MISSOURI HEIGHTS GROUNDWATER MONITORING PROGRAM

Basalt Water Conservancy District
Colorado Water Conservation Board

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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 and Phase IIa 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 studies involved the establishment of continuous groundwater recorders, development of a 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 provides water allotment contracts within the Fryingpan and Roaring Fork River basins generally extending from Aspen to Glenwood Springs, Colorado. However, the District's service area is more broadly described as the Roaring Fork River watershed east of the Crystal River. **Figure 1** shows the extent and location of the District's division boundary. The division boundary was created as the initial service area for which a small mill levy is applied. Properties located outside this area must be included into the division boundary before a water allotment contract can be considered.

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 from 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 600 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 allotment 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 of the groundwater to better understand the Missouri Heights aquifer. The Phase II study was completed in 2014; however, the study was extended as Phase IIa to gather more data and to confirm the trends and conclusions established in Phase II. All of the groundwater data taken under Phase II was reanalyzed in conjunction with the Phase IIa data and summarized in this report. For simplicity, the Phase II and Phase IIa studies are herein referred to as the Phase II Study or "Study."

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** provide 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 Phase II 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 6th 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 6th 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 6th 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. A pressure transducer was added to the well in April 2015 as discussed later in this report.

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 6th 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 6th 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 6th 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 6th 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. From 1994 through 2008 Ditch diversions from Cattle Creek through the Park, Mountain Meadow, and Needham ditches import approximately 9,056 AF of water annually. This amount accounts for approximately 28% of the water that enters the Missouri Heights hydrologic system. Precipitation accounts for the remaining 72%, with approximately 23,775 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 Phase II study focused on the recent 2009 through 2019 time period (Study Period) and 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 seven 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 development trends.

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

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

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 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

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

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 underemphasized, factor in ensuring the sustainability and proper management of groundwater resources."[3] For the purposes of this Study, RESOURCE analyzed the climatic precipitation trends to determine if the 2009 to 2019 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 2019 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 Aspen or GWS weather stations were supplemented with data from the US Climate Data and Weather Underground (South Glenwood Springs weather station) websites. 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 2019 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. When necessary due to

[3] U.S. Geological Survey, 1999

equipment malfunctions or erroneous readings, data from the nearby Spring Park Weather Station from Weather Underground was utilized. However, most of the data came from the BWCD weather station. 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**.

3.4.1 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 2017, the precipitation data from the Aspen and the GWS weather stations recorded over this same period.[4] 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 and 2014, 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 2017. The relationship between the Aspen and the BWCD weather stations produced an R^2 value of 0.70. While the comparison between the GWS and the BWCD weather stations resulted in a R^2 value of 0.85.

[4] Data from Water Years 2018 and 2019 were also not included in the regression analysis due to some months missing data from all available sources.

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 (30% Aspen and 70% Glenwood). This regression analysis resulted in an R^2 value of 0.89. 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 19.32 inches, compared to the 2009 to 2019 average of 14.56 inches measured at the weather station. This indicates that the 2009 to 2019 Study Period was drier than the long-term average, experiencing approximately 4.76 inches of less annual rain than during the 1980 to 2008 period.

Analysis of the data shows that over a 37-year period from 1981 to 2019, the Study Area experienced alternating wet and dry cycles and show an overall wet period and dry period during the Study Period. These precipitation cycles and wet and dry periods are shown on **Figure 7**. The year 2000 began the current dry period and includes the entire Phase II Study Period.

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 2005 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. A review of the irrigated areas on recent 2019 NAIP photography indicated that the irrigated areas have not substantially changed since 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 2019 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 6,235 AF respectively. This estimate represents an approximate 31% 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 in 2008 or 2009. A seventh well was added in May 2015 within the Spring Park Reservoir watershed at the Fender Well, which was previously a Phase I study well that experienced a significant drawdown after nearby irrigated fields were converted from flood irrigation to sprinkler irrigation. Study Wells were located geographically in the upper and lower regions of the West, Central, and East watersheds. A pressure transducer was not installed in a well located within the upper region of the Spring Park Reservoir Watershed due to a lack of response from the owners of suitable wells for the Study.

The pressure transducers installed in each of the seven 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 seven 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 were graphed on **Figures 9 through 12** to show trends in groundwater level movement throughout the Study Period. The water level data was displayed utilizing a methodology used by the USGS.[5] 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.

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

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 generally occurs in October, November, or December. The Hart Well reached its highest annual water level of 6,702.3 feet in September 2011 (wet year) and its lowest level of 6,671.8 feet in late June 2018 (drought year). This represents a maximum high water level change of 30.5 feet over the Study Period. The annual high groundwater elevation recovered to an elevation of 6,677.5 in October 2019. 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, 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 typically in late June or July. The Cerise Well reached its highest level of 6,654.6 feet in June 2009 and June 2018 and its lowest level of 6,638.2 feet in June 2012. This represents a maximum change of 16.4 feet over the Study Period. The transducer failed in November 2018 and was not replaced as the Phase II study period was ending the following year and the water levels in the well have been increasing over the last several years. 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. Volcanics, 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 August, September, or October. When comparing the high annual water levels in the Mitchell Well during the Study Period, the highest water level reached was 7,049.9 feet in October 2011 and the lowest level was 7,038.3 feet in late June of 2018. This represents a maximum change of 11.6 feet over the Study Period. The transducer failed in 2016 and was ultimately replaced in early 2017 after troubleshooting. 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 – Crouch Well

The Crouch 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 Crouch Well was drilled in June 1967 to a depth of 270 feet. At the time of well construction, static water level was at 210 feet from TOC, and the well produced 10 gpm during a 1-hour pumping test. The well was drilled in volcanics. 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 landscape irrigation.

The water level at the Crouch Well does not fluctuate much seasonally. However, there are large variations in the water level during the irrigation season. 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 Crouch Well reached its highest level of 6,887.4 feet in October 2016 and its lowest level of 6,881.2 feet in February 2013. This is a maximum change of 6.2 feet; however, with the exception of 2013, the annual high groundwater level fluctuated less than 1 foot. The transducer failed in November 2017 and was ultimately not replaced as the aquifer generally recharges to the same level every year. A summary of the annual high groundwater elevations over the Study Period for the Crouch Well is provided in **Table 2**.

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 primarily in late July and August. In comparing the high annual water levels during the Study Period, the Pietsch Well reached its highest level of 7,056.6 in July 2019 and its lowest level of 7,045.5 feet in November 2018. This represents a maximum change of 11.1 feet. The annual high groundwater elevation in 2018 was likely delayed due to heavy pumping of the well during the Lake Christine Fire. 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 6th 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 later in the water year. In comparing the high annual water levels during the Study Period, the Elmore Well reached its highest level of 6,879.1 feet in April 2012 and its lowest level of 6,862.1 feet in January 2015. This represents a maximum change of 17.0 feet. The transducer failed in March 2019 and was not replaced as the Phase II study period was concluding later in the year. A summary of the annual high groundwater elevations over the Study Period for the Elmore Well is provided in **Table 2**.

3.6.7 Spring Park Watershed – Fender Well

The Fender Well was added to the Study in April 2015. The Fender Well is located in the southeast quarter of Section 27, Township 7 South, Range 87 West, of the 6th P.M. According to the well completion report, the Fender Well was redrilled in June 2012 to a depth of 365 feet. At the time of well construction, static water level was at 245 feet from TOC and the well produced over 10 gpm during a 2-hour pumping test. The well was constructed in volcanics. The well is located near irrigated fields fed from the Mountain Meadow Ditch and Spring Park Reservoir. The well serves a single family home, a barn, livestock, and up to 1 acre of irrigation.

The water level at the Fender Well fluctuates seasonally as shown on **Figure 12**. The water level in the well begins to rise after the irrigation season until it reaches peak elevation later in the water year. In comparing the high annual water levels from May 2015 through October 2019, the Fender Well reached its highest level of 6,825.2 feet in October 2019 and its lowest level of 6,817.3 feet in January 2018. This represents a maximum change of 7.9 feet. A summary of the annual high groundwater elevations during Phase II for the Fender Well is provided in **Table 2**.

3.7 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.

3.7.1 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 2019 NAIP aerial photography. As of November 2019, RESOURCE estimates that there was approximately 680 residential or building units in the West, Central, East, and Spring Park watersheds. The Spring Park watershed was limited to those residential units on the plateau as most of the structures in the El Jebel area have water supplied by Crawford Properties, LLC or the Mid Valley Metropolitan District that have alluvial wells hydraulically tied to the Roaring Fork River. 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 267 AF of water is diverted annually for residential in-house uses of which approximately 40 AF is consumed and not available to the groundwater system.

For purpose of estimating water demands associated with residential landscape irrigation, each building or 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[6]. Irrigation consumptive use (CU) was estimated using the Modified Blaney-Criddle methodology outlined in SCS TR-21 for bluegrass. The irrigation

[6] Subdivisions include Kings Row and Stirling Ranch.

water demand for landscape bluegrass was calculated to be 2.0 feet. Therefore, for 156 acres of irrigation (10,000 square feet x 680 parcels), the irrigation depletion is approximately 312 AF (156 acres x 2.0 feet). A copy of the Modified Blaney-Criddle calculation can be found in **Appendix D.** The total amount of groundwater depletions from in-house and irrigation use is estimated to currently be 352 AF (40 AF + 312 AF).

3.7.2 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**.

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 12** 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 seven wells were overlain with the previously described trends in precipitation and agricultural diversions that were recorded over the Study.

Of the seven Study wells, four are located in proximity to irrigated fields and three are located away from irrigated areas. The Hart, Cerise, Crouch, and Fender 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 13** 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 diversion 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 0.21 to 0.63.

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: 2013 and 2016. These two years were selected as diversions were lower than the historic average in 2013 and slightly exceeded historic averages in 2016.

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 14**. In 2013, water elevations within the well begin to rise approximately one week after the Park Ditch headgate was opened.

Even in 2016 when diversion imports were approximately 137 percent of what occurred in 2013, the groundwater level at the Hart Well responded approximately one week after the Park Ditch headgate was opened. RESOURCE also observed that in 2013, the groundwater levels stabilized approximately six weeks after Park Ditch diversions and when ditch flows were reduced below 1.2 cfs. The water level then began to rise again after ditch flows increased. In addition, the groundwater level rise in 2013 was not as pronounced in 2016.

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 15 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 there was no lag between annual precipitation and observed annual average groundwater levels. The second and third analyses assumed 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 0.02 to 0.17.

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. This analysis utilized the 2009 and 2012 as representative years from the Study.

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 16**.

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 Study Period average of 1,073 AF.

Precipitation in 2012 was 12.14 inches as compared to the Study Period average of 14.56 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, 11-year average = 670 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 17**. 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 Crouch Well and receive irrigation supply from the Mountain Meadow Ditch. The water elevation in the Crouch Well, which remained fairly constant throughout the Study Period, was recorded at 6,880.4 feet in December 2015. December was selected because aquifer fluctuations are minimized by eliminating irrigation pumping and 2015 was a representative year where data was collected for all seven Study wells. Thus, the maximum water elevation associated with the closest irrigated fields is only 3.4 feet higher 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 Study wells and recorded groundwater depths from December 2015 are summarized in **Table 3**.

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. Several analyses were completed; the first analysis assumed that there was no lag between annual precipitation and observed annual average groundwater levels. Subsequent analyses assumed that the precipitation took either 3 to 15 months to reach the aquifer at 3-month intervals. 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 9 months. The calculated R^2 value describing the relationship is 0.82. This strong relationship indicates that the Mitchell Well is influenced by some precipitation from the prior year. **Figure 17** displays the seasonal groundwater trends with annual precipitation amounts.

4.1.4 Crouch Well

The groundwater hydrograph developed for the Crouch Well is shown on **Figure 18.** 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 Crouch 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 Crouch 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 generally fluctuated 5 to 12 feet seasonally with lowest levels occurring during the late spring to mid-summer. 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 Crouch Well and the Elmore Well, were 6,880.4 feet and 6,862.7 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 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.

Subsequent analyses assumed that the precipitation took either 3 to 15 months to reach the aquifer at 3 month intervals. 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 3 to 6 month lag and R^2 values of 0.63 and 0.65. These moderate R^2 values are higher than those calculated for the Hart and Cerise wells and is located upgradient from irrigated fields. For these reasons, RESOURCE believes that the Pietsch Well is primarily influenced by precipitation. **Figure 19** 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 14 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 20** displays the seasonal groundwater trends with annual precipitation amounts and irrigation diversions representative of this area. Visually, it does not appear that the groundwater reacts to precipitation or ditch diversions. RESOURCE verified this performing regression analyses as described above for both parameters. As such, there are likely other factors such as geology and the groundwater gradient affecting the timing of the groundwater recharge.

4.1.7 Fender Well

As stated previously, the Fender Well was added to the Study in April 2015. Therefore, there is only 4.5 years of real-time monitoring. The groundwater hydrograph developed for the Fender Well indicates that the water levels generally exhibited significant variations throughout the year. Water levels rise and fall 7 to 10 feet seasonally with lowest levels occurring in the irrigation season. The Fender Well is located within an irrigated region that receives water supplied by the Mountain Meadow Ditch and Spring Park Reservoir releases. RESOURCE compared the groundwater trends to both precipitation and diversion imports.

Figure 21 displays the seasonal groundwater trends with annual precipitation amounts and irrigation diversions representative of this area. Visually, it appears that the groundwater reacts primarily to ditch diversions. That is, in years with higher than normal irrigation imports, groundwater levels rise. In contrast, in years with low agricultural diversions, groundwater appears to drop. However, in an effort to determine which variable has the most influence on the local aquifer, RESOURCE examined precipitation and diversion trends separately.

Precipitation. RESOURCE conducted a regression analysis to examine the relationship between the annual average height of the groundwater level observed in Fender Well each year compared to that same year's annual precipitation. For this well, 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.

Results from 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 0.28 to 0.57.

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 Spring Park Reservoir releases. This analysis utilized 2018 and 2019 (dry year and wet year respectively) as representative years from the Study.

The diversion records maintained by the DWR over the Study Period indicates that in both 2018 and 2019, groundwater levels in the Fender Well immediately fell at the start of

Spring Park Reservoir releases. This drop in the groundwater levels coincides with the beginning of the irrigation season and increased pumping from the well for irrigation. However, the differences between 2018 and 2019 are significant. In 2018, there were minimal Spring Park Reservoir releases (892 AF versus average of 2,746 AF) and those releases ceased in late May. Groundwater levels slightly dropped over the course of the irrigation season and started to rebound after the irrigation season. In contrast, Spring Park Reservoir releases were significantly higher in 2019 (3,844 AF versus average of 2,746 AF) and continued during the summer. Approximately 4 weeks after releases began, the groundwater levels at the Fender Well began to rise and continued to rise over the irrigation season. Spring Park Reservoir flows were sufficient to provide water to the pasture grass, maintain the soil moisture, and recharge the aquifer. This relationship between Spring Park Reservoir releases and the Fender Well for the 2018 and 2019 representative years are shown graphically on **Figure 22**.

In summary, groundwater elevations within the Fender 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.

4.2 DEVELOPMENT TRENDS

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

4.2.1 In-House and Irrigation Depletions

Section 3.7.1 in-house domestic and irrigation depletions associated with residences at Missouri Heights was estimated at 352 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 1,056 AF. These future depletions represent approximately 1/6 (1,056 AF / 6,235 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.

4.2.2 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 DWR's database to examine areas where wells were recently redrilled. Based upon the review of the DWR's database, RESOURCE discovered that fifteen wells were reconstructed during the Study Period. The locations of the nine replacement wells redrilled during the Study Period are shown on **Figure 23.** Six of the fifteen wells are located high in the West, Central, and East watersheds, one well is located in the central area of the East Watershed and the remaining eight wells are concentrated in the lower part of the Spring Park Reservoir Watershed, near the Fender Well. The eight replacement wells, including the Fender Well, were all redrilled during and after 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 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 24**. Results show that the groundwater level fluctuations at the Fender Well generally follow wet and dry periods of precipitation. **Figure 24** 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 12 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.

4.3 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 2018 where data was available. 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 exception to this is the Fender Well when real-time monitoring began in 2015; therefore, December 2015 was utilized. The water level in each of the Study wells fluctuated on a yearly basis as shown on **Table 4**.

On average, the groundwater level in the Study Area increased from 2008 through 2011, but started to decline in 2012 due to the drought and lagged responses. Overall, groundwater levels declined during the Study Period. 2018 was also a drought year and was more severe than the drought in 2012.

The change in groundwater levels in December for each well during their respective monitoring periods were highly variable throughout the Study Area as shown on **Figure 25.** However, in general, the groundwater table showed declines in the northern part of the Study Area and the groundwater levels increased further to the south.

4.4 GROUNDWATER RECHARGE

An additional objective of the Phase II Study was to estimate the amount of recharge the aquifer in the study area receives. To accomplish this, RESOURCE utilized a simplified water balance approach. The approach provides an assessment of the major components of the hydrologic system and includes interactions with the surface water and groundwater systems. This approach provides a general understanding of the magnitude of the recharge and discharge components. As such, its accuracy is limited and should not be relied on as the sole tool for groundwater management. The components of the simplified water balance equation is expressed as the following:

Recharge = Precipitation + Ditch Import Water – Evapotranspiration – Runoff

Each of these water balance components are further described below:

- **Recharge** is the portion of precipitation that infiltrates in the ground past the root zone and percolates down through the soil until it reaches the water table. A significant percentage of groundwater later remerges into the area streams. Under natural conditions, all of the recharge will eventually emerge and pass through rivers and streams via springs and seeps. Water pumped from aquifers interrupts this natural balance.

- **Precipitation** is the amount of rain, snow, etc., that has fallen within the Study Area within the Water Year as measured or estimated at the BWCD Weather Station. For this analysis, we assume that the amount of precipitation is uniform over the Study Area and converted to acre-feet.

- **Ditch Import Water** is the amount of water imported (in acre-feet) from Cattle Creek to irrigate lands within the Study Area. Ditch records examined for this water balance are the Park Ditch, C and M Ditch, Needham Ditch, Monarch Ditch, and the Mountain Meadow Ditch.

- **Evapotranspiration** is water that is returned to the atmosphere consisting of moisture that is transpired by crops/plants and evaporated from either soil or plant surfaces. Evaporative losses are at their highest during the summer when temperature conditions and plant activity are at their maximum. For this analysis, it was assumed that evapotranspiration was constant at 15,873 acre-feet annually as estimated on **Table 6**.

- **Runoff** is the amount of water that collects on the land surface or shallow subsurface and flows quickly to the area drainages and streams. The amount of runoff is controlled in part by local soil conditions, topography, and vegetation. To estimate the amount of runoff, RESOURCE utilized the USGS Streamflow Statistics and Spatial Analysis Tool StreamStats to estimate the mean monthly runoff (in cubic feet per second) for various water years with differing annual precipitation amounts. In certain cases certain parameters such as the drainage basin area, mean basin elevation, and/or mean annual precipitation were outside of the program's suggested range. However, the program provided estimates that appeared to be reasonable when compared to estimates that had parameters within the suggested ranges. The mean monthly runoff was subsequently converted to acre-feet for the water balance equation.

Recharge estimate results from the water balance equation indicate that approximately 6,100 acre-feet on average percolated to the Study Area water table during the Study Period. In wet years such as 2011, the recharge was approximately 9,200 acre-feet. In drought years such as 2012 and 2018, recharge was negative by 223 acre-feet and 1,050 acre-feet respectively. In a year with above-average precipitation and above-average ditch imports, the recharge can be as high as 11,300 acre-feet. The results of the groundwater recharge estimates are provided in **Table 7**.

As also shown in **Table 7**, the Ditch Import water is of significant importance. Without it, the recharge rate would be negative in most years as the evapotranspiration would exceed the precipitation (less runoff).

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 approximately 11 years of continuous measurements at six well sites and a local weather station. In 2015, the Fender Well was added to the Study. 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.

<u>Long-Term Precipitation Trends</u> – Long-term precipitation trends were developed for the Study Area by taking portions of data from the Aspen and Glenwood weather stations (30% Aspen and 70% Glenwood, respectively resulting in an R^2 value of 0.89) 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 and overall wet and dry periods as shown on **Figure 7**. The Missouri Heights area is currently within an overall dry period that started in 2000.

<u>Imported Agricultural Water</u> – 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 5**, the average annual estimated amount of water diverted into Cattle Creek to Missouri Heights was 6,235 AF for the Study Period. This is a decrease from the 9,056 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 period that began in 2010 and better record keeping by DWR and ditch diverters.

<u>Groundwater Level Trends</u> – The Study Area was divided into four watersheds: West, Central, East, and Spring Park. As mentioned previously, the Fender Well was added in

2015 to the Spring Park Reservoir Watershed. Well sites were selected in the upper and lower geographic regions of West, Central, and East watersheds and the Fender well is located below Spring Park Reservoir in the lower reach of the Spring Park 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 12**. 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 (typically 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 40 AF and irrigation consumption was estimated at 312 AF for a total groundwater depletion of 352 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 various monthly 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 had strong R^2 values of 0.82 with a 9 month lag. The Pietsch Well had R^2 values of 0.63 to 0.65 for 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, Cerise, and Elmore wells had low R^2 values ranging from 0.02 to 0.63 depending on the lagging interval.

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, Cerise, and Fender wells, which were both located near irrigated fields and had a quick response when irrigation commenced (see **Figures 15, 16, and 22**). The Crouch 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. In addition, the regression analysis did not find a strong relationship between precipitation and groundwater levels. RESOURCE believes that there are other factors such as geology and the groundwater gradient that also affect the timing of groundwater discharge.

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 response to irrigation after 2 to 4 weeks. However, in low diversion years, the response of the aquifer can take several weeks or show no response.

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 1,056 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 in 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 12 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.

Lastly, utilizing a simplified approach, groundwater recharge was estimated at approximately 6,100 acre-feet on average during the Study Period. In wet years such as 2011, the recharge was approximately 9,200 acre-feet. In drought years such as 2012 and 2018, recharge was negative by 223 acre-feet and 1,050 acre-feet respectively. In a year with above-average precipitation and above-average ditch imports, the recharge can be as high as 11,300 acre-feet.

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. From 1994 through 2008, an average of 9,056 AF of water was imported annually from Cattle Creek and an average of 23,775 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 6,235 AF per year during the Study Period, while average annual precipitation from snowpack and rainfall was estimated at 18,531 AF as shown on **Table 5**. 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 2000 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 3 to 9 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 flood irrigation to sprinkler 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.[7] 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.

While the conclusions derived from this Study are also limited by the fact that no new significant development has occurred. However, the conclusions drawn in this report are largely the same as in the April 2014 report. In addition, the BWCD weather station and some of the transducers are no longer working. For these reasons, RESOURCE is not recommending continued monitoring of the aquifer.

Please don't hesitate to contact us with any questions you may have.

Sincerely,

RESOURCE ENGINEERING, INC.

Eric F Mangeot, P.E.
Water Resources Engineer

EFM
File: 033-8.1.6

[7] The Hart Well shows a groundwater elevation drop of 26.6 feet from December 2008 to December 2018; however, 2018 was a drought year and the well has rebounded to an elevation drop of 10.3 feet as of October 31, 2019.

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- 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.

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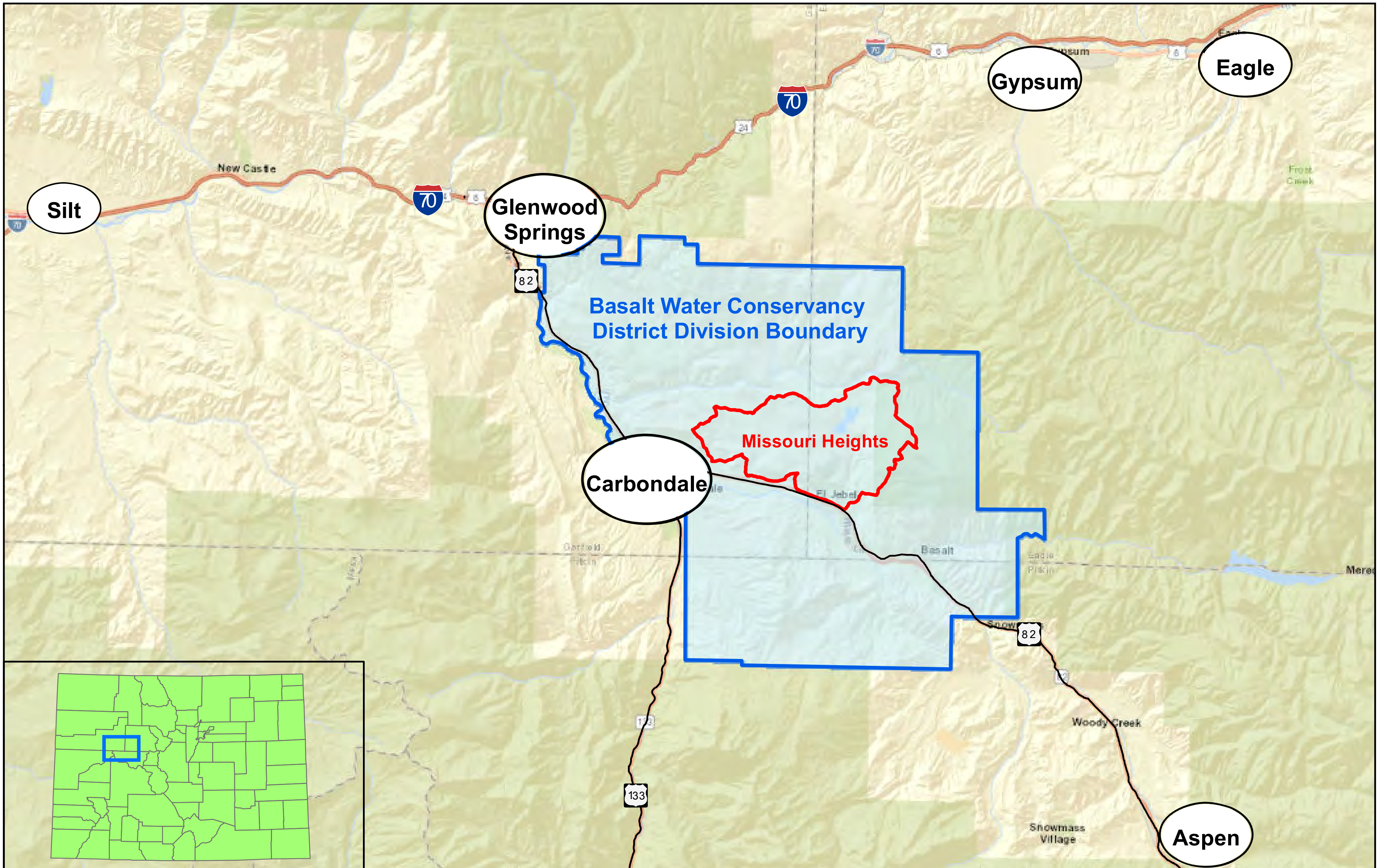

Source: World Street Map

Figure 1: Basalt Water Conservancy District Division Boundary Map

0 2.5 5 10 Miles

1 in = 5 miles

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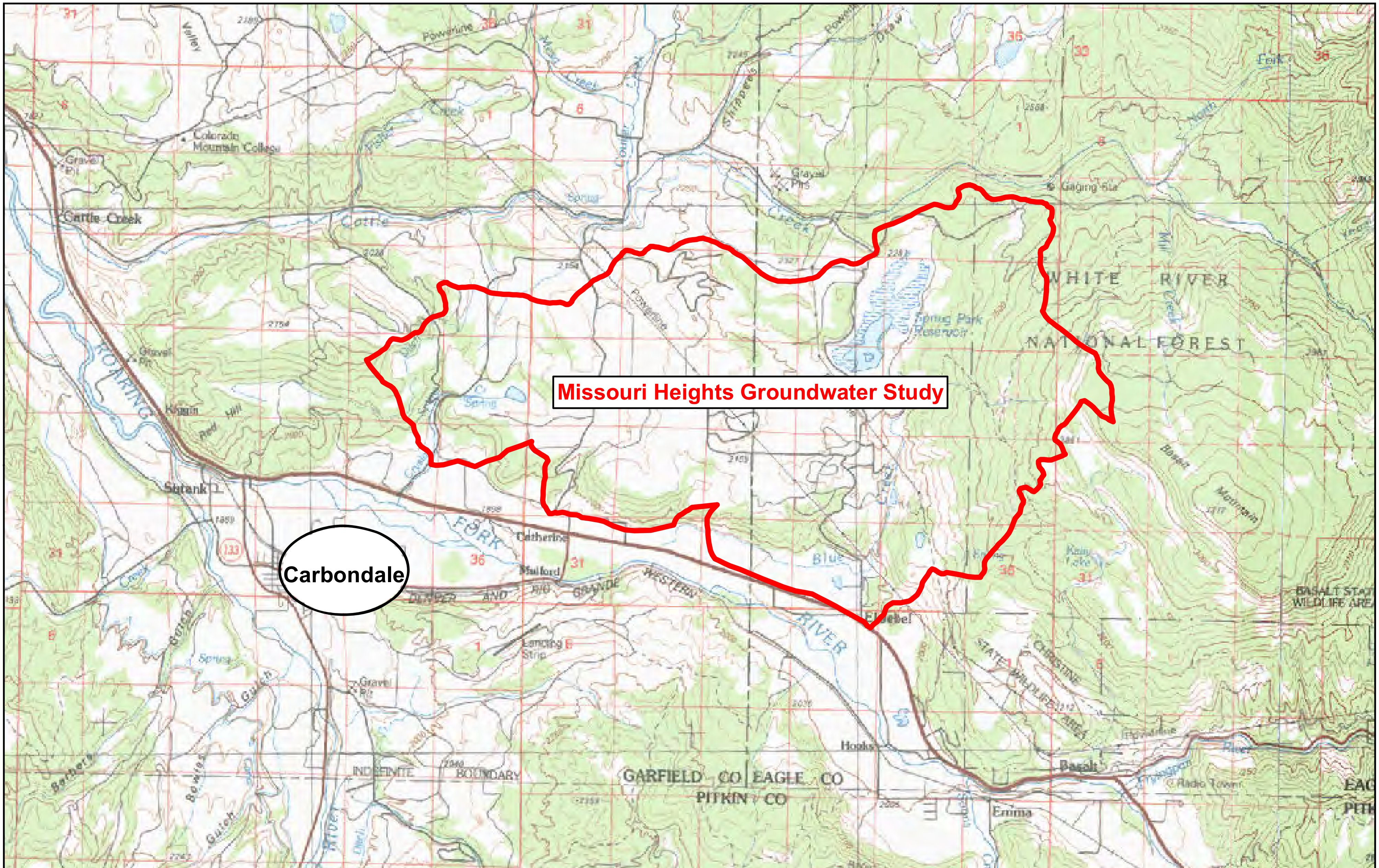
Date: 5/04/2020
File: 033-8.1.6
Drawn: RKM/RP
Approved: EFM



Source: Carbondale and Leadville 100K Quadrangles

Figure 2: Missouri Heights Groundwater Study Location Map

0 0.75 1.5 3 Miles

1 in = 1.5 miles

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Source: 2019 NAIP Aerial Photography

Figure 3: Site Location Map

0 0.5 1 2 Miles

1 in = 1 mile

- Phase I Wells and Springs
- Phase II Wells
- Phase I & Phase II Wells
- Weather Station

N W E S

Date: 5/04/2020
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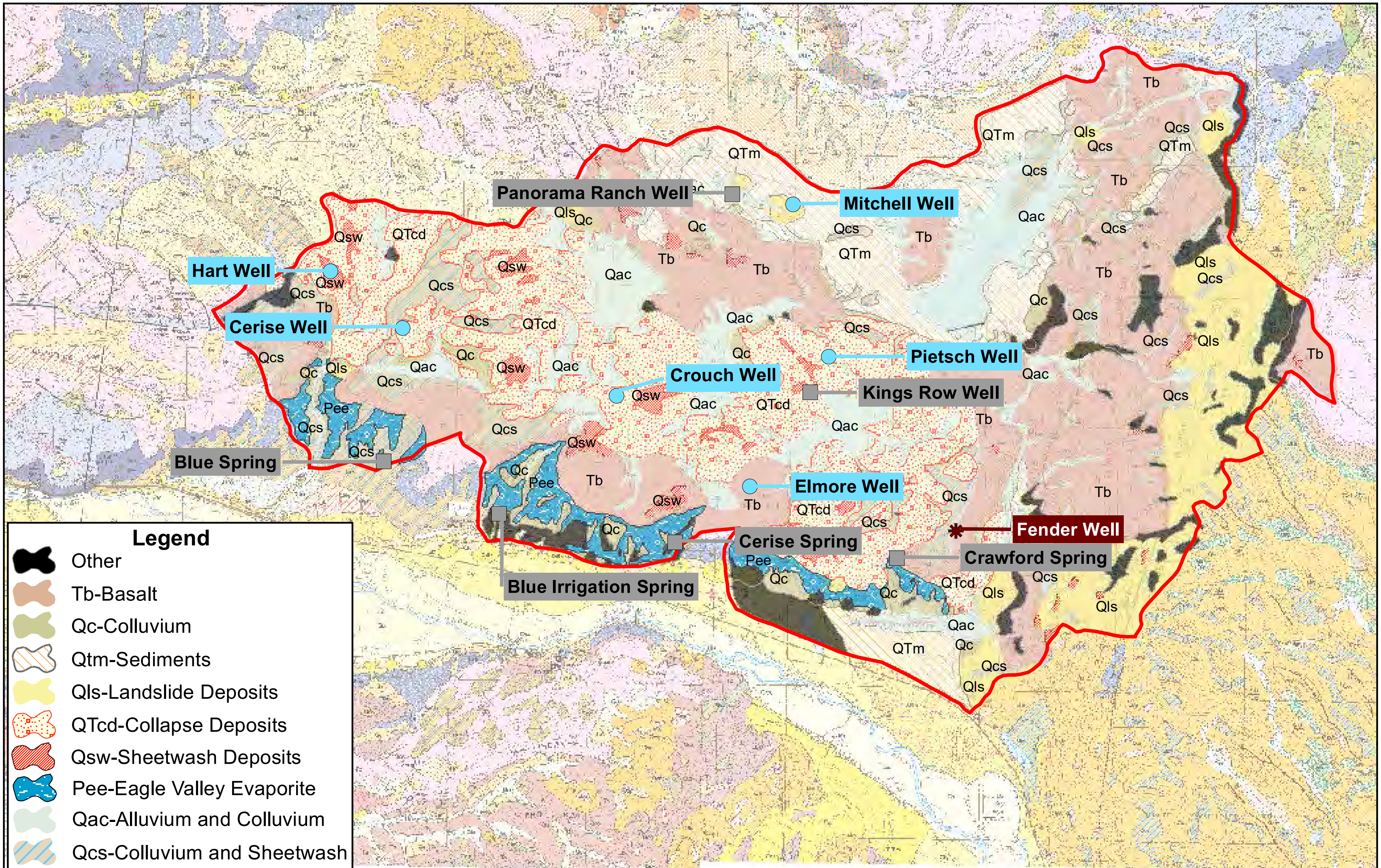

Source: USGS Leon and Carbondale Geologic Maps

Figure 4: Geology Location Map

0 0.5 1 2 Miles

1 in = 1 mile

Phase I Wells and Springs

Phase II Wells

Phase I & Phase II Wells

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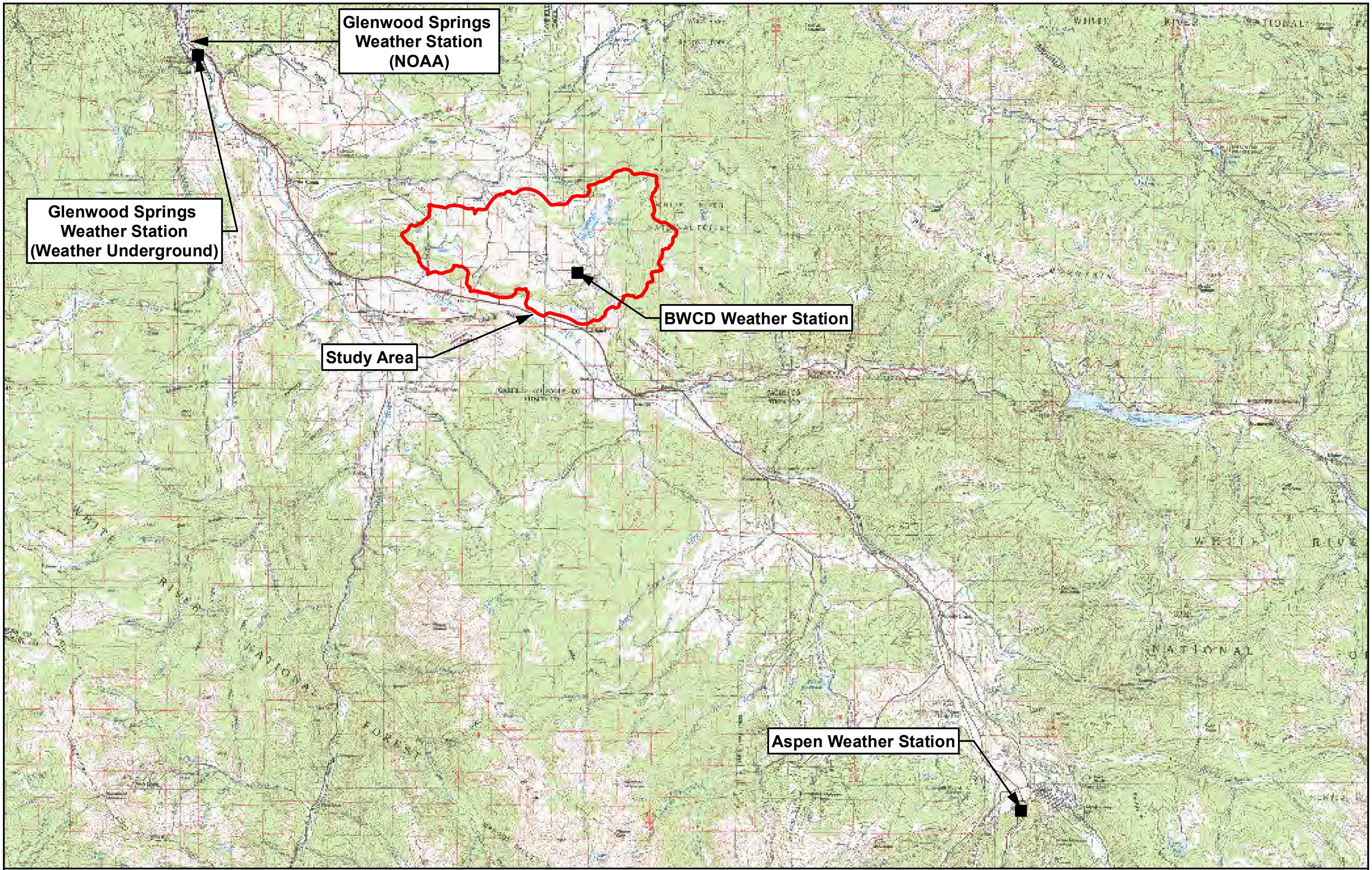

Source: Leadville, Vail, Carbondale and
Glenwood Springs 100K Quadrangles

Figure 5: Weather Stations Location Map

0 2 4 8 Miles
1 in = 4 miles

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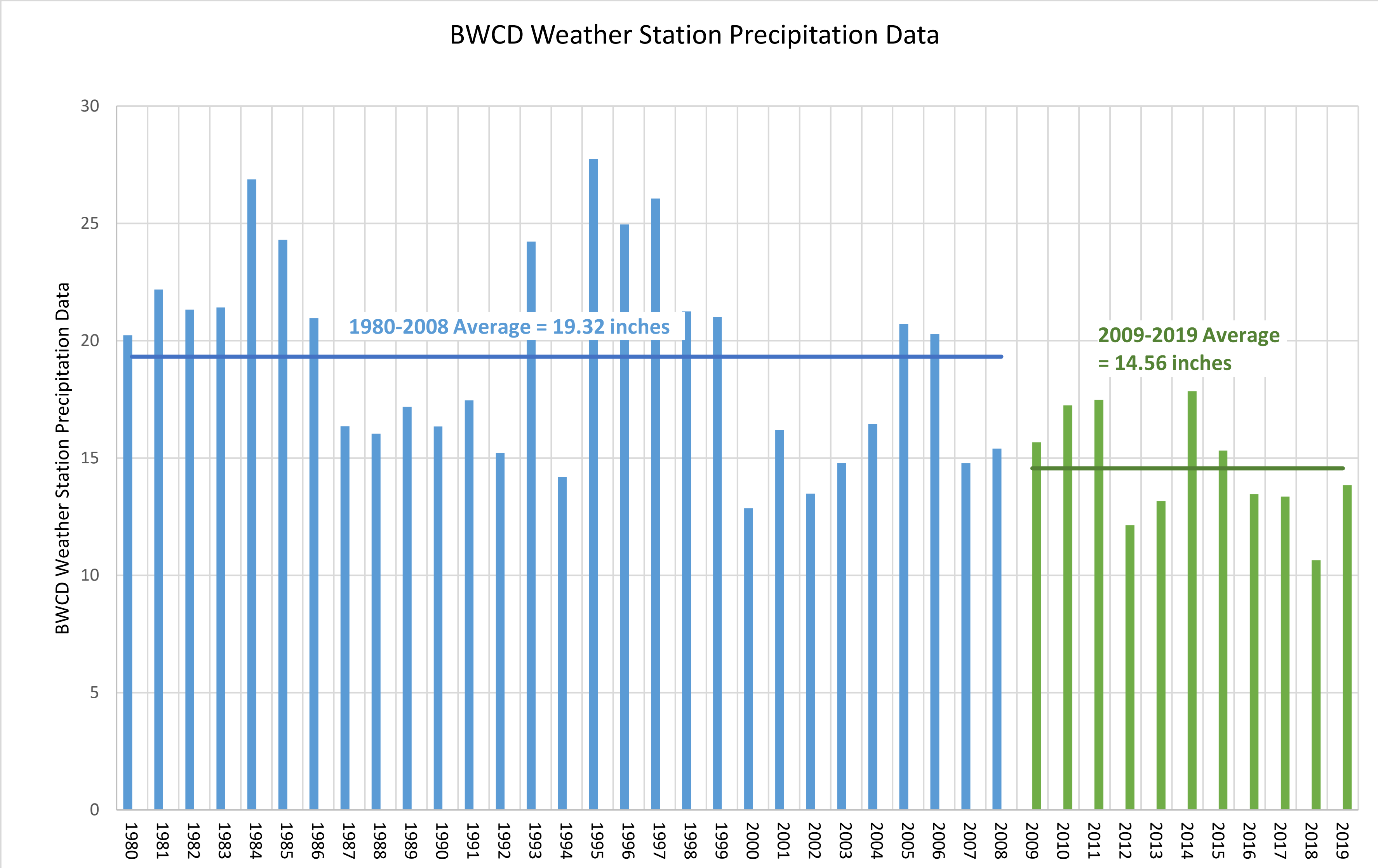
Figure 6



Note: 1980-2008 precipitation data is calculated using Aspen and Glenwood Springs Weather Stations Data
2009-2019 precipitation data is actual data measured at the BWCD ad Spring Park Weather Stations

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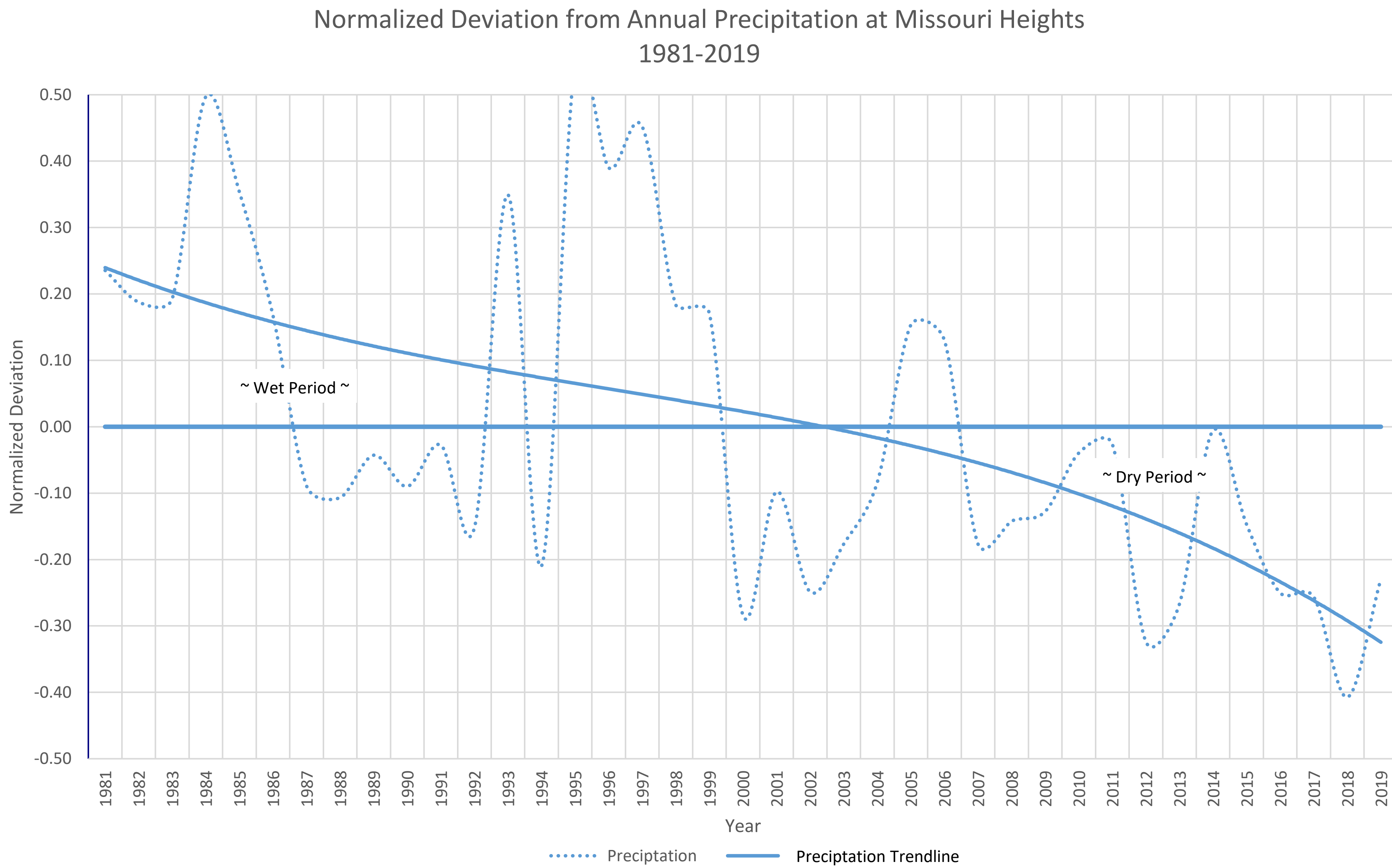
FIGURE 7



Note: 1981 - 2008 weather data was calculated using 2009 - 2017 measured data.

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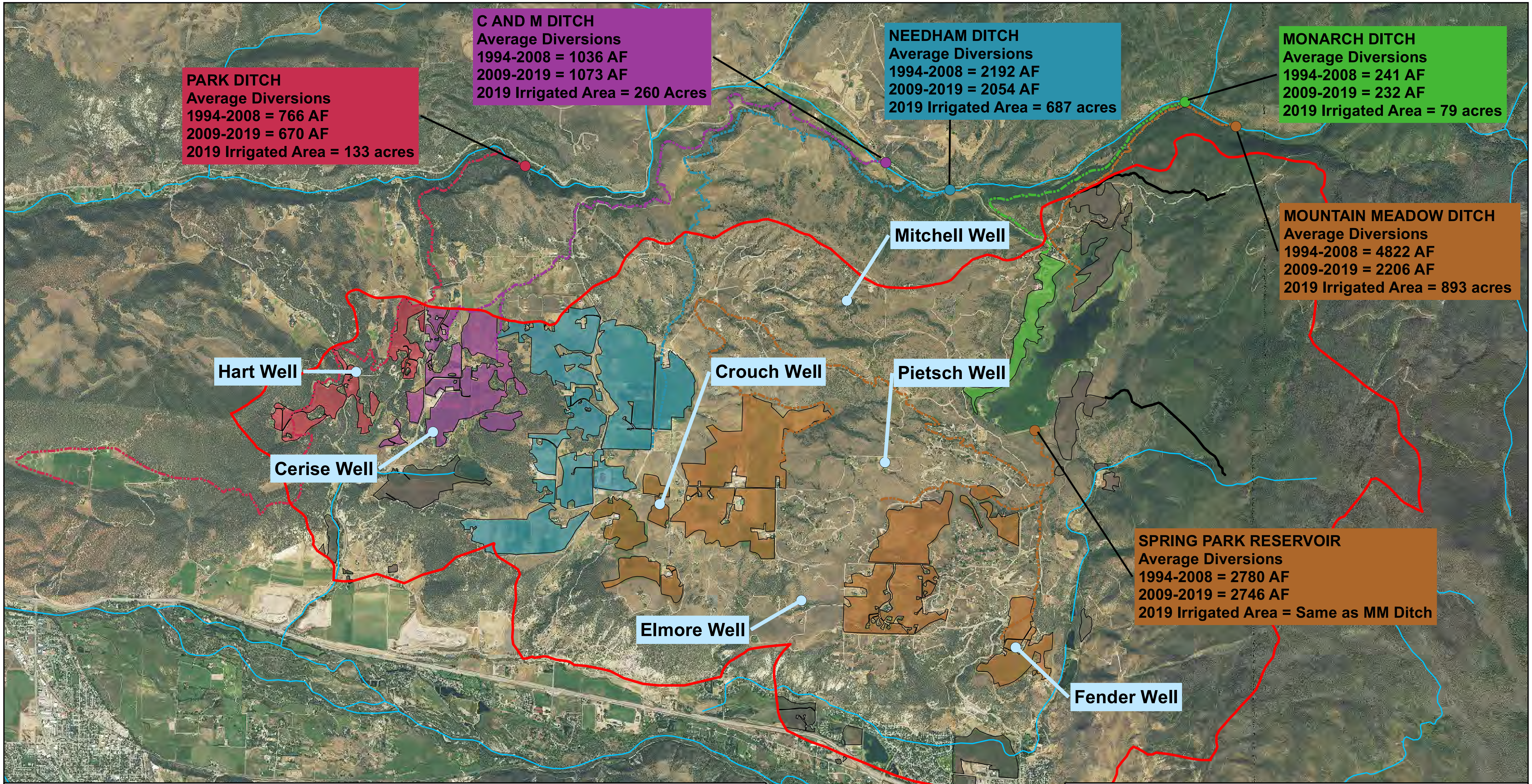

Figure 8: Missouri Heights Irrigation Location Map

Source:
2019 NAIP Aerial Photography
DWR CDSS

0 1,750 3,500 7,000 Feet

1 inch = 3,500 feet

Date: 5/04/2020
File: 033-8.1.6
Drawn: RKM/RP
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2019 Irrigated Area

- C and M Ditch
- Needham Ditch
- Monarch Ditch
- Park Ditch
- Mountain Meadow Ditch
- Other Ditches
- Missouri Heights Boundary

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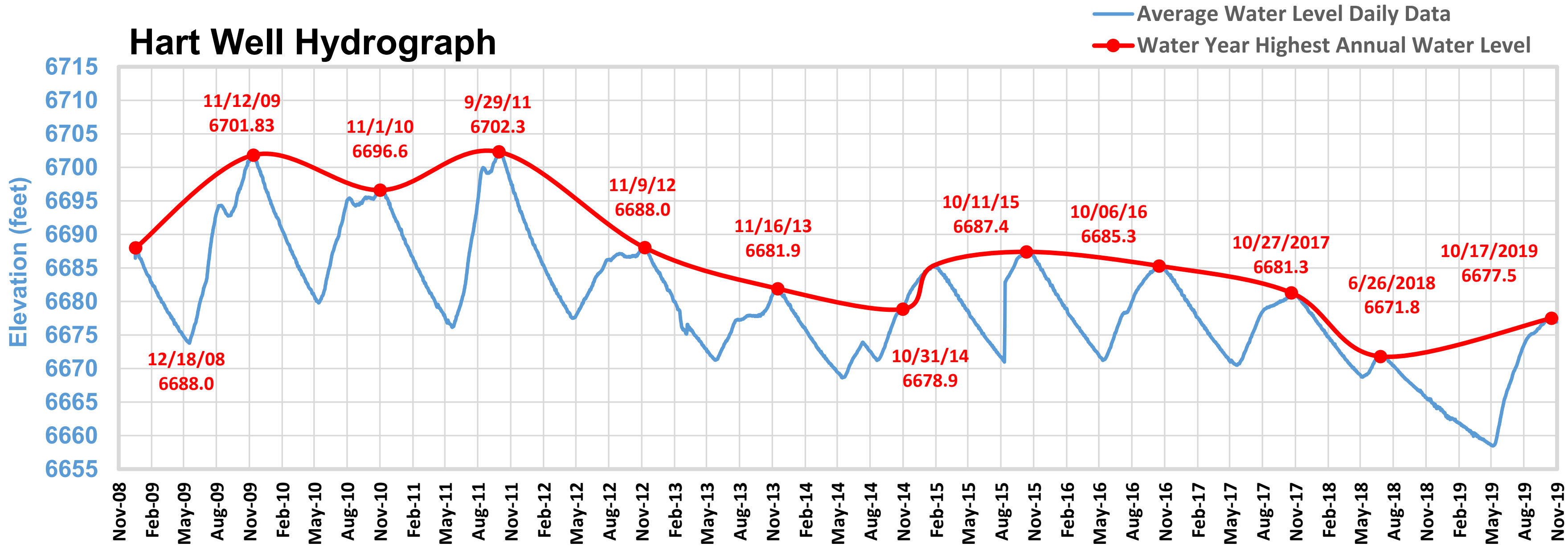
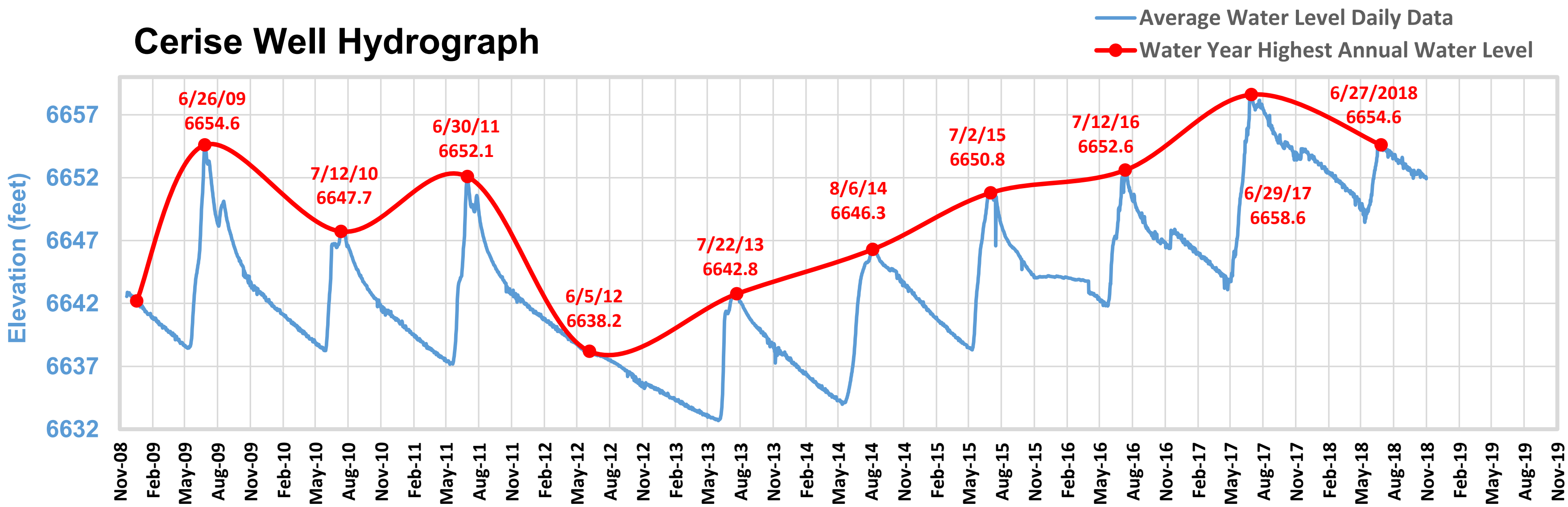
Figure 9: West Watershed



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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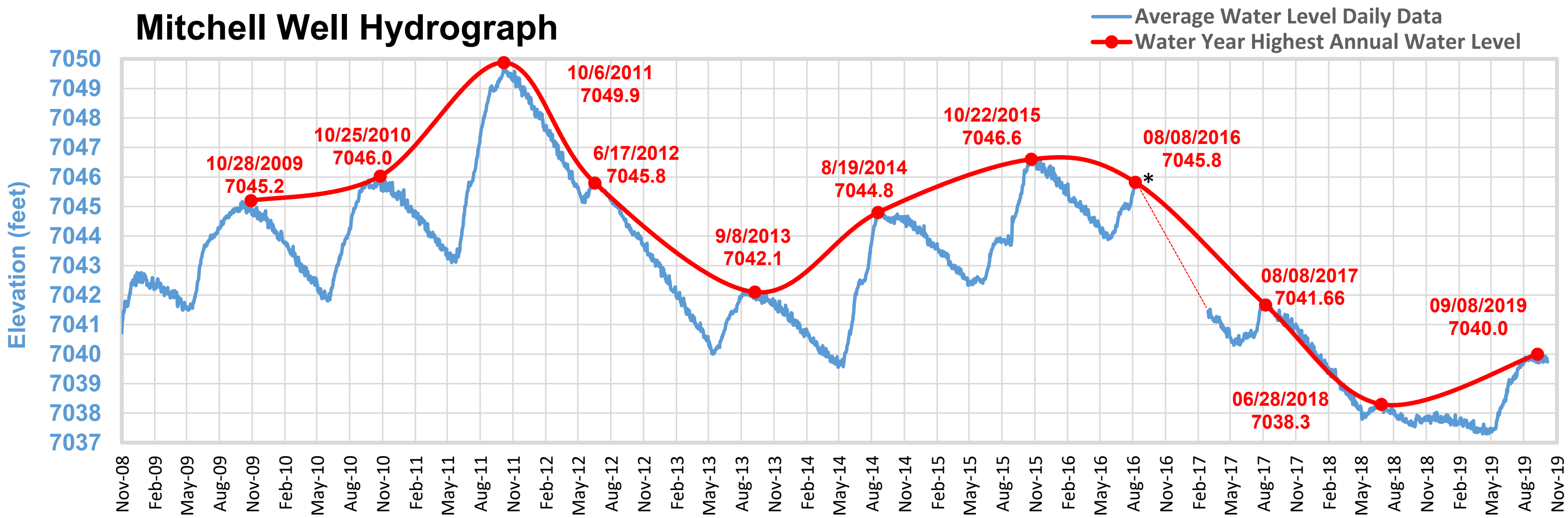
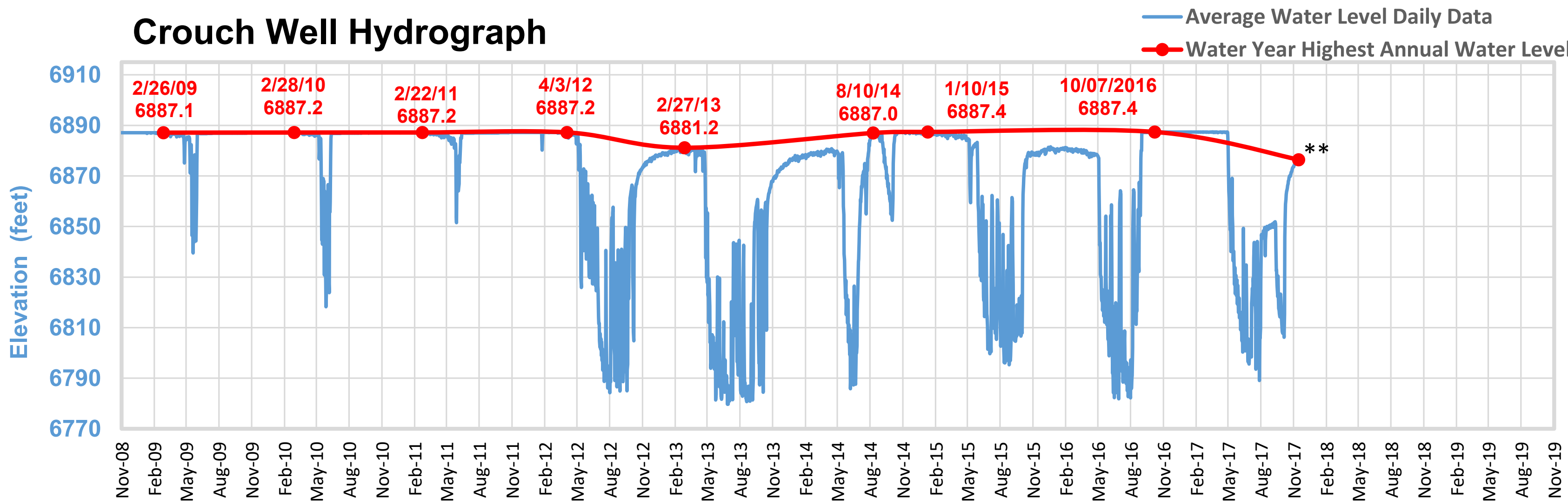
Figure 10: Central Watershed



Note: Highest Annual Water Levels in 2012 and 2013 were manually adjusted. Data not available for May-Oct 2016.



* Data not available. Pressure Transducer failed on 2016-08-09. Replaced on 2017-02-28.

** Data not available. Crouch Pressure Transduce failure 2017-11-15. Transducer was not replaced.

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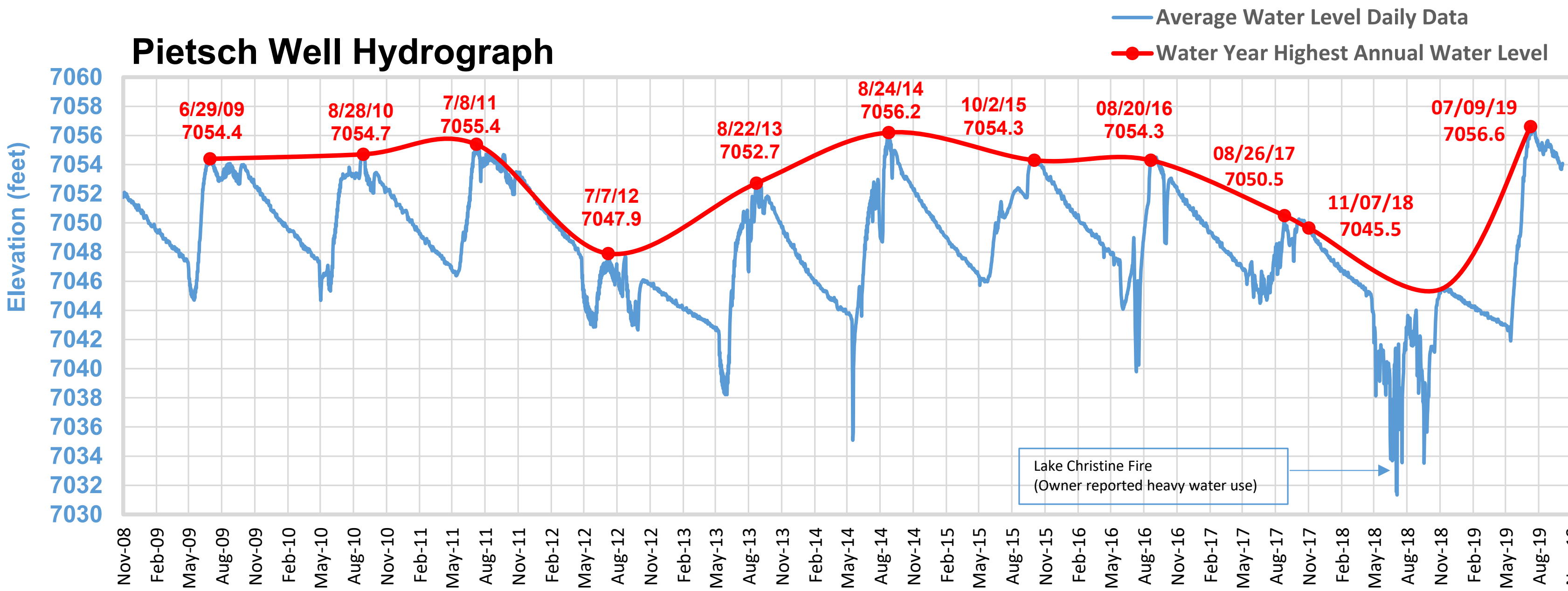
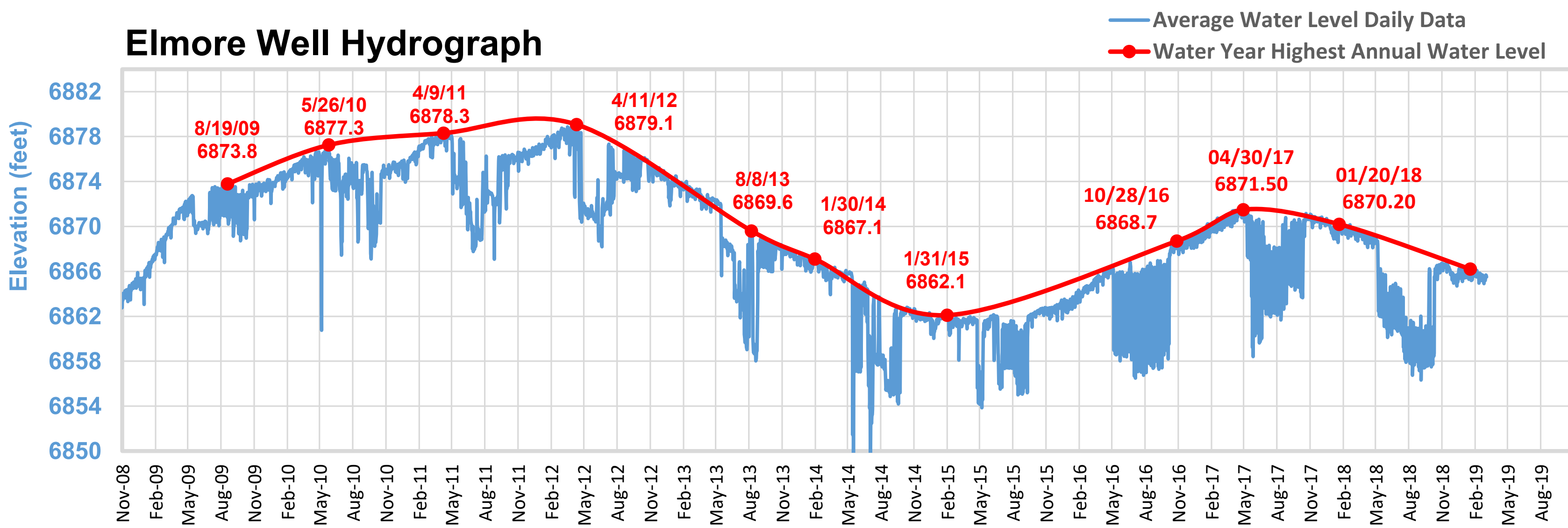
Figure 11: East Watershed



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



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

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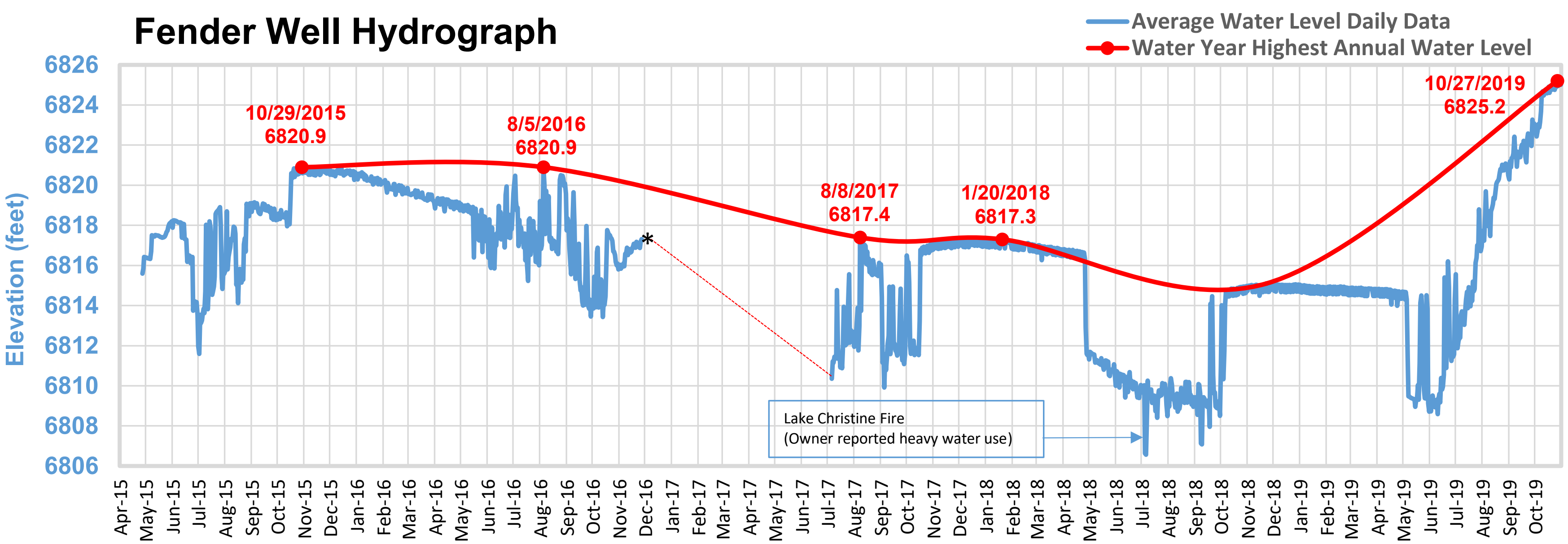
Figure 12: Spring Park Reservoir Watershed



* Data not available. Pressure Transducer failed on 2016-10-28. Replaced on 2017-07-05

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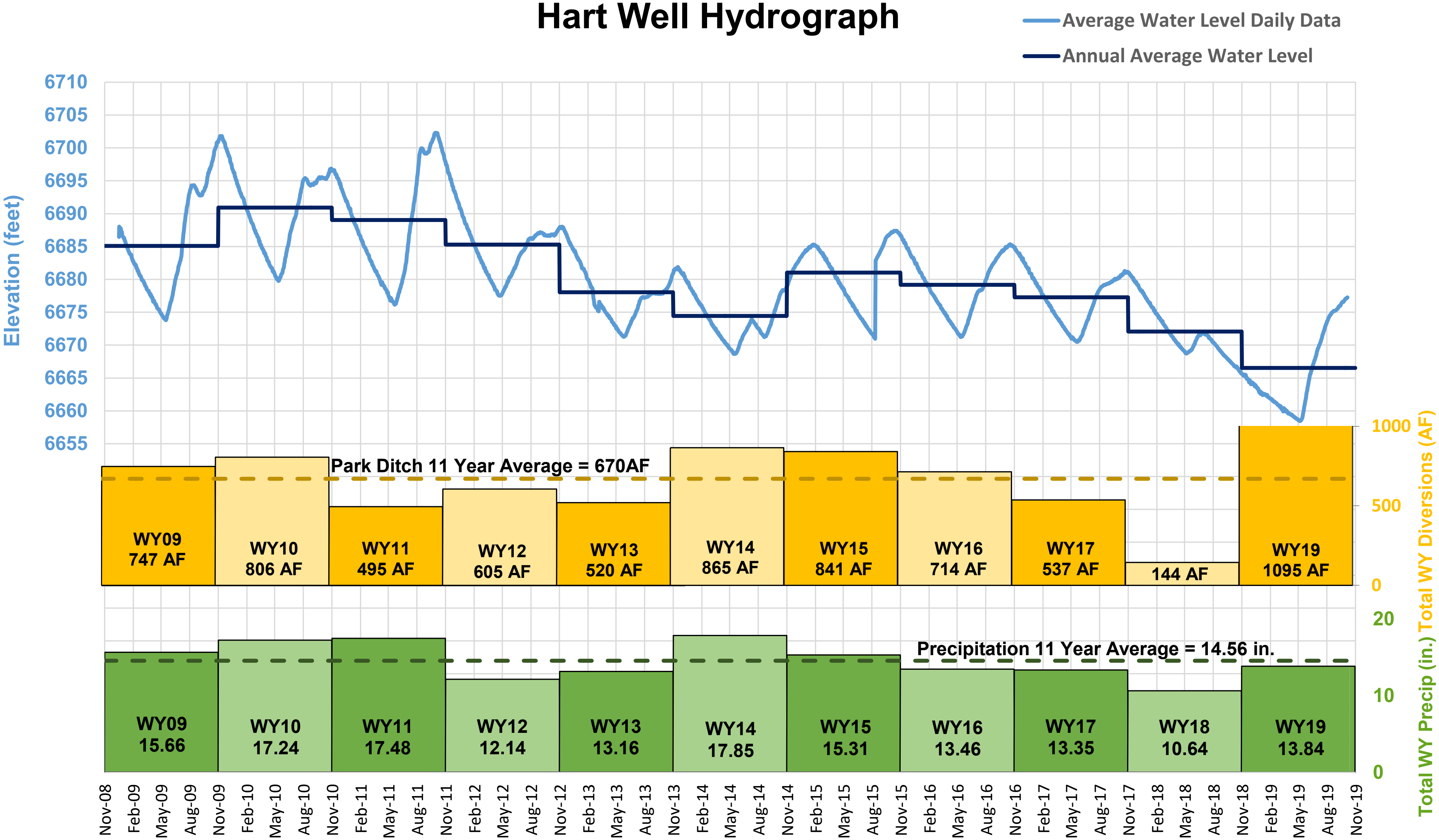
Figure 13

Hart Well Hydrograph



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

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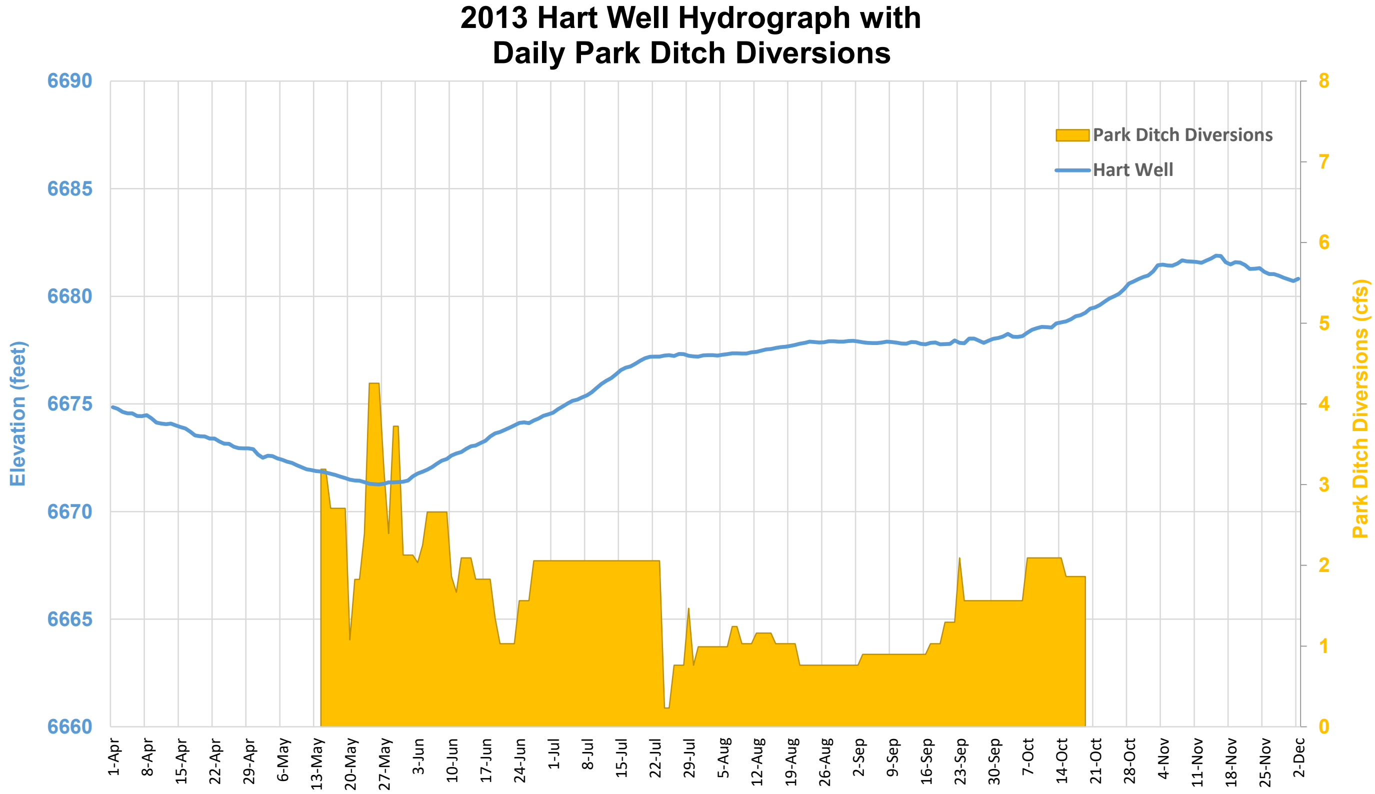
Figure 14



2013 Hart Well Hydrograph with
Daily Park Ditch Diversions
Park Ditch Diversions
Hart Well
Elevation (feet)
Park Ditch Diversions (cfs)
6690
6685
6680
6675
6670
6665
6660
8
7
6
5
4
3
2
1
0
1-Apr
8-Apr
15-Apr
22-Apr
29-Apr
6-May
13-May
20-May
27-May
3-Jun
10-Jun
17-Jun
24-Jun
1-Jul
8-Jul
15-Jul
22-Jul
29-Jul
5-Aug
12-Aug
19-Aug
26-Aug
2-Sep
9-Sep
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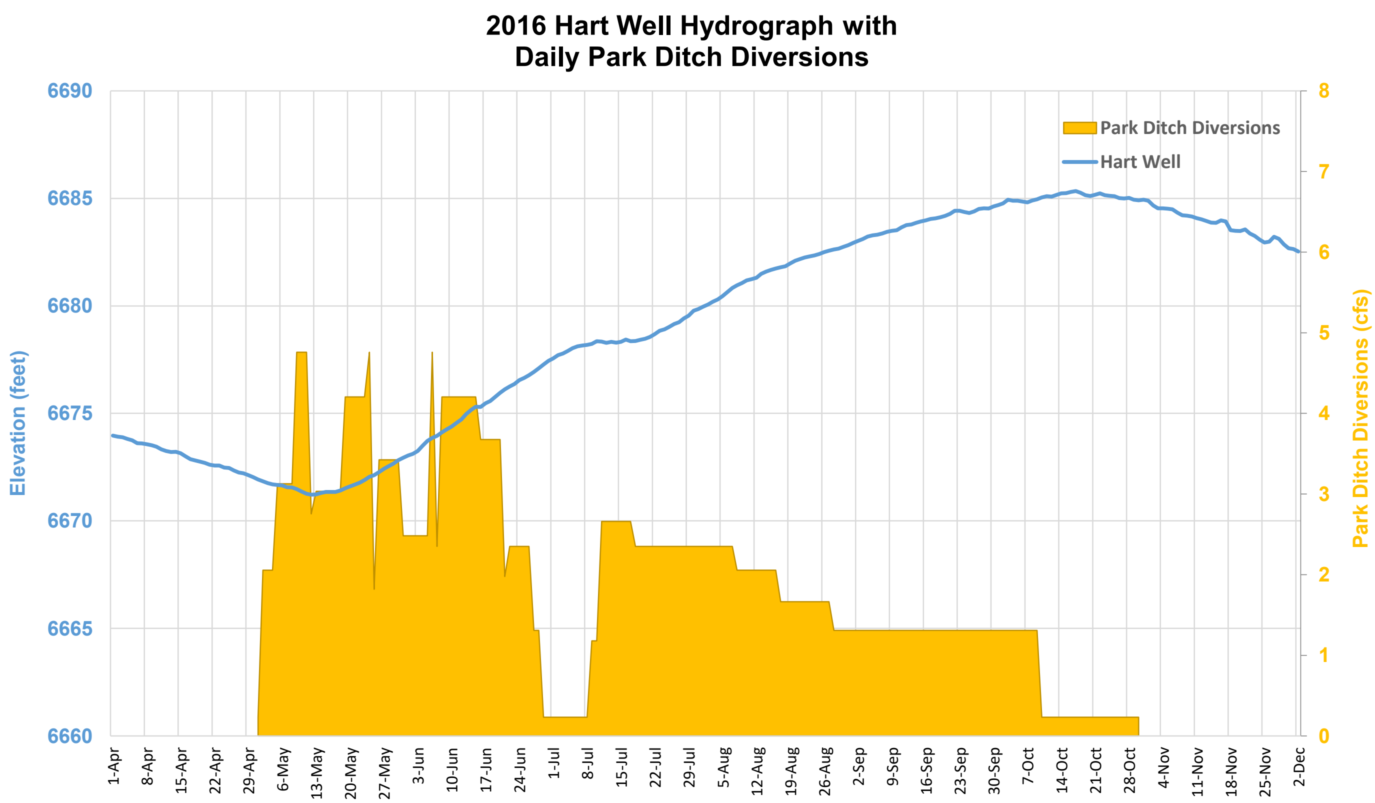
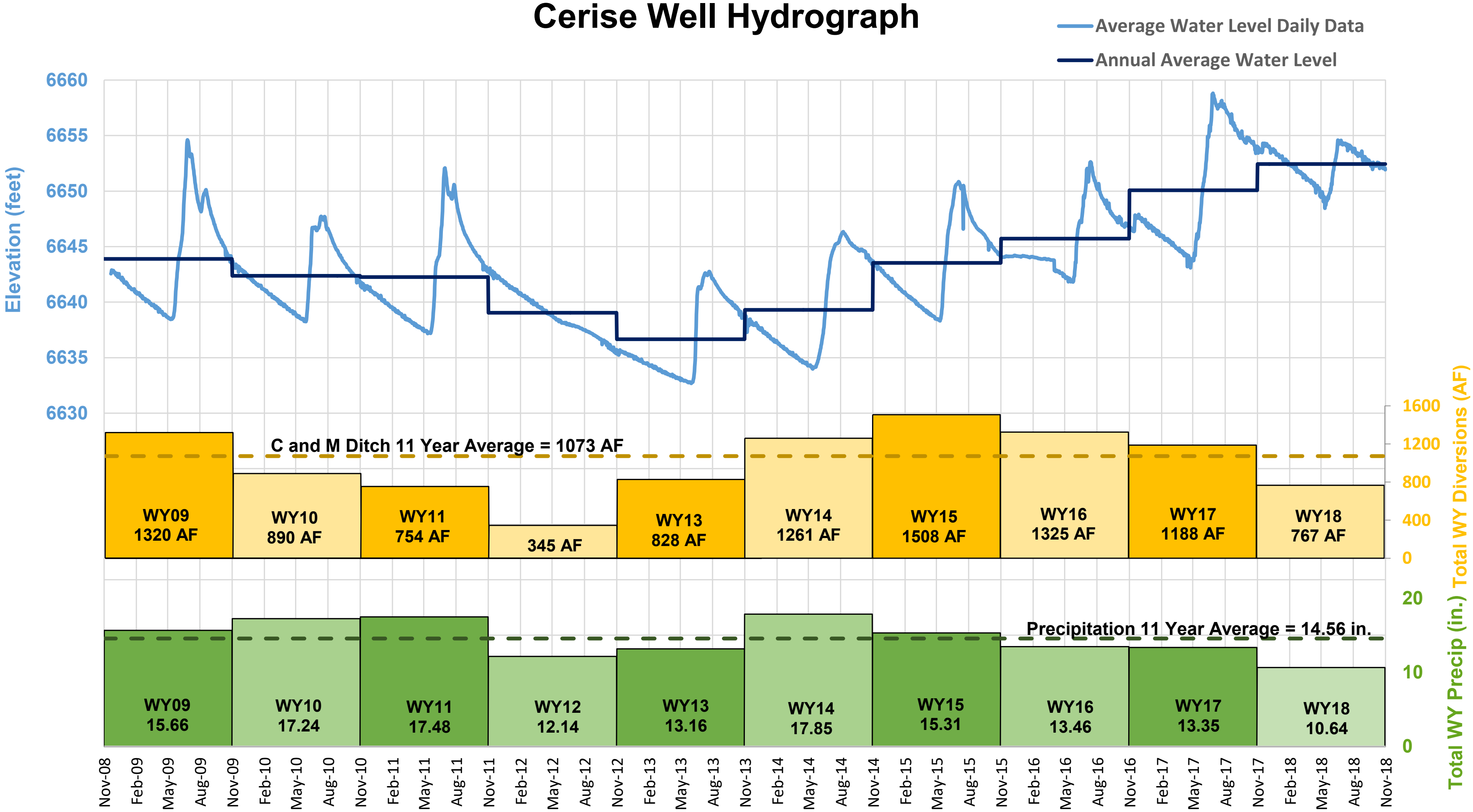
11-Nov
18-Nov
25-Nov
2-Dec



2016 Hart Well Hydrograph with
Daily Park Ditch Diversions
Park Ditch Diversions
Hart Well
Elevation (feet)
Park Ditch Diversions (cfs)
6690
6685
6680
6675
6670
6665
6660
8
7
6
5
4
3
2
1
0
1-Apr
8-Apr
15-Apr
22-Apr
29-Apr
6-May
13-May
20-May
27-May
3-Jun
10-Jun
17-Jun
24-Jun
1-Jul
8-Jul
15-Jul
22-Jul
29-Jul
5-Aug
12-Aug
19-Aug
26-Aug
2-Sep
9-Sep
16-Sep
23-Sep
30-Sep
7-Oct
14-Oct
21-Oct
28-Oct
4-Nov
11-Nov
18-Nov
25-Nov
2-Dec

Figure 15
Cerise Well Hydrograph



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

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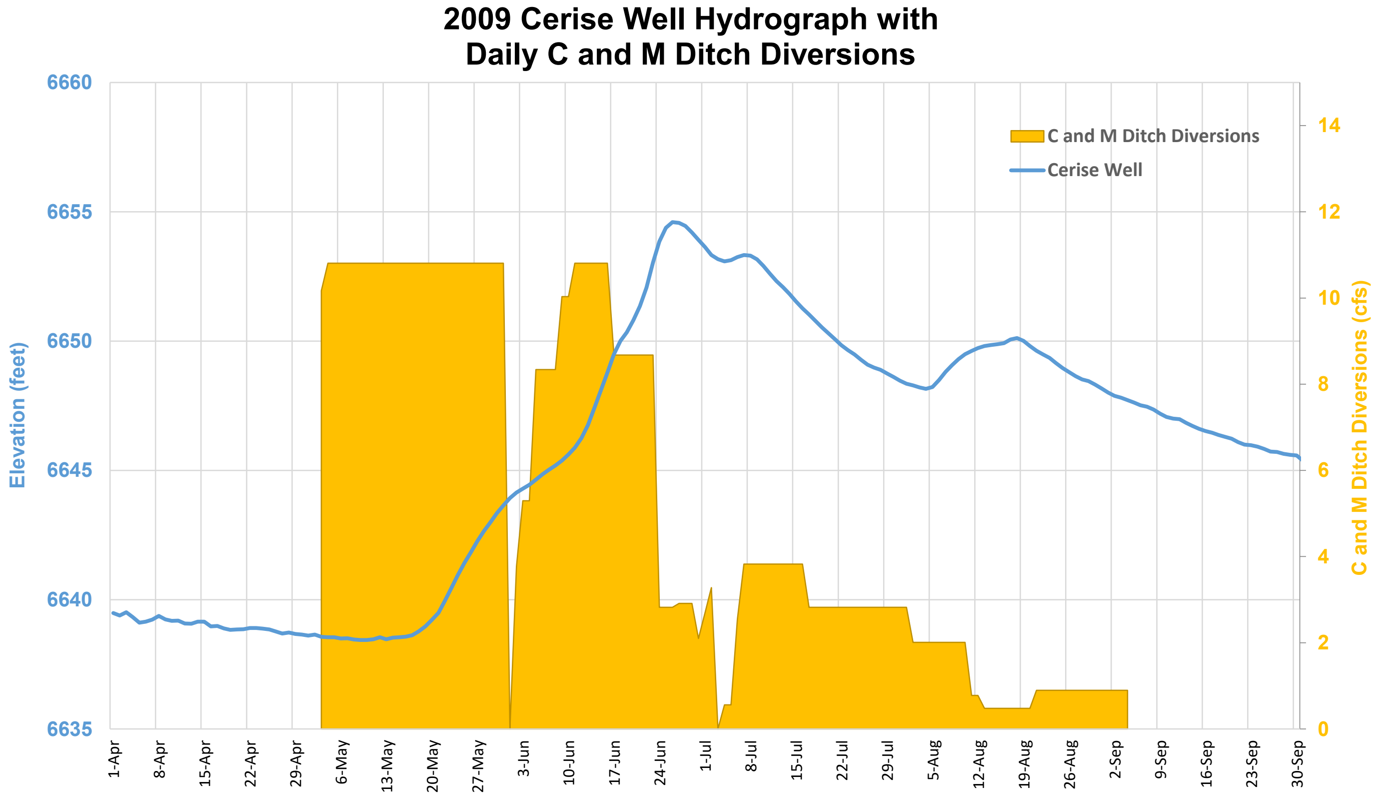
Figure 16



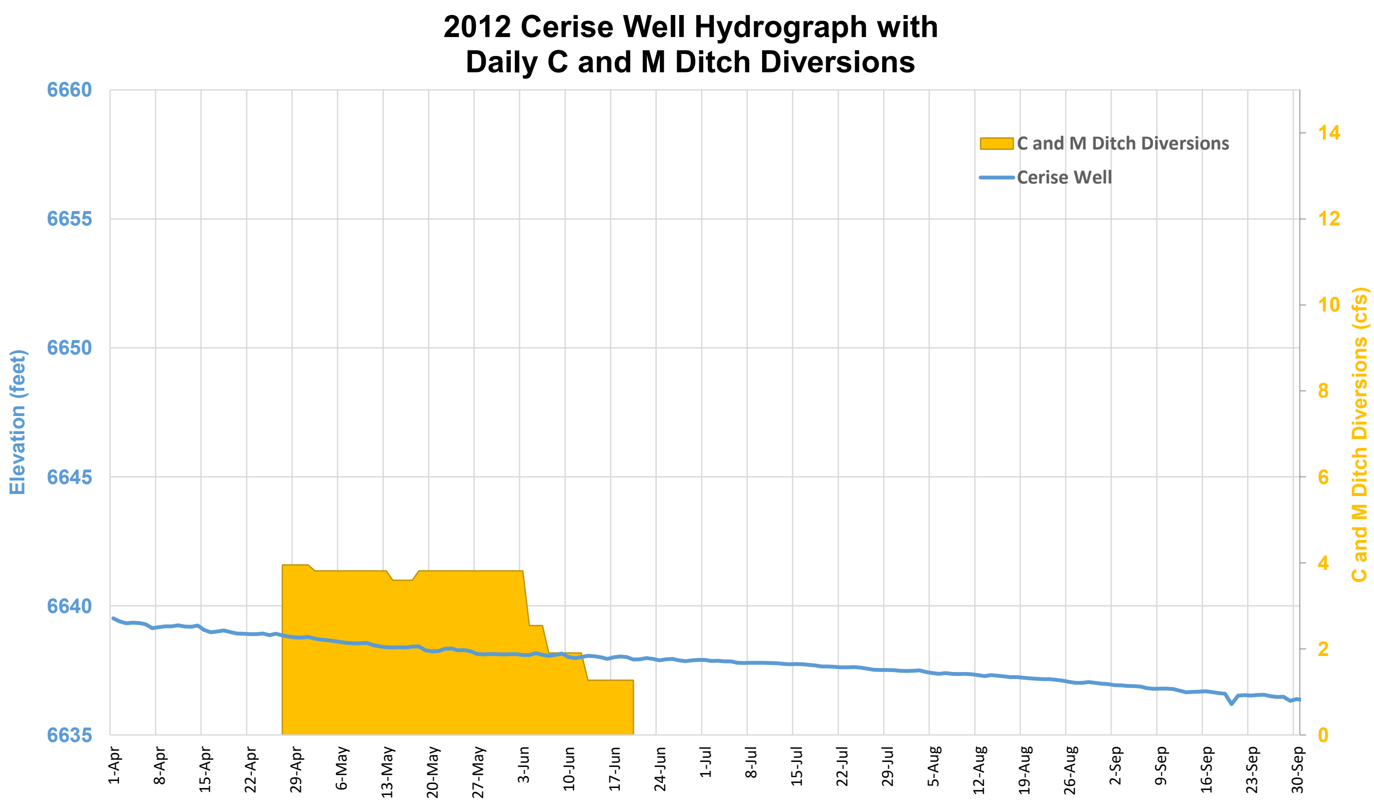


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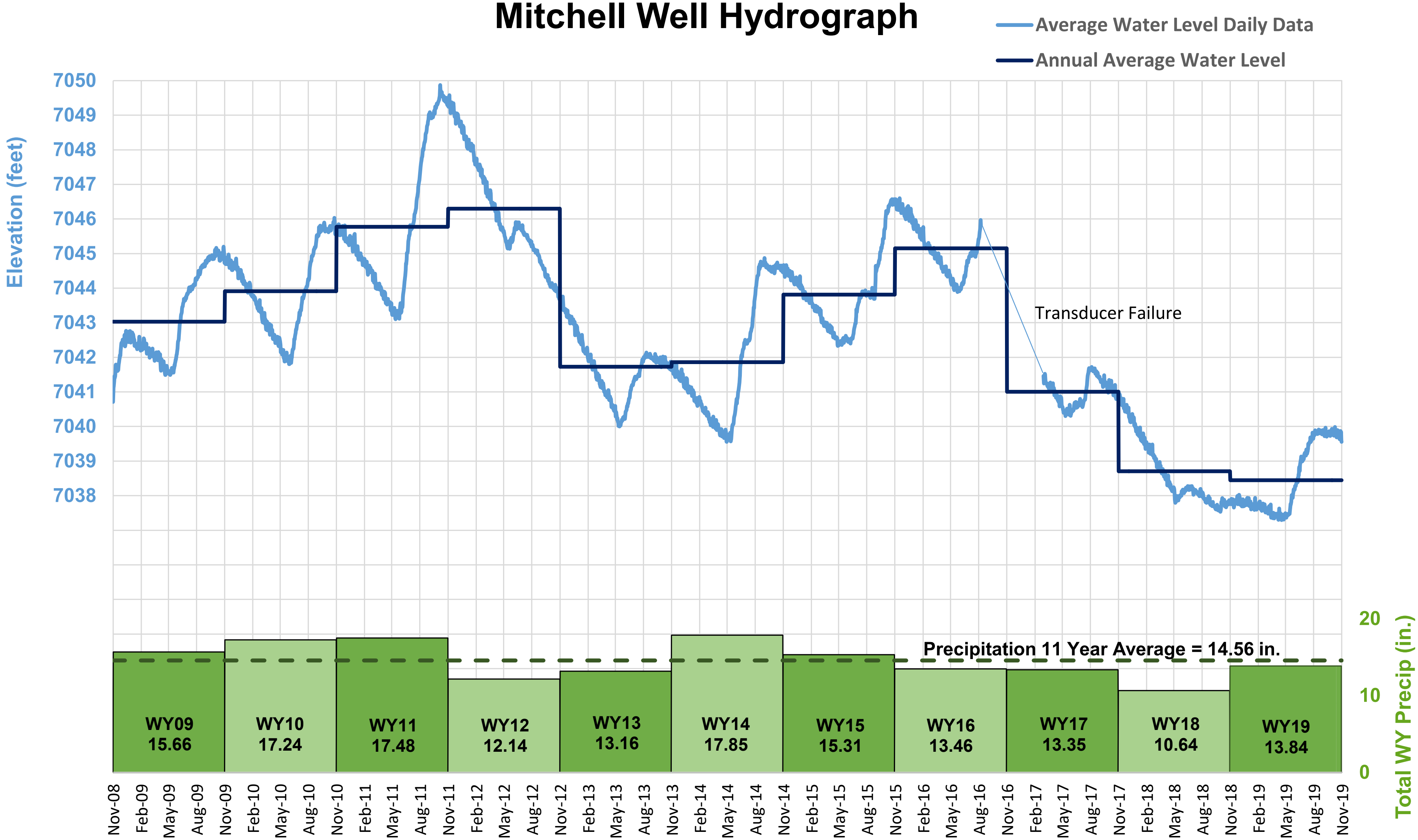
Figure 17

Mitchell Well Hydrograph



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

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Figure 18

Crouch Well Hydrograph

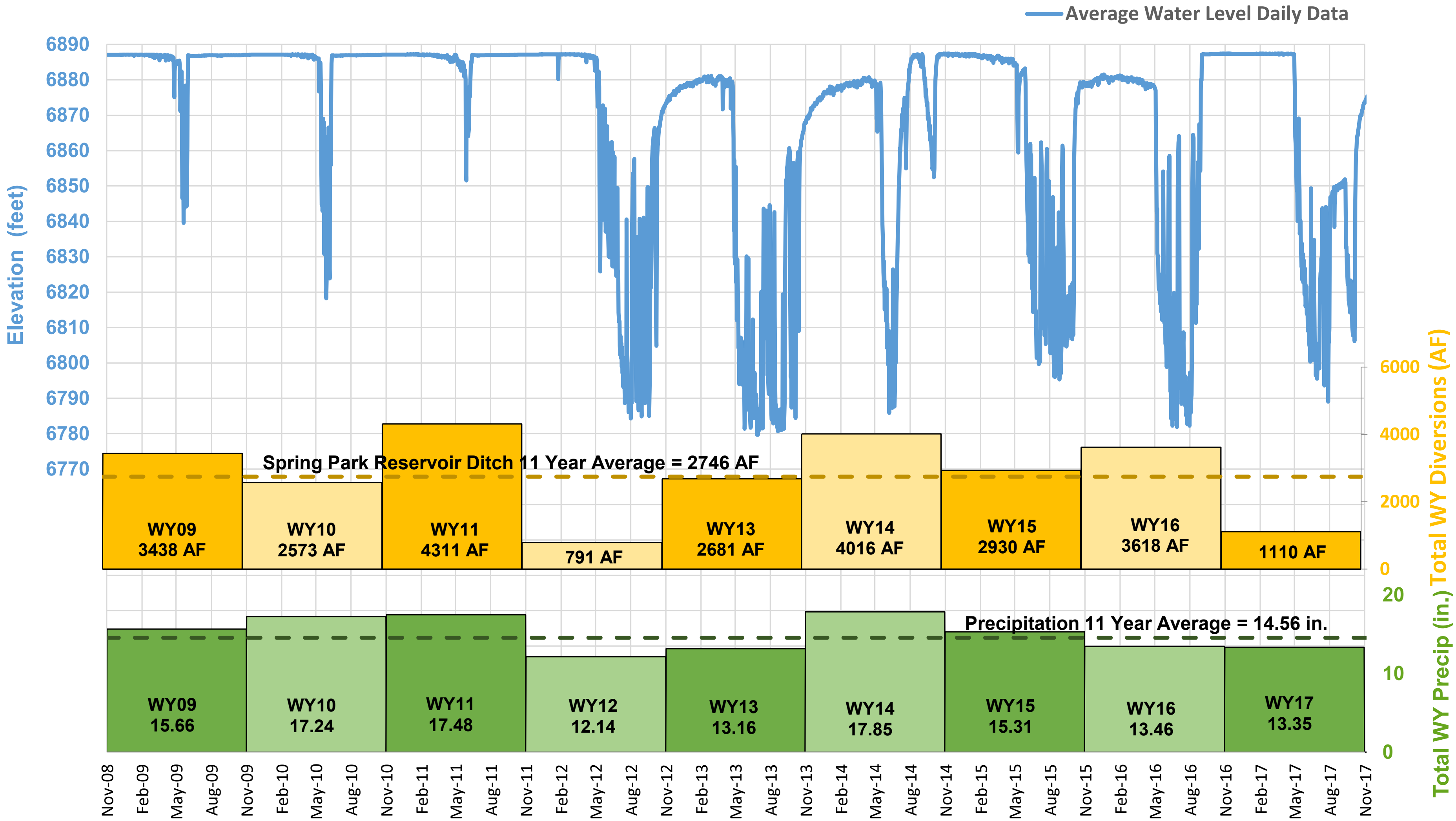

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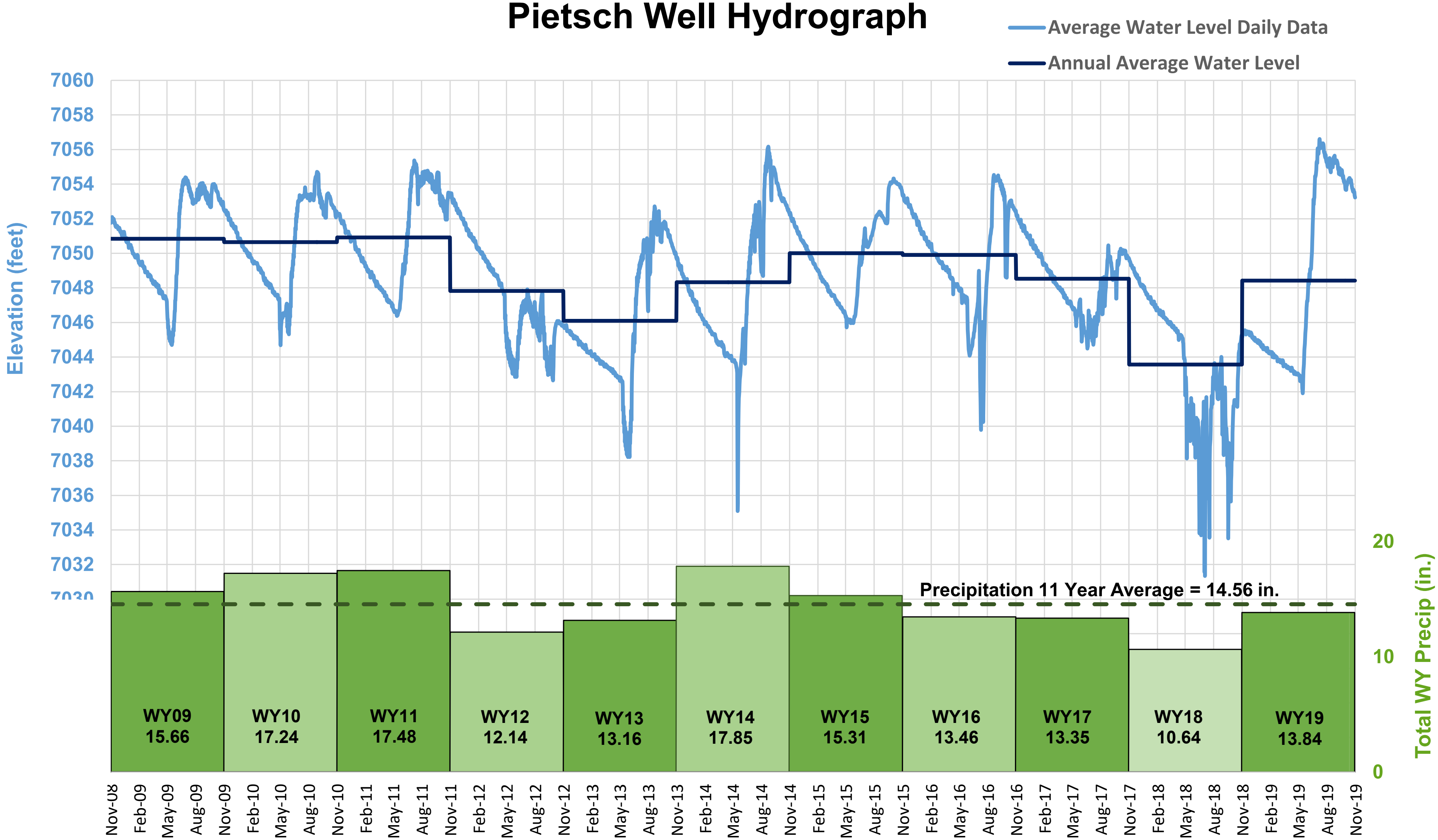
Figure 19

Pietsch Well Hydrograph



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

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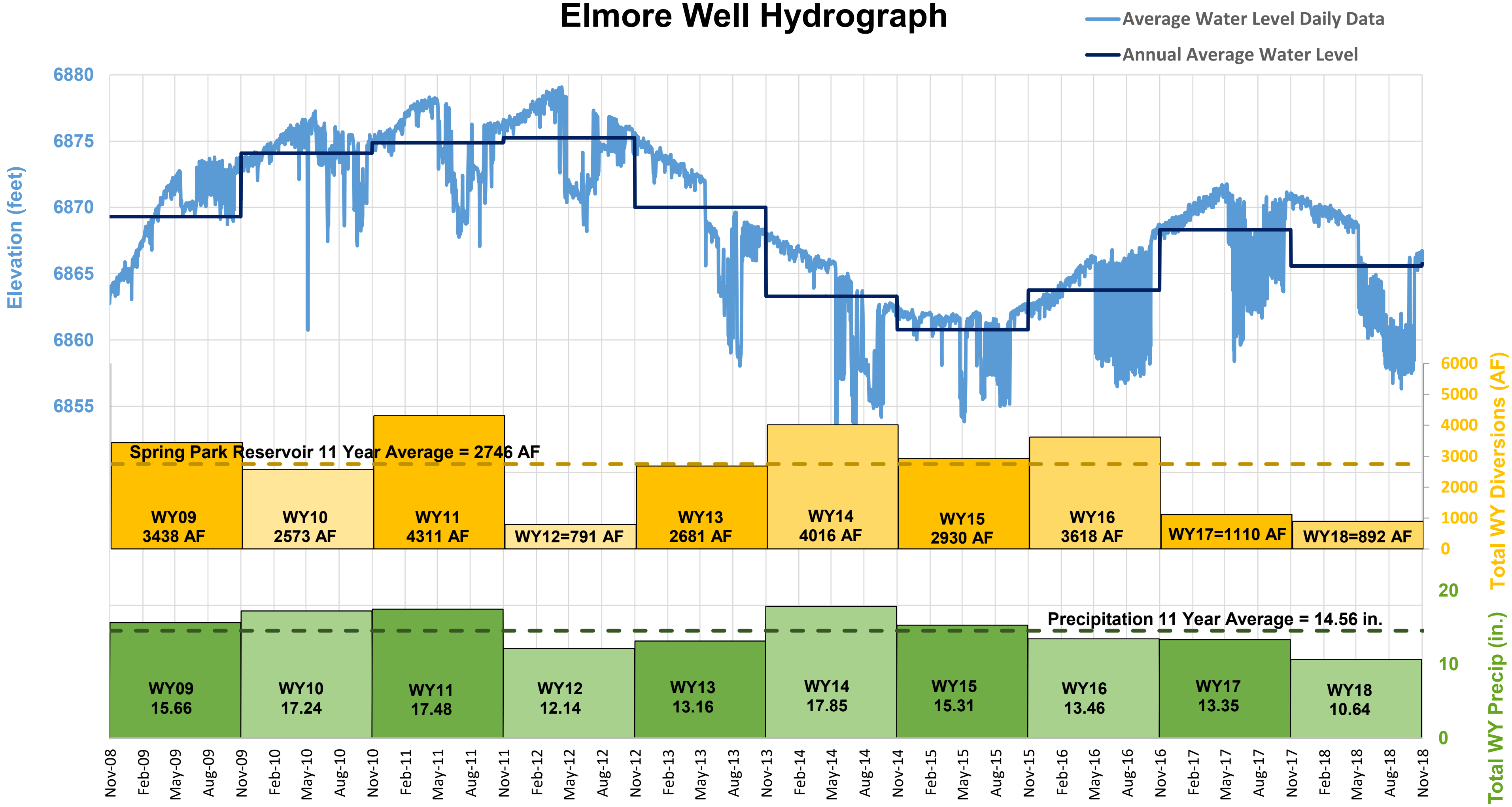
Figure 20
Elmore Well Hydrograph



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

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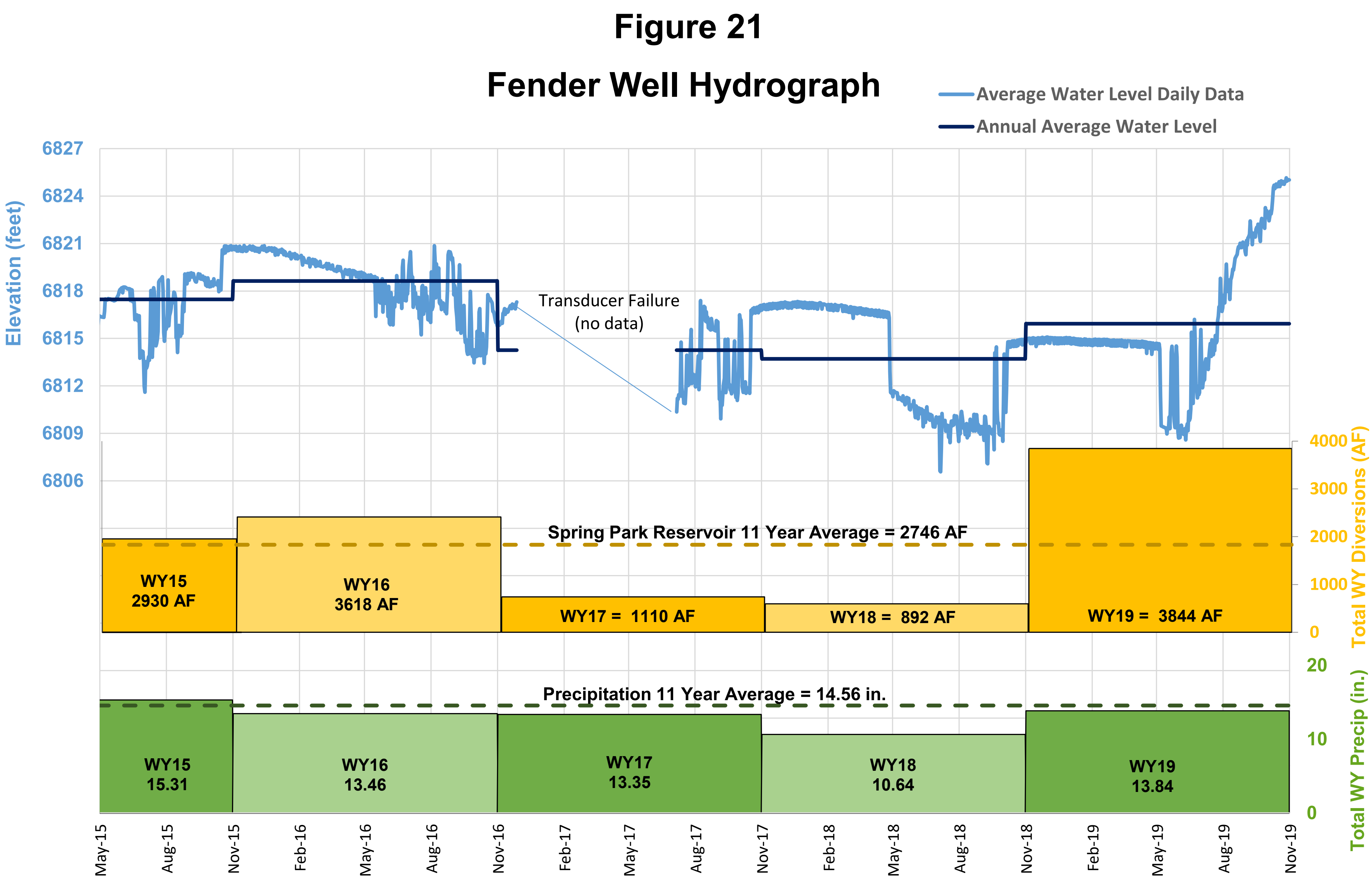

Note: Data was divided into water years (WY).

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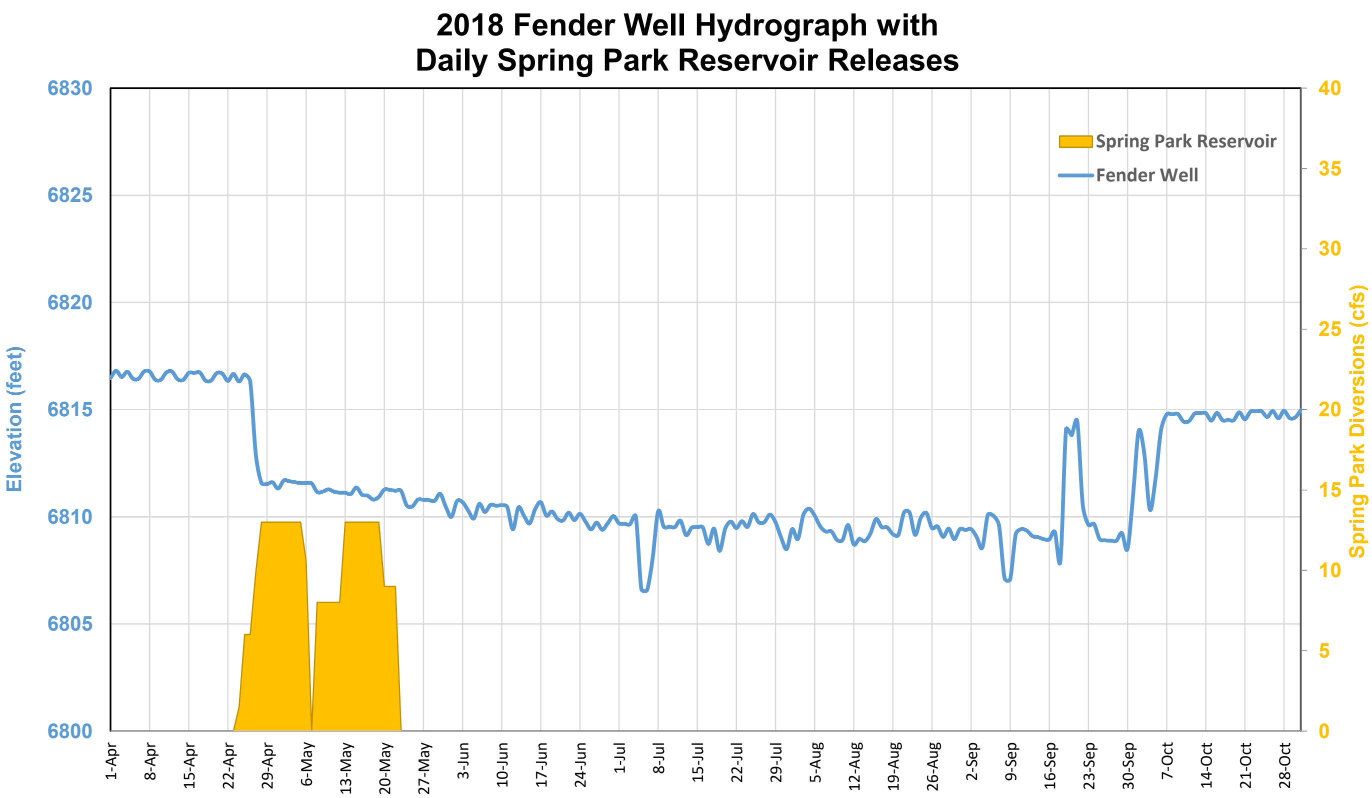
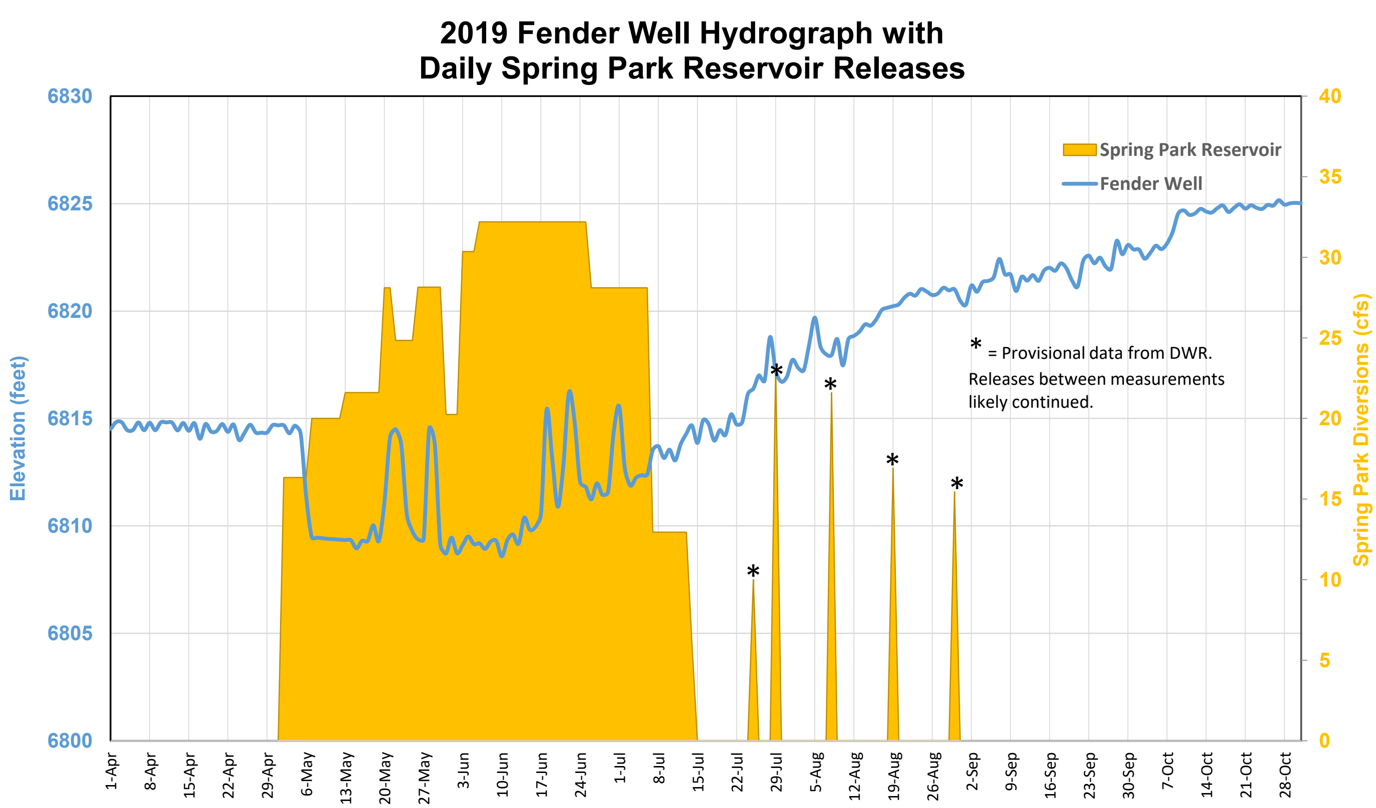
Figure 22


2018 Fender Well Hydrograph with
Daily Spring Park Reservoir Releases
Spring Park Reservoir
Fender Well
Elevation (feet)
Spring Park Diversions (cfs)
6830
6825
6820
6815
6810
6805
6800
40
35
30
25
20
15
10
5
0
1-Apr
8-Apr
15-Apr
22-Apr
29-Apr
6-May
13-May
20-May
27-May
3-Jun
10-Jun
17-Jun
24-Jun
1-Jul
8-Jul
15-Jul
22-Jul
29-Jul
5-Aug
12-Aug
19-Aug
26-Aug
2-Sep
9-Sep
16-Sep
23-Sep
30-Sep
7-Oct
14-Oct
21-Oct
28-Oct


2019 Fender Well Hydrograph with
Daily Spring Park Reservoir Releases
Spring Park Reservoir
Fender Well
* = Provisional data from DWR.
Releases between measurements
likely continued.
Elevation (feet)
Spring Park Diversions (cfs)
6830
6825
6820
6815
6810
6805
6800
40
35
30
25
20
15
10
5
0
1-Apr
8-Apr
15-Apr
22-Apr
29-Apr
6-May
13-May
20-May
27-May
3-Jun
10-Jun
17-Jun
24-Jun
1-Jul
8-Jul
15-Jul
22-Jul
29-Jul
5-Aug
12-Aug
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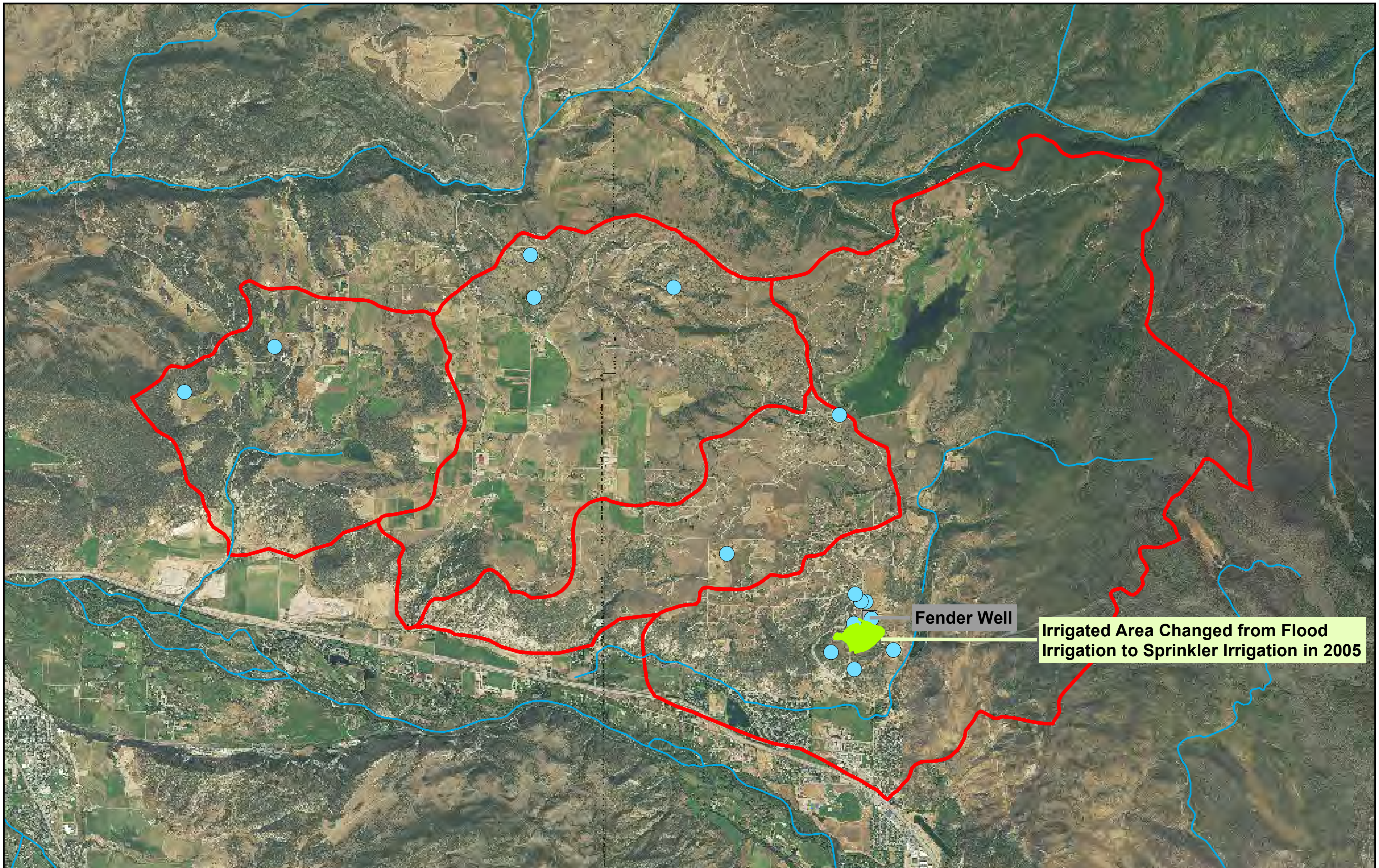
2-Sep
9-Sep
16-Sep
23-Sep
30-Sep
7-Oct
14-Oct
21-Oct
28-Oct



Source: 2019 NAIP Aerial Photography

Figure 23: Missouri Heights Replacement Wells

0 0.5 1 2 Miles

1 in = 1 mile

Wells Replaced During Study Period (2009-2019)

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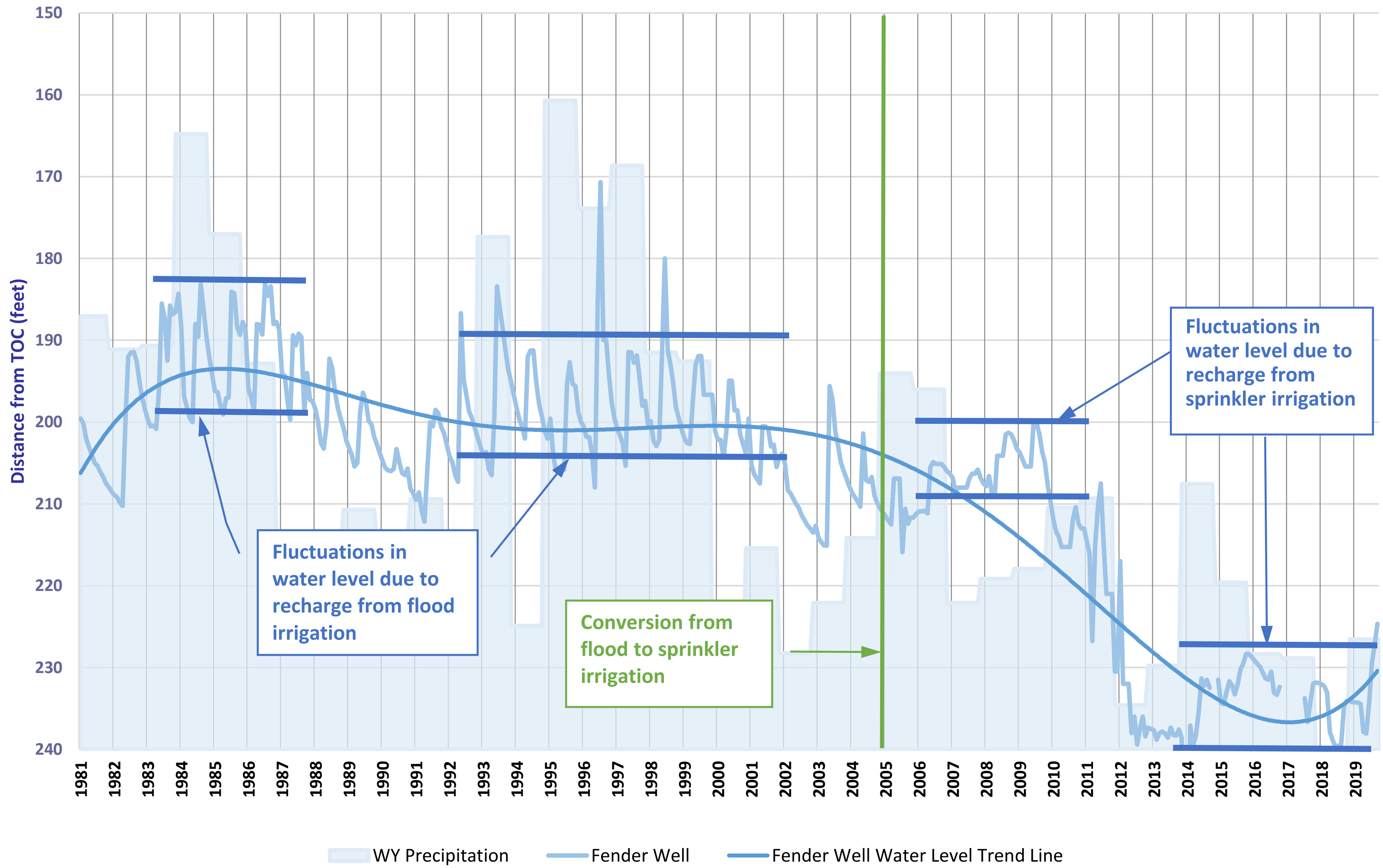
Date: 5/04/2020
File: 033-8.1.6
Drawn: RKM/RP
Approved: EFM

Figure 24

Fender Well Phase I and Phase II Hydrograph



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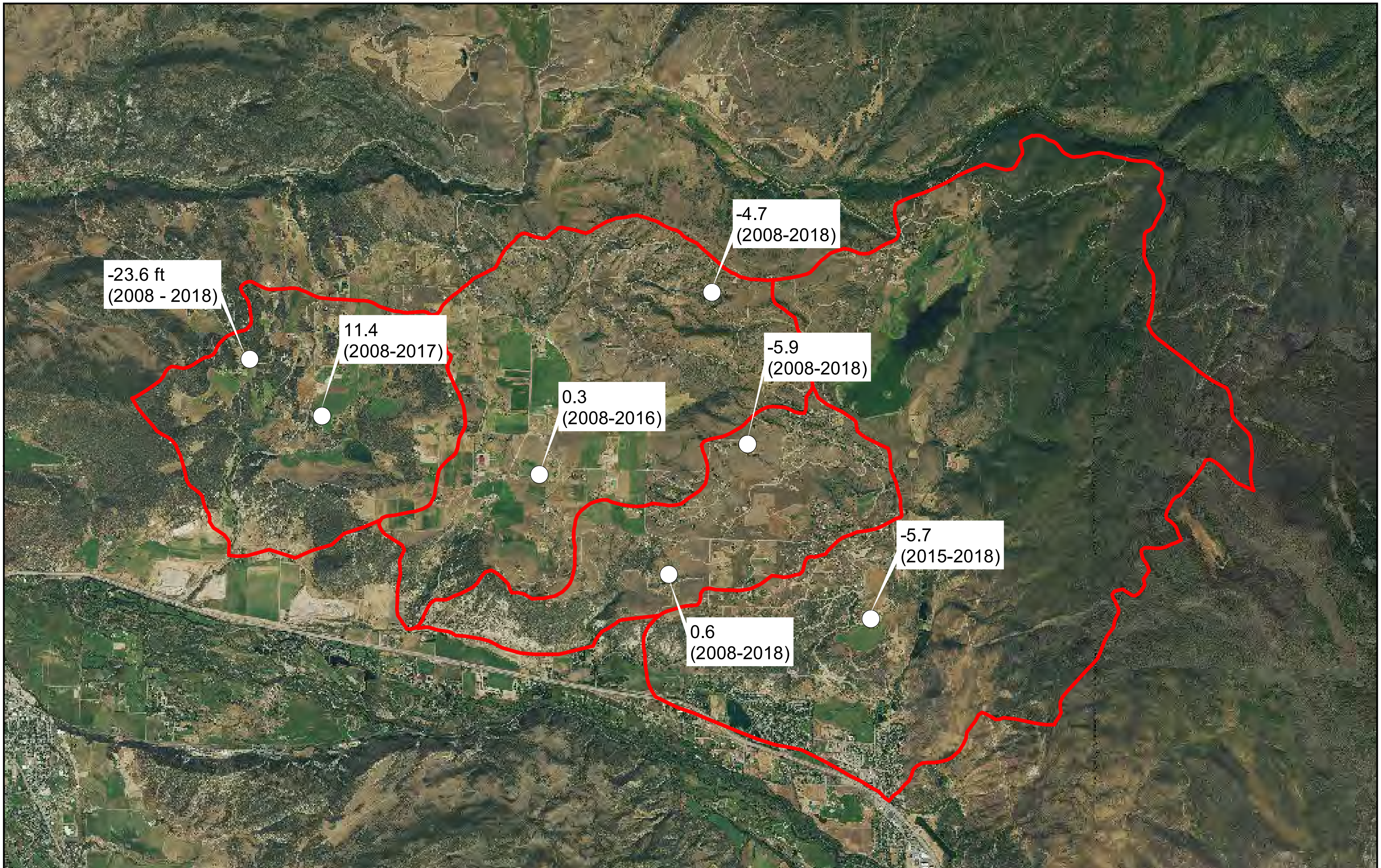

Source: 2019 NAIP Aerial Photography

Figure 25: December Water Level Changes

0 0.5 1 2 Miles

1 in = 1 mile

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Date: 5/04/2020
File: 033-8.1.6
Drawn: RKM/RP
Approved: EFM

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
Crouch Well	1967	270	ND	ND	210
Pietsch Well	1994	300	280	240	227.6
Elmore Well	1995	220	210	125	145
Fender Well	2012	365	ND	ND	245

ND = No Data

Table 2

Annual Highest Groundwater Level Summary

(All elevation values are in feet)

Year	West Watershed			
	Hart		Cerise	
2009	12-Nov	6701.8	26-Jun	6654.6
2010	1-Nov	6696.6	12-Jul	6647.7
2011	29-Sep	6702.3	30-Jun	6652.1
2012	9-Nov	6688.0	5-Jun	6638.2
2013	16-Nov	6681.9	22-Jul	6642.8
2014	31-Oct	6678.9	6-Aug	6646.3
2015	11-Oct	6687.4	2-Jul	6650.8
2016	6-Oct	6685.3	12-Jul	6652.6
2017	27-Oct	6681.3	29-Jun	6658.6
2018	26-Jun	6671.8	27-Jun	6654.6
2019	17-Oct	6677.5	---	---

Year	Central Watershed			
	Mitchell		Crouch	
2009	28-Oct	7045.2	26-Feb	6887.1
2010	25-Oct	7046.0	28-Feb	6887.2
2011	6-Oct	7049.9	22-Feb	6887.2
2012	17-Jun	7045.8	3-Apr	6887.2
2013	8-Sep	7042.1	27-Feb	6881.2
2014	19-Aug	7044.8	10-Aug	6887.0
2015	22-Oct	7046.6	10-Jan	6887.4
2016	8-Aug	7045.8	7-Oct	6887.4
2017	8-Aug	7041.7	---	---
2018	28-Jun	7038.3	---	---
2019	8-Sep	7040.0	---	---

Year	East Watershed			
	Pietsch		Elmore	
2009	29-Jun	7054.4	19-Aug	6873.8
2010	28-Aug	7054.7	26-May	6877.3
2011	8-Jul	7055.4	9-Apr	6878.3
2012	7-Jul	7047.9	11-Apr	6879.1
2013	22-Aug	7052.7	8-Aug	6869.6
2014	24-Aug	7056.2	30-Jan	6867.1
2015	2-Oct	7054.3	31-Jan	6862.1
2016	20-Aug	7054.3	28-Oct	6868.7
2017	26-Aug	7050.5	30-Apr	6871.5
2018	7-Nov	7045.5	20-Jan	6870.2
2019	9-Jul	7056.6	---	---

Year	Spring Park Watershed	
	Fender	
2015	29-Oct	6820.9
2016	5-Aug	6820.9
2017	8-Aug	6817.4
2018	20-Jan	6817.3
2019	27-Oct	6852.2

Table 3

Phase II Well Site Elevation Summary

(All elevation values are in feet)

Well Name	Surface Elevation (TOC)	Dec-2015 Groundwater Elevation	Top of Screen	Bottom of Well
Hart Well	6750	6682.7	unknown	6560
Cerise Well	6760	6644.1	6630	6590
Mitchell Well	7540	7046.1	6977	6877
Crouch Well	6960	6880.4	6750	6690
Pietsch Well	7280	7051.9	7030	6980
Elmore Well	7000	6862.9	6810	6780
Fender Well	7049	6820.6	6809	6684

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

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Table 4

Water Level Change from 2008 through 2018

Well Name	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018
Hart Well	0.0	9.8	4.9	3.8	-2.8	-7.6	-3.8	-4.5	-5.8	-9.2	-23.6
Cerise Well	0.0	0.1	-1.5	-0.4	-7.1	-4.6	0.0	1.9	5.0	11.4	---
Mitchell Well	0.0	2.0	2.8	6.1	0.4	-1.3	1.7	3.6	---	-2.3	-4.7
Crouch Well	0.0	0.0	0.1	0.1	-8.9	-11.5	0.0	-6.7	0.3	---	---
Pietsch Well	0.0	0.1	0.0	0.9	-5.9	-3.2	-0.3	1.0	-0.1	-2.9	-5.9
Elmore Well	0.0	8.7	10.3	11.8	9.1	2.3	-3.4	-2.0	3.9	5.1	0.6
Fender Well	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.0	---	-3.4	-5.7

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

Table 5

Influx of Water to the Missouri Heights Hydrologic System

Basin Area = 15,276 acres

Year	Missouri Heights Ditch Diversions (AF) Park	C & M	Monarch	Needham	Mtn Meadow	Total AF	Precipitation (inches)	(feet)	Total AF	Total AF
1994	867	1,088	391	1,709	3,038	**7,094**	14.2	1.18	18,065	**25,159**
1995	1,207	1,587	207	2,745	7,906	**13,651**	27.7	2.31	35,321	**48,972**
1996	947	1,037	150	2,055	5,595	**9,785**	25.0	2.08	31,766	**41,552**
1997	1,669	784	278	2,350	5,005	**10,085**	26.1	2.17	33,176	**43,261**
1998	1,230	1,326	80	2,644	6,515	**11,795**	21.2	1.77	27,044	**38,839**
1999	593	1,572	200	2,855	4,096	**9,316**	21.0	1.75	26,744	**36,061**
2000	428	587	127	2,205	4,354	**7,700**	12.9	1.07	16,362	**24,062**
2001	816	739	397	1,757	4,569	**8,279**	16.2	1.35	20,619	**28,898**
2002	193	375	70	814	927	**2,379**	13.5	1.12	17,169	**19,548**
2003	444	957	292	1,994	5,178	**8,865**	14.8	1.23	18,816	**27,681**
2004	518	932	219	1,937	2,455	**6,061**	16.5	1.37	20,942	**27,003**
2005	761	1,283	172	2,241	6,752	**11,209**	20.7	1.73	26,360	**37,569**
2006	801	1,122	249	2,373	5,182	**9,727**	20.3	1.69	25,825	**35,553**
2007	327	1,131	437	2,592	4,310	**8,796**	14.8	1.23	18,814	**27,610**
2008	687	1,017	353	2,603	6,445	**11,104**	15.4	1.28	19,605	**30,710**
2009	747	1,320	274	2,827	5,314	**10,483**	15.7	1.31	19,935	**30,418**
2010	806	890	213	2,026	2,482	**6,416**	17.2	1.44	21,947	**28,362**
2011	495	754	160	1,959	3,566	**6,933**	17.5	1.46	22,252	**29,185**
2012	605	345	6	1,211	0	**2,168**	12.1	1.01	15,454	**17,622**
2013	520	828	220	1,591	585	**3,743**	13.2	1.10	16,753	**20,496**
2014	865	1,261	327	2,515	1,917	**6,884**	17.9	1.49	22,723	**29,607**
2015	841	1,508	279	2,354	1,293	**6,275**	15.3	1.28	19,490	**25,765**
2016	714	1,325	224	2,075	823	**5,162**	13.5	1.12	17,135	**22,296**
2017	537	1,188	289	1,895	463	**4,373**	13.4	1.11	16,995	**21,367**
2018	144	767	190	1,131	584	**2,815**	10.6	0.89	13,545	**16,360**
2019	1,095	1,617	375	3,006	7,239	**13,333**	13.8	1.15	17,618	**30,951**
1994-2008 Average	**766**	**1,036**	**241**	**2,192**	**4,822**	**9,056**	**18.68**	**1.56**	**23,775**	**32,832**
2009-2019 Average	**670**	**1,073**	**232**	**2,054**	**2,206**	**6,235**	**14.56**	**1.21**	**18,531**	**24,766**

	Diversion (AF)	Percent	Precipitation (AF)	Percent	Total (AF)
1994-2008 Average	**9,056**	**28%**	**23,775**	**72%**	**32,832**
2009-2019 Average	**6,235**	**25%**	**18,531**	**75%**	**24,766**

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Table 6

Evapotranspiration for Native Vegation and Pasture Grass

Vegetation Type	Watershed Area (Acres)	ET (feet)	Amount Loss to ET (acre feet)
Barren (Rocks/Water)	693	0	0
Alpine Trees	1,270	1.7	2,159
Grasses/Shrubs	10,839	0.9	9,755
Pasture Grass	2,474	1.6	3,958
Total	**15,276**		**15,873**

Table 7

Groundwater Recharge Estimate

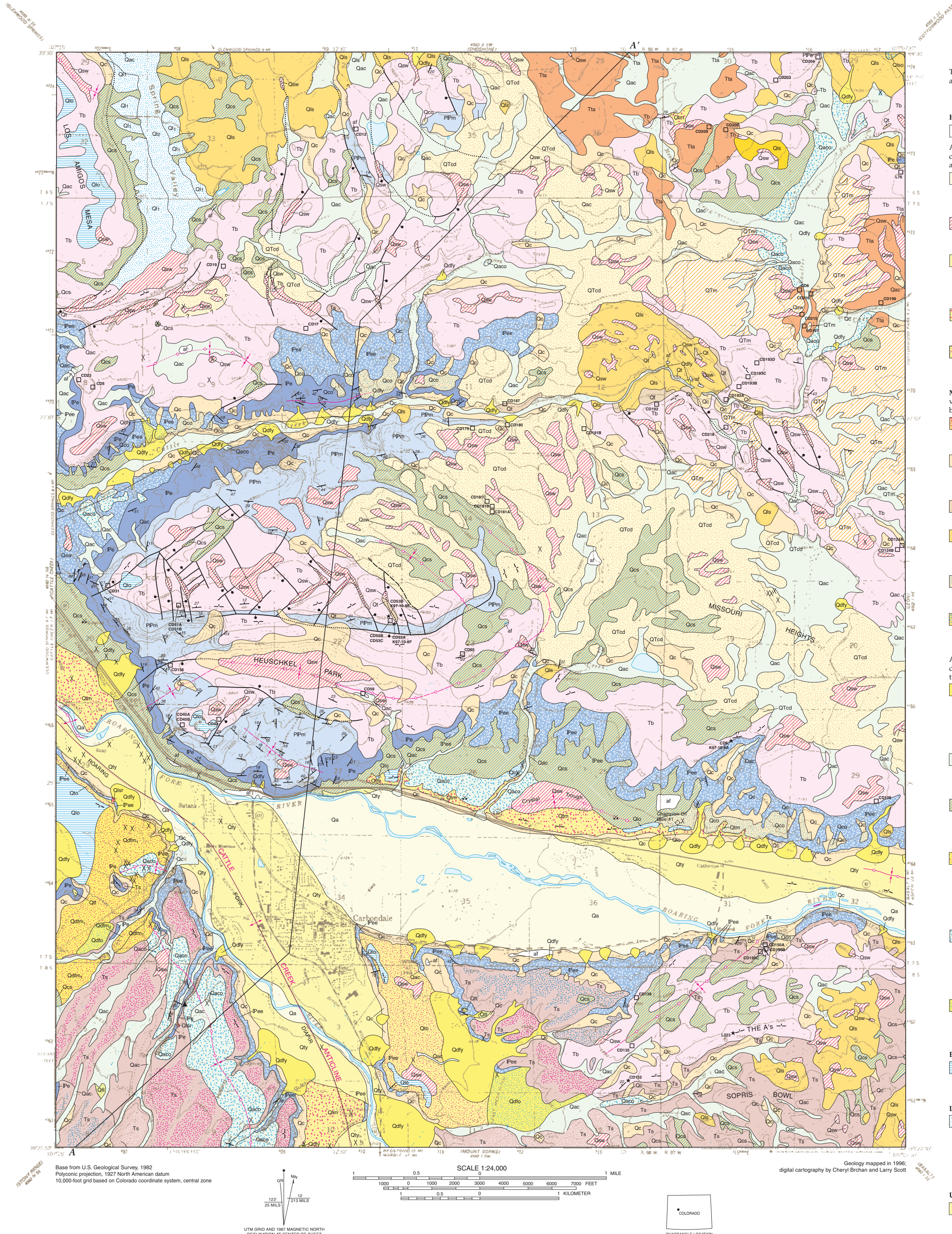
Type Year	Precipitation (AF)	Ditch Import (AF)	Evapotranspiration (AF)	Runoff (AF)	Recharge (AF)
Study Average	18,531	6,235	15,873	2,817	6,077
Wet (2009)	19,935	10,483	15,873	3,241	11,304
Wet (2011)	22,252	6,933	15,873	4,109	9,204
Dry (2012)	15,454	2,168	15,873	1,972	(223)
Dry (2018)	13,545	2,815	15,873	1,538	(1,050)

Note: Equal to Precipiation + Ditch Import Water - Evapotraspiration - Runoff

APPENDIX A: CARBONDALE AND LEON GEOLOGIC MAPS

COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
DENVER COLORADO

MAP SERIES 36
GEOLOGIC MAP OF THE CARBONDALE QUADRANGLE,
GARFIELD COUNTY, COLORADO
Booklet accompanies map



Base from U.S. Geological Survey, 1982
Polyconic projection, 1927 North American datum
10,000-foot grid based on Colorado coordinate system, central zone

SCALE 1:24,000

Geology mapped in 1996;
digital cartography by Cheryl Brchan and Larry Scott

CONDENSED DESCRIPTION OF MAP UNITS

The complete description of map units and references is in the accompanying booklet.

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af — **Artificial fill (latest Holocene)**

ALLUVIAL DEPOSITS—Sediments deposited in stream channels, flood plains, glacial outwash terraces, and sheetwash areas

Qa — **Stream-channel, flood-plain, and low-terrace deposits (Holocene and late Pleistocene)**—Mostly poorly sorted, clast-supported gravel in a sandy or silty matrix. Includes terraces up to about 12 ft above modern river level

Qsw — **Sheetwash deposits (Holocene and late Pleistocene)**—Pebbly silty sand, sandy silt, and clayey silt deposited in ephemeral and intermittent stream valleys, on gentle hillslopes, and in basinal areas

Qty — **Younger terrace alluvium (late Pleistocene)**—Mostly poorly sorted, clast-supported, locally bouldery, pebble and cobble gravel in a sand and silt matrix. Deposited as glacial outwash. Underlies terraces 14–45 ft above modern stream level. May include fine-grained overbank deposits

Qtm — **Intermediate terrace alluvium (late Pleistocene)**—Deposits texturally and depositionally similar to younger terrace alluvium (Qty). Underlies terraces 55–110 ft above modern streams

Qto — **Older terrace alluvium (late middle Pleistocene)**—Deposits texturally and depositionally similar to younger terrace alluvium (Qty). Clasts slightly to moderately weathered. Underlies terraces 160–200 ft above modern streams

MASS-WASTING DEPOSITS—Sediments on valley sides, valley floors, and hillslopes transported and deposited primarily by gravity

Qlsr — **Recent landslide deposits (latest Holocene)**—Includes active and recently active landslides with fresh morphological features. Heterogeneous unit consisting of unsorted, unstratified gravel, sand, and silt

Qc — **Colluvium (Holocene and late Pleistocene)**—Ranges from unsorted, clast-supported, pebble to boulder gravel in a sandy silt matrix to matrix-supported gravelly, clayey, sandy silt. Usually coarser grained in upper reaches of colluvial slopes and finer grained in distal areas

Qt — **Talus (Holocene and late Pleistocene)**—Angular, cobbly and bouldery rubble derived from outcrops of basalt or basalt-rich collapse debris (QTcd)

Qls — **Landslide deposits (Holocene and Pleistocene)**—Includes various types of landslide deposits. Consists of unsorted, unstratified gravel, sand, silt, clay, and rock debris. Ranges from recently active landslides to long-inactive Pleistocene landslides

Qco — **Older colluvium (Pleistocene)**—Texturally similar to colluvium (Qc), but found on drainage divides, ridge lines, and dissected hillslopes. Generally not subject to future deposition.

Qlso — **Older landslide deposits (Pleistocene)**—Landslide deposits dissected by erosion lacking distinctive landslide geomorphology. Similar in texture to landslide deposits (Qls)

ALLUVIAL AND MASS-WASTING DEPOSITS—Sediments in debris fans, stream channels, flood plains, and hillslopes along tributary valleys

Qdfy — **Younger debris-flow deposits (Holocene and late Pleistocene)**—Poorly sorted to moderately well-sorted, matrix- and clast-supported deposits ranging from gravelly clayey silt to sandy, silty, cobbly, pebbly, and bouldery gravel. Fan heads tend to be bouldery, while distal fan areas are finer grained. Includes debris-flow, hyperconcentrated-flow, fluvial, and sheetwash deposits on active fans and in some drainage channels

Qac — **Alluvium and colluvium, undivided (Holocene and late Pleistocene)**—Moderately well-sorted to well-sorted, stratified, interbedded sand, pebbly sand, and sandy gravel to poorly sorted, unstratified or poorly stratified, clayey, silty sand, bouldery sand, and sandy silt

Qcs — **Colluvium and sheetwash deposits, undivided (Holocene and late Pleistocene)**—Consists of colluvium (Qc) on steeper slopes and sheetwash deposits (Qsw) on flatter slopes. Mapped where contacts between the two types of deposits are very gradational and difficult to locate

Qdfm — **Intermediate debris-flow deposits (Holocene? and late Pleistocene)**—Similar in texture and depositional environment to younger debris-flow deposits (Qdfy), but found 20–100 ft above Edgerton Creek. Numeric subscripts on unit symbol indicate relative ages of deposits, with $Qdfm_1$ being older than $Qdfm_2$. Generally not subject to future deposition except during unusually large events or when drainage channels plug with debris and are overtopped

Qaco — **Older alluvium and colluvium, undivided (Pleistocene)**—Deposits texturally and depositionally similar to alluvium and colluvium (Qac) that underlie terraces and hillslopes above the floor of tributary valleys. Includes locally derived sediments and the Lava Creek B volcanic ash that were deposited within a large subsidence trough developed in oldest terrace alluvium (Qtt) southwest of Carbondale

Qdfo — **Older debris-flow deposits (Holocene? and Pleistocene)**—Remnants of inactive debris fans found on mesas and adjacent to stream drainages 20–160 ft above nearby streams. Similar in texture and genesis to younger debris-flow deposits (Qdfy)

EOLIAN DEPOSITS–sediments deposited by wind

Qlo — **Loess (late and middle? Pleistocene)**—Slightly clayey, sandy silt and silty, very fine to fine sand deposited by wind on level to gently sloping surfaces. Usually unstratified, friable, and plastic or slightly plastic when wet

LACUSTRINE DEPOSITS

Ql_2/Ql_1 — **Lacustrine deposits (Holocene and Pleistocene)**—Stratified deposits of medium- to dark-gray, organic-rich, silty clay and silt, yellow-brown clayey silt, and medium-red-brown, well-sorted, fine to coarse sand deposited in Spring Valley. Locally includes thick deposits of Lava Creek B ash. Numeric subscripts indicate relative ages of deposits. Ql_1 deposits are older than and lie 20–40 ft above Ql_2

UNDIFFERENTIATED SURFICIAL DEPOSITS

Q — **Surficial deposits, undifferentiated (Quaternary)**— Shown only on cross section. May include any of the above surficial deposits

ALLUVIAL, MASS-WASTING, LACUSTRINE, AND DELTAIC DEPOSITS

QTm — **Sediments of Missouri Heights (early Quaternary and/or late Tertiary)**—Locally derived gravel, sand, silt, and clay deposited in the Missouri Heights-Cottonwood Pass region in alluvial, mass-wasting, and either lacustrine or deltaic environments. Deposited in areas topographically lowered by collapse or subsidence related to dissolution or flow of salt deposits in the underlying Eagle Valley Evaporite. Overlies Miocene basaltic rocks (Tb) and Pliocene trachyandesitic rocks (Tta). Typically is less deformed than underlying rocks

COLLAPSE DEPOSITS

QTcd — **Collapse deposits (Pleistocene and late Tertiary)**—Heterogeneous deposits of slightly to highly deformed bedrock and overlying undeformed to moderately deformed surficial deposits. Locally includes large intact blocks of basalt (Tb) that are lowerd by collapse. Several flows in these blocks were geochemically analyzed. Formed in response to differential collapse resulting from dissolution of underlying evaporite

BEDROCK

Tta — **Trachyandesite undifferentiated (Pliocene)**—Multiple flows of basaltic trachyandesite and trachyandesite. Contains varying amounts of quartz, sanidine, and plagioclase xenocrysts

Tb — **Basalt (Miocene)**—Multiple flows of basalt, basaltic andesite, and basaltic trachyandesite. Petrographically most flows are olivine basalt; many are porphyritic. Groundmass predominantly plagioclase and pyroxene. Phenocrysts chiefly olivine and occasionally plagioclase. May contain rare xenocrysts or xenoliths of quartz and quartzite. Locally includes slightly indurated sediments

Ts — **Sedimentary deposits (Miocene)**—Mostly fluvial, clast-supported, silty, sandy pebble and cobble gravel, but locally contains silty and sandy deposits of probable alluvial and/or colluvial origin. Locally slightly to moderately indurated. Patterns indicate a younger erosion surface is present on the unit. Thin mantle of younger sediments locally underlies these erosion surfaces. Upper pattern indicates erosion surface is of late middle Pleistocene age; middle pattern indicates a middle and early? age; lower pattern indicates early Pleistocene and/or late Tertiary age

PIPm — **Maroon Formation (Lower Permian? and Upper Pennsylvanian)**—Red beds of sandstone, conglomerate, mudstone, siltstone, and shale and minor, thin beds of gray limestone. Top of formation not exposed in quadrangle

IPe — **Eagle Valley Formation (Middle Pennsylvanian)**—Reddish-brown, gray, reddish-gray, and tan siltstone, shale, sandstone, gypsum, and carbonate rocks which are gradational between and intertonguing with the Maroon Formation and Eagle Valley Evaporite

IPee — **Eagle Valley Evaporite (Middle Pennsylvanian)**—Evaporitic sequence of gypsum, anhydrite, and halite interbedded with marine mudstone, fine-grained sandstone, thin carbonate beds, and black shale. Commonly intensely folded, faulted, and ductily deformed

MAP SYMBOLS

Contact—Dashed where approximately located; queried where very uncertain

Diapiric contact—Contact between evaporitic formations and overlying formations where the evaporitic rocks are intrusive or piercing into the overlying formations. Teeth are on the intrusive side of the contact

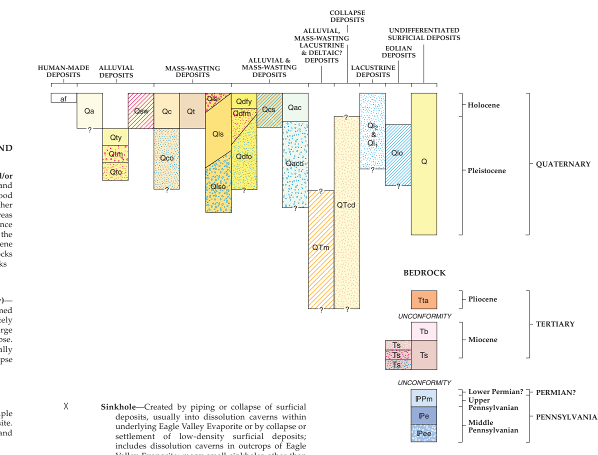
Fault—Dashed where approximately located; dotted where concealed; bar and ball on downthrown side; includes faults related to dissolution and flowage of evaporite

Anticline—Showing axial trace; dashed where approximately located; dotted where concealed; arrow on end of axis indicates direction of plunge

Syncline—Showing axial trace; dashed where approximately located; dotted where concealed; these structures may be synclinal sags, but they lack supportive evidence for this origin

Synclinal sag or subsidence trough—Showing axial trace of synclinal sag or subsidence trough related to evaporite tectonism; synclinal sags occur in bedrock, subsidence troughs are in river terraces and overlying deposits; dashed where approximately located; dotted where concealed; limbs of synclinal sags and subsidence troughs may be faulted; closed and nearly closed depressions in collapse debris (QTcd), which likely are at least in part sags or troughs, are not mapped

CORRELATION OF MAP UNITS



Sinkhole—Created by piping or collapse of surficial deposits, usually into dissolution caverns within underlying Eagle Valley Evaporite or by collapse or settlement of low-density surficial deposits; includes dissolution caverns in outcrops of Eagle Valley Evaporite; many small sinkholes other than those shown on the map are probably present in the quadrangle

Strike and dip of beds—Angle of dip shown in degrees; most attitudes in basalt and terrace deposits were measured on top of apparent surface

23 **Inclined beds**

Vertical beds

Inclined beds—Showing approximate attitude of surface on terraces and basalt flows as determined from stereoscopic models set on a Kelsh PG-2 plotter; dip between 0 and 30

65 **Strike and dip of foliation or flow layering in volcanic rocks**—Angle of dip shown in degrees

Zone of shearing and bleaching

Gravel pit

CD42 **Location and identification number of rock sample with geochemical analysis (Unrah and others, 2001; Budahn and others, 2002). See table 1 and Appendix A in booklet**

CD53D **Location and identification number of rock sample with geochemical analysis (Unrah and others, 2001; Budahn and others, 2002) and $^{40}Ar/^{39}Ar$ age date (Kunk and others, 2002). See Table 1 and Appendix A in booklet**

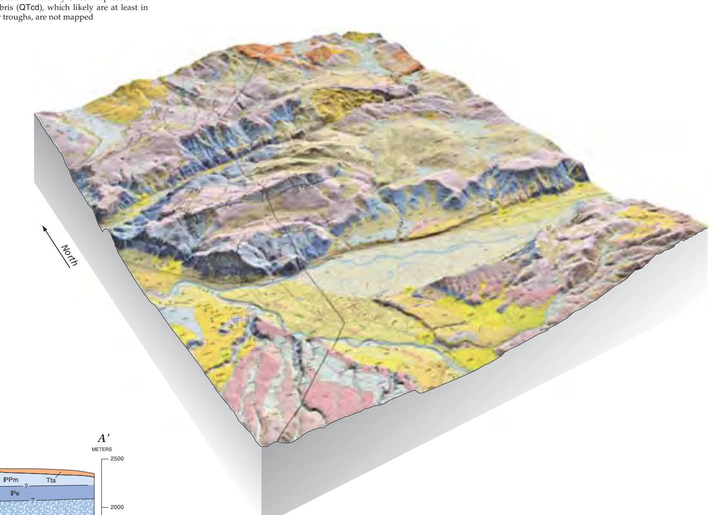
Outcrop of Lava Creek B volcanic ash—Ash correlated by Izett and Wilcox (1982)

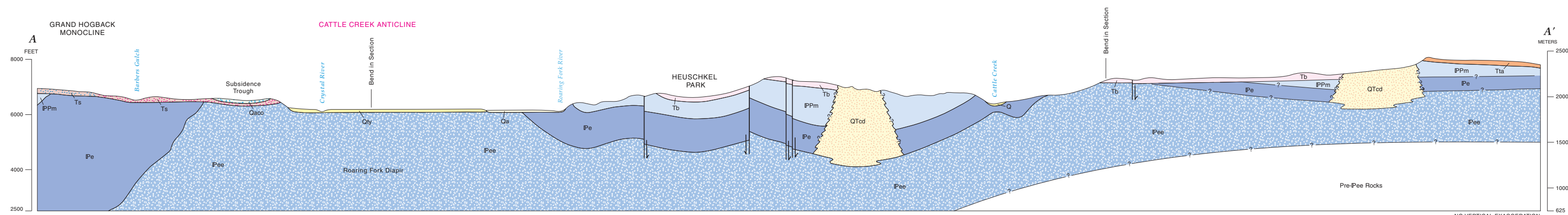
A——*A'* **Alignment of cross section**

Oil or gas exploration test hole—Plugged and abandoned; operator, well name, and total depth shown

ACKNOWLEDGEMENTS

This mapping project was funded jointly by the Colorado Geological Survey and the STATEMAP component of the National Geologic Mapping Program, which is administered by the U.S. Geological Survey Agreement Nos. 1434-96-AG-01477 and 01HGAG0094.





GEOLOGIC MAP OF THE CARBONDALE QUADRANGLE, GARFIELD COUNTY, COLORADO

By Robert M. Kirkham and Beth L. Widmann
2008

Bill Ritter Jr., Governor
State of Colorado

Harris D. Sherman, Executive Director
Department of Natural Resources

Vincent Matthews
State Geologist and Director
Colorado Geological Survey

COLORADO GEOLOGICAL SURVEY
DEPARTMENT OF NATURAL RESOURCES
DENVER, COLORADO

MAP SERIES 40
GEOLOGIC MAP OF THE LEON QUADRANGLE
EAGLE AND GARFIELD COUNTIES, COLORADO
Booklet accompanies map

Base from U.S. Geological Survey, 1987
Polyconic projection, 1927 North American datum
10,000-foot grid based on Colorado coordinate system, central zone

Geology mapped in 1997
Digital map prepared by Cheryl Brchan and Larry Scott

SCALE 1:24,000

CONDENSED DESCRIPTION OF MAP UNITS

The complete description of map units and references is in the accompanying booklet.

SURFICIAL DEPOSITS

HUMAN-MADE DEPOSITS

af — **Artificial fill (latest Holocene)**

ALLUVIAL DEPOSITS

Qa — **Modern stream-channel, flood-plain, and low-terrace deposits (Holocene and late Pleistocene)**—Mostly poorly sorted, clast-supported gravel in a sandy or silty matrix. May locally include clayey deposits in some subsidence troughs. Includes terraces up to about 12 ft above modern river level

Qsw — **Sheetwash deposits (Holocene and late Pleistocene)**—Pebbly silty sand, sandy silt, and clayey silt deposited in ephem-eral and intermittent stream valleys, on gentle hillslopes, and in basins

Qty — **Younger terrace alluvium (late Pleistocene)**—Mostly poorly sorted, clast-supported, locally bouldery, pebble and cobble gravel in a sand and silt matrix. Deposited as glacial outwash. Underlies terraces 15 to 52 ft above modern stream level. May include fine-grained overbank deposits

Qtm — **Intermediate terrace alluvium (late Pleistocene)**—Deposits texturally and depositionally similar to younger terrace alluvium (Qty). Underlies terraces 55 to 100 ft above modern streams

Qtt — **Oldest terrace alluvium (middle and early? Pleistocene)**—Deposits texturally and depositionally similar to younger terrace alluvium (Qty). Clasts moderately to highly wea-thered. A single small terrace remnant in the southeast corner of the quadrangle that is about 380 to 400 ft above the Frying Pan River

QTg — **High-level gravel (early Pleistocene and/or late Tertiary)** —Chiefly clast-supported, sandy, silty, cobble and pebble gravel occurring on a subtle ridge line about 1 mi east of El Jebel and about 1,300 to 1,350 ft above the Roaring Fork River. Clasts are moderately to very highly weathered

QTm — **Sediments of Missouri Heights (early Quaternary and/or late Tertiary)**—Locally derived gravel, sand, silt, and clay deposited in the Missouri Heights area in alluvial and colluvial environments. May include pediment deposits derived from and deposited on the sediments of Missouri Heights in area between Spring Park Reservoir and Cattle Creek. Deposited in topographic depressions created by evaporite tectonism. Overlies Miocene basaltic rocks (Tb). Typically is less deformed than underlying rocks. Occurs about 1,000 to 1,650 ft above the Roaring Fork River

MASS-WASTING DEPOSITS

Qlsr — **Recent landslide deposits (latest Holocene)**—Includes a recently active landslide near the northeast corner of the map with very fresh morphological features. Heterogeneous unit consisting of unsorted, unstratified rock debris, sand, and silt

Qc — **Colluvium (Holocene and late Pleistocene)**—Ranges from unsorted, clast-supported, pebble to boulder gravel in a sandy silt matrix to matrix-supported gravelly, clayey, sandy silt. Usually coarser grained in upper reaches of colluvial slope and finer grained in distal areas

Qt — **Talus (Holocene and late Pleistocene)**—Angular, cobbly and bouldery rubble derived from outcrops of basalt, trachyandesite, sandstone, or basalt-rich landslide deposits

Qbf — **Boulder-field deposits (Holocene and late Pleistocene)**—Angular boulders and cobbles of basalt with little or no matrix on moderate to steep slopes. Commonly has an undulatory surface suggestive of flowage as a rock glacier or related to periglacial processes

Qls — **Landslide deposits (Holocene and Pleistocene)**—Includes various types of landslide deposits. Consists of unsorted, unstratified gravel, sand, silt, clay, and rock debris

Qco — **Older colluvium (Pleistocene)**—Texturally similar to colluvium (Qc), but found on drainage divides, ridge lines, and dissected hillslopes

Qlso — **Older landslide deposits (Pleistocene)**—Landslide deposits dissected by erosion and lacking distinctive landslide geomorphology. Similar in texture to landslide deposits (Qls)

ALLUVIAL AND MASS-WASTING DEPOSITS

Qdfy — **Younger debris-flow deposits (Holocene and late Pleistocene)**—Poorly sorted to moderately well-sorted, matrix- and clast-supported deposits ranging from gravelly clayey silt to sandy, silty, cobbly, pebbly, and bouldery gravel. Fan heads tend to be bouldery, while distal fan areas are finer grained. Includes debris-flow, hyper-concentrated-flow, fluvial, and sheetwash deposits on active fans and in some drainage channels. Numeric subscripts indicate relative ages of younger debris-flow deposits in the southwest corner of the quadrangle. Deposits labeled $Qdfy_1$ are younger than and derived from deposits labeled $Qdfy_2$

Qac — **Alluvium and colluvium, undivided (Holocene)**— Moderately well-sorted to well-sorted, stratified, interbedded sand, silt, pebbly sand, and sandy gravel to poorly sorted, unstratified or poorly stratified, clayey, silty sand, bould-ery sand, sandy silt, and silty clay

Qcs — Colluvium and sheetwash deposits, undivided (Holocene and late Pleistocene)—Consists of colluvium (Qc) on steeper slopes and sheetwash deposits (Qsw) on flatter slopes. Mapped where contacts between the two types of deposits are very gradational and difficult to locate. May locally include lacustrine deposits in large subsidence troughs

Qaco — **Older alluvium and colluvium, undivided (Pleistocene)**—Deposits texturally and depositionally similar to alluvium and colluvium (Qac) that underlie terraces and hillslopes ranging from about 10 to 60 ft above the floor of tributary valleys

Qcso — **Older colluvium and sheetwash deposits, undivided (Pleistocene)**—Deposits texturally and depositionally similar to colluvium and sheetwash (Qcs) that underlie surfaces 20 to 160 ft above adjacent stream beds

Qdfo — **Older debris flow-deposits (Pleistocene)**—Remnant of an inactive debris fan on a ridge line about 80 to 120 ft above the adjacent stream bed near the southeast corner of the quadrangle. Similar in texture and genesis to younger debris-flow deposits (Qdfy)

SINTER DEPOSITS

Qtu — **Tufa (Holocene and late Pleistocene?)**—Low-density, porous, calcium carbonate deposits precipitated from a mineral spring along the Basalt Mountain Fault immediately north of Cattle Creek

UNDIFFERENTIATED SURFICIAL DEPOSITS

Q — **Surficial deposits, undivided (Quaternary)**—Shown only on cross section

COLLAPSE DEPOSITS

QTcd — **Collapse deposits (Quaternary and late Tertiary)**—Heterogenous deposits of moderately to highly deformed bedrock and overlying undeformed to moderately deformed surficial deposits within the Carbondale Collapse Center. Locally includes large but displaced blocks of volcanic rocks. Formed in response to differential collapse resulting from dissolution and flow of underlying evaporite

BEDROCK

Tsp — **Trachyandesite of Spring Park (Pliocene)**—Medium-gray basaltic flows from an eruptive center about 0.5 mi east of the dam for Spring Park Reservoir. Petrographically the unit is xenocrystic olivine basalt, while geochemically it is a basaltic trachyandesite. Groundmass predominantly plagioclase and pyroxene. Contains sparse phenocrysts of mainly olivine and rare plagioclase. Locally contains abundant xenocrysts of quartz, sanidine, and plagioclase. Included in compositional group 6b′ of Budahn and others (2002). $^{40}Ar/^{39}Ar$ of 2.90 ± 0.02 Ma (Kunk and others, 2002)

Tspc — **Cinder deposits of Spring Park (Pliocene)**—Red and red-brown scoriaceous, unconsolidated cinder deposits associated with an eroded eruptive center about 0.5 mi east of the dam for Spring Park Reservoir. Petrographically the rock is olivine basalt with locally abundant xenocrysts of quartz, sanidine, and plagioclase. Geochemically these rocks are basaltic trachyandesite and are included in compositional group 6b′ of Budahn and others (2002). $^{40}Ar/^{39}Ar$ of 2.96 ± 0.02 Ma (Kunk and others, 2002)

Tcc — **Trachyandesitic flows of Cattle Creek (Pliocene)**—Medium- to dark-gray basaltic trachyandesite and trachybasalt flows along Cattle Creek between Shippes Draw and Sleepy Creek. Contains varying amounts of quartz and sanidine xenocrysts. Included in compositional group 6c of Budahn and others (2002). $^{40}Ar/^{39}Ar$ of 3.09 ± 0.02 Ma (Kunk and others, 2002)

Tccc — **Trachyandesite cinder deposits of Cattle Creek (Pliocene)**—Dark-gray to black, scoriaceous, cinder deposit exposed in cinder quarries along Cattle Creek between Shippes Draw and Sleepy Creek. Petrographically this deposit is a xenocrystic olivine basalt; geochemically it is basaltic trachyandesite. Included in compositional group 6c of Budahn and others (2002). $^{40}Ar/^{39}Ar$ of 3.01 ± 0.01 Ma (Kunk and others, 2002)

Tta — **Trachyandesitic flows, undifferentiated (Pliocene)**—Multiple flows of basaltic trachyandesite, trachyandesite, and trachybasalt. Contains varying amounts of quartz, sanidine, and plagioclase xenocrysts

Tsb — **Sediments of Basalt Mountain (Pliocene or Miocene)**—Chiefly medium-red-brown, weakly indurated, pebble and cobble gravel in a sandy or silty matrix. Locally bouldery. Deposited over basalt flows on northern edge of Basalt Mountain shield volcano by ancestral Cattle Creek

Tb — **Basaltic flows (Miocene)**—Multiple flows of basalt, basaltic andesite, and basaltic trachyandesite. Petrographically most flows are olivine basalt; many are porphyritic. Groundmass predominantly plagioclase and pyroxene. Phenocrysts chiefly olivine and occasionally plagioclase. May contain rare xenocrysts or xenoliths of quartz and quartzite. Locally includes slightly indurated sediments. Included in compositional groups 1b, 1c, 2b′, 4b, and 4b′ of Buhdan and others (2002). $^{40}Ar/^{39}Ar$ age dates range from 7.75 ± 0.03 Ma to 10.84 ± 0.06 Ma.

Ts — **Sedimentary deposits (Miocene)**—Mostly fluvial, clast-supported, silty, sandy pebble and cobble gravel but locally contains silty and sandy deposits of probable alluvial and/or colluvial origin. Locally slightly to moderately indurated

Km — **Mancos Shale (Upper Cretaceous)**—Light- to dark-gray, carbonaceous, silty to sandy shale and thin bentonite beds, gray limestone, and light- to medium-gray, grayish-yellow-weathering, clayey sandstone. Includes the Fort Hays Limestone Member, a thick-bedded, coarse-grained, gray limestone

Kd — **Dakota Sandstone (Lower Cretaceous)**—Light-gray to tan, medium- to very coarse-grained, quartzose sandstone and conglomeratic sandstone interbedded with carbonaceous siltstone, sandstone, and shale. May include Burro Canyon Formation in southern part of quadrangle

Jm — **Morrison Formation (Upper Jurassic)**—Pale-green, greenish-gray, and maroon variegated siltstone and claystone, buff to tan sandstone, and gray limestone. A thick-bedded, coarse-grained, oolitic, tan- and white-weathering, medium-dark-gray limestone at the base of the formation overlies the Entrada Sandstone

Je — **Entrada Sandstone (Upper Jurassic)**—Light-gray, tan, and white, medium- to very fine-grained, well-sorted sand-stone with large-scale crossbedding. Weakly to mod-erately indurated

TRc — **Chinle Formation (Upper Triassic)**—Thin, even-bedded, and structureless beds of dark-reddish-brown, orangish-red, and purplish-red, calcareous siltstone and mudstone and scattered thin lenses of light-purplish-red and gray lime-stone and limestone-pebble conglomerate. Locally in-cludes a thin, basal conglomeratic sandstone

TRPsb — **State Bridge Formation (Lower Triassic and Permian)**—Reddish-orange, grayish-red, and pale-reddish-pink silty sandstone, clayey siltstone, arkosic sandstone, and conglomeratic sandstone. Includes lenses of sandy dolo-mite and limestone of the South Canyon Creek Dolomite Member that are up to 18 inches thick and occur about 200 ft above the base of the formation. Sandstone beds are well sorted, equigranular, and have rounded to sub-rounded sand grains with a high degree of sphericity

TRPcs — **Chinle and State Bridge Formations, undivided (Triassic and Permian)**

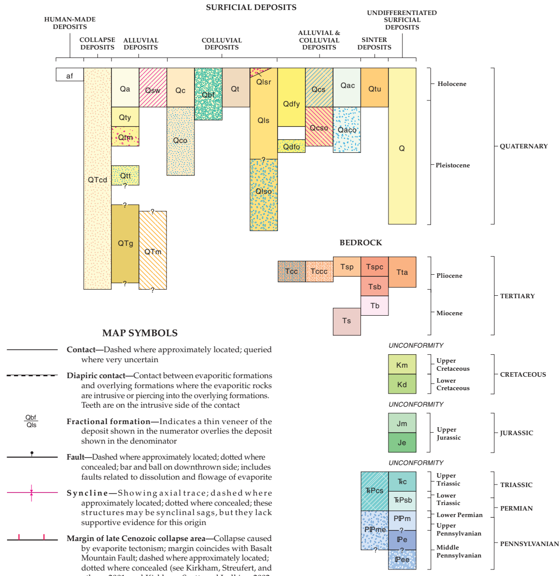
PPm — **Maroon Formation (Lower Permian? and Upper Pennsylvanian)**—Red beds of sandstone, conglomerate, mudstone, siltstone, and shale and minor, thin beds of gray limestone

Pe — **Eagle Valley Formation (Middle? Pennsylvanian)**—Reddish-brown, gray, reddish-gray, and tan siltstone, shale, sandstone, gypsum, and carbonate rocks which are gradational between and intertonguing with the Maroon Formation and Eagle Valley Evaporite

PPme — **Maroon and Eagle Valley Formations, undivided (Lower Permian and Upper and Middle? Pennsylvanian)**

Pee — **Eagle Valley Evaporite (Middle Pennsylvanian)**—Evaporitic sequence of gypsum, anhydrite, and halite interbedded with mudstone, fine-grained sandstone, thin carbonate beds, and black shale. Commonly intensely folded, faulted, and ductily deformed

CORRELATION OF MAP UNITS



MAP SYMBOLS

Contact—Dashed where approximately located; queried where very uncertain

Diapiric contact—Contact between evaporitic formations and overlying formations where the evaporitic rocks are intrusive or piercing into the overlying formations. Teeth are on the intrusive side of the contact

Qbf/Qls — **Fractional formation**—Indicates a thin veneer of the deposit shown in the numerator overlies the deposit shown in the denominator

Fault—Dashed where approximately located; dotted where concealed; bar and ball on downthrown side; includes faults related to dissolution and flowage of evaporite

Syncline—Showing axial trace; dashed where approximately located; dotted where concealed; these structures may be synclinal sags, but they lack supportive evidence for this origin

Margin of late Cenozoic collapse area—Collapse caused by evaporite tectonism; margin coincides with Basalt Mountain Fault; dashed where approximately located; dotted where concealed (see Kirkham, Streufert, and others, 2001; and Kirkham, Scott, and Judkins, 2002, for description of collapse)

Synclinal sag or subsidence trough—Showing axial trace of synclinal sag or subsidence trough related to evaporite dissolution and/or flowage; synclinal sags occur in bedrock, subsidence troughs are found on river terraces; dashed where approximately located; dotted where concealed; limbs of synclinal sags and subsidence troughs may be faulted; closed and nearly closed depressions in collapse debris (QTcd), which likely are at least in part sags or troughs, are not mapped

Sinkhole—Created by piping or collapse of surficial deposits, usually into dissolution caverns within underlying Eagle Valley Evaporite or by collapse or settlement of low-density surficial deposits; includes dissolution caverns in outcrops of Eagle Valley Evaporite; "x" denotes one or more small sinkholes; many small sinkholes other than those shown on the map are probably present in the quadrangle

55 — **Strike and dip of beds**—Angle of dip shown in degrees; most attitudes in basalt were measured on top of apparent surface

Inclined beds—Showing approximate attitude of surface on basalt flows as determined from stereoscopic models set on a Kelsh PG-2 plotter; dip between 0° and 30°

65 — **Strike and dip of foliation in extrusive flow rocks**—Includes measurements on flows within collapse debris (QTcd). Angle of dip shown in degrees

Linear ridge within landslide on west side of Basalt Mountain— Ridge is underlain by tilted slump blocks of basalt that range from nearly intact to very rubbly flows

Linear swale of uncertain origin along the Basalt Mountain Fault

Approximate boundary of a subsidence trough developed in surficial deposits—Resultant from collapse into voids created by dissolution or flowage of underlying evaporitic rocks. Queried where very approximate

Approximate boundary of a lava-filled crater at the crest of Basalt Mountain—Exposed part of crater has been filled with two thick, ponded lava flows. The lower flow averages about 200 to 250-ft thick and the upper flow averages about 40 to 50-ft thick

Adit

Gravel pit

Cinder quarry

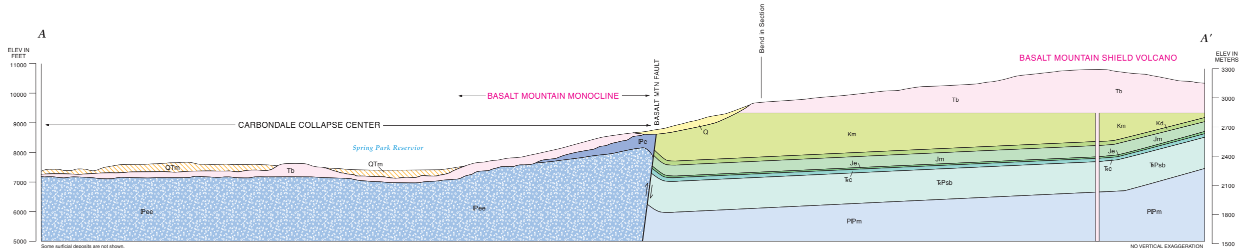
L-23 — **Location and identification number of geochemical rock sample—(Table 1 and Appendix A in booklet; Unruh and others, 2001; Budahn and others, 2002)**

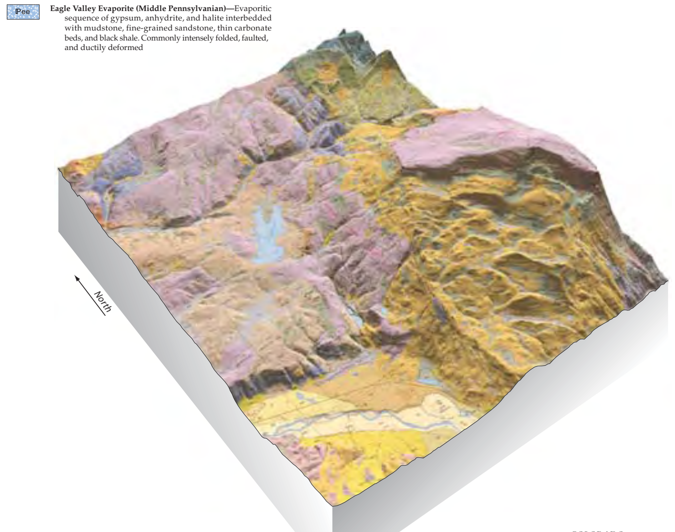
L-39 — **Location and identification number of rock sample with geochemical analysis (Unruh and others, 2001; Budahn and others, 2002) and $^{40}Ar/^{39}Ar$ age date (Kunk and Snee, 1998; Kunk and others, 2001). See Table 1 and Appendix A in booklet**

A ——— A′ — **Alignment of cross section**

ACKNOWLEDGEMENTS

This geologic map was funded in part by the U.S. Geological Survey National Geologic Mapping Program and by State of Colorado General Funds and Colorado Department of Natural Resources Severance Tax Operational Funds.





GEOLOGIC MAP OF THE LEON QUADRANGLE, EAGLE AND GARFIELD COUNTIES, COLORADO

By Robert M. Kirkham, Beth L. Widmann, and Randall K. Streufert

2008

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State of Colorado

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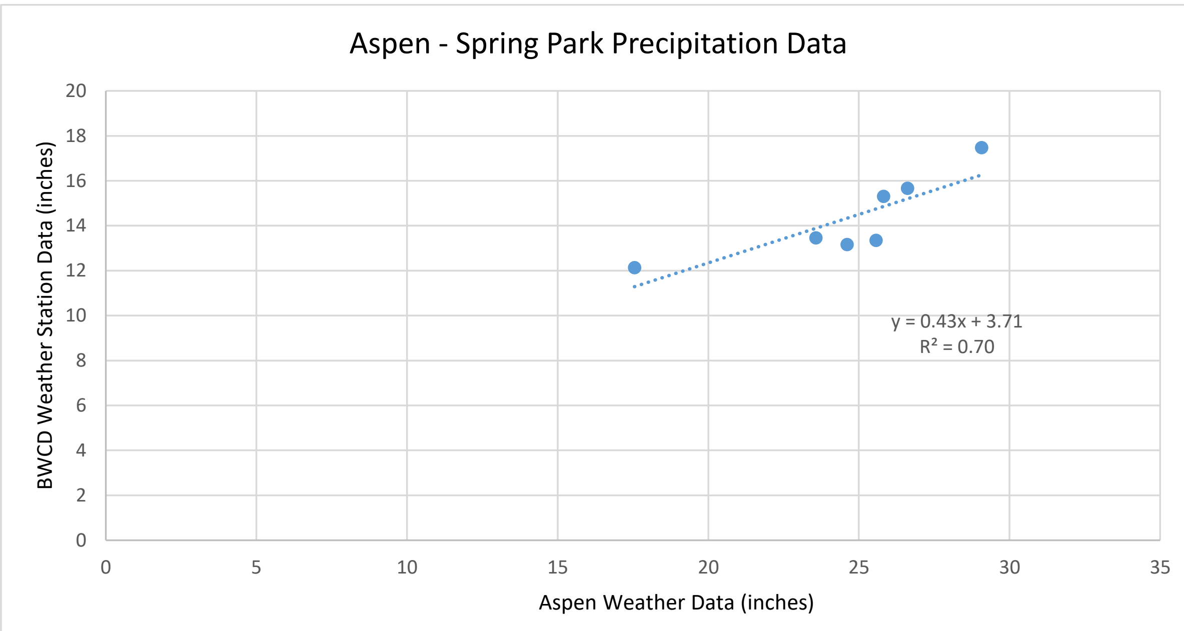
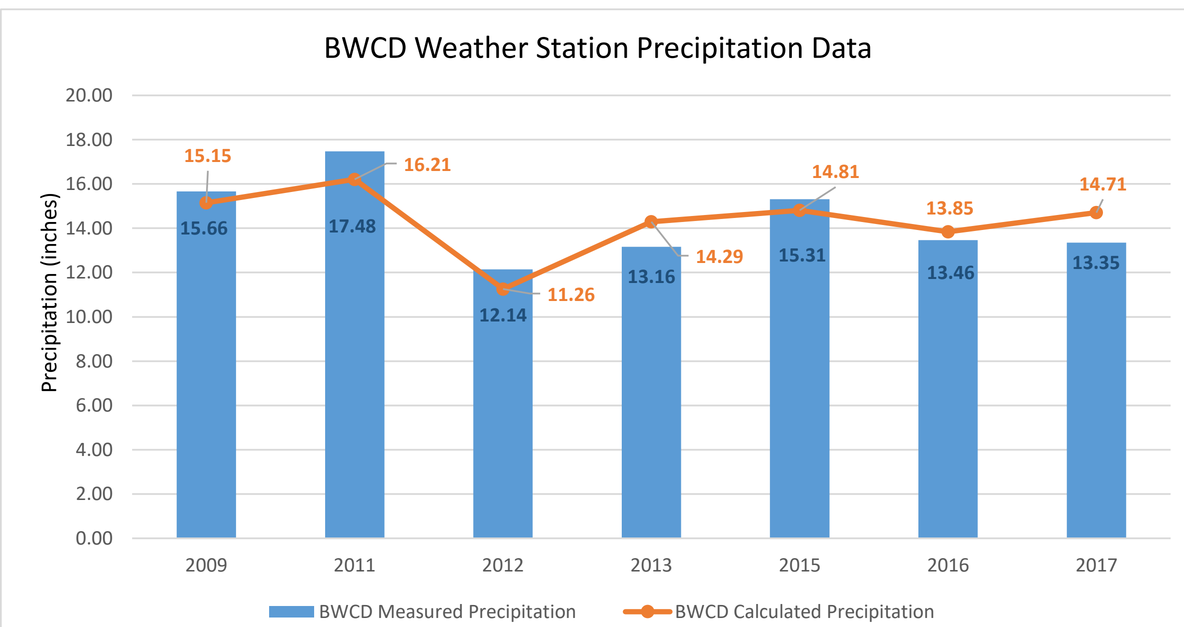
APPENDIX B: PRECIPITATION ANALYSIS RESULTS

Total Annual Precipitation Data

Water Year	Weather Station BWCD	Weather Station Aspen	BWCD Calculated	Percent Difference
2009	15.66	26.61	15.15	96.8%
2011	17.48	29.07	16.21	92.7%
2012	12.14	17.55	11.26	92.7%
2013	13.16	24.61	14.29	108.6%
2015	15.31	25.82	14.81	96.8%
2016	13.46	23.57	13.85	102.9%
2017	13.35	25.57	14.71	110.2%
			Ave.	100.1%

Note: Data from WY2018/19 not used due to incomplete Aspen Weather Station Data.
WY2010, WY2014 removed due to being outliers.





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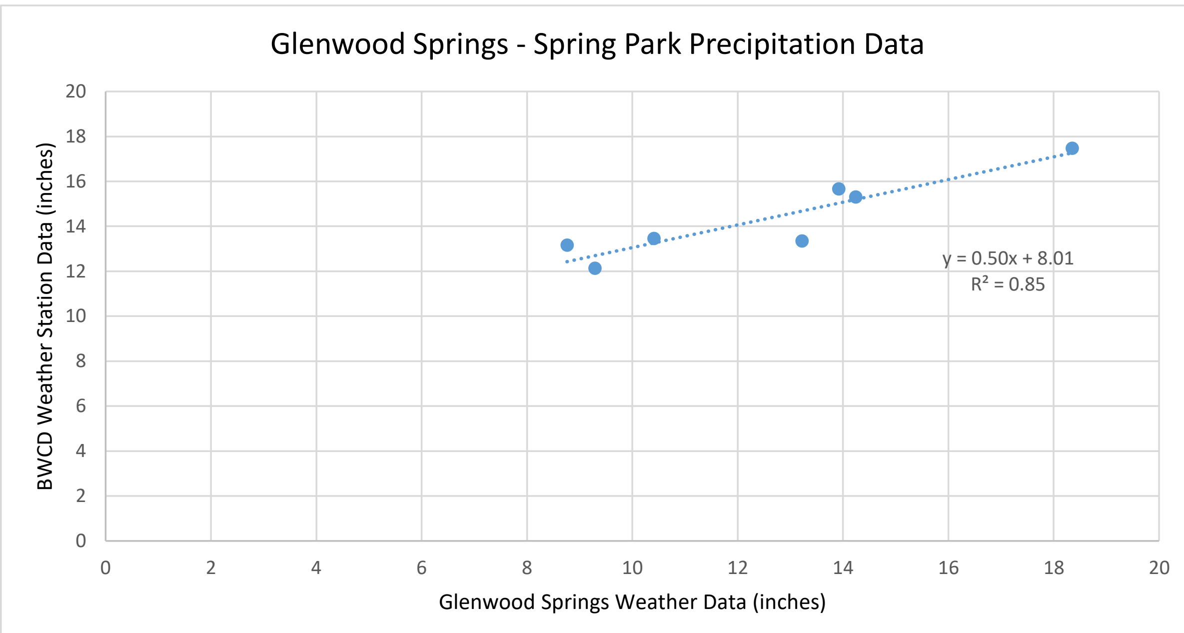
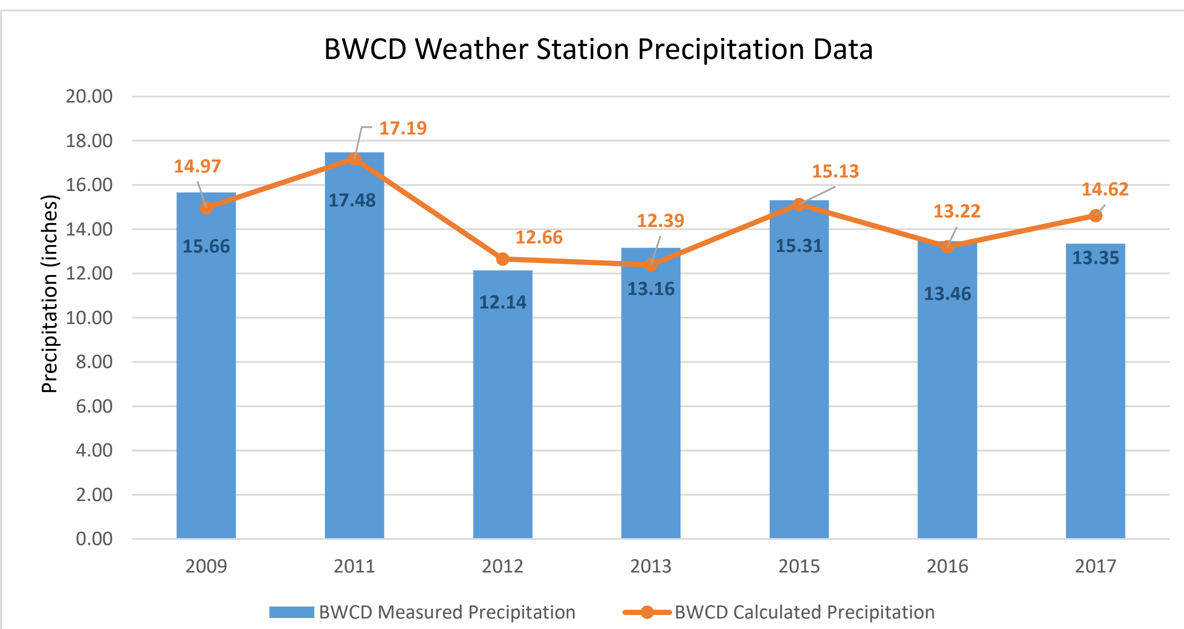
Total Annual Precipitation Data

Water Year	Weather Station BWCD	Weather Station Glenwood	BWCD Calculated	Percent Difference
2009	15.66	13.92	14.97	95.6%
2011	17.48	18.35	17.19	98.3%
2012	12.14	9.29	12.66	104.2%
2013	13.16	8.76	12.39	94.1%
2015	15.31	14.24	15.13	98.8%
2016	13.46	10.41	13.22	98.2%
2017	13.35	13.22	14.62	109.5%
			Ave.	99.8%

Note: Data from WY2018/19 not used due to incomplete Aspen Weather Station Data.
WY2010, WY2014 removed due to being outliers.





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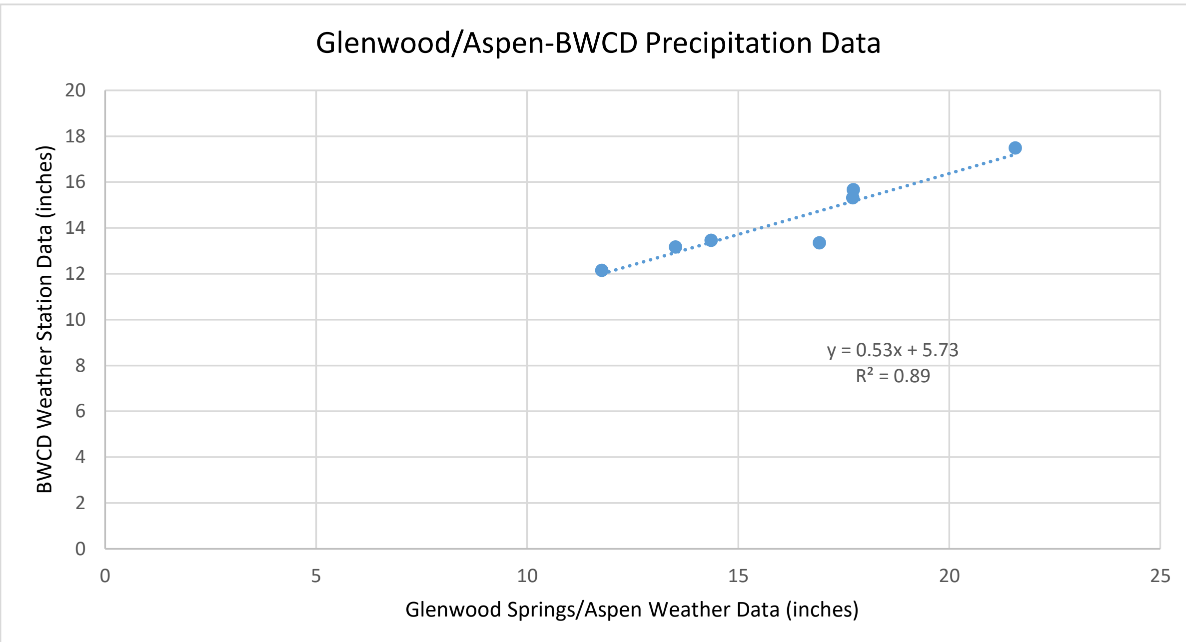
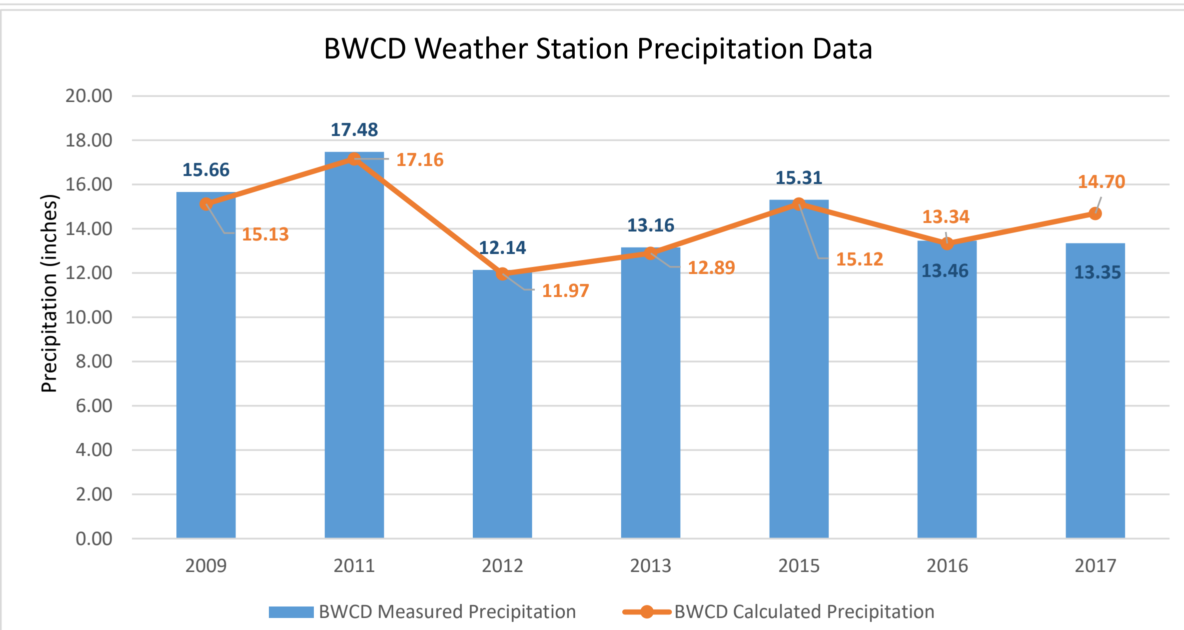
Total Annual Precipitation Data

	Weather Station			
Water Year	BWCD	Aspen / Glenwood	BWCD Calculated	Percent Difference
2009	15.66	17.73	15.13	96.6%
2011	17.48	21.57	17.16	98.2%
2012	12.14	11.77	11.97	98.6%
2013	13.16	13.52	12.89	98.0%
2015	15.31	17.71	15.12	98.7%
2016	13.46	14.36	13.34	99.1%
2017	13.35	16.93	14.70	110.1%
			Ave.	99.9%

Note: Data from WY2018/19 not used due to incomplete Aspen Weather Station Data.
WY2010, WY2014 removed due to being outliers.





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Aspen Weather Station Data

(values in inches)

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	**Total**
1980	2.19	2.08	1.91	2.10	2.65	2.60	2.17	1.19	0.52	1.17	0.84	2.25	**21.67**
1981	1.38	1.45	0.71	0.89	3.63	1.63	3.83	0.70	2.34	1.38	1.55	2.71	**22.20**
1982	1.75	3.68	2.59	0.83	3.03	1.61	2.05	1.02	1.69	0.95	3.33	1.57	**24.10**
1983	2.39	0.92	0.46	1.59	3.68	2.80	4.75	1.87	0.82	1.78	0.61	1.75	**23.42**
1984	5.05	4.87	0.88	1.78	4.07	2.70	1.45	4.35	3.20	3.45	1.31	5.47	**38.58**
1985	1.50	3.10	0.32	2.40	4.09	2.75	2.30	1.00	2.42	0.61	5.08	3.20	**28.77**
1986	4.30	0.88	1.91	2.10	1.30	2.60	1.54	1.63	2.00	2.45	2.95	0.75	**24.41**
1987	0.15	0.85	1.55	2.50	2.09	1.00	1.45	2.53	1.24	2.08	0.62	1.40	**17.46**
1988	1.68	2.17	2.55	0.95	2.15	1.20	1.95	1.86	0.84	0.75	1.85	0.22	**18.17**
1989	3.95	1.55	1.50	3.77	3.20	2.29	1.00	0.40	1.73	1.20	0.99	0.44	**22.02**
1990	2.00	2.08	0.86	1.18	1.82	3.80	0.89	0.50	2.30	1.00	1.78	3.42	**21.63**
1991	2.50	1.82	1.34	1.22	3.24	3.28	1.40	2.22	1.45	1.60	1.70	2.19	**23.96**
1992	2.18	0.56	1.18	0.98	3.52	1.45	3.07	0.89	1.89	1.73	1.90	0.98	**20.33**
1993	4.01	1.44	1.67	4.07	3.36	3.42	2.42	1.13	1.64	1.59	1.98	2.70	**29.43**
1994	2.19	1.49	0.97	2.97	1.62	2.90	1.08	0.83	0.32	1.71	1.01	2.05	**19.14**
1995	3.05	2.08	1.70	3.84	5.52	3.26	5.41	2.39	2.75	1.45	2.09	1.43	**34.97**
1996	1.87	2.08	2.53	4.73	2.65	3.11	1.31	1.20	1.79	0.55	2.31	3.54	**27.67**
1997	3.03	2.80	3.40	1.57	1.93	3.68	2.64	1.20	0.40	1.78	2.62	3.30	**28.35**
1998	1.88	0.99	1.76	2.54	3.15	3.05	0.55	1.34	4.26	1.10	0.98	2.01	**23.61**
1999	3.30	1.79	2.58	2.55	1.45	3.87	3.71	1.08	2.63	2.74	2.66	1.49	**29.85**
2000	0.42	1.23	2.31	2.30	2.80	1.69	2.03	1.06	1.79	1.79	2.01	0.50	**19.93**
2001	2.42	1.28	0.78	1.21	1.67	2.58	2.74	1.60	2.30	2.97	2.12	1.03	**22.70**
2002	2.40	1.30	1.71	1.40	2.20	1.42	0.21	0.00	1.70	1.22	3.30	1.80	**18.66**
2003	2.55	1.00	0.55	1.62	2.97	2.47	2.91	1.35	0.49	0.90	2.70	0.50	**20.01**
2004	2.19	2.30	1.90	2.36	0.90	1.73	1.03	1.59	1.36	0.78	2.60	1.68	**20.42**
2005	3.00	1.30	3.89	1.98	1.67	2.48	1.29	1.76	1.84	2.12	2.65	3.51	**27.49**
2006	2.40	2.69	2.74	1.14	2.15	0.99	1.06	0.30	3.55	1.52	2.74	3.34	**24.62**
2007	2.64	1.41	1.92	2.01	1.89	1.78	2.02	0.87	3.73	1.20	2.74	2.95	**25.16**
2008	0.46	5.27	4.24	3.17	3.55	2.50	2.56	0.60	0.90	1.51	0.83	0.71	**26.30**
2009	2.12	4.61	2.85	1.27	2.63	2.82	2.54	1.47	2.06	1.06	1.42	1.76	**26.61**
2010	1.37	1.90	0.86	2.49	2.27	3.96	1.70	1.55	1.92	4.92	0.69	2.31	**25.94**
2011	2.38	2.55	1.96	2.75	2.89	6.39	2.46	0.80	3.15	0.85	0.92	1.97	**29.07**
2012	1.71	0.76	2.38	1.39	0.55	1.72	1.07	0.37	2.38	2.28	1.44	1.50	**17.55**
2013	0.44	2.11	1.23	1.67	1.83	3.99	2.40	0.12	2.40	2.07	4.26	2.09	**24.61**
2014	2.11	2.17	3.62	2.17	3.28	1.67	2.31	0.30	1.86	2.74	2.22	1.57	**26.02**
2015	2.39	3.12	0.34	1.60	2.44	1.85	4.69	1.07	3.29	1.81	1.22	2.00	**25.82**
2016	1.80	2.59	2.50	2.01	2.48	2.97	1.71	0.65	1.44	2.93	1.36	1.13	**23.57**
2017	1.60	2.92	4.22	1.60	1.85	2.00	2.51	0.28	2.29	1.72	1.73	2.85	**25.57**
2018	0.81	2.08	1.49	3.19	1.65	3.62	0.77	1.19	1.02	1.58	0.52	2.49	**20.41**
2019	1.86	2.08	2.55	2.24	6.04	2.40	3.86	1.26	1.35	0.82	0.39	2.01	**26.86**
Average	2.19	2.08	1.91	2.10	2.65	2.60	2.17	1.19	1.93	1.70	1.90	2.01	**24.43**

Notes:

The 1980-2019 average was used in months with missing data.

When data from the NOAA weather station was missing, available data from US Climate Data for Aspen was used.

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Glenwood Springs Weather Station Data

(values in inches)

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
1980	1.20	1.14	2.65	2.73	1.78	0.47	2.41	0.05	1.96	0.90	1.76	2.57	**19.62**
1981	0.86	0.90	0.73	1.16	3.16	1.15	1.70	1.42	4.10	1.52	1.46	4.01	**22.17**
1982	0.99	2.45	2.60	0.69	2.83	0.37	1.53	0.48	0.79	1.14	4.40	1.86	**20.13**
1983	1.27	0.51	0.55	1.59	1.61	3.21	4.14	2.80	1.54	1.41	0.49	1.44	**20.56**
1984	2.67	3.60	0.42	0.23	1.22	1.96	2.32	0.91	1.63	2.03	0.66	4.21	**21.86**
1985	0.74	2.14	1.00	0.27	3.24	3.12	1.66	1.12	1.76	1.23	3.62	2.48	**22.38**
1986	2.05	1.80	0.57	1.93	1.63	1.55	1.70	0.91	0.99	0.85	3.09	2.41	**19.48**
1987	2.88	0.56	1.22	1.15	1.00	1.32	1.70	0.46	1.54	1.07	1.22	1.76	**15.88**
1988	1.33	1.53	2.48	0.81	0.96	0.92	1.70	0.22	0.25	2.50	2.15	0.27	**15.12**
1989	1.91	1.01	1.34	2.78	0.65	1.09	0.38	0.36	0.79	1.24	1.76	1.80	**15.11**
1990	0.67	0.61	0.33	0.56	1.16	1.62	1.13	0.86	1.88	0.61	1.44	3.20	**14.07**
1991	1.14	1.09	0.77	0.20	2.02	1.03	0.82	2.74	0.86	1.21	1.29	1.50	**14.67**
1992	0.98	0.38	0.35	1.16	1.27	0.08	2.82	0.38	1.16	1.13	1.61	1.71	**13.03**
1993	2.02	0.51	1.66	2.64	2.60	2.99	3.57	1.07	0.50	1.55	1.08	1.80	**21.99**
1994	0.67	0.39	0.25	1.23	0.38	1.55	0.41	0.77	0.65	1.29	1.60	2.88	**12.07**
1995	2.46	1.10	1.51	2.54	1.67	1.81	5.82	1.90	2.02	0.88	1.80	1.14	**24.65**
1996	2.54	2.80	4.43	2.71	0.67	1.96	1.21	0.74	1.18	0.30	2.92	2.33	**23.79**
1997	1.60	2.52	3.84	0.40	0.77	1.83	2.36	1.31	1.77	1.67	4.19	2.82	**25.08**
1998	1.39	0.80	2.17	1.43	2.05	1.82	0.44	2.23	2.10	1.78	1.35	2.67	**20.23**
1999	0.56	0.61	0.97	0.90	0.60	3.96	3.39	1.02	0.50	1.98	2.28	0.45	**17.22**
2000	0.13	0.99	1.99	0.10	1.10	0.36	1.07	1.45	0.75	1.14	0.64	0.10	**9.82**
2001	0.79	1.20	0.55	0.89	1.00	1.05	1.65	0.60	1.05	1.13	1.70	1.80	**13.41**
2002	1.20	1.14	0.19	0.31	0.61	1.24	0.00	0.00	0.45	0.73	3.49	1.91	**11.27**
2003	1.66	0.38	0.00	0.83	0.79	0.88	3.39	0.47	0.69	1.19	2.26	0.00	**12.54**
2004	2.19	1.14	0.34	0.42	0.77	2.84	0.82	1.14	0.62	1.24	1.95	1.28	**14.75**
2005	1.30	1.12	1.82	0.98	1.21	1.54	1.07	2.17	0.80	0.77	2.91	2.11	**17.80**
2006	1.42	0.83	0.93	0.11	3.11	1.59	0.81	0.34	1.16	2.85	1.46	3.82	**18.43**
2007	0.92	0.30	0.51	0.66	0.70	0.38	0.24	0.23	0.00	1.24	2.88	2.27	**10.33**
2008	0.06	0.61	1.75	1.61	1.02	0.92	1.52	0.32	0.49	0.75	1.49	0.19	**10.73**
2009	1.00	1.38	0.84	0.93	0.43	0.89	3.00	1.85	0.66	0.77	1.15	1.02	**13.92**
2010	0.70	1.32	0.69	0.98	0.00	0.78	0.38	0.85	1.08	1.57	0.81	1.66	**10.82**
2011	0.83	1.35	0.55	0.91	1.19	3.41	2.50	0.43	3.16	1.32	1.13	1.57	**18.35**
2012	0.82	0.10	0.60	1.04	0.13	1.26	0.00	0.91	1.87	1.22	1.00	0.34	**9.29**
2013	0.26	0.59	0.34	0.00	0.33	1.79	1.32	0.00	0.15	0.32	1.43	2.23	**8.76**
2014	0.23	0.40	1.12	0.76	0.31	0.23	0.64	0.10	1.51	3.20	2.09	1.19	**11.78**
2015	1.03	1.19	0.43	0.49	0.91	0.73	3.92	0.76	1.27	1.32	1.07	1.12	**14.24**
2016	1.49	0.61	0.58	0.86	0.46	1.50	1.38	0.47	0.33	0.82	1.22	0.69	**10.41**
2017	1.50	2.12	2.52	1.22	0.62	1.93	0.85	0.08	0.62	0.24	1.10	0.42	**13.22**
2018	0.00	1.14	0.94	0.98	0.90	3.00	0.00	0.57	0.07	1.22	0.24	3.33	**12.39**
2019	0.69	1.14	1.51	1.64	2.09	1.68	2.32	1.97	0.45	0.20	0.38	1.80	**15.87**
Average	1.20	1.14	1.20	1.07	1.22	1.55	1.70	0.91	1.13	1.24	1.76	1.80	**15.93**

Notes:

The 1980-2019 average was used in months with missing data.

When data from the NOAA weather station was missing, available data from Weather Underground and US Climate Data was used.

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BWCD Weather Station Data

(values in inches)

Water Year	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	**Total**
2008										0.92	0.94	0.57	
2009	0.78	2.79	1.31	0.98	1.59	2.03	2.03	1.74	1.06	0.25	0.08	1.02	**15.66**
2010	0.13	1.89	1.22	1.84	1.06	2.54	1.03	1.54	1.41	1.73	0.84	2.01	**17.24**
2011	1.09	0.82	1.03	1.43	1.53	3.12	2.05	0.55	1.93	0.88	1.27	1.78	**17.48**
2012	1.18	0.27	1.17	1.45	0.73	1.19	0.64	0.22	2.26	1.35	1.24	0.44	**12.14**
2013	1.10	1.54	1.34	0.19	0.77	1.32	1.41	0.01	1.09	0.31	2.52	1.56	**13.16**
2014	0.80	1.20	2.17	1.18	2.10	1.34	1.67	0.18	1.18	2.67	2.57	0.79	**17.85**
2015	0.54	1.52	0.37	0.81	0.99	0.82	3.45	0.90	2.29	1.56	0.71	1.35	**15.31**
2016	1.54	1.21	1.88	0.64	0.87	1.11	1.26	0.54	2.16	1.04	0.70	0.51	**13.46**
2017	2.22	1.46	2.15	0.81	0.55	1.20	1.15	0.14	0.54	0.73	0.86	1.54	**13.35**
2018	0.21	0.40	0.69	0.88	0.71	2.74	0.06	0.37	0.35	1.55	0.34	2.34	**10.64**
2019	0.97	0.53	0.92	0.83	2.08	1.99	2.53	1.82	1.26	0.15	0.28	0.48	**13.84**
Average	0.96	1.24	1.30	1.00	1.18	1.76	1.57	0.73	1.41	1.11	1.04	1.26	**14.56**

Note:

Data from Spring Park Weather Station (Weather Underground) was used.

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APPENDIX C: IRRIGATION DIVERSION RECORDS

Missouri Heights Park Ditch Diversion Records

Diversion Summary in Acre Feet

YEAR	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	TOTAL
1994	0	0	0	0	0	0	136	301	244	66	81	39	**867**
1995	0	0	0	0	0	0	72	246	366	191	99	233	**1207**
1996	0	0	0	0	0	0	26	236	163	186	127	209	**947**
1997	27	0	0	0	0	0	127	242	139	402	350	381	**1669**
1998	0	0	0	0	0	0	246	295	173	234	282	0	**1230**
1999	0	0	0	0	0	0	44	129	122	162	110	25	**593**
2000	0	0	0	0	0	0	86	93	63	53	57	75	**428**
2001	0	0	0	0	0	0	167	84	141	152	134	138	**816**
2002	0	0	0	0	0	4	85	40	14	17	22	11	**193**
2003	0	0	0	0	0	0	162	136	79	20	23	23	**444**
2004	0	0	0	0	0	34	205	93	42	15	60	69	**518**
2005	0	0	0	0	0	0	234	223	169	36	91	8	**761**
2006	0	0	0	0	0	0	165	183	151	101	127	73	**801**
2007	0	0	0	0	0	0	17	91	99	64	32	24	**327**
2008	0	0	0	0	0	0	47	220	163	131	35	89	**687**
2009	0	0	0	0	0	0	117	256	185	31	159	0	**747**
2010	0	0	0	0	0	0	27	277	149	62	107	184	**806**
2011	0	0	0	0	0	0	0	142	166	98	89	0	**495**
2012	0	0	0	0	0	75	141	156	37	74	61	62	**605**
2013	0	0	0	0	0	0	104	114	106	59	68	70	**520**
2014	0	0	0	0	0	0	257	187	178	133	110	0	**865**
2015	0	0	0	0	0	18	266	240	106	133	65	11	**841**
2016	0	0	0	0	0	0	201	175	111	116	78	33	**714**
2017	0	0	0	0	0	7	115	168	100	59	59	28	**537**
2018	0	0	0	0	0	13	69	50	12	0	0	0	**144**
2019	0	0	0	0	0	10	189	268	211	227	174	15	**1095**
1994-2008 Average	**2**					**3**	**121**	**174**	**142**	**122**	**109**	**93**	**766**
2009-2019 Average	**0**					**11**	**135**	**185**	**124**	**90**	**88**	**37**	**670**

Note: Diversions were reduced to 26.6% (133 acres out of 500 acres) of total diversions to account for only diversions that irrigated fields within the Missouri Heights Study Area.

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Missouri Heights C and M Ditch Diversion Records

Diversion Summary in Acre Feet

YEAR	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	TOTAL
1994	0	0	0	0	0	0	359	318	139	29	123	121	**1088**
1995	53	0	0	0	0	0	353	477	169	226	156	152	**1587**
1996	0	0	0	0	0	0	41	448	220	148	65	116	**1037**
1997	71	0	0	0	0	0	177	264	189	84	0	0	**784**
1998	0	0	0	0	0	0	311	408	358	162	86	0	**1326**
1999	0	0	0	0	0	99	487	405	235	144	141	62	**1572**
2000	0	0	0	0	0	0	166	268	106	21	10	17	**587**
2001	0	0	0	0	0	0	204	284	120	72	55	5	**739**
2002	0	0	0	0	0	24	235	117	0	0	0	0	**375**
2003	0	0	0	0	0	0	413	336	191	18	0	0	**957**
2004	0	0	0	0	0	69	482	308	71	1	0	0	**932**
2005	0	0	0	0	0	0	426	533	223	101	0	0	**1283**
2006	0	0	0	0	0	0	534	349	170	69	0	0	**1122**
2007	0	0	0	0	0	0	497	380	133	53	39	30	**1131**
2008	0	0	0	0	0	0	205	454	223	72	63	0	**1017**
2009	0	0	0	0	0	0	619	302	221	146	32	0	**1320**
2010	0	0	0	0	0	0	80	379	237	160	34	0	**890**
2011	0	0	0	0	0	0	0	328	276	44	106	0	**754**
2012	0	0	0	0	0	31	233	81	0	0	0	0	**345**
2013	0	0	0	0	0	0	380	380	68	0	0	0	**828**
2014	0	0	0	0	0	0	533	465	194	69	0	0	**1261**
2015	0	0	0	0	0	153	496	469	163	151	76	0	**1508**
2016	0	0	0	0	0	0	473	468	209	92	57	26	**1325**
2017	0	0	0	0	0	141	472	427	148	0	0	0	**1188**
2018	0	0	0	0	0	168	362	195	42	0	0	0	**767**
2019	0	0	0	0	0	30	498	454	358	185	78	15	**1617**
1994-2008 Average	**8**					**13**	**326**	**356**	**170**	**80**	**49**	**33**	**1036**
2009-2019 Average	**0**					**48**	**377**	**359**	**174**	**77**	**35**	**4**	**1073**

Note: Diversions were reduced to 63.6% (260 acres out of 409 acres) of total diversions to account for only diversions that irrigated fields within the Missouri Heights Study Area.

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Missouri Heights Needham Ditch Diversion Records

Diversion Summary in Acre Feet

YEAR	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	TOTAL
1994	0	0	0	0	0	0	509	537	172	151	168	173	**1709**
1995	92	0	0	0	0	0	410	918	521	371	175	259	**2745**
1996	0	0	0	0	0	0	276	903	334	172	200	170	**2055**
1997	132	0	0	0	0	7	501	595	430	222	224	238	**2350**
1998	46	0	0	0	0	0	457	831	616	181	199	314	**2644**
1999	59	0	0	0	0	256	920	902	212	170	165	171	**2855**
2000	163	0	0	0	0	0	752	529	170	175	184	233	**2205**
2001	0	0	0	0	0	0	432	648	176	173	150	178	**1757**
2002	0	0	0	0	0	20	223	160	151	117	125	18	**814**
2003	0	0	0	0	0	0	427	732	110	224	247	253	**1994**
2004	0	0	0	0	0	0	699	620	181	150	141	147	**1937**
2005	48	0	0	0	0	0	0	935	466	190	265	336	**2241**
2006	0	0	0	0	0	0	971	675	173	175	169	211	**2373**
2007	0	0	0	0	0	0	920	753	331	204	187	196	**2592**
2008	0	0	0	0	0	0	623	845	634	182	165	153	**2603**
2009	0	0	0	0	0	0	932	904	441	192	175	183	**2827**
2010	0	0	0	0	0	0	502	798	205	182	185	154	**2026**
2011	0	0	0	0	0	0	0	572	666	373	200	148	**1959**
2012	0	0	0	0	0	0	402	165	170	170	165	139	**1211**
2013	0	0	0	0	0	0	456	578	171	168	141	77	**1591**
2014	0	0	0	0	0	0	943	853	226	170	165	158	**2515**
2015	0	0	0	0	0	44	593	856	369	170	165	157	**2354**
2016	0	0	0	0	0	0	603	838	189	170	165	110	**2075**
2017	0	0	0	0	0	0	614	687	170	170	144	110	**1895**
2018	0	0	0	0	0	0	594	195	161	82	53	44	**1131**
2019	0	0	0	0	0	0	1002	922	596	172	165	148	**3006**
1994-2008 Average	**36**	**0**	**0**	**0**	**0**	**19**	**541**	**706**	**312**	**190**	**184**	**203**	**2192**
2009-2019 Average	**0**	**0**	**0**	**0**	**0**	**4**	**604**	**670**	**306**	**184**	**157**	**130**	**2054**

Note: Diversions were reduced to 92.3% (687 acres out of 744 acres) of total diversions to account for only diversions that irrigated fields within the Missouri Heights Study Area.

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Missouri Heights Monarch Ditch Diversion Records

Diversion Summary in Acre Feet

YEAR	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	TOTAL
1994	0	0	0	0	0	0	222	170	0	0	0	0	**391**
1995	0	0	0	0	0	0	0	79	128	0	0	0	**207**
1996	0	0	0	0	0	0	40	110	0	0	0	0	**150**
1997	0	0	0	0	0	0	175	95	8	0	0	0	**278**
1998	0	0	0	0	0	0	28	43	9	0	0	0	**80**
1999	0	0	0	0	0	0	76	124	0	0	0	0	**200**
2000	0	0	0	0	0	0	97	30	0	0	0	0	**127**
2001	0	0	0	0	0	2	125	176	73	16	5	0	**397**
2002	0	0	0	0	0	3	67	0	0	0	0	0	**70**
2003	0	0	0	0	0	0	129	163	0	0	0	0	**292**
2004	0	0	0	0	0	0	111	108	0	0	0	0	**219**
2005	0	0	0	0	0	0	72	101	0	0	0	0	**172**
2006	0	0	0	0	0	0	74	176	0	0	0	0	**249**
2007	0	0	0	0	0	0	97	193	148	0	0	0	**437**
2008	0	0	0	0	0	0	31	176	128	19	0	0	**353**
2009	0	0	0	0	0	0	65	153	57	0	0	0	**274**
2010	0	0	0	0	0	0	31	151	31	0	0	0	**213**
2011	0	0	0	0	0	0	0	123	38	0	0	0	**160**
2012	0	0	0	0	0	0	6	0	0	0	0	0	**6**
2013	0	0	0	0	0	0	94	126	0	0	0	0	**220**
2014	0	0	0	0	0	0	139	156	33	0	0	0	**327**
2015	0	0	0	0	0	0	139	140	0	0	0	0	**279**
2016	0	0	0	0	0	0	94	130	0	0	0	0	**224**
2017	0	0	0	0	0	0	113	176	0	0	0	0	**289**
2018	0	0	0	0	0	0	153	37	0	0	0	0	**190**
2019	0	0	0	0	0	0	155	165	56	0	0	0	**375**
1994-2008 Average	**0**	**0**	**0**	**0**	**0**	**0**	**89**	**116**	**33**	**2**	**0**	**0**	**241**
2009-2019 Average	**0**	**0**	**0**	**0**	**0**	**0**	**90**	**123**	**19**	**0**	**0**	**0**	**232**

Note: Diversions were reduced to 50% (2.5 cfs out of 5.0 cfs) of total diversions to account for only diversions that irrigated fields within the Missouri Heights Study Area.

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Missouri Heights Mountain Meadow Ditch Diversion Records

Diversion Summary in Acre Feet

YEAR	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	TOTAL
1994	115	148	148	134	148	143	1948	253	0	0	0	0	**3038**
1995	66	62	62	56	40	621	2512	3009	1472	8	0	0	**7906**
1996	101	105	105	98	135	800	2938	1313	0	0	0	0	**5595**
1997	60	62	62	56	33	238	2641	1675	181	0	0	0	**5005**
1998	0	0	0	0	454	1579	2376	1984	123	0	0	0	**6515**
1999	0	0	0	0	464	687	2050	895	0	0	0	0	**4096**
2000	0	0	0	0	119	1436	2602	196	0	0	0	0	**4354**
2001	0	0	0	0	165	1081	2781	544	0	0	0	0	**4569**
2002	0	0	0	0	173	754	0	0	0	0	0	0	**927**
2003	0	0	0	0	20	1301	3158	699	0	0	0	0	**5178**
2004	0	0	0	0	286	1053	1102	14	0	0	0	0	**2455**
2005	0	0	0	0	79	1821	3195	1657	0	0	0	0	**6752**
2006	0	0	0	0	167	2381	2348	286	0	0	0	0	**5182**
2007	0	0	0	0	654	1839	1817	0	0	0	0	0	**4310**
2008	0	0	0	0	0	716	2504	2776	449	0	0	0	**6445**
2009	0	0	0	0	0	127	3300	1717	170	0	0	0	**5314**
2010	0	0	0	0	0	0	945	1537	0	0	0	0	**2482**
2011	0	0	0	0	0	193	1477	1617	279	0	0	0	**3566**
2012	0	0	0	0	0	0	0	0	0	0	0	0	**0**
2013	0	0	0	0	0	0	353	232	0	0	0	0	**585**
2014	0	0	0	0	0	0	1092	825	0	0	0	0	**1917**
2015	0	0	0	0	0	0	454	839	0	0	0	0	**1293**
2016	0	0	0	0	0	0	375	449	0	0	0	0	**823**
2017	0	0	0	0	0	0	0	268	196	0	0	0	**463**
2018	0	0	0	0	0	121	463	0	0	0	0	0	**584**
2019	0	0	0	0	372	1770	2082	2245	663	107	0	0	**7239**
1988-2008 Average	**23**	**25**	**25**	**23**	**196**	**1097**	**2265**	**1020**	**148**	**1**	**0**	**0**	**4822**
2009-2019 Average	**0**	**0**	**0**	**0**	**34**	**201**	**958**	**884**	**119**	**10**	**0**	**0**	**2206**

Note:

1: All of the diversions from the Mountain Meadow Ditch irrigated fields are located in Missouri Heights (no reduction).

2: Mountain Meadow Ditch diversions equal total diversions minus reservoir releases.

3: Per water commissioner comments, the 2009-2013 average was used in April and May 2011, due to lack of diversion records

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Missouri Heights Spring Park Reservoir Diversion Records

Diversion Summary in Acre Feet

YEAR	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	TOTAL
1994	0	0	0	0	0	0	1446	530	601	442	0	0	**3019**
1995	0	0	0	0	0	0	1203	3009	1490	792	470	40	**7005**
1996	0	0	0	0	0	0	2908	1313	649	704	188	59	**5822**
1997	0	0	0	0	0	0	1372	1440	805	531	0	0	**4148**
1998	0	0	0	0	0	0	1206	1293	481	603	190	83	**3856**
1999	0	0	0	0	14	305	419	573	565	399	104	324	**2702**
2000	0	0	0	0	0	79	988	658	639	194	0	109	**2666**
2001	0	0	0	0	0	0	1079	480	553	449	250	104	**2916**
2002	0	0	0	0	0	373	240	20	0	0	0	0	**632**
2003	0	0	0	0	0	60	698	369	0	0	0	0	**1127**
2004	0	0	0	0	0	0	679	14	0	0	0	0	**693**
2005	0	0	0	0	0	0	1686	1207	0	0	0	0	**2893**
2006	0	0	0	0	0	60	1459	286	0	0	0	0	**1804**
2007	0	0	0	0	0	0	0	0	0	0	0	0	**0**
2008	0	0	0	0	0	0	331	1852	232	0	0	0	**2415**
2009	0	0	0	0	0	0	649	845	555	959	431	0	**3438**
2010	0	0	0	0	0	0	0	1195	428	527	423	0	**2573**
2011	0	0	0	0	0	0	0	1617	831	916	835	111	**4311**
2012	0	0	0	0	0	0	791	0	0	0	0	0	**791**
2013	0	0	0	0	0	0	365	978	1187	151	0	0	**2681**
2014	0	0	0	0	0	0	1104	1124	1309	479	0	0	**4016**
2015	0	0	0	0	0	0	454	893	381	453	535	215	**2930**
2016	0	0	0	0	0	0	375	449	371	1186	676	562	**3618**
2017	0	0	0	0	0	0	48	273	542	248	0	0	**1110**
2018	0	0	0	0	0	124	463	305	0	0	0	0	**892**
2019	0	0	0	0	0	0	1328	1817	592	107	0	0	**3844**
1994-2008 Average	**0**	**0**	**0**	**0**	**1**	**58**	**1048**	**870**	**401**	**274**	**80**	**48**	**2780**
2009-2019 Average	**0**	**0**	**0**	**0**	**0**	**11**	**507**	**863**	**563**	**457**	**264**	**81**	**2746**

Note:

1: All of the diversions from the Mountain Meadow Ditch irrigated fields are located in Missouri Heights (no reduction).

2: Spring Park Reservoir Diversions equal Mountain Meadow Ditch diversions minus diversions from cattle creek, Equals direct flow plus releases.

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APPENDIX D: BLANEY-CRIDDLE CALCULATIONS

Title: Missouri Heights Groundwater Study

Crop Consumptive Use Estimate, Modified Blaney-Criddle methodology (S.C.S. Technical Release 21)
enter data in shaded cells
Crop = BLUEGRASS (utilizes Pochop Borelli & Burman's temperature and growth stage coefficients and elevation factors)

Climate Data source: BWCD Weather Station

	Month #	Day #	Date
Start of Growing Season =	4	27	117
End of Growing Season =	10	11	284
Season Length (inclusive) =	168	days	

Latitute (deg.min) = 39.43 — 39.72 Decimal Degrees

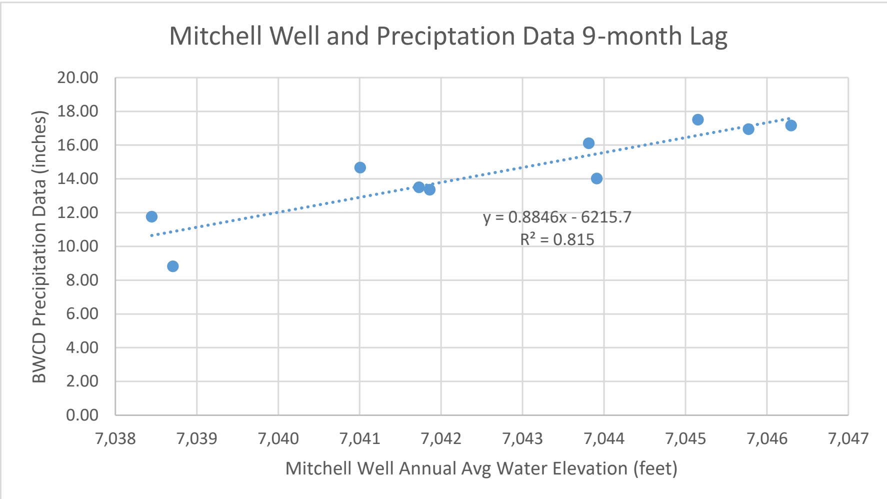
Depth of Application (in) = 1

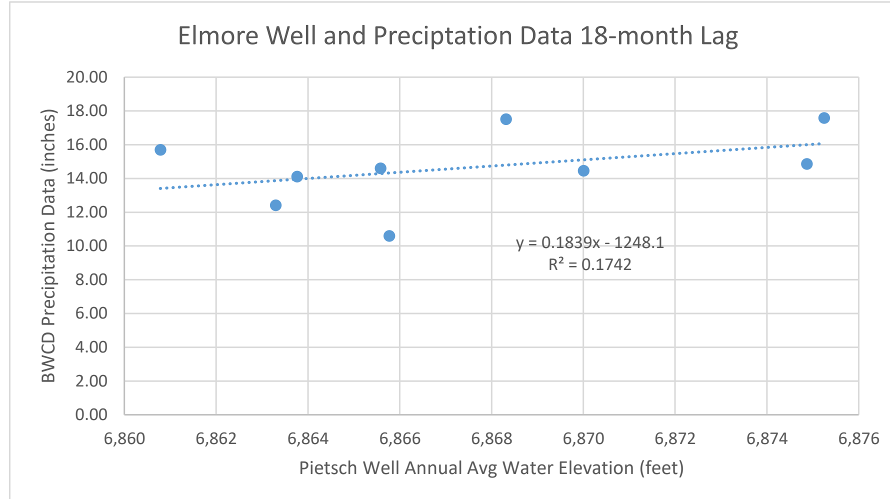
Elevation (ft) = 6700
Elevation Factor = 1.07 (+2.865% per 1,000 ft above 4,429 ft)

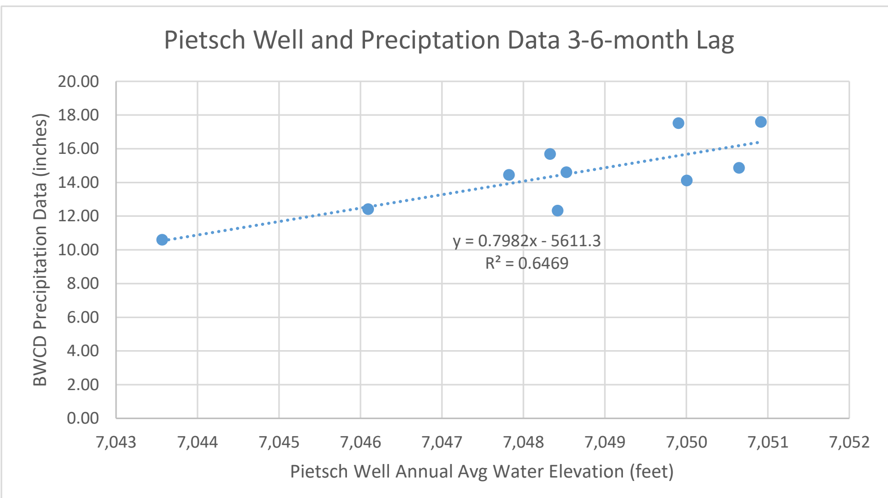
Month	Temp (^oF)	Precip. (in.)
Jan	21.9	1.2
Feb	24.2	1.2
Mar	35.0	1.1
Apr	41.2	2.0
May	50.5	1.4
Jun	61.4	0.8
Jul	65.5	1.6
Aug	63.5	0.9
Sep	56.0	1.2
Oct	43.2	1.4
Nov	32.9	0.9
Dec	22.9	1.5
Annual		15.14

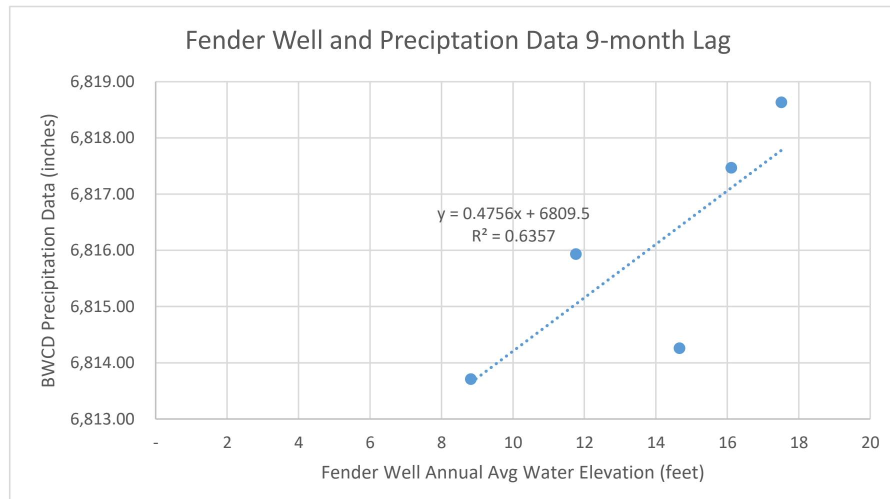
Growing Period	Avg. Period Temp (^oF)	% Daylight	(t*p)/100	Kt	Growth Stage Coefficient Kc	Consumptive Crop Demand (in.)	Period Precip. (in.)	Period Effective Precip. (in.)	Consumptive Irrigation Requirment (in.)	Consumptive Irrigation Requirment (ft.)
Jan										
Feb										
Mar										
Apr	45.2	1.24	0.56	0.80	0.97	0.46	0.27	0.10	0.36	0.03
May	50.5	10.01	5.06	0.82	1.00	4.39	1.43	0.83	3.57	0.30
Jun	61.4	10.02	6.15	0.85	1.10	6.14	0.81	0.52	5.61	0.47
Jul	65.5	10.19	6.68	0.87	1.06	6.52	1.55	1.00	5.52	0.46
Aug	63.5	9.56	6.07	0.86	0.98	5.44	0.90	0.56	4.88	0.41
Sep	56.0	8.37	4.69	0.83	0.97	4.04	1.19	0.68	3.36	0.28
Oct	47.4	2.83	1.34	0.81	0.89	1.03	0.48	0.22	0.80	0.07
Nov										
Dec										
Annual						28.02	6.64	3.92	24.10	2.0

APPENDIX E: PRECIPITATION LAG RESULTS









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