Mancos Watershed Drought Resilience Planning

Basin Characteristics and Model Development Final Report

Prepared for the
Mancos Conservation District

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1 Introduction

The Mancos Conservation District (District) is leading the Mancos Watershed Drought Resilience Planning effort in order to “improve water security for all water uses and values in the Mancos River Basin” (Rank, 2018). The District partnered with Mountain Studies Institute, Mancos Water Conservancy District, Mancos Valley Watershed Group, and Colorado State University’s Colorado Natural Heritage Program to achieve the goals of the effort, which include:

- Engage stakeholders
- Enhance stakeholder relationships and communication
- Identify proactive strategies and actions to:
    - Improve water quality
    - Improve and maintain water-use infrastructure
    - Improve and maintain aquatic and riparian habitat
    - Increase conservation and efficiency among all users

The Drought Resilience Planning effort also required decision support tools in order to describe the current conditions in the basin and evaluate future alternatives. This report presents the current basin characteristics, data availability and gaps, and documents the development of the decision support tools. The decision support tools are intended to be used by the District and their partners in later phases of the Planning effort for comparative analysis.

The report is organized into the following sections:

- Section 1: Introduction
- Section 2: Basin Characteristics, Data Availability, and Current Consumptive Use
- Section 3: Model Development and Example Scenarios
- Section 4: Recommendations and Next Steps

To support the Drought Resilience Planning, Wilson Water Group (WWG) was selected to refine the Mancos River representation in the State of Colorado’s Colorado Decision Support System (CDSS) water rights allocation model. The Mancos River was represented at a high-level in the San Juan CDSS model, appropriate for investigating big-picture planning questions in Southwestern Colorado. The CDSS model includes Jackson Gulch Reservoir, the total consumptive use from irrigation, and the streamflow leaving the Mancos River at the Colorado-New Mexico state line. WWG refined the model to provide more detail in the Mancos River basin, specifically for use in understanding smaller tributary flows, ditch-to-ditch interactions, and “what-if” scenarios on a stream reach scale. The details of model refinement are presented in Section 3.

2 Basin Characteristics and Data Availability

The Mancos River Basin stretches from the southern San Juan Mountains through a semi-arid, fertile river valley and encompasses Mesa Verde National Park and the desert canyons near the Colorado-New Mexico state line. The basin includes a great diversity of habitats, ranging from the alpine tundra of the mountain tops to the desert scrublands of the canyon district. Landowners in the basin include the Ute Mountain Ute Tribe, a variety of government agencies, and private owners. The need to maintain and enhance the resources offered by this diverse basin is the motivation for embarking on a Drought Resilience Planning effort.

The primary objective of this section is to provide a summary of existing consumptive water use within the Mancos River basin, with an emphasis on irrigation and municipal use. A major task for the Drought Resilience Planning was to review and assess the available information; update and refine the information; identify data gaps; and recommend future data collection efforts. The information collected as part of the data inventory process served as a key component to both identify needs in the Mancos River basin and to develop modeling tools, which will be used in future stages of the effort.

Figure 2-1 shows the Mancos River watershed boundaries, major highways, streamflow gages, reservoirs, and land ownership designation. Approximately 65 percent of the land within the watershed boundary is part of an Indian Reservation, with the Ute Mountain Ute Tribe holding the largest portion, followed by the Navajo Tribe in New Mexico and then a very small portion held by the Southern Ute Indian Tribe. Approximately 23 percent of the land is held by Federal or State government, with the primary agencies being the National Park Service (Mesa Verde), Bureau of Land Management (BLM), the Forest Service, and the State of Colorado. The remaining 12 percent of the land is privately owned (Mancos Valley Watershed Group, 2011). A significant portion of the private land is concentrated in “The Valley” portion of the basin, located around the Town of Mancos. As the map in **Figure 2-2** illustrates, the majority of the irrigation and municipal use takes place around the Town of Mancos. This area is the focus of this report, and includes an active agricultural community, which primarily produces cattle. In recent years, the character of the community has started to change, as some of the large ranches are being sub-divided and more people are moving to the area to pursue other interests.

The major reservoir in the basin is Jackson Gulch Reservoir. This Bureau of Reclamation project is located on the small tributary of Jackson Gulch, between the West Mancos River and Chicken Creek, and provides supplemental irrigation water to farms throughout the valley - either by direct reservoir release or by exchange. In addition to providing irrigation water, releases from Jackson Gulch Reservoir generate hydropower and pipelines deliver water directly to the three municipal water providers: the Town of Mancos, Mancos Rural Water, and Mesa Verde National Park. The reservoir is the heart of Mancos State Park, providing recreational benefits to the community. Water is diverted from West Mancos River into the Jackson Gulch Inlet Canal for storage in the reservoir. Water is primarily released from the reservoir and delivered back to West Mancos River by the Jackson Gulch Outlet, with a small amount released down Jackson Gulch. More details on Jackson Gulch Reservoir operations are found in the “Reservoir and Diversion System Operations” Subsection.

Starting about ten years ago, the agricultural community began transitioning from open-channel ditches and primarily flood irrigation to pressurized delivery systems, which provides more opportunity for gated pipe and sprinkler irrigation. In 2004, the Mancos Conservation District achieved the designation of Salinity Control area by the NRCS. This opened the possibility for ranches to apply for grants from NRCS and financing from CWCB to convert to underground pipe delivery systems. This change has increased the irrigation efficiency, which in turn, reduces the amount of salt leaching. More information on historical and current irrigation practices can be found in the "Irrigation Practices and Return Flows" Subsection.

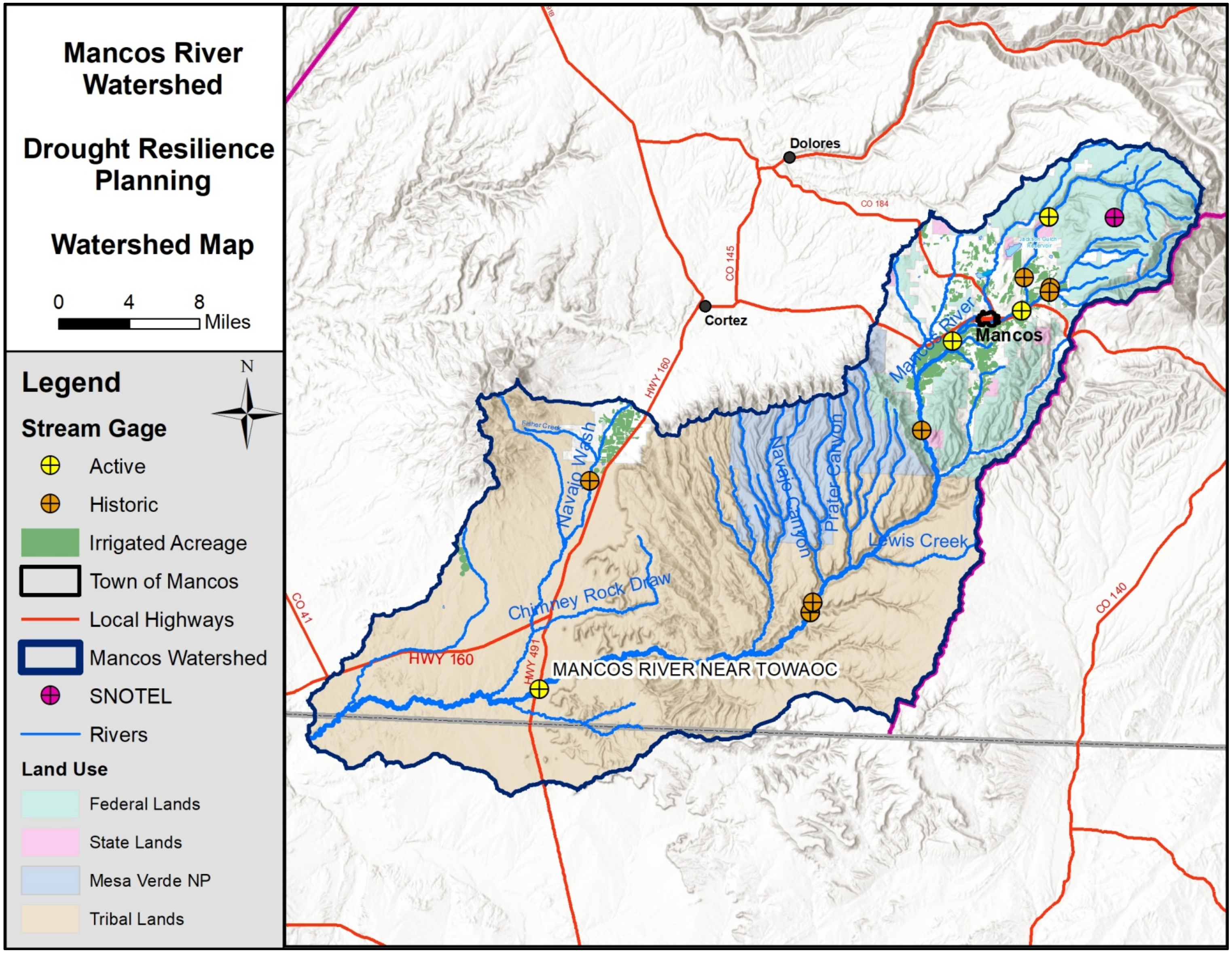


Figure 2-1: Mancos River Basin Vicinity Map

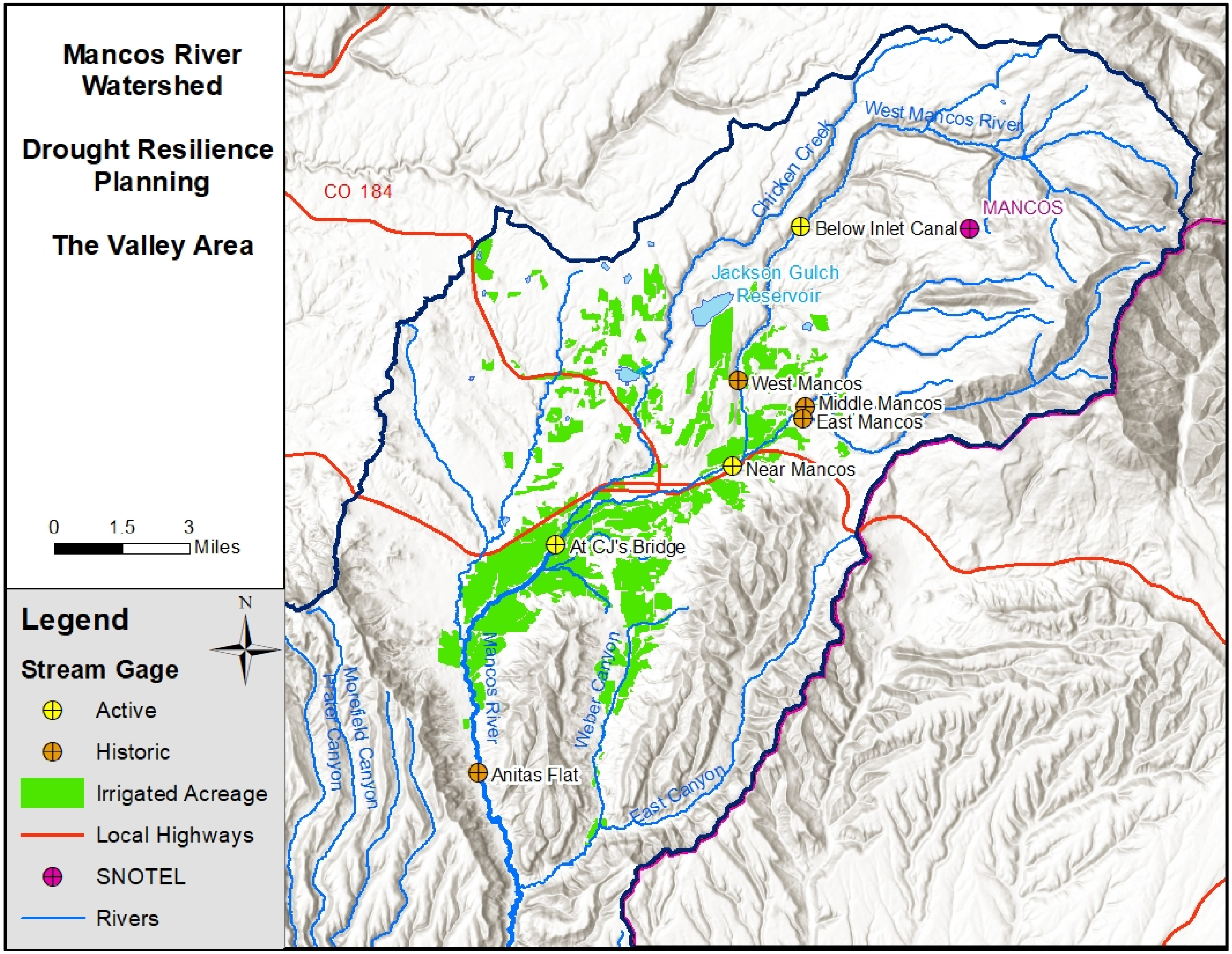


Figure 2-2: Mancos River Valley Area Map

Data Assessment and Basin Characteristics

The following information is used to understand basin characteristics, quantify existing water use, and develop a planning model to investigate options to meet stakeholder concerns:

1. Streamflow measurements
2. Climate data
3. Irrigated acreage
4. Water rights
5. Diversion records
6. Reservoir and Diversion System Operations
7. Irrigation practices
8. Return flow parameters

The Colorado Water Conservation Board (CWCB) and the Colorado Division of Water Resources (DWR) have developed and updated the Colorado Decision Support System (CDSS) to aid in water resources planning. The data assessment was not only used to understand basin characteristics, it was also used to enhance the CDSS consumptive use model (StateCU) and water rights allocation model (StateMod). StateCU is used to understand the existing crop demands, consumptive use, and shortages outlined in Section 3. StateMod should only be used in a comparative fashion, to understand expected changes in streamflow and existing consumptive use due to proposed projects and operations.

2.1.1 Streamflow Measurements

There are four stream gages currently measuring streamflow in the Mancos River basin - one is operated by the United States Geological Survey (USGS) and three are operated by Colorado Division of Water Resources (DWR). In addition, seven inactive gages with varying periods of record provide additional information about flow in the basin.

Table 2-1 summarizes the drainage area, period of record, and average annual flow for both the active and inactive streamflow gages. **Figure 2-1** includes the location of the gages. Although more streamflow information is always helpful, the spatial coverage in the basin is adequate for modeling and planning efforts. When asked, DWR did not identify additional gage locations that would help with water right administration. Depending on the focus of future alternatives, it may be useful to re-activate the Mancos River at Anitas Flat below Mancos or the gages on either East Mancos or Middle Mancos. Note that Mancos Water Conservancy District (MWCD) is currently exploring options with DWR to install a gage on the East Mancos, below the confluence with the Middle Mancos.

Table 2-1: Summary of Active and Inactive Streamflow Gages in the Mancos River Basin

Stream Gage Name	Gage ID	Status	Drainage Area (Sq. Mi.)	Period of Record	Average Annual Flow (Acre-Feet)
West Mancos River Near Mancos	09368500	Inactive	39.4	1939 - 1953	27,585
West Mancos River Below Jackson Gulch Reservoir Inlet Canal	MANJACCO	Active/ DWR	30.8	2005 - Present	8,446
East Mancos River Near Mancos	09369000	Inactive	11.9	1937 - 1951	7,716
Middle Mancos River Near Mancos	09369500	Inactive	12.1	1938 - 1951	5,426
Mancos River Near Mancos	MANMANCO (09370000)	Active/ DWR	72	1932 - 1938, 1954 - 1957, 1971 - Present	25,432
Mancos River at CJ's Bridge near Mancos	MANCHICO	Active/ DWR	106	2016 - 2018	41,789
Mancos River At Anitas Flat Below Mancos	09370600	Inactive	162	2004 - 2015	21,543
Mancos River Near Cortez	09370800	Inactive	302	1976 - 1979	19,016
Mancos River Below Johnson Canyon Near Cortez	09370820	Inactive	320	1979 - 1982	46,909
Mancos River Near Towaoc	09371000	Active	526	1921 - 1943, 1951 - Present	34,667
Navajo Wash Near Towaoc	09371002	Inactive	26.3	1986 - 1993	6,817

The Mancos River near Mancos stream gage has been moved twice. According to the Division Hydrographer Brian Leavesley, the gage was originally operated by the USGS from 1932 through 1938 under ID 09370000 and was located upstream of the Root and Ratliff/Smith Ditch diversion structure. DWR began to operate the gage from 1954 through 1956 and again from 1971 through 1974 at the original USGS gage site. In 1974, the USGS gaging site was discontinued and a new gage was installed at Montezuma County Road 43 Bridge over the Mancos River, downstream of the Root and Ratliff/Smith Ditch diversion structure. Then in 1999, DWR moved the gage to its current location, which is again upstream of the Root and Ratliff/Smith Ditch diversion structure. The location during different periods is important to understand since the Root and Ratliff/Smith Ditch diversions are often a significant portion of the streamflow.

The streamflow in the Mancos River basin is highly variable depending on snowpack and late summer monsoons.

Figure 2-3 shows average daily streamflow flow for the gage at Towaoc (most downstream location and the longest period of record, providing data from 1921 through 1943 and 1951 to present) and the gages near the end of the Mancos Valley. The Anitas Flat gage provides data from 2004 through 2015 and the CJ's Bridge gage provides data from 2016 to present. The figure examines 2007 through 2017, a recent period that is representative of the range of streamflow in the basin. **Figure 2-4** features the same gages, but focuses on the period 2015 through 2017, to show the average daily streamflow more clearly. Similarly, **Figure 2-5** shows average daily flow from 2007 through 2017 for the Mancos River near Mancos gage and the West Mancos River below the Jackson Gulch Inlet Canal gage.

The following observations can be made based on **Figures 2-3, 2-4 and 2-5**:

- The runoff patterns are similar across the basin, with the Mancos River near Towaoc gage showing a much larger response to late summer monsoon rains. For example, the Towaoc gage has very similar streamflow magnitudes as the Anitas Flat or CJ Bridge gages during the winter and spring runoff. The Towaoc gage has more flow during the late summer and early fall, generally for only a few days. This indicates a quick streamflow response to rain events.
- The upper gages for the Mancos River near Mancos and the West Mancos River do not have a strong monsoon signature.
- This period includes a relatively wet year, 2017, followed by one of the driest years on record, 2018, as highlighted in **Figure 2-4**. The only gage that shows an increase in flow during the spring runoff is the Mancos River near Mancos gage, as highlighted in **Figure 2-5**.
- The West Mancos River below the Inlet Canal gage is highly influenced by the reservoir operations. Jackson Gulch Reservoir Inlet Canal diverts water both for storage and hydropower generation.
- Reservoir storage releases, and contributing flow from the Middle and East Mancos Rivers, are included in the Mancos River near Mancos gaged flow.

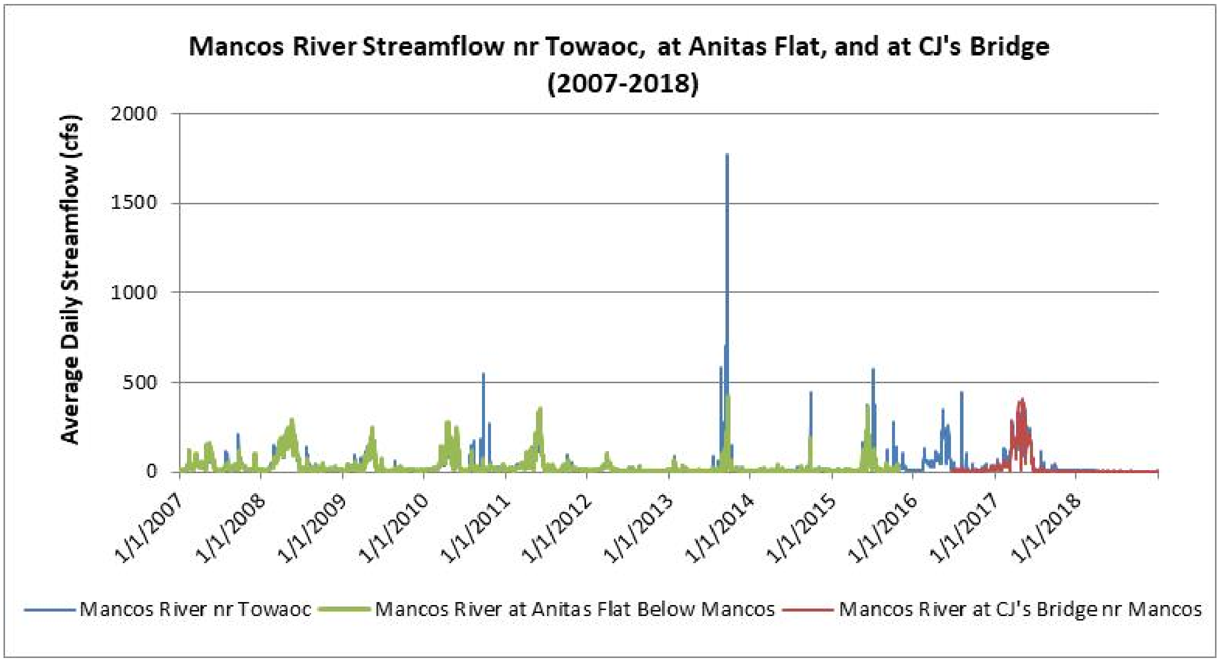


Figure 2-3: Mancos River Average Daily Streamflow near Towaoc, at Anitas Flat below Mancos, and at CJ's Bridge near Mancos (2007-2018)

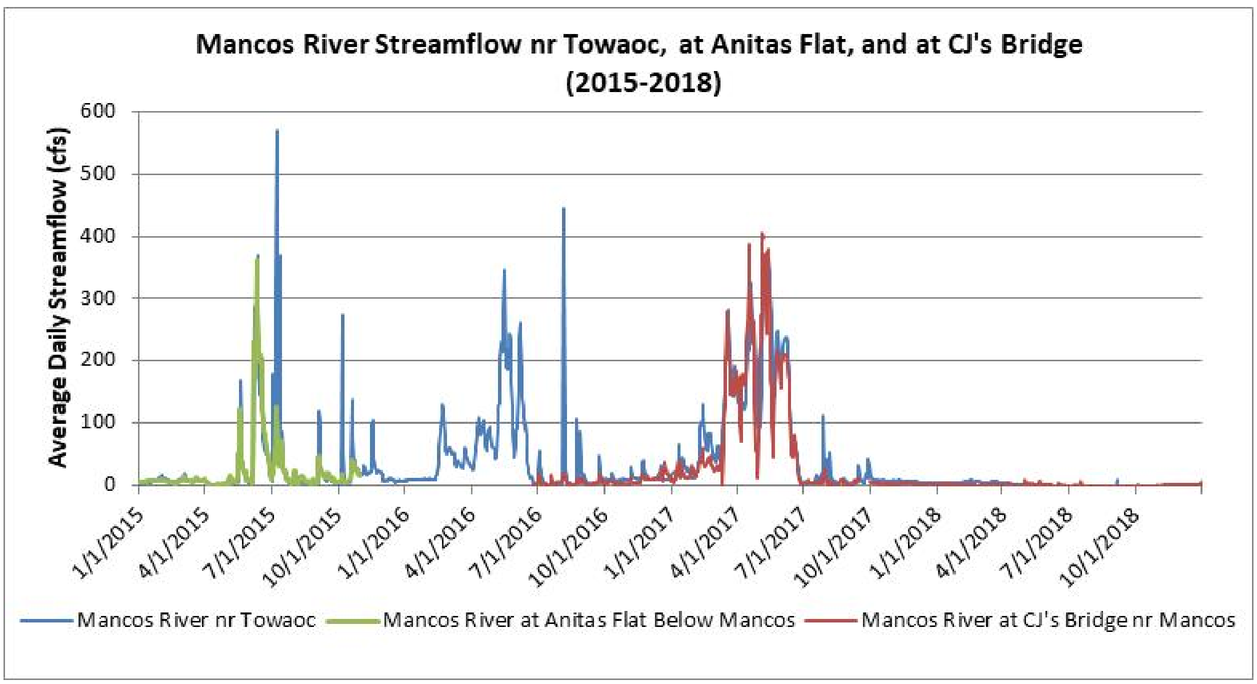


Figure 2-4: Mancos River Average Daily Streamflow near Towaoc, at Anitas Flat below Mancos, and at CJ's Bridge near Mancos (2015-2018)

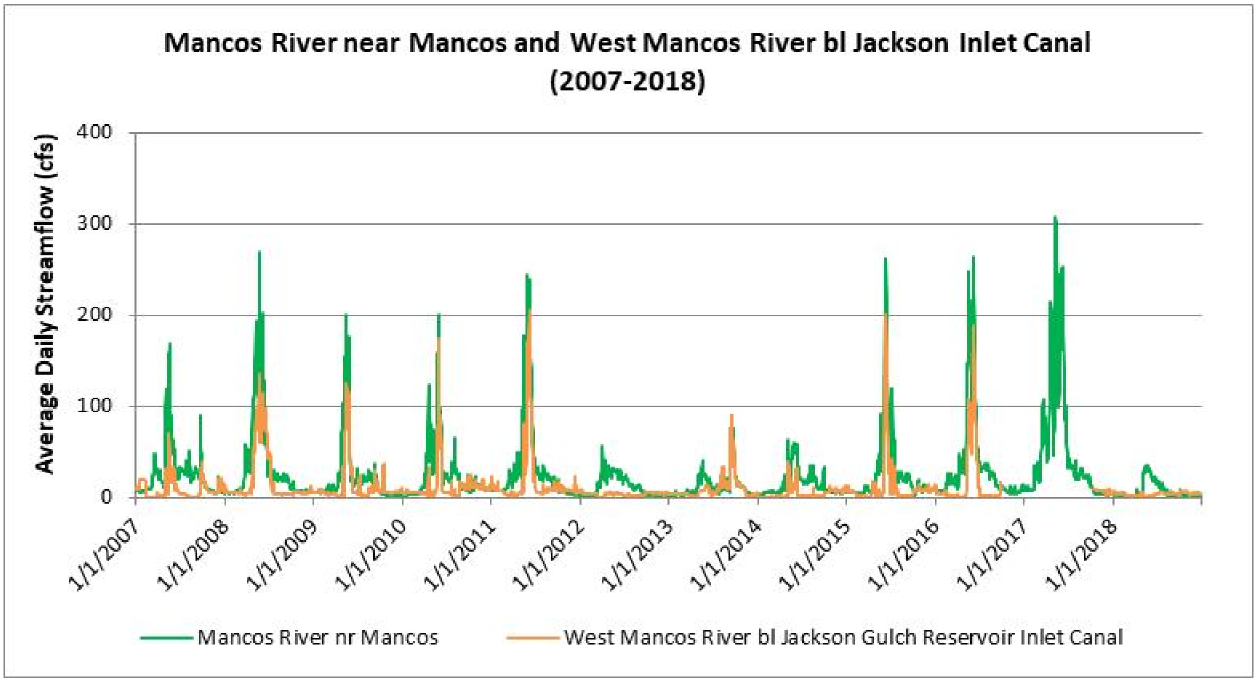


Figure 2-5: Mancos River near Mancos and West Mancos River below Jackson Inlet Canal Average Daily Streamflow (2007-2018)

Figure 2-6 shows the average monthly flow at the Mancos River near Mancos gage from 1951 through 2018. The monthly flows are also highly variable, with streamflow in May providing 31 percent of the average annual streamflow, and January and February only providing 1 percent of the average annual streamflow. Snowmelt runoff in April, May, and June accounts for nearly 70 percent of the average annual streamflow.

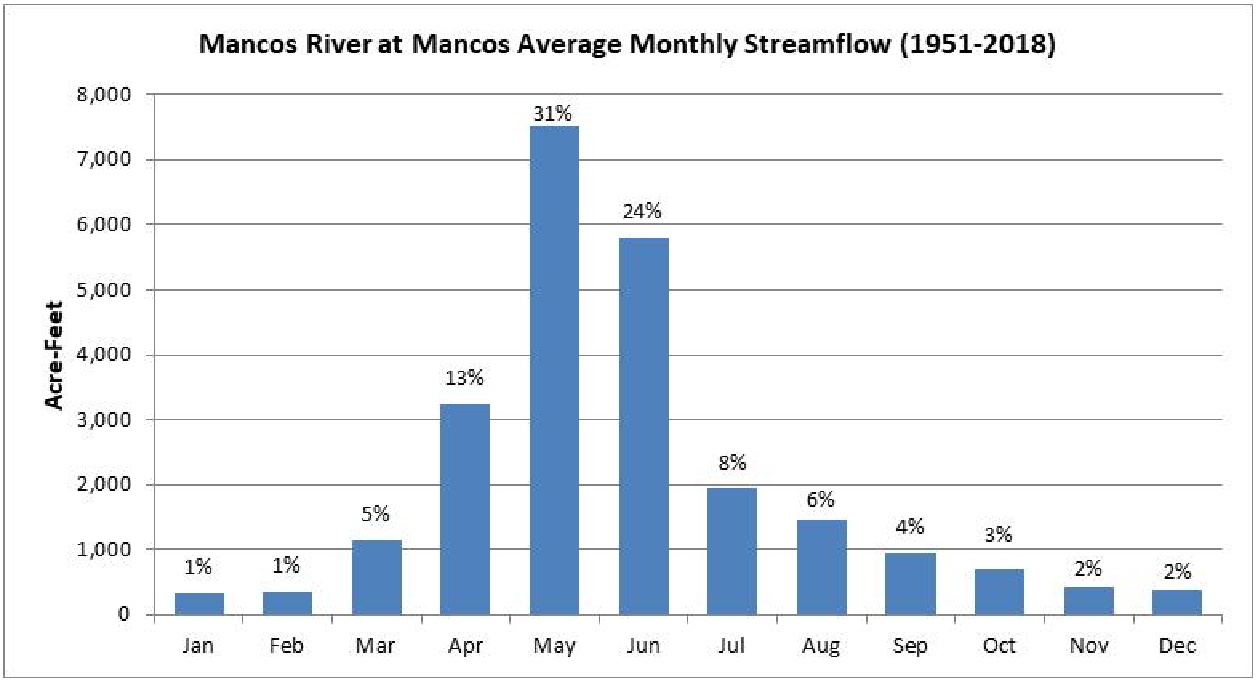


Figure 2-6: Mancos River at Mancos Average Monthly Streamflow (1951-2018)

Figure 2-7 shows this historical annual streamflow volume for Mancos River near Towaoc for the period 1922 through 2018 (the period 1945 through 1952 is missing from the gage record), along with the 10-year running average. As shown, streamflow varies significantly over the period. The following observations can be made based on the figure:

- The 10-year running average is also highly variable; the 10-year running average based on flow during the 1950s is similar to the recent 10-year running average.
- The dry years during the drought of the 1950s and early 1960s were punctuated with infrequent above average years, and the more recent period appears to have a similar trend.
- The driest year on record at the Mancos River near Towaoc gage location was 2018, followed by 2002, 1977, and 1959.
- The difference in annual streamflow between 2017 and 2018 is more than 47,800 acre-feet at the Mancos River near Towaoc gage; streamflow in 2018 was 3 percent of the 2017 annual streamflow.
- As a point of comparison, annual streamflow in 2018 was 16 percent of 2017 annual streamflow at the Mancos River near Mancos gage.

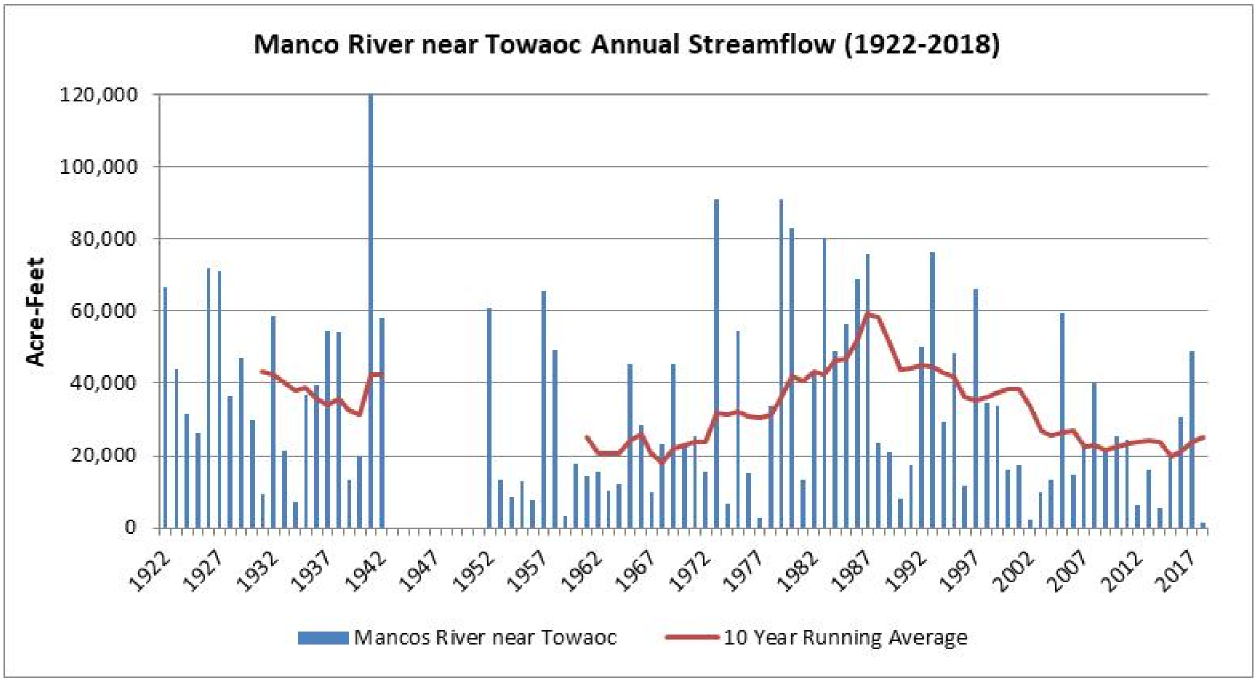


Figure 2-7: Mancos River near Towaoc Annual Streamflow Volume (1922 - 2018)

Although the focus of this effort is on drought resiliency, floods can also be a concern for the Mancos River. The Mancos River near Mancos measures the streamflow just upstream of the town of Mancos. The Colorado Basin River Forecast Center issues long-term water supply forecasts and short-term streamflow forecasts for the gage. More details on water supply forecasts are presented in the Water Supply Forecasting Section 2.1.3. The graph in **Figure 2-8** shows an example streamflow forecast. The “Action Stage” is 5 feet, or about 300 cfs. This level indicates that preparations for a flood event should begin. The “Flood Stage” is 6 feet, or about 800 cfs. This level indicates the stream is creating a hazardous situation for life, property, or commerce. In 2017, the maximum daily flow in the river was 302 cfs. In 2005, the maximum daily flow in the river reached 682 cfs, just shy of flood stage. The maximum recorded flow at the gage was 1,040 cfs on June 15, 1975. During this time period, the gage was located below the Root and Ratliff/Smith Ditch diversion structure, which was diverting about 27 cfs on the same day, putting the total streamflow at the current gage location closer to 1,067 cfs.

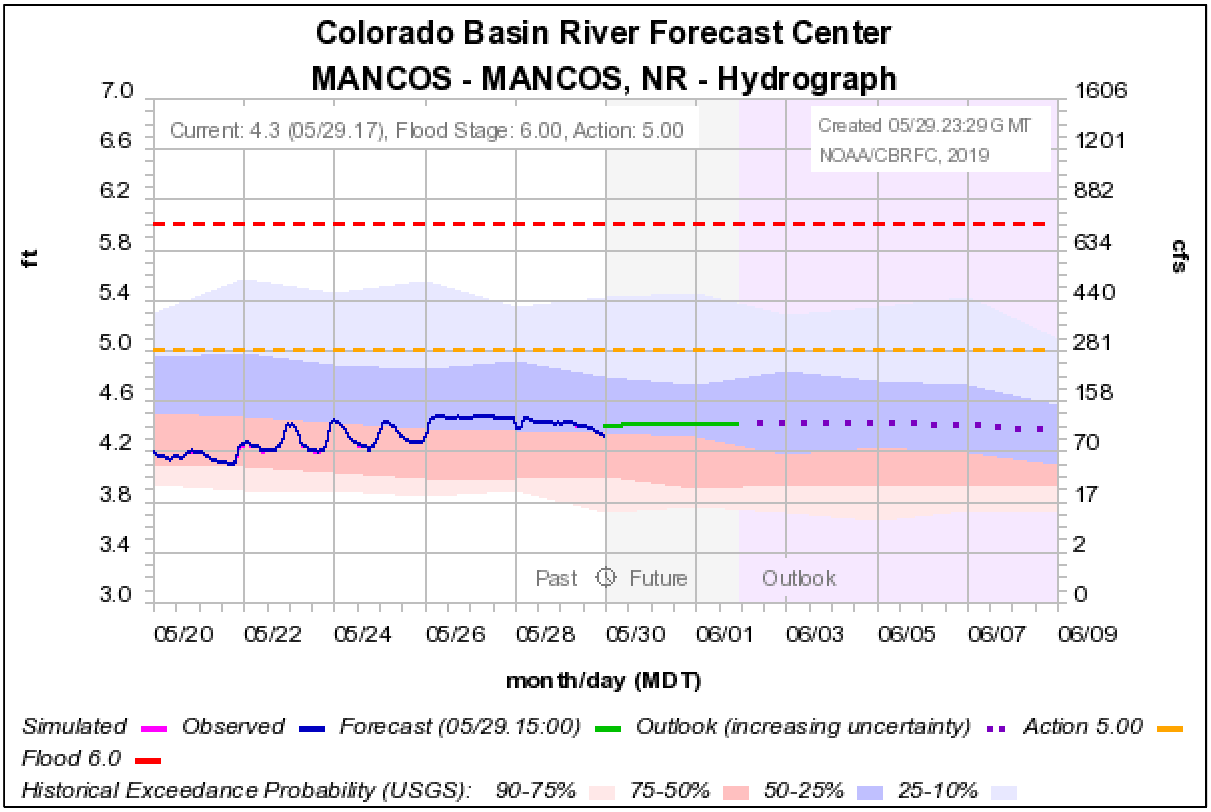


Figure 2-8: Example Streamflow Forecast for Mancos River near Mancos

Throughout this report, a representative dry, average and wet hydrologic year are used to illustrate varying basin characteristics and water use. The representative dry year selected is 2012; it was a significantly dry year and had similar timing and runoff volume as other severe drought years, including 1977, 2002, 2014 and 2018. 2012 was selected instead of the more recent 2018 drought year because the diversion records were not yet available for 2018. The representative average year is 2015. This recent year was similar to other average years, such as 2007, 2009, 2010, and 2011; however, 2015 was a particularly cool year and the peak runoff was delayed until June. Generally, the peak runoff occurs in May. The selected representative wet year is 2005. This was the wettest year in the recent period, and had similar runoff patterns to 2017. The three representative years are plotted together in **Figure 2-9**. The monthly streamflow volume for the three years is shown in **Figure 2-10**. This highlights the large variability in volume and timing of streamflow in the basin.

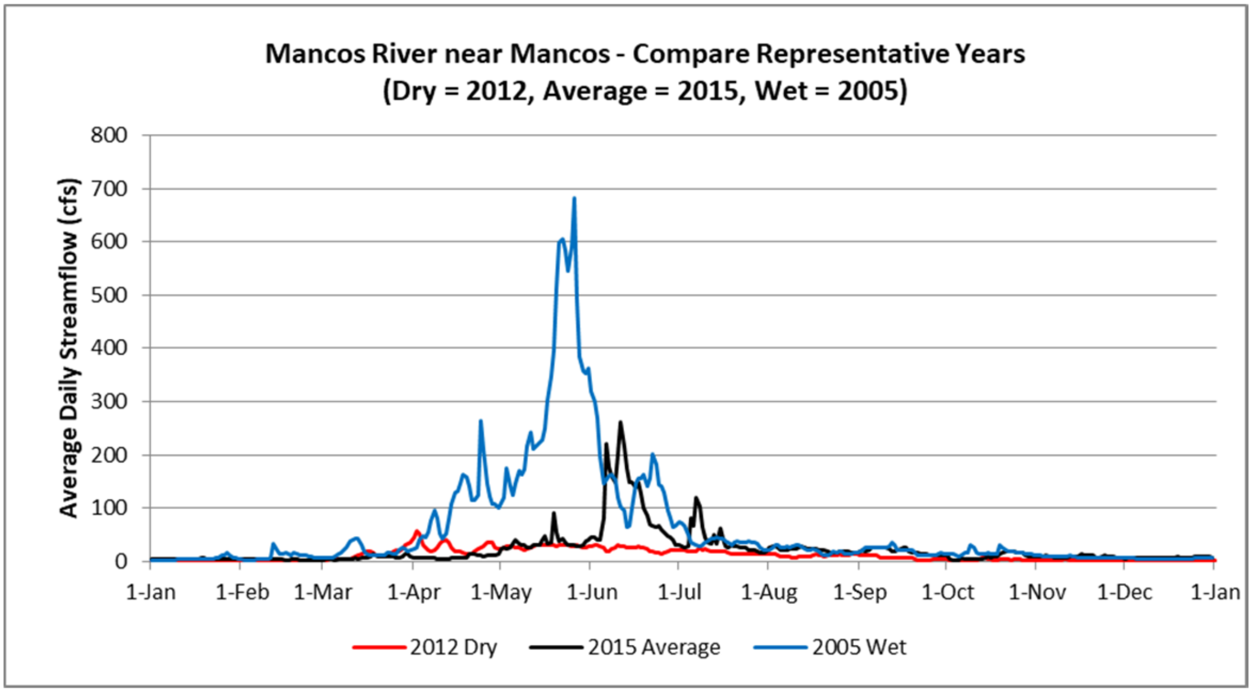


Figure 2-9: Average Daily Streamflow in Representative Dry, Average, and Wet Years for the Mancos River near Mancos

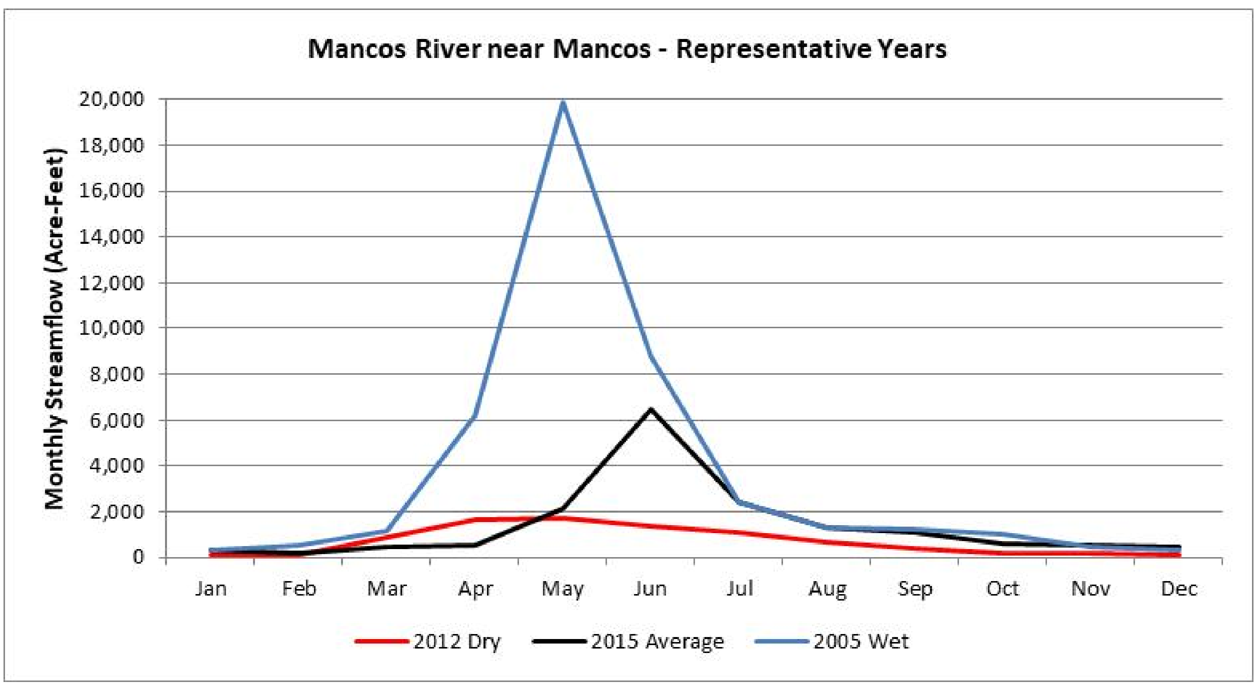


Figure 2-10: Monthly Streamflow Volume for Representative Dry, Average, and Wet Years for the Mancos River near Mancos

2.1.2 Climate Data

Crop irrigation demands are dependent on weather during the irrigation season, with temperature being the primary driver. **Figure 2-11** highlights the variability of average irrigation season temperature (April through September) at the National Weather Service Cooperative Observer Program (COOP) station in Mesa Verde National Park. This station was selected for the graph because of long term data availability (1924 to present). The climate station shows a large amount of year-to-year variability. The 10-year running average does not show a clear long-term trend; however, there appears to be a recent trend (since the 1990s) towards warmer temperatures during the irrigation season. This upward temperature trend coincides with the recent trend (since the 1990s) of low streamflow, combining to stress the hydrologic system. However, the higher current temperatures are still cooler during the irrigation season than during the 1930s, which was also a period of severe drought that helped motivate the construction of Jackson Gulch Reservoir.

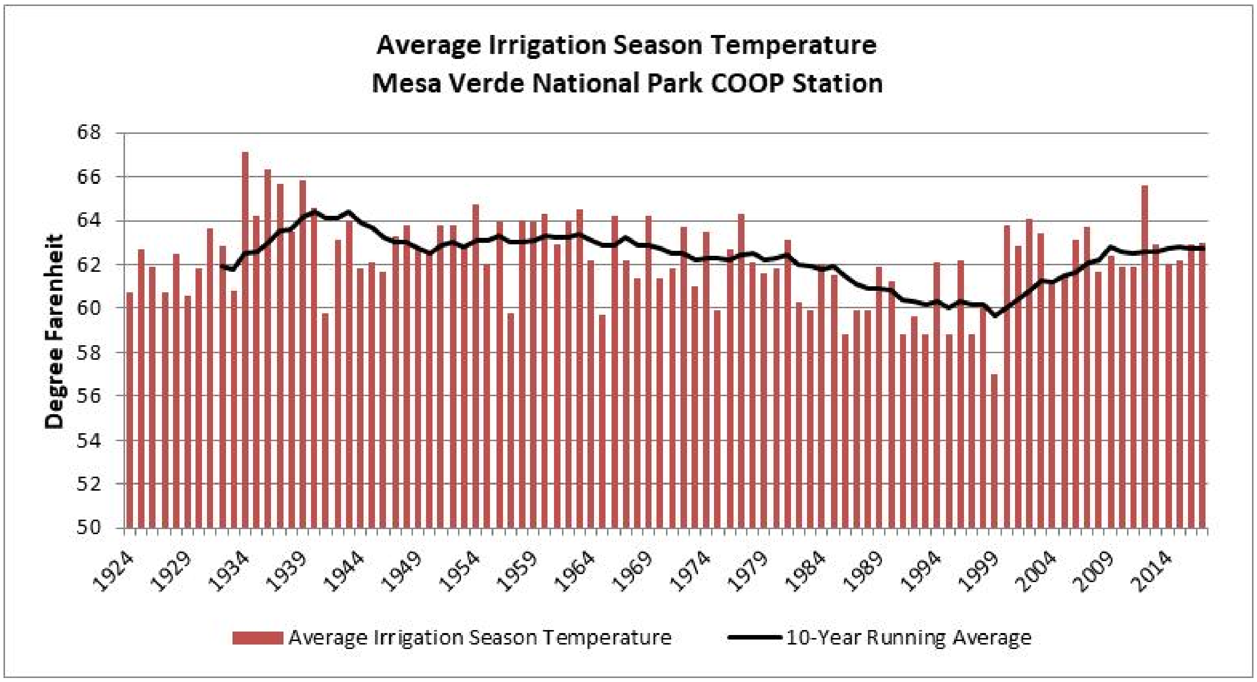


Figure 2-11: Average Irrigation Season Temperature at Mesa Verde National Park (1924 - 2017)

Precipitation during the irrigation season reduces the amount of water required from irrigation diversions to meet crop demands. **Figure 2-12** highlights the variability of total irrigation season precipitation (April through September) at the long-term COOP station in Mesa Verde National Park. As shown, the total irrigation season precipitation varies from a high of 16 inches in 1957 to a low of only 3.6 inches in 2012. The 10-year running average shows that the recent period is relatively typical for the area.

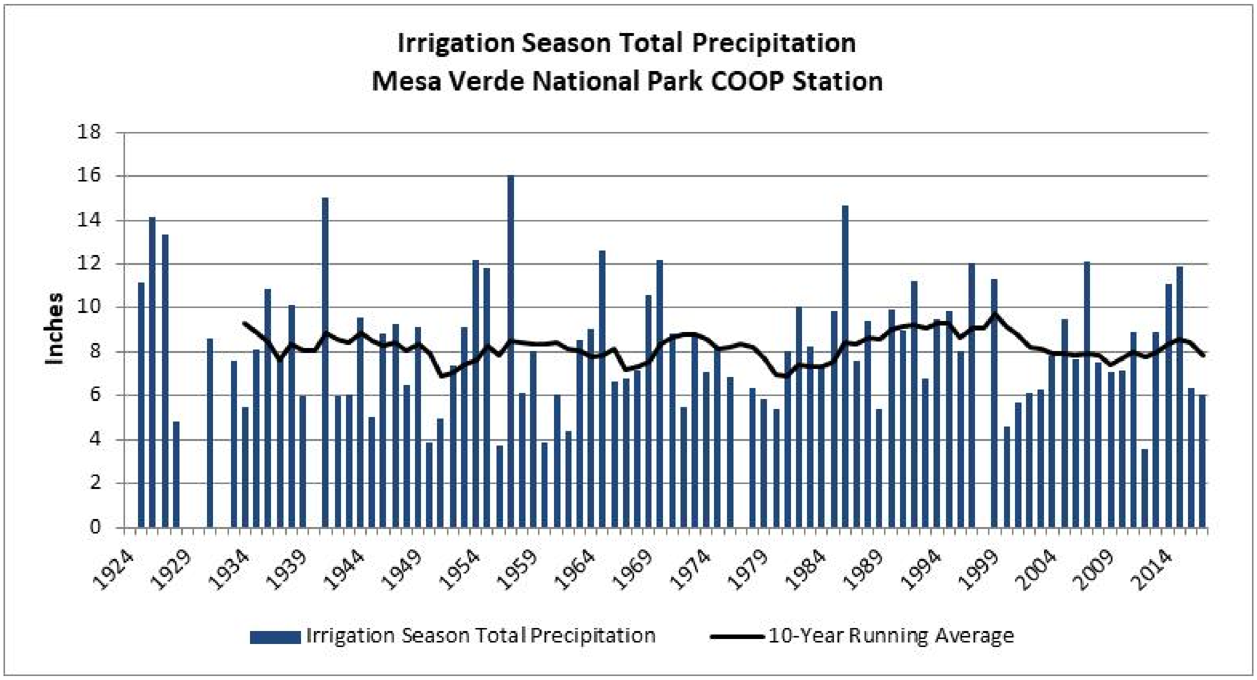


Figure 2-12: Total Irrigation Season Precipitation at Mesa Verde National Park (1924-2017)

There is very good temperature and precipitation data coverage for the Mancos River valley, covering an extended historical period. A COOP station in Mancos was re-commissioned in September 1990 and provides temperature and precipitation data immediately adjacent to the majority of the irrigation fields. A Colorado Agricultural Meteorological Network (CoAgMet) station measuring other key climate information, including wind speed and solar radiation, was installed in 2010 a few miles southwest of Mancos in an agricultural area. This station provides additional information, including reference crop demands. Temperature is generally about 3 degrees Fahrenheit cooler at the two Mancos climate stations than at the Mesa Verde Station due to their location within the Mancos River valley. The basin has a good climate station network and new stations are not recommended for future planning efforts in the basin.

2.1.3 Water Supply Forecasting

In Colorado, two Federal agencies are responsible for developing annual runoff projections for streamgage locations around the state; the Natural Resource Conservation Service (NRCS) under the U.S. Department of Agriculture, and the Colorado River Basin Forecast Center (CRBFC) under the Department of Commerce. These forecasts are used by water managers to help plan for, and better utilize, available water supplies each year. Historically, the two agencies have worked collaboratively to develop joint monthly runoff forecasts. The forecasts are primarily generated using data from snowpack conditions recorded at SNOTEL sites positioned in the headwaters of high elevation watersheds, such as the Mancos site (shown in **Figure 2-1** and **Figure 2-2)**.

The Mancos Water Conservancy District operates Jackson Gulch Reservoir and, because the reservoir is off-channel and not managed for flood control, streamflow forecasts are not a significant consideration to reservoir operations. However, Reclamation does use the streamflow forecast from CBRFC to predict water allocation. CBRFC provides forecasts on the first of the month from January through June that estimate the total volume of water supplies (natural flow) from April through July, corresponding to the runoff season. CBRFC publishes the percent error between the forecasted versus actual water supply to help Reclamation, and other water planners, understand the reliability of their forecasts. A forecast that is highly prone to error may benefit from a new SNOTEL site in the watershed. The accuracy estimates for the April 1 and May 1 fifty percent exceedance forecast volumes for 2014 through 2018 are shown in **Table 2-2**.

As shown, with the exception of 2015, the April 1 forecasts are within 15 percent of actual water supply and the May 1 forecasts are within 10 percent of actual water supply. These are considered very accurate forecasts; and additional snow measurement sites in the Mancos watershed are not recommended. Note that CBRFC was unable to accurately forecast conditions in 2015. This was due to what became known as the "Miracle May" when the entire state of Colorado received above average precipitation that bolstered runoff after the May 1 forecasts. The 2015 May 1 forecast under-predicted runoff in the Mancos River basin by over 50 percent; this level of significant under-prediction was typical around the state.

Table 2-2: Colorado River Basin Forecast Center
Historical Water Supply Percent Error for the Mancos River near Mancos

Year	Percent Error*	
	April 1 Forecast	May 1 Forecast
2014	13%	9%
2015	-26%	-55%
2016	7%	-1%
2017	14%	9%
2018	6%	-5%

*Percent Error = (Actual Flow - Estimated Flow)/Actual Flow

2.1.4 Basin Yield

Streamflow gages measure actual flow that is influenced by upstream water uses and reservoir operations. To support Drought Resilience Planning, it is helpful to understand natural flows. Natural flows are an estimate of stream flows without the effect of current water uses (i.e. streamflow prior to all water development). Total volume and timing of natural flow provides helpful context for watershed management planning. For example, projects to restore streamflow should not create goals that exceed estimated natural flows without an explicit reason. Characterizing natural flows also assists in identifying potential options to re-time (store or release) water to meet shortfalls for both consumptive and non-consumptive uses. In addition, natural flows are developed so we can "superimpose" other water use and management options on the basin, regardless of what has occurred historically.

For the Mancos Watershed, WWG has estimated monthly natural flow for the West Mancos River, Middle Mancos River, and East Mancos River watersheds; and the Mancos River near Towaoc streamflow gage from 1975 through 2017. As shown in **Figure 2-13**, the average monthly natural flow for the West Mancos River is significantly higher than the Middle or East Mancos. Note that the primary source of water for Jackson Gulch Reservoir is the West Mancos River; it is filled from the higher yielding tributary. During natural flow development, several other key observations were made:

- East Mancos, Middle Mancos, and West Mancos River natural flows increase from headwaters to their confluence.
- The majority of the natural flow for the Mancos watershed is derived from snowmelt from East Mancos, Middle Mancos, and West Mancos. These tributaries combine to form the Mancos River just upstream of the Mancos River near Mancos gage.
- Between Mancos River near Mancos and Mancos River near Towaoc, natural flow generally remains the same, and actually decreases in some years, likely from riparian corridor vegetation consuming water.

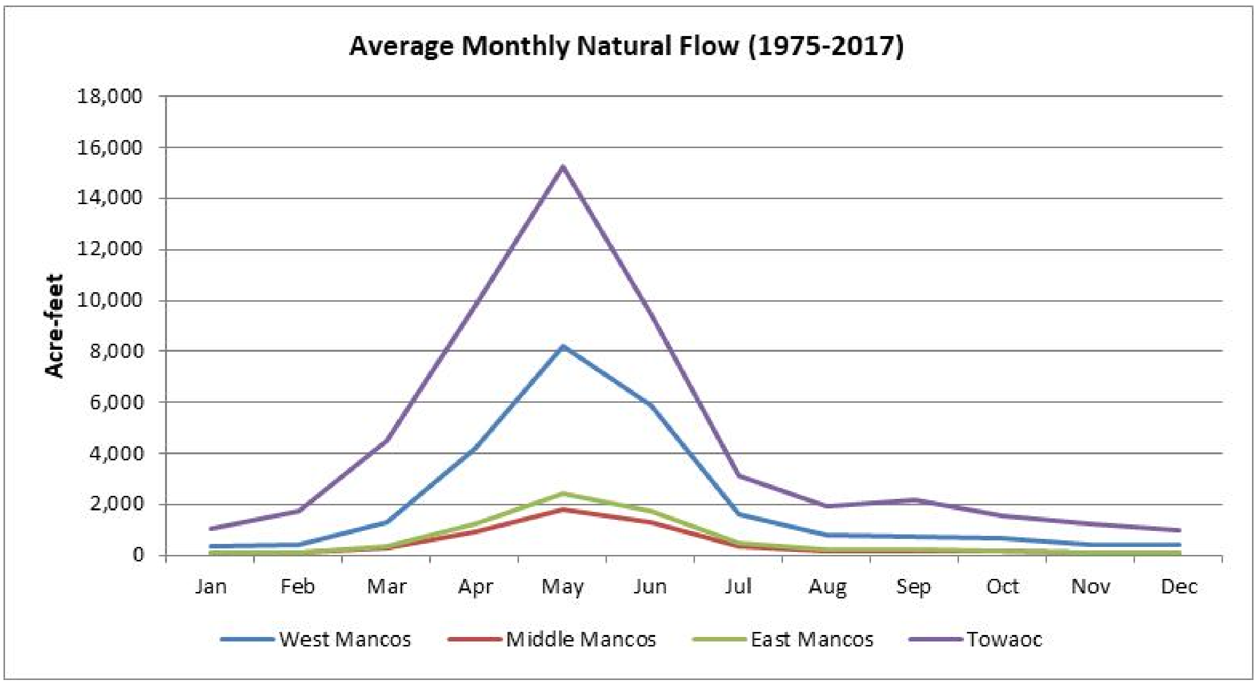


Figure 2-13: Average Monthly Natural Flow at Select Locations in the Mancos Watershed (1975-2017)

2.1.5 Irrigated Acreage

The majority of consumptive water use in the Mancos River valley is for irrigation; therefore it is essential to accurately represent the irrigated acreage and associated irrigation demands. CWCB developed irrigated acreage snapshots for the west slope of Colorado representing 1993, 2005, 2010, and 2015 as a key component of the Colorado Decision Support System. The data sets include acreage, crop type, irrigation method, and associated river diversion ditch or canal. The total irrigated acreage in the Mancos River valley as of 2015 is approximately 11,300 acres.

Wilson Water Group worked with the Mancos water commissioner to review the irrigated acreage for the Mancos River valley. An additional 1,000 acres of irrigation was identified, and the field boundary delineation was updated for about 2,500 acres. The original CDSS association between acreage and the supply ditch was not detailed enough to accurately tie the acreage to diversions, associated water rights, and supplemental storage in Jackson Gulch Reservoir for approximately 3,100 acres. These assignments were updated by refining and disaggregating field boundaries to allow for a unique association. Updating the irrigated acreage was a significant effort and results in a more accurate representation of irrigation demands for each of the 49 active ditches. This information was provided to the state, and Wilson Water Group continues to work with CWCB to update their master GIS coverage and make the corresponding updates to the historical GIS snapshot coverages (2010, 2005, and 1993) for inclusion in the State's records. Each of the updated coverages will be made available on the CDSS website.

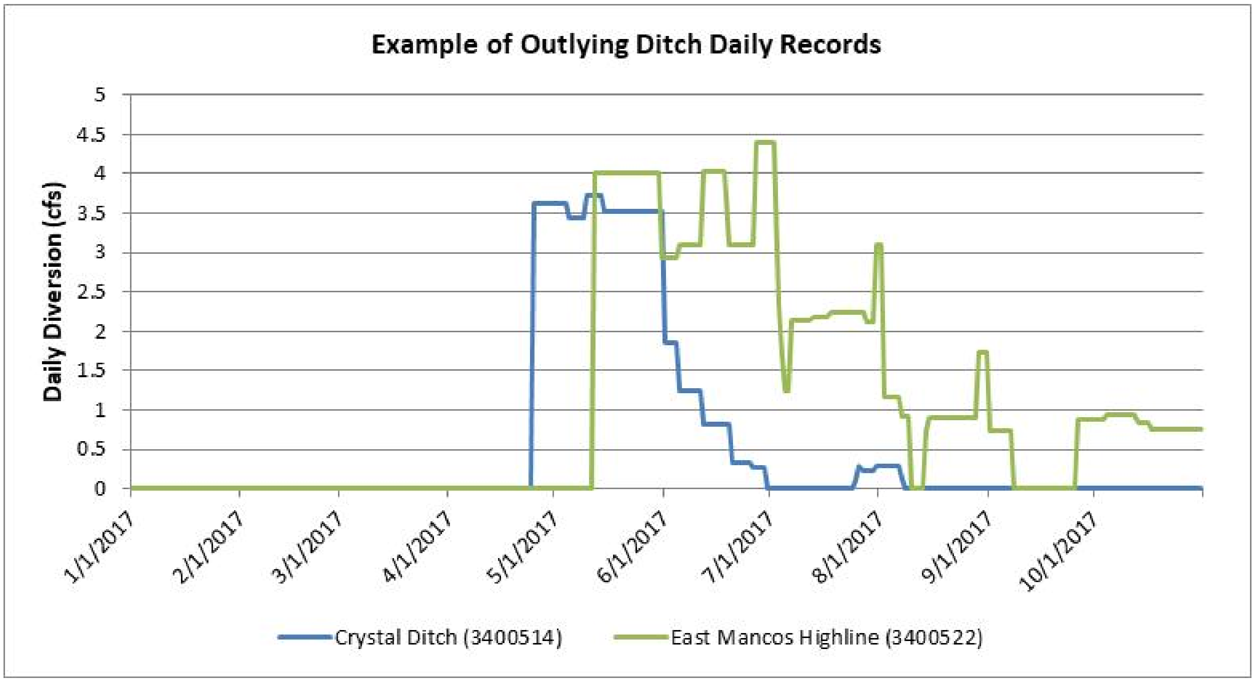
The crop type in the Mancos River valley has changed throughout history. When Jackson Gulch Reservoir was being constructed during the 1940s, approximately half of the irrigated acreage was growing alfalfa, and the remaining half was used for pasture, wheat, barley and oats, with a few orchards and potato fields (Stene, 1994). Over time, the valley has transitioned away from alfalfa. Currently, the dominate crop type is pasture to raise cattle, with only a few fields irrigating alfalfa. The overall acreage under irrigation has remained relatively constant through the history of the Jackson Gulch Reservoir project. Recently, some of the larger ranches have been sub-divided into smaller ranches or "ranchettes". These ranchettes are generally too small to make a profit for a cattle operation, and have been primarily purchased by people who do not depend on agriculture as their main source of income; rather they are interested in a rural life-style.

2.1.6 Diversion Records

The water commissioner is responsible for administering diversions at the 49 ditches and other structures that divert water in Water District 34. Diversion records include a code to identify both the source and use of water through the ditch headgate. The two sources commonly used in the Mancos River basin are "from river" representing natural flow diverted under a direct water right, and "from reservoir" representing the portion of headgate diversions that came from storage. Common use codes in the Mancos River basin include irrigation, municipal, and storage.

There are no ditches with continuous records, so diversion records are either provided by the water user annually or, more commonly, are "spot diversions" reported when the water commissioner visits the headgate and records the amount of water diverted on that day. Ditches in the Mancos are generally fitted with a Parshall flume or similar measuring device. Exceptions include two continuous recording devices on Jackson Gulch Reservoir Inlet Canal.

DWR uses the "fill-forward" approach where the spot-diversion record is repeated for each day until the water commissioner visits the headgate and reports an updated diversion rate. Based on the review of diversion records and discussions with the water commissioner, it is common for the water commissioner to visit most headgates about twice a week during the irrigation season; ditch headgates in remote higher elevation elevations (outlying ditches) are generally recorded about once a week. The Mancos River valley benefits from relatively frequent record-keeping, which is not typical of many water districts in western Colorado. Most water districts have significantly more structures for the water commissioner to visit.



[Figure 2-14](#) provides examples of 2017 diversion records for outlying structures and

Figure 2-15 provides examples of diversion records for structures in the Mancos River valley. Both figures demonstrate the standard fill-forward approach was used by DWR.

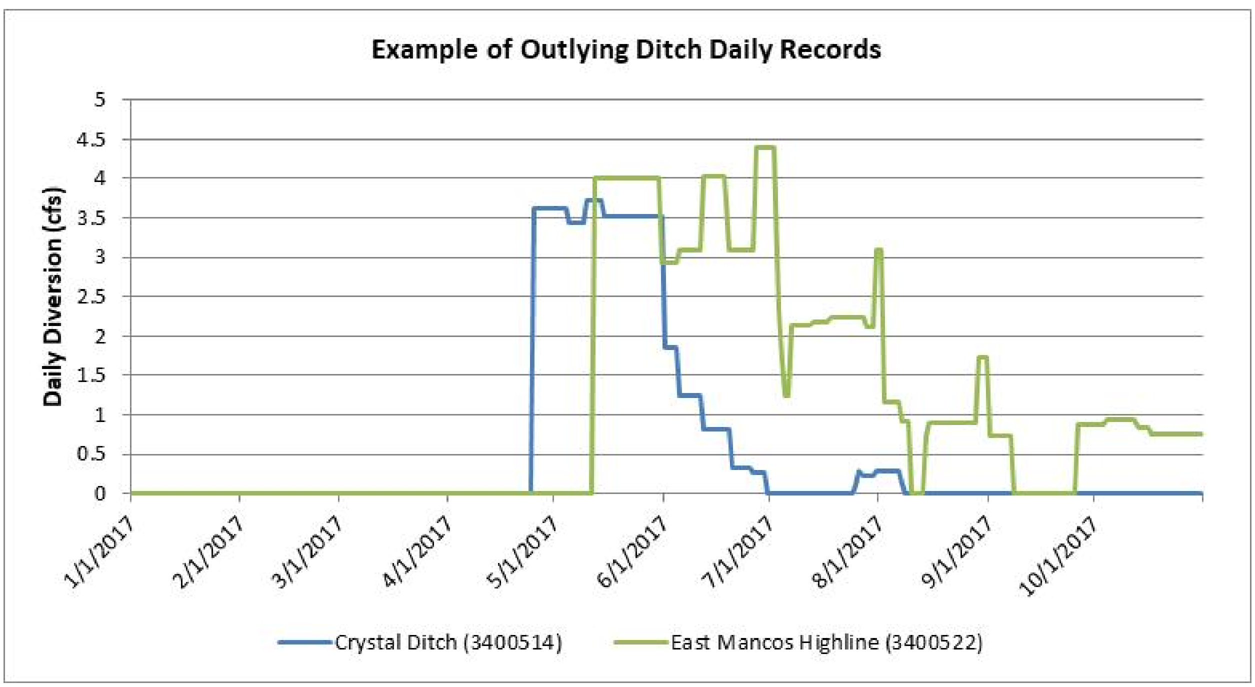


Figure 2-14: Example of Outlying Ditch Daily Diversion Reporting (2017)

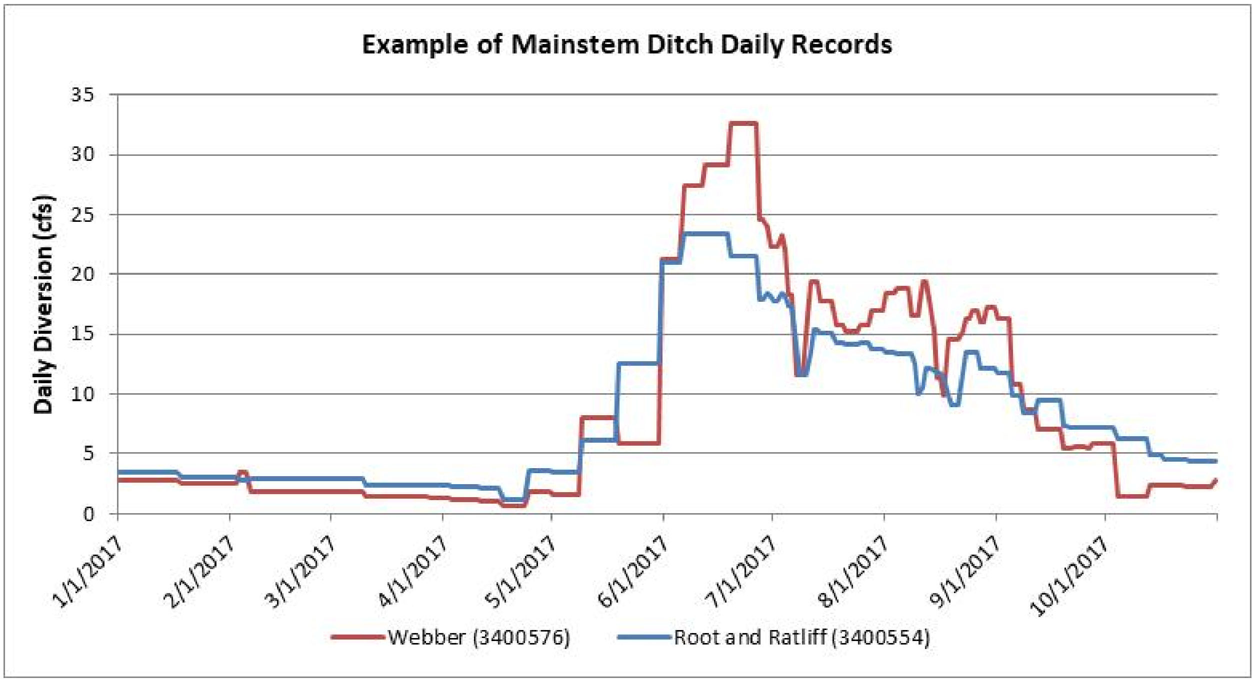


Figure 2-15: Example of Mainstem Ditch Daily Diversion Reporting (2017)

The diversion records for the Mancos River valley are of good quality and the frequency of data collection is high. The records are appropriate for building a daily decision support tool. While they are the best source of data available, diversion records have some inherent limitations. For example, daily variations in flows, most notably during runoff or following large precipitation events, can cause diversion rates to change throughout the day, which cannot be captured by spot diversion reporting. In addition, the diversion records can only record *what* happened, without providing insight into *why*. For example, reduced diversions could be caused by equipment failure, to allow the fields to dry before haying, or limited water supply. More information is needed to understand the reasons, and a decision support tool can be helpful.

From 2008 to 2017, the 49 ditches in the Mancos River valley diverted an average of 30,000 acre-feet per year. This is a decline from the long-term average from 1975 to 2017 of 35,000 acre-feet per year. Similar to streamflow, annual diversions are variable, as show in **Figure 2-16**. Note that the diversion records are shown for the total amount of water taken from the river, including native streamflow under direct diversion water rights and releases from reservoir storage. In addition to hydrology, the source of water contributes to the total annual diversions. For example, 2012 was a dry year, but Jackson Gulch Reservoir was able to release water as a supplemental supply to irrigation and the reservoir did not carry-over storage for the next year. Therefore in 2013, which was also dry during the early irrigation season, the reservoir did not have carry-over storage and was not able to fill; therefore did not provide a significant supplemental supply.

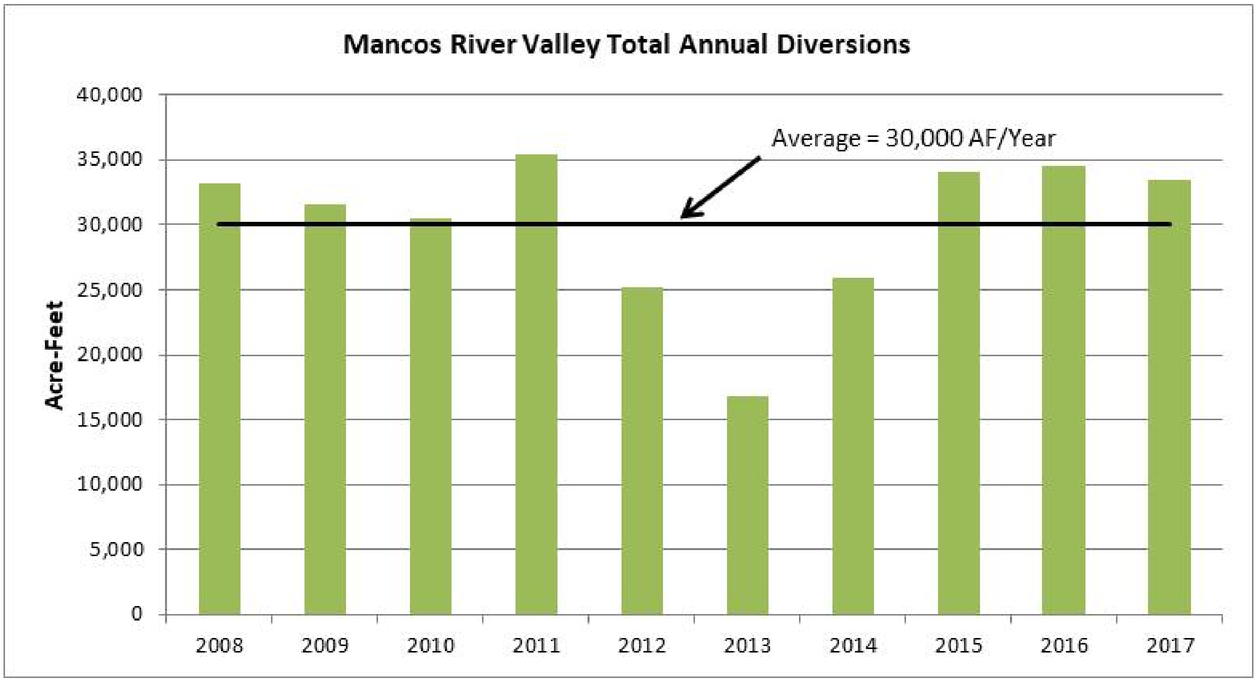


Figure 2-16: Annual Mancos River Valley Diversions (2008-2017)

Figure 2-17 shows total monthly diversions for the representative average (2015), wet (2005), and dry (2012) hydrologic years. As shown, the monthly diversions during dry and average years tend to be earlier in the season in order to capture as much of the runoff as possible. During the wet year, when water continued to be available later in the summer, significant diversions continued through August.

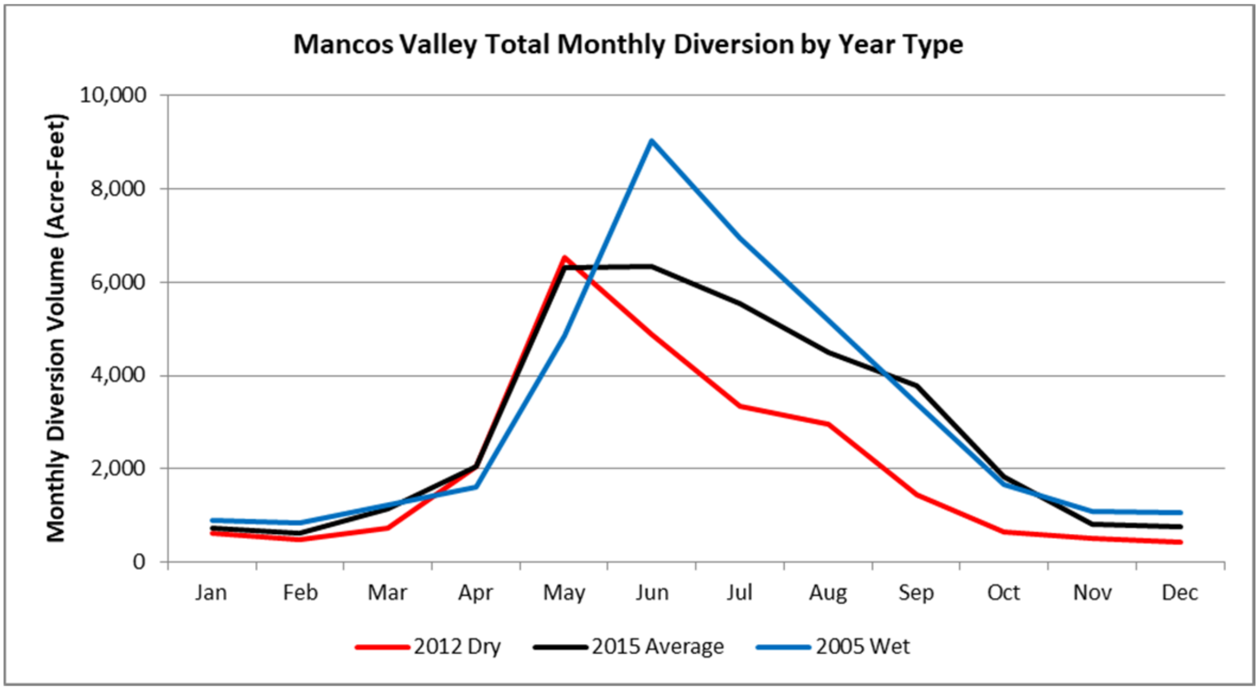


Figure 2-17: Mancos Valley Total Monthly Diversions for Irrigation for Representative Years

Figure 2-18 shows the location and magnitude of average annual diversions in the Mancos River basin. Ditches on the tributaries and upper reaches of the rivers tend to have a less reliable water supply. Most of these ditches divert less than 500 acre-feet per year. Ditches on the mainstem of the Mancos near Mancos have the best water supply. The largest 8 ditches divert over 50 percent of the total diversions (18,200 acre-feet/year). The two largest ditches (green dots) are Webber Ditch and the Root & Ratliff Ditch. The next largest ditch (yellow dot) is the Henry Bolen Ditch, which is generally the calling right.

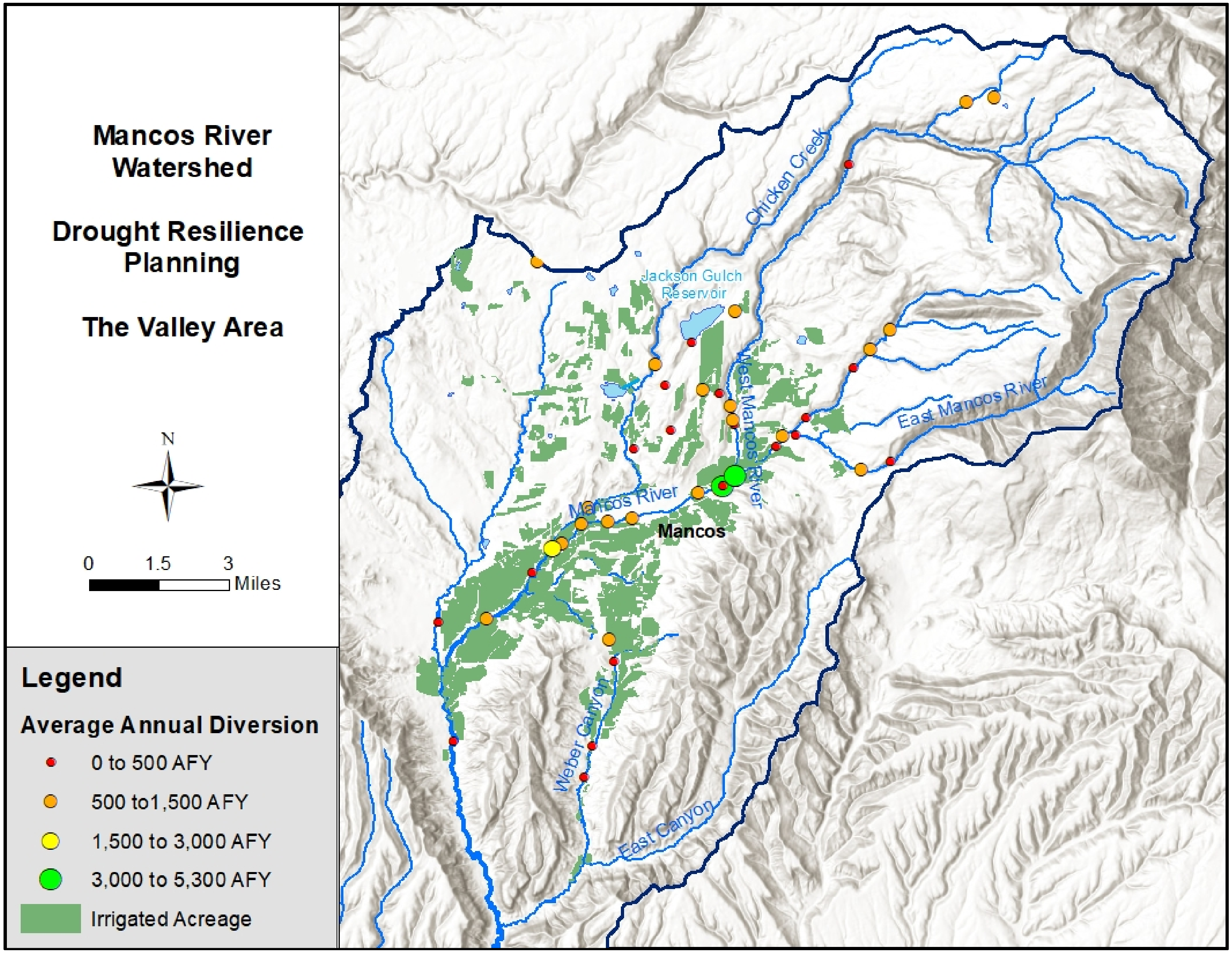


Figure 2-18: Average Annual Historical Irrigation Diversions (1975 - 2017)

2.1.7 Direct Diversion Water Rights

DWR stores information in their water rights database under unique identifiers that have been created for each ditch and reservoir in the state. Water rights, diversion records, location coordinates, irrigated acreage, and other information are stored under these unique identifiers. Based on Wilson Water Group's experience in the Southwest Basin, and other basins throughout Colorado, the water rights assignments in HydroBase are believed to be accurate and appropriate for use in the Drought Resiliency Planning efforts.

One interesting feature of the Mancos River valley is the association of water rights to irrigated acreage. In many parts of Colorado, ditches are operated as a mutual ditch company, meaning that the users under the ditch share in the various water rights held by the ditch company. In the Mancos River valley, the majority of ditches are not operating as mutual ditch companies. Instead, shares of the water rights diverted at the headgate are specifically owned by landowners under the ditch and water rights conveyed down the ditch are used on specific fields. In general, the most senior water right is tied to the fields at the top of the ditch and the water rights become increasingly junior further down-ditch. This means that users under a ditch may not be experiencing the same amount of water supply at any given time. This point is particularly important when ranches become sub-divided. Different pieces of the ranch may have different water rights and therefore, different water supplies. Specific land and water ownerships were not reviewed as part of the Drought Resiliency Planning efforts. Instead, information was grouped and analyzed at the ditch level.

Figure 2-19 presents the cumulative absolute direct flow water rights in the Mancos River valley, highlighting major basin adjudication dates and key water rights. The DWR Administration Number indicates the water right priorities based on both appropriation date and adjudication date and is used by DWR for administration throughout the state. In total, there are 161 water rights associated with the 49 active irrigation structures, for a total of 326 cfs of direct diversion irrigation water rights.

Figure 2-19 also shows the major adjudications that took place in the basin (1893 and 1933), the priority of the Jackson Gulch Reservoir storage right, the date of the Colorado River Compact, and the priority of the Ute Mountain Ute Tribe's reserved water rights. Note that although Colorado and the other upper Colorado River Basin states (Wyoming, Utah, and New Mexico) have always met their non-depletive obligations on the Colorado River, the extended drought since 2000 and recent upper Colorado River Drought Contingency Planning efforts highlight the Compact's importance to all water users in Colorado. As shown, almost 70 percent of the direct diversion rights in the Mancos River basin were appropriated senior to the Colorado River Compact. The Ute Mountain Ute Tribe's reserved water rights have an appropriate date that is senior to all uses in the Mancos River basin; however during the settlement and adjudication of their water rights, the Tribe agreed to subordinate to water rights with a priority senior to 1976 in the Mancos River basin. In laymen's terms, this means development of Tribal water rights will not impact existing irrigation uses, which are senior to 1976.

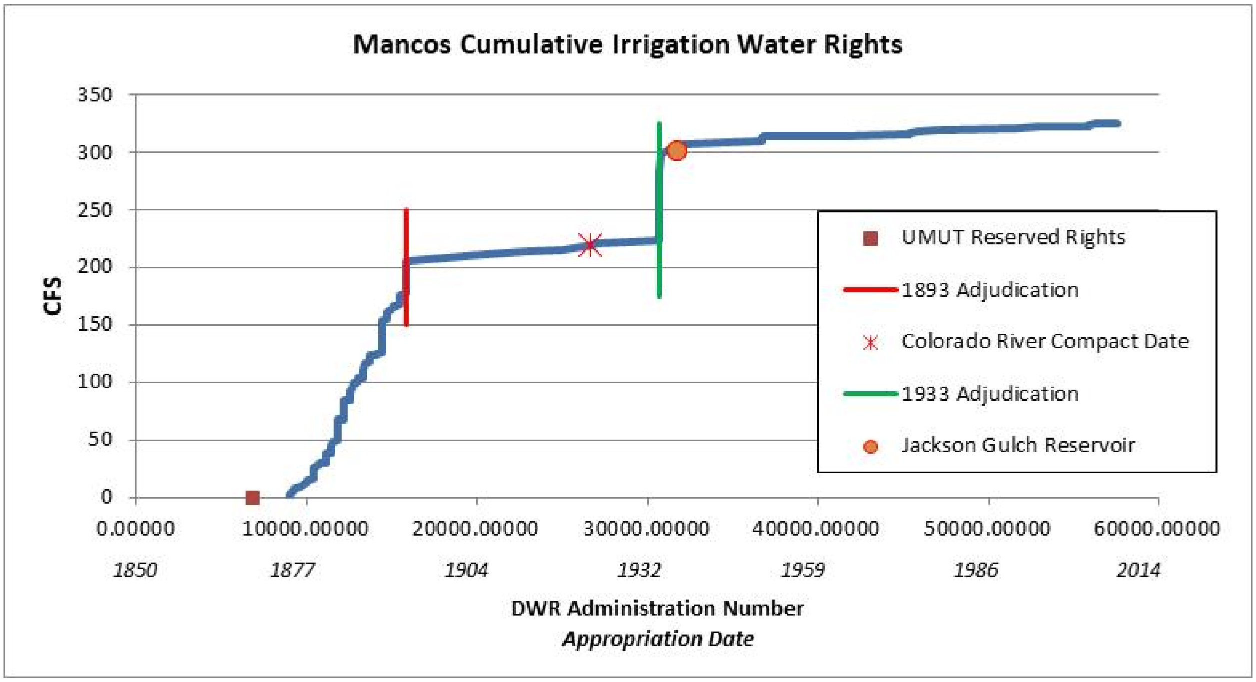


Figure 2-19: Mancos River Valley Cumulative Direct Flow Water Rigths

In addition to absolute direct flow water rights, there are conditional direct flow water rights totally 11.4 cfs in the Mancos River Basin. These are primarily small pumps and wells decreed for irrigation and domestic use.

The map in **Figure 2-20** shows the location of decreed springs that have absolute water rights greater than zero. The vast majority of these springs are located inside Mesa Verde National Park or near the Ute Mountain, which is considered holy by the Ute Mountain Ute Tribe. The springs are decreed as federally reserved rights for the Ute Mountain Ute Tribe and Mesa Verde National Park. The springs do not have measurement devices, so information regarding when and how much they flow is anecdotal. The Ute Mountain Ute Tribe water resources staff and the National Park Service have observed a significant decrease in spring flows since the early 2000s.

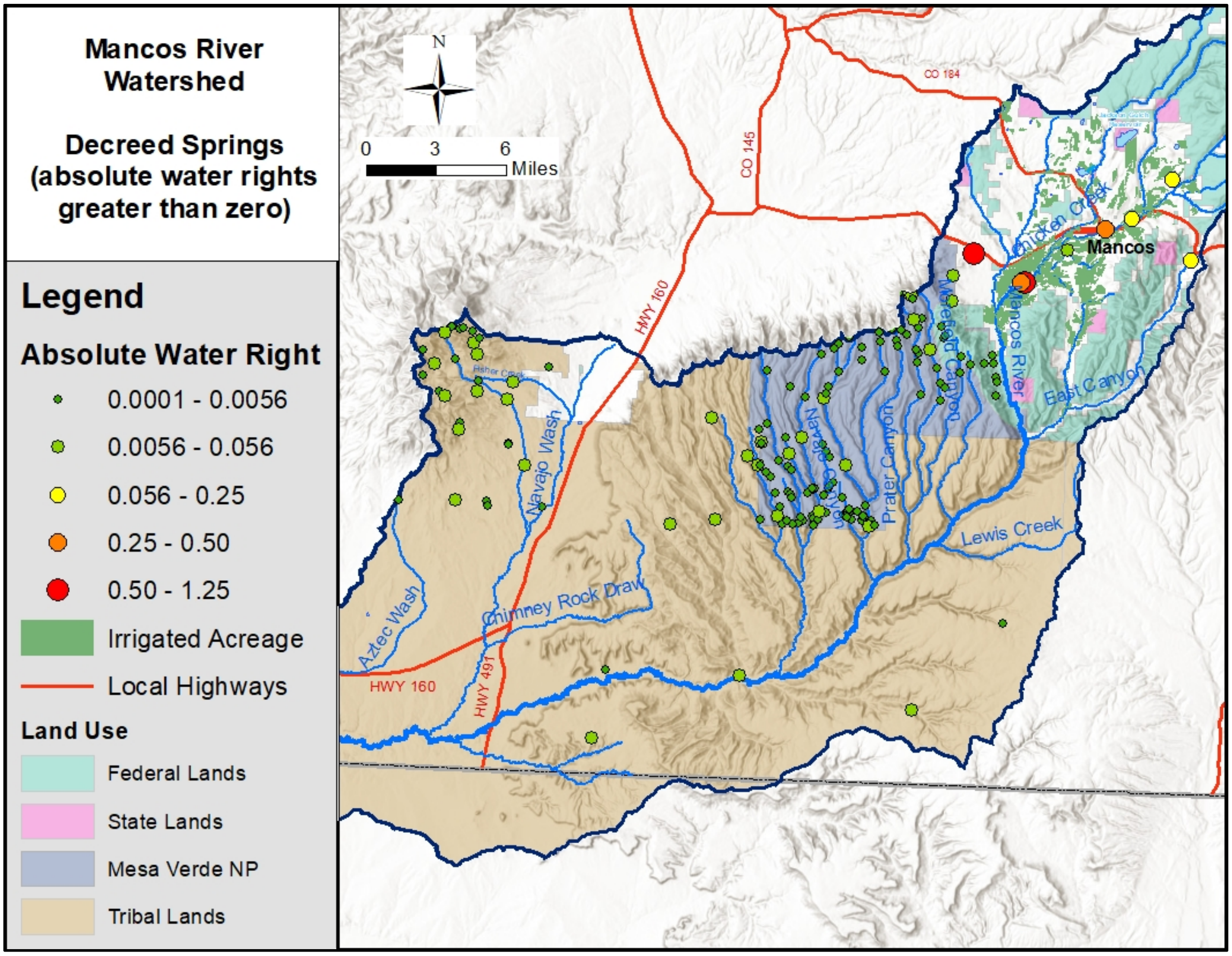


Figure 2-20: Decreed Springs Location Map

2.1.8 Storage Water Rights

Reservoir storage in the Mancos River valley is dominated by Jackson Gulch Reservoir, but there are several other smaller facilities as well. In total, there are around 14,880 acre-feet of absolute storage water rights in the basin. Of these, 11,981 acre-feet are for Jackson Gulch Reservoir. Three other storage structures are important for water administration in the basin and are represented in the basin model: Weber Reservoir (442 acre-feet water right), Bauer Reservoir No 2 (1,393 acre-feet water right), and Bauer Reservoir No 1 (549 acre-feet first-fill water right with 320 acre-feet refill right). In addition, there are conditional storage water rights totally 20 acre-feet in the Mancos River Basin, primarily for small stock ponds.

2.1.9 Instream Flow Water Rights

The Mancos River basin includes five decreed instream flow water rights, summarized in **Table 2-3** and shown in **Figure 2-21**. These rights are junior to most of the irrigation rights in the basin. The four CWCB instream flow rights were appropriated in 1984 for the same flow rate throughout the year and are located in the headwaters. The Mancos River instream flow is a federal water right reserved for Mesa Verde National Park; the rate varies throughout the year.

Table 2-3: Existing Instream Flow Water Rights in the Mancos River Basin

Name	Case Number	Adjudication Date	Appropriation Date	Decreed Flow Rate (cfs)
North Fork West Mancos River	7-84CW267	12/31/1984	7/13/1984	2
West Mancos River	7-84CW266	12/31/1984	7/13/1984	4
Middle Mancos River	7-84CW269	12/31/1984	7/13/2014	3
East Mancos River	7-84CW268	12/31/1984	7/13/1984	2
Mancos River	W-1633-76	12/31/1976	1/1/1995	5 (8/1 to 1/31) 10 (2/1 to 2/28) 15 (3/1 to 3/31) 30 (4/1 to 4/30) 45 (5/1 to 5/31) 12 (6/1 to 6/30) 6 (7/1 to 8/31)

The North Fork West Mancos instream flow reach and the Middle Mancos instream flow reach are located upstream of existing diversion structures. The flow in these reaches is dictated by the naturally occurring hydrology. The West Mancos instream flow reach starts at the confluence of the North and South Fork. There are irrigation diversions on Crystal Creek, a tributary to the West Mancos River, and diversions for Mesa Verde's water supply. The instream flow reach ends at the Jackson Gulch Reservoir Inlet Canal. Since January 2005, DWR has measured the diversions through the Jackson Gulch Inlet Canal and the remaining flow in the West Mancos River. WWG added these two gage records together to estimate the amount of flow in the West Mancos River at the terminus of the instream flow reach. From January 24, 2005 through December 2018 the daily instream decreed flow rate of 4 cfs was met on 91 percent of the days. **Table 2-4** presents the data by month and shows that the instream flow rate is met or exceeded on the majority of days throughout the year.

The East Mancos instream flow reach starts in the headwaters, continues through the confluence with the Middle Mancos, and ends at the confluence with West Mancos River. There are five current diversion structures in the reach and two on minor tributaries to East Mancos River. There is a historical gage located on the East Mancos, downstream of five of the diversion structures. An analysis of the daily streamflow recorded by East Mancos River near Mancos (09369000) from April 1937 through September 1951 shows that the daily instream decreed flow rate of 2 cfs was only met on 38 percent of the days. A break down by month in **Table 2-4** shows that the winter time flow in the river is generally below 2 cfs. There are no diversions for irrigation during the winter, so the options for increasing the flow in the river are limited.

The Mancos River instream flow right reach is where the Mancos River flows through Mesa Verde National Park. There is a historical gage located within this reach. An analysis of the daily streamflow recorded by Mancos River at Anitas Flat below Mancos from October 2003 through November 2015 shows that the varying monthly instream flow rates were met 69 percent of the days. **Table 2-4** presents analysis results by month.

Table 2-4: Percent of Days in Month that Meet or Exceed the Decreed Instream Flow Rates for the West Mancos, East Mancos, and Mancos River Instream Flows

	Percent of Days Streamflow Meets or Exceeds Decree Instream Flow Rates		
Month	**West Mancos River (2005-2018)**	**East Mancos River (1937-1951)**	**Mancos River (2003-2015)**
January	75%	7%	92%
February	68%	0%	63%
March	82%	25%	66%
April	98%	96%	59%
May	100%	100%	50%
June	100%	95%	45%
July	97%	52%	44%
August	94%	22%	55%
September	90%	17%	81%
October	93%	15%	91%
November	92%	7%	90%
December	92%	7%	90%

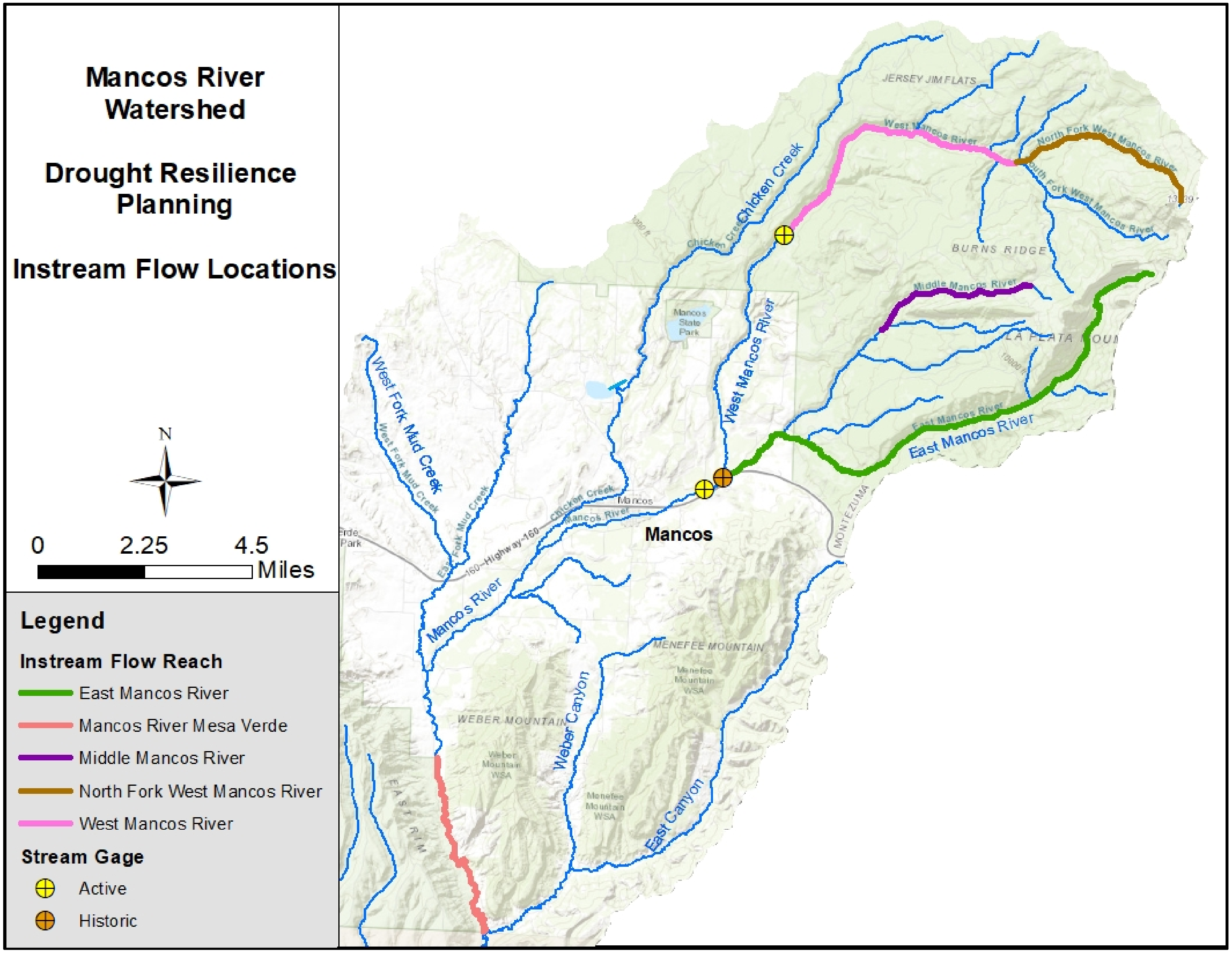


Figure 2-21: Instream Flow Reaches in the Mancos River Basin

2.1.10 Reservoir and Diversion System Operations

In order to understand uses on the Mancos River, it is important to understand the connection between diversions, irrigated acreage, and reservoir operations. This section includes maps showing the location of ditch headgates and their associated irrigated acreage. It also provides an overview of the reservoir operations in the Mancos River valley. The focus is on the larger, more complicated irrigation systems.

2.1.10.1 Rush Reservoir Ditch and Crystal Creek Ditch

Rush Reservoir Ditch and Crystal Creek Ditch have headgates located on Crystal Creek, a tributary to West Mancos River. These are very long ditch systems that convey the water to irrigated acreage much lower in the basin. As shown in **Figure 2-22** Crystal Creek Ditch (3400514, dark blue dot) irrigates acreage near Jackson Gulch Reservoir (blue cross-hatch). Rush Reservoir Ditch (3400560, purple dot) irrigates acreage on the west side of Chicken Creek (purple cross-hatch).

By decree, Rush Reservoir Ditch can divert from Crystal Creek for irrigation from November 1 to May 1. During the winter months, Rush Reservoir Ditch fills small ponds and reservoirs, such as Bauer No. 1 Reservoir and L A Bar Reservoir. When there is excess water, stored water in Bauer Reservoir No 1 can be delivered to Bauer Reservoir No 2. During the summer season, Rush Reservoir Ditch can pick up water from various seeps and springs tributary to West Mancos River and can divert from the headwaters of Chicken Creek. This water is used for irrigation and delivered to acreage colored purple in **Figure 2-22**. Grass pasture is irrigated under the ditch and the irrigation method is a mix of flood; gated pipe; and sprinkler, depending on the parcel.

Crystal Creek Ditch can divert from Crystal Creek from May 1 to November 1. Traditionally, the water commissioner has been responsible for opening the diversion structure on Crystal Creek. This is done as close to the decreed days as possible, depending on accessibility due to snow cover. Crystal Creek Ditch runs parallel to West Mancos River and irrigates the acres colored blue in **Figure 2-22**. Additionally, Crystal Creek Ditch has a decreed alternate point of diversion at the Jackson Gulch Inlet Canal (3400535). It can divert water from the West Mancos River through Jackson Gulch Reservoir Inlet to the Crystal Creek Ditch via the Crystal Creek Inlet Turn Out; measured under 3400515.Crystal Creek Ditch also receives water from storage in Jackson Gulch Reservoir. Reservoir water can be delivered from Jackson Gulch Reservoir via the Jackson Gulch Outlet Canal to the Crystal Creek Ditch via the Crystal Creek Outlet Turn Out; measured under WDID 3400516. Jackson Gulch Reservoir can also deliver water by exchange to the upstream diversion points. Grass pasture is irrigated under the ditch and the irrigation method is either flood or gated pipe, depending on the parcel.

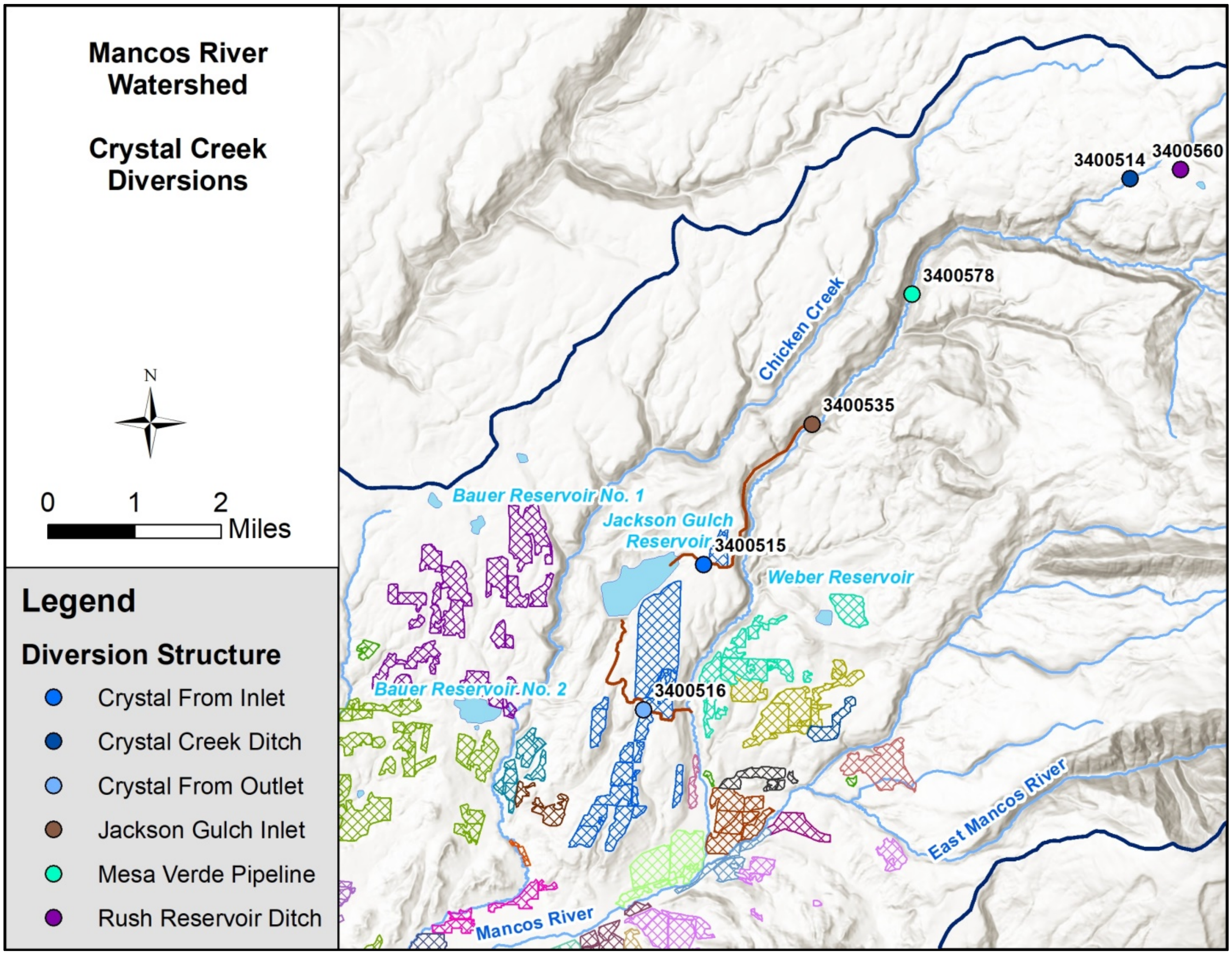


Figure 2-22: Crystal Creek Ditch and Rush Reservoir Ditch Location and Irrigated Acreage Map

2.1.10.2 Jackson Gulch Reservoir

Jackson Gulch Reservoir was constructed by the U.S. Bureau of Reclamation (Reclamation) during the 1940s. Today, it is owned by Reclamation and operated by the Mancos Water Conservancy District. The reservoir has a storage capacity of 9,980 acre-feet. The reservoir supplies supplemental irrigation water and municipal water to 253 individual users throughout the valley and provides numerous benefits to the community. It is located off-channel, between West Mancos River and Chicken Creek. The infrastructure associated with Jackson Gulch Reservoir is integral to irrigation and municipal operations throughout the basin. The map in **Figure 2-23** shows the reservoir location, the inlet and outlet canals, and illustrates how various users can access reservoir water.

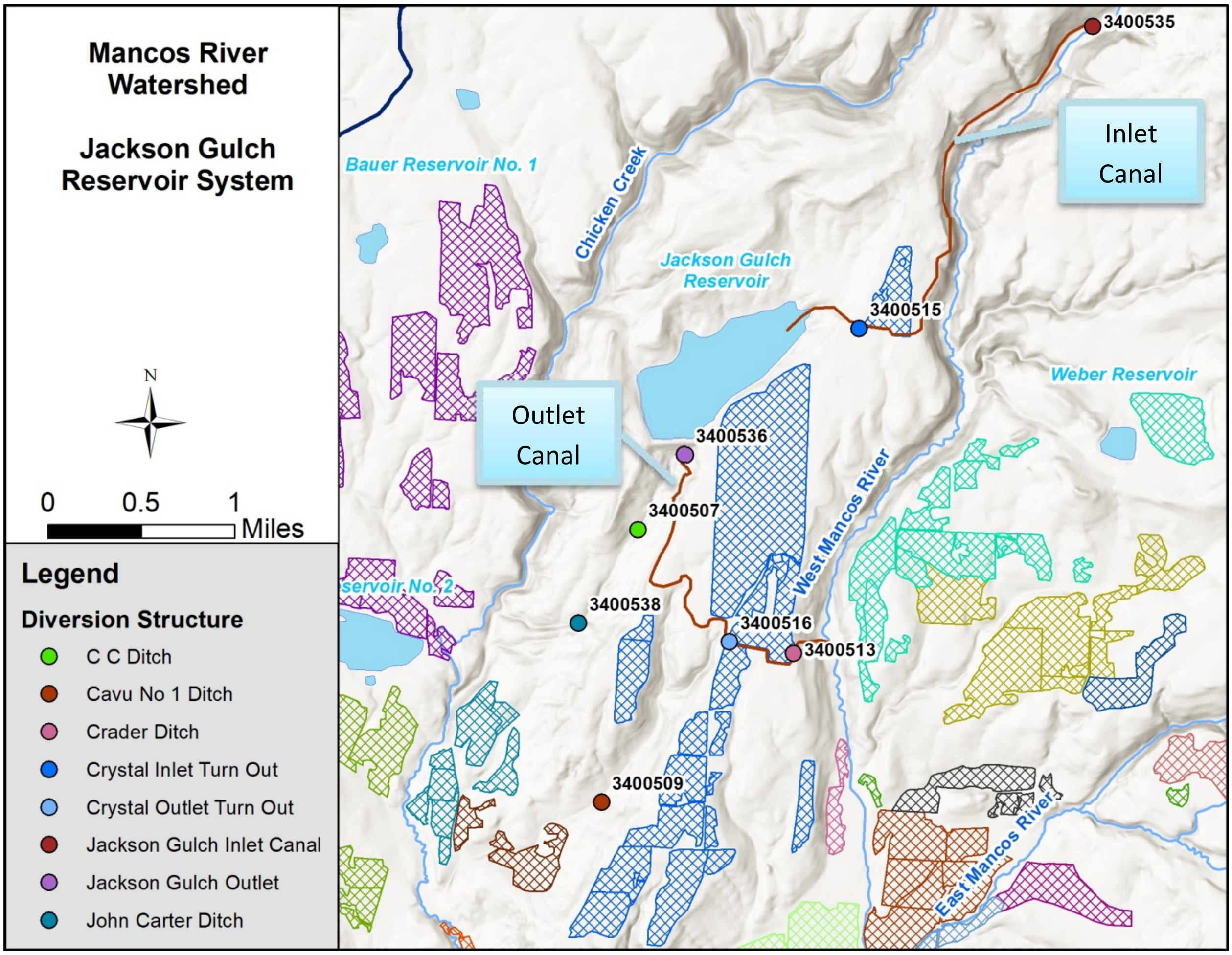


Figure 2-23: Jackson Gulch Reservoir and Related Infrastructure

The Jackson Gulch Reservoir Inlet Canal is the primary source of water for the reservoir. The canal diverts water from the West Mancos River under WDID 3400535. As soon as the weather permits, the reservoir operator will begin to fill. There is a small amount of native flow on Jackson Gulch, but this water is dwarfed by the West Mancos River supply. The inlet canal headgate is located about 2.5 miles upstream of the Town of Mancos. The canal is primarily an open, earthen ditch that originally included about 1,000 feet of concrete box culverts to protect the canal in areas with steep hillslopes. Since then, about 1,000 additional feet has been put into pipe and an additional 2,000 feet has been concrete lined. Prior to 2010, the inlet canal had a restricted capacity of 160 cfs due to infrastructure problems. The current inlet canal capacity is 258 cfs, which corresponds to the water rights for the project. Running the full 258 cfs for extended periods of time could cause damage to the earthworks. Therefore, the reservoir operator targets a maximum flow of 200 cfs and generally operates diversions around 150 cfs.

The Division of Water Resources operates three gages in the area:

- Jackson Gulch Reservoir Inlet Canal (Upper), ID = JACUPPCO
- Jackson Gulch Reservoir Inlet Canal, ID = JACCANCO
- West Mancos River below Jackson Gulch Reservoir Inlet Canal, ID = MANJACCO

The first two gages measure the Reservoir Inlet Canal near the headgate and near the reservoir. An analysis was performed to see if the Inlet Canal had significant seepage or gains for local runoff. From 2005 through 2017, the Inlet Canal did not experience significant changes in flow between the two gage locations. Therefore, no seepage or gains are considered in the model.

The reservoir can deliver water to irrigation users in a variety of ways. The primary delivery infrastructure is the Jackson Gulch Outlet Canal. Similar to the inlet canal, the outlet canal is an open, earthen ditch. About 1,000 feet of original construction was in concrete box culverts and an additional 600 feet has been put into pipe. Releases from the reservoir into the outlet canal generate hydropower, and the canal returns water to the West Mancos River. The reservoir releases are measured by a flume well down-ditch, immediately before the canal discharges to the West Mancos River. There are no measurements closer to the dam, so a seepage analysis could not be performed. The reservoir operator suggested that some seepage is occurring from the outlet canal because it passes over a shale deposit and there are several small ponds that are most likely filled from seepage. Ditch seepage rate of 10 percent was used in the modeling effort.

In addition to the West Mancos River through the outlet canal, water can be delivered from the Jackson Gulch Reservoir, Inlet Canal, or Outlet Canal to the following locations:

- Crystal Creek Ditch Inlet Canal is measured at 3400515. Water can be turned-out from the Jackson Gulch Inlet Canal to Crystal Creek Ditch. It supplies irrigation water to the acreage shown in blue in **Figure 2-23**.
- Crystal Creek Ditch Outlet Canal is measured at 3400516. This is a turn-out from the Jackson Gulch Outlet Canal to Crystal Creek Ditch (blue acreage) and Cavu No 1 Ditch (brown acreage, measured at 3400509).
- Crader Ditch Outlet Canal is measured at 3400513. This is a turn-out from the Jackson Gulch Outlet Canal and irrigates the light pink acreage.
- Jackson Gulch Reservoir releases directly to Jackson Gulch. This water can be re-diverted from the natural streambed to be carried through the C-C Ditch for delivery to Chicken Creek (3400507) or diverted by the John Carter Ditch (3400538, teal acreage).
- Jackson Gulch Reservoir can release directly to pipelines supplying the Town of Mancos, Mancos Rural Water, and Mesa Verde National Park.

In addition to releasing directly to water users on the West Mancos and Mancos Rivers via the Jackson Gulch Outlet Canal, Jackson Gulch Reservoir can release water for users by exchange. In general, the Henry Bolen Ditch (3400534) is the calling structure and it is located near the bottom of the valley. Water users can release their reservoir water to the Henry Bolen Ditch (or other calling structure) in exchange for diversions at their upstream headgates.

With the exception of the three municipal water providers, the majority of the 253 individual water users irrigated with their Jackson Gulch Reservoir water. In general, the Mancos Water Conservancy District (MWCD) sets the initial reservoir allocation in May based on Jackson Gulch Reservoir storage, and may be updated in June if more water becomes available. Like most Reclamation projects, user's allotments are based on their acreage. Water users place their water orders on Mondays and Thursdays before 6 pm by calling the reservoir operator. The reservoir operator summarizes the water orders and makes any necessary changes to the reservoir releases on Tuesdays and Fridays. The minimum water order is 0.25 cfs and water will be released for either 3 or 4 days. The reservoir operator informs the water commissioner how much water is to be delivered to each ditch and informs the ditch rider which users under the ditch have ordered water. Individual water users under the ditches listed in **Table 2-5** generally receive Jackson Gulch Reservoir water, either by direct release or by exchange. **Figure 2-24** shows the locations of the headgates that typically receive Jackson Gulch Reservoir. Water that is not used by the end of the year is dedicated back to the Project and made available for allocation in the next year; there are no individual carry-over storage accounts.

Table 2-5: Irrigation Ditches Regularly Receiving Jackson Gulch Reservoir Water

WDID	Ditch Name
3400504	Bauer Reservoir No. 2 Ditch
3400538	John Carter Ditch
3400509	Cavu No. 1 Ditch
3400542	Lee and Burke Ditch
3400576	Webber Ditch
3400554	Root & Ratliff Ditch
3400543	Lee Ditch
3400583	Willis Ditch
3400574	Veits Ditch
3400506	Boss Ditch
3400552	No. 6 Ditch
3400565	Sheek Ditch
3400505	Beaver Ditch
3400534	Henry Bolen Ditch
3400524	Exon Ditch
3400514	Crystal Creek Ditch
3400582	Williams Ditch
3400513	Crader Ditch
3400522	East Mancos Highline Ditch
3400562	Samson Ditch
3400577	Weber Reservoir Inlet Ditch
3400544	Long Park Ditch
3400567	Smouse Ditch
3400532	Greybeal Ditch
3400560	Rush Reservoir Ditch
3400521	E C Smith Ditch
3400508	Carpenter & Mitchell Ditch

Transit losses for reservoir deliveries are not generally charged to individual users. Instead, the Mancos Conservancy District maintains an account in the reservoir to cover transit losses. In 2018, the reservoir content was not sufficient for the District to cover transit losses, so the water commissioner assessed transit losses of 5 percent above the Willis Ditch and 10 percent below the Willis Ditch.

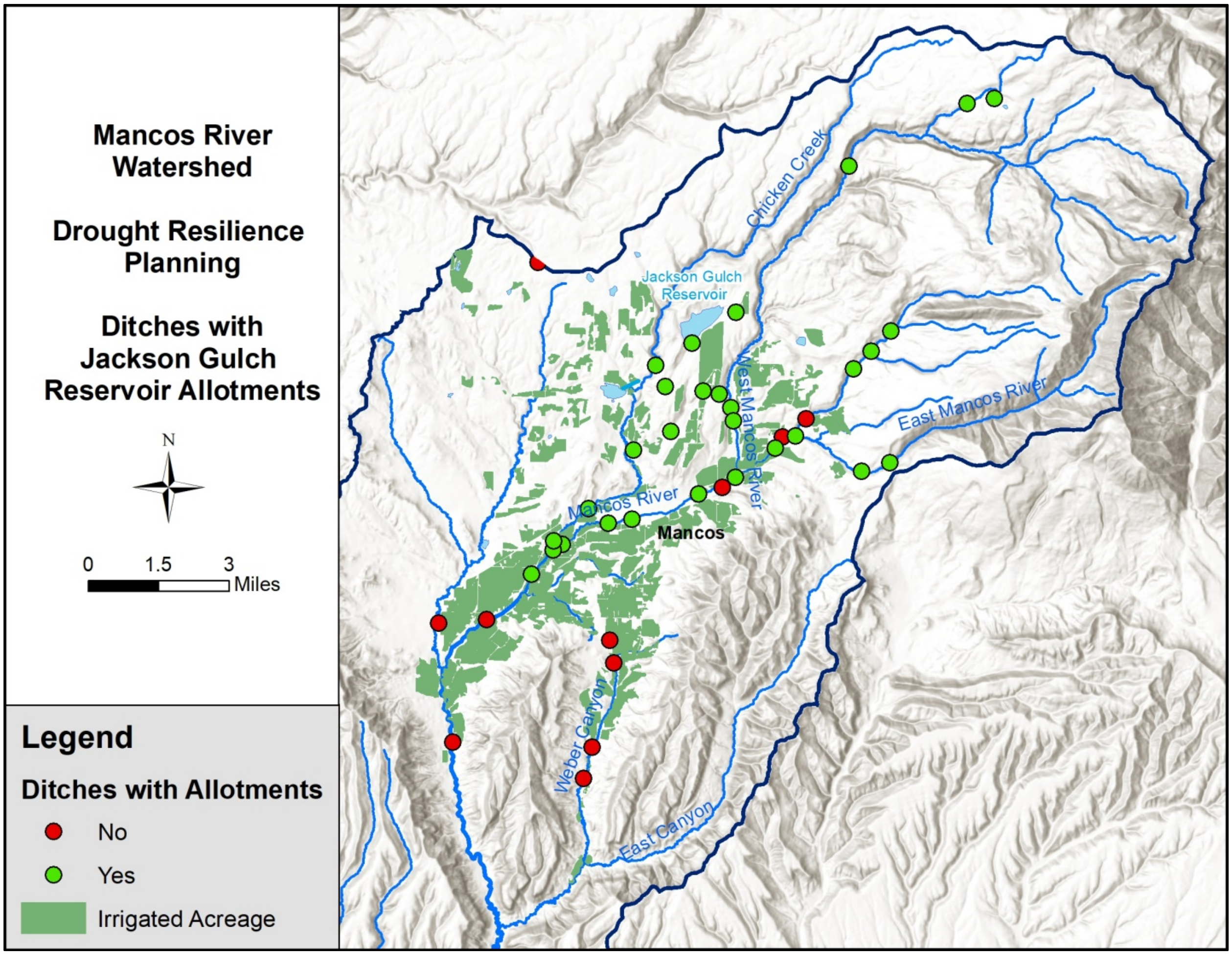


Figure 2-24: Map of Ditches with Jackson Gulch Reservoir Allotments

Jackson Gulch Reservoir is a high elevation reservoir, and as such is generally is covered in ice during the winter. The operator tries to fill the reservoir as soon as possible, and generally the reservoir will reach capacity by mid-May or early June at the latest. Once the reservoir is full, the operator coordinates with the water commissioner to continue running West Mancos River water through the reservoir inlet and outlet canal in order to produce hydropower. There are no diversions located on West Mancos River between the inlet canal and where the outlet canal returns water to West Mancos River. Therefore, the reservoir can divert water for non-consumptive hydropower production regardless of a call on the river. In additional to producing hydropower, diverting a significant portion of the flows in the West Mancos River helps to reduce the diurnal streamflow fluctuations during the runoff. The water commissioner has reported diurnal swings as large as 50 cfs during a 24-hour period. The variability is difficult to predict and adjust irrigation operations accordingly, especially as more ditches covert to pipes and sprinkler systems. The reservoir operator and the water commissioner coordinate daily on opportunities to dampen the diurnals.

The reservoir operator noted that reservoir operations have changed slightly through time. The most significant change has been the number of reservoir users. In the late 1990s, there were about 160 individual water users; today there are 253 individual water users. The increase in water users has been driven by the subdivision of large ranches. Because the allotments are tied to acreage, the new owners of the subdivided acreage become individual water users. The Mancos Water Conservancy District has started encouraging users with relatively small allotments to coordinate with other users under their ditch and to coordinate their water orders. For example, a single water user has a 5 acre-foot allotment. The user must place a minimum order of 0.25 cfs, and therefore could only irrigate for 10 days. However, if four water users under a ditch each have 5 acre-foot allotments, they could join together and place a minimum order of 0.25 cfs and each take 0.06 cfs. This would allow all four users to irrigate for 40 days, albeit at a lower rate. This would significantly extend the length of time they could irrigate their properties.

The reservoir operator has also noted changes in how large ditches order water because of their conversion to pipe. The pipes are more efficient at delivering water than the open channel ditches, so users can order water at a lower rate from the reservoir. This potentially allows users to extend their growing season.

2.1.10.3 Upper Tributary Diversions

Diversions from West Mancos River (downstream of Jackson Gulch Reservoir Outlet), Middle Mancos River, and East Mancos River and their corresponding irrigated acreage are shown on the map in **Figure 2-25**. Several of the headwater ditches are relatively long, as they travel across the landscape to reach the irrigated acreage. In particular, the East Mancos Highline and Extension Ditches travel a significant distance. Currently, these ditches are being converted to piped conveyance systems.

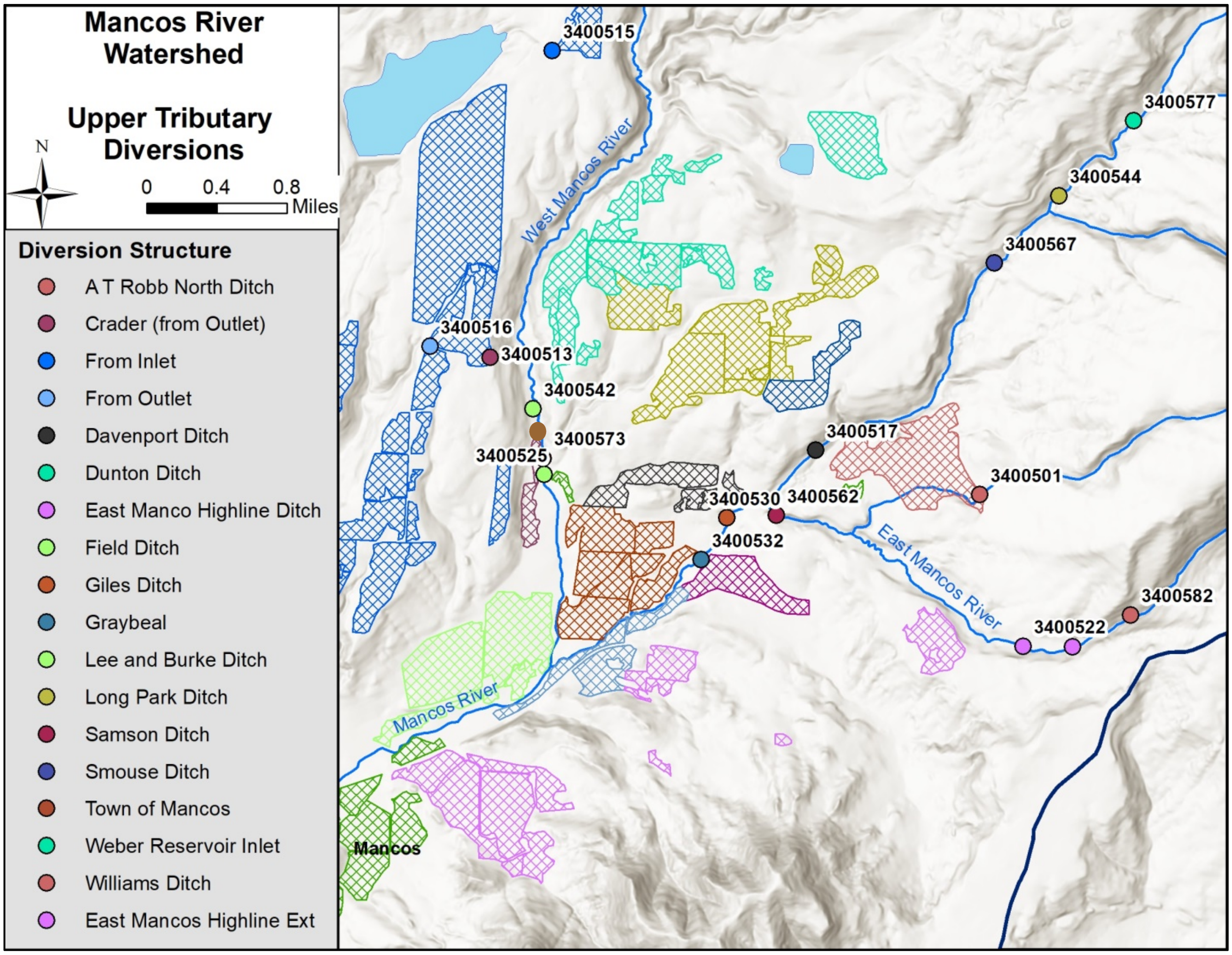


Figure 2-25: Upper Tributary Diversions and Irrigated Acreage Location Map

2.1.10.4 Weber Reservoir

As shown on the map in **Figure 2-26**, Weber Reservoir is located between Middle Mancos River and West Mancos River. The reservoir is privately owned and operated, and has an operating capacity of 460 acre-feet and storage water rights of 442 acre-feet. It is supplied with water from the Weber Inlet Canal (3400577), which diverts from the Middle Mancos River. The Weber Inlet Canal also delivers water directly to irrigation. Portions of the system are in pipe. Grass pasture is irrigated under the ditch and the irrigation method is a mix of flood, gated pipe, or sprinkler, depending on the parcel.

Middle Mancos River has a smaller yield than East or West Mancos River, but the stream is more reliable than Chicken Creek. Some of the parcels under the Weber Reservoir system have allotments in Jackson Gulch Reservoir. Reservoir water is delivered by exchange to the Weber Inlet Canal and delivered to water users with allotments. Even in dry years, Middle Mancos has enough exchange potential to deliver Jackson Gulch water for about a week. Jackson Gulch Reservoir water cannot be stored in Weber Reservoir.

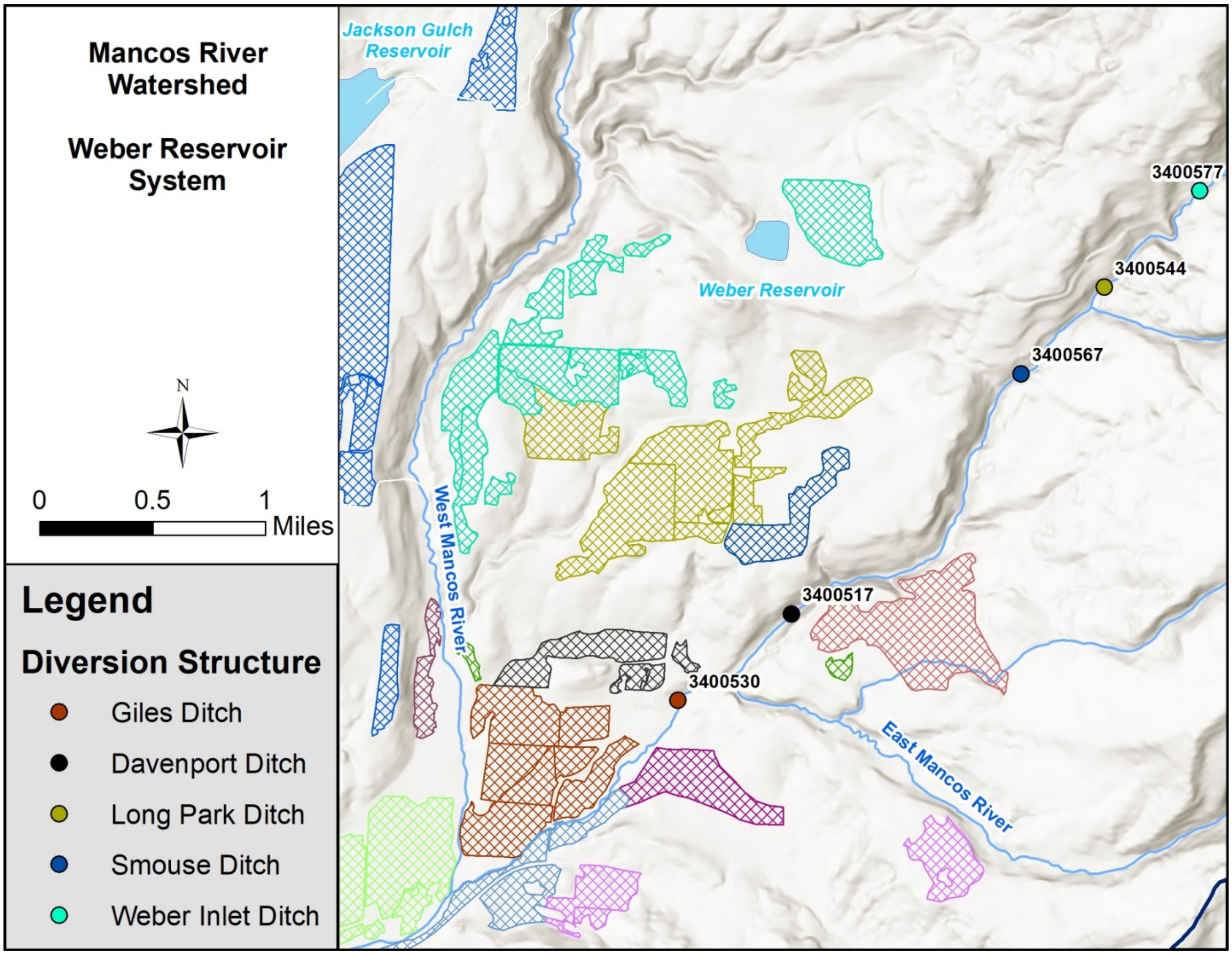


Figure 2-26: Weber Reservoir and Irrigated Acreage Location Map

2.1.10.5 Bauer No 2 Reservoir and Bauer No 2 Reservoir Ditch

As shown on the map in **Figure 2-27**, Bauer No 2 Reservoir is located off-channel, between Chicken Creek and Mud Creek, and is privately owned and operated. It has an operating capacity of 1,533 acre-feet and water rights for 1,393 acre-feet. It is primarily supplied with water by the Bauer No 2 Reservoir Ditch, which diverts from Chicken Creek. It is also possible for excess water from Bauer Reservoir No 1 to be delivered to No 2. The Bauer No 2 Ditch system also delivers irrigation water directly to ditch users. Almost all of the system is piped. Grass pasture is irrigated under the ditch and the irrigation method is a mix of flood, gated pipe, or sprinkler, depending on the parcel.

Jackson Gulch Reservoir water can be stored in Bauer No 2 Reservoir to supplement limited supplies from Chicken Creek. Water is released from Jackson Gulch Reservoir to Jackson Gulch, diverted by the C C Ditch (3400507) and delivered to Chicken Creek, where it is picked up by the Bauer No 2 Reservoir Ditch. This water is used in the late season to top off the reservoir, or is delivered to water users under the ditch.

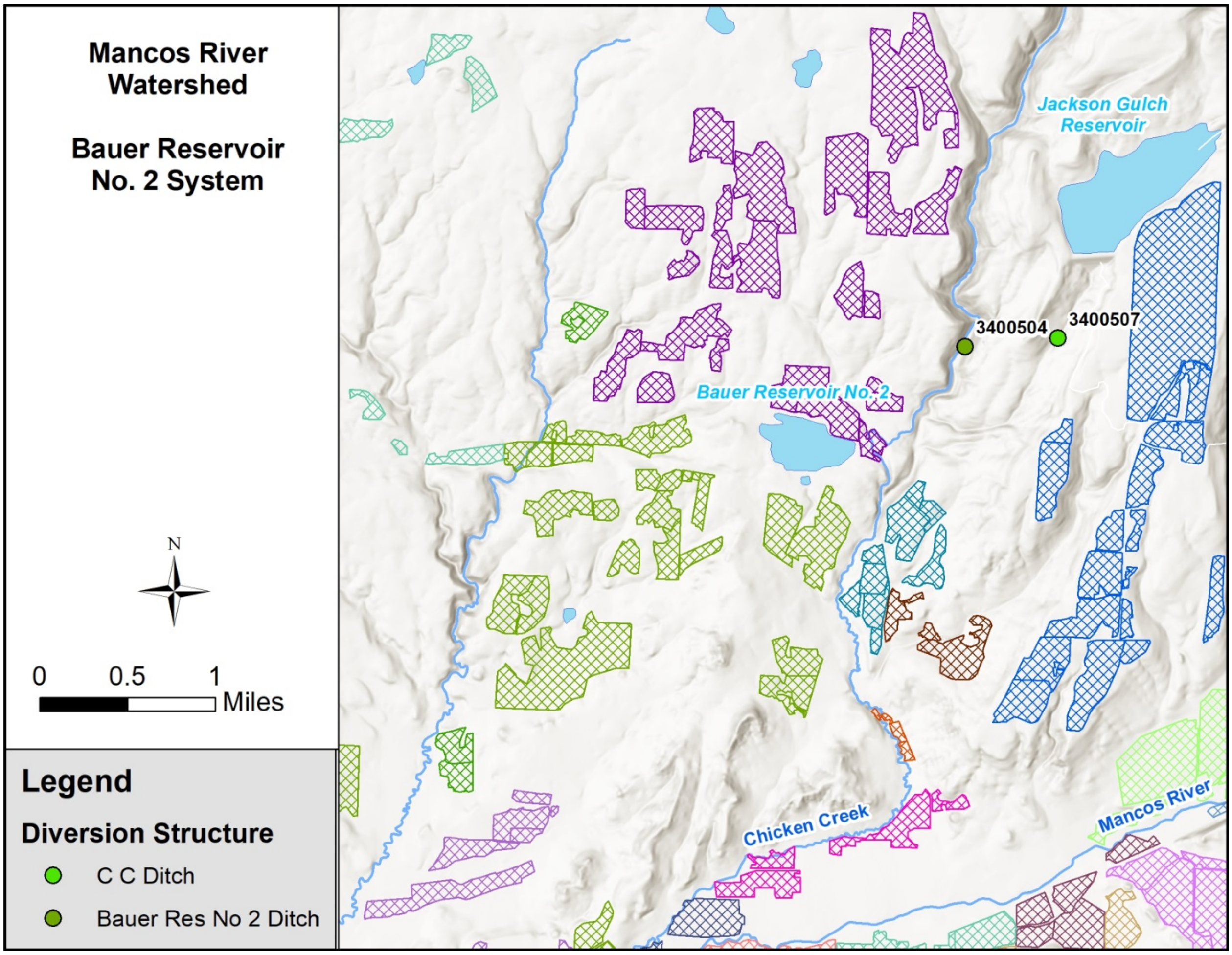


Figure 2-27: Bauer Reservoir No 2 Ditch and Irrigated Acreage Location Map

2.1.10.6 Summit Irrigation

The Summit Irrigation system imports water to the Mancos basin from the Dolores Basin. The Summit Reservoir, located on Lost Canyon Creek, is a privately owned and operated reservoir that supplies water the Summit Irrigation System. Water is carried via the Summit Ditch or via Turkey Creek Ditch to irrigation in upper McElmo Creek and the upper Mancos. The irrigated acreage served by the Summit system in the Mancos system is show in light green on **Figure 2-28**. The return flows from irrigation accrue to Mud Creek.

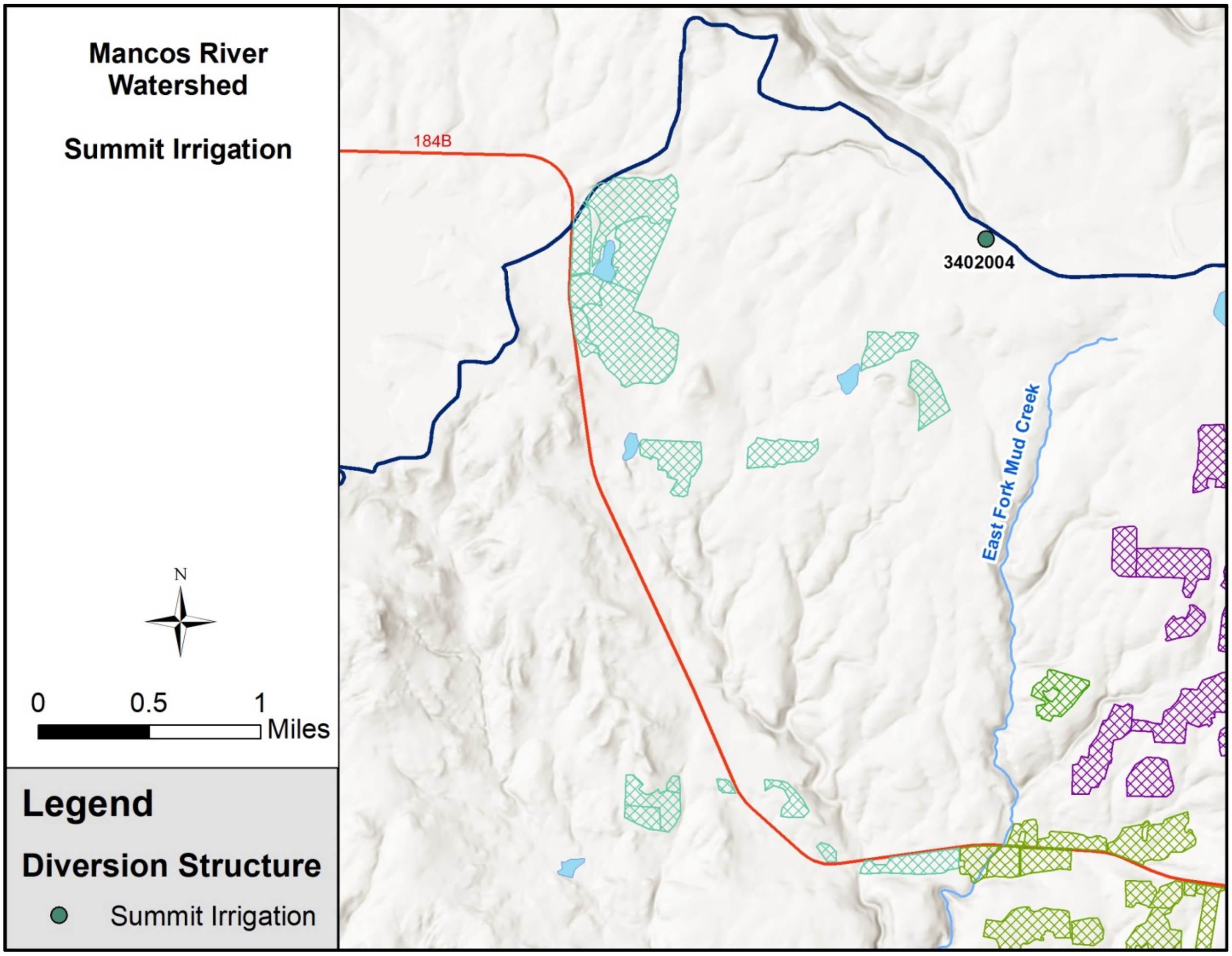


Figure 2-28: Summit Irrigation Ditch and Irrigated Acreage Location Map

2.1.10.7 Mainstem Diversion Structures

The majority of diversions in the Mancos Basin occur along the mainstem of the Mancos River, above the confluence with Weber Canyon, as shown in **Figure 2.29**. The Weber Ditch (3400576) is the most upstream ditch and irrigates acreage to the south of the river and into Weber Canyon. The Smith Ditch (3400566) and the Root & Ratliff Ditch (3400554) share a river diversion structure. The Smith Ditch irrigates a relatively small amount of acreage to the south of the river, while the Root & Ratliff irrigates a large amount of acreage along the southern portion of the river valley and a few parcels in Weber Canyon. The Viets/Boss/No. 6 ditches and the Sheek Ditch are explained in more detail below. The Henry Bolen Ditch (3400534) is toward the bottom of the valley and is generally the calling water right.

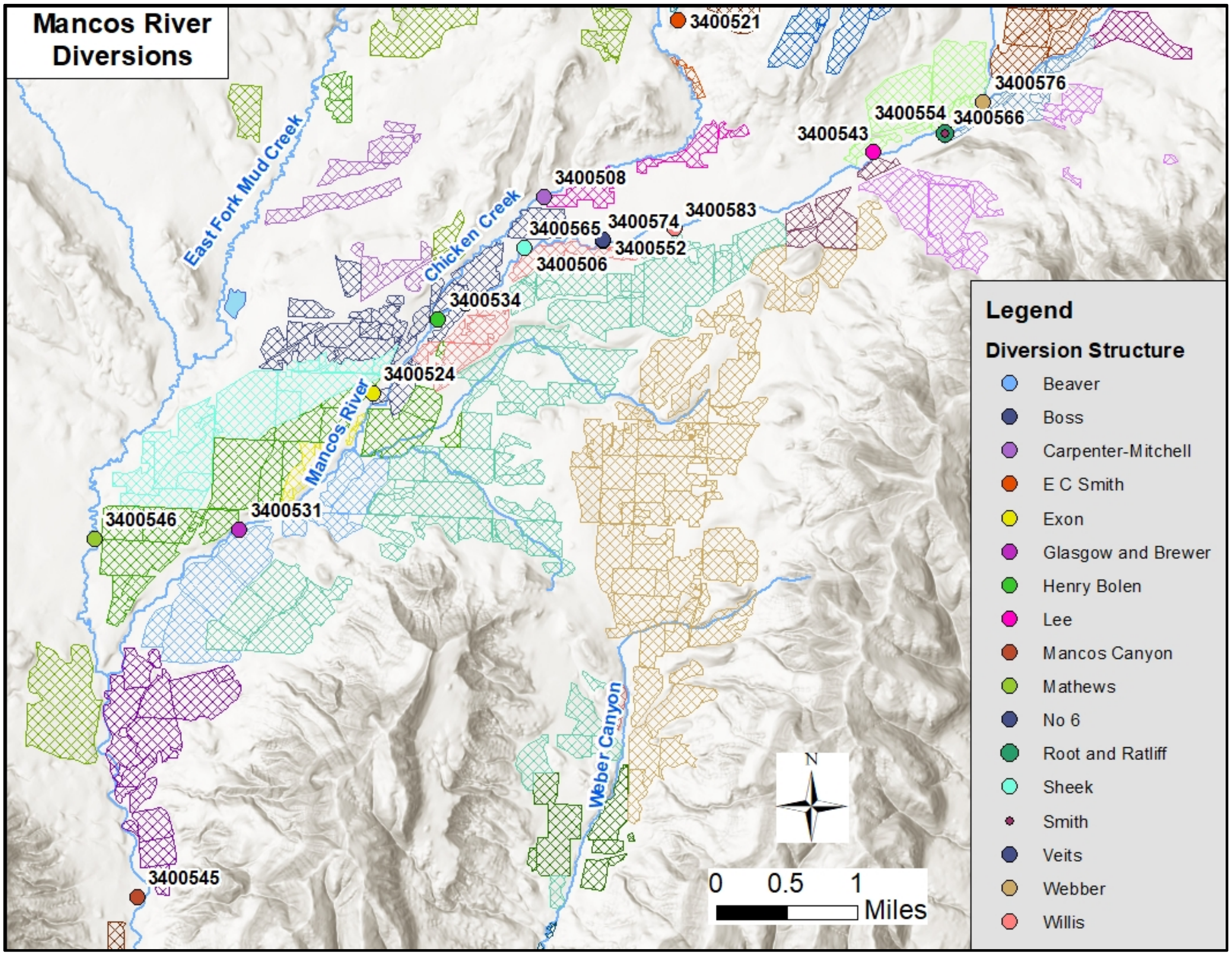


Figure 2-29: Mancos River Mainstem Diversion Structures and Irrigated Acreage Map

2.1.10.8 Veits/Boss/No. 6 Ditches and Sheek Ditch

Originally, the Veits, Boss and No. 6 ditches each had headgates on the Mancos River and served distinct acreage. Through time, the ditches have been physically combined and the water rights have been either transferred or the remaining headgate has been made an alternate point of diversion. As shown on the map in **Figure 2-30**, Veits Ditch (3400574), Boss Ditch (3400506), and No. 6 (3400552) now share a headgate. The three entities are managed together to serve irrigated acreage on the west and east side of the Mancos River. Physically, water is diverted from the common headgate into a common pipeline and flumed across Chicken Creek. Water is also flumed back across the Mancos River to irrigate a few parcels on the east bank.

The next downstream diversion structure is the original point of diversion for the No. 6 Ditch, which is now used exclusively by the Sheek Ditch (3400565). The Sheek Ditch diverts from the Mancos River in an open ditch, which then drops into Chicken Creek. The water is picked back up at the Sheek Alternate Point No 2 (3400850) and piped to the irrigated acreage. If there is no call on Chicken Creek, Sheek Alternate Point No 2 can pick up additional water from Chicken Creek.

The irrigation method on individual parcels under these ditches is primarily sprinkler, with some gated pipe and a few flooded parcels remaining.

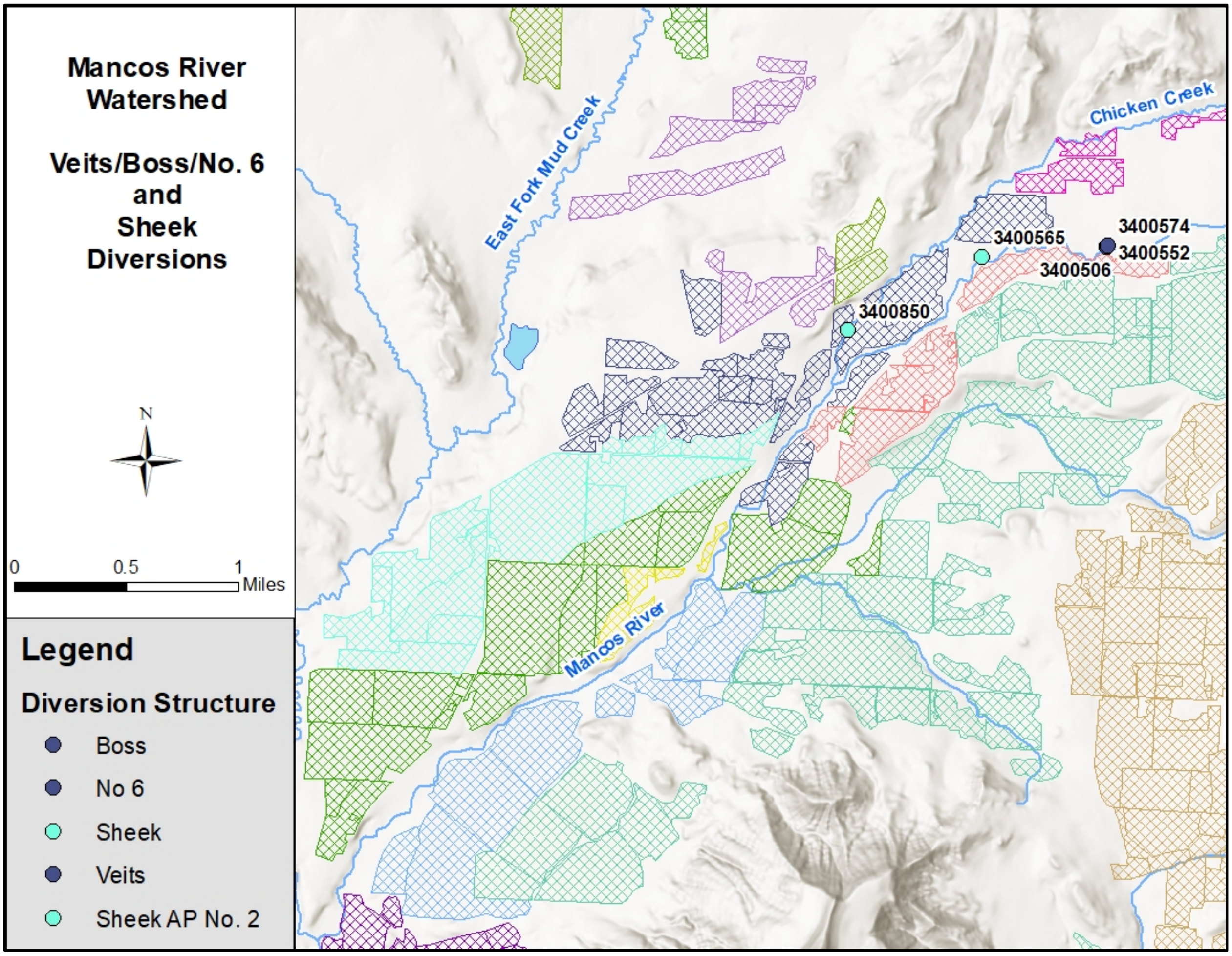


Figure 2-30: Viets/Boss/No. 6 Ditches, Sheek Ditch and Irrigated Acreage Location Map

2.1.10.9 Weber Canyon Diversions

Weber Canyon produces almost no natural flow; although there is some minor spring runoff from the surrounding mountains. The majority of the flow in the canyon is from irrigation return flows generated from the Weber Ditch and the Root & Ratliff Ditch. The return flows are re-diverted by the structures on Weber Canyon shown in **Figure 2-31**. These structures may experience less available flow in the future as irrigation methods become more efficient; however water users did not indicate there was a problem at this time.

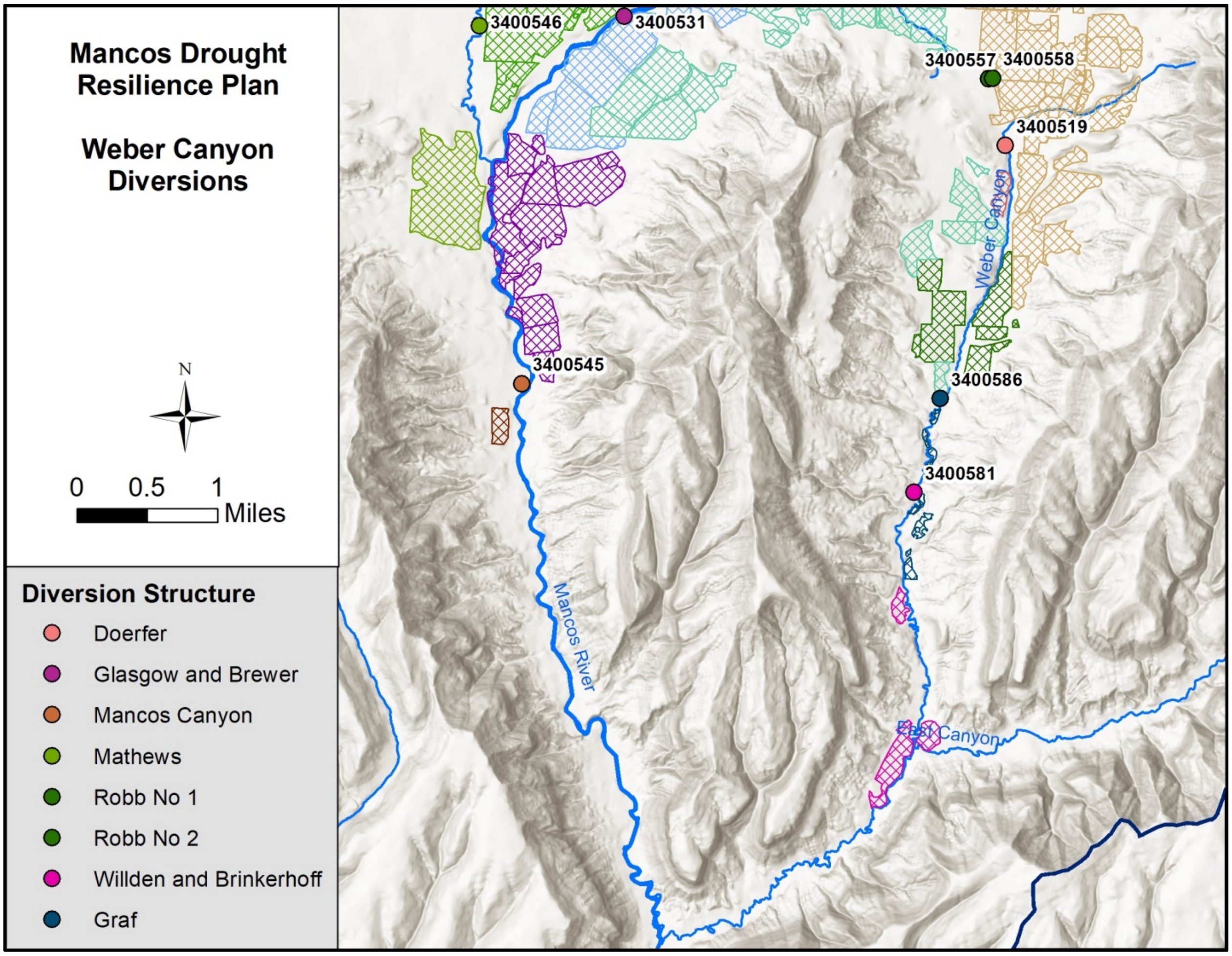


Figure 2-31: Weber Canyon Diversion Structures and Irrigated Acreage Location Map

2.1.11 Municipal Water Providers

There are three entities that supply municipal water in the Mancos Valley Area:

- Mesa Verde National Park
- Town of Mancos
- Mancos Rural Water

Mesa Verde National Park diverts river water from the West Mancos River at the West Mancos Water Supply System (3400578), denoted by the teal dot in **Figure 2-22** above. The water is moved via pipeline to the water treatment facility at the Mesa Verde National Park Visitor Center. The Park also has storage in Jackson Gulch Reservoir, which can be released in exchange for water at their river headgate, or can be taken directly from the reservoir via pipeline to the water treatment facility. The water quality from the river is better than the reservoir, so the Park prefers to use their storage by exchange. The Park also operates a waste water treatment facility.

The Town of Mancos provides water to domestic and commercial water users inside the Town boundaries. River water is diverted from the West Mancos River at the Town of Mancos Ditch

(3400573), denoted by the brown dot in **Figure 2-25**. The water is moved via pipeline to the water treatment facility located between Jackson Gulch Reservoir and the Town. The Town also has storage in Jackson Gulch Reservoir, which can be released via the outlet to the headgate on West Mancos, or can be taken directly from the reservoir via pipeline to the water treatment facility. The Town can also use Jackson Gulch Reservoir Inlet as an alternative point and divert their water right through the reservoir infrastructure. The water treatment needs of the river water and the reservoir water are different, so the Town prefers not to switch between the two sources frequently. The Town operates a waste water treatment facility and discharges back to the Mancos River.

Mancos Rural Water supplies drinking water for domestic use to water users outside the Town of Mancos boundaries. Their treatment facility is located on Jackson Gulch and they divert water from the reservoir via pipeline. The majority of their users are on septic systems; however, a few businesses close to the edge of town are connected to the Town of Mancos sewer system.

2.2 Current Crop Consumptive Use and River Depletions

Consumptive use in the Mancos Basin is dominated by agriculture. Irrigators in the Mancos Basin are supplied by surface water; groundwater is not used for irrigation. In order to understand the current status of the basin, it is important to understand the needs of agriculture and how water is used by irrigators. This section addresses historical practices, current trends, and highlights crop consumptive use in the three representative hydrologic years.

2.2.1 Irrigation Practices and Return Flows

Pasture grass is the primary crop grown in the Mancos River and supports cattle operations, many that have been in business for generations. Irrigated grass is both cut for cattle feed (haying) and, later in the irrigation season, used for direct grazing.

Historically, irrigation has been accomplished with earthen ditches and flood irrigation. However, the Mancos Basin is water supply limited, meaning that there is less water available than the crops would normally use to generate a maximum crop yield. This motivates ranchers to increase the efficiency of their system to deliver more water to the crops. Additionally, the Mancos Basin has been designated as a Salinity Control area by the NRCS. Larger return flows from both ditch seepage and irrigation application carry naturally occurring salinity in the soil to the river. The NRCS has provided funding for ranchers to convert their conveyance system to pipe and to improve their on-farm application methods. In practice, this means that irrigators are moving away from flood irrigation and toward irrigation through gated pipes or sprinklers. It is important to note that some ranchers in the area had already started converting from flood irrigation to more efficient application methods prior to the Salinity Control program, but this was limited to areas where the ditch provided enough head to support a pressurized system since flood irrigation can be accomplished on low-head ditches, but sprinklers require significantly more pressure. By converting to pipe, the delivery system can be pressurized and more users under the ditch can convert to gated pipe or sprinklers.

The water commissioner and water users provided estimated dates when ditches first started using piped conveyance, as shown in **Table 2-6**.

Table 2-6: Year Ditches Converted to Pipe Conveyance System

WDID	Name	Year in Pipe
3400504	Lower Bauer West Lateral	2006
3400505	Beaver Ditch	2008
3400508	Carpenter and Mitchell Ditch	2008
3400509	Cavu No 1 Ditch	2006
3400519	Doerfer Ditch	2006
3400521	E C Smith Ditch	2006
3400522	East Mancos Highline and Extension Ditch	2018
3400531	Glasgow & Brewer Ditch	2006
3400534	Henry Bolen	2005
3400538	John Carter	2006
3400546	Mathews Ditch/Sheek Pump	2006
3400557/3400558	Robb No 1 and Robb No 2 Ditch	2006
3400565	Sheek Ditch	2006
3400573	Town of Mancos	2006
3400574/3400506/ 3400552	Veits/Boss/No. 6 Ditch	2006
3400586	Graf Ditch	2006
3400850	Sheek No 2 Pump	2006

Changing conveyance and irrigation application efficiencies impact the return flows and, potential, water available for downstream users in ways that can be difficult to measure directly. Therefore, watershed modeling can be a useful tool to understand the importance of return flows to the river system. Diversions measure the amount of water taken from the river. Crop consumptive use is the amount of water used by the crops and therefore, permanently depleting the river. Return flows are the difference between diversions and consumptive use. Return flows come back to the river via the surface (quickly) or through the shallow alluvial aquifer (lagged over several months). To estimate the amount of return flows that are re-diverted by downstream ditches, the natural flow is compared to the total basin diversions. In any given month, if the natural flow is less than the total basin diversions, the diversions are either from reservoir storage water or from return flows. The amount of reservoir water released from Jackson Gulch can be calculated by the reservoir change in storage, and in addition, headgate diversions from storage are coded by the water commissioner.

Total basin diversions compared to natural flow are plotted for the representative wet year in **Figure 2-32**, representative average year in **Figure 2-33**, and representative dry year in **Figure 2-34**. Key observations include the following:

- Even in a wet year, the timing of the runoff is not necessarily at the same time as the crop demand. Therefore, reservoir storage and return flows were needed in July, August, and September of 2005 to meet the crop demand. Return flows provided more water in July than the reservoir storage, but reservoir storage is needed in September.
- During 2015, which was an average runoff year by volume but had a delayed peak, reservoir storage was needed in August and September. Return flows contributed a significant amount of water to diversions in August.
- During the dry year of 2012, the runoff started in March and peaked in April, which was too early to meet crop demands. Diversions occurred in April to boost soil moisture, but a large amount of the diverted water returned to the system in May and was re-diverted. Reservoir storage was critical during June, July, August, and September. The additional supply from the reservoir helped to generate return flows which could be re-diverted downstream.
- Note the large range in natural flow, which essentially doubles from the dry year to the average year and then doubles again from the average year to the wet year. Total diversions also vary, but less dramatically. This is only possible because of the reservoir storage in the basin.
- The amount of diversions as a percent of natural flow increases with decreasing hydrology. As shown on the figures, in the representative wet year, diversions are 47 percent of natural flow. Diversion increase to 81 percent of natural flow during the representative average year and to 130 percent of natural flow during the representative dry year – again highlighting the reliance on both return flows and storage.

In the **Example Scenario: Changes to Irrigation Practices Section**, the model is used to compare diversions, consumptive use, reservoir storage, and streamflow assuming flood irrigation verses sprinkler irrigation. The section presents results that further highlight the importance of return flows. Although the example scenario highlights the model results with extreme efficiency improvements , the model was also used to understand whether changes in conveyance efficiency due to piping since 2006 has impacted downstream water users that rely on return flows to meet a portion of their demands. The results show that the ditch piping to date has not impeded the ability for users to divert under their direct flow rights and has not resulted in increased reservoir use.

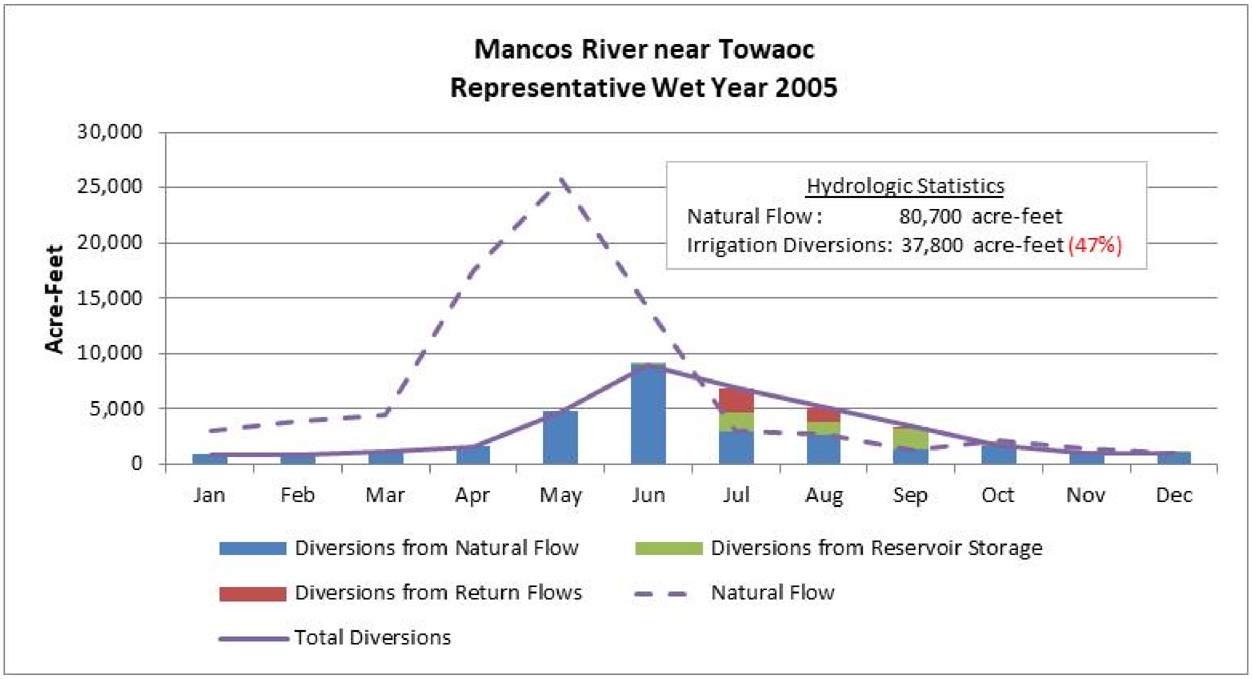


Figure 2-32: Source of Diversion Water for Wet Year 2005

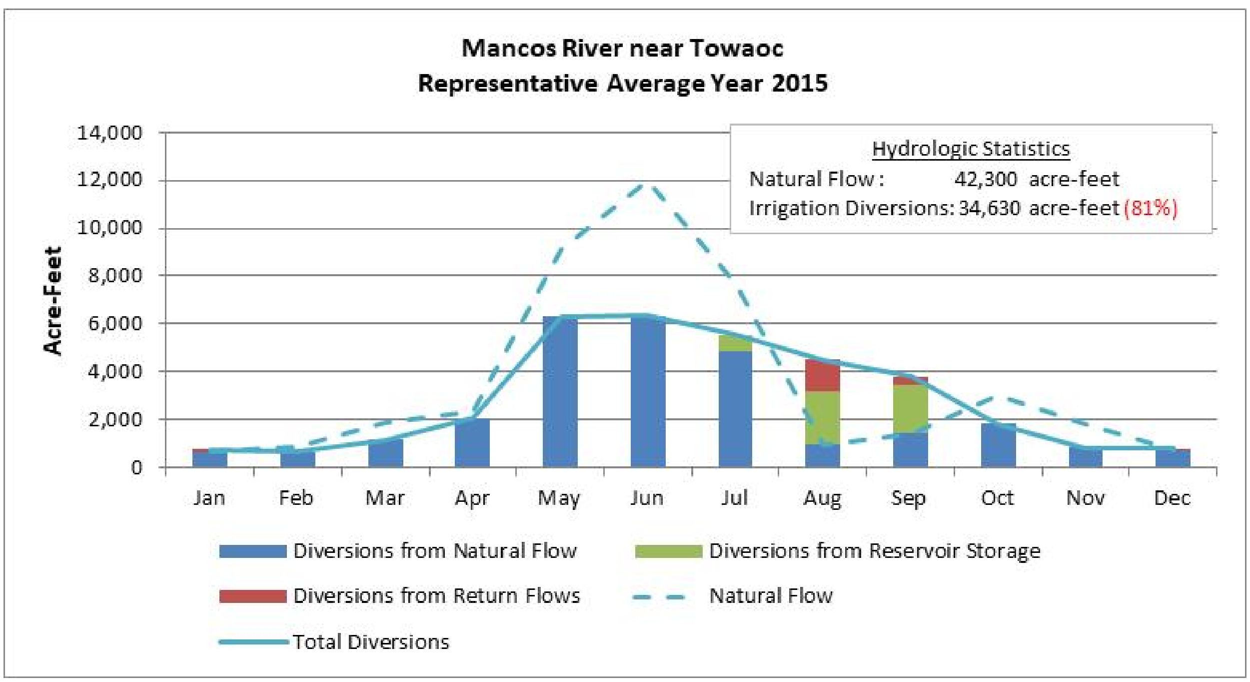


Figure 2-33: Source of Diversion Water for Average Year 2015

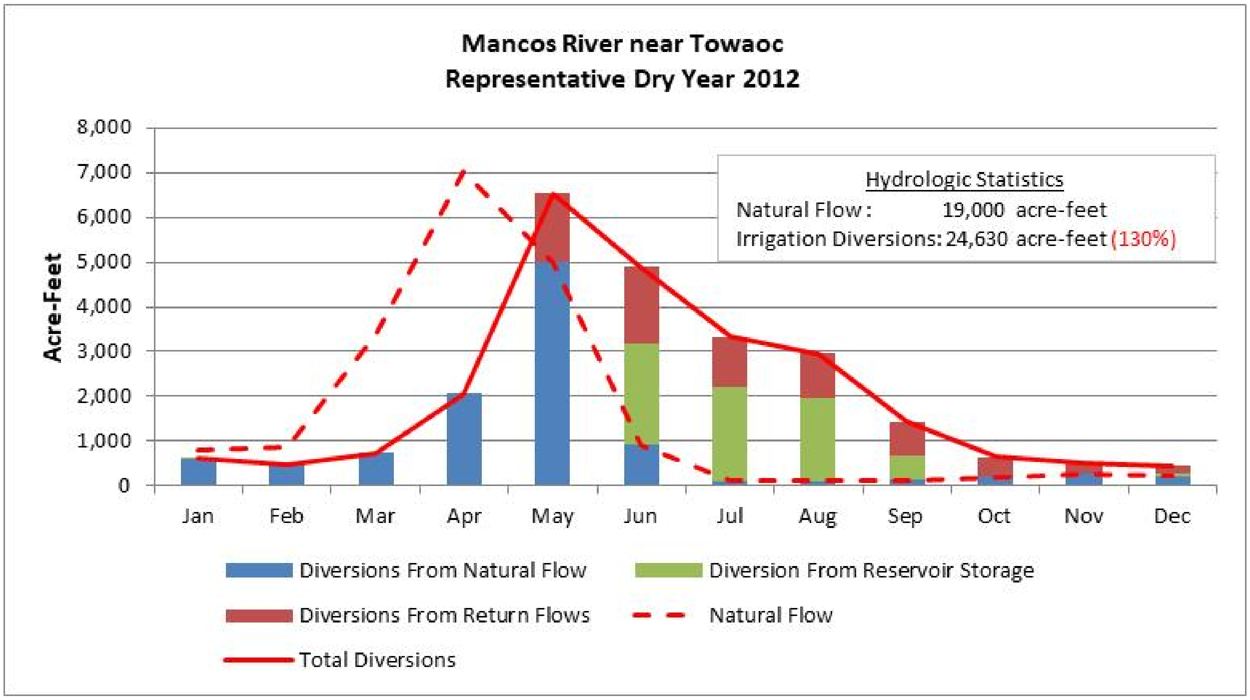


Figure 2-34: Source of Diversion Water for Dry Year 2012

2.2.2 Crop Consumptive Use

Consumptive use analyses compare expected crop water demand to actual crop water use to identify consumptive use shortages. Consumptive use analyses also estimate permanent depletions to the river attributed to crop consumptive use, and temporary depletions to the river which are caused by conveyance and irrigation application inefficiencies. Conveyance loss is water that infiltrates into the soil in route to the field. Conveyance losses return to the river through the shallow alluvium, generally within the same month as diversion. Application losses are the portion of water applied to an irrigated field that returns to the river through surface runoff or infiltrates beyond the crop root zone and lags back the river.

StateCU was used to estimate crop consumptive use and shortages from 1975 through 2017. First, StateCU estimates crop demand, the amount of water the crops could use if provided a full irrigation supply based on monthly climate data and irrigated acreage. Next, StateCU uses diversion records and estimated conveyance and application efficiencies to determine the actual (supply-limited) crop consumptive use and associated shortages. Consumptive use shortages occur when the crop demand is greater than the crop consumptive use. Diversion records in the Mancos Basin are frequently recorded and are generally believed to be an accurate measurement of flow rates. This increases the confidence in the consumptive use analysis for the Mancos Basin.

Conveyance efficiencies vary based on several factors, including underlying soil permeability and ditch length. However, many of the ditches in the Mancos have been put into pipe, which essentially eliminates conveyance losses. WWG estimated the conveyance efficiency for short earthen ditches to be 90 percent, meaning that 10 percent of the diverted water seeps into the shallow alluvium in route to the irrigated acreage. For long earthen ditches, such as Rush Reservoir Ditch and Crystal Creek Ditch, WWG discussed conveyance efficiencies with the water commissioner and assigned 80 percent efficiency. In order to estimate conveyance efficiency for each ditch, a spatial coverage of ditch alignments would be helpful. This could be an option for future enhancements.

Irrigation application efficiency depends on the irrigation method, soil types, soil thickness, and underlying geology. The most common types of irrigation methods in the Mancos are flood irrigation, gated pipe, and sprinkler irrigation. Most of the sprinklers are side-rolls, although some ranchers are transitioning to center pivots. WWG used the general accepted efficiency values for western Colorado as follows:

- 60 percent for flood irrigation
- 70 percent for gated pipe irrigation
- 80 percent for sprinkler irrigation

A more detailed analysis of irrigation efficiencies could be performed for the Mancos Basin as a potential future enhancement.

The amount of water diverted at the river headgate that is available to the crop is the diverted water less ditch conveyance and irrigation application losses. For example, if 100 acre-feet is diverted and the conveyance loss is 10 percent, only 90 acre-feet is available at the farm turnout. The maximum flood application efficiency is 60 percent; therefore of the 90 acre-feet available at the farm turnout, only 54 acre-feet is available to meet crop demands. This example highlights why so many irrigators are converting to more efficient methods of irrigation. For a ditch that has converted to pipe and sprinkler irrigation, the conveyance loss is essentially 0 percent, so if 100 acre-feet has been diverted, then 100 acre-feet is available at the farm turnout. The maximum sprinkler application efficiency is 80 percent; therefore 80 acre-feet are available to meet crop demand. In a water supply limited basins such as the Mancos, the additional 26 acre-feet of water available to the crops can make a big difference in crop yield.

Excess water applied to the fields during irrigation returns to the river over time. Estimates of lagged return flow timing were adopted from CDSS efforts in the San Juan River basin. For parcels that are within 1,200 feet of a stream or drainage feature, over 66 percent of diversions not consumed by crops are estimated to return to the river within four days of application, with about 85 percent returning within two months of application. For parcels that are greater than 1,200 feet of a stream or drainage feature, less than 50 percent of return flows are estimated to reach the river within four days of application, primarily as surface runoff, with about 70 percent returning within two months of application. These general return flow patterns could be refined for the Mancos Basin in the future.

Figure 2-35 shows the annual variability of agricultural water use for the period 1975 through 2017. The results are for the Mancos River basin; but each ditch was represented individually in the consumptive use analysis. Average annual crop consumptive use from irrigation for 1975 through 2017 was estimated to be 17,000 acre-feet, varying from a low of 6,000 acre-feet in the extremely dry year of 2002 to over 19,600 acre-feet in 2008, a relatively average year.

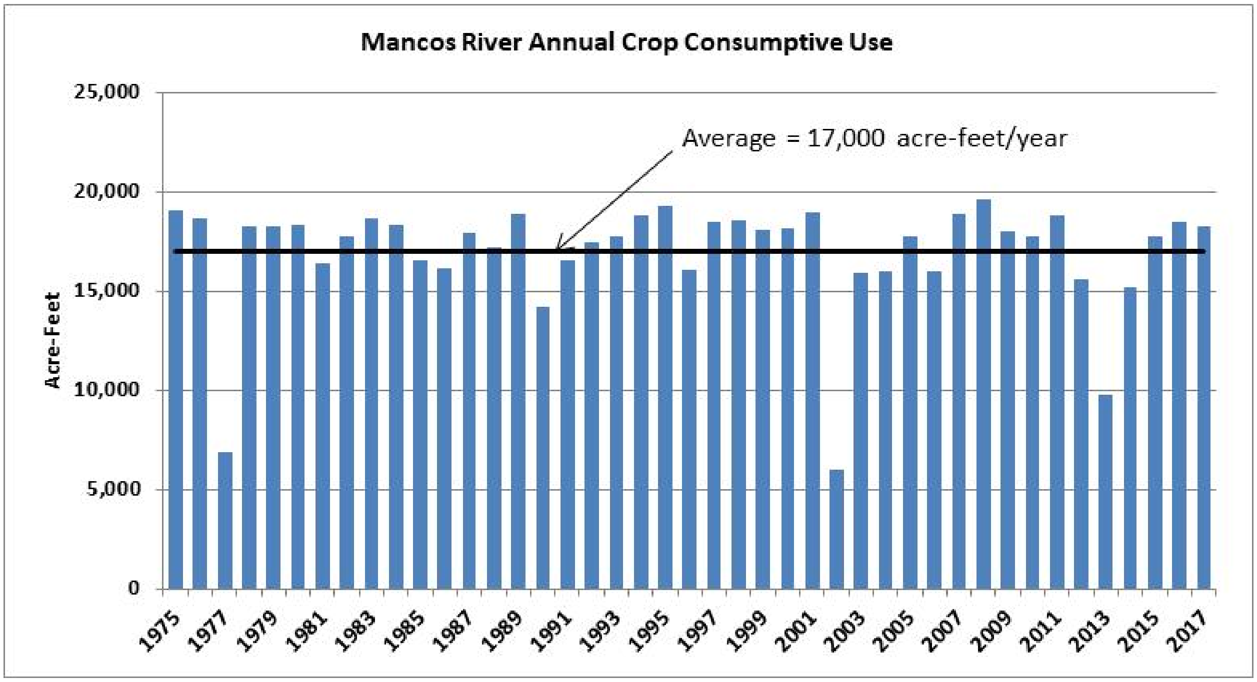


Figure 2-35: Annual Mancos Basin Crop Consumptive Use, 1975-2017

2.2.3 Depletions

As discussed in Section 2.1.4 "Basin Yield", the stream flow gage record includes the influence of humans on the system and natural flow is estimated by removing the influence of man. Therefore, the difference between the natural flow and the gaged flow are the depletions, caused primarily by crop consumptive use, and reservoir operations. The graphs in **Figure 2-36** through **Figure 2-38** compare the monthly gage flow and natural flow for the Mancos River near Towaoc gage location for the three representative hydrologic years. The y-axis scale is held constant on the graphs to facilitate comparisons between the three representative hydrologic year types. The statistics included on each graph also indicate depletions as a percent of natural flows. This location is downstream from the irrigated acreage and highlights how the agricultural depletions, return flows, and reservoir operations have changed the river. The following observations can made based on the three graphs:

- The range of natural flow is large, an annual volume of 80,700 acre-feet in the representative wet year to only 19,000 acre-feet in the representative dry year
- The depletions are similar between the three years, primarily because reservoir storage provides supplemental supply to agriculture
- Depletions as a percentage of natural flow changes significantly with year type, from only 22 percent for the representative wet year to 81 percent for the representative dry year.

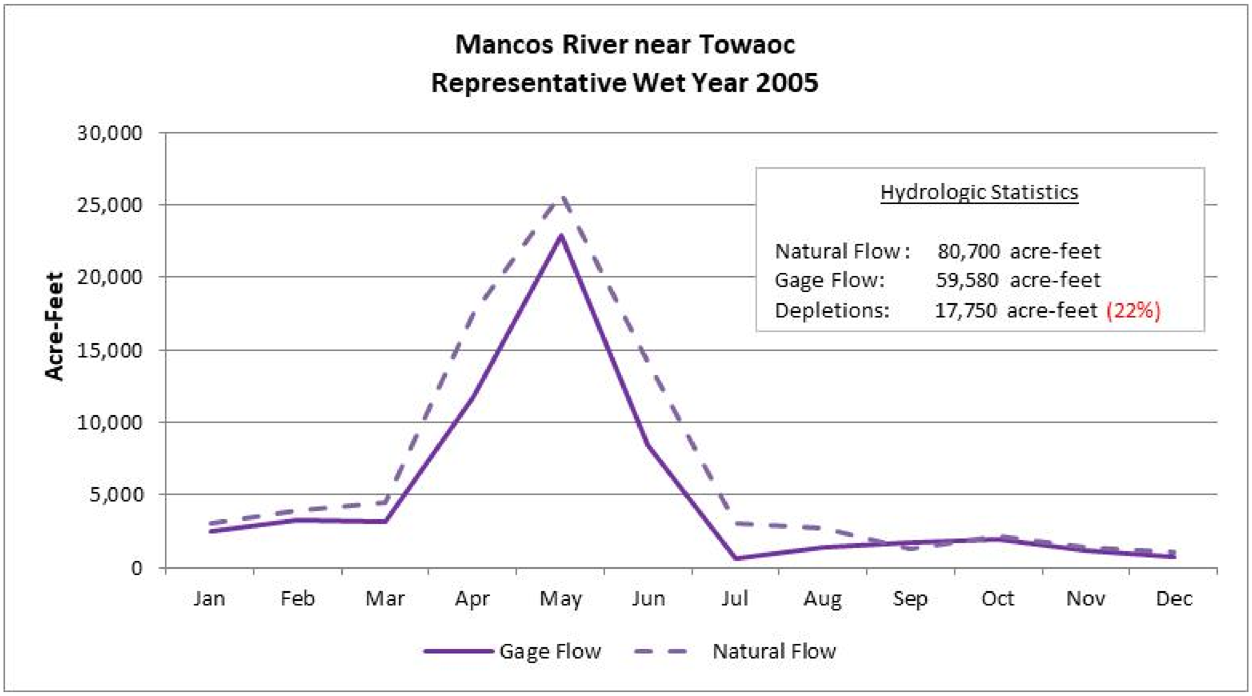


Figure 2-36: Monthly Gage Flow Compared to Natural Flow for Representative Wet Year 2005

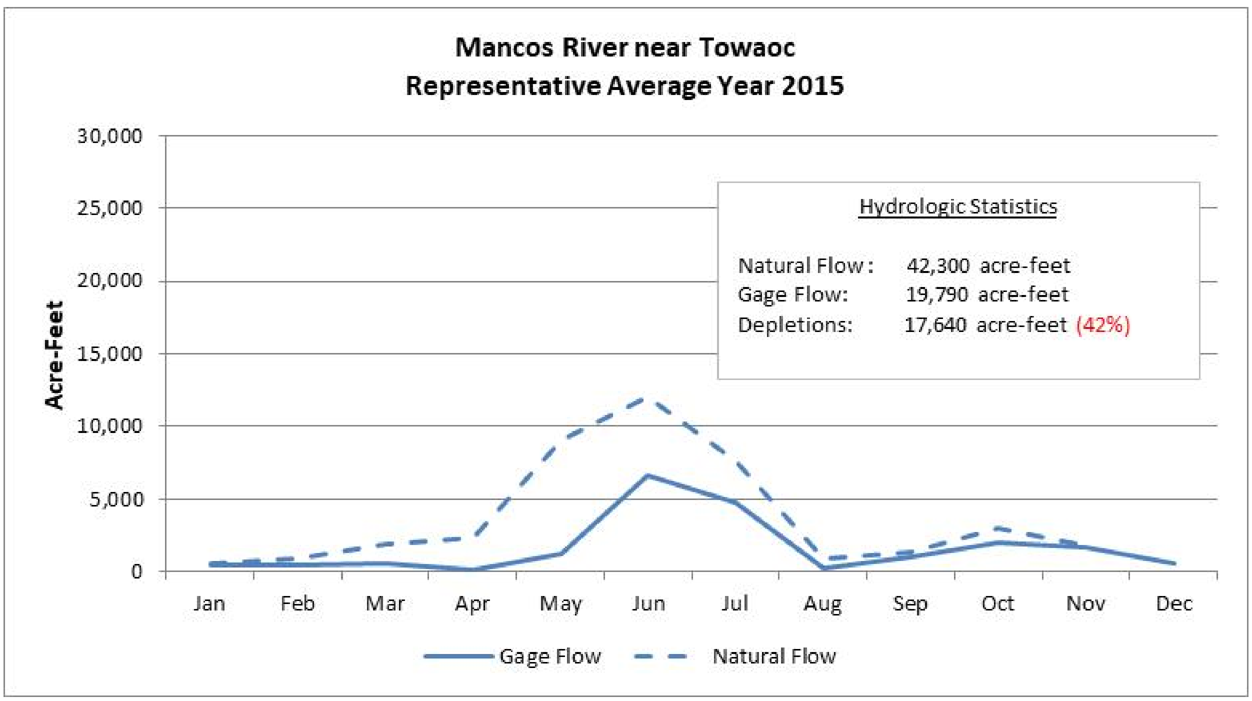


Figure 2-37: Monthly Gage Flow Compared to Natural Flow for Representative Average Year 2015

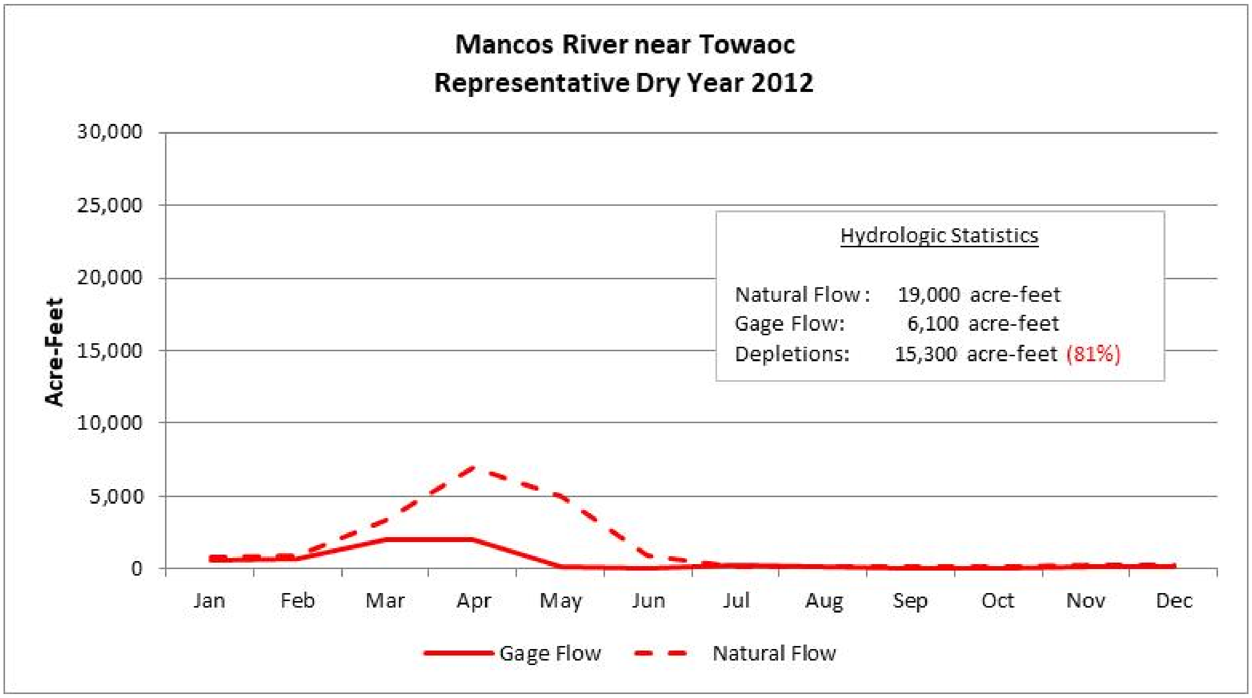


Figure 2-38: Monthly Gage Flow Compared to Natural Flow for Representative Dry Year 2012

Figure 2-39 compares the three representative years and highlights the amount of variability that the river experiences from year to year. Representative wet year 2005 has a typical runoff pattern, with the runoff starting in April, reaching peak volume in May, and declining in June with low flows during the rest of the year. Representative average year 2015 has cool temperatures and above average precipitation during the irrigation season, which delays the peak runoff by almost a month. The low flow season is also delayed until August. There is a slight streamflow recovery in October due to monsoon rains. Representative dry year 2012 has hot temperatures and below average precipitation during the irrigation season, in addition to low snowpack during the winter. The streamflow runoff is very low and the peak volume occurs in April, a month before the normal peak. The streamflow is zero or near zero from June to the end of the year. Without reservoir storage, the agricultural depletions would have been much lower.

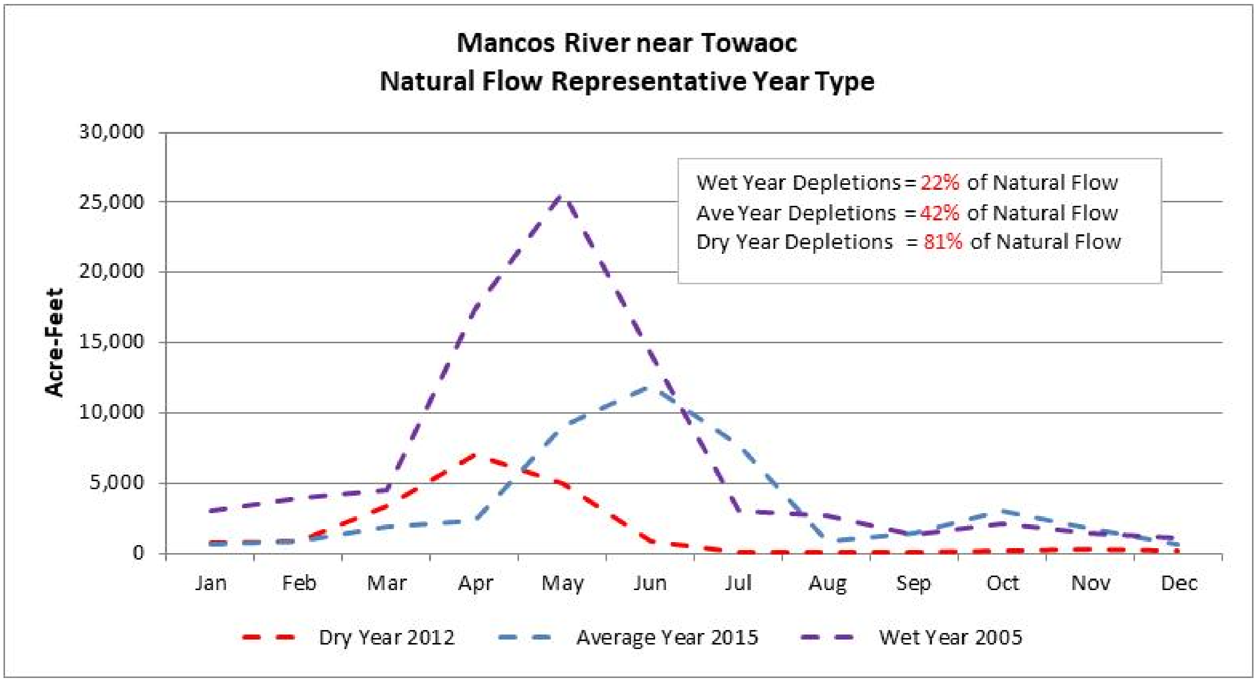


Figure 2-39: Monthly Natural Flow Compared for Three Representative Years (2005, 2012, and 2015)

3 Model Development, Results, and Example Scenarios

This section outlines the refinements and updates performed made to the decision support modeling tools, provides results from the tools, and gives examples of how the models could be used in future phases of the Drought Resilience Planning.

3.1 Decision Support Modeling Tools Development

Decision support tools can be used for Drought Resilience Planning effort in two primary ways:

- To help understanding the drivers that influence current basin consumptive uses, irrigation practices, and system operations
- To explore how the system would change under varying conditions; including changes in hydrology and climate, demands, irrigation practices, basin operations, or basin administration

As discussed in the Introduction Section, the State of Colorado represented the Mancos River as an integral part of the CDSS San Juan River Basin models, which include representing 100 percent of the irrigated acreage in a StateCU crop consumptive use analysis and a high-level representation of irrigation diversions, reservoirs, and municipal uses in a StateMod water right allocation model. WWG refined the models so they could be used to look at smaller tributary flows, ditch-to-ditch interactions, and “what-if” scenarios on a stream reach scale. The following substantial changes were made:

- Worked with the water commissioner to update the irrigated acreage developed for CDSS, as discussed above.

- Updated the irrigation method assigned to each parcel by reviewing recent aerial imagery. This update included assigning gated pipe as an irrigation method, which was previously classified as flood irrigation.
- Refined the representation of conveyance loss to account for the timing of ditches going into pipe and made a best estimate of when irrigation methods had been improved.
- Added the Mancos River near Mancos streamflow gage in the model, and corrected the streamflow record to account for the two different gage locations.
- Added Chicken Creek, Mud Creek, and Weber Canyon to the model.
- Added Bauer No 1 Reservoir, Bauer No 2 Reservoir, and Weber Reservoir to the model.
- Added Town of Mancos and Mancos Rural Water to the model.
- Updated the operating rules for Jackson Gulch Reservoir to deliver water to the ditches that currently receive allocations.
- Refined the model to represent each ditch individually, at the physically correct location on the river and included each water right.
- Refined the characterization of return flow locations for each ditch based on updated irrigated acreage assignments, topo maps, and water user knowledge.
- Updated the lag pattern assigned to different ditches, depending on the distance from the irrigated acreage to the stream.
- Extended the model from 2013 to 2017.

The refinements to the StateCU and StateMod models allow them to be more useful tools for Drought Resilience Planning.

3.2 Model Results

The current agricultural depletions reported in Section 2.2 were derived from StateCU, the CDSS crop consumptive use model. StateCU starts with the irrigated acreage and crop type. Using monthly temperature and precipitation data, the crop irrigation requirement (CIR) is calculated. Finally, the diversion records and estimates of efficiencies are provided to find the actual crop consumptive use and the shortages to crop consumptive demands.

Irrigated acreage and crop type in the Mancos Basin have not significantly changed in recent years. **Figure 3-1** shows the variability of annual crop irrigation requirement (primary y-axis) and the average irrigation season temperature measured by the Mesa Verde National Park COOP station (secondary y-axis) over the 1975 to 2017 period. As shown in **Figure 2-11** above, irrigation season temperature not appear to have a long term trend towards warming. However, the temperature and corresponding crop irrigation requirement appear to have increased, starting with the hot and dry years of the early 2000s and remaining warmer in the recent past. There is less of a correlation between precipitation during the irrigation season and crop irrigation requirement. This is most likely because the Mancos River basin is a semi-arid climate and the volume of precipitation is too small to meet a significant portion of the crop irrigation requirement.

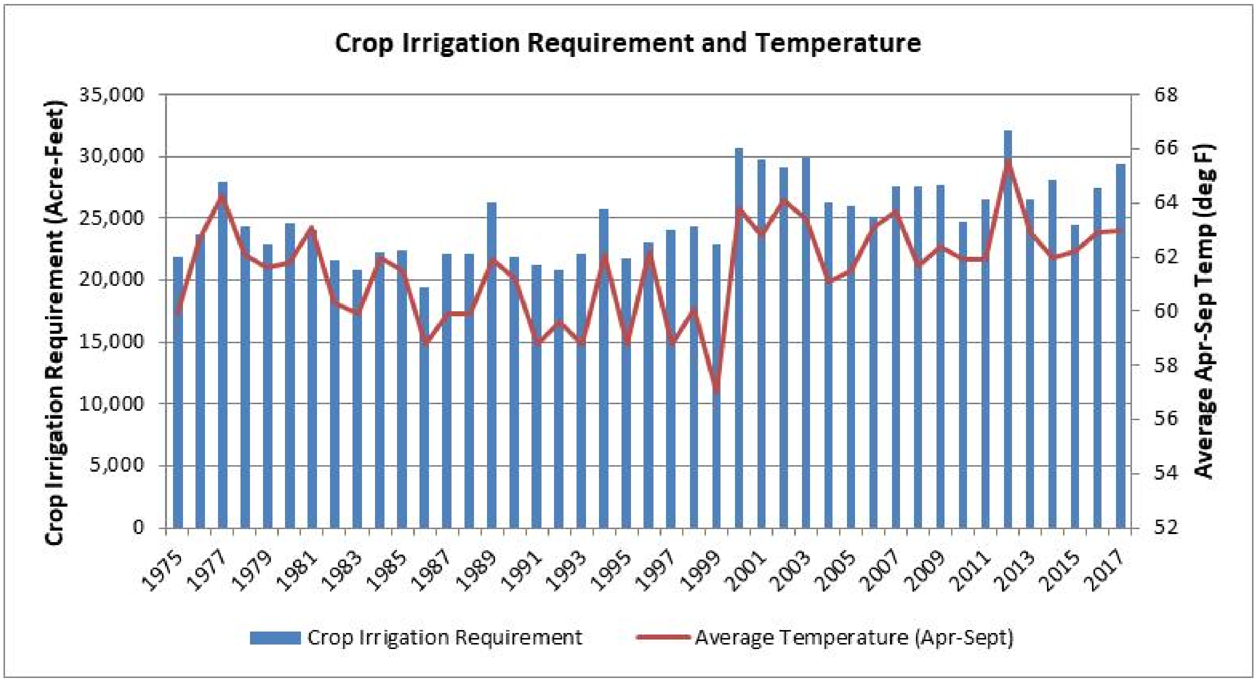


Figure 3-1: Annual Crop Irrigation Requirement and Average Irrigation Season Temperature Graph (1975 - 2017)

As with most snowmelt dominated basins in Colorado, there is a miss-match between the timing of runoff and when the crops need water. **Figure 3-2** shows the average monthly crop irrigation requirement and the average monthly natural flow for the Mancos River. The average monthly CIR starts near zero in March, grows during April, May, and June, reaches the peak in July, and slowly tapers off to zero in November. In contrast, the average monthly natural flow starts to increase in March, but peaks two months earlier than CIR, in May. The river quickly declines in June and reaches low flow conditions in July, just as the crop irrigation requirement is reaching its peak. This miss-match in timing can cause shortages to crop consumptive use.

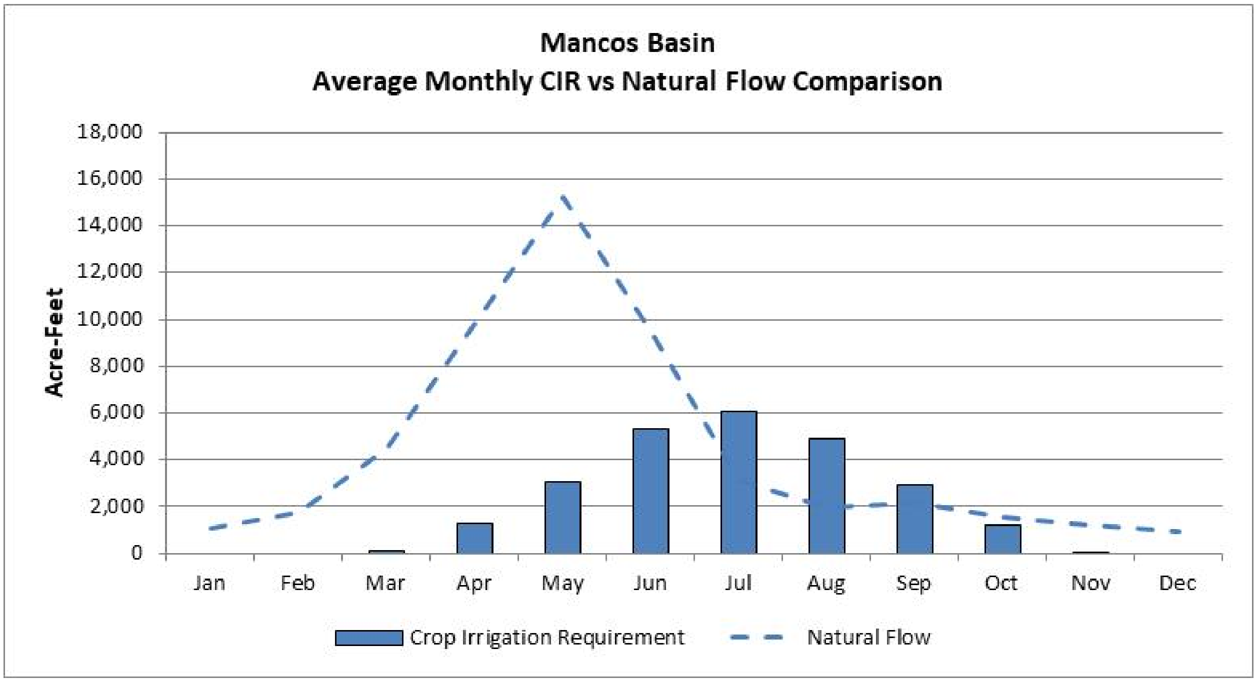


Figure 3-2: Mancos Basin Average Monthly Crop Irrigation Requirement Compared to Natural Flow (1975 - 2017)

Crop consumptive use shortage is one of the useful outputs from the StateCU model. The graphs in **Figure 3-3**, **Figure 3-4**, and **Figure 3-5** show the crop consumptive use and the crop consumptive use shortage for the representative wet year, average, and dry year, respectively. Although individual ditches are represented in the model, the total for the basin is presented in the graphics. The largest portion of consumptive use shortages throughout the basin are caused by physical and legal water availability. For example, diversions on Weber Canyon have a limited physical supply, and junior diversions may be called-out by senior direct rights during the late irrigation season, as the natural water supply declines.

It seems counter intuitive that there are substantial shortages in the 2005 wet year, but recall comparison of natural flow and irrigation diversions from **Figure 2-32**. There was sufficient natural flow to meet the diversion demands in June, but then irrigators needed water from the reservoir and from return flows starting in July, as the natural streamflow hydrograph dropped. Also, shortages reported by the model could potentially be a reflection of inaccurate data or information. Shortages may also be reported based on differences in modeling assumptions and common irrigation practices. For example, when irrigators turn off diversions so their fields will dry out before haying, the model accurately reflects supply limitations to the crop – even though the user would not consider this routine irrigation practice as contributing to shortages. The annual basin shortage in 2005 was 32 percent.

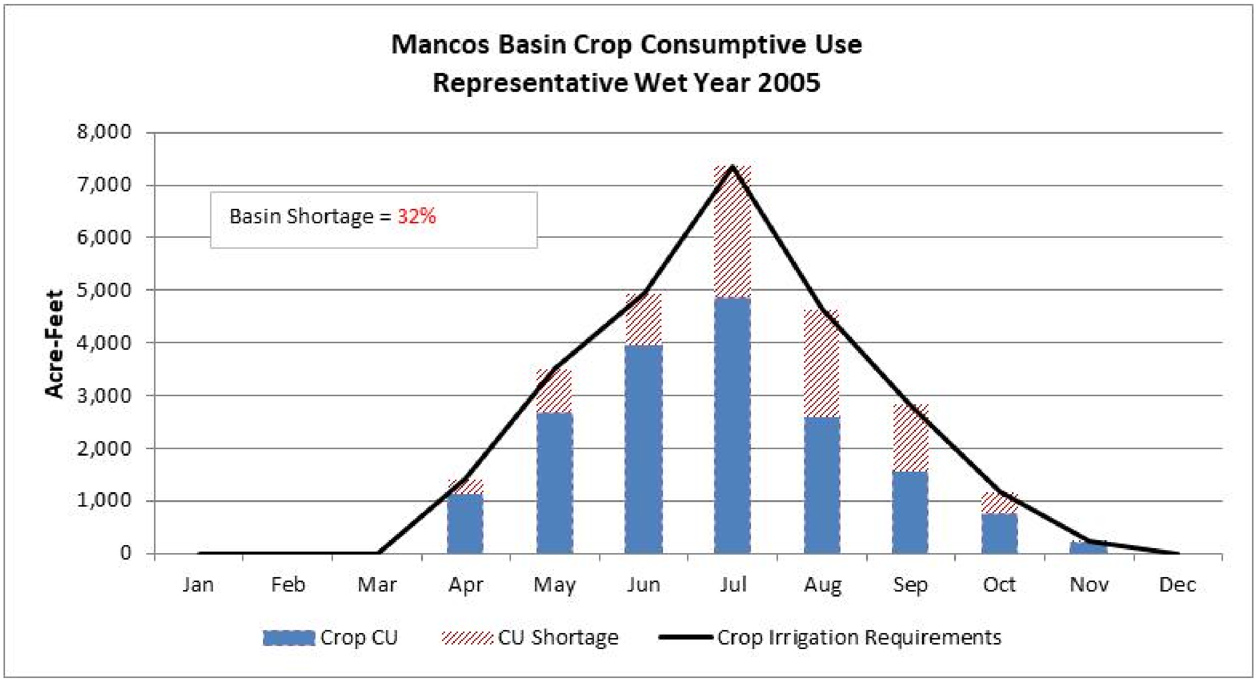


Figure 3-3: Mancos Basin Crop Consumptive Use in Representative Wet Year 2005

Representative average year 2015 had cooler temperature and was one of the wettest precipitation irrigation seasons on record. These two climate factors help to reduce the overall crop irrigation requirement. Note how the CIR in 2005 peaked at over 7,000 acre-feet in July; but in 2015 CIR never exceeded 5,500 acre-feet. More of the lower CIR was met, even though 2015 was an average run-off year. It is interesting to note that there was still a miss-match in runoff timing. Recall from **Figure 2-33**, the runoff in 2015 peaked in June. **Figure 3-4** shows that the CIR does not peak until August. The annual basin shortage in 2015 was 27 percent.

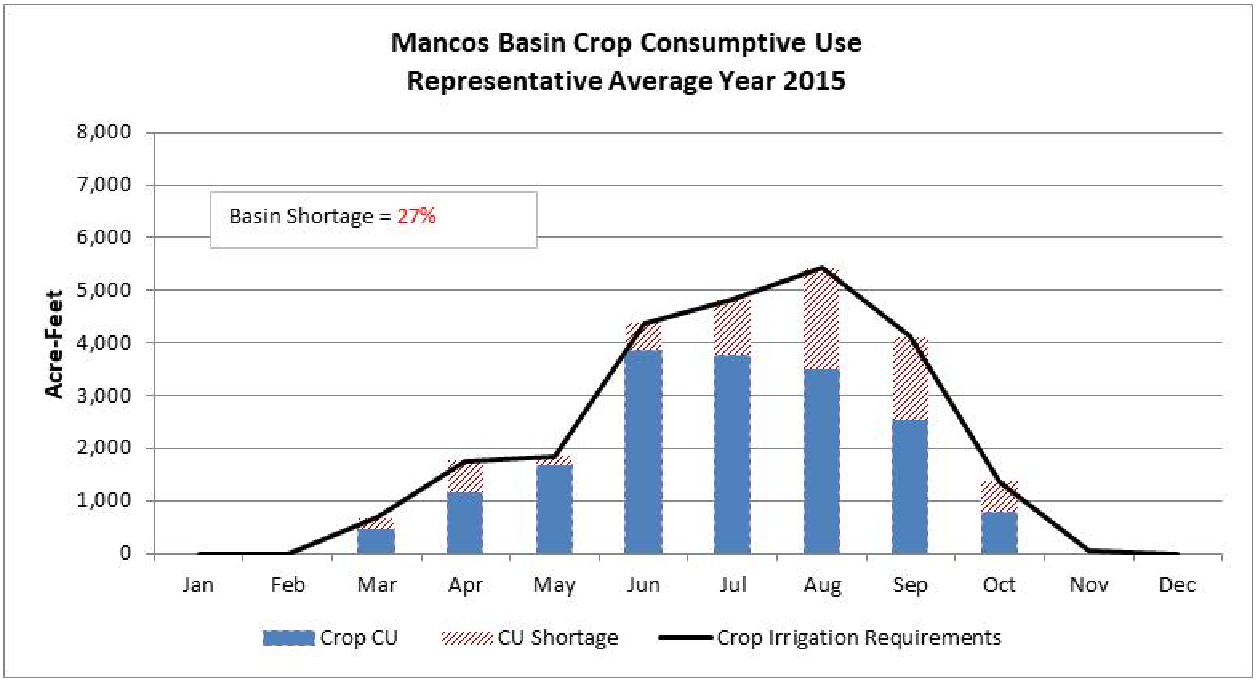


Figure 3-4: Mancos Basin Crop Consumptive Use in Representative Average Year 2015

Representative dry year 2012 had higher temperatures and low irrigation season precipitation. This caused the crop irrigation requirements to be especially high (note the spike in annual crop demand shown in **Figure 3-1**). High crop demand, coupled with the extremely low streamflow, produced substantial shortages. Recall in **Figure 2-34**, the streamflow peaked in April, while the CIR is highest in June and July. The water users depended on reservoir storage during the late irrigation season, but there was not enough to meet the large crop demands. The annual basin shortage in 2012 was 51 percent, significantly higher than other years resulting in a poor crop yield.

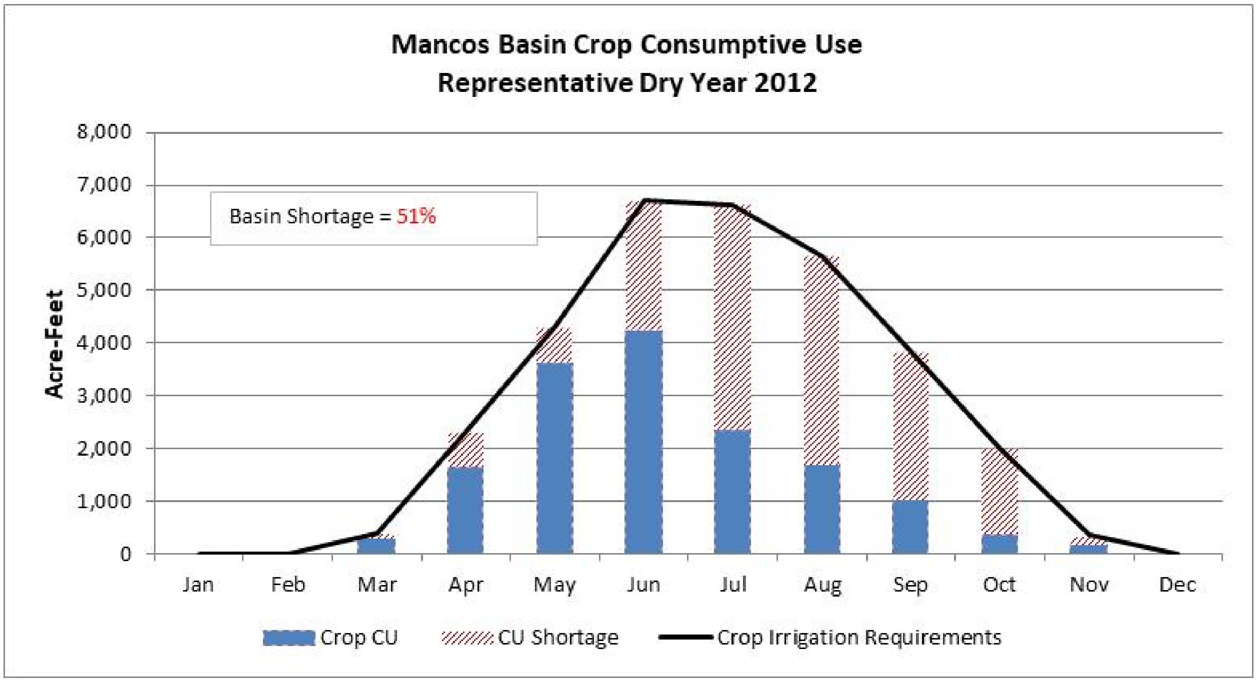


Figure 3-5: Mancos Basin Crop Consumptive Use in Representative Dry Year 2012

In **Figure 3-6**, the map shows the average annual percent crop consumptive use shortage throughout the basin. The shortage is based on the historical crop irrigation requirement and the historical diversions. Structures that exhibit frequent and large shortages are less resilient to drought conditions; as they have more limited supplies to fully irrigate crops. The map shows that the upper headwaters and tributaries are more likely to have consistent shortages than the mainstem of the Mancos. The three ditches that fall into the highest level of shortages are the Mancos Canyon Ditch, the Williams Ditch and the Mathews Ditch. All three have periods of inactivity in their historical record, which means the historical diversions are zero and the crop shortage is 100%. This may reflect historically sporadic operation of the ditches, and not water availability.

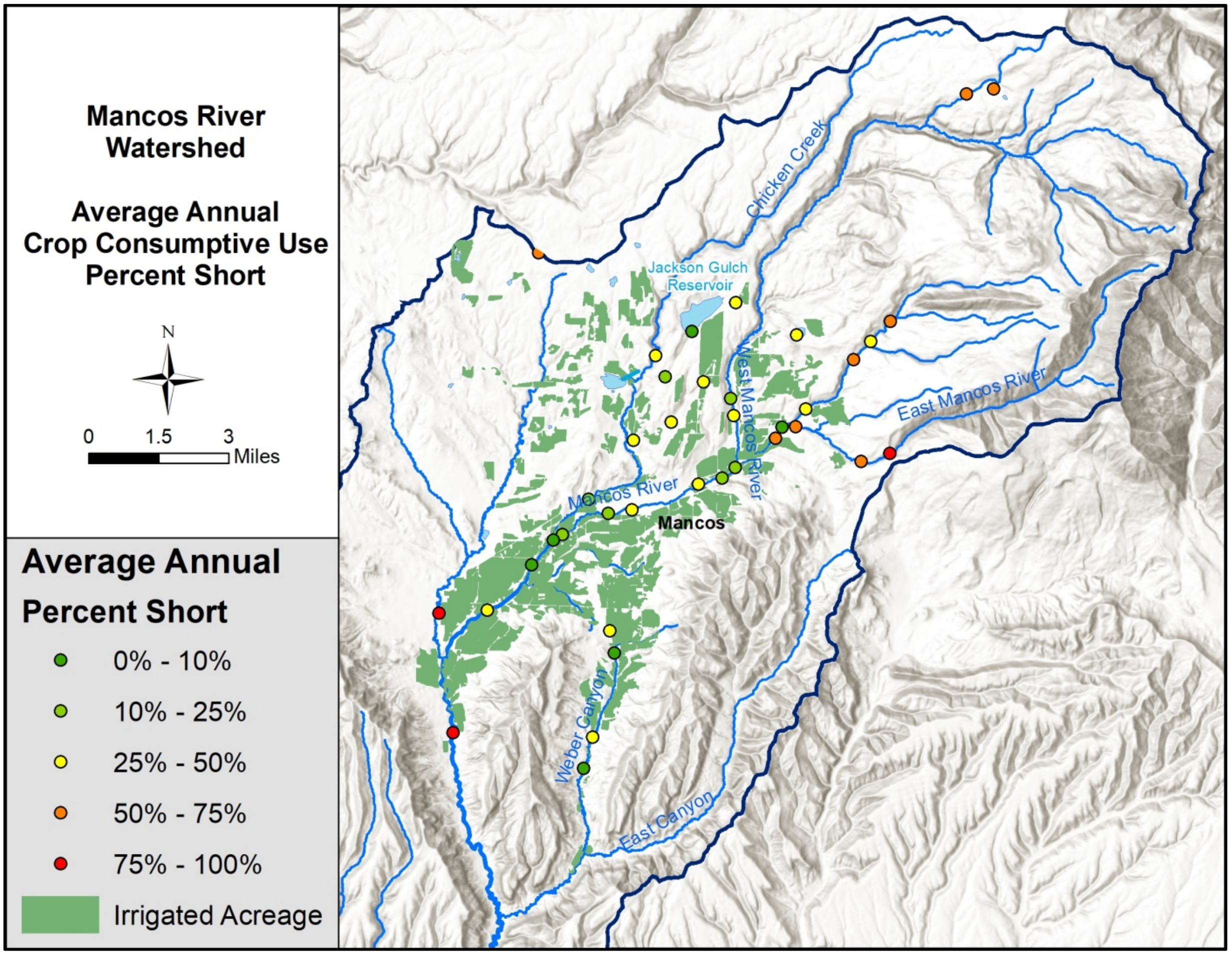


Figure 3-6: Average Annual Historical Crop Consumptive Use Percent Shortage (1975 - 2017)

The StateCU model also takes into consideration water held in soil moisture and available for crop consumptive use when surface water supplies are limited. The soil root zone functions as a reservoir that can store irrigation deliveries in excess of the CIR, generally during fall or runoff irrigation events. Stored soil moisture is then used by the crops when irrigation deliveries are less than crop demands.

Figure 3-7 and **Figure 3-8** show the actual crop consumptive use from direct irrigation and the soil root zone in the representative wet year and representative dry year. In both years, the consumptive use from soil moisture is around 20 percent.

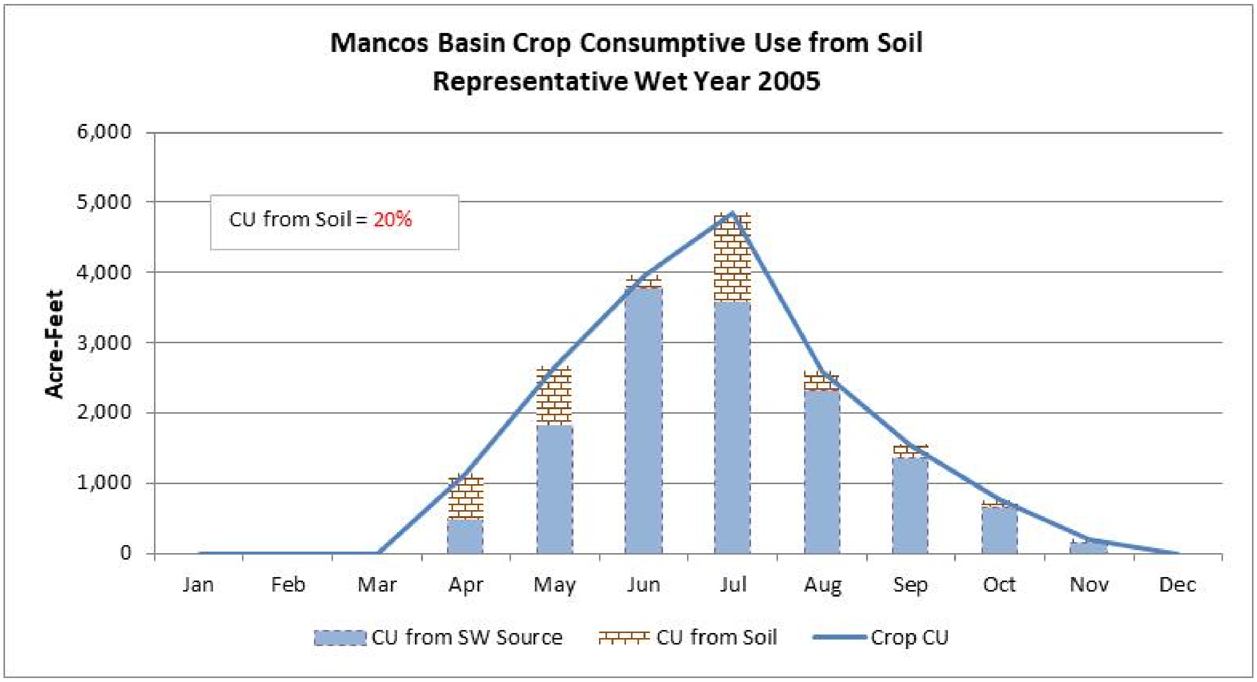


Figure 3-7: Mancos Basin Crop Consumptive Use from Soil Moisture for Representative Wet Year 2005

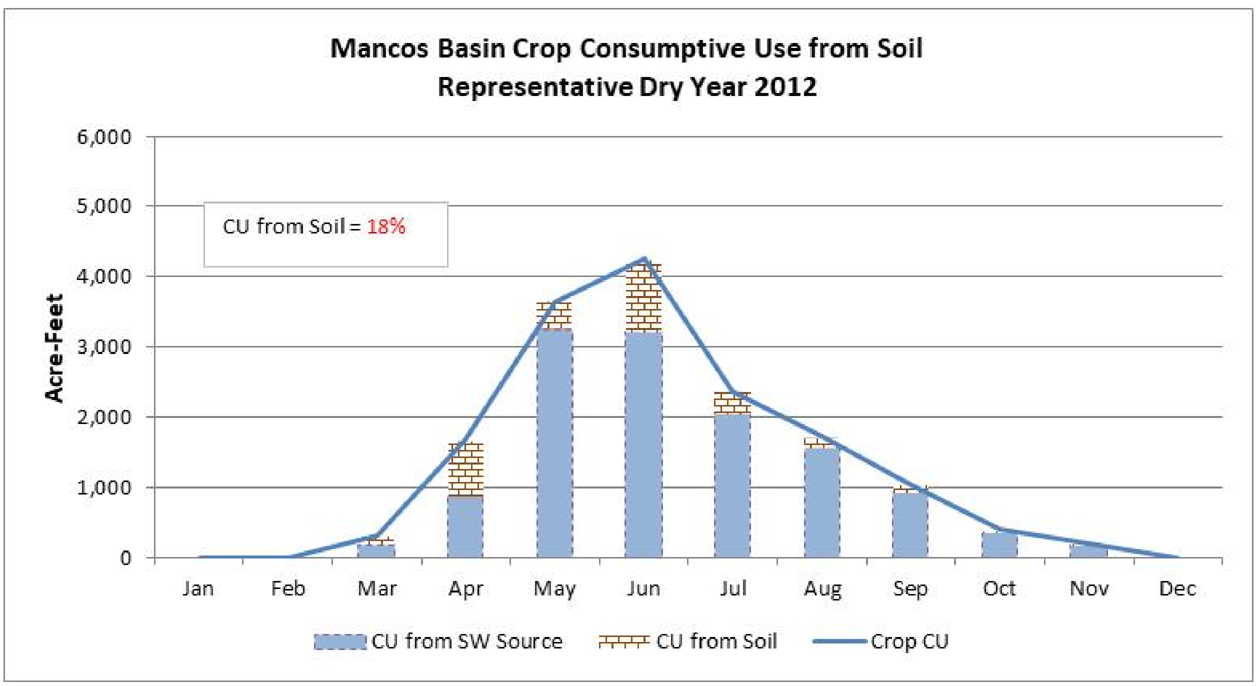


Figure 3-8: Mancos Basin Crop Consumptive Use from Soil Moisture for Representative Dry Year 2012

The reservoir storage in the Mancos Basin is a critical component to agricultural productivity. As noted above, the Division of Water Resources tracks direct flow diversions and diversion from reservoir storage releases in the official diversion record. However, the diversion records only represent the amount delivered to the headgate, not the amount that was consumed by the crops. Therefore, the StateMod model was used to estimate how much of the historical crop consumptive use can be attributed to releases from reservoir storage.

From 2011 through 2017, the model estimated average annual consumptive use of 16,660 acre-feet, including consumptive use from reservoir releases. The historical StateMod model was then simulated without Jackson Gulch Reservoir; and the difference in the consumptive use between the two model runs can be attributed to reservoir releases. On average, approximately 3,310 acre-feet of total crop consumptive use, or 20 percent of the consumptive use in the basin, is from reservoir releases. The monthly timing of the consumptive use is shown in **Figure 3-9**. As highlighted in 2012, reservoir storage is critical in dry years when releases from Jackson Gulch account for 40 percent of the consumptive use in the basin. One interesting point to note is the timing of the reservoir releases. In most years, the reservoir contributes to consumptive use later in the irrigation season. The exception is 2013, which started with a depleted Jackson Gulch Reservoir, low streamflow, and a hot and dry irrigation season. The limited amount of reservoir storage available was needed earlier in the season and basin-wide crop consumptive use was low due to lack of supply. However, there were significant monsoon rains in September, which provided water for consumptive use at the end of the irrigation season.

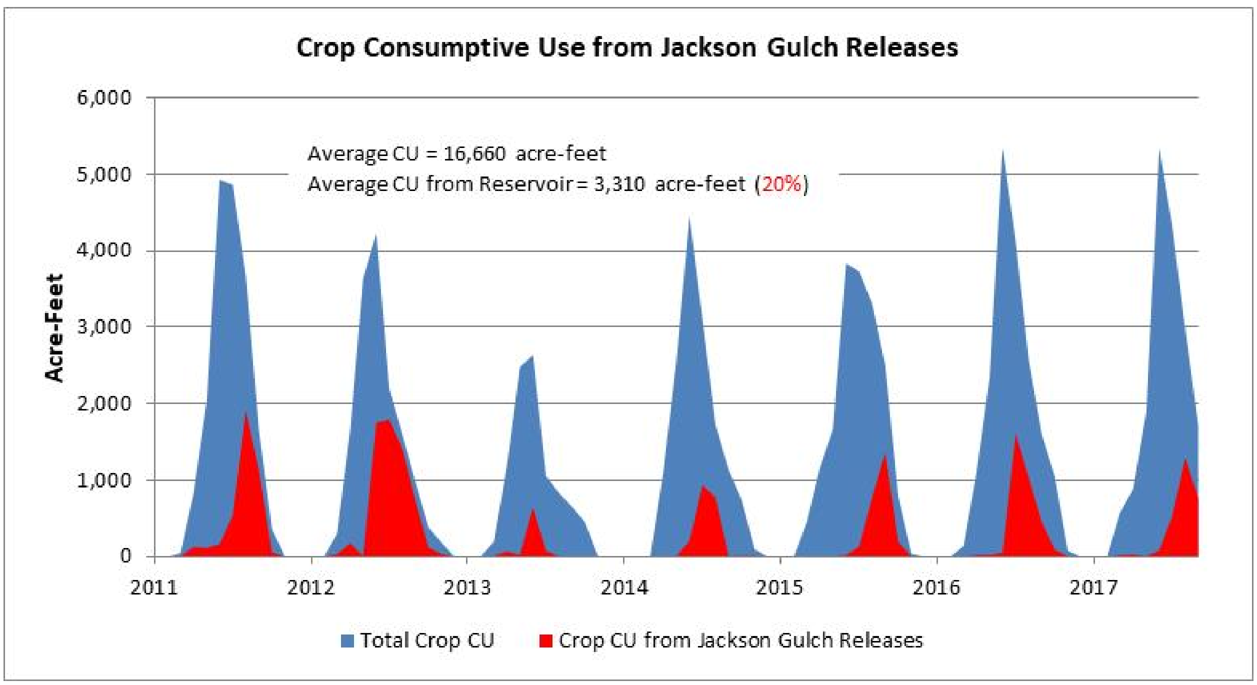


Figure 3-9: Crop Consumptive Use from Jackson Gulch Reservoir Releases (2011 - 2017)

3.3 Example Scenarios

During this phase of the Drought Resilience Planning, the decision support tools were refined and updated so they can be useful in future phases. In order to help decision makers use the tools effectively, WWG prepared some example scenarios. These are intended for illustrative purposes only, and were not considered as future alternatives by the group.

Models are useful tools to explore how different aspects of the watershed system interact. For example, physical water availability within a watershed varies by year, and varies throughout the year. Interactions between Colorado water rights, diversions, and return flows add further complexity. As StateMod represents the physical supply allocation based on water rights and basin operations, it is an appropriate tool to understand these interactions. The most appropriate use of the model is in a comparative fashion, meaning that different model simulations should be compared and contrasted against each other. The model can identify consumptive use and streamflow differences based on hydrologic variability, demand changes, diversion modifications, changes in current irrigation practices, changes in reservoir operations or capacities, and shifts in water rights administration. The three example scenarios presented focus on changes to hydrology, changes in irrigation practices, and changes to reservoir capacity.

3.3.1 Example Scenario: Changes in Hydrology

The State of Colorado is currently working on the Colorado Water Plan Technical Update, which is exploring water supplies and gaps under various assumptions regarding population growth, future technology, and climate change. Two potential future climate conditions are being considered, which are referred to as the "Hot and Dry" hydrology (a potential worst-case warming scenario) and the "In Between" hydrology (a potential warming scenario about half way between current conditions and the Hot and Dry conditions). Note that the scenarios are for investigating potential future hydrology that includes additional stresses on Colorado's supplies and demands, and no scenarios investigated are more likely to occur.

Figure 3-11 shows the average monthly natural flow for the Mancos River near Towaoc gage based on the hydrology scenarios selected for the Colorado Water Plan. The black line is current conditions - the natural flow previously discussed in this report. The red line is the estimated average monthly natural flow for the Hot and Dry hydrology and the blue line is the In Between hydrology. Both of these climate change conditions exhibit an increase in streamflow during January, February and March, and a decline in streamflow in all other months. Particularly worrying is the overall decline in average annual streamflow volume. Less streamflow in the major runoff months of April, May, and June will make it more difficult for irrigated agriculture to fill soil moisture and supply water directly to crops. This also reduces the amount of streamflow available for reservoir storage. The decline in streamflow during the late irrigation season of July, August, and September will further stress the system, which currently experiences late season crop consumptive use shortages.

Very similar patterns are seen in the representative dry year 2012 and representative wet year 2005, as shown in **Figure 3-10** and **Figure 3-12**. As shown, in 2012, the In Between hydrology has slightly larger peak flows than the historical hydrology. However, the In Between flows are lower in May and June flows, which are critical monthly for irrigation supplies.

In addition to climate projected hydrology, crop irrigation requirements are also be updated as part of the Colorado Water Plan efforts based on increases in temperature. The projected demands can be coupled with the projected hydrology to analyze future drought conditions in the Mancos River basin. The State's analysis was completed using the existing CDSS model representation of the Mancos River; however both the hydrology and demands could be incorporated in future Drought Resiliency Planning efforts.

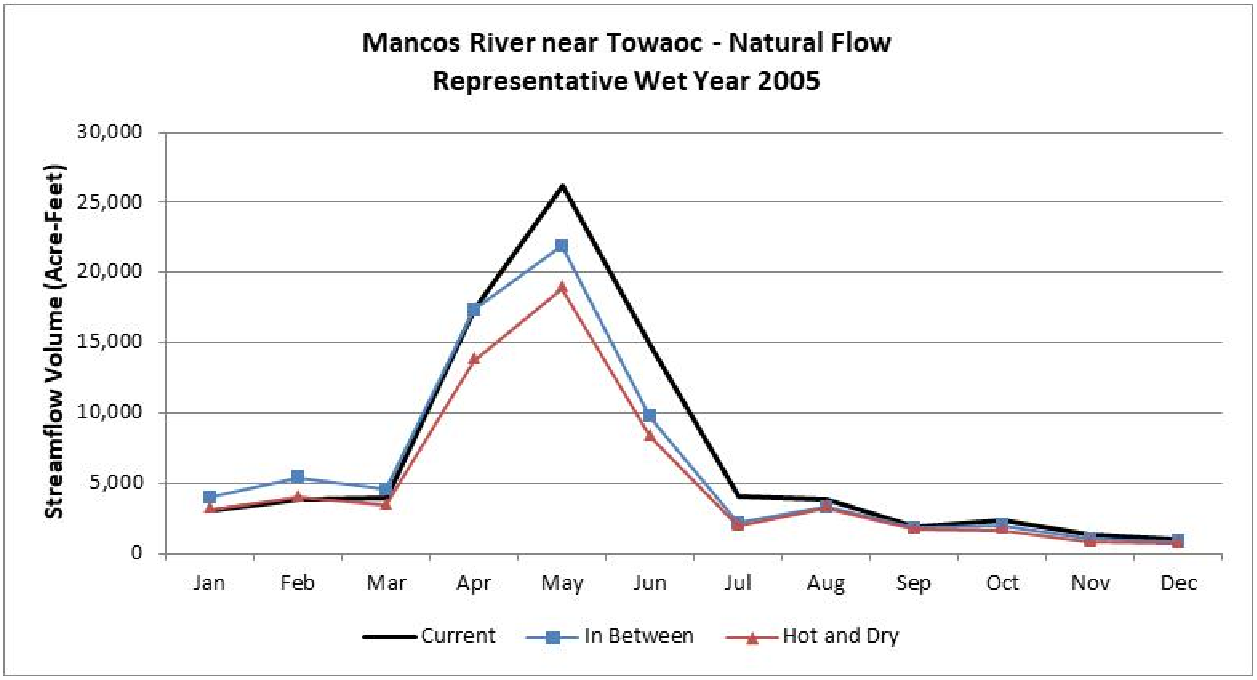


Figure 3-10: Representative Wet Year 2005 Natural Flow at Mancos River near Towaoc under Current Hydrology and Climate Projected Hydrology

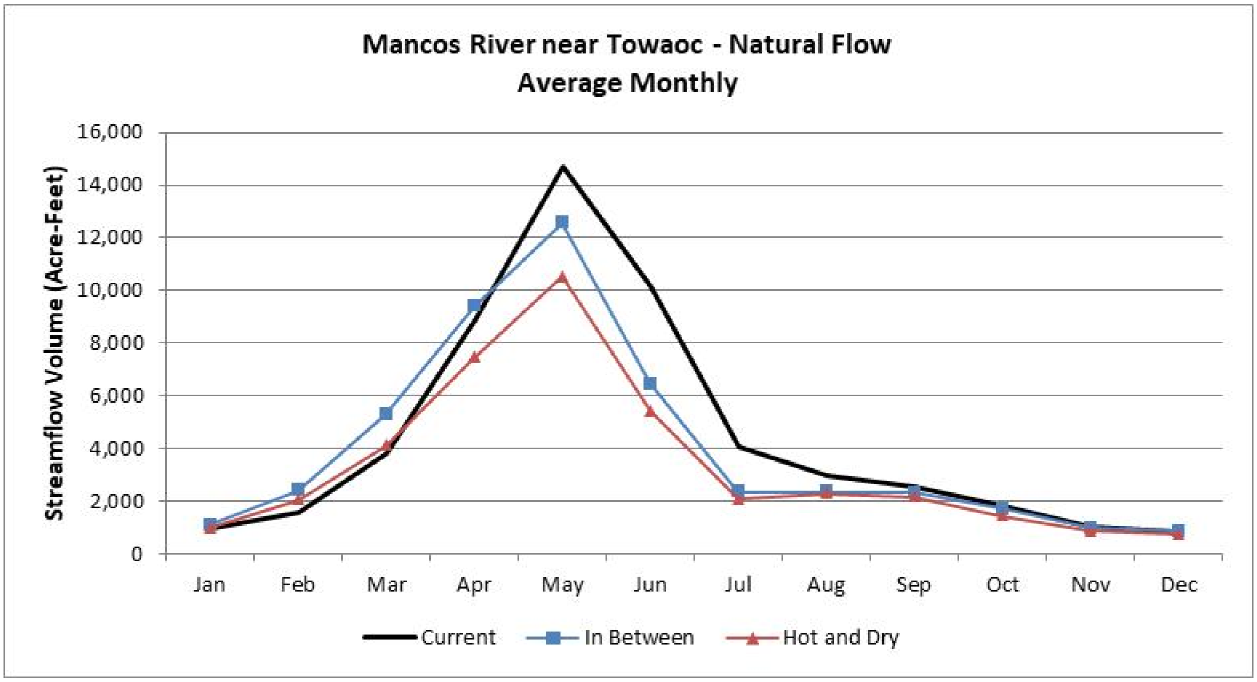


Figure 3-11: Average Monthly Natural Flow at Mancos River near Towaoc under Current Hydrology and Climate Projected Hydrology (1950-2013)

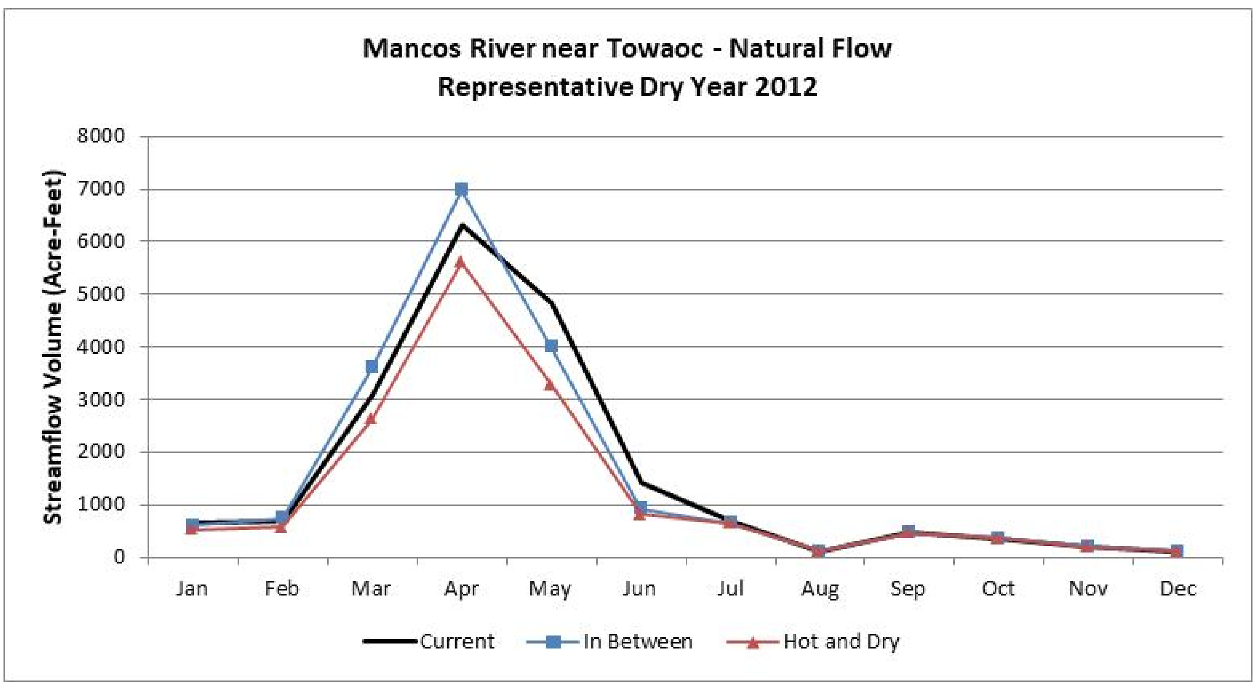


Figure 3-12: Representative Dry Year 2012 Natural Flow at Mancos River near Towaoc under Current Hydrology and Climate Projected Hydrology

3.3.2 Example Scenario: Changes in Jackson Gulch Reservoir Capacity

As previously discussed, Jackson Gulch Reservoir is an important facility for water users in the Mancos River. For illustrative purposes only, comparative scenarios were developed to explore what the basin might look like if Jackson Gulch Reservoir had been built a different size with the same priority water right. The following Jackson Gulch Reservoir capacities were considered:

- No reservoir (0 acre-feet)
- ½ current capacity (~5,000 acre-feet)
- Current capacity (~10,000 acre-feet)
- 1.5 times current capacity (~15,000 acre-feet)
- 2 times current capacity (~20,000 are-feet)

The agricultural consumptive use from the five model simulations were compared for the period 1975 through 2017, as show in **Figure 3-13**. Note that this is the maximum agricultural consumptive use possible in the basin under current irrigation acreage and methods, not constrained by individual irrigation practices, so the values are slightly higher than the historical consumptive use. The average annual agricultural consumptive use for the 43 year model simulation period is plotted on the y-axis. The Jackson Gulch Reservoir capacity is plotted on the x-axis. The biggest change in consumptive use is from no reservoir to a 5,000 acre-foot reservoir, which increases consumptive use by about 3,000 acre-feet. From a 5,000 acre-foot reservoir to the current Jackson Gulch Reservoir capacity of 10,000 acre-feet increases consumptive use by another 850 acre-feet, on average. The increase in consumptive use from a 10,000 acre-foot reservoir to a 15,000 acre-foot reservoir is an additional 780 acre-feet. Finally, increasing the reservoir to a 20,000 acre-foot capacity only increases the consumptive use by an additional 270 acre-feet. This example illustrates that a larger reservoir does not necessarily produce corresponding increases in consumptive use. It appears that the Reclamation engineers in the 1940s did a good job of sizing the reservoir appropriately.

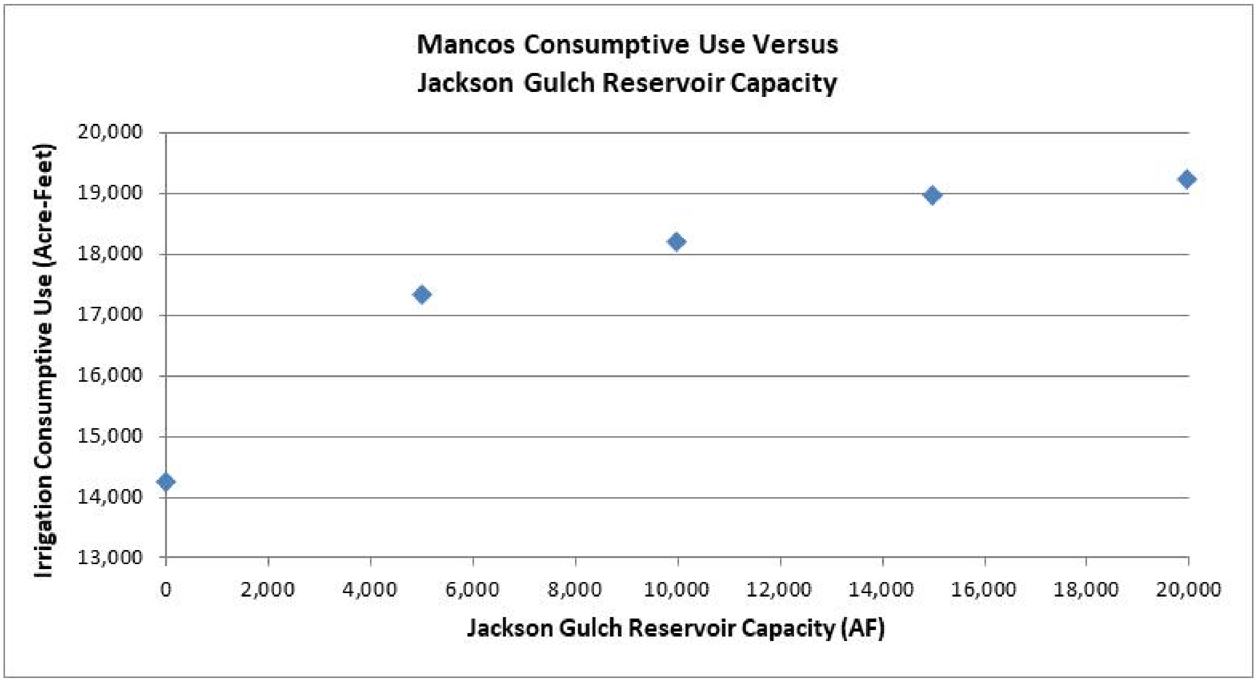


Figure 3-13: Comparing Agricultural Consumptive Use for Five Jackson Gulch Capacity Scenarios (1975-2017)

Another way to consider the model scenarios is to investigate Jackson Gulch Reservoir contents. The graph in **Figure 3-14** shows the current capacity and 20,000 acre-feet capacity simulation results. As shown, in most wet and average years a similar amount of water is released from the reservoir regardless of starting content. In the dry years of 1977, 2002, and 2012, the larger reservoir had more carry-over water at the beginning of the irrigation season and, therefore, was able to meet more irrigation demands. However, water available to fill the reservoir in the below average years following both 2002 and 2012 was limited, and the larger reservoir did not provide additional benefit.

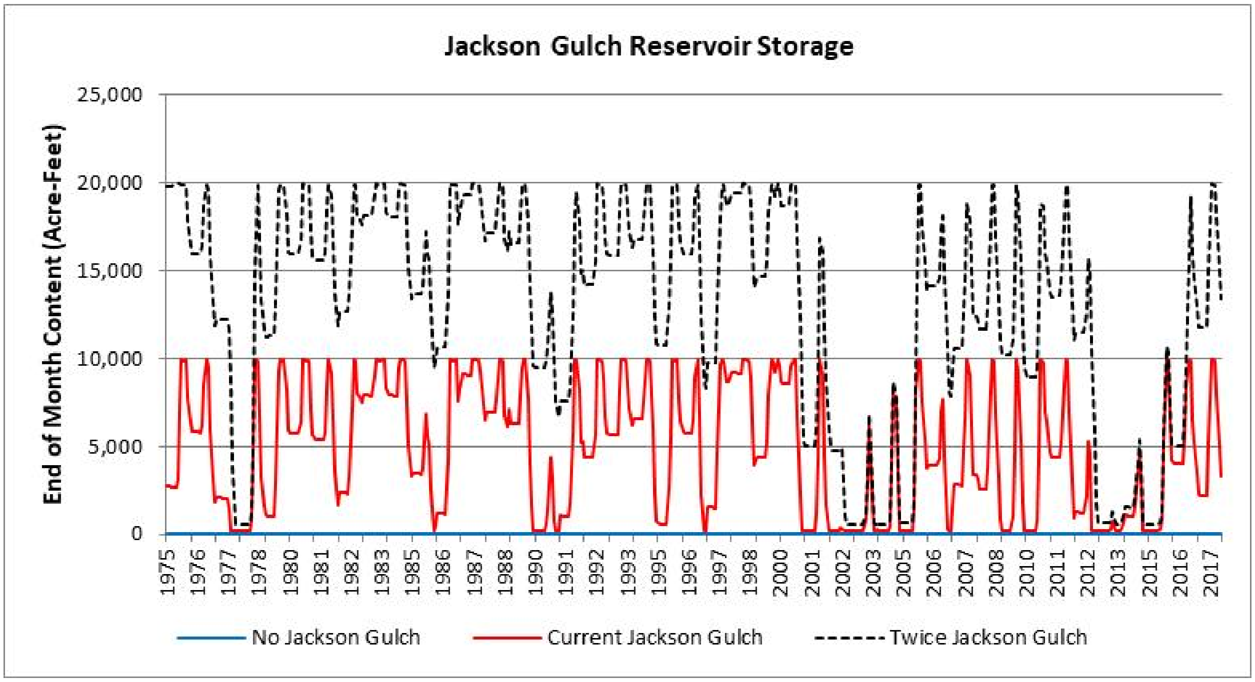


Figure 3-14: Comparing Reservoir Storage Contents from the Jackson Gulch Capacity Scenarios (1975-2017)

The model can also show us how varying reservoir capacities influence the streamflow in the Mancos River. **Figure 3-15** presents the streamflow at the bottom of the Valley area, downstream of irrigation diversions and return flows for the period 2011 through 2017. The most obvious difference between the no reservoir and reservoir scenarios is the size of the peak flows. The reservoir is capturing a significant portion of the spring runoff in many years. It is also important to note the streamflow volume during the low flow season. For example, 2012 shows higher streamflow with the reservoir than without the reservoir, because the reservoir releases are generating return flows that accrue back to the river later in the irrigation season. This is also seen in 2015 and 2016. For the most part, the two reservoir sizes have very similar streamflow. The exception is the low flow period of 2012, when the larger reservoir is able to meet more irrigation demands and generate more return flows; and in 2016, when the larger reservoir is diverting more water from the river in order to refill.

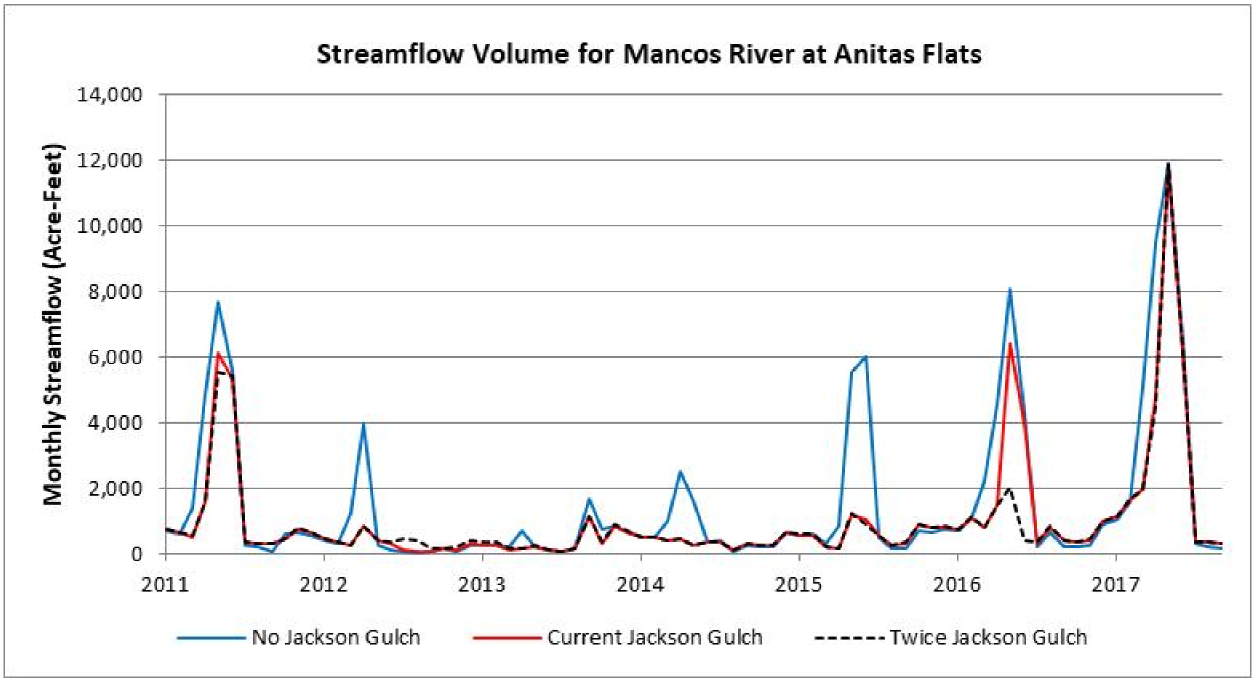


Figure 3-15: Comparing Monthly Streamflow Volume for Jackson Gulch Reservoir Capacity Scenarios (2011-2017)

3.3.3 Example Scenario: Changes to Irrigation Practices

Water users in the Mancos are actively switching to more efficient irrigation practices. Unlined earthen canals are being converted to pipe conveyance systems and flood irrigation methods are being replaced with gated pipe and sprinklers. To illustrate the comparative power of the model, WWG took these changes to an extreme. In the “Flood” scenario, it is assumed that all of the ditches are unlined earthen canals and all of the fields are flood irrigated. This means that irrigators need to divert additional water to meet their crop demand and are generating larger return flows due to inefficiencies. In the “Sprinkler” scenario, it is assumed all of the ditches are piped and all of the fields are sprinkler irrigated. This means that irrigation diversions can meet more than the crop demand and are generating relatively small return flows.

The average annual consumptive use for irrigation between the two scenarios for the 1975 through 2015 period is shown in

Table 3-1. The sprinkler scenario has a higher consumptive use because more water is available to the crops. In **Figure 3-16**, an example of the monthly consumptive use by irrigation is compared for five of the model years (2012 through 2017). Consumptive use is very similar when there is sufficient streamflow to meet the crop demands, such as in the early irrigation season (April and May) or during high flow years (2016 and 2017). Even in average flow years, such as 2015, the crop consumptive use is about the same. The biggest differences in consumptive use are during dry years, such as 2012 and 2013.

Table 3-1: Average Annual Consumptive Use for Irrigation Practice Scenarios (1975-2015)

Average Annual Consumptive Use (acre-feet)	
Flood Scenario	Sprinkler Scenario
17,888	20,303

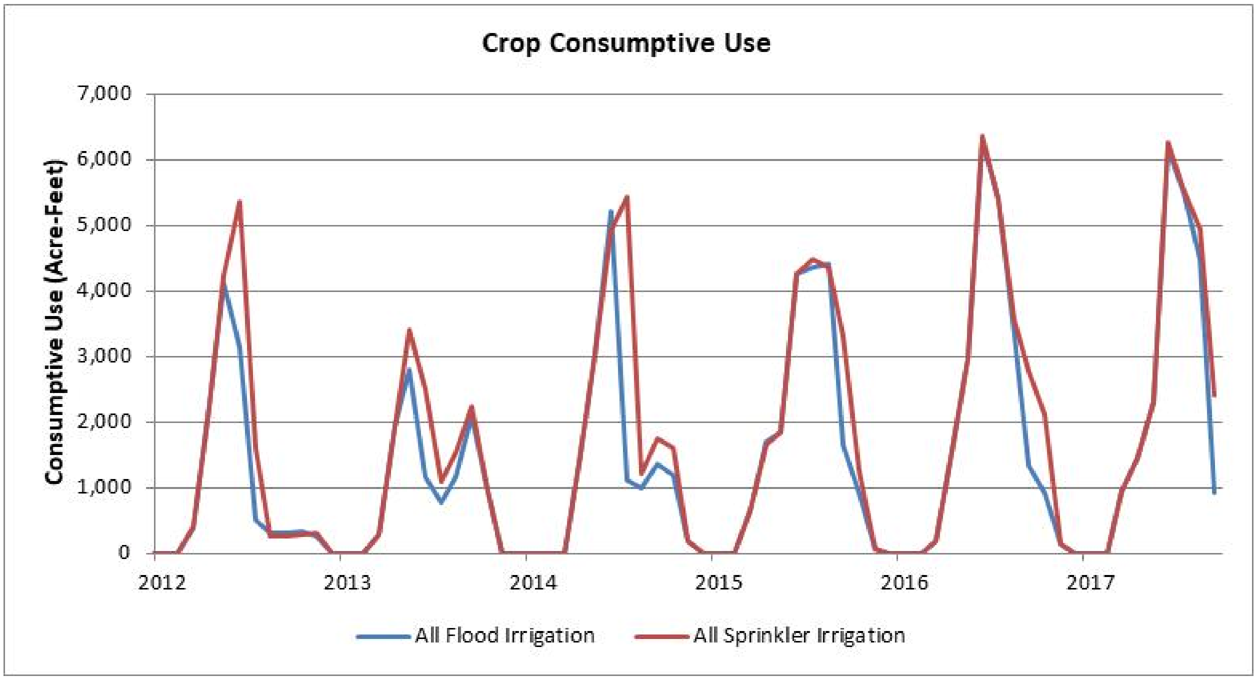


Figure 3-16: Comparing Monthly Crop Consumptive Use for the Irrigation Practices Scenarios (2012-2017)

The change in irrigation practices can have an impact on Jackson Gulch Reservoir storage, as show in **Figure 3-17** for the period 2000 through 2017. Flood irrigation requires more diversions at the headgate to meet the crop demand; therefore, more reservoir water needs to be released when to supplement diversion of natural flow. Under the sprinkler irrigation scenario, the reservoir contents are greater in average and wet years, such as 2015 and 2005; however there is little impact to the reservoir in dry years.

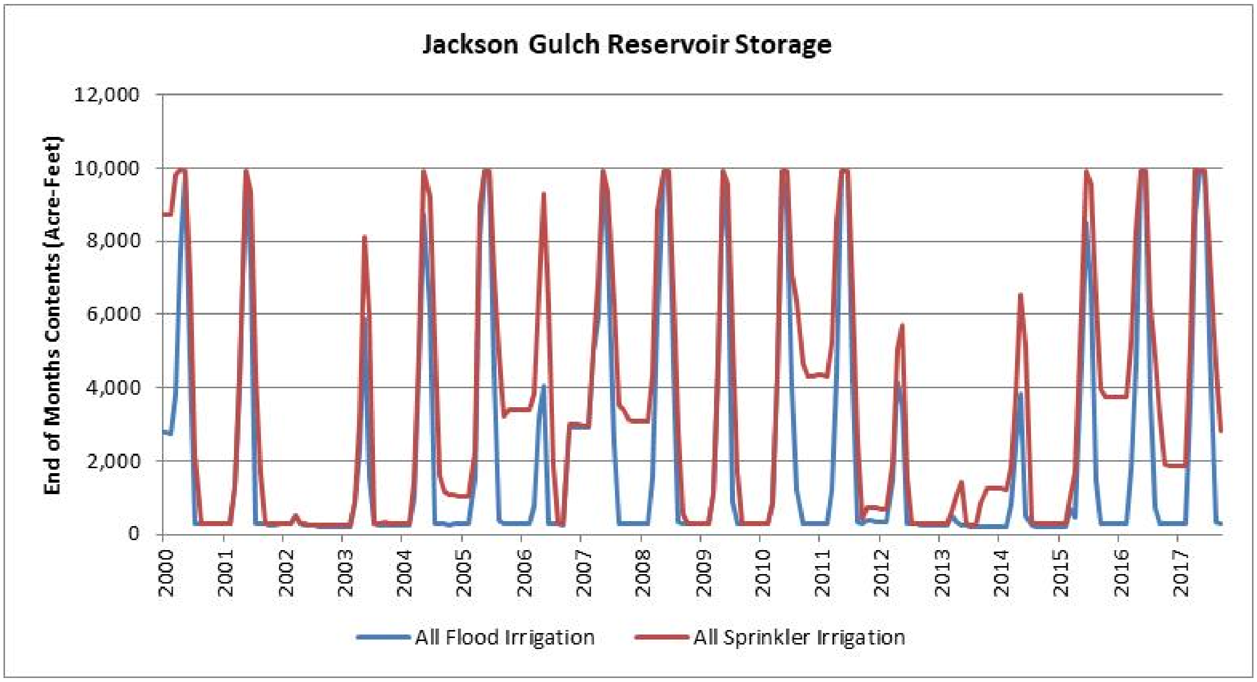


Figure 3-17: Comparing Jackson Gulch Reservoir Storage for the Irrigation Practices Scenarios (2000-2017)

Finally, **Figure 3-18** compares the monthly streamflow for the Mancos River at Anitas Flats for the two scenarios for the period 2008 through 2017. The sprinkler scenario generally has higher streamflow peaks for two reasons:

- Jackson Gulch Reservoir has more carry over storage and does not need to store as much of the peak run off in some years
- Diversions to irrigation are less

In contrast, the sprinkler scenario generally has lower streamflow during the low flow season because there are fewer return flows lagging back to the river. Flood irrigation generally produces more return flows in the late irrigation season and winter.

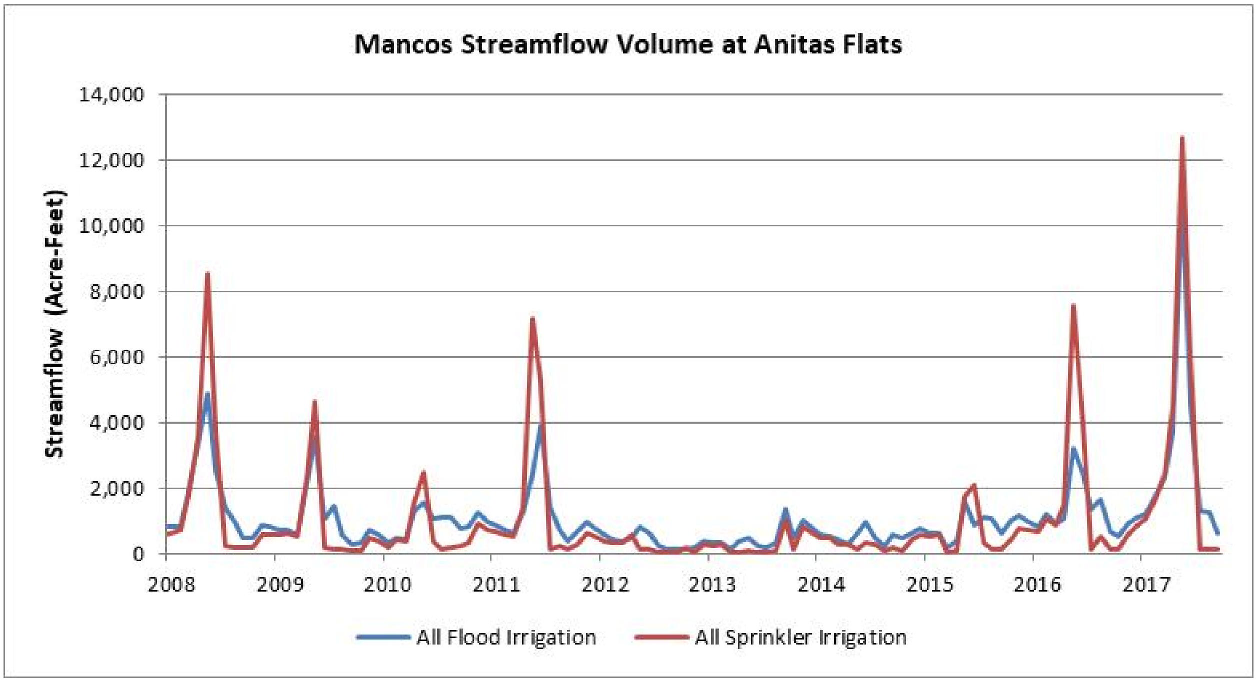


Figure 3-18: Comparing Monthly Mancos River Streamflow for the Irrigation Practices Scenarios (2008-2017)

3.3.4 Example Scenario: New Storage

Another potential scenario to consider for drought resiliency is the usefulness of new storage in the basin. For this scenario, it was assumed that Jackson Gulch Reservoir is enlarged by 10,000 acre-feet, but the enlargement can only be filled with a present day water right. This limits the ability of the reservoir to store except during free river conditions. The scenario releases water from the enlargement pool to supplement streamflow at the bottom of valley and the current reservoir capacity continues to serve the consumptive uses in the basin; therefore average annual consumptive use in the basin remains the same. For this example scenario, water was released, when available, to assure a minimum streamflow of 25 cfs at the Mancos near Towaoc streamflow gage. Note that 25 cfs was only to illustrate the usefulness of the model and does not have a biological or environmental basis.

The results from the scenario suggest that there are many years with free river conditions when water would be available for new storage. **Figure 3-19** compares the Jackson Gulch Reservoir contents for current conditions and the enlarged reservoir. The black line shows that an enlarged reservoir is able to fill in about four years from 1975 to 2017. The enlarged reservoir is able to hold substantially more water than the current reservoir in about 20 additional years. The free river conditions are primarily during the peak run-off months. New or enlarged storage would need to be situated in a location that could be filled from the West Mancos River, as that tributary still has the most reliable remaining available supply.

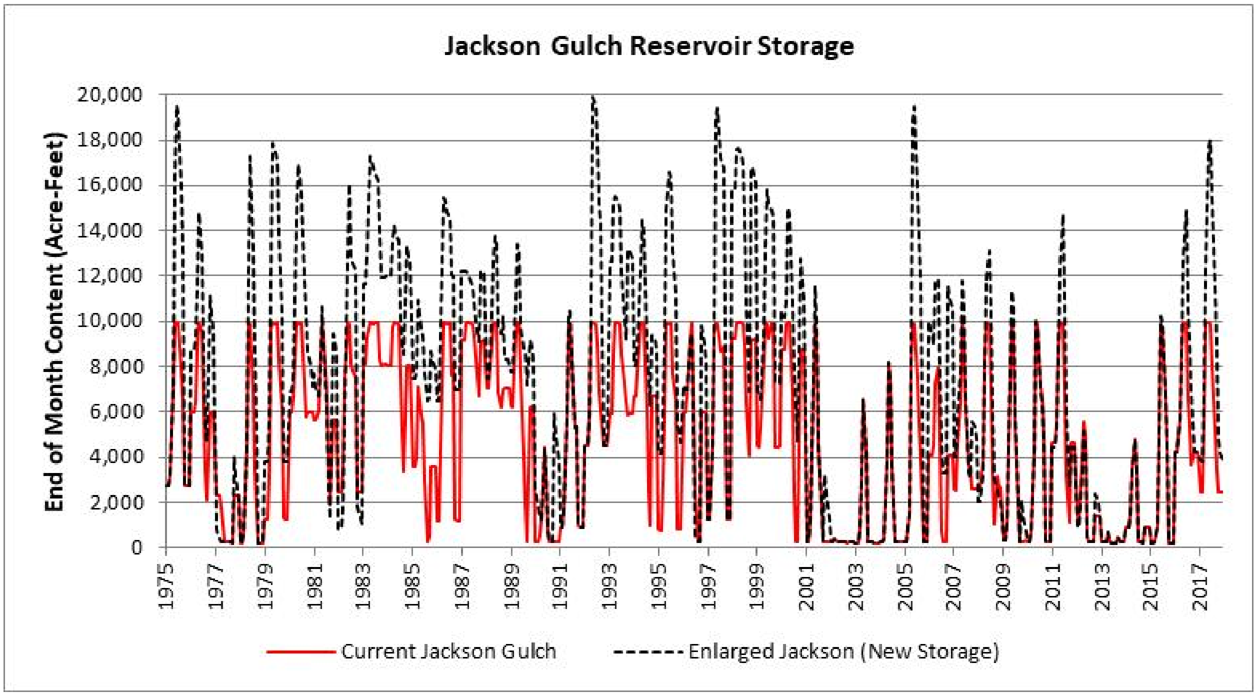


Figure 3-19: Comparing Jackson Gulch Reservoir Storage for the New Storage Scenario (1975-2017)

New storage is able to increase the streamflow during low flow periods, but the supply is exhausted during longer droughts. **Figure 3-20** compares the Mancos River near Towaoc streamflow with and without new storage to supplement flows. The streamflow is greater in 2008, 2009, 2011, 2016, and 2017. However, the streamflow is the same in some of the more severe drought years, such as 2012. The storage supply was depleted in 2011 and there was not enough runoff in 2012 to refill the supplemental streamflow account. This scenario assumed that the streamflow target did not vary by month or year type; however a more dynamic streamflow target could potentially allow better use of the supply.

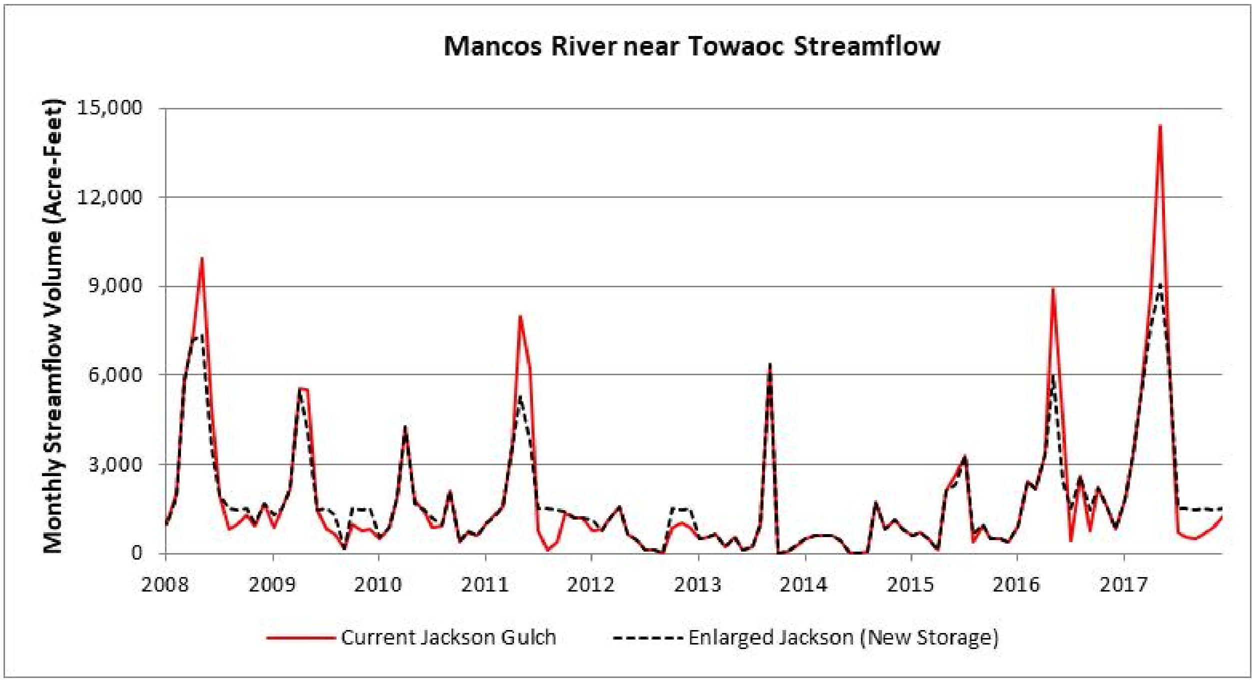


Figure 3-20: Comparing Mancos River near Towaoc Streamflow for the New Storage Scenario

4 Recommendations and Next Steps

The following are recommended additional data collection and potential model refinements for future Drought Resilience Planning efforts:

- The streamflow gages in the Mancos River Basin are critical for administering the river; therefore, they are located near the agricultural diversions. However, Drought Resilience Planning efforts may also be interested in streamflow in other parts of the basin. Depending on the focus of future alternatives, it may be useful to re-activate the Mancos River at Anitas Flat below Mancos (perhaps DWR could operate the gage in partnership with Mesa Verde National Park) or if water quality concerns from abandoned historical mines are of interest, it may be useful to re-activate both of the historical USGS gages on the East Mancos River and Middle Mancos River.
    - Note that Mancos Water Conservancy District (MWCD) is currently exploring options with the Division of Water Resources to install a gage on the East Mancos, below the confluence with the Middle Mancos.
- The existing SNOTEL site is appropriate for forecasting runoff, and no additional sites are recommended.
- Jackson Gulch Reservoir Inlet Canal and the reservoir storage contents are well measured. MWCD is in the process of installing a measurement device at the reservoir outlet. This additional gaging location could be used to quantify the outlet canal seepage and losses.
- For future model refinement, it would be helpful to better understand lagged return flow timing from gated pipe and sprinkler irrigated fields. The majority of the modeling

assumptions were based on flood irrigation and modified to account for efficiency improvements. It would be illuminating to perform field studies to measure the real-world conditions.

- For future model refinements, it would be helpful to delineate the ditch alignments. Open, unlined earthen canals could then be analyzed based on soil parameter in order to better estimate conveyance losses. Delineating piped ditch alignments would be useful, as they cannot easily be determined from aerial photos or field surveys.

5 References

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Mancos Valley Watershed Group, *Mancos Watershed Plan*, May 24, 2011

Rank, Gretchen, *Mancos Watershed Drought Resilience Planning,* CWCB Watershed Restoration Planning Grant Application, 2017

Colorado Division of Water Resources Water Database (http://cdss.state.co.us)

Colorado Decision Support System Models (http://cdss.state.co.us)

Colorado River Basin Forecast Center (https://www.cbrfc.noaa.gov/)

Personal Communication with Russell Crangle

Personal Communication with Tom Weaver

Personal Communication with Gary Kennedy

Personal Communication with Ben Wolcott

Personal Communication with Stephen Monroe