wells redrilled during the Study Period are shown on **Figure 20.** Four of the nine wells are located high in the West and Central watersheds and the remaining five wells are concentrated in the lower part of the Spring Park Reservoir Watershed, near the Phase I Fender Well. The five replacement wells, including the Fender Well, were all redrilled during the 2012 drought year, raising concerns that the groundwater elevations in the region were in decline.

To better understand why the groundwater elevation was in decline in the vicinity of the five replacement wells, RESOURCE reviewed current and historic aerial photography and monthly well data from the Phase I Fender Well. RESOURCE observed that the irrigated field located in the middle of the five replacement wells was converted from flood to sprinkler irrigation in 2005.

Sprinkler irrigation is considered more efficient than conventional flood irrigation and generally results in reduced diversions and associated return flows. In general, flood irrigation has an efficiency of approximately 30% to 40%, while sprinkler irrigation is typically 60% to 70% efficient. This suggests that a decline in groundwater elevations near irrigated fields may be a result of changed irrigation methods.

To examine if the change from flood irrigation to sprinkler irrigation near the Fender Well caused the groundwater level to decline, monthly data from the Fender Well since 1981 was compared to annual precipitation trends. The resulting long-term trend of groundwater elevations and precipitation amounts near the Fender Well is shown on **Figure 21**. Results show that the groundwater level fluctuations at the Fender Well generally follow wet and dry periods of precipitation. **Figure 21** also shows that groundwater levels trended at or above the precipitation trendline from 1981 through 2006. However, beginning in 2007, the precipitation trendline shows an increase in precipitation while the groundwater level trendline begins to decline. Also, during the 1981 through 2005 period, the seasonal amplitude (rise and fall) of the groundwater level was typically between 10 to 15 feet during the time of flood irrigation. However, after the sprinkler system was converted from flood irrigation to sprinkler irrigation in 2005, the amplitude of groundwater level dropped to 5 to 10 feet. Based upon these observations, RESOURCE concludes that the localized decline in the aquifer near the Fender Well is likely caused by the change from flood to sprinkler irrigation.

As demonstrated at the Fender Well, imported irrigation water caused the groundwater level to be artificially higher than it normally would have been. In other words, the additional water infiltrated into the aquifer and caused the groundwater to "mound" below the irrigated fields and create an artificially higher groundwater level. When the amount of water available for recharge to the aquifer dropped due to the change from flood to sprinkler irrigation, the groundwater level dropped from the artificial level to a more natural level that is maintained by precipitation. As a result, area wells needed to be redrilled to greater depths.

4.4 GROUNDWATER LEVEL CHANGES DURING STUDY PERIOD

The overall change in groundwater levels during the Study Period at each of the Phase II wells was analyzed. The change in water level in each well was compared for December 2008 and December 2013. December was selected because it was the first month that most of the Study wells had complete monthly data and aquifer fluctuations are minimized by eliminating irrigation pumping. December 2008 was selected as the baseline to which all of the remaining years in the Study Period are compared. The water level in each of the Study wells fluctuated on a yearly basis as shown on **Table 7**.

On average, the groundwater level in the Study Area increased from 2008 through 2011, but declined from 2012 through 2013 due to the 2012 drought and lagged responses. Overall, the groundwater showed a decline during the Study Period. Based on current snowpack levels, it is anticipated that in Water Year 2014, groundwater levels of the aquifer will begin to increase.

The change in groundwater levels from December 2008 to December 2013 was highly variable throughout the Study Area as shown on **Figure 22.** However, in general, the groundwater table showed a slight decline in the northern part of the Study Area and the groundwater level declines increased further to the south. An exception to this is the Elmore Well, which is located in the southern part of the East Watershed and had an average water level increase of 2.3 feet.

The following section provides a summary of the Study and its conclusions.

5.0 PHASE II SUMMARY AND CONCLUSIONS

In 2008, the Basalt Water Conservancy District and Colorado Water Conservation Board sponsored Phase II of a groundwater investigation of the Missouri Heights region to evaluate any effect that increased development and changing land use patterns may have on the local aquifer. Phase II of the Missouri Heights Groundwater Monitoring Program provided five years of continuous measurements at six well sites and a local weather station. The data gathered from these wells and weather station was reviewed and analyzed to judge the relationship of groundwater levels to irrigation return flows, climatic events, and land use.

Section 3.0 summarized the existing conditions and discussed precipitation, imported agricultural water, groundwater level trends, and development trends observed in the Study Area. Each of these trends are summarized below.

Long-Term Precipitation Trends – Long-term precipitation trends were developed for the Study Area by taking portions of data from the Aspen and Glenwood weather stations (39% Aspen and 61% Glenwood, respectively resulting in an R^2 value of 0.99) and data from the BWCD weather station as further explained in **Section 3.4**. The analysis showed that the Study Area experienced alternating wet and dry cycles as shown on **Figure 7**. The Missouri Heights area is currently within a dry cycle that started in 2012.

Imported Agricultural Water – Agricultural irrigation is a predominant land use within the Study Area. Thousands of acre feet of water are annually diverted from Cattle Creek and imported into the Study Area from five primary ditches: Park Ditch, C and M Ditch, Needham Ditch, Monarch Ditch, and the Mountain Meadow Ditch via releases from Spring Park Reservoir. These diversions play a significant role in maintaining the Missouri Heights aquifer. As summarized on **Table 8**, the average annual estimated amount of water diverted into Cattle Creek to Missouri Heights was 6,063 AF for the Study Period. This is a decrease from the 9,057 AF that was diverted from the 1994 to 2008 period. This water drop is likely due to a reduction in available streamflows due to the dry precipitation cycle that began in 2012 and better record keeping by DWR and ditch diverters.

Groundwater Level Trends – The Study Area was divided into four watersheds. However, Study wells were only installed in three of the four watersheds: West, Central, and East. As mentioned previously, wells were not studied in the Spring Park Reservoir Watershed due to lack of response from area well owners. Well sites were selected in the upper and lower geographic regions of each watershed. Technical data for each Study well is summarized in **Table 1** and the groundwater level data collected from each well is presented on **Figures 9 through 11**. In general, Study wells (i.e., Hart and Cerise wells) that had large water level fluctuations (greater than 10 feet) were constructed near irrigated fields with alluvial deposits and collapse deposits. Conversely, Study wells that were constructed away from irrigated fields in volcanic clays and other fines (i.e., Mitchell and Elmore wells) experienced small water level fluctuations (less than 10 feet).

Development Trends – Due to limited development during the Study Period, RESOURCE was not able to evaluate any data associated directly with new development. Therefore, RESOURCE estimated existing and future depletions to the aquifer associated with in-house and irrigation use from domestic wells and compared it to groundwater hydrology developed in the Study. In-house and irrigation use was estimated using standard engineering assumptions and methodology. Current in-house depletions were estimated at 36 AF and irrigation consumption was estimated at 285 AF for a total groundwater depletion of 321 AF.

New developments within the Study Area are typically constructed within historic ranches. Some of the land previously irrigated is either removed from irrigation or significantly reduced as open space parcels within the subdivision. Often, remaining irrigated areas within subdivisions are converted from flood to sprinkler irrigation to more efficiently use the water. Some of the water not consumed by the various crops infiltrates into the groundwater aquifer and provides additional recharge. Therefore, examining areas where irrigation practices have changed is a useful tool to help assess how future development might impact the aquifer.

Section 4.0 presented various Study analyses and their results. The Study primarily examined the effect of precipitation and imported irrigation water on groundwater levels. Results indicate that groundwater levels fluctuate on a seasonal basis due to irrigation return flows and natural climatic dry and wet periods. The effect of precipitation and irrigation return flows depends on the location within the Study Area.

To determine if groundwater levels at a well were heavily influenced by precipitation, regression analyses between annual precipitation and annual average groundwater levels were performed. Since groundwater infiltration and aquifer recharge associated with precipitation can be a slow process that can take several months or years, the regression analysis was conducted by lagging the precipitation at 0, 6, and 12 months intervals for each Study well. Wells that had a high R^2 value (greater than or equal to 0.75) were found to be largely influenced by precipitation. The Mitchell Well and Elmore Well had strong R^2 values of 0.97 and 0.98 respectively with a 12 month lag. The Pietsch Well had R^2 values of 0.74 to 0.75 for a 0 and 6 month lags; however, due to its location upgradient of irrigated fields, the well is believed to be primarily influenced by precipitation. The Hart and Cerise wells had low R^2 values ranging from 0.45 to 0.70.

For wells that are located near irrigated fields, aquifer levels appear to be more responsive to irrigation return flows. Examples of this relationship include the Hart and Cerise wells, which were both located near irrigated fields and had a quick response when irrigation commenced (see **Figures 13 and 15**). The Bright Well is also located near irrigated fields; however, no significant changes in groundwater levels were observed during the Study Period. For wells that were located away and upgradient of irrigated fields, such as the Mitchell and Pietsch wells, aquifer levels are more responsive to precipitation. The Elmore Well is not located within irrigated fields, but is adjacent and downgradient from irrigated fields. The Elmore Well appeared to be more influenced by precipitation, but with a one year lag.

RESOURCE's analysis of the irrigation return flows revealed that water from irrigation return flows infiltrated into the aquifer quickly in average and wet years. The amount of time it took for the aquifer to recharge from irrigation return flows depends on the location and depth of the well. In years with large ditch diversions such as 2009, relatively shallow wells located near irrigated fields showed an immediate response to irrigation. However, in low diversion years, the response of the aquifer can take several weeks or show no response. In dry years such as 2012, the groundwater level can take a month or longer to rise from the effects of the irrigation.

In addition to examining the effects of precipitation and imported irrigation water on aquifer levels, the impact due to development on Missouri Heights was also analyzed. Since little development has occurred over the Study Period, RESOURCE assumed that the region's population tripled over the next 50 years. Total annual depletions due to development were calculated at 1,000 AF or approximately a sixth of the average annual import of irrigation water from Cattle Creek. This suggests that even with substantial future development, recharge of the groundwater from imported irrigation water and precipitation should far exceed new depletions from development. However, the impact of future development on local groundwater supplies will be more pronounced if irrigated lands are removed from production. Since large reductions in irrigated lands could not be documented during the Study Period, RESOURCE analyzed the reduction of water being applied to irrigated lands through changes in irrigation practices.

Lands within the vicinity of the Phase I Fender Well were converted from flood to sprinkler irrigation in 2005 reducing the amount of water applied. To examine if the change irrigation practices near the Fender Well caused the groundwater level to decline, monthly data from the Fender Well was compared to annual precipitation trends. Results show that the groundwater level fluctuations at the Fender Well generally follow wet and dry periods of precipitation. However, beginning in 2007, increases in precipitation did not correspond with increases in the water level elevation. Also, the water level amplitude was typically 10 to 15 feet before and 5 to 10 feet after the conversion from flood to sprinkler irrigation. Based on these observations, RESOURCE concludes that the localized decline in the aquifer near the Fender Well is likely caused by the change in irrigation practices.

6.0 PHASE I AND PHASE II COMPARISONS

Phase I of the groundwater monitoring program concluded that imports of agricultural water from Cattle Creek play a significant role in maintaining the Missouri Heights aquifer. Approximately 12,264 AF of water was imported annually from Cattle Creek and an average of 21,387 AF of water was also added from snowpack and rainfall to the Study Area. In addition, Phase I concluded that groundwater levels appear to vary with natural climatic fluctuations and take approximately one year to respond. Lastly, Phase I concluded that groundwater levels have not shown a distinct downward trend in response to steady development. However, development involving the dry up of irrigated lands may have an impact on groundwater levels.

Phase II of the groundwater monitoring program confirms that imports from Cattle Creek play a vital role in maintaining the water levels in the aquifer. Average imports from Cattle Creek were approximately 6,063 AF per year during the Study Period, while average annual precipitation from snowpack and rainfall was estimated at 19,268 AF as shown on **Table 8**. The reduction in average ditch imports from Phase I to Phase II is largely due to diversion records being refined to only include irrigated areas located within the Study Area. Remaining differences in irrigation imports from Phase I to Phase II are likely attributable to reductions in available streamflow due to the dry precipitation cycle that began in 2012 and better record keeping by the DWR and ditch diverters.

Depending upon the location in the Study Area, Phase II concludes that groundwater levels are primarily influenced by either precipitation, irrigation diversions, or both. For wells primarily influenced by precipitation, the time for the groundwater to respond to precipitation was 6 to 12 months depending upon the location. However, for wells primarily influenced by irrigation diversions, the groundwater level response is much faster (0 to 1 month). In addition, wells that were heavily influenced by irrigation diversions experienced larger annual water level fluctuations (greater than 10 feet) than wells influenced primarily by precipitation.

Phase II also confirms that groundwater levels did not experience a downward decline in response to development, but closely mimic precipitation and irrigation diversion trends. However, Phase II also concludes that the conversion from sprinkler irrigation to flood irrigation can cause a localized decline in the aquifer.

7.0 RECOMMENDATIONS

Continuous monitoring of groundwater levels and local weather, as well as daily diversion records of imported irrigation water from Cattle Creek, provide a better understanding of the importance of precipitation and irrigation of large fields to groundwater recharge. While groundwater levels varied over the Study Period, they have not significantly decreased. Water level fluctuations appear to closely mimic long-term variations in precipitation and/or irrigation diversions. The similarities between long-term fluctuations in groundwater level, precipitation, and imported irrigation diversions over the Study Period indicate that development on Missouri Heights has not significantly depleted the local aquifer. However, the conclusions derived from this Study are also limited by the length of the Study Period and the fact that no new significant development has occurred.

Continued monitoring of the aquifer at the Study wells is recommended to verify the trends and conclusions established in this report. For example, based on current snowpack conditions, the Missouri Heights region is coming out of a dry-cycle period and overall groundwater levels are expected to rise. In addition to continued monitoring of the Study wells, RESOURCE also recommends that the District continue to monitor local weather patterns using the BWCD weather station and keep track of irrigation diversion imports from Cattle Creek on an annual basis. The continued monitoring of the Study wells and weather station combined with continued tracking of irrigation diversions will allow for updates to this report and provide additional data to better assess the impact due to development as it occurs. RESOURCE recommends that updates to this report be made every 5 years.

Lastly, further refinements to this Study are recommended to calculate the amount of precipitation and imported irrigation water from Cattle Creek that recharges the aquifer. This calculation will provide a refined assessment of the relative importance of each variable to the overall health of the aquifer. This recharge calculation will include a water balance for the Study Area.

We look forward to continuing assisting the BWCD in the implementation of the recommendations included in this report. Please don't hesitate to contact us with any questions you may have.

Sincerely,

RESOURCE ENGINEERING, INC.

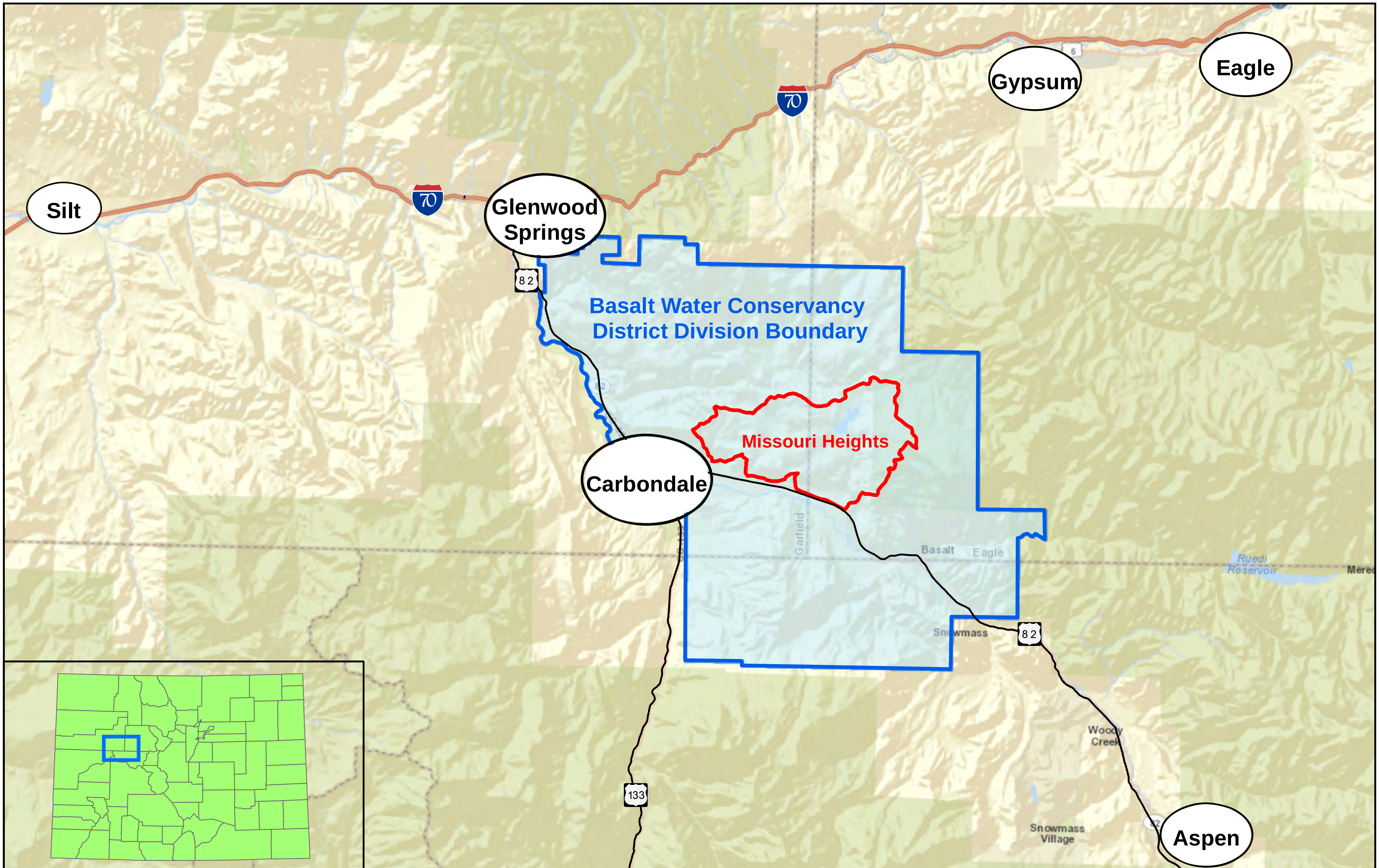
Ryan K. McBride, P.E.
Water Resources Engineer

Eric F Mangeot, P.E.
Water Resources Engineer

RKM/rkm
File: 033-8.1.6

REFERENCES

- U.S. Geological Survey, 1999. Alley, W.M., Reilly T.E., Franke, O.L. Sustainability of Ground-Water Resources
- U.S. Geological Survey, 2008. Kirkham, R.M., Widmann, B.L., Streufert, R.K. Geologic Map of the Leon Quadrangle, Eagle and Garfield Counties, Colorado
- U.S. Geological Survey, 2008. Kirkham, R.M., Widmann, B.L. Geologic Map of the Carbondale Quadrangle, Garfield County, Colorado
- USDA Natural Resources Conservation Services. Soil Survey of Aspen-Gypsum, Colorado, Parts of Eagle, Garfield and Pitkin Counties; and Holy Cross Area, Colorado, Parts of Eagle, Garfield, Mesa, Pitkin, and Summit Counties.
- U.S. Geological Survey, 2011. Falk, S.E., Bexfield, L.M., Anderholm, S.K. Estimated 2008 Groundwater Potentiometric Surface and Predevelopment to 2008 Water-Level Change in the Santa Fe Group Aquifer System in the Albuquerque Area, Central New Mexico



Source: World Street Map

Figure 1: Basalt Water Conservancy District Division Boundary Map

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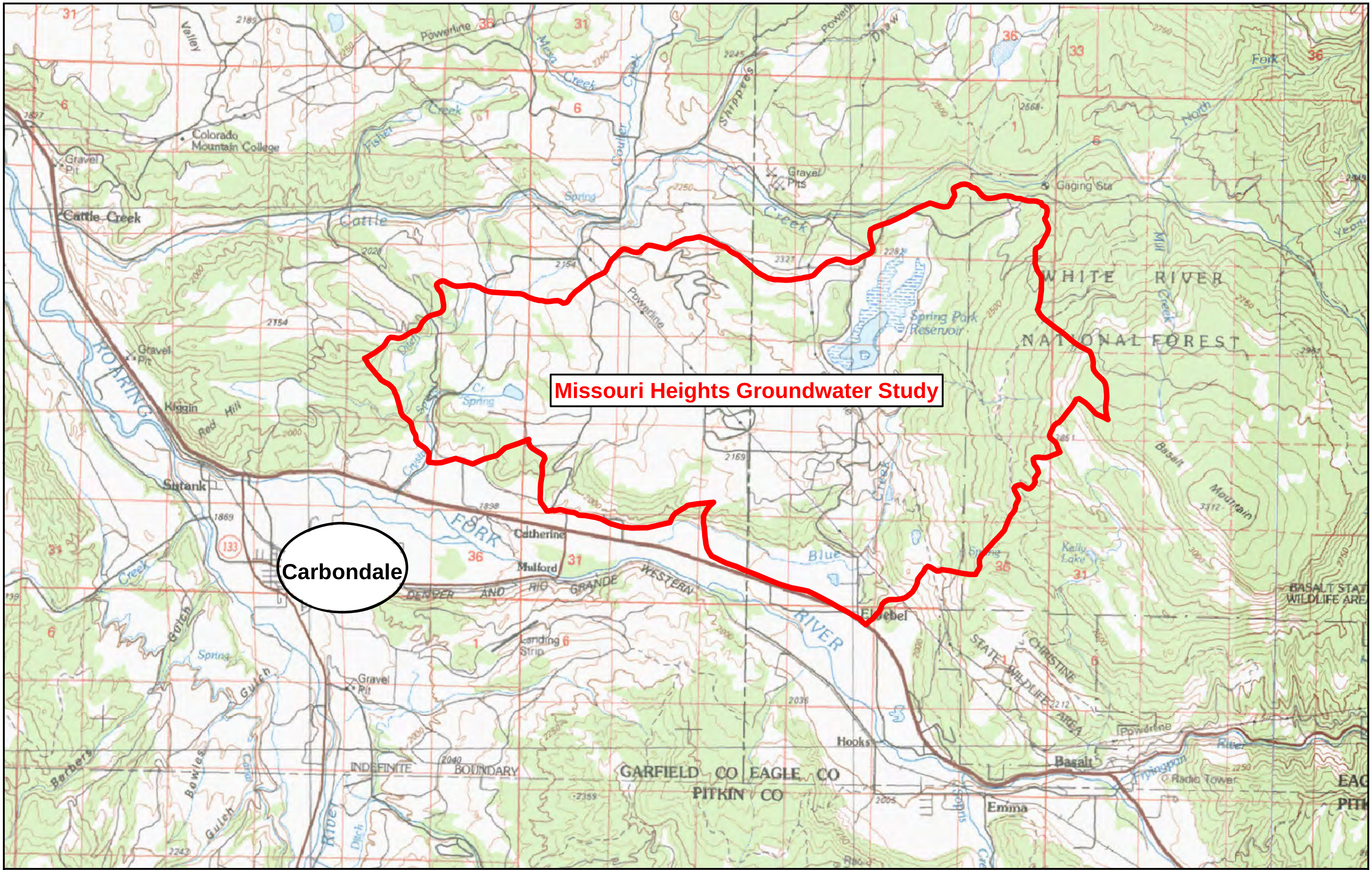
0 2.5 5 10 Miles
1 in = 5 miles

Date: 3/23/2014
File: 033-8.1.6
Drawn: RKM
Approved: EFM



Source: Carbondale and Leadville
100K Quadrangles

Figure 2: Missouri Heights Groundwater Study Location Map

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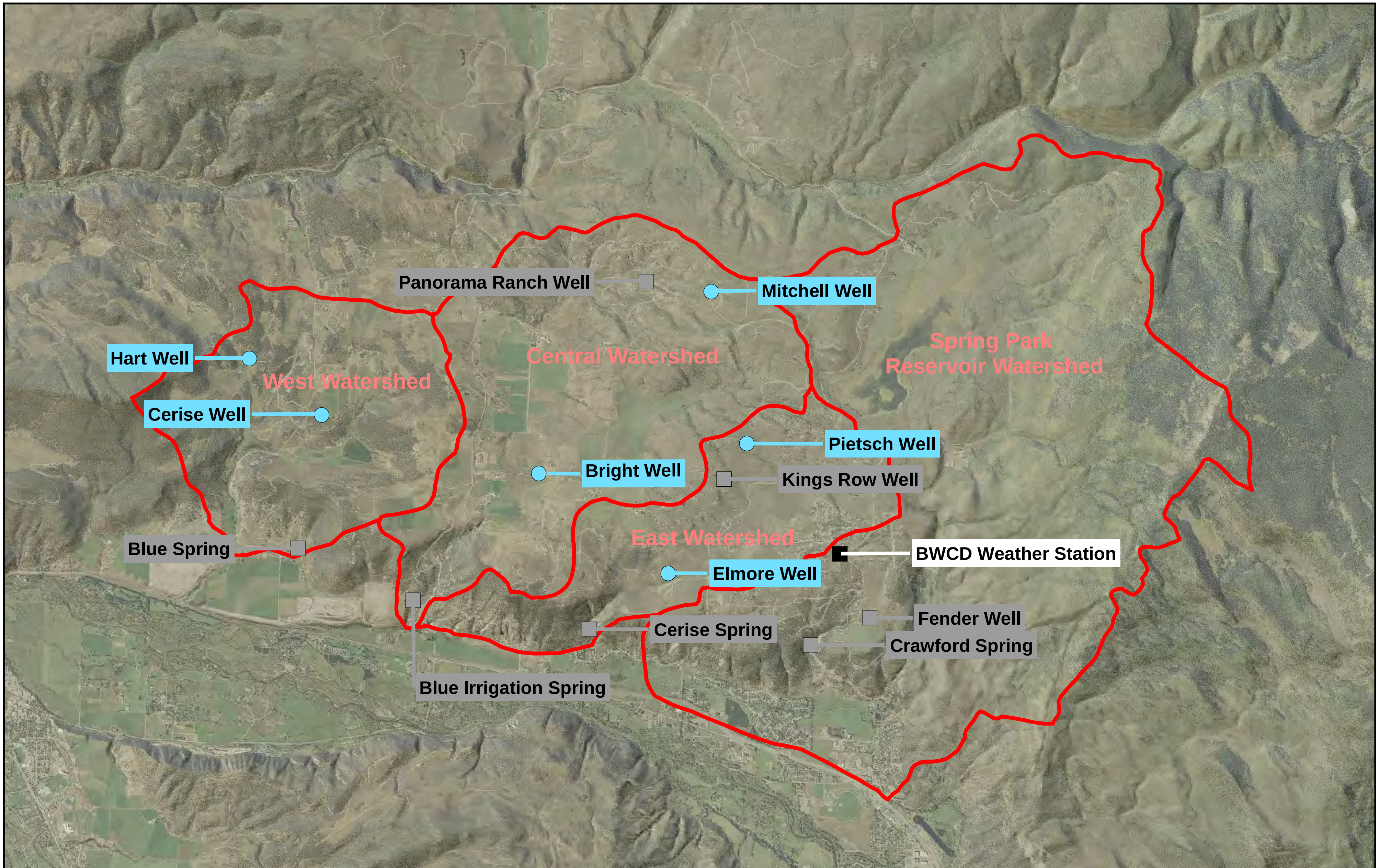
0 0.75 1.5 3 Miles

1 in = 1.5 miles

Date: 3/21/2014
File: 033-8.1.6
Drawn: RKM
Approved: EFM



Source: 2013 NAIP Aerial Photography

Figure 3: Site Location Map

Phase I Wells and Springs

Phase II Wells

Weather Station

0 0.5 1 2 Miles

1 in = 1 mile

Date: 3/23/2014
File: 033-8.1.6
Drawn: RKM
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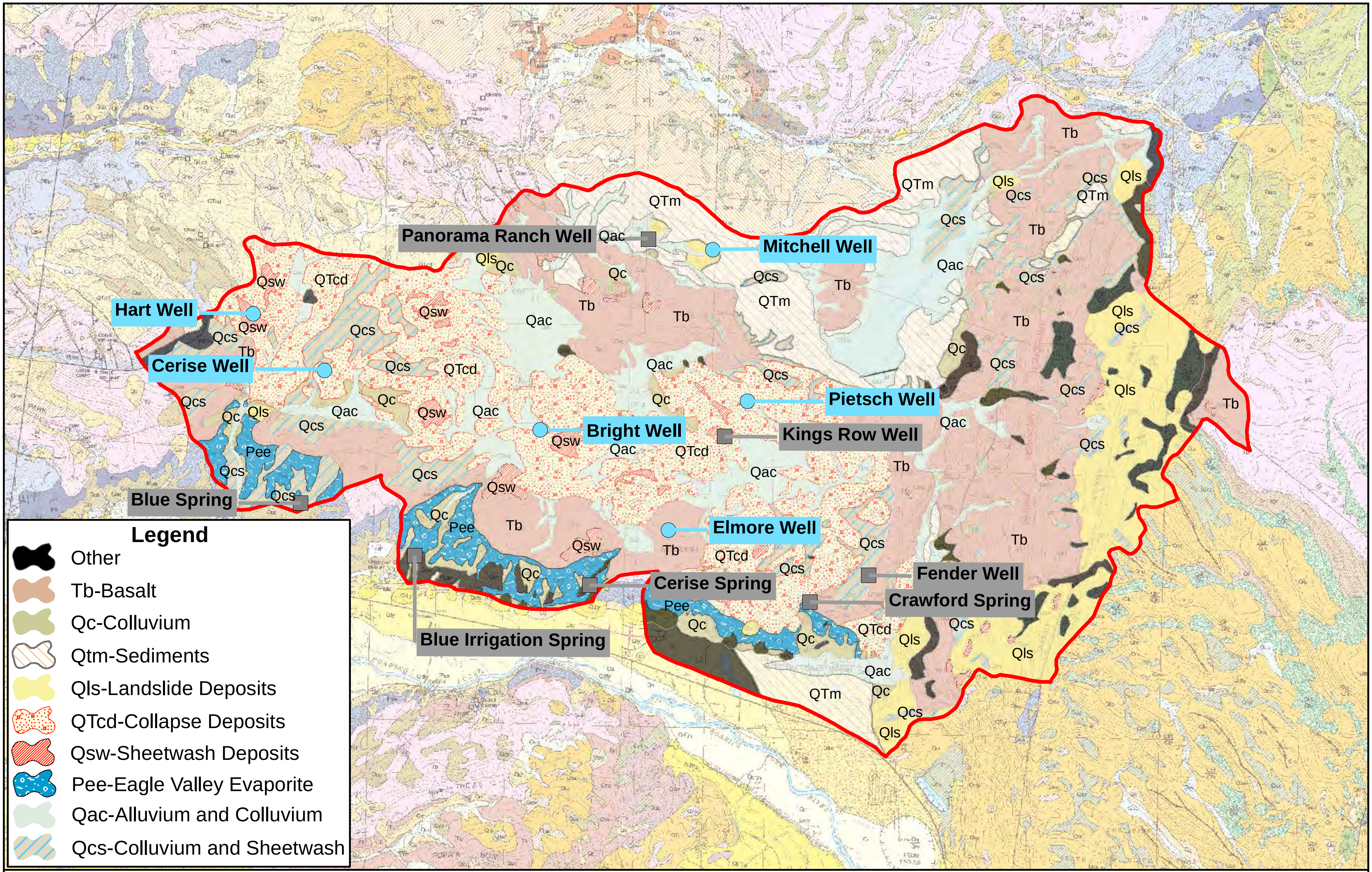

Source: USGS Leon and Carbondale Geologic Maps

Figure 4: Geology Location Map

Phase I Wells and Springs

Phase II Wells

0 0.5 1 2 Miles

1 in = 1 mile

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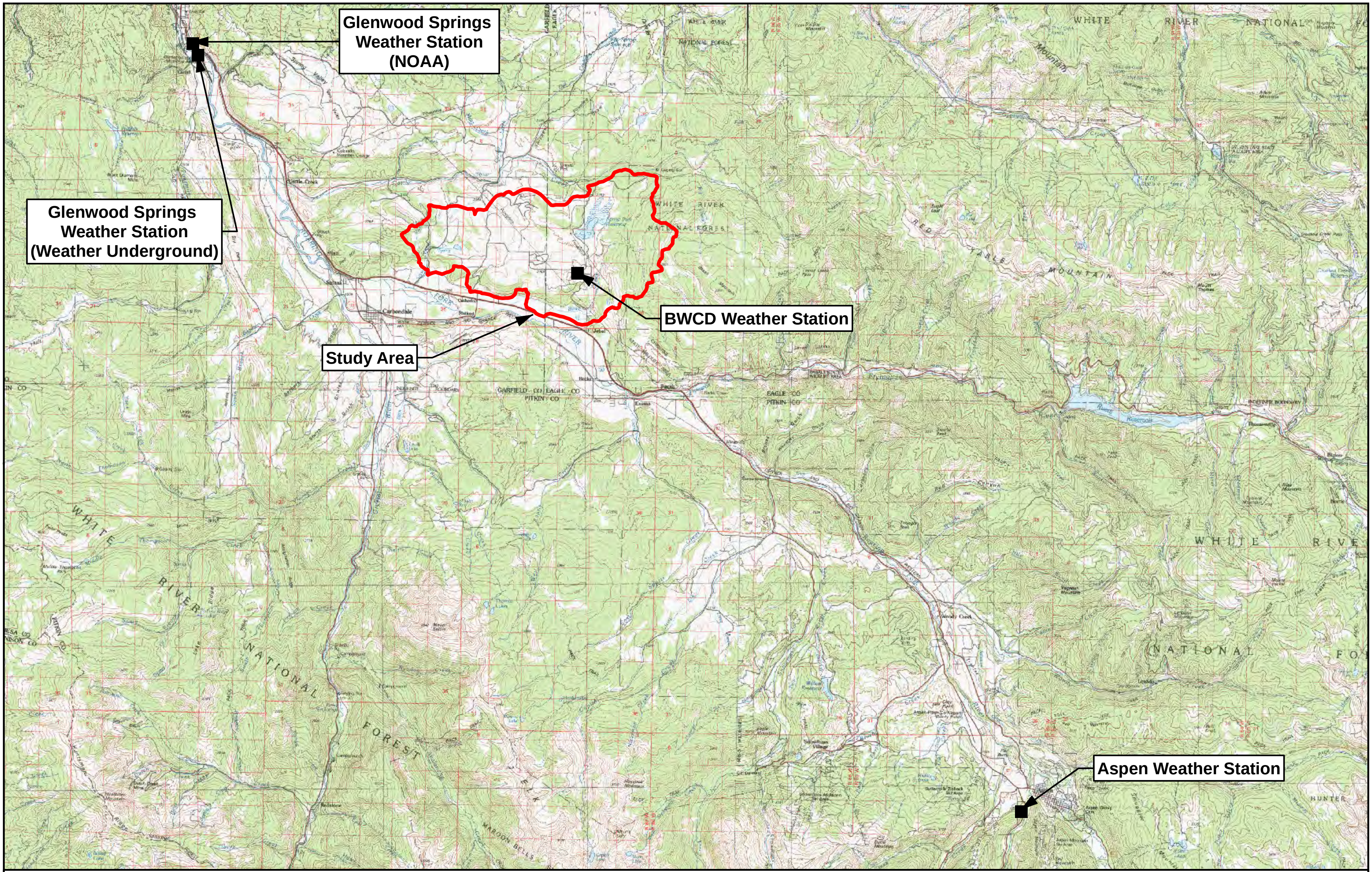

Source: Leadville, Vail, Carbondale and Glenwood Springs 100K Quadrangles

Figure 5: Weather Stations Location Map

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0 1 2 4 Miles
1 in = 4 miles

Date: 1/22/2013
File: 033-8.1.6
Drawn: RKM
Approved: EFM

Figure 6

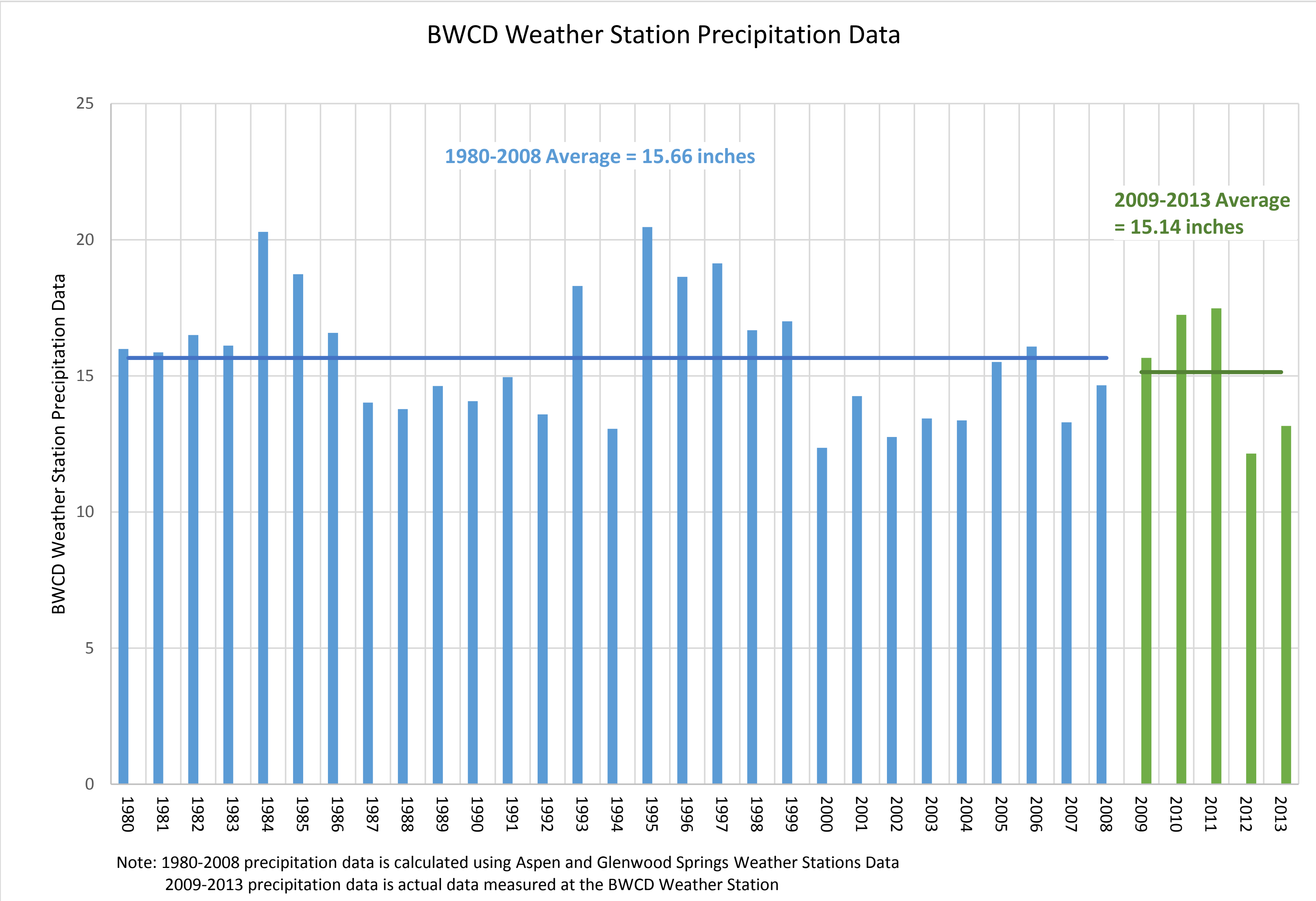

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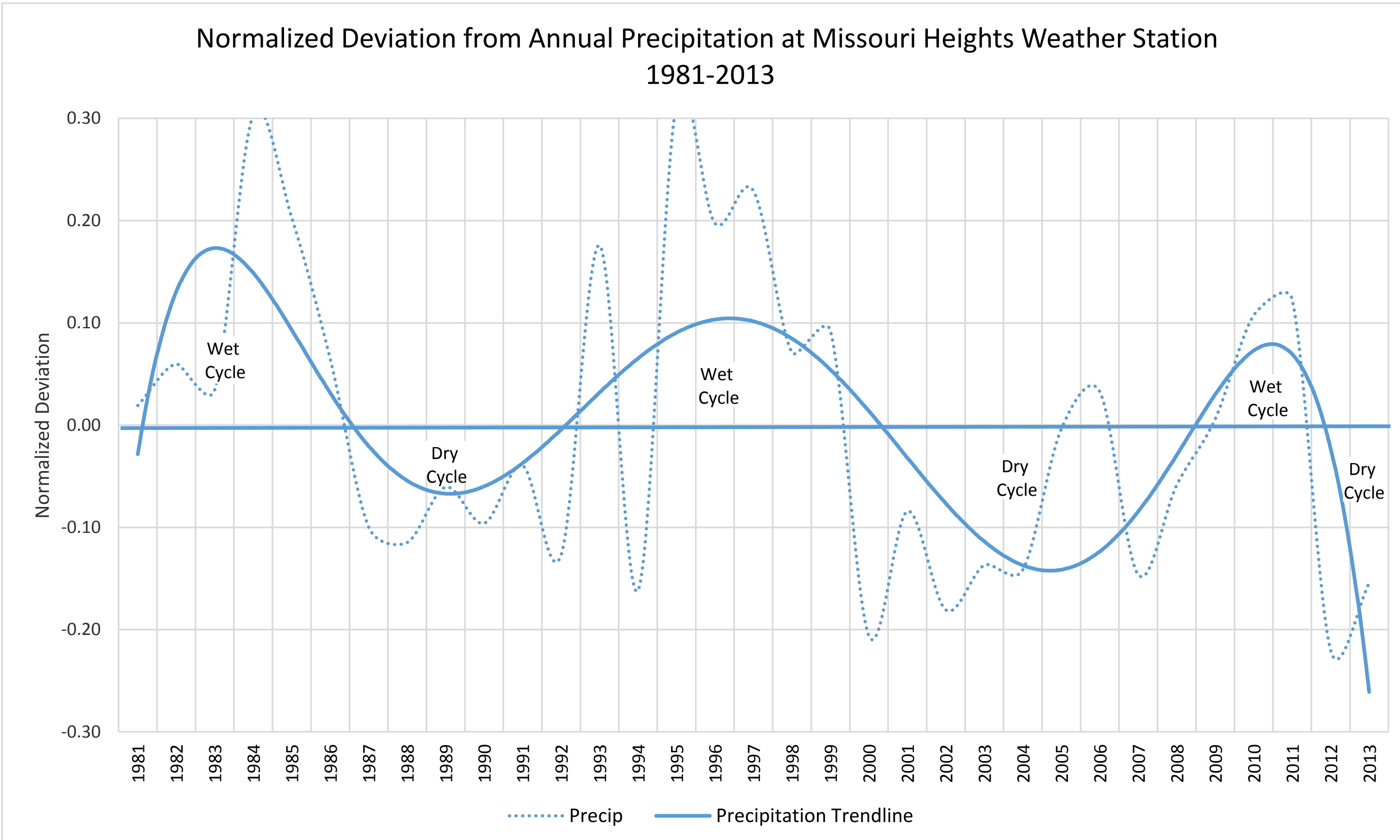
FIGURE 7



Note: 1981-2008 weather data was calculated using 2009-2013 measured data.

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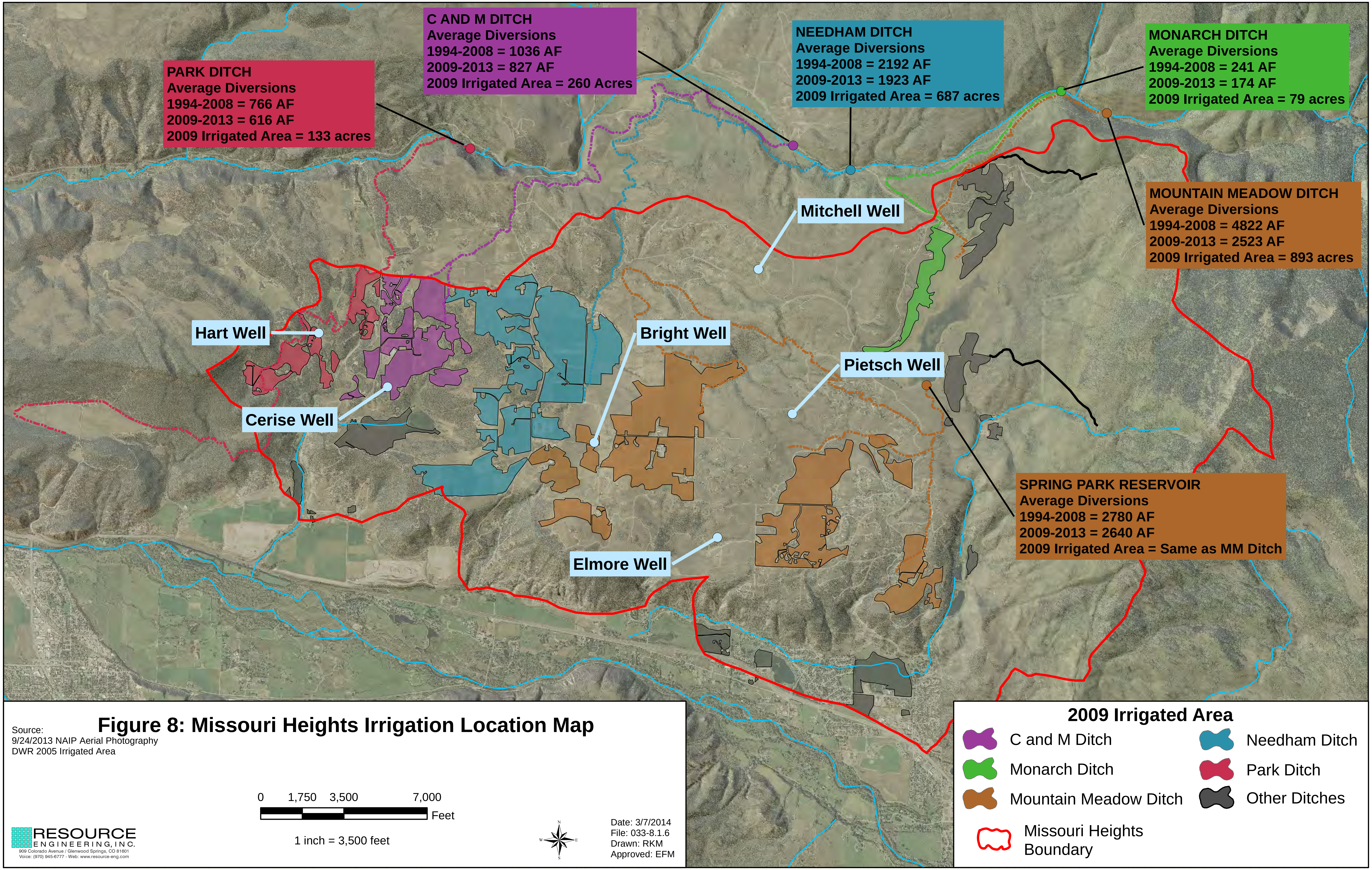

Figure 8: Missouri Heights Irrigation Location Map

Source:
9/24/2013 NAIP Aerial Photography
DWR 2005 Irrigated Area

0 1,750 3,500 7,000 Feet

1 inch = 3,500 feet

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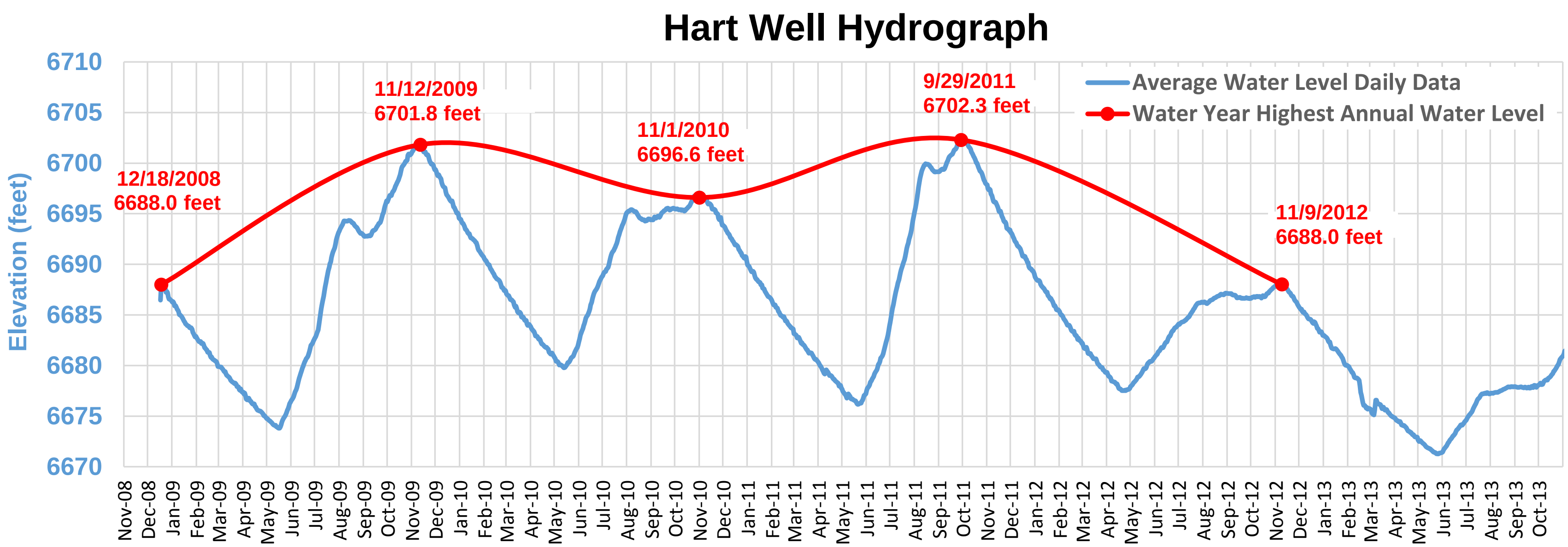
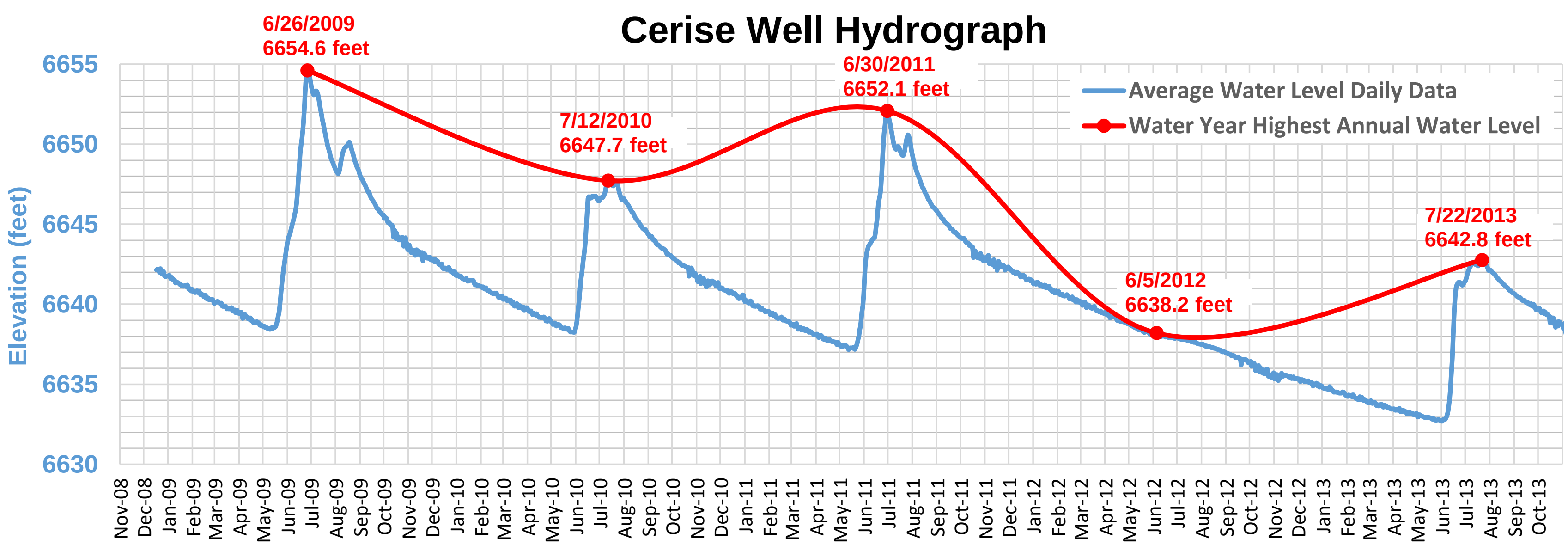
Figure 9: West Watershed



Note: Highest Annual Water Levels in 2009, 2011, and 2012 were manually adjusted.



Note: Highest Annual Water Level in 2012 was manually adjusted.

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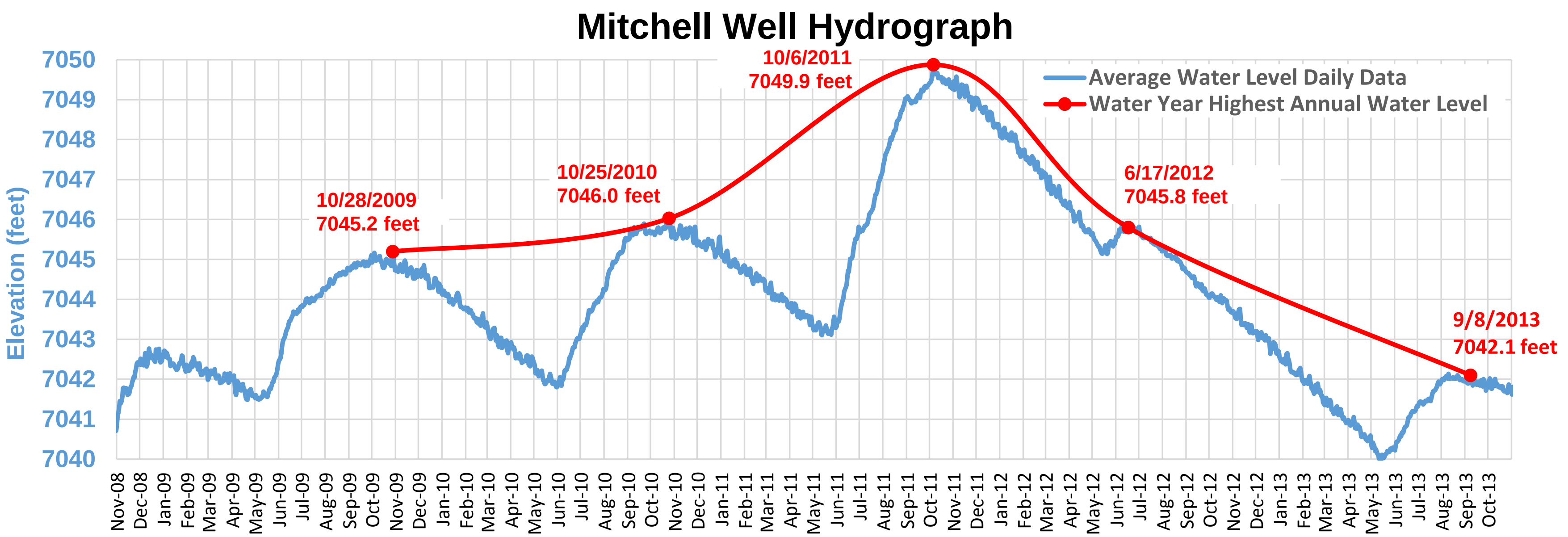
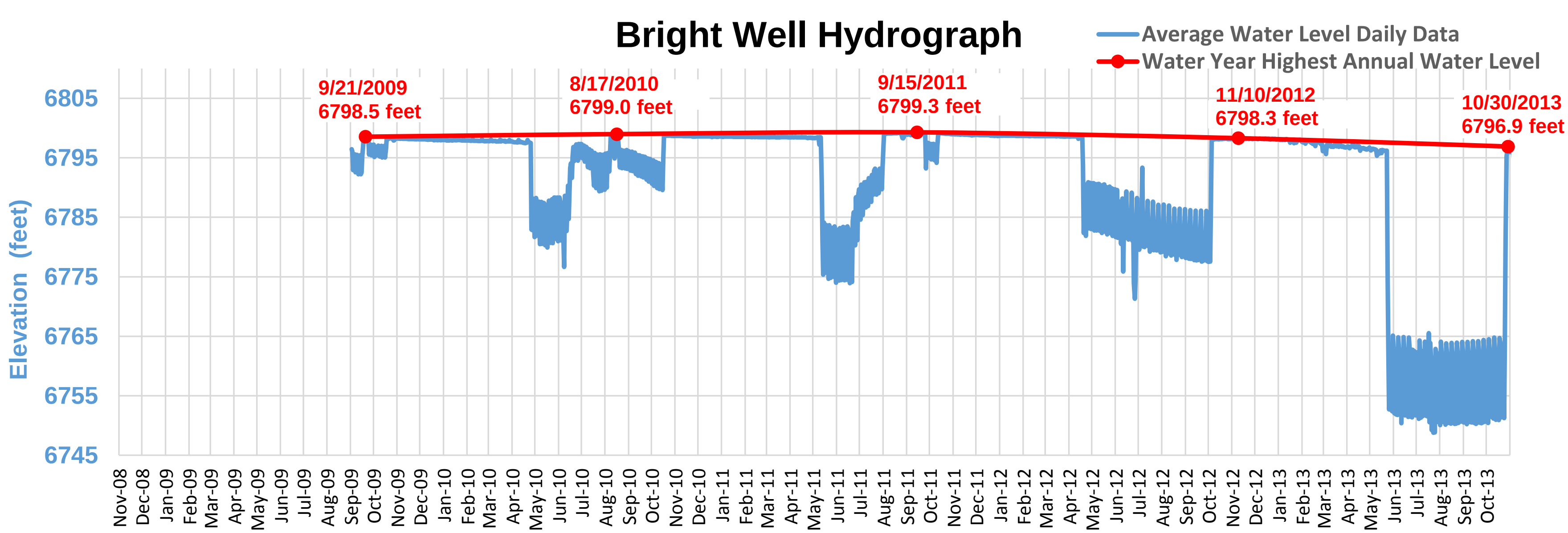
Figure 10: Central Watershed



Note: Highest Annual Water Levels in 2012 and 2013 were manually adjusted.



Note: Highest Annual Water Levels in 2012 and 2013 were manually adjusted.

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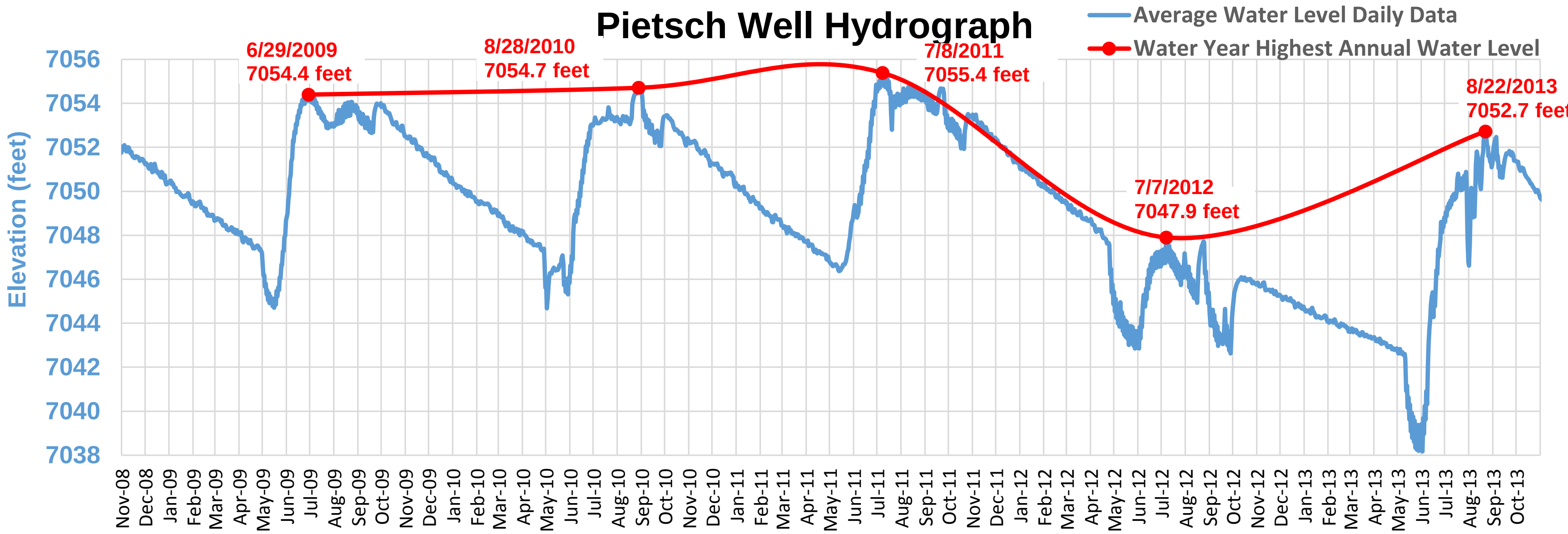
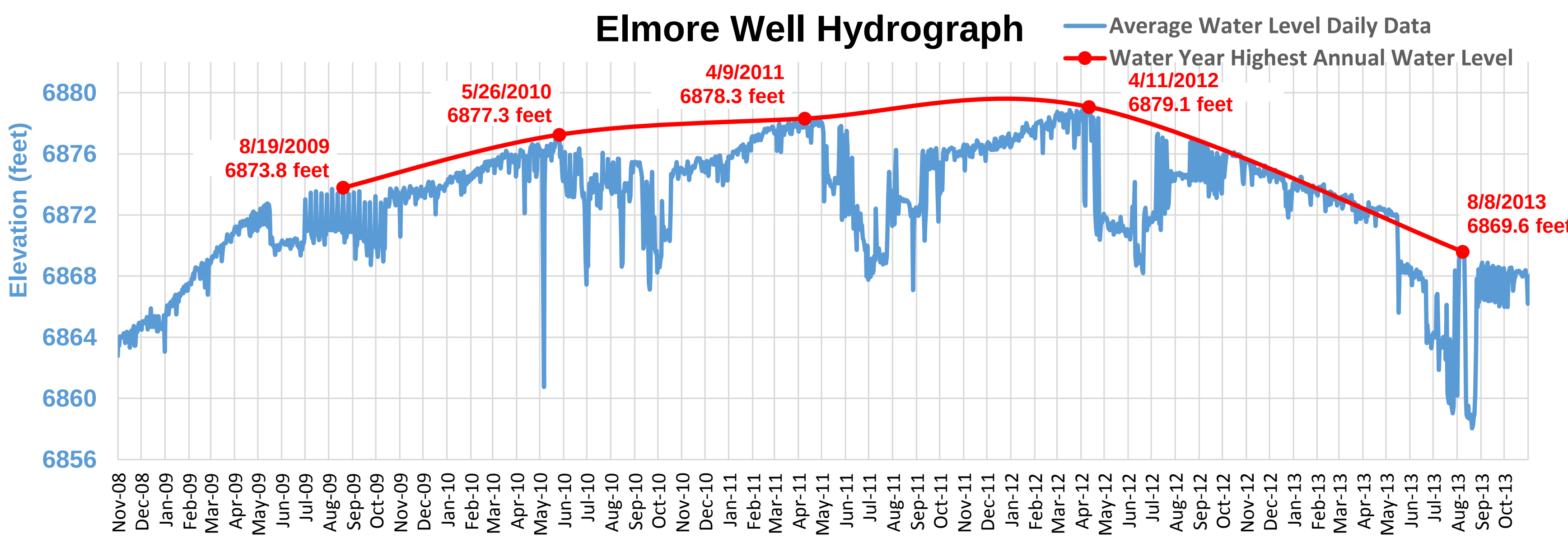
Figure 11: East Watershed

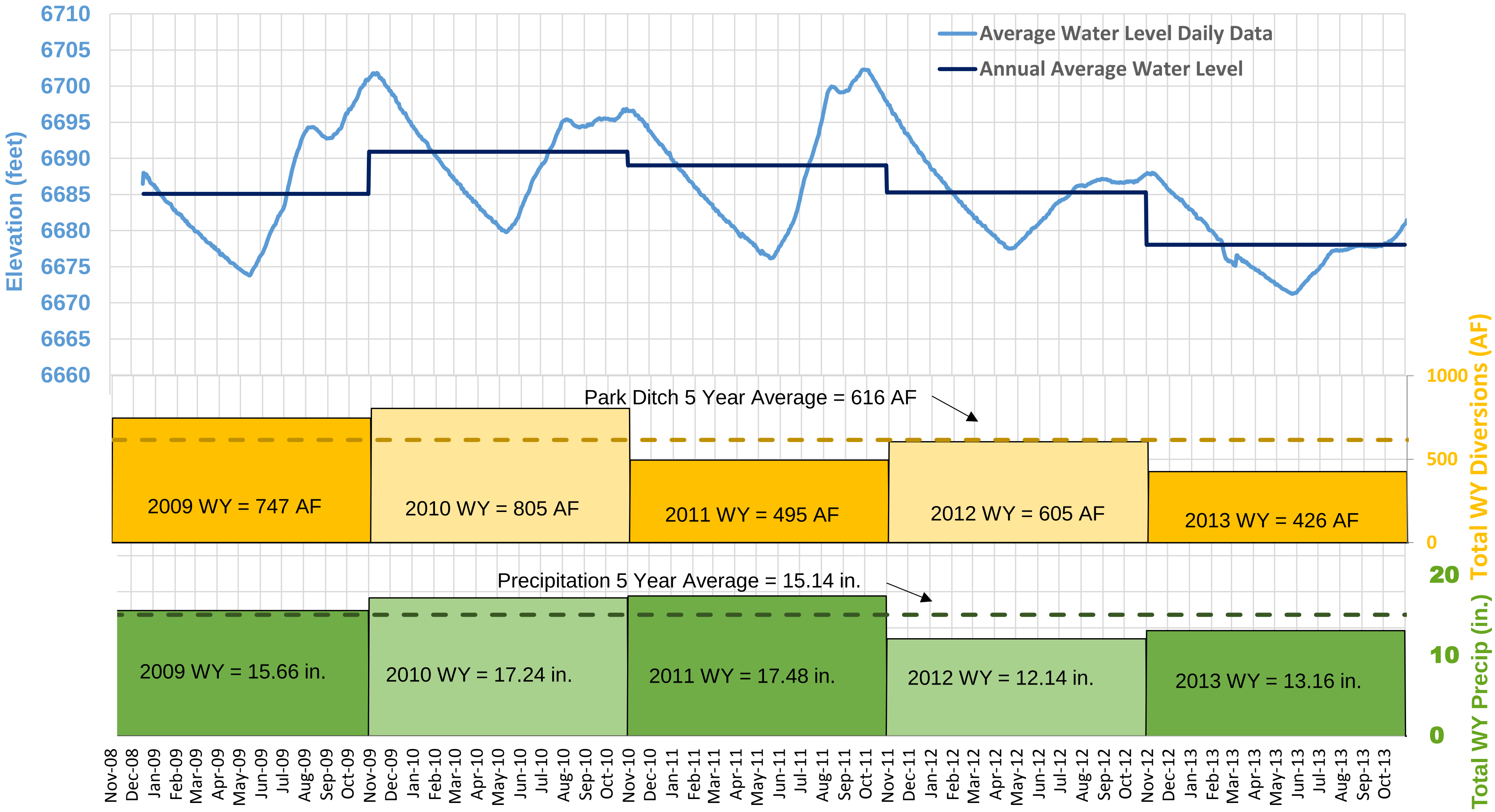


Note: Highest Annual Water Level in 2012 was manually adjusted.



Note: Highest Annual Water Level in 2013 was manually adjusted.

Figure 12
Hart Well Hydrograph



Note: Data was divided into water years (WY).

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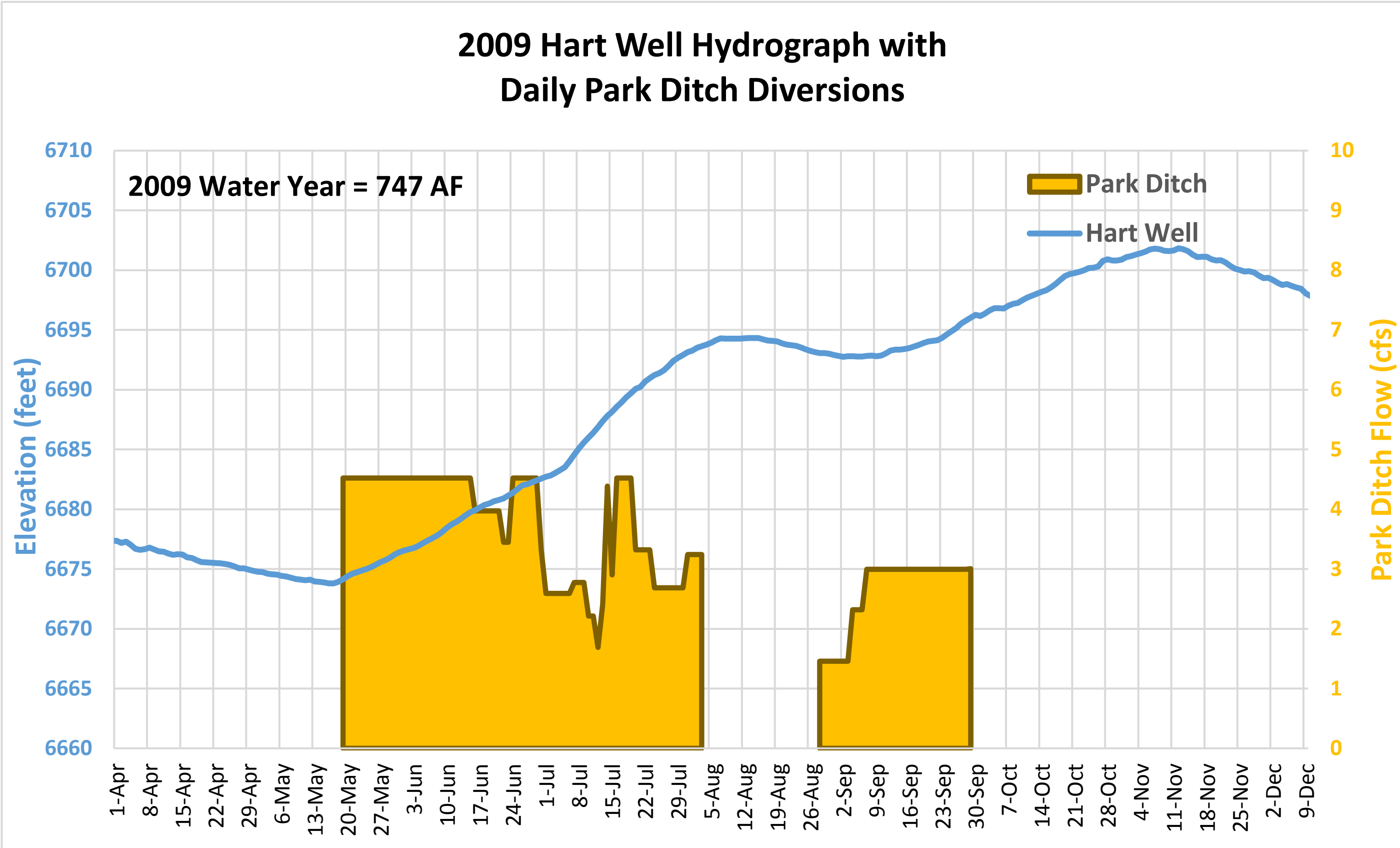
Figure 13



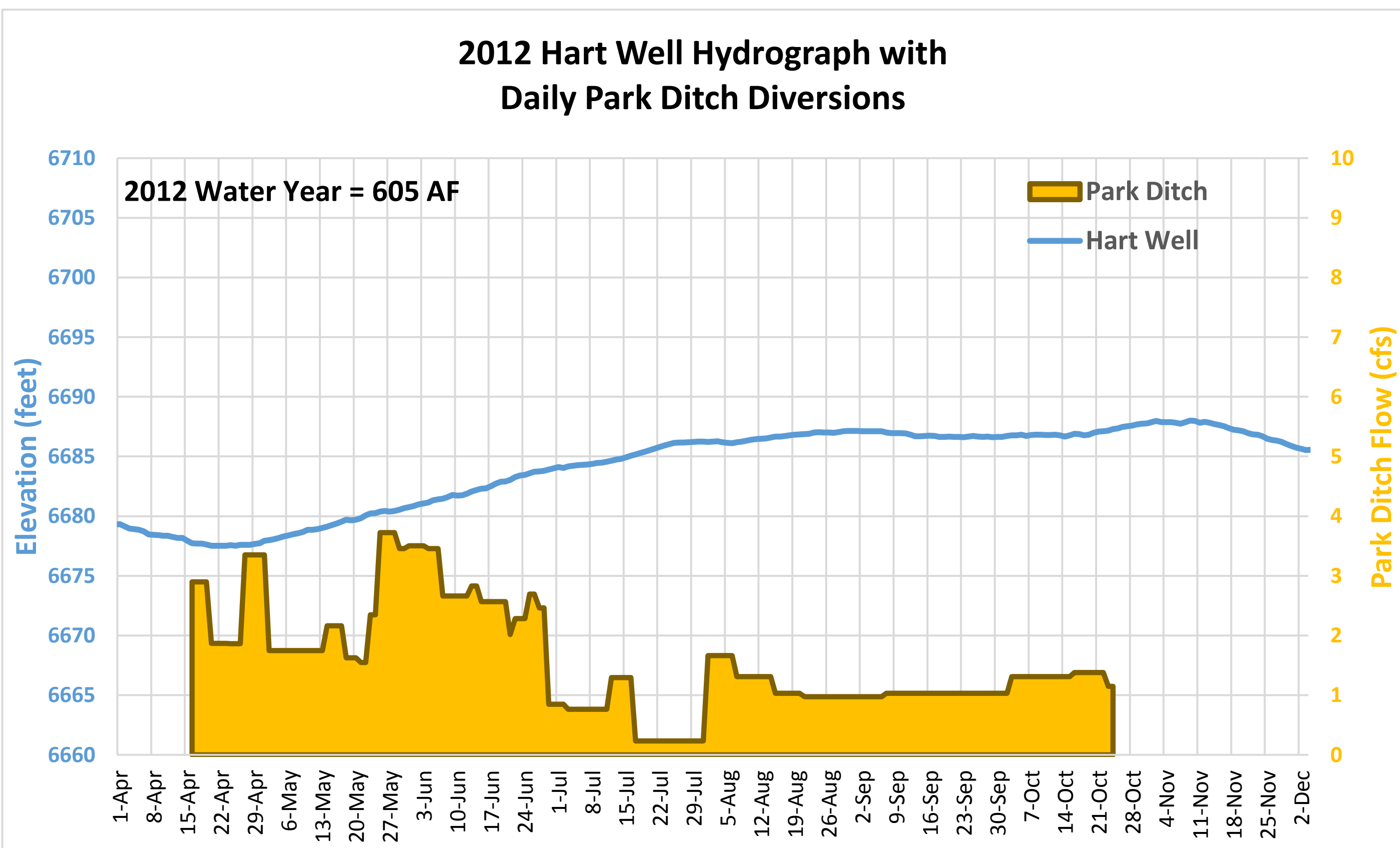


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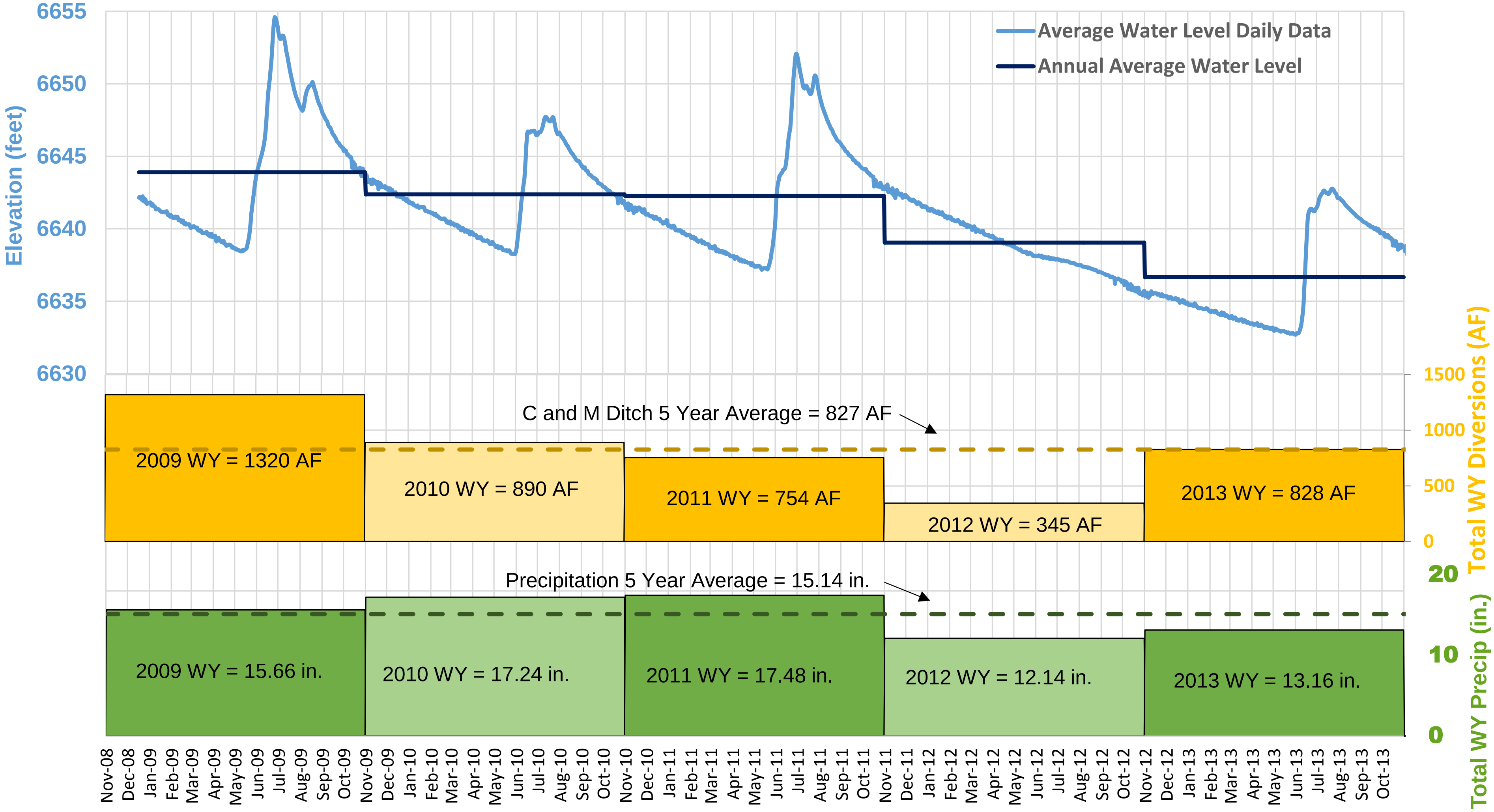
Figure 14

Cerise Well Hydrograph



Note: Data was divided into water years (WY).

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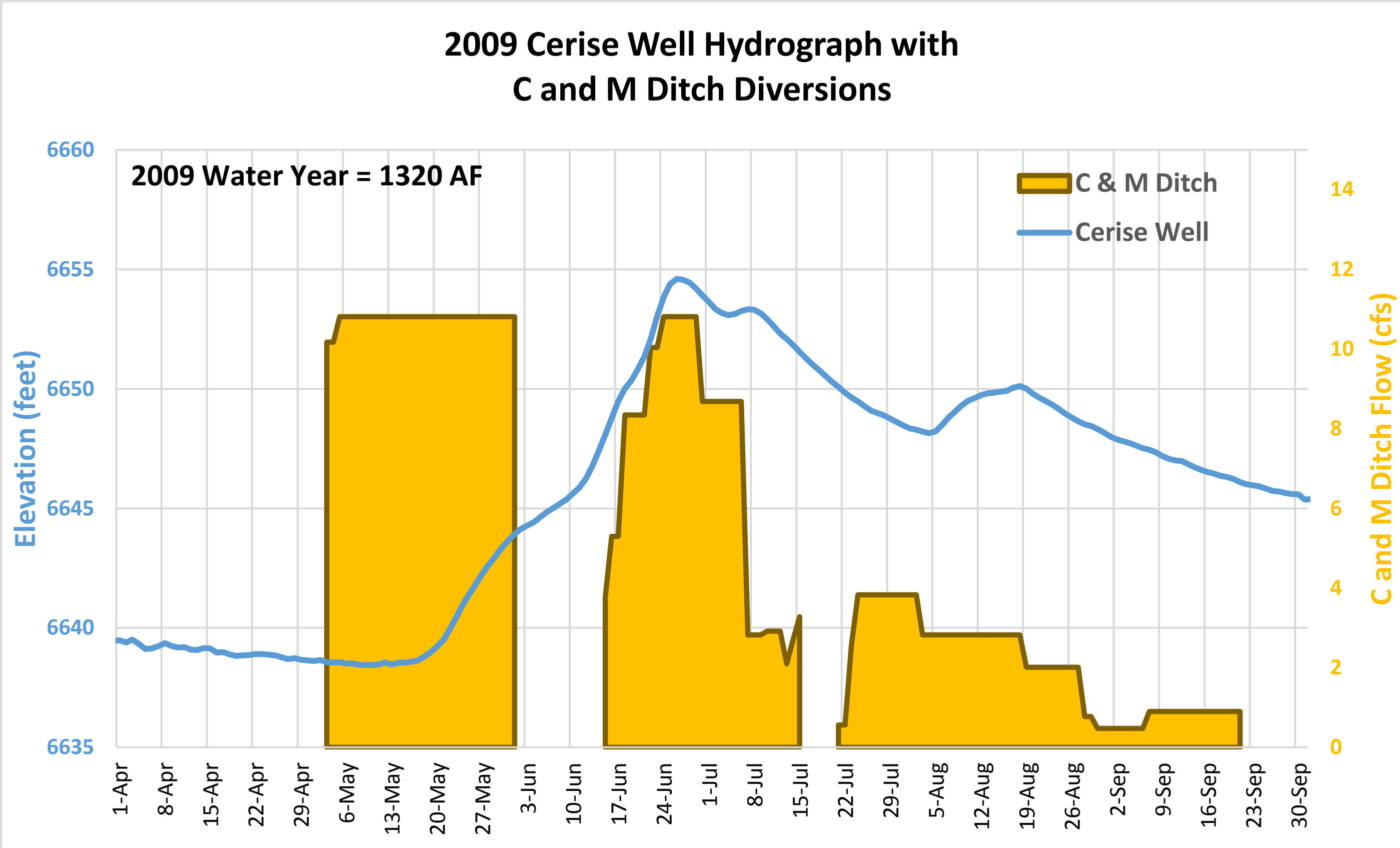
Figure 15



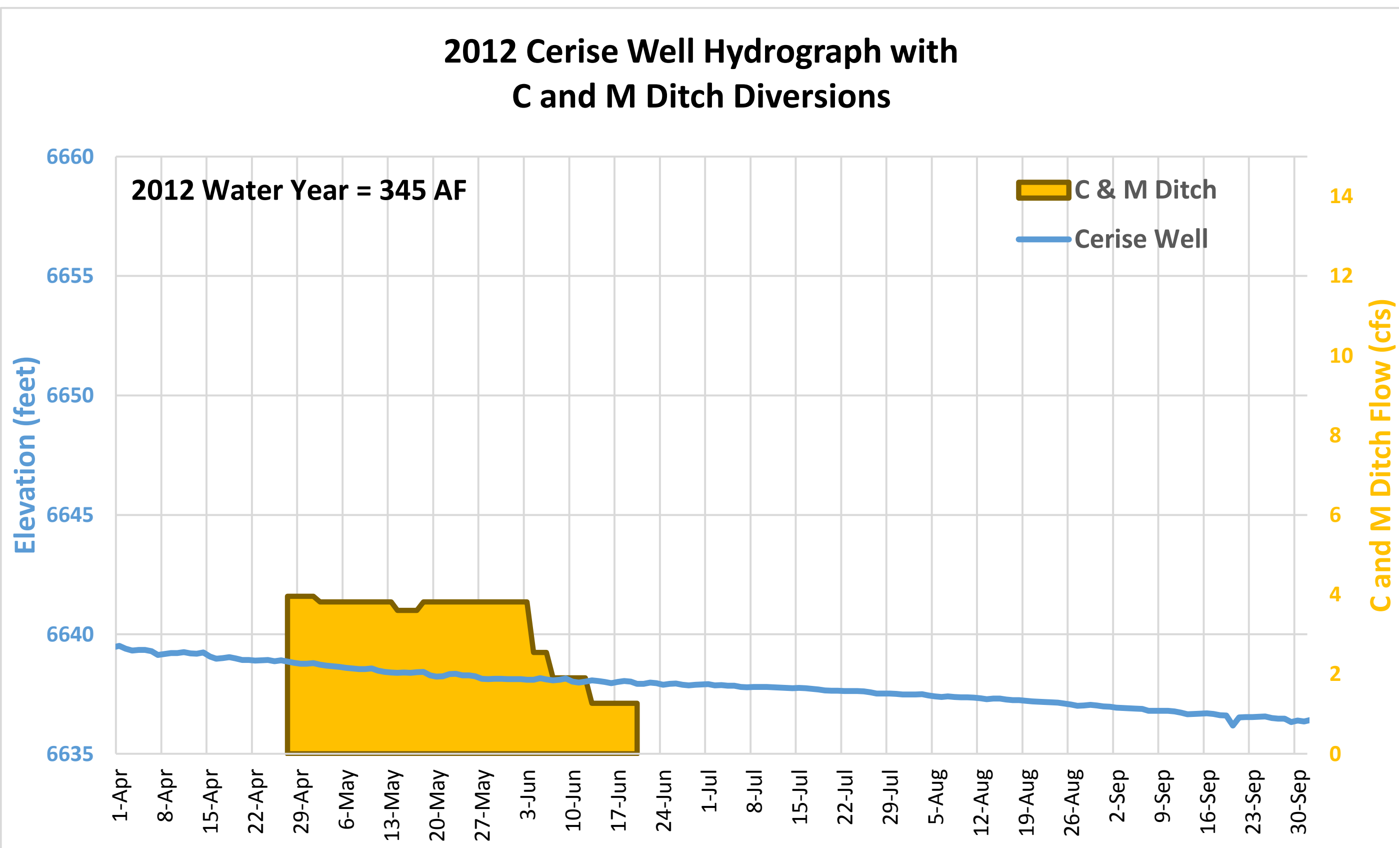


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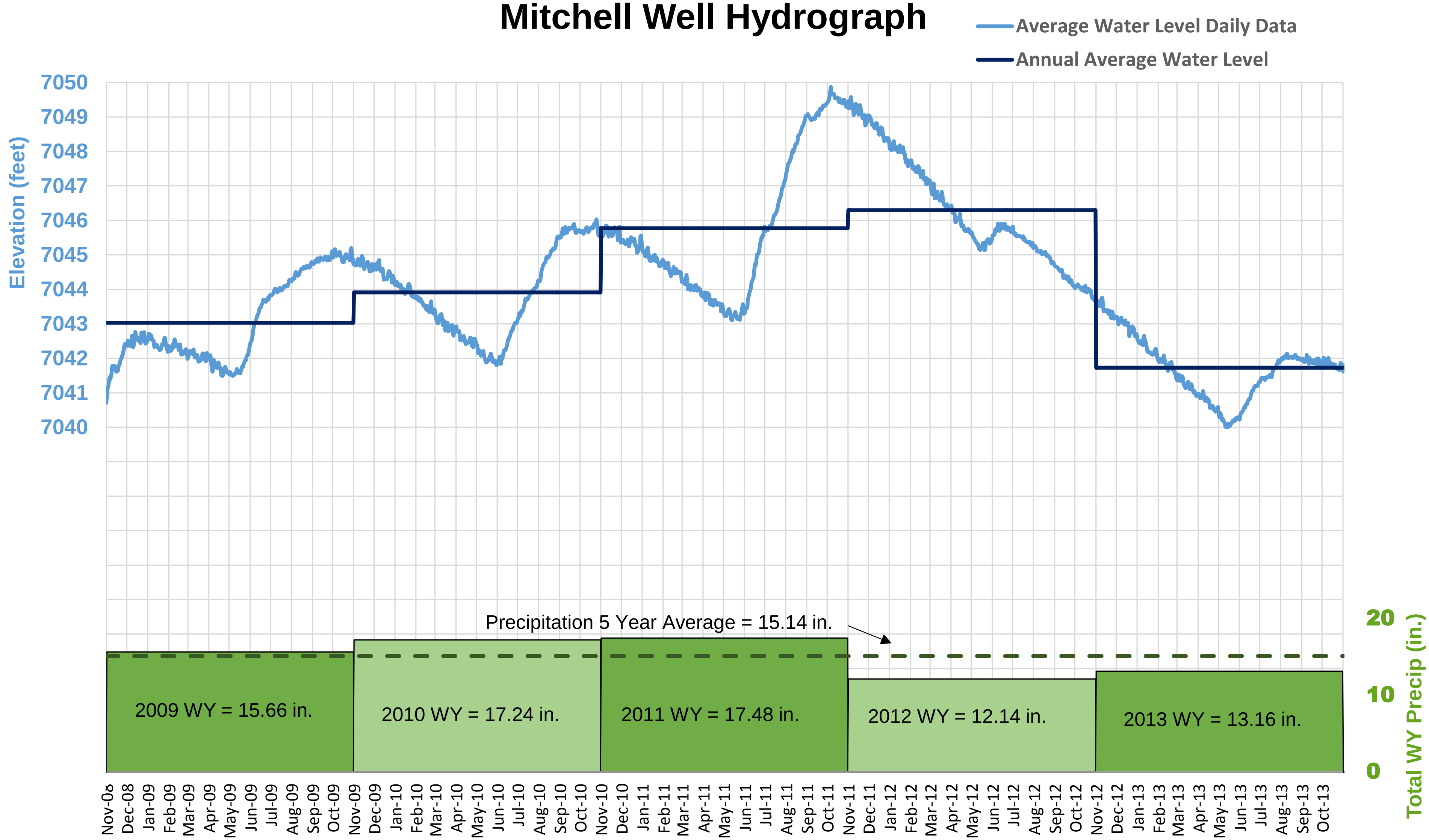
Figure 16

Mitchell Well Hydrograph



Note: Data was divided into water years (WY).

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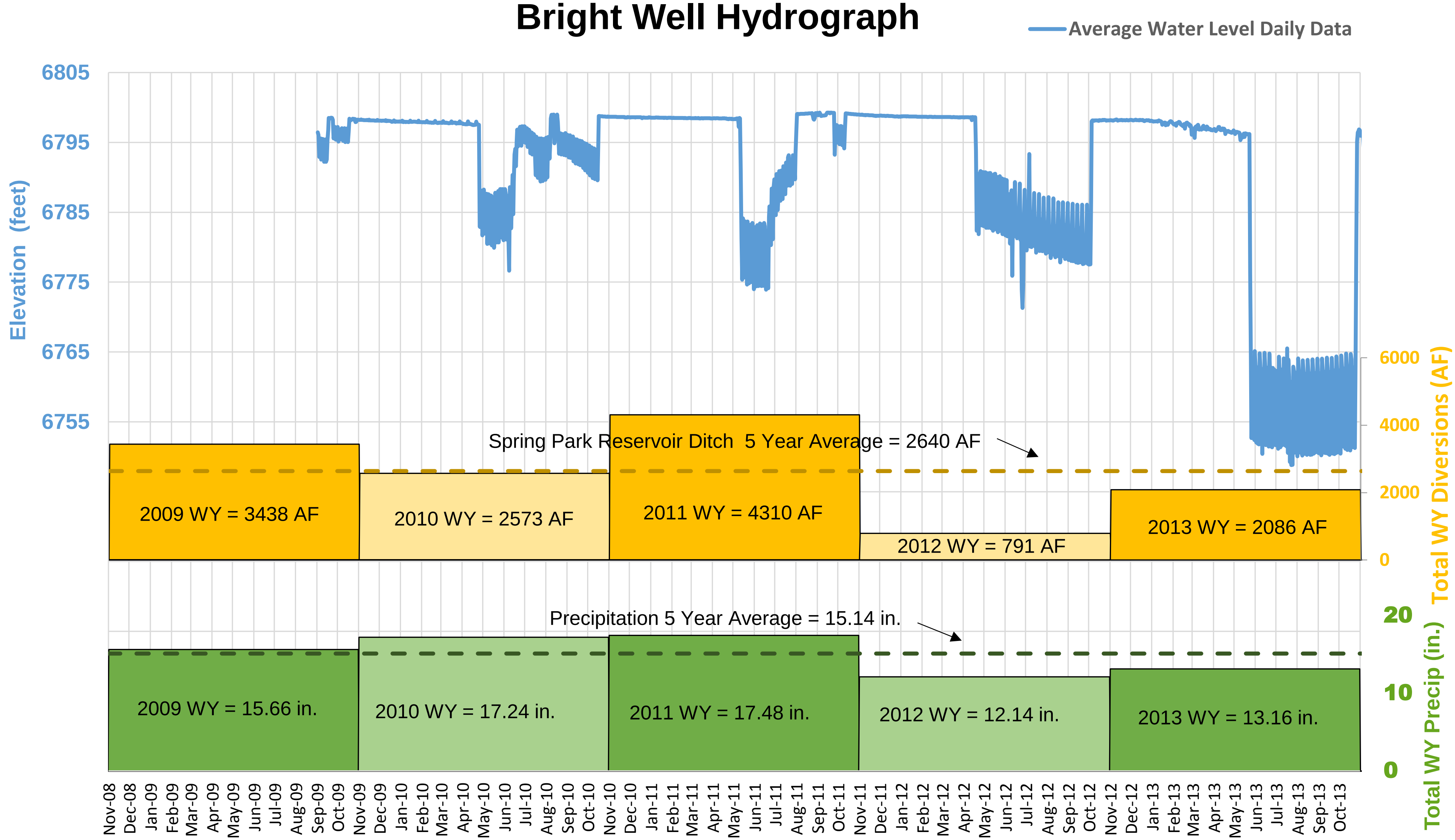
Figure 17

Bright Well Hydrograph



Note: Data was divided into water years (WY).

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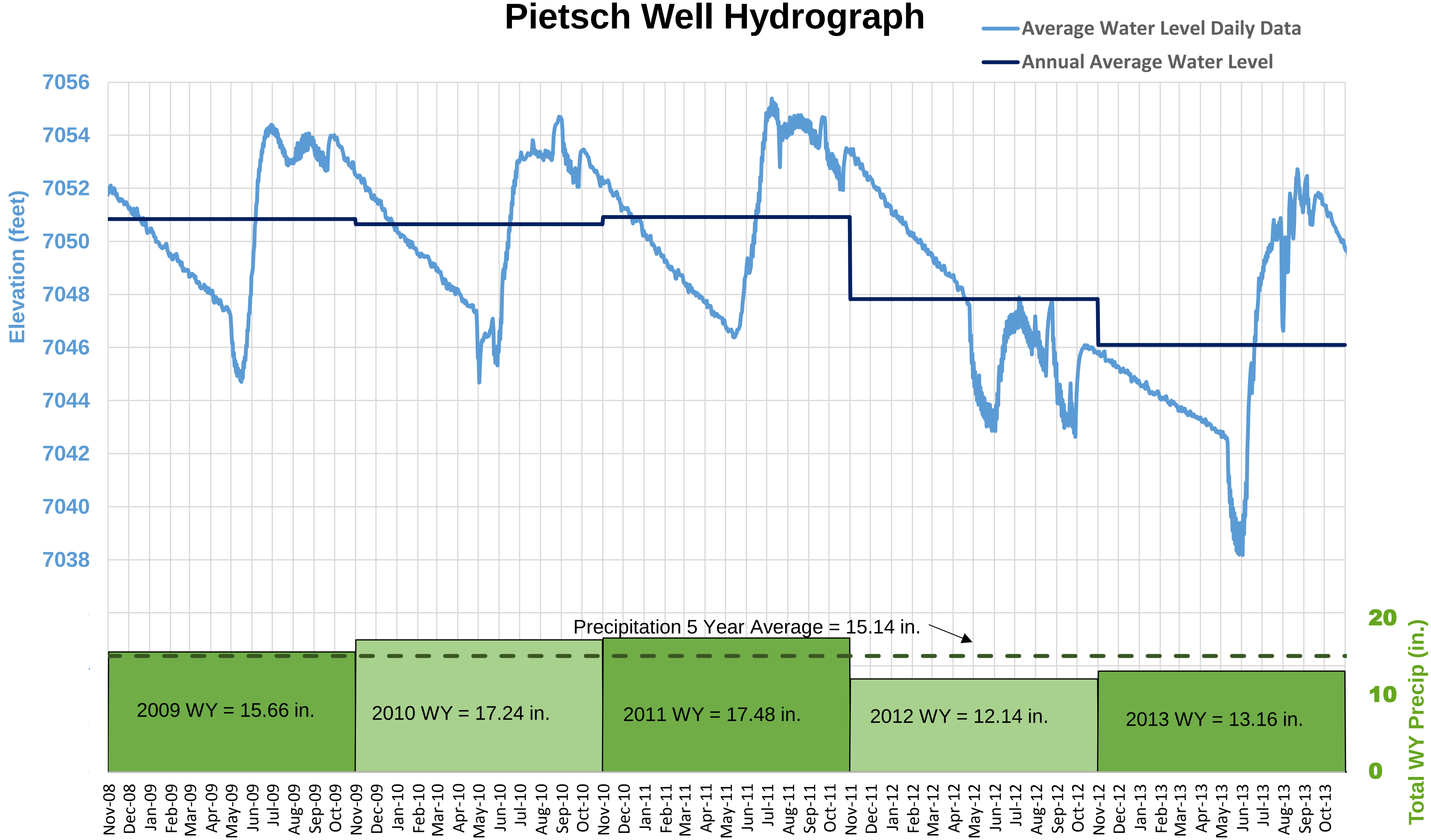
Figure 18

Pietsch Well Hydrograph



Note: Data was divided into water years (WY).

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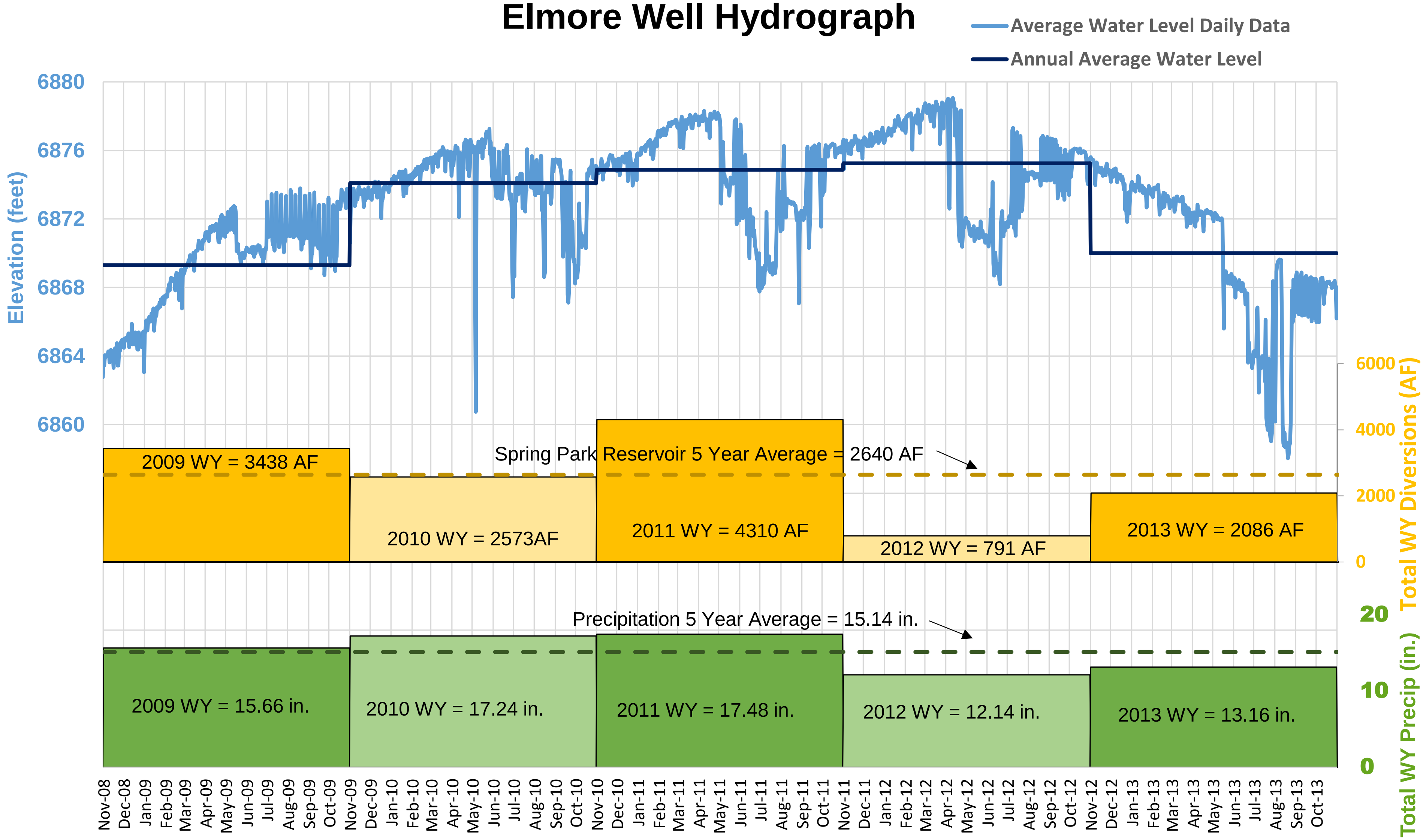
Figure 19

Elmore Well Hydrograph



Note: Data was divided into water years (WY).

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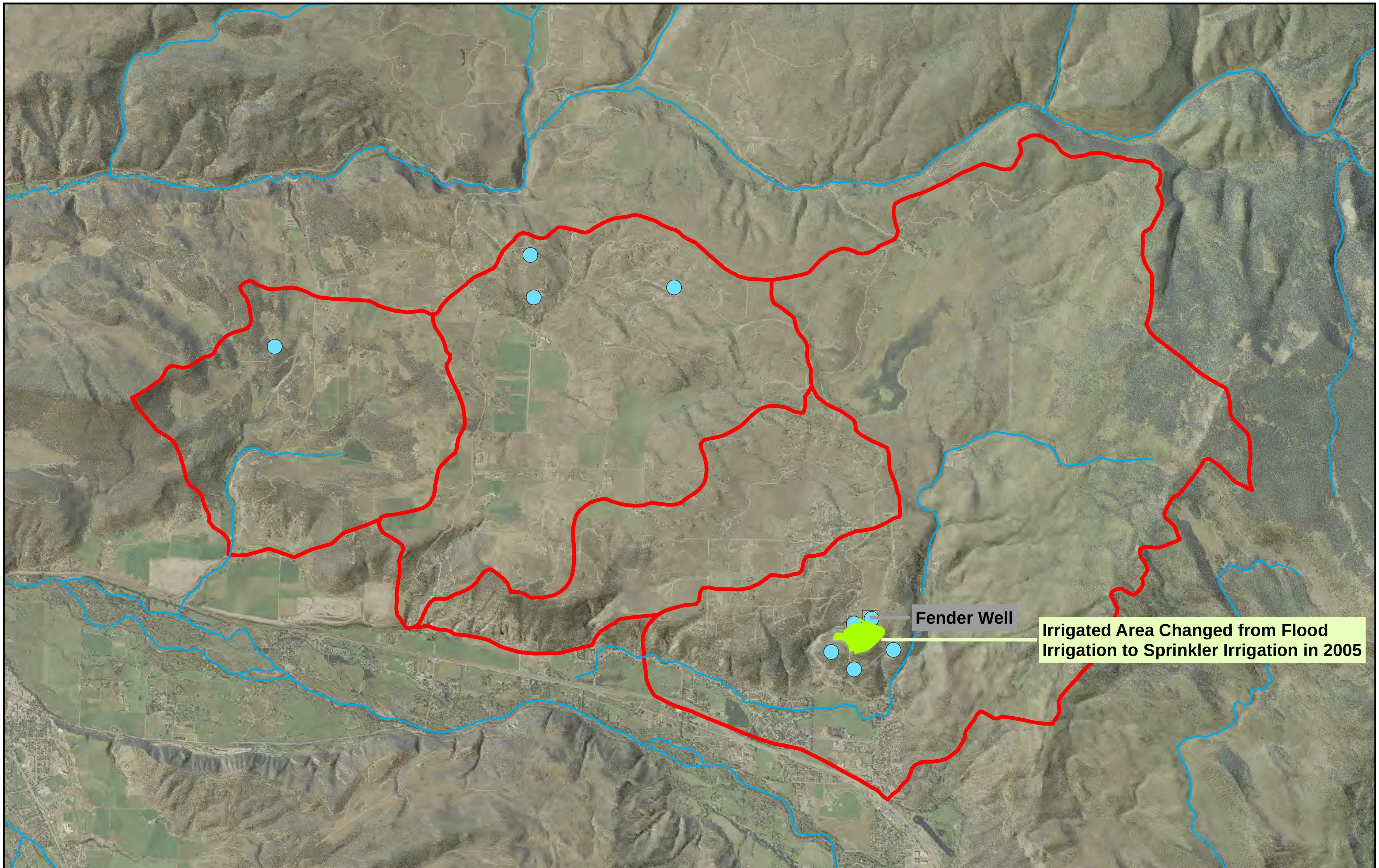

Source: 2013 NAIP Aerial Photography

Figure 20: Missouri Heights Replacement Wells

Wells Replaced During Study Period (2009-2013)

0 0.5 1 2 Miles

1 in = 1 mile

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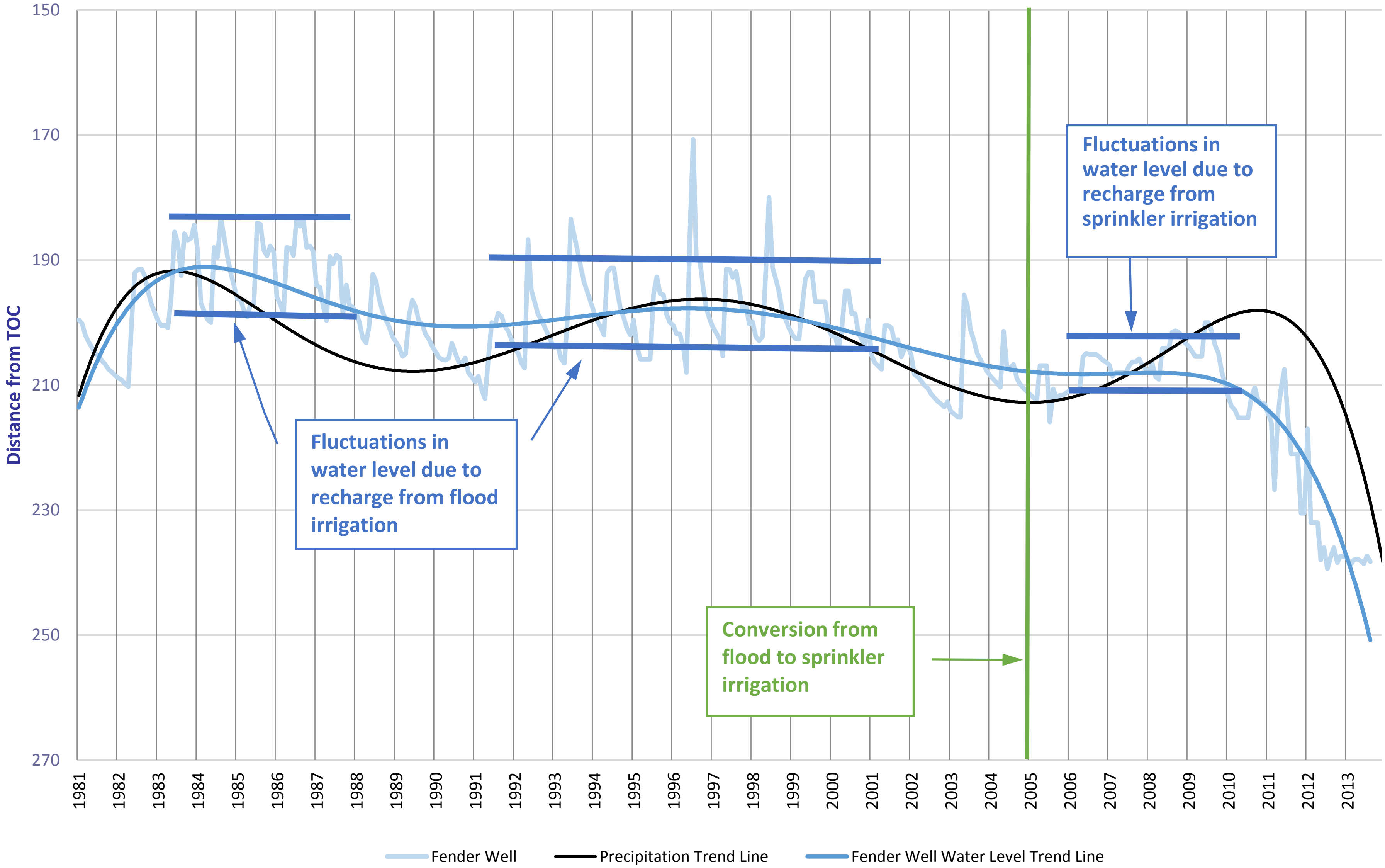
Figure 21
Fender Well Hydrograph



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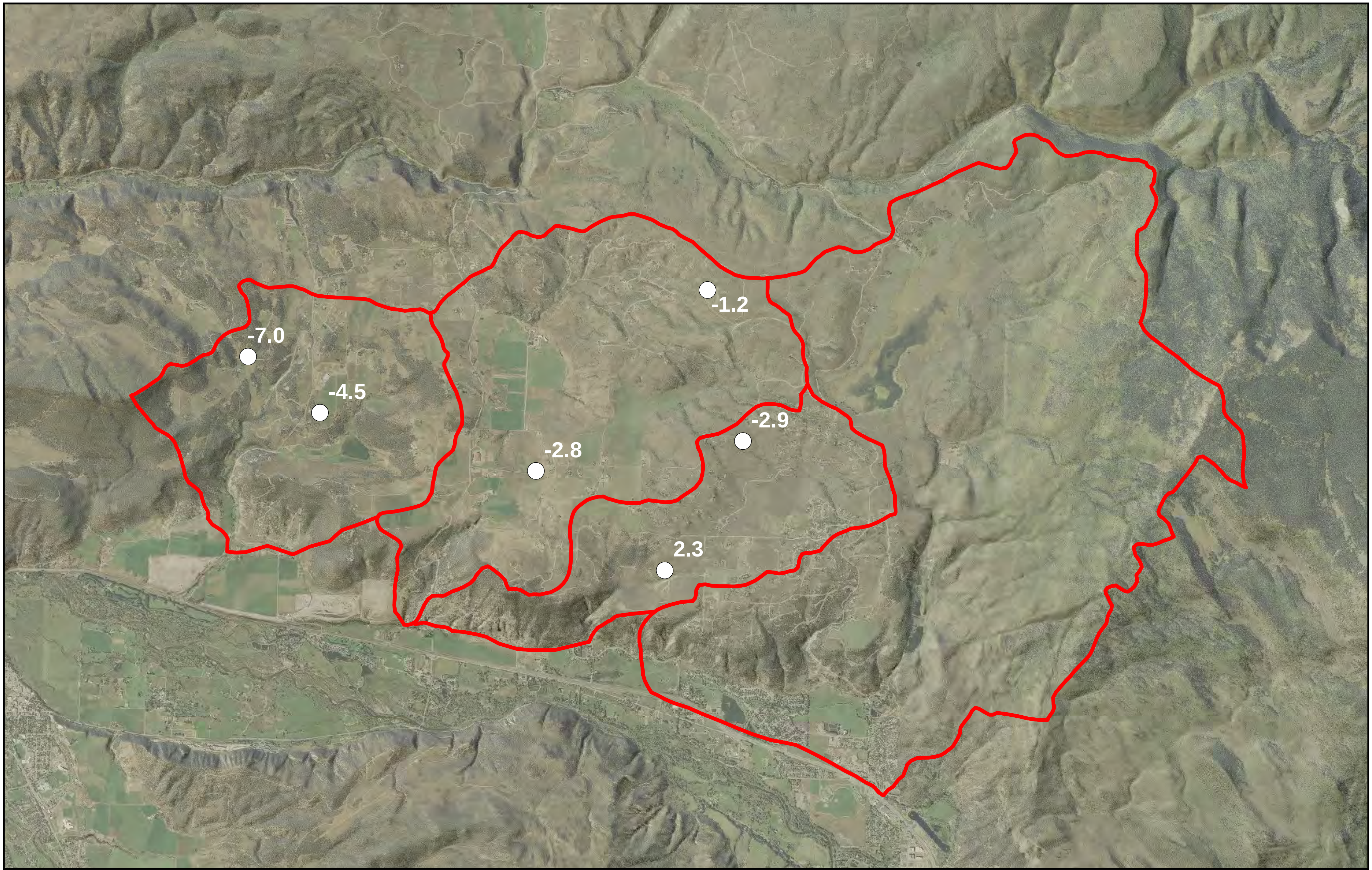

Source: 2013 NAIP
Aerial Photography

Figure 22: Water Level Change Between Dec-2008 and Dec-2013

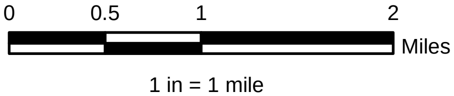

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Table 1
Phase II Well Site Summary

Well Name	Well Construction Report				Observed
	Year Well Drilled	Well Depth (feet)	Pump Depth (feet)	Static Water Level (feet)	Static Water Level (feet)
Hart Well	1968	190	ND	ND	64
Cerise Well	2001	170	160	120	112.5
Mitchell Well	2000	663	ND	510	498
Bright Well	1995	200	190	130	125.5
Pietsch Well	1994	300	280	240	227.6
Elmore Well	1995	220	210	125	145

ND = No Data

Table 2

Annual Highest Groundwater Level Summary

(All elevation values are in feet)

Year	West Watershed			
	Hart		Cerise	
2009	12/18/2008	6688.0	12/18/2008	6688.0
2010	11/12/2009	6701.8	7/12/2010	6647.7
2011	11/1/2010	6696.6	6/30/2011	6652.1
2012	9/29/2011	6702.3	6/5/2012	6638.2
2013	11/9/2012	6688.0	7/22/2013	6642.8

Year	Central Watershed			
	Mitchell		Bright	
2009	10/28/2009	7045.2	9/21/2009	6798.5
2010	10/25/2010	7046.0	8/17/2010	6799.0
2011	10/6/2011	7049.9	9/15/2011	6799.3
2012	6/17/2012	7045.8	11/10/2012	6798.3
2013	9/8/2013	7042.1	10/30/2013	6796.9

Year	East Watershed			
	Pietsch		Elmore	
2009	6/29/2009	7054.4	8/19/2009	6873.8
2010	8/28/2010	7054.7	5/26/2010	6877.3
2011	7/8/2011	7055.4	4/9/2011	6878.3
2012	7/7/2012	7047.9	4/11/2012	6879.1
2013	8/22/2013	7052.7	8/8/2013	6869.6

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Table 3

Hart Well 2008 Water Quality Results

Status	Contaminant	Results	Units	National Standards		MDL
Inorganic Analytes - Metals						
	Calcium	40.3	mg/L	--		0.2
	Magnesium	22.8	mg/L	--		0.2
	Potassium	0.9	mg/L	--		0.3
	Sodium	49.9	mg/L	20	Guidance Level	0.3
Wet Chemistry						
	Alkalinity (Total as CaCO3)	244	mg/L	--		2
B	Chloride	11	mg/L	250	EPA Secondary	1
	Conductivity	515	umhos/cm			
	Hardness	194	mg/L	--		1
B	Nitrogen, Nitrate	0.42	mg/L	10	EPA Primary	0.02
B	Nitrogen, Nitrite	U	mg/L	1	EPA Primary	0.02
	pH	8.4	pH Units	6.5 to 8.5	EPA Secondary	0.1
B	Sulfate	40	mg/L	250	EPA Secondary	1
B	Total Dissolved Solids	316	mg/L	500	EPA Secondary	10
A	Turbidity	6.8	NTU	1	EPA Action Level	0.1

Hart Well 2013 Water Quality Results

Status	Contaminant	Results	Units	National Standards		MDL
Inorganic Analytes - Metals						
	Calcium	41	mg/L	--		0.2
	Magnesium	21	mg/L	--		0.2
	Potassium	1.4	mg/L	--		0.3
	Sodium	48.7	mg/L	20	Guidance Level	0.3
Wet Chemistry						
	Alkalinity (Total as CaCO3)	229	mg/L	--		2
B	Chloride	10	mg/L	250	EPA Secondary	1
	Conductivity	552	umhos/cm			
	Hardness	189	mg/L	--		1
B	Nitrogen, Nitrate	0.42	mg/L	10	EPA Primary	0.02
B	Nitrogen, Nitrite	U	mg/L	1	EPA Primary	0.02
	pH	8.3	pH Units	6.5 to 8.5	EPA Secondary	0.1
B	Sulfate	38	mg/L	250	EPA Secondary	1
B	Total Dissolved Solids	305	mg/L	500	EPA Secondary	10
B	Turbidity	0.2	NTU	1	EPA Action Level	0.1

Notes:
B - Below National Standards
A - Above National Standards

Table 4

Pietsch Well 2008 Water Quality Results

Status	Contaminant	Results	Units	National Standards		MDL
Inorganic Analytes - Metals						
	Calcium	0.4	mg/L	--		0.2
	Magnesium	0.3	mg/L	--		0.2
	Potassium	0.3	mg/L	--		0.3
	Sodium	115	mg/L	20	Guidance Level	0.3
Wet Chemistry						
	Alkalinity (Total as CaCO3)	218	mg/L	--		2
B	Chloride	5	mg/L	250	EPA Secondary	1
	Conductivity	440	umhos/cm			
	Hardness	2	mg/L	--		1
B	Nitrogen, Nitrate	0.43	mg/L	10	EPA Primary	0.02
B	Nitrogen, Nitrite	U	mg/L	1	EPA Primary	0.02
	pH	8.3	pH Units	6.5 to 8.5	EPA Secondary	0.1
B	Sulfate	20	mg/L	250	EPA Secondary	1
B	Total Dissolved Solids	278	mg/L	500	EPA Secondary	10
B	Turbidity	U	NTU	1	EPA Action Level	0.1

Pietsch Well 2013 Water Quality Results

Status	Contaminant	Results	Units	National Standards		MDL
Inorganic Analytes - Metals						
	Calcium	35.7	mg/L	--		0.2
	Magnesium	26.9	mg/L	--		0.2
	Potassium	2.7	mg/L	--		0.3
	Sodium	14.6	mg/L	20	Guidance Level	0.3
Wet Chemistry						
	Alkalinity (Total as CaCO3)	192	mg/L	--		2
B	Chloride	6	mg/L	250	EPA Secondary	1
	Conductivity	434	umhos/cm			
	Hardness	200	mg/L	--		1
B	Nitrogen, Nitrate	0.31	mg/L	10	EPA Primary	0.02
B	Nitrogen, Nitrite	U	mg/L	1	EPA Primary	0.02
	pH	8.4	pH Units	6.5 to 8.5	EPA Secondary	0.1
B	Sulfate	20.4	mg/L	250	EPA Secondary	1
B	Total Dissolved Solids	228	mg/L	500	EPA Secondary	10
B	Turbidity	0.2	NTU	1	EPA Action Level	0.1

Notes:

B - Below National Standards

A - Above National Standards

Table 5

Elmore Well 2008 Water Quality Results

Status	Contaminant	Results	Units	National Standards		MDL
Inorganic Analytes - Metals						
	Calcium	47.4	mg/L	--		0.2
	Magnesium	29.9	mg/L	--		0.2
	Potassium	2.2	mg/L	--		0.3
	Sodium	21.9	mg/L	20	Guidance Level	0.3
Wet Chemistry						
	Alkalinity (Total as CaCO3)	250	mg/L	--		2
B	Chloride	9	mg/L	250	EPA Secondary	1
	Conductivity	489	umhos/cm			
	Hardness	241	mg/L	--		1
B	Nitrogen, Nitrate	3.35	mg/L	10	EPA Primary	0.02
B	Nitrogen, Nitrite	U	mg/L	1	EPA Primary	0.02
	pH	8.3	pH Units	6.5 to 8.5	EPA Secondary	0.1
B	Sulfate	20	mg/L	250	EPA Secondary	1
B	Total Dissolved Solids	295	mg/L	500	EPA Secondary	10
B	Turbidity	0.3	NTU	1	EPA Action Level	0.1

Elmore Well 2013 Water Quality Results

Status	Contaminant	Results	Units	National Standards		MDL
Inorganic Analytes - Metals						
	Calcium	46.8	mg/L	--		0.2
	Magnesium	28.4	mg/L	--		0.2
	Potassium	2.3	mg/L	--		0.3
	Sodium	22.2	mg/L	20	Guidance Level	0.3
Wet Chemistry						
	Alkalinity (Total as CaCO3)	226	mg/L	--		2
B	Chloride	11	mg/L	250	EPA Secondary	1
	Conductivity	527	umhos/cm			
	Hardness	234	mg/L	--		1
B	Nitrogen, Nitrate	2.81	mg/L	10	EPA Primary	0.02
B	Nitrogen, Nitrite	U	mg/L	1	EPA Primary	0.02
	pH	8.3	pH Units	6.5 to 8.5	EPA Secondary	0.1
B	Sulfate	23.1	mg/L	250	EPA Secondary	1
B	Total Dissolved Solids	285	mg/L	500	EPA Secondary	10
B	Turbidity	0.1	NTU	1	EPA Action Level	0.1

<u>Notes:</u>

B - Below National Standards

A - Above National Standards

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Table 6
Phase II Well Site Elevation Summary
(All elevation values are in feet)

Well Name	Surface Elevation (TOC)	Dec-2013 Groundwater Elevation	Top of Screen	Bottom of Well
Hart Well	6750	6680	unknown	6560
Cerise Well	6760	6638	6630	6590
Mitchell Well	7540	7041	6977	6877
Bright Well	6924	6795	6784	6724
Pietsch Well	7280	7048	7030	6980
Elmore Well	7000	6867	6810	6780

Note:
Surface Elevations are from USGS Digital Elevation Model (DEM)

Table 7
Water Level Change from 2008 through 2013

Well Name	2008	2009	2010	2011	2012	2013
Hart Well	0.0	9.8	4.9	3.9	-2.7	-7.0
Cerise Well	0.0	0.1	-1.5	-0.4	-7.1	-4.5
Mitchell Well	0.0	2.0	2.8	6.1	0.4	-1.2
Bright Well	0.0	0.0	0.5	0.7	0.1	-2.8
Pietsch Well	0.0	0.2	0.0	0.9	-5.9	-2.9
Elmore Well	0.0	8.7	10.3	11.8	9.1	2.3

Note:
Water levels are the average December water levels for Phase II wells.

Table 8

Influx of Water to the Missouri Heights Hydrologic System

Basin Area = 15,276 acres

	Missouri Heights Ditch Diversions (AF)						Precipitation			
Year	Park	C & M	Monarch	Needham	Mtn Meadow	Total AF	(inches)	(feet)	Total AF	Total AF
1994	867	1,088	391	1,709	3,038	**7,094**	13.1	1.09	**16,654**	**23,749**
1995	1,207	1,587	207	2,745	7,906	**13,651**	20.5	1.71	**26,107**	**39,758**
1996	947	1,037	150	2,055	5,595	**9,786**	18.7	1.55	**23,750**	**33,536**
1997	1,669	784	278	2,350	5,005	**10,086**	19.2	1.60	**24,378**	**34,464**
1998	1,231	1,326	80	2,644	6,515	**11,796**	16.7	1.39	**21,244**	**33,039**
1999	592	1,572	200	2,855	4,096	**9,316**	17.1	1.42	**21,719**	**31,035**
2000	428	587	127	2,205	4,354	**7,700**	12.4	1.03	**15,796**	**23,496**
2001	816	739	397	1,757	4,569	**8,279**	14.3	1.19	**18,202**	**26,481**
2002	193	375	70	814	927	**2,379**	12.8	1.07	**16,278**	**18,657**
2003	444	957	292	1,994	5,178	**8,864**	13.5	1.12	**17,147**	**26,011**
2004	517	932	219	1,937	2,455	**6,061**	13.4	1.12	**17,070**	**23,130**
2005	761	1,283	172	2,241	6,752	**11,210**	15.6	1.30	**19,819**	**31,029**
2006	801	1,122	249	2,373	5,182	**9,727**	16.1	1.34	**20,498**	**30,226**
2007	327	1,131	437	2,592	4,310	**8,796**	13.4	1.11	**17,014**	**25,810**
2008	687	1,017	353	2,603	6,445	**11,104**	14.7	1.23	**18,737**	**29,841**
2009	747	1,320	274	2,827	5,314	**10,483**	15.7	1.31	**19,935**	**30,418**
2010	805	890	213	2,026	2,482	**6,416**	17.2	1.44	**21,947**	**28,362**
2011	495	754	160	1,959	1,896	**5,263**	17.5	1.46	**22,252**	**27,515**
2012	605	345	6	1,211	0	**2,168**	12.1	1.01	**15,454**	**17,622**
2013	426	828	220	1,591	2,925	**5,989**	13.2	1.10	**16,753**	**22,741**
1994-2008 Average	**766**	**1,036**	**241**	**2,192**	**4,822**	**9,057**	**15.42**	**1.28**	**19,628**	**28,684**
2009-2013 Average	**616**	**827**	**174**	**1,923**	**2,523**	**6,063**	**15.14**	**1.26**	**19,268**	**25,332**

	Diversion	Percent	Precip	Percent	Total
1994-2008 Average	**9,057**	**32%**	**19,628**	**68%**	**28,684**
2009-2013 Average	**6,063**	**24%**	**19,268**	**76%**	**25,332**