

# Middle Rio Grande Conservancy District

## Drought Contingency Plan



Prepared by the Middle Rio Grande Conservancy District with WEST Consultants and Davids Engineering

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## Executive Summary

The Middle Rio Grande Conservancy District (MRGCD) provides irrigation water to about 60,000 acres, along a 150 mile stretch of the Rio Grande in Central New Mexico. The MRGCD is primarily a run of the river system, with the ability to store supplemental water in an upstream reservoir when regulatory conditions allow. Additionally the MRGCD has an annual contract allocation of 20,900 acre-feet, imported from the Colorado River Basin through Reclamation's San Juan Chama project. Substantial reliance on naturally occurring river flows in the Rio Grande, combined with the natural variability of the climate and potential for increased variability due to climate change makes the MRGCD vulnerable to water shortages under drought conditions. The MRGCD has developed this plan to identify, mitigate and respond to drought.

With matching funds from the United States Bureau of Reclamation's (Reclamation) WaterSMART drought program the MRGCD has prepared a Drought Contingency Plan (DCP). The DCP includes an index for monitoring drought and corresponding triggers for drought severity, identified current and future vulnerabilities, proposed long term mitigation actions, drought response actions, administrative framework, and a plan update process.

Drought monitoring and triggers in the DCP utilize a modified version of the Surface Water Supply Index (SWSI-Mod) to calculate the drought severity. The SWSI-Mod accounts for surface supplies in the MRGCD system and added a temperature component. The calculated SWSI-Mod and corresponding hydrologic conditions are as follows:

- $SWSI-Mod > 4$ - Extremely wet
- $3 \leq SWSI-Mod < 4$ - Severely Wet
- $2 \leq SWSI-Mod < 3$ - Moderately Wet
- $1 \leq SWSI-Mod < 2$ - Slightly Wet
- $-1 \leq SWSI-Mod < 1$ - Near Normal
- $-2 \leq SWSI-Mod < -1$ - Slightly Dry
- $-3 \leq SWSI-Mod < -2$ - Moderately Dry
- $-4 \leq SWSI-Mod < -3$ - Severely Dry
- $SWSI-Mod < -4$ - Extremely Dry

When there is a risk of drought conditions, the MRGCD will calculate the SWSI-Mod a minimum of once a month. The MRGCD Board of Directors may then elect to put into effect the response actions recommended for the level of drought identified. These drought response actions are intended to minimize the impact of water shortages on the MRGCD. In addition to taking actions in response to drought conditions, the MRGCD may elect to pursue mitigation actions developed in this plan in order to increase the MRGCD's long-term resilience to drought and water shortage. Mitigation actions include infrastructure projects, operational changes, and pursuit of greater operational flexibility.

It is recommended that the DCP be evaluated every two years and updated as the evaluations deem necessary. Implementation of the DCP will be at the discretion of the MRGCD Board of Directors, but once it is finalized the MRGCD Board of directors will review and approve the plan.

## Acronyms and Abbreviations

AF	acre-feet
BBER	Bureau of Business Economics Research
DCP	Drought Contingency Plan
DET	Drought Evaluation Team
ET	evapotranspiration
GCM	Global Climate Model
HUC6	Hydrologic Unit Code 6
MRG	Middle Rio Grande Valley (geographic region)
MRGCD	Middle Rio Grande Conservancy District
NRCS	Natural Resource Conservation Service
RCP45	Representative Concentration Pathways 4.5
RCP85	Representative Concentration Pathway 8.5
Reclamation	US Bureau of Reclamation
SJC	San Juan Chama
SWE	Snow water equivalent
SWSI	Surface Water Supply Index
SWSI-Mod	Surface Water Supply Index Modified
USACE	United States Army Corps of Engineers

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## 1.0 Introduction

The Middle Rio Grande Conservancy District (MRGCD) is a Conservancy District (a political subdivision of the State of New Mexico), established by the New Mexico Conservancy Act of 1923 in the Middle Rio Grande (MRG) region of central New Mexico. Its Boundaries encompass approximately 150 river miles of the Rio Grande and approximately 123,267 irrigable acres. The MRGCD provides drainage and mainstem river flood control functions, and supplies water to agricultural users within its jurisdictional boundaries. The variability of the region's weather and hydrology and the MRGCD's limited water storage capacity make the MRGCD vulnerable to periods of water shortage. Climate projections in the region suggest that droughts may become more frequent and severe in the coming decades.

The MRGCD currently coordinates extensively with entities to make informed decisions regarding water management during periods of water shortages. Despite this highly coordinated effort to manage water within the planning area, no formal drought contingency plan exists for the MRGCD. To increase the MRGCD's ability to meet its obligations in the face of water shortages, it has developed a Drought Contingency Plan (DCP) with matching funds from the Bureau of Reclamation (Reclamation) as a part of Reclamation's WaterSMART Drought Response Program.

The MRGCD is governed by a publicly elected Board of Directors. There are seven board member positions, one at large position, three board members from Bernalillo County and one member each from Sandoval, Socorro, and Valencia Counties. The term for all Board of Director positions is four years with the MRGCD holding public elections every two years. All official policies are at the discretion of the Board of Directors and it must be noted that all recommended activities within the DCP will be subjected to that discretion. Once the DCP has been finalized and reviewed the MRGCD Board of Directors will review and approve the plan.

### 1.1 Goals and Objectives of Plan

The overarching goal of this DCP is to increase MRGCD's resilience to water shortages, should they occur, while meeting obligations to water users, the Rio Grande Compact, and the US Fish and Wildlife Service's 2016 Biological Opinion for the MRG. This plan has been developed with funding from the Bureau of Reclamation (Reclamation) under Reclamation's Drought Contingency Planning process, and has been designed to include the six required elements of a Drought Contingency Plan, which are as follows:

**Drought Monitoring:** This DCP establishes, in Section 2, a process for monitoring near- and long-term water availability, and a framework for predicting the probability of future droughts or confirming an existing drought. A modified version of the Natural Resource Conservation Service's (NRCS) Surface Water Supply Index (SWSI) was developed as a part of the DCP. The developed index is referred to as SWSI-Mod in this document. Section 2 describes the process for how the SWSI-Mod will be utilized to monitor water supply components (reservoir storage, streamflow, snow water equivalent, precipitation, and temperature) to characterize current and predict near-term water availability conditions. This process includes how the collection, analysis, and dissemination of water availability and other drought related data will be conducted. As a part of drought monitoring, the SWSI-Mod was calculated for historical water availability, which informed the development of triggering criteria for the different stages of drought. These triggers will be connected to the response actions in Section 5 of the DCP.

**Vulnerability Assessment:** The DCP includes, in Section 3, a vulnerability assessment evaluating the risks and impacts of drought. The vulnerability assessment includes an inventory of resources critical to the MRGCD, the risks that are posed

by drought to the identified resources, and the factors that contribute to those risks. This inventory utilized projections of potential future conditions to identify future potential risks to MRGCD resources. The effects of climate change were evaluated for the first half and the second half of the 21<sup>st</sup> century, but for planning and mitigation purposes the MRGCD focused on the period of 2000-2049. The vulnerability assessment was utilized to inform the development of recommended mitigation and response actions in Sections 4 and 5.

**Mitigation Actions:** In Section 4, this DCP identifies, evaluates, and prioritizes mitigation actions and activities designed to mitigate the risks posed by drought and to build long-term resiliency to drought. The developed mitigation measures are actions, programs, and strategies implemented over time to address risks and impacts of droughts as they occur. These actions are outside of regular water management activities and are intended to decrease vulnerabilities to reduce the need for short-term response actions during periods of drought.

**Response Actions:** In Section 5, this DCP identifies, evaluates, and prioritizes response actions and activities that the MRGCD can implement during a drought to mitigate the impacts. Each specific response action developed is tied to the triggers for the different drought stages developed in the drought monitoring framework of Section 2, in order to manage the limited supply and decrease the severity of immediate impacts. The developed response actions can be quickly implemented and provide rapid benefits to the MRGCD in drought scenarios.

**Operational and Administrative Framework:** The operational and administrative framework for this DCP is described in Section 6. This framework identifies who is responsible for undertaking the actions necessary to implement each element of the DCP, including communication with the public about those actions. Section 6 identifies roles, responsibilities, and procedures necessary to: conduct drought monitoring, initiate response actions (including emergency response actions), initiate mitigation actions, and update the plan.

**Plan Development, Stakeholder Engagement, and Update Process:** Section 7 of this DCP describes the process that was undertaken to develop the plan, including how stakeholders were engaged and how input was considered. In addition, the DCP describes a process and schedule for monitoring, evaluating, and updating the DCP.

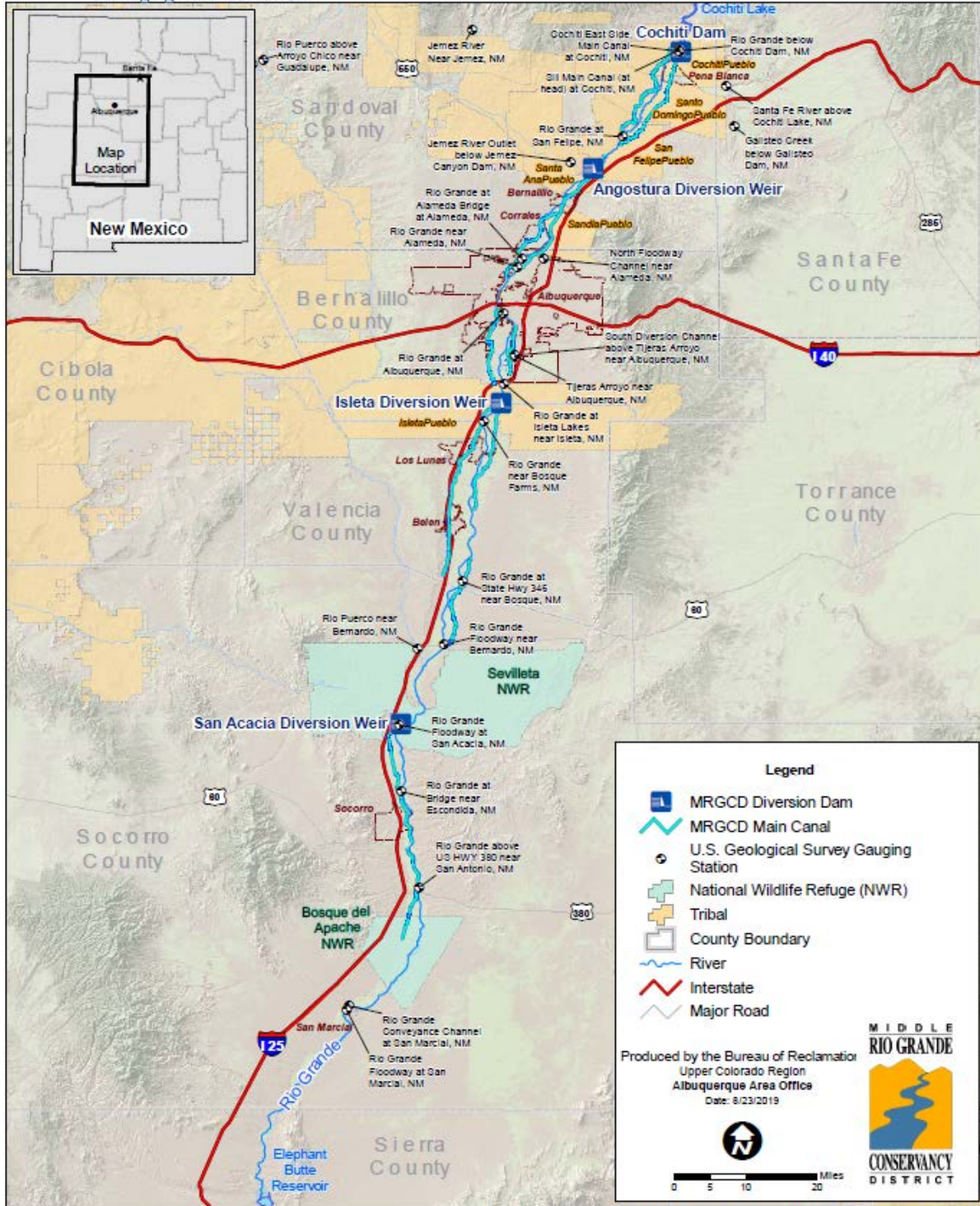
This DCP is designed to provide a plan for additional conservation actions separate from actions required to comply with the 2016 Biological Opinion. These actions, if approved by the MRGCD Board of Directors, could be employed if it is determined that a drought is predicted to occur.

## 1.2 Planning Area

The MRGCD is located in the Middle Rio Grande (MRG) Valley of central New Mexico. The planning area for this DCP includes all lands within the jurisdictional boundaries of the MRGCD. Figure 1 is a map of the planning area that shows where the MRGCD's jurisdictional area is located in New Mexico.

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**Middle Rio Grande Conservancy District (MRGCD) Diversion Dams**

Figure 1: Map of the planning area

### **1.3 Background Information**

The MRGCD is a political subdivision of the State of New Mexico, established by state law under the Conservancy Act of 1923, which gave it broad authority to acquire lands and water rights, assess taxes and water service charges, design, construct and maintain facilities for the purposes of providing flood protection from the Rio Grande, control groundwater levels and reduce evaporative losses, and provide irrigation water to farmland to the four counties and six Pueblos within the middle Rio Grande valley (MRG). This authority included the consolidation of more than 70 separate headings and community acequias (canals) that once served lands throughout the MRG.

The service area, which is home to about a third of state's population and its economic center, encompasses 150 miles of the historic flood plain of the Rio Grande through central New Mexico -- from Cochiti Dam in the north to Bosque del Apache Wildlife Refuge in the south, running through the counties of Sandoval, Bernalillo, Valencia and Socorro. The MRGCD has worked closely with Federal agencies, particularly Reclamation and the U.S. Army Corps of Engineers (USACE), following the authorization of the Flood Control Acts of 1948 and 1950. Reclamation's Middle Rio Grande Project provides river maintenance to assist the MRGCD in utilizing the Rio Grande as its primary water supply, and Reclamation's San Juan Chama Project provides contract water to augment that supply.

The MRGCD holds permits from the New Mexico Office of the State Engineer to divert water to serve up to 123,267 acres. As part of the total water rights associated with the diversion permits, the six Middle Rio Grande Pueblos collectively have statutorily recognized water rights for a total of 8,847 acres of federally recognized Prior and Paramount (priority) lands along with 11,951 acres of newly reclaimed lands for the six Middle Rio Grande Pueblos within and serviced by the MRGCD. Permit 1690 allows the MRGCD and the U.S. to store up to 198,000 AF (approximately 180,000 AF under present conditions) of supplemental water at El Vado Reservoir. The MRGCD also receives an annual allocation of 20,900 AF of San Juan-Chama Project water, under contract with Reclamation. Water rights in the MRGCD are complex, and include several different types. In general rights are either considered "MRGCD", or "pre-1907" rights. MRGCD holds some pre-1907 water rights in the MRG, but most pre-1907 rights are held privately by land owners within the MRG. Pre-1907 water rights are the only water rights in this un-adjudicated basin that may be sold, leased or transferred for uses other than irrigation on the original lands. The MRG basin was declared "closed" in 1956, meaning that any new use of water must be offset by the retirement of an existing use. State of NM Permit 0620 entitles the MRGCD to divert and utilize "reclaimed" water associated with drainage of lands within the benefitted area, the source of so-called MRGCD rights.

The operation and maintenance of MRGCD canals are divided into four separate divisions. From north to south the four divisions are Cochiti, Albuquerque, Belen, and Socorro. Division Boundaries are delineated by diversion structures. The Cochiti Division starts at the diversion from the Rio Grande at USACE's Cochiti Dam to the MRGCD Angostura Dam. The Albuquerque Division starts at the Angostura Diversion Dam and ends at the Isleta Diversion Dam. The Belen Division starts at the Isleta Diversion Dam and ends at the Sevilleta Wildlife Refuge that lies between the Belen and Socorro Divisions. The Socorro Division starts at the San Acacia Diversion Dam and ends at the North Boundary of the Bosque Del Apache Wildlife Refuge, which is also the southern boundary of MRGCD jurisdiction.

The MRGCD currently delivers water to approximately 60,000 acres. In addition to agricultural water delivery, the MRGCD's system of canals and drains support a number of critical environmental services including over 30,000 acres of a unique and contiguous riparian forest known as the Rio Grande Bosque (bosque). These lands are generally owned by the MRGCD and include existing and future high quality habitat for endangered, threatened and sensitive species. Irrigation of MRGCD lands also provides shallow aquifer recharge and mitigation of air pollution and heat island effects. Agricultural lands also provide important wildlife habitat and urban open space. Within the MRG, the U.S. Fish and

Wildlife Service administers the Valle de Oro National Wildlife Refuge, Sevilleta National Wildlife Refuge and Bosque del Apache National Wildlife Refuge. The State of NM administers several state game refuges that receive water through MRGCD facilities. The MRG is home to endangered species including the Rio Grande silvery minnow and southwestern willow flycatcher, and portions of the MRG may provide critical habitat for the western yellow-billed cuckoo.

Recreation has become an important benefit that is provided by the MRGCD. In the Albuquerque metropolitan area the canals and canal banks provide approximately 230 miles of recreational use. They serve as horse trails, bike runs, wildlife habitat, fishing holes, running paths, and open space. Of the nearly 1,200 miles of waterways in the entire MRGCD service area, 414 miles are classified as having recreational use: 56% of these miles are in the Albuquerque division; 35% in Belen; 7% in Cochiti; and 2% in Socorro. As the MRGCD becomes increasingly urban, the undeveloped canals and the riverbank create a natural preserve with connecting trails within and between communities.

Over time, lands owned and under the jurisdiction of the MRGCD have become some of the most valuable assets in the MRG. These natural assets are the source of high quality recreation, environmental and ecological activity that provide regional economic returns. They also comprise a regional savings account of water and land -- two natural resources that have become increasingly valuable over time. Urban growth in the MRG had created significant pressure for water transfers from agriculture to municipal uses, increasingly impacting the Rio Grande as well as the MRGCD. Specific actions to mitigate the increasing pressure the MRGCD faces due to the growth of the urban corridor were deemed beyond the scope of this drought plan. The MRGCD's mission includes preserving the agricultural economy and culture of the communities along the Rio Grande.

During the 1930s and 1940s, the MRGCD absorbed over 70 community canals and acequias, most of which had their own headings from the Rio Grande. Today, in many MRG communities, traditional farming continues because the MRGCD's canals provide a reliability of water delivery that the old headings could not provide. In turn, farmers have been sheltered from the changes in the river, the rising cost of maintaining an irrigation system, and the competition for water in a complicated and urbanizing region.

The MRGCD currently delivers water via gravity to over 10,000 irrigators in the MRG. The average annual diversion (2013-2017) to meet these needs was approximately 276,000 AF. The annual farm delivery is estimated at about 210,000 AF. Actual consumptive use of water by agricultural crops is estimated at around 150,000 AF. The majority of water diverted but not consumed is returned to the river system through wasteways and drains. Some water evaporates directly from the surface of canals (estimated 12,000 AF annually) or may be consumed by riparian vegetation along canals. Most canals are earthen and incur some seepage loss, though silt/clay sediments commonly transported by the Rio Grande tend to keep canal seepage relatively low. Seepage loss is either intercepted by drains and returned to the river, or may recharge local shallow aquifers which in turn may support additional riparian consumption or non-MRGCD water users (domestic wells).

Evapotranspiration rises due to increasing average temperatures, as is currently predicted in the region by the Bureau's *West-Wide Climate Risk Assessment: Upper Rio Grande Impact Assessment* (USBR, 2013), indicate an increase in water consumption on both riparian and agricultural lands is expected to occur over the next 30 years.

According to estimates by the US Census Bureau, the population of New Mexico grew at a rate of 1.4% over the period of 2010 to 2017 (U.S. Census Bureau, 2018). Much of the growth is expected to occur in the Middle Rio Grande. In the past, increased needs for municipal and industrial uses were met by retirement of irrigated agriculture. Today, the state's largest water utility, ABCWUA, is shifting its water development policy toward preserving irrigated agriculture in the MRG. Due to water conservation efforts conducted by the ABCWUA starting in the mid 1990's, the per capita water

use has been cut nearly in half, decoupling the direct correlation between population growth and water consumption in the planning area (ABCWUA, 2016).

Due to a number of factors the value of agricultural production within the MRGCD is difficult to quantify. According to internal MRGCD documents the estimated value generated from agricultural production on MRGCD lands ranges from \$35 to \$70 million per year. Major crops include alfalfa/hay, irrigated pasture, and corn.

## 2.0 Drought Monitoring

This drought contingency plan establishes a process for monitoring near and long-term water availability, and a framework for predicting the probability of future droughts or confirming an existing drought. This includes a process for the collection, analysis, and dissemination of water availability and other drought-related data. This plan also explains how these data will be used to predict and confirm droughts, including identifying metrics and triggers that are used to define stages of drought, to trigger mitigation or response actions, and to define the different stages of severity of drought.

### 2.1 Drought Index

An index was developed for the MRGCD to identify and quantify drought conditions. This index utilizes a modified version of the Natural Resource Conservation Service's (NRCS) Surface Water Supply Index, named SWSI-Mod. How this index was developed and validated is described in greater detail in Appendix 4 (WEST, 2018) of the DCP. Below is a description of the SWSI-Mod and how it will be used as a Drought Index, the method that the MRGCD will use to compute it, and a brief description of its application.

#### ***SWSI-Mod***

SWSI-Mod is composed of two components: (1) the Supply Component (SC) and (2) the Demand Component (DC). The SC represents the combined effects of the major water supplies to the MRGCD system. The DC represents the effect of temperature on water demand to the MRGCD system. SC and DC represent the relative deviation from normal of the water supply and the water demand, respectively. The two components add together to produce the SWSI-Mod:

$$\text{SWSI-Mod} = \text{SC} + \text{DC}$$

SWSI-Mod is set up to be calculated at a monthly timestep.

#### ***Supply Component***

The equation for the SC of SWSI-Mod is:

$$\text{SC} = [a * P(\text{Otowi}) + b * P(\text{ElVado}) + c * P(\text{Heron}) + d * P(\text{Abiquiu}) + e * P(\text{Cochiti}) + f * P(\text{Intbasin}_M) - 50]/12$$

#### **Equation 1**

Where P(x) represents the non-exceedance probability (%) of the current or forecast volume relative to the historical record. *Otowi* represents the contribution from the upper Rio Grande Basin, estimated based on the inflow at the Otowi Bridge gauge. *ElVado*, *Heron*, *Abiquiu*, and *Cochiti* represent the storage in each of the reservoirs. *Intbasin*

represents the runoff contribution from the intermediate basin between the Otowi Bridge gauge and the Elephant Butte Reservoir.

In the SC of the SWSI-Mod, the variables a, b, c, d, e and f are weighted coefficients that represent the approximate contribution of each parameter to surface water supplies. The SC of the SWSI-Mod assumes that the sum of the parameters defined above (Otowi, ElVado, Heron, Abiquiu, Cochiti, and IntBasin) equals the total water supply for the MRGCD. The approximate contribution of each parameter to the surface water supply is simply the value of the parameter divided by the total water supply. The monthly weighted coefficient for each parameter in the SWSI-Mod can be found in Table 1. For further information on the formulation of these coefficients refer to Appendix 4 (WEST, 2018).

**Table 1: Monthly weighted coefficients for the ElVado, Heron, Intbasin, Otowi, Temperature, and API**

Month	El Vado (b)	Heron (c)	Intbasin (f)	Otowi (a)	Temperature (g)
1	0.3972	0.026	0.0736	0.503	0.2
2	0.3972	0.026	0.0736	0.503	0.2
3	0.3972	0.026	0.0736	0.503	0.2
4	0.3972	0.026	0.0736	0.503	0.2
5	0.3972	0.026	0.0736	0.503	0.2
6	0.3494	0.029	0.09314	0.529	0.2
7	0.3594	0.028	0.09515	0.517	0.2
8	0.3751	0.028	0.12037	0.476	0.2
9	0.3774	0.029	0.14866	0.445	0.2
10	0.3862	0.031	0.16237	0.421	0.2
11	0.3816	0.029	0.17061	0.419	0.2
12	0.3853	0.027	0.16897	0.418	0.2

### ***Demand Component***

The equation for DC of SWSI-Mod is:

$$DC = g * [50 - (P(Temperature))]/12$$

**Equation 2**

Where *Temperature* represents the average temperature in the Middle Rio Grande during the previous twelve months. The DC of the SWSI-Mod assumes that the sum of *Temperature* and other unidentified water demands equals the total water demand for the MRGCD. In the DC of the SWSI-Mod, the variables g is a weighted coefficient that represent the approximate contribution of *Temperature* to water demand. Throughout the entire record of PRISM temperature data, evapotranspiration varies by 20% so the coefficient g is set to 0.2.

### ***SWSI-Mod Parameters***

The SWSI-Mod parameters in Equation 1 and Equation 2 are:

- Otowi
- ElVado

- Heron
- Abiquiu
- Cochiti
- IntBasin
- Temperature

Otowi represents the forecast natural streamflow at the USGS Otowi Bridge stream gauge as provided by the NRCS.

ElVado, Heron, Abiquiu, and Cochiti represent corresponding reservoir storage levels on the Rio Chama system (ElVado, Heron, and Abiquiu) and Rio Grande system (Cochiti). Abiquiu and Cochiti parameters do not contribute to the total MRGCD water supply. They are defined here because they could theoretically be used for MRGCD supply in the future, although current policies prohibit this practice. The weighted coefficients d (Abiquiu) and e (Cochiti) are set to 0.0 so that these parameters do not contribute to the SWSI-Mod.

Intbasin represents the water supply generated in the intermediate basin between the Otowi Bridge gauge and the Elephant Butte Reservoir. The Antecedent Precipitation Index, developed in Appendix 4, to account for antecedent soil moisture and groundwater levels.

Temperature represents the average temperature in the Middle Rio Grande during the previous twelve months.

Using the NRCS water supply forecast, the Otowi and El Vado parameters for January – June represent the forecast total March – July streamflow volume. This allows the SWSI-Mod to function as a planning tool to assist MRGCD in preparing for future drought conditions. A list of the parameters to be used in the SWSI-Mod in each month can be found in Table 2.

**Table 2: Parameters used in the SWSI-Mod**

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Otowi (Current)							X	X	X	X	X	X
Otowi (Forecast)	X	X	X	X	X	X						
Heron (Current)	X	X	X	X	X	X	X	X	X	X	X	X
ElVado (Current)							X	X	X	X	X	X
ElVado (Forecast)	X	X	X	X	X	X						
Abiquiu (Current) *												
Cochiti (Current) *												
IntBasin (Current)	X	X	X	X	X	X	X	X	X	X	X	X
Temperature (Current)	X	X	X	X	X	X	X	X	X	X	X	X

\*The MRGCD is not currently authorized to store water in Cochiti or Abiquiu and therefore are not parameters used to calculate the SWSI-Mod. They are included in this table to accommodate any future changes in those authorizations that may one day occur.

For drought identification purposes, the water supply index calculated by the SWSI-Mod translates directly to MRGCD’s Drought Stages, as illustrated in Table 3.

Table 3: MRGCD drought stages and corresponding SWSI-Mod values

MRGCD Drought Stage	SWSI-Mod Index
Slightly Dry	$-2 \leq \text{SWSI-Mod} < -1$
Moderately Dry	$-3 \leq \text{SWSI-Mod} < -2$
Severely Dry	$-4 \leq \text{SWSI-Mod} < -3$
Extremely Dry	$\text{SWSI-Mod} < -4$

The most up-to-date current or forecasted SWSI-Mod value, regardless of whether it triggers a drought stage, as well as links to all the hydrologic metrics used to calculate the SWSI-Mod can be found on the MRGCD website at the following URL: <https://www.mrgcd.com/hydrology.aspx> .

A tool has been developed in a Microsoft Excel spreadsheet (Appendix 11) that will enable the MRGCD to easily utilize the SWSI-Mod for the purpose of drought monitoring throughout the year. At the beginning of each month the tool will be used to either forecast the drought index for the upcoming irrigation season or to calculate the current drought condition, depending on the month. The spreadsheet used to calculate SWSI-Mod can be downloaded from the MRGCD website at the following URL: <https://www.mrgcd.com/hydrology.aspx>.

## 2.2 Historic Long-Term Water Availability

The MRGCD evaluated the past 30 years of SWSI-Mod to identify periods of drought in recent history. The frequency and duration of each drought indicator stage will be updated as SWSI-Mod is calculated according to the schedule in Section 2.5, to be included in the drought monitoring reporting outlined in Section 2.6. The intention of this calculation is to attempt to identify any trends in drought frequency, duration, and severity in the planning area to potentially aid the MRGCD in drought planning.

Figure 2 is a graph of the monthly SWSI-Mod calculated for the period of January 1, 1953 to December 1, 2018, which is the time period that the SWSI-Mod can be calculated based on the availability of data. Over this period there have been 97 months where extremely or severely dry conditions have been identified by the SWSI-Mod. From the historical SWSI-Mod calculations there have been five identified periods that lasted six months or more of severely dry or extremely dry conditions. The average duration of these persistent and intense periods of drought is 13.6 months and the longest lasted 24 months. Table 4 depicts the percentage of occurrence of each drought indicator class. Slightly wet to slightly dry classification occurs 56.3% of the time, extremely wet to moderately wet 16.7% of the time, and moderately dry to extremely dry conditions 27% of the time.

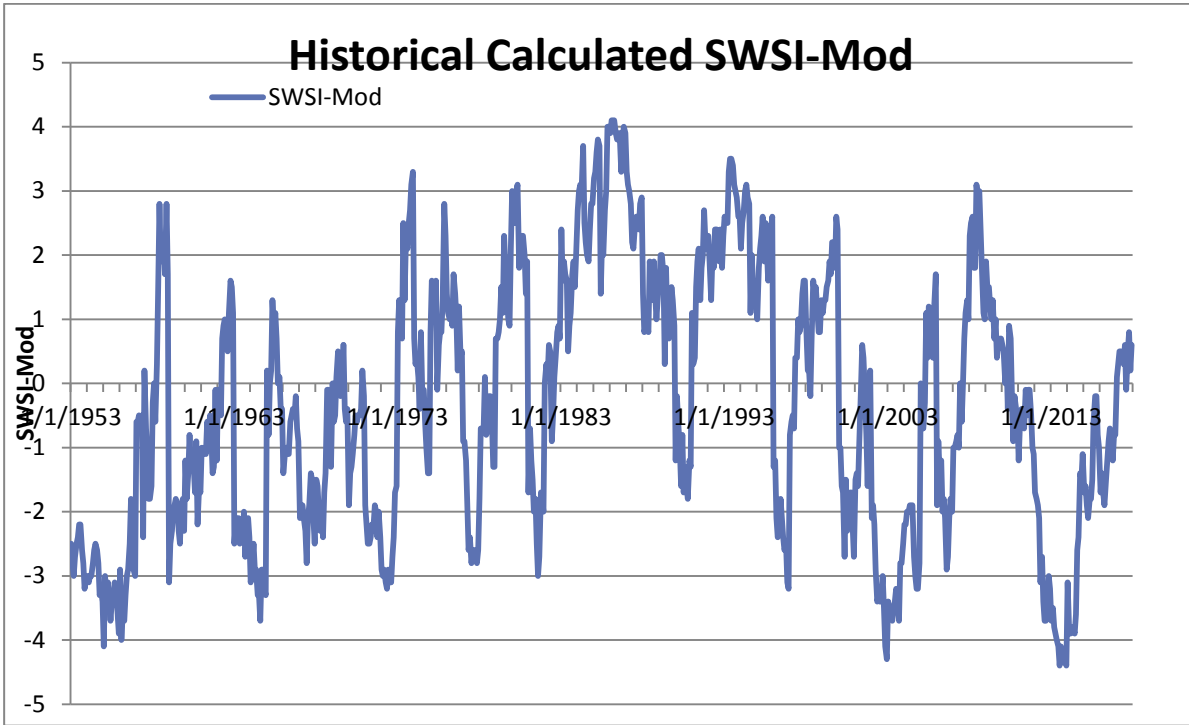


Figure 2: Historical Calculated SWSI-Mod

Table 4: Percentage of each drought indicator class

Month	Extremely wet	Severely wet	Moderately wet	Slightly wet	Near Normal	Slightly dry	Moderately dry	Severely dry	Extremely dry
Jun	0.0	4.6	9.2	16.9	29.2	13.8	15.4	9.2	1.5
Jul	0.0	3.1	15.4	15.4	27.7	9.2	16.9	10.8	1.5
Aug	0.0	4.6	13.8	12.3	32.3	9.2	15.4	10.8	1.5
Sep	0.0	3.1	12.3	15.4	32.3	9.2	18.5	7.7	1.5
Oct	0.0	3.1	10.8	20.0	23.1	16.9	16.9	7.7	1.5
Nov	0.0	4.6	12.3	15.4	26.2	16.9	10.8	10.8	3.1
Dec	0.0	4.6	15.4	13.8	21.5	16.9	13.8	10.8	3.1
<b>Average</b>		<b>16.7</b>		<b>56.3</b>			<b>27.0</b>		

### 2.3 Future Supply and Demand

Future supply and demand conditions were considered as a part of the DCP. The factors considered in the evaluation of future conditions include: increased demands for supply due to increases in upstream needs and decreased supplies due to climate change. In Appendix 3 (WEST, 2018), an in-depth analysis of a range of potential future conditions due to climate change was conducted to assess prospective vulnerabilities to the MRGCD and a summary of that analysis can be found in the following section 2.4. These projected future conditions were used to inform the development of the mitigation actions in Section 5 of this DCP.

The practice of transferring water rights from agricultural lands to urban water uses is a potential vulnerability of the MRGCD. Irrigated acreage in Bernalillo county, the most urban of the counties in the MRGCD, declined 32% in the period of 2010 to 2013 (USDA NASS, 2014). Although ABCWUA no longer acquires pre-1907 water rights as part of their long term water resources acquisition plan (ABCWUA Water 2120, 2016), some municipalities and other water users in the region continue to pursue these water rights transfers to offset the impacts of groundwater pumping. The MRGCD acknowledges that these urban water-rights transfers represent a vulnerability to future water supplies to the MRGCD, but addressing this vulnerability is beyond the scope of this Drought Contingency Planning project and is not addressed in the mitigation and response actions developed and presented below.

### 2.4 Range of Future Conditions

In Appendix 3(WEST, 2018), the effects of climate change were evaluated for the period of 2000 to 2049 and 2050 to 2100. However, for drought planning and mitigation purposes, the MRGCD is focusing on the first half of the century. Climate projections multi-model ensembles are recommended in the analysis of the possible effects of climate change. The applications of more than one model to evaluate possible climate change scenarios is recommended due to intrinsic uncertainties in climate predictions that arise from model structure, initial conditions or model parameterizations. Multi-model ensembles are constructed by running several global climate models for a common set of experiments.

Ten Global Climate Models (GCMs) were evaluated under two different greenhouse gas emission scenarios: the Representative Concentration Pathways 4.5 (RCP45) and the Representative Concentration Pathways 8.5 (RCP85). The results of the analysis are presented in terms of the multi-model ensemble mean or median, or the ensemble range (minimum and maximum) among all 10 GCM applied in the analysis for each gas emission scenario. The number of models that predicted positive or negative trends is also discussed when relevant.

Hydrologic Unit Code Six (HUC6) (NRCS, 2013) was used to delineate different areas of interest as follows:

- The analyses were performed separately for each location, subdivided according to the Hydrologic Unit Code six (HUC6). The HUC 130100 sub-Basin covers the Rio Grande Headwaters up to the Rio Grande near Lobatos gauge (HUC name *Rio Grande Headwaters*, area equal to 19,705 km<sup>2</sup>).
- The HUC 130201 goes from the Rio Grande near Lobatos gauge to Rio Grande near Otowi (HUC name *Upper Rio Grande*, area equal to 16,606 km<sup>2</sup>).
- The HUC 130202 covers the main area of the MRGCD from Rio Grande near Otowi gauge to Rio Grande at Elephant Butte Dam (HUC name *Rio Grande-Elephant Butte*, area equal to 53,620 km<sup>2</sup>).
- The HUC 140801 covers the watershed from where water is transposed to the SJC system (HUC name *Upper San Juan*).

Evaluations for the area that comprise the Rio Grande Basin until the Rio Grande-Elephant Butte Reservoir plus the area of the Upper San Juan were also performed, and is referred as “combined area”. Streamflow projections were evaluated in multiple locations in the watershed, including the Rio Grande near Lobatos gauge, the Rio Grande near Abiquiu, the Rio Grande near Otowi gauge, and the Rio Grande at Elephant Butte dam.

The following changes identified by WEST Consultants Inc. in Appendix 3 may be experienced by MRGCD for the period of 2000 to 2049, under RCP45 and RCP85 scenarios:

- **Temperature** increases are identified at all locations, by all GCM with both RCPs, and for all months of the year. Minimum and maximum temperatures are projected to increase on average by 1.8°C (3.2 °F). Multi-model projected changes range from 0.9°C to 2.6°C increase in maximum temperature, and 1.1°C to 2.2°C increase in minimum temperature.
- **Snow Water Equivalent (SWE)** is projected to decrease for all Basins and months for which snow occurs. Changes are relatively higher for the Upper Rio Grande Basin, but the loss of water volume is most significant for the headwaters, where the volume of water stored as snow is higher. Projected changes are most significant for the month of May. For the Rio Grande headwater, the May SWE is projected to decrease on average by 14 mm (19.4%, 0.55 inches) for RCP45 and RCP85, and multi-model projected changes range from a 27.7 mm (38.2%, 1.1 inches) decrease to a 1.7 mm (2.3%, 0.07 inches) increase in SWE. For the Upper Rio Grande Basin, the May SWE is projected to decrease on average by 8.1 mm (36.1%, 0.32 inches) for RCP45 and by 8.6 mm (0.33 inches) for RCP85, and multi-model projected changes range from 11.8 mm (52.6%, 0.46 inches) to 3.3 mm (14.7 %, 0.13 inches) decrease in SWE. Changes in SWE for the Upper San Juan Chama (SJC) are also significant and might affect the delivery of water to the Upper SJC system.
- **Annual Potential Evapotranspiration** for the area irrigated by MRGCD is expected to increase on average by approximately 5% for both RCPs. Multi-model projected changes range from 1.1% to 8.4 % increase in potential evapotranspiration. Significant increases occur mainly from March to November. Assuming irrigation techniques, crops, and served area are kept constant, this percentage increase correspond to expected relative increase in irrigation demand.
- **Actual Evapotranspiration** increases for some of the winter and fall months, but decrease for June and July for both RCPs. This decrease may be explained by a decrease in soil water availability during these months (crop stress). Note that climate models do not take into consideration irrigation. Therefore, the reduction of actual evapotranspiration for June and July indicates that irrigation will have to increase in order to provide plants access to water;

- **Soil Moisture (naturally occurring)** is projected to decrease for all months for the combined area for both RCPs. Soil moisture in the combined area is the lowest for the period of July to October, when irrigation is mostly needed. To achieve the same production, irrigation will have to increase to provide vegetation access to water ;
- The magnitude of projected changes in **Annual Runoff** vary significantly among all models.
- Changes in **Runoff Seasonality** occur in snow dominant Basins. For the Rio Grande Headwaters, May runoff increases while June runoff decreases. For the Upper Rio Grande, March and April runoff increases while May and June runoff decreases changes for the Rio Grande-Elephant Butte reach are much less significant since snow is not predominant in the Basin and average runoff volumes are lower than the ones observed in the Upper watersheds. For the period of July to October, when localized storms can alleviate droughts in the region, no significant trends in runoff are detected.
- Multi-model ensemble **Streamflow** indicates decreasing trends in mean annual streamflow for all scenarios and locations, but changes occur mainly in the second half of the 21<sup>st</sup> century. The range of projections provided by the different GCM models is very large and both positive and negative trends are identified for the first part of the century.
- Changes in **the Seasonality of Streamflow** are clear in the Rio Grande Basin. Monthly streamflow variability increases for the projected period. Streamflow at Rio Grande at Otowi gauge increases for the months of March and April, and decrease for the months of May, June and July. The major loss in streamflow volume for the Rio Grande at Otowi gage location occurs in June. Negative trends in streamflow volumes also occur for the summer and fall months, which is likely the result of higher evaporation caused by higher temperatures resulting in drier soils and higher hydrologic losses but could also be attributed to a shift in the timing of the annual runoff to earlier in the year. Streamflow changes patterns for the Rio Chama and the Rio Grande at Albuquerque are similar to the ones observed for the Rio Grande at Otowi gage, with exception of the month of April for the Rio Chama, for which no increase in streamflow is projected.
- **The Intensity, Frequency, Duration, and Persistency of Droughts** are also evaluated. The frequency of dry years (below average mean annual streamflow) increases for the projected period for all sites. However, increases are more significant for the period of 2050 to 2099. For the Rio Grande at Otowi gage, the frequency of dry years increases by 4.6% for a 1-year window, 7.9% for a 2-year window, 10.4% for a 3-year window, and 17.7% for a 30-year window for the period of 2000 to 2049.
- Projected changes in **Drought Persistency** are also evaluated. The number of consecutive dry years also increases for the projected period for all observed locations, with larger changes occurring for 2050 to 2099. For the observed period, a maximum of 12 consecutive dry years were registered at the Rio Grande at Otowi gage. This number is projected to increase to 16 for the period of 2000 to 2049. For the Vallecito gauge in the Colorado River Basin, a maximum of 9 consecutive dry years were observed, and this number is projected to increase to 18 for 2000 to 2049. Short duration droughts (2 to 10 years) also become more intense for all sites, with reduced mean annual streamflow when compared to the observed record.

## 2.5 Recommendations

There is consensus across different models that the frequency and duration of droughts are projected to increase, but the degree of those changes is variable from model to model. In order to keep the DCP current and ensure that the most

accurate possible projections are used to develop appropriate mitigation and response actions in the future, it is recommended to incorporate an evaluation of new climate studies as a part of the DCP update process.

## **2.6 Drought Monitoring Reporting**

The framework for conducting drought monitoring includes the following steps:

1. Utilize the spreadsheet posted on <https://www.mrgcd.com/hydrology.aspx> and fill in the data from the appropriate data sources, which are hyperlinked on the same webpage. This will calculate the current SWSI-Mod.
2. Identify the drought stage that corresponds to the calculated SWSI-Mod value.
3. Prepare a brief report that describes the drought stage, duration, and the response actions that correspond to the identified drought stage.
4. Post this brief report on the MRGCD website at <https://www.mrgcd.com/hydrology.aspx>.
5. Present the report to the MRGCD Board of Directors.

## **2.7 Schedule**

A requirement of Reclamation's drought planning program is to establish a group of stakeholders in the planning area to coordinate drought monitoring and plan updates that is to be called the Drought Task Force. To avoid confusion with already established groups using the title "Drought Task Force" in the planning area, the name of this coordination entity is referred to in this document as the Drought Evaluation Team (DET). Further discussion of membership and how the DET was utilized to develop this plan can be found in Section 7 in this DCP.

As most data sources for the SWSI-Mod tool are available on a monthly basis, the drought indicator will be calculated monthly as data is available. The MRGCD will be responsible for calculating the drought indicator, reporting it to the Board of Directors and posting it on the MRGCD website. The tool will be available to the public on the MRGCD website, to allow for the public to access the data and to calculate the indicator on their own. Directions for calculating SWSI-Mod are included in the spreadsheet, along with links to the data sources.

The MRGCD will convene the DET in years when a drought status of slightly dry to severely dry, which is indicated by a calculated SWSI-Mod value of less than or equal to -1, is identified in the months of February or March. At these meetings there will be a discussion of current or projected conditions, and the potential response actions that the MRGCD could make in the upcoming irrigation season. Other entities in the planning area may also provide updates on their own drought response activities. The DET may meet again later in the irrigation season if it is deemed necessary by the MRGCD water operations staff.

A review of the drought monitoring process will be evaluated every two years by the DET or after a drought has occurred to discuss the efficacy of the MRGCD DCP. Further discussion of the plan update process can be found in Section 7 of the DCP.

## **3.0 Vulnerability Assessment**

The purpose of this section of the DCP is to inventory critical resources of the MRGCD and identify the risks to those resources, as well as the factors that contribute to those risks. This inventory of resources and risks were utilized to inform the development of mitigation actions proposed in following sections.

The MRGCD relies mostly on native water diverted from the Rio Grande, with some water imported from the Colorado River Basin, through Reclamation’s San Juan Chama (SJC) Project. El Vado Reservoir on the Chama River, a major tributary to the Rio Grande, is the only reservoir that is authorized to store native Rio Grande water. Native water can only be stored in El Vado Reservoir when certain conditions in the Rio Grande Compact have been met. There are irrigators who irrigate with ground water (pumps), although in most cases it is supplemental to surface water delivered through MRGCD conveyance facilities and represents only a small portion of total annual crop water use. The limited flow available for storage on the Rio Chama and restrictions on storing water imposed by the RGC, coupled with minimal groundwater use makes the MRGCD particularly vulnerable to climate variability and water shortage.

### 3.1 Critical Resources

Drought impacts the resources that are critical to the MRGCD. Table 5 is a list of the critical resources, the priority of those resources to the operations of the MRGCD, the risks to these resources and how drought could impact them.

Table 5: Resources critical to the MRGCD

Critical Resource	Resource Priority	Contributing Risks	Drought Impacts
Rio Grande Basin Surface Supply	High	Increased competition for supply through increases in upstream needs for water	Reduced water supplies, limiting the MRGCD’s ability meet its obligations
El Vado Storage	Medium-High	Natural variability in temperature and precipitation within the planning area	Less predictability in supplies due to the changes in the timing and spatial distribution of precipitation and streamflow
San Juan Chama Project Water		Reduction of volume and changes in timing of supplies due to climate change	

The identified critical resources of the MRGCD are the sources of water supply; Rio Grande Basin Surface Water Supply, El Vado storage water, and San Juan Chama Project Water. The Rio Grande Surface Water supply was identified as the highest priority resource as this is the main source of water for the MRGCD. Contributions from El Vado storage and the San Juan Chama Project are substantial but less critical than annual surface water supplies from the Rio Grande.

### 3.2 Infrastructure Vulnerability

MRGCD faces many challenges in reliably providing water to irrigators in the face of increasing demands paired with the high variability of supplies within the Middle Rio Grande. In order to minimize the potential impacts of these challenges, MRGCD has invested heavily in improvements to its conveyance and diversion facilities, updated water delivery policies,

and improved coordination and communication with outside agencies. Due to these efforts, MRGCD has been able to decrease the average volume of water it diverts annually which ultimately has provided greater flexibility to meet Rio Grande Compact and endangered species requirements and allowed for more closely managed storage releases. Even though the changes implemented have been extensive and fruitful, MRGCD vulnerabilities to drought continue to exist.

WEST consultants worked closely with MRGCD staff to identify the challenges experienced by the MRGCD in making irrigation deliveries in times of water shortage. These challenges were used to inform the identification of the vulnerabilities listed below. These vulnerabilities were used to develop strategies and ultimately a prioritized list of recommendations to address these vulnerabilities.

El Vado reservoir presents a short-term infrastructure vulnerability, as Reclamation and the MRGCD are planning improvements (“corrective action”) to the dam that will hinder the MRGCD’s ability to store water in the reservoir for one to two irrigation seasons. The improvements are anticipated to be completed by the end of 2022. If drought occurs in the time that the improvements are underway, it will be significantly more difficult to mitigate that drought with limited storage capabilities.

#### *Limited storage downstream of El Vado Reservoir*

MRGCD has limited ability to store water downstream of El Vado reservoir. El Vado lies over 70 linear miles to the north-west of the closest MRGCD diversion facility. The time to convey water released from El Vado to the MRGCD system is approximately three days. The limited ability to store water downstream of El Vado forces MRGCD water managers to make decisions regarding reservoir releases based on weather projections days in advance (in coordination with other water managing entities). When water is released from El Vado and there are rainfall events or demand is less than predicted, MRGCD is unable to store the excess water and the water continues downstream to Elephant Butte Reservoir.

Flow fluctuations occur throughout the MRGCD system, which could potentially be mitigated through small ponds that would regulate flow in canals. As no regulating reservoirs exist there is no way for MRGCD to store brief supply surpluses in order to augment deficits. The Rio Grande compact does not allow for new storage facilities to be constructed in the river channel but small ponds that regulate flow within the MRGCD system would be in compliance. More accurate estimates of demand in the service area could enable the MRGCD to help mitigate the impacts of having a storage facility a long distance from the points of delivery.

#### *Limited ability to operate canals with reduced flows*

MRGCD canals do not have broad coverage of the appropriate infrastructure to operate at reduced rates of flow. In supply limited years MRGCD currently rotates water through canals which limits the ability of irrigators to schedule water deliveries when crops need them most and results in higher conveyance losses due to canal recharge. The ability to operate canals at lower flows would help mitigate the effects of turning ditches on and off.

#### *Variable delivery timing and variable inflows cause flow rates in drains and the river to fluctuate diurnally*

Fluctuations can be caused by irrigators turning irrigation off at night such that the water flows to the drains. Fluctuations can also be caused by diurnal fluctuations in wastewater outflows and storm runoff.

- Variable drain flow causes variable river flow causing flow at diversion points to fluctuate: Variable flows in the drains at the lower end of one division result in variable inflows to the next division downstream.
- Variable canal flow makes it difficult for ISOs to accurately deliver water: The intent of the operators is to keep the canal inflow constant. High flows can be diverted to the river or one of the drains for use further

downstream. When flows are too low, deliveries somewhere downstream will suffer.

- Variable drain flows make it difficult for the water operations manager to accurately do the following:
  - Estimate return flows. The water operations manager uses the drain flows to monitor whether there is enough water for downstream diversion. Measurement of these flows tells him if his current inflow is appropriate.
  - Schedule reservoir releases: If the water operations manager does not know whether current inflow is appropriate, it is difficult to decide when flow adjustments from the reservoir are needed.

#### *Need for installation of additional measurement and control structures*

Within the MRGCD there are over 200 measurement and automatic control structures, combined. These structures enable water managers to assess water demands, control deliveries to canals, and maintain water levels for efficient water deliveries to irrigators. Despite the large number of structures there are many canals that are currently unmeasured or not automated or both. Improved measurement and control at many of these locations would enable MRGCD to control deliveries more effectively to increase how reliably water deliveries are scheduled.

#### *Need to more precisely manage the amount of water discharged into the river in some locations*

In years when supplies are limited, an ability to control the amount of water that is discharged into the river is crucial to limiting the amount of water lost to evaporation, seepage, and evapotranspiration from phreatophytes. Losses due to these factors tend to be greater in the river channel than within MRGCD facilities. In some river reaches MRGCD has the ability to control the amount of water discharged to the river with some precision through interconnected drains and canals that cross division boundaries. Opportunities exist in many locations to further develop connections between canals, drains, and wasteways with the intent of controlling the amount of water that is discharged from MRGCD facilities.

#### *Need to maximize supply through alternative sources of water*

The MRGCD has no alternative source of water supply outside of its allocation of the natural flows in the Rio Grande, its stored water in El Vado Reservoir, and its contracted annual supply from Reclamation's San Juan Chama Project. In years when water supplies are limited, the ability utilize other sources of water, such as groundwater, on a short term basis, would enable the MRGCD to more reliably provide water to its constituents.

#### *Need to reduce conveyance inefficiencies of MRGCD infrastructure*

The MRGCD conveyance system while more efficient than utilizing the Rio Grande to convey water, loses water to evapotranspiration and seepage to groundwater. In years when supplies are limited, a more efficient system of conveyance could enhance the ability of the MRGCD to meet its obligations.

## **4.0 Drought Mitigation**

To enable the MRGCD to operate during periods of reduced supplies (droughts), and in the longer term as water supplies decrease and demands increase, the DCP includes recommendations for actions the MRGCD can take to reduce its long term vulnerability to drought and water shortage.

## 4.1 Infrastructure and Operation Recommendations

The recommendations in this section include projects and strategies that will enable the MRGCD to reduce its long term vulnerability to drought. These recommendations are categorized according to the vulnerabilities listed in Section 3.2 above:

- Limited storage downstream of El Vado Reservoir
  - Develop a formalized online system for irrigators to schedule water deliveries
  - Improve estimates of evapotranspiration in the planning area by conducting an energy balance remote sensing analysis on a wet and dry year
- Limited ability to operate canals with reduced flows
  - Installation of additional water control structures throughout the MRGCD
- Variable delivery timing and variable inflows cause flow rates in drains and the river to fluctuate diurnally
  - Build small regulating reservoirs throughout the MRGCD system.
- Need for installation of additional measurement and control structures
  - Installation of additional measurement and control structures throughout the MRGCD
- Need to more precisely manage the amount of water discharged into the river in some locations
  - Utilize the connections between the drains and the low flow conveyance channel (LFCC) in the Belen and Socorro Divisions
  - Equip diversion structures at the Angostura and Isleta Diversion Dams to precisely regulate flow and account for inter-divisional flow to more closely match demand
- Need to maximize supply through alternative sources of water
  - Utilizing existing MRGCD well permits, rehab existing or construct new groundwater wells
  - Develop a voluntary water leasing program that will allow the MRGCD to facilitate temporary leasing of water between irrigators in the MRGCD service area
- Need to reduce conveyance inefficiencies of MRGCD infrastructure
  - In locations where appropriate, put sections of open channel canals into closed pipes
  - Use pumping plants to pump water from drains if depending on gravity is not as effective
  - Construct a siphon from the lower San Juan Drain into the Unit 7 Drain near Bernardo
  - Develop a program to maximize on farm/application efficiency on the lands within the MRGCD

Recommendations for mitigation projects and strategies along with basic feasibility analyses and cost estimates were developed and can be found in Appendix 7 (WEST, 2018).

Changes in infrastructure can assist MRGCD with improving control of water. Water supply for irrigation is highly variable from year to year. Summer storms can add to the complexity of water control since water can enter the system for short periods. The goal of the improvements is to allow the MRGCD to make irrigation deliveries when supplies are limited. The recommended improvements are organized around allowing MRGCD to deliver water if supplies were reduced by 10, 25, and 40 percent.

If the MRGCD were to experience a drought where supplies were reduced by 10%, irrigation deliveries could continue to be made with relatively minor infrastructure improvements; projects costing from \$1,000 to \$20,000. At this level of supply, fluctuations in canal flow can be minimized through automated control, and by sending the fluctuations to drains where possible. If supplies are reduced by 25% irrigation deliveries could continue to be made by providing more water to canals by pumping water from drains to supply canals. In some cases, this can also be used to minimize flow fluctuations. These projects are in the range of \$20,000 to \$100,000. To accommodate a supply reduction of 40% more

aggressive measures are recommended. These include methods that allow MRGCD to control the amount of water discharged to the river channel through wasteways and drains, improve operations in the Socorro Division, and use reservoirs to capture drainage flows and flow fluctuations. The cost of these projects exceeds \$100,000.

Table 6 outlines the cost of, supply reduction addressed by, and the developmental timeframe of each recommendation. Table 6 develops a basic cost/benefit analysis of each recommendation but true prioritization of the recommendations will be conducted by MRGCD staff as funding opportunities are identified and as site-specific project opportunities arise. Some recommendations may meet the requirements of certain funding opportunities and may be funded and implemented based on those circumstances. Other recommendations may be prioritized by identification of operational shortcomings at specific sites and the best mitigation recommendation will be implemented based on the circumstances at that site.

**Table 6: Recommend Mitigation Actions**

Cost Estimate	Recommended Action	Reduction In Supply That Recommendation Addresses	Developmental Timeframe
\$1,000-\$20,000	Installation of additional water control and measurement structures throughout the MRGCD:  i.e. flumes, automatic gates, and weirs	10%	Ongoing. The MRGCD adds new control and measurement structures.
	Utilize the connections between the drains and the low flow conveyance channel (LFCC) in the Belen and Socorro Divisions	10%	<1 year to implement this recommendation.
	Equip diversion structures at the Angostura and Isleta Diversion Dams to precisely regulate flow and account for inter-divisional flow to more closely match demand	10%	<1 year to implement this recommendation.
\$20,000-\$100,000	Develop a formalized online system for irrigators to schedule water deliveries	25%	This recommendation would take <1 year to implement.

	Improve estimates of evapotranspiration in the planning area by conducting an energy balance remote sensing analysis on a wet and dry year	25%	1-2 years to develop and implement if  necessary data to conduct the energy balance exists for years that meet the dry and wet year criteria.
	In locations where appropriate, put sections of open channel canals into closed pipes	25%	This recommendation is in the conceptual phase.  This recommendation would take 1-2 years to implement
	Utilizing existing MRGCD well permits, rehab existing or construct new groundwater wells	25%	This recommendation is still in the conceptual phase

\$100,000=<	Use pumping plants to pump water from drains if depending on gravity is not as effective	40%	2-3 years to develop and install pumping plants. The MRGCD is expected to complete the construction of a pumping plant in the Socorro Division in 2019
	Build small regulating reservoirs throughout the MRGCD system. Potential locations for these reservoirs include: <ul style="list-style-type: none"> <li>• In the Albuquerque Main Canal at Bernalillo Acequia heading</li> <li>• In the North Diversion Channel Outfall Sediment Basin</li> <li>• In the Barr-Chical Diversion Connection</li> <li>• At the Belen Canal</li> </ul>	40%	This recommendation is in the conceptual phase and would likely require 2 or more years to implement

	downstream of the Feeder three heading <ul style="list-style-type: none"> <li>• In the San Juan Feeder Connection above the San Juan Main Heading</li> <li>• On the San Juan Main Canal upstream of the La Joya Acequia</li> <li>• In the Unit 7 Drain 3 miles North of the San Acacia Dam</li> </ul>		
	Construct a siphon from the lower San Juan Drain into the Unit 7 Drain near Bernardo	40%	This recommendation is still in the conceptual phase and will take more than 2 years to implement
	Develop a voluntary water leasing program that will allow the MRGCD to facilitate temporary leasing of water between irrigators in the MRGCD service area	40%	This recommendation is still in the conceptual phase
	Develop a program to maximize on farm/application efficiency on the lands within the MRGCD	40%	This recommendation is still in the conceptual phase

## 5.0 Drought Response Actions

In this section of the DCP response actions that correlate with identified drought triggers in Table 3 have been outlined. These actions are designed to guide the MRGCD through water management decisions when drought conditions are either observed or forecast.

Appendix 5 presents recommendations provided by WEST (2018) as alternatives for drought response and conservation. MRGCD staff evaluated each of the recommendations, and ultimately decided to not include the proposed recommendations in this version of the DCP, as many of them were not appropriate for the physical and political constraints of the Middle Rio Grande system. Other recommendations were somewhat controversial and may be included in future updates to the DCP after more consideration and evaluation.

## 5.1 Preparedness Actions

When not in irrigation season the MRGCD will monitor drought conditions monthly with the appropriate SWSI-Mod formulation and post the value on its website. From January to February the MRGCD will begin to disseminate information regarding forecasted drought conditions through the MRGCD website and reports to the MRGCD Board of Directors. If forecasted drought conditions are identified in February or March, the MRGCD will hold a Drought Evaluation Team Meeting in order to disseminate information regarding drought conditions and to discuss the potential actions to be taken during irrigation season. Further description of DET can be found in section 7 of the DCP.

## 5.2 Observed Drought

Due to limited flexibility on reservoir operations and limited storage capacity, the MRGCD has a restricted number of possible actions that can be taken to minimize the effects of droughts during the irrigation season. Table 7 lists the actions that can be taken by the MRGCD to minimize the effects of drought during the irrigation season, from June to December, based on the current SWSI-Mod. All of the drought responses are cumulative as the drought stage progresses in severity.

Table 7: Response Actions for Current Drought

<b>Drought Stage</b>	<b>Triggering Criteria</b>	<b>Strategy</b>	<b>Drought Response Actions</b>
Slightly Dry	-2= $\leq$ SWSI $\leq$ -1	Monitor conditions as they change	Monitor drought conditions to prepare for potential change in conditions
		Coordinate with outside entities as needed	Convene DET if drought conditions occur in February or March
Moderately Dry	-3= $\leq$ SWSI $\leq$ -2	Ensure that MRGCD water users remain apprised current water supply conditions	Disseminate information about water supply conditions to water users through MRGCD website and local media outlets; continue to update this information as conditions change
		Ensure water rights receive priority to leased water during shortages	Enforce Water Bank Revised Rule No. 23 (Appendix 9) when the reservoir and flow conditions outlined in the Revised Rule 23 are met
Severely Dry	-4= $\leq$ SWSI $\leq$ -3	Maximize water delivery efficiency, ensure equitable distribution of water	Actively enforce the one-acre-per-hour on-farm delivery requirement laid out in MRGCD's Water Distribution Policy (Appendix 9)
		Maximize conveyance efficiencies	Implement rotational deliveries to lower-order canals (smaller canals that are not the main supply canal) for entire division or large service areas.
Extremely Dry	SWSI $\leq$ -4	Maximize conveyance efficiencies	Rotate diversions between divisions while ensuring that required deliveries for Prior and Paramount lands continue to be made

		Supply water to MRGCD water users as possible	As flows may be intermittent and the MRGCD will be entirely dependent on natural river flows, the MRGCD will have to divert water opportunistically from the river
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### 5.3 Implementing Response Actions

Response actions may be undertaken once the drought status has been determined at the beginning of the month. The impending actions may be communicated to the water users through reports to the MRGCD Board of Directors and on the MRGCD website. The implementation of the response actions is at the discretion of the MRGCD Board of Directors.

## 6.0 Operational and Administrative Framework

This section describes who is responsible for undertaking the actions necessary to implement each element of the DCP as well as the procedures that need to be followed in order to implement those elements. A brief overview of the MRGCD emergency response plan can be found in this section with the plan in its entirety attached in Appendix 9.

### 6.1 Responsibilities

The MRGCD staff, especially the Water Operations staff, will be responsible for implementation of this DCP. The recommended responsibilities are as follows:

**Drought monitoring:** The developed drought monitoring index relies upon the NRCS’s streamflow forecast and USGS stream gage data, therefore the MRGCD will depend on the NRCS to release these reports and for USGS to make stream gage data available before the MRGCD water operations staff can use the developed tool to conduct the forecasted drought monitoring, and identify drought status. MRGCD water operations staff will be responsible for calculating the drought indicator and posting it to their website every month.

**Notification of drought status to water users:** MRGCD water operations staff will use the regular meetings of its Board of Directors and the MRGCD website to inform water users of the current drought status.

**Notification of potential water shortages to water users:** The MRGCD water operations staff will provide updates at regular meetings of its Board of Directors and on the MRGCD website to inform water users of potential water shortages. Information may also be provided to local media (newspapers, radio, television, etc.) about water shortages.

**Implementation of drought mitigation actions:** Implementation of the recommended drought mitigation actions is at the discretion of the MRGCD Board of Directors. MRGCD water operations staff may coordinate with MRGCD engineering staff and the MRGCD CEO/Chief Engineer to pursue recommended drought mitigation actions that are deemed necessary and approved by the Board of Directors.

**Implementation of drought response measures or policies:** Implementation of the recommended drought response actions is at the discretion of the MRGCD Board of Directors. MRGCD water operations staff, in coordination with the MRGCD CEO/Chief Engineer, may implement appropriate recommended actions as drought conditions occur. Certain drought responses actions may need to be coordinated with entities within the planning area. To accomplish this MRGCD water operations staff may convene the DET as deemed necessary.

**Regular Evaluation and Updating of the MRGCD Drought Contingency Plan:** MRGCD water operations staff will convene the DET every two years to evaluate the effectiveness of the DCP. These meetings may result in updates to the plan as deemed necessary.

## **6.2 Emergency Response Plan**

The MRGCD has an emergency response plan that provides a framework for action in the event of a major emergency, such as flooding, fire, drowning, ditch breaks, overflows, and other unforeseen emergencies. The full plan, with names and phone numbers removed, is attached in Appendix 9. This plan describes the internal processes and communication for the MRGCD in the event of an emergency. The plan details the entities and the personnel in those entities who would need to be coordinated with in the event of an emergency.

## **7.0 Plan Development, Stakeholder Engagement, and Update Process**

This section of the DCP describes how the DCP was developed, how the stakeholders were engaged in the planning process, what role will stakeholders play moving forward, and what is the process for updating the plan.

### **7.1 Key Water Management Partner Agencies and Stakeholders**

In order to develop the MRGCD DCP, the MRGCD was required to identify key stakeholders to be members of the Drought Task Force. The MRGCD chose to change the name of the Drought Task force to the Drought Evaluation Team (DET) to avoid confusion with the existing State of New Mexico Drought Task Force. Input from and communication with stakeholders in the planning area is necessary for the DCP to be successful. The following is a list of key stakeholder organizations that the MRGCD will invite to participate in DET meetings:

- U.S. Bureau of Reclamation (Reclamation)
- U.S. Fish and Wildlife Service (USFWS)
- U.S. Army Corps of Engineers (USACE)
- NM Interstate Stream Commission (ISC)
- Bureau of Indian Affairs (BIA)
- Albuquerque Bernalillo County Water Utility Authority (ABCWUA)
- City of Albuquerque
- City of Belen
- Town of Bernalillo
- Village of Bosque Farms
- Village of Los Lunas
- City of Rio Rancho
- City of Socorro
- Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA)
- Southern Sandoval County Arroyo Flood Control Authority (SSCAFCA)
- Coalition of Six Middle Rio Grande Basin Pueblos
- New Mexico Acequia Association
- New Mexico State Forestry Division
- The Nature Conservancy New Mexico
- Audubon New Mexico
- Middle Rio Grande Water Assembly
- Sandoval, Bernalillo, Valencia, and Socorro County
- Local and state fire response and prevention teams
- Pueblo De Cochiti
- Santo Domingo Tribe

- Pueblo De San Felipe
- Santa Ana Pueblo
- Pueblo of Sandia
- Pueblo of Isleta
- Elephant Butte Irrigation District (EBID)
- Soil and Water Conservation Districts

This list is not intended to be exhaustive and if there is a need to include additional entities the MRGCD may do so at its discretion.

## 7.2 Role of the DET

The DET will be convened in times of drought to inform stakeholders about drought conditions and coordinate drought operations with other water management agencies, tribes, and stakeholders. The DET members will be asked to participate in the DCP plan update, as outlined in section 7.4.

## 7.3 Plan Development

The DET met three times during the development of the MRGCD DCP.

- A kick-off meeting was held at Reclamation’s Albuquerque Area Office to discuss the goals and scope of the DCP.
- The second meeting was held on January 25<sup>th</sup>, 2017 to update the DET members of the progress and next steps of the DCP.
- The third meeting was held on August 10<sup>th</sup>, 2017 to discuss the scope of work for Vulnerability and Infrastructure contracts that would conduct much of the technical work needed to support the DCP.

Notes and sign-in sheets from these meetings can be found in Appendix 8.

The MRGCD awarded the developed Vulnerability Assessment and Infrastructure Assessment contracts to WEST Consultants INC. The reports produced from these contracts are attached in Appendices 2 through 7. This DCP was developed from the information in the reports produced by WEST Consultants INC. and with MRGCD records, documents and water operations staff.

## 7.4 Drought Plan Evaluation

In order to evaluate the effectiveness of the plan, it is recommended that the MRGCD water operations staff evaluate the following components of the DCP:

- **Drought Monitoring:** Assess drought indicator and trigger effectiveness, evaluate process for reporting drought status to the public.
- **Vulnerability Assessment:** Review new reports documenting climate change, changes in demand or supply, incorporate updates into DCP.
- **Mitigation Actions:** Review the status of recommended mitigation actions, propose new mitigation actions.
- **Response Actions:** Evaluate how effective drought response actions have been, propose additional drought response actions if deemed necessary.
- **Administrative Framework:** Evaluate the how effective the plan has been for plan implementation, consider updates to framework.

The recommended timeline for this review is as follows:

- In November of even numbered years, the MRGCD emails or calls DET Members, asking them to provide recent data or reports that could contribute to the MRGCD DCP update.
- December to February of odd numbered years, the MRGCD water operations staff conduct the assessments described in the evaluation above.
- February of odd numbered years MRGCD water operations staff provide proposed changes to plan to DET for comments.
- In March of odd numbered years the MRGCD updates this Drought Contingency Plan and presents the update to the Board of Directors.
- Once changes to the plan have been made, the MRGCD water operations staff sends copies of the updated plan to DET members and post it on the MRGCD website.

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# Appendices

Appendix 1:  
Long-term Focus of the MRGCD on Preparing  
For  
Severe and Long-term Drought

April 2019

## Discussion

Most early community development in the arid Rio Grande valley dating back to before recorded history was tied to geography and its relationship to a reliable water supply and fertile soils. The middle Rio Grande region from Cochiti to San Marcial New Mexico had numerous pueblos and villages that were spread within a day's horse and wagon ride along the Rio Grande. These communities were supported mostly by subsistence farming with a growing commerce as routes were established south to El Paso via the Comino Real and east toward Saint Louis via the Santa Fe Trail. After the Treaty of Guadalupe Hildalgo between the United States and Mexico was signed in 1848, the flood gates of immigration and development in this region were opened.

Water development and agricultural expansion occurred rapidly particularly in the San Luis Valley of the upper Rio Grande basin that began to impact water availability and peak flows that, combined with heavily grazed watersheds, led to a sediment laden floodplain that had poor drainage and no flood protection for the growing communities in the middle valley. Many of the irrigation acequias and ditches were managed by groups of farmers that had organized by communities these systems served that had poor heading structures and limited economies of scale to deal with the new problems of flash flooding and sedimentation.

In the late 1800s, the United States was asked to intervene regarding concerns of water shortages resulting from heavy expansion in Colorado leaving more senior water uses to the south high and dry when crops needed water most in the late summer. A "Joint Investigations" process was initiated between the three states (or territories) of Colorado, New Mexico and Texas and the US to determine water availability, demands and other water management issues that prevented water deliveries through the system to Fort Quitman Texas. This led to the Rio Grande Compact ratification by all three states and the US in 1936 that established the operating rules between the states that resulted in the "equitable" sharing of the highly variable supply of water within the Rio Grande system.

As the need arose to address the factors discussed above, the state of New Mexico passed into law the Conservancy Act of 1923 that authorized the formation of the Middle Rio Grande Conservancy District (MRGCD) and the construction of works to address the serious problems associated with flooding and poor drainage. The Act gave broad powers to MRGCD including the establishment of "reclaimed water rights" as a result of the benefits of the constructed works. These rights are in the name of the MRGCD for the beneficial uses within the boundaries established by the Official Plan and the original appraisals that have been amended from time-to-time. This system of management is similar to acequia practices within the state as water is distributed on an equal basis so, in times of shortage, all water users share in the net reduction of the available water supply. This is accomplished through scheduling and evaluation of crop types and other factors whereby the available supplies are distributed on a rotational basis, not by priority given that the MRGCD service area is only partially adjudicated.

Since the mid-1990s, the Middle Rio Grande water agencies were dealt another important management factor through the Endangered Species Act where the Rio Grande silvery minnow and the Southwestern willow

flycatcher were listed. This required the MRGCD to re-evaluate the operational premise that guided its operational strategy since the 1930s. Through a major investment in water measuring technology and structures, the MRGCD and its partners, the US Bureau of Reclamation (BOR) and the NM Interstate Stream Commission (ISC), began a concerted effort to manage water generally in a manner to continue meeting human needs while doing the collective best to keep water in the river at rates and times to theoretically match the known or presumed life-cycle needs of the species, with heavy emphasis on the RG silvery minnow. This fundamentally altered the diversion and distribution practices of the MRGCD for the foreseeable future in that net diversions were reduced by half and return flows are strategically managed to minimize river drying and targeted for desirable habitat maintenance. This has necessarily required a much more active management process that has also impacted New Mexico's ability in meeting annual Rio Grande Compact delivery obligations.

This has led MRGCD to an operational strategy with three general priorities as follows:

- 1) Continue meeting irrigation demands utilizing scheduling, metering and operational techniques that optimizes available water supplies to assure that agricultural producers continue to be successful in the middle Rio Grande valley; and
- 2) By working closely with our partners to meet or exceed the requirements of the December 2016 MRG Biological Opinion that directs the action agencies to perform numerous tasks and studies to avoid jeopardy of the species with a focus on optimizing presumed life-cycle needs of the Rio Grande silvery minnow through managing spawn and recruitment flows in late spring and minimizing river drying as the irrigation season progresses, then evaluating management actions through a sound, scientific process under DOI adaptive management procedures; and
- 3) Continue to assist in meeting the requirements of the Rio Grande Compact through managing water operations to assure deliveries to Elephant Butte Reservoir while designing projects and features required by the 2016 BO that minimizes or offsets new depletions.

All three of these major objectives can be severely impacted by sustained drought and the last 15 years has already challenged water managers in meeting these simultaneously during the highly variable supply conditions. Collective efforts have been relatively successful to date but agencies must be proactively planning for drought and severe weather impacts beyond what has been recently experienced as a matter of sound business practice and MRGCD, in working the BOR, ISC, NRCS and others, will be strategically developing these responsible actions.

### Additional Actions for Drought Contingencies and System Resilience

The MRGCD has a number of planned actions that are not refined sufficiently at this time to include them as a formal drought response as discussed in the body of the plan but we believe it is important to inform Reclamation regarding our longer term planning objectives in addition to those items already discussed. Following are bullets of intended actions the MRGCD is factoring into future budgets and work plans that help to address impacts due to more severe drought and summer storm intensity if they occur.

- System improvements to meet irrigation demands
  - MRGCD will continue to invest \$2-3M annually in measuring and delivery system improvements to future aide in meeting crop demand for producer success and food security in the region
  - MRGCD has received approval to utilize Clean Water Act funds through the NMED for a pilot low interest loan program for producers to pay cost-share on NRCS EQIP projects – need Board approval for future loans and District reserve set aside for a larger loan program if successful.
  - MRGCD will continue to work with water users to achieve the one-hour per acre efficiency requirement through a myriad of programs leveraging state and federal dollars
  - MRGCD will apply for WaterSMART drought resilience and other grants for system and on-farm improvements as contemplated by these programs
  - MRGCD can now apply under the 2018 Farm Bill for NRCS EQIP funds to make system-wide water efficiency improvements and will be applying this year
  - Strategically locate and build re-regulation reservoirs to optimize available water to balance deliveries more evenly within and across MRGCD divisions.
  - To help provide supplemental water under severe drought conditions, the MRGCD will be investigating the option of putting existing supplemental groundwater wells back into production. There are a number of pre-1956 wells that Reclamation and the MRGCD installed in the 1950s and may be of use in a comprehensive conjunctive use strategy during times of shortages.
- Flood protection and storm water salvage and use programs
  - MRGCD is working with the Corps of Engineers on the Bernalillo to Belen Levee project estimated at \$250M to protect the southern Bernalillo County and northern Valencia County from Rio Grande 100-year flooding. Riverside drains will be rehabilitated likely resulting in higher recovery and use of captured river infiltration during high flow events.
  - MRGCD and other local governments will be making application this year for a planning grant from NRCS to address upland flooding and storm water salvage through the Watershed and Flood Prevention Operations program. This plan will position the MRGCD and others for project funding in a coordinated regional approach to addressing severe damages caused by intense summer monsoon events within the MRGCD benefitted area as well as the surrounding uplands. Water stored and released into MRGCD conveyance facilities will serve as supplemental supplies to assist in post-storm water deliveries during the late summer when surface flows and reservoir supplies are limited.
- Meeting 2016 BO goals
  - MRGCD has made significant commitments within the current biological opinion that focuses heavily on water operations to provide positive population responses for the RG silvery minnow. The Board of Directors authorized \$750,000 annually for MRGCD commitments toward science and projects. Not included are all the other infrastructure investments that indirectly benefit the BO goals by incrementally allowing for less diversions from the river to

meet irrigation demands as well as better use of return flows to help in minimizing river drying later in the season and wetting more desirable habitat.

- MRGCD will continue to refine operations in order to help optimize water provided by others to minimize losses and target specific flows and/or locations as determined to assist in spawn and recruitment as well as minimizing drying.
- Water Conservation Program with Reclamation and NFWF Grant
  - MRGCD has entered into an MOA with Reclamation and a grant contract with NFWF to begin a pilot water leasing program that will look at optimizing farm-to-farm, farm-to-environment, farm-to-M&I, M&I-to-environment water leasing options. This has the potential for helping farmers get through tough years through field fallowing, helping to identify and secure a block of water for environmental purposes, as well as address some concerns associated with the current “buy-and-dry” approach for M&I junior groundwater pumping impacts.

Appendix 2:  
Compilation of Records

Prepared by

WEST Consultants

For the

Middle Rio Grande Conservancy District

October 2018



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# 1 Climatic variability

## Past climate variability

Instrumental records of precipitation and streamflow usually date back about 100 years. This period of record does not provide a complete picture of the full range of variability in climate. Tree-ring datasets extend back hundreds and even thousands of years and therefore provide valuable additional information on the length and severity of past droughts. This data should be applied to put current droughts into a more comprehensive perspective.

Past droughts will be evaluated based on reconstructed time series of streamflow and precipitation for the Rio Grande Basin based on tree-ring data. Available datasets are listed in Table 8. Water supply in the Middle Rio Grande is composed mainly of inflow from the Colorado Headwaters and by runoff generated in minor and major (Rio Chama and Jemez) tributaries in New Mexico. Annually a total of 20,900 acre-feet of water from the San Juan Chama (SJC) Project is also allocated for the Middle Rio Grande Conservancy District (MRGCD).

To quantify changes in supply from the Colorado Headwaters the updated reconstructed time series of natural streamflow at the Rio Grande Basin at Otowi Bridge gauge will be used. This dataset was updated at the request of the New Mexico Interstate Stream Commission (NMISC) and encompasses the time period of 1450-2012. As described by Woodhouse (2006) streamflow reconstructed time series for the San Juan River present low correlation with observed data and contain a high level of uncertainty. Streamflow time series for the Middle Rio Grande area are also not available. Therefore, to evaluate changes in the supply in the incremental basin between the Otowi Bridge gauge and Elephant Butte Dam, contributions from the SJC Project time series of reconstructed precipitation based on the El Mapais tree-ring data will be applied. While the El Malpais data refers to a unique location, the dataset is correlated with seasonalized precipitation (November to May and July, respectively) for all divisions in New Mexico.

**Table 8: Tree-ring based annual streamflow reconstruction time series**

Variable	Location (Period)	Reference
Streamflow	Rio Grande near Del Norte, CO – USGS 08220000 (1508-2002), Saguache Creek near Saguache, CO – USGS 08227000 (1520-2000), Alamosa River above Terrace Res., CO – USGS 08236000 (1632-2002), Conejos River near Mogote, CO – USGS 08246500 (1508-2002)	Woodhouse, C.A., D.W. Stahle, and J. Villanueva-Díaz. 2012. Rio Grande and Rio Conchos water supply variability from instrumental and paleoclimatic records. <i>Climate Research</i> , 51: 125-136. doi: 10.3354/cr01059
	Rio Grande at Otowi, NM – USGS 08313000 (1450-2012)	This dataset was published by Connie Woodhouse, June 26, 2014. Refer to the

Variable	Location (Period)	Reference
		following link for more information: <a href="http://www.treeflow.info/content/rio-grande-owoti-new-mexico-update">http://www.treeflow.info/content/rio-grande-owoti-new-mexico-update</a>
	Santa Fe River near Santa Fe, NM – USGS 08316000 (1305-2007)	Margolis, E. Q., Meko, D. M., and R. Touchan. 2011. A tree-ring reconstruction of streamflow in the Santa Fe River, New Mexico. <i>Journal of Hydrology</i> , 397(1-2): 118-127.
Cool- (November–May) and early-warm season (July) precipitation	El Malpais. The data is significantly correlated with seasonalized precipitation (November–May and July, respectively) for all divisions in New Mexico (137 B.C. and A.D. 2004)	Stahle, David W., Malcolm K. Cleaveland, Henri D. Grissino-Mayer, R. Daniel Griffin, Falko K. Fye, Matthew D. Therrell, Dorian J. Burnette, David M. Meko, and J. Villanueva Diaz. "Cool-and warm-season precipitation reconstructions over western New Mexico." <i>Journal of Climate</i> 22, no. 13 (2009): 3729-3750.

### Climate change effects in droughts

Future climate variability induced either by natural recurring cycles or human activities or both are expected to significantly affect the intensity and duration of future droughts. New Mexico climate is naturally characterized by strong inter-annual variability, multi-decadal periods of persistent wet and dry conditions, and abrupt changes between those periods. The U.S. Global Climate Research Program, for example, concluded in a 2009 assessment report that the Southwest will likely experience increased water scarcity as a result of the combined impacts of projected temperature increases and substantial reductions in rain and snowfall in the spring months. The U.S. Bureau of Reclamation’s (USBR’s) “Upper Rio Grande Impact Assessment” (2013) demonstrated that man-induced climate change will affect drought in New Mexico as a result of increasing temperatures that will lead to lower snowpack, earlier runoff (more runoff during winter and early spring), lower stream flows during the summer, and higher water demand for irrigation.

Global Climate Models (GCMs) are important tools that can be used to understand potential effects of climate change and variability. However, the results of GCMs should be used with caution due to their coarse spatial resolution, high uncertainties, and the lack of agreement between different models. Limitations and uncertainties in GCMs are especially high with the predictions of extreme dry or wet events.

Downscaling techniques are used to increase the resolution of GCM results. Downscaling techniques include methods to transform output at the GCM scale (e.g. 50 km or more) to higher resolution scales (e.g. 5 km). The downscaled results are intended to be more representative of watershed scale processes. Since GCM results must be interpreted with caution, downscaled results must also be used with caution as the GCM output is used as input to the downscaling processes.

The USBR (2013) evaluated the potential hydrologic impacts of climate change in the Upper Rio Grande Basin. This study will serve as a base for the evaluations performed in the project. The 2013 study was based on the World Climate Research Programme (WCRP) Coupled Model Inter-comparison Project Phase 3 (CMIP3) (Meehl et al. 2007). The coarse resolution GCM projections were downscaled using the statistical method Bias Correction and Spatial Disaggregation (CMIP3-BCSD) technique of Wood et al (2002). These downscaled GCMs were then used as forcing to the variable infiltration capacity (VIC) hydrological model to generate projections of runoff across the United States, including the state of New Mexico (USBR, 2014). The project runoff was used as input for an operation model at the river network level.

The USBR (2013) concluded that climate change will cause a decrease in water availability with implications for water management, human infrastructure, and ecosystems. According to the study, simulated average supplies of all native sources to the Upper Rio Grande Basin would decrease on average by about one third, while flows in the tributaries which supply the imported water of the SJC Project would decrease by about one quarter. Increases in temperature will also cause an increase in water demand, which would widen the gap between supply and demand. The study also concludes there will be changes in the timing and spatial distribution of flows and an increase in the month to month or year to year runoff volume variability.

All the conclusions from the USBR (2013) study are based on the WCRP CMIP3-BCSD climate projections. The WCRP develops global climate projections through its Coupled Model Inter-comparison Project roughly every 5 to 7 years. During 2012-2013, WCRP released global climate projections from CMIP phase 5 (WCRP-CMIP5) (Taylor et al., 2011), which informed the IPCC Fifth Assessment. Since the publication of the report, other downscaled climate datasets have become available, including:

- BCSD-CMIP5 Climate Monthly Projections: monthly bias-correction and spatial disaggregation based on the most updated WCRP-CMIP5. The approach is a quantile mapping technique operated on a monthly and location-specific basis to identify and remove bias from the projection datasets.
- BCCAv2-CMIP5 Climate Daily Projections: daily bias-correction and constructed analogs (BCCA) (Maurer et al., 2007; USBR, 2011; USBR, 2013; USBR, 2014).
- LOCA-CMIP5 Climate Daily Projections: Statistical downscaling using Localized Constructed Analog (LOCA) is a statistical scheme used to produce downscaled estimates based on a multi-scale spatial matching scheme that picks appropriate analog days from observations (Pierce, D et al., 2014).

Hydrological projections using VIC were also generated based on the BCSO-CMIP5 Hydrology Projections. The following variables are available at a 12km by 12km grid spatial, monthly, temporal scale, for the period of 1950 to 2100:

- Hydrologic Modeling Inputs:
  - total precipitation, mm
  - minimum surface air temperature, °C
  - maximum surface air temperature, °C
  - mean wind speed, m/s
- Hydrologic Modeling Outputs:
  - soil moisture, mm (state, 1st day of month, summed across the three VIC soil layers)
  - snow water equivalent (SWE), mm (state, 1st day of month)
  - total runoff depth, mm (sum of surface runoff and baseflow)
  - potential evapotranspiration, mm
    - natural vegetation, no water limit, summed over all vegetation classes and also over all snow bands
    - open water surface with fixed albedo (analogous to pan evaporation)
    - tall reference crop (alfalfa)
    - short reference crop (short grass)
  - actual evapotranspiration, is moisture limited and summed over all vegetation classes and also over all snowbands, mm

For few locations of interest, VIC gridded runoff results were routed to generate streamflow based on the unit hydrograph routing model (Lohmann et. al, 1996). The procedure consists of identifying the upstream basin tributary to a given downstream runoff location based on flow accumulation and flow direction classification from a digital elevation model. The VIC routing model is then applied to translate gridded surface runoff components above the runoff location into streamflow. Two sets of routing model implementations were used. The first set consisted of the West-Wide Climate Risk Assessments (WWCRA) sites also used by the USBR (2013) study in the CMIP3 version. The second ensemble referred to the location points developed for the National Center for Atmospheric Research (NCAR), 2014. These datasets provide daily routed flow, surface runoff, and baseflow for the points of interest listed in Table 9 and shown in Figure 3.

**Table 9: NCAR and WWCRA sites with available BCSO-CMIP5 streamflow projections**

<b>NCAR sites</b>				
Site ID	Latitude	Longitude	Loc	Name
VLCTO	37.37800	-107.57300	COLO	Vallecito
NAVJO	36.80000	-107.61200	COLO	Navajo
LOBAT	37.07800	-105.75600	RIOG	Grande R near Lobatos CO
CHAMA	36.07400	-106.11100	RIOG	Chama R near Chamita NM
ALBUQ	35.08900	-106.68000	RIOG	Grande R at Albuquerque NM
DELNO	37.68900	-106.46100	RIOG	Grande R near Del Norte CO
<b>WWCRA sites</b>				
Site ID	Latitude	Longitude	Loc	Site_name

28	37.07861	-105.75639	RIOG	Rio Grande near Lobatos
29	36.31833	-106.59722	RIOG	Rio Chama near Abiquiu
30	35.87624	-106.14334	RIOG	Rio Grande near Otowi
31	33.15634	-107.19054	RIOG	Rio Grande at Elephant Butte Dam
42	36.99307	-106.03863	RIOG	San Antonio River at Ortiz
43	36.54241	-105.55637	RIOG	Rio Hondo near Valdez
44	35.96475	-105.90446	RIOG	Santa Cruz River near Cundiyo

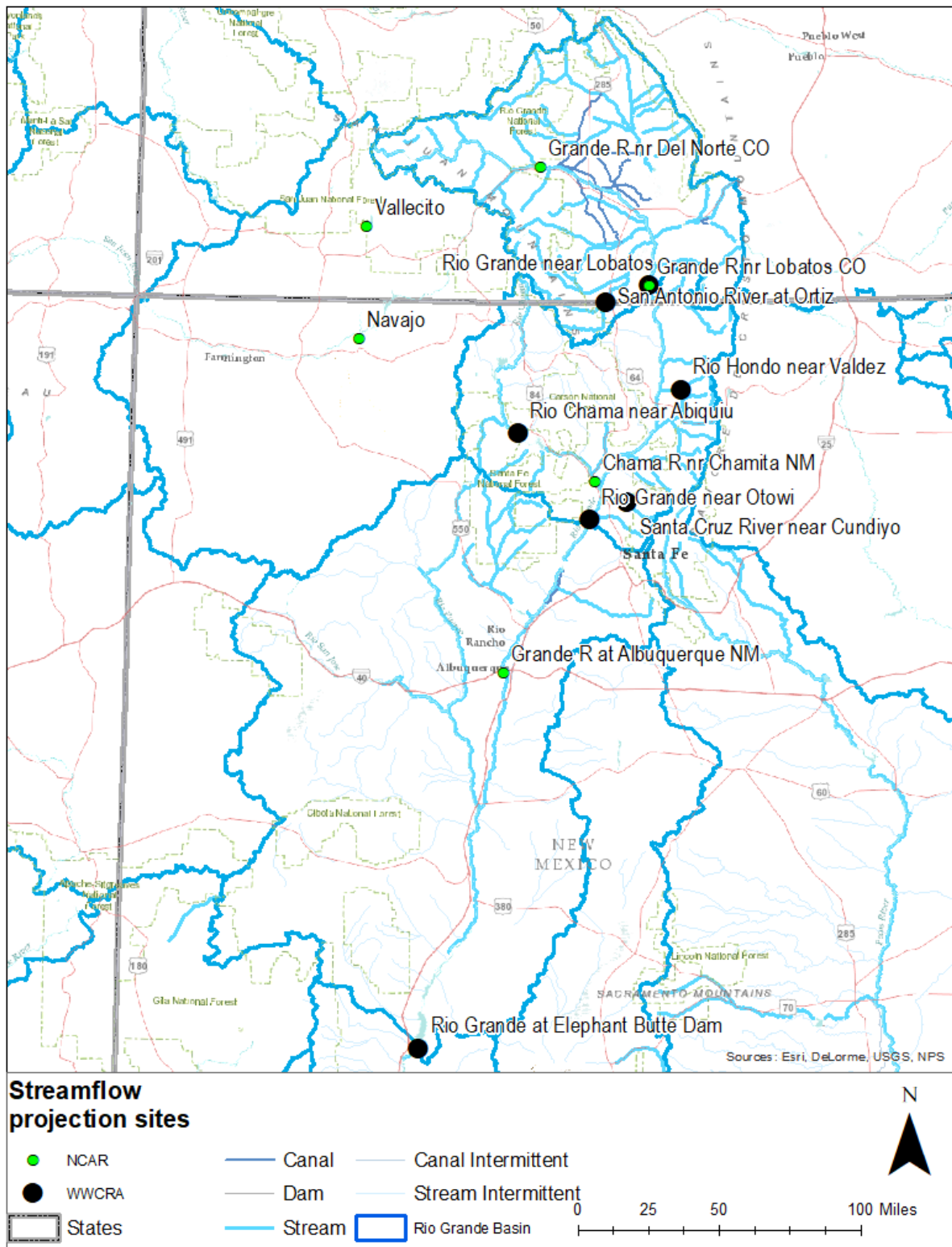


Figure 3: NCAR and WW CRA sites with available BCSD-CMIP5 streamflow projections

Since hydrological projections based on the LOCA model are still not available, BCSD-CMIP5 climate and hydrological projections will be evaluated in this project.

BCSD-CMIP3 provides 112 GCM projections based on 16 different GCMs and 3 different emission scenarios. The USBR (2013) applied the results of the 112 models in their analysis. CMIP5 includes a total of 231 BCSD5 climate projections that could be translated into hydrologic projections. However, hydrologic projections based on BCSD-CMIP5 were generated for a smaller number of projections limited to 31 CMIP5 climate models and 4 greenhouse gas emission scenarios (97 projections). The models shown in Table 10 will be included in the analysis. These models were selected by the California Department of Water Resources' (DWR's) Climate Change Technical Advisory Group (CCTAG), which was created to advise the DWR on the scientific aspects of climate change as the result of a collaborative effort to guide the consideration of both man-induced and natural climate variability for water resources management in California. A technical document (DWR, 2015) was prepared containing the preliminary findings. The report included recommendations on which CMIP5 GCMs are most appropriate for California water resources projects. The document serves as a guide for accounting for both man-induced and natural climate variability for water resources management in California. While the model selection was performed for California, there are many useful criteria that can also be applied for New Mexico. The first two steps of the process evaluate GCM simulations of historical climate at the global and western United States scales. Regional metrics included in the evaluation contained correlation and variance of mean seasonal spatial patterns, amplitude of seasonal cycle, diurnal temperature range, annual- to decadal-scale variance, long-term persistence, and western United States regional precipitation teleconnections to El Niño Southern Oscillation (ENSO). Moreover, CCTAG also considers model genetics in model selection. GCMs are numerical codes that solve the fundamental conservation and process equations, so to some extent they are all related (Knutti et al. 2013; Swanson 2013). Some are very closely related because they share common numerics or physical components. The CCTAG screening exercise tried to avoid redundancy by not selecting more than two GCMs from the same modeling group.

Table 10: GCMs selected for California water resources planning (CCTAG, 2015)

Model No.	Model Name	Model Institution	Model Resolution*
1	ACCESS-1.0	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)	192 x 145 (165 km)
2	CCSM4	National Center for Atmospheric Research	288 x 192 (110 km)
3	CESM1-BGC	National Science Foundation, Department of Energy, National Center for Atmospheric Research	288 x 192 (110 km)
4	CMCC-CMS	Centro Euro-Mediterraneo per I Cambiamenti Climatici	192 x 96 (165 km)
5	CNRM-CM5	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique	256 x 128 (123 km)
6	CanESM2	Canadian Centre for Climate Modeling and Analysis	128 x 64 (247 km)
7	GFDL-CM3	Geophysical Fluid Dynamics Laboratory	144 x 90 (219 km)
8	HadGEM2-CC	Met Office Hadley Centre	192 x 145 (165 km)
9	HadGEM2-ES	Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)	192 x 145 (165 km)
10	MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	256 x 128 (123 km)

\* Indicates the size of the model's atmospheric grid (number of columns by number of lines) and the resolution of the grid in km

## 2 Water Supply

In this session the datasets that can be used to evaluate water supply are described. In the next session, the datasets that can be used to represent water demand are described.

Water supply for the Middle Rio Grande is constituted by the following (U.S. Army Corps of Engineers {USACE} et. al, 2004):

- Inflow from the Upper Rio Grande: This inflow is measured at the Otowi Bridge gauge. The amount of water available for MRGCD use is limited by the Rio Grande Compact, an interstate agreement that regulates the delivery obligations downstream of the Middle Rio Grande. On average, 310 thousand acre-feet are available annually for MRGCD use (USACE et. al, 2004).
- Inflow from SJC: On average, the SJC provides 81 thousand acre-feet annually to the Middle Rio Grande system. The MRGCD annual allowance is 20.9 thousand acre-feet.

- Inflow from tributaries between the Otowi Bridge gauge and Elephant Butte Reservoir: The main tributaries are Rio Jemez, Rio Puerco, and Rio Salado. A total of 316 thousand acre-feet are provided annually by the Middle Rio Grande tributaries and groundwater contributions.
- Reservoir Storage: The Middle Rio Grande system includes multiple reservoirs with the purpose of reserving water for consumptive use. The amount of water in storage should be taken into consideration when evaluating the likelihood and impact of droughts.

## Streamflow

Runoff in the upstream parts of the Rio Grande Basin are generated in large part by snowmelt. Some runoff can also be generated by local precipitation that mostly occurs during summertime. The inflow from the Upper Rio Grande will be evaluated based on streamflow measurements obtained at the Rio Grande at the Otowi Bridge gauge (08313000) adjusted to account for the SJC Project diversion and evaporation and storage effects of reservoirs on the Rio Chama. This gauge has been active since 1895, providing an ideally long period of record for drought analysis. Moreover, this gauge will continue in operation since it is a requirement of the Water Compact, is used to monitor the delivery of water from Colorado to New Mexico, and is needed to estimate the scheduled deliveries from New Mexico to Texas.

The streamflow at Otowi Bridge gauge will most likely be one of the main components for defining the drought indicator. There are multiple advantages of using the Otowi Bridge gauge streamflow for the quantification of water supply in the Rio Grande Watershed:

- The main sources of runoff in the basin are upstream from this gauge.
- Streamflow measured at that gauge is the integrated response to multiple hydrological processes that occur upstream, including snow melt and hydrological losses from evapotranspiration or percolation.
- Reconstructed tree-ring record for this gauge location is available for the period of 1450 to 2012, which will allow a more in-depth evaluation of natural climate variability.
- Forecasted streamflow for this gauge is provided by the United States Department of Agriculture Natural Resource Conservation Service (USDA-NRCS). The forecast takes into consideration observed SWE at selected measurement sites, precipitation, and antecedent streamflow.
- The continuous operation of this gauge is guaranteed by the Rio Grande Water Compact.

Streamflow in other locations across the basin might also be used to evaluate the incremental runoff generated in the intermediate basin, between the Otowi Bridge gauge and Elephant Butte Dam. Monthly streamflow for the time of record was obtained for all gauges shown in Figure 4.

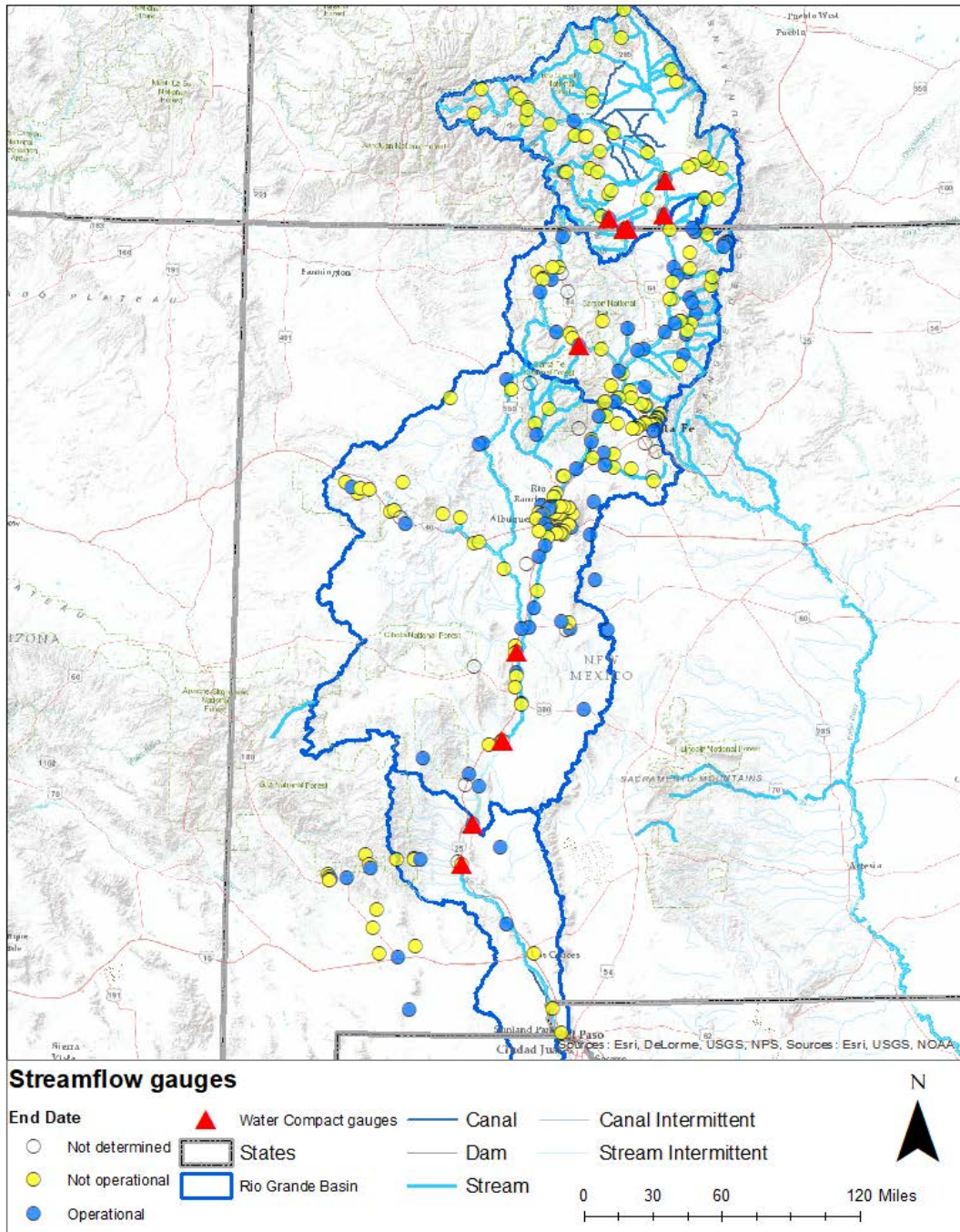


Figure 4: Streamflow gauges map

The Natural Resources Conservation Service (NRCS) provides a probabilistic water supply forecast for multiple locations in the Rio Grande Basin. These forecasts correspond to the prediction of streamflow volume that will naturally flow past a point on a stream during a specified season (spring and summer) without any upstream influences. The forecast takes into consideration current snowpack and precipitation. The forecast is provided at the beginning of each month, and includes a range of numbers

that reflect risk and forecast uncertainty. Forecasted streamflow values are provided for the 10, 30, 50, 70, and 90% chance of exceedance. For example, there is a 90% chance that the actual streamflow volume will be higher than the 90% chance of exceedance forecasted streamflow volume and a 10% chance that the actual volume will be lower. To reduce the risk of having less water than planned, the 90 or 70% chance of exceedance forecasted streamflow volumes are recommended for operational decisions. Forecasted streamflow are provided for the following points of interest to estimate the deliverables to New Mexico:

- Conejos index supply: Forecast values are provided for Conejos River near Mogote, Los Pinos River near Ortiz, and San Antonio River at Ortiz;
- Rio Grande index supply: Rio Grande near Del Norte
- Otowi index supply: Rio Grande at Otowi Bridge

Forecasts for the period of 1995 to 2018 are available online<sup>1</sup>. This forecast will be an essential component to evaluate the risk of droughts.

Ultimately, droughts in New Mexico during a certain year are affected by the volume of water that enter the state line as measured by the Otowi Bridge gauge. However, the volume in this gauge should be isolated from the volume that is provided by the SJC system. To quantify the trans-mountain diversion to Rio Chama the flow diversion measured at the Azotea tunnel can be used. This dataset was obtained from the USBR at <https://www.usbr.gov/rsvrWater/HistoricalApp.html>. The measured inflow at the Otowi Bridge gauge for each month will be corrected by the contributions from the SJC system. The following equation will be used:

$$Otowi_c = Otowi + \Delta S - SJC$$

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<sup>1</sup> [https://www.wcc.nrcs.usda.gov/ftpref/support/water/westwide/forecast\\_table/](https://www.wcc.nrcs.usda.gov/ftpref/support/water/westwide/forecast_table/)

Where:

$O_{towi_c}$  = corrected inflow at Otowi Bridge gauge

$O_{towi}$  = inflow at Otowi Bridge gauge as measured at 08313000

$\Delta S$  = storage change in Heron, El Vado, and Abiquiu reservoirs

$SJC$  = Inflow measured at the Azotea Tunnel

## Precipitation

Precipitation will be used to quantify the effects of summer localized storms. Point data and grid-based data can be used to estimate precipitation. Point data are usually collected by rainfall and snow gauges and directly observe precipitation hitting the ground. Ground rainfall instruments usually present high accuracy and long periods of data are available for a few specific locations for which gauges have been operational for more than 100 years. Grid-based datasets usually combine multiple sources of precipitation data including data obtained by ground instruments and remote sensing techniques such as radar and satellite-based methods. The advantage of grid-based datasets is the spatially explicit characterization of rainfall. Datasets based on gauge-only data are highly affected by gauge density.

Gauge information is provided by several networks in the United States. Quality controlled daily precipitation data is available from the Global Historical Climatology Network (GHCN). GHCN is a comprehensive database of global climatological daily data which contains records from over 80,000 stations in 180 countries and territories. A description of the database is provided by Menne et al. (2012). This database compiles data from multiple sources, including:

- United States Historical Climatology Network (USHCN)
- U.S. Cooperative Summary of the Day (NCDC DSI-3200)
- CDMP Cooperative Summary of the Day (NCDC DSI-3206)
- U.S. Cooperative Summary of the Day -- Transmitted via WxCoder3 (NCDC DSI-3207)
- U.S. Automated Surface Observing System (ASOS) real-time data (since January 1, 2006)
- U.S. ASOS data for October 2000 – December 2005 (NCDC DSI-3211)

When possible, the use of grid-based, multi-sensor rainfall maps is recommended. Table 11 lists available grid-based multi-sensor precipitation datasets and their main characteristics. Grid-based datasets are evaluated based on the following criteria: spatial and temporal resolution, temporal coverage, and accuracy. Only datasets that cover, at a minimum, the whole area of interest were included.

For the evaluation of droughts, daily datasets are not required, since monthly precipitation datasets are sufficient. The main criteria to select the dataset for drought evaluation is the period for which the data is available. The University of Delaware (55 x 55 km) and PRISM monthly (800 m x 800 m and 4 x 4 km) datasets present the longest period of record. The University of Delaware precipitation (55 x 55 km) product is generated based on station data from several updated sources (Willmott and Matsuura, 2001). Monthly PRISM is a dataset generated with a focus on long-term consistency, and uses only

station networks having at least some stations with more than 20 years of data. PRISM (PRISM, 2016) is generated based on climatologically-aided interpolation (CAI) which uses long-term average datasets as predictors for the interpolation procedure. The 4 x 4 km PRISM product is freely available on the internet (<http://www.prism.oregonstate.edu/>) and the 800 m x 800 m is available for purchase. **For this project, the PRISM 4000-meter monthly dataset is recommended.** A map of normal precipitation based on the PRISM dataset is shown in Figure 6.

**Table 11: List of grid-based multi-sensor precipitation datasets**

Datasets	Areal Coverage	Grid Size*	Time Frequency	Start date
CPC Hourly Precipitation	U.S.	2.0 ° x 2.5°	Hourly	1948
NCAR Stage IV	U.S.	4 km	Hourly	2002
NLDAS - forcing	CONUS	1/8°	Hourly	1979
North American Regional Reanalysis (NARR)	Northern Hemisphere	32 km	3 hours	1979
NCEP/NCAR Reanalysis	Global	2.5°	6 hours	1948
PRISM gridded climate data (daily)	CONUS	800 m and 4 km	Daily	1981
PRISM gridded climate data (monthly)	CONUS	800 m and 4 km	Monthly	1895
CPC .25x.25 Daily US Unified Precipitation	U.S.	0.25°	Daily	1948
Livneh daily CONUS	CONUS	0.06°	Daily	1915
NWS Precp	CONUS	4 km	Daily	2005
U. of Delaware Precipitation	Global	0.5°	Monthly	1901
Daymet	North America	1 km	Daily	1980
GHCN-Daily Temperature and Precipitation Dataset, Version 1	U.S.	5 km	Monthly	1895
NOAA's PRECipitation REConstruction over Land (PREC/L)	Global	2.5°	Monthly	1948

## Reservoir levels

The risk of drought is affected by the amount of water that is being stored in water supply reservoirs in the project area. Therefore, reservoir storage should be taken into consideration in the quantification and prediction of droughts. Time series of reservoir levels for the reservoirs shown in Figure 5 and listed in Table 11 were provided by the USDA-NRCS. Table 5 lists all the reservoirs in the Rio Grande Basin.

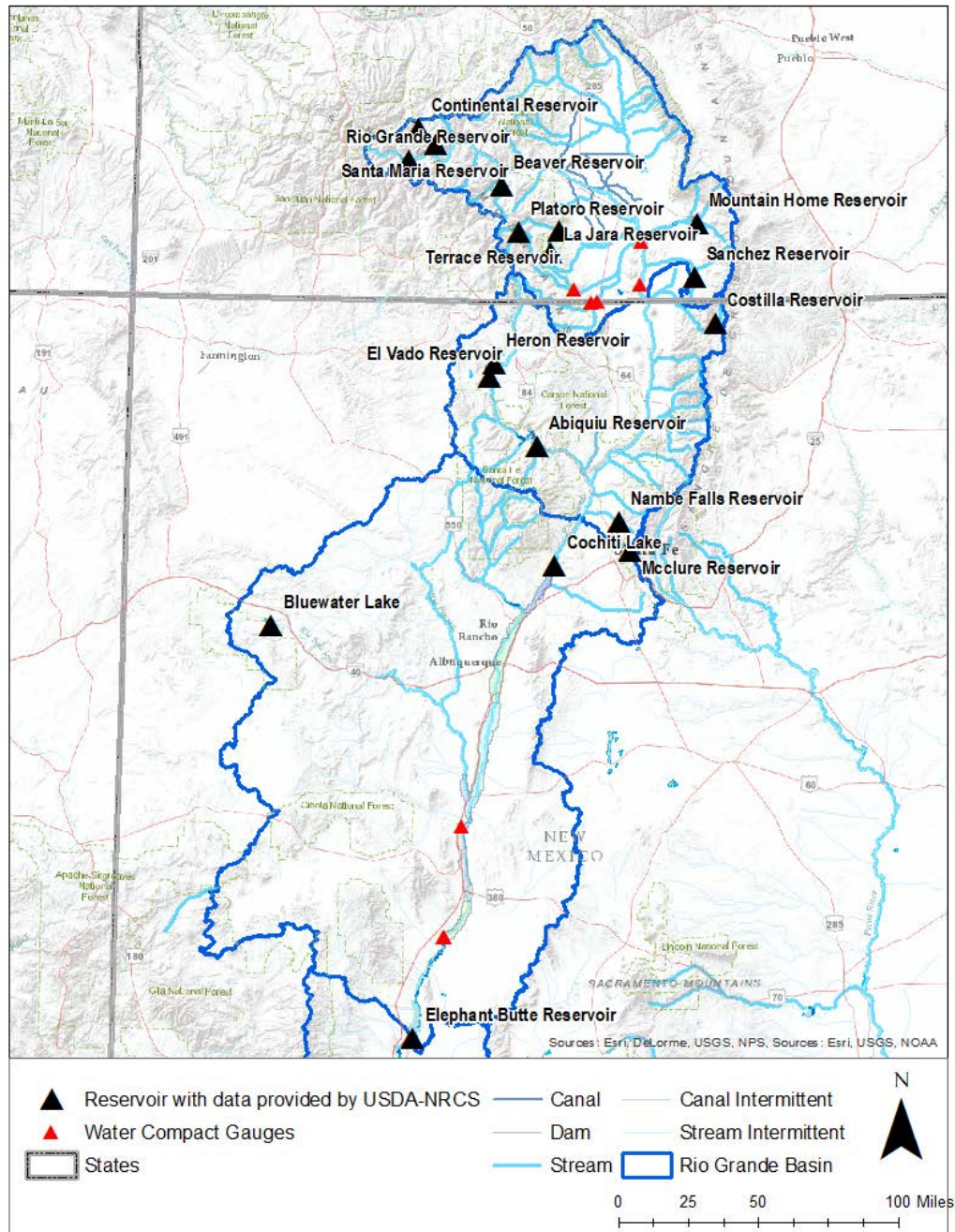


Figure 5: Location of the dams for which data was provided by USDA-NRCS

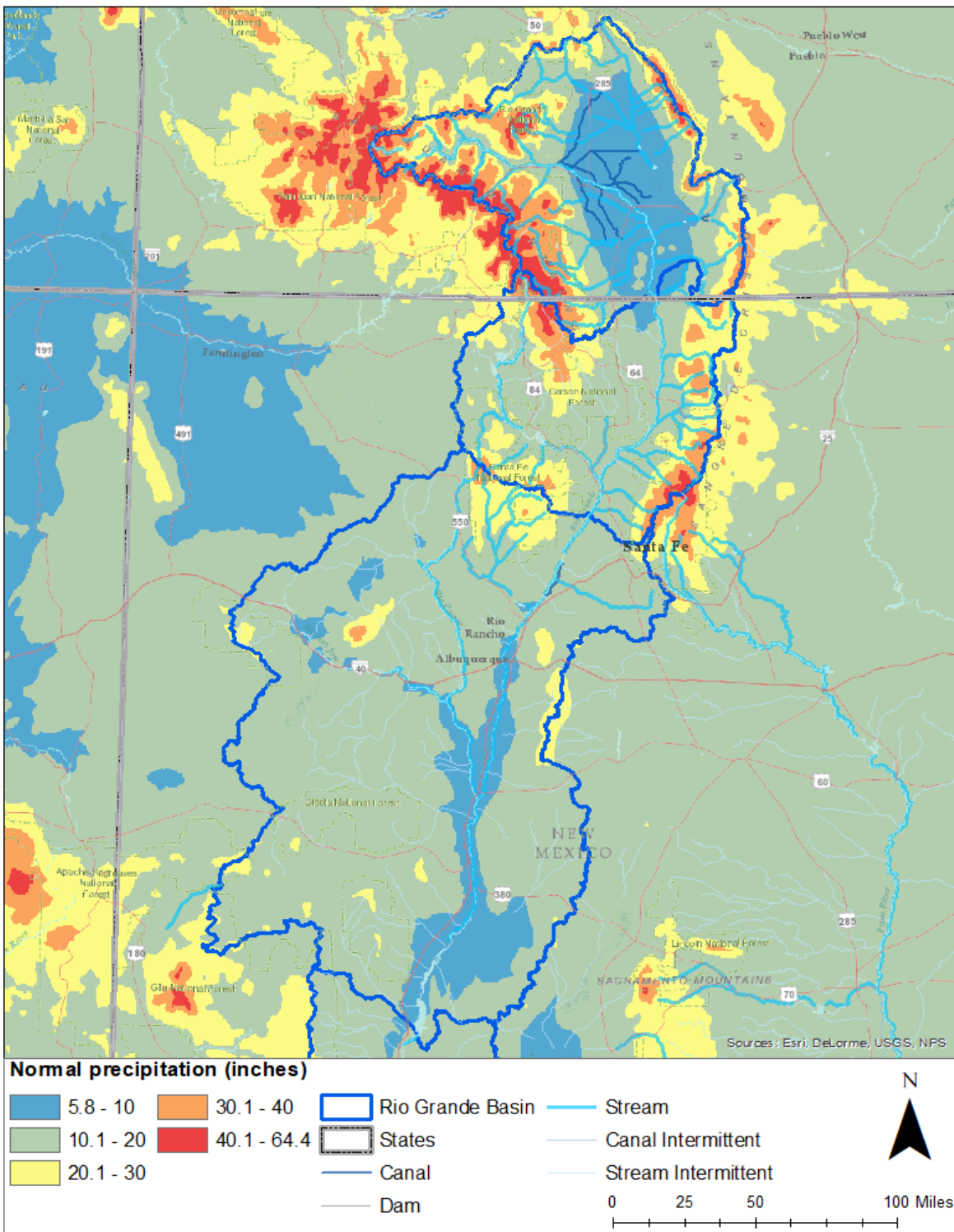


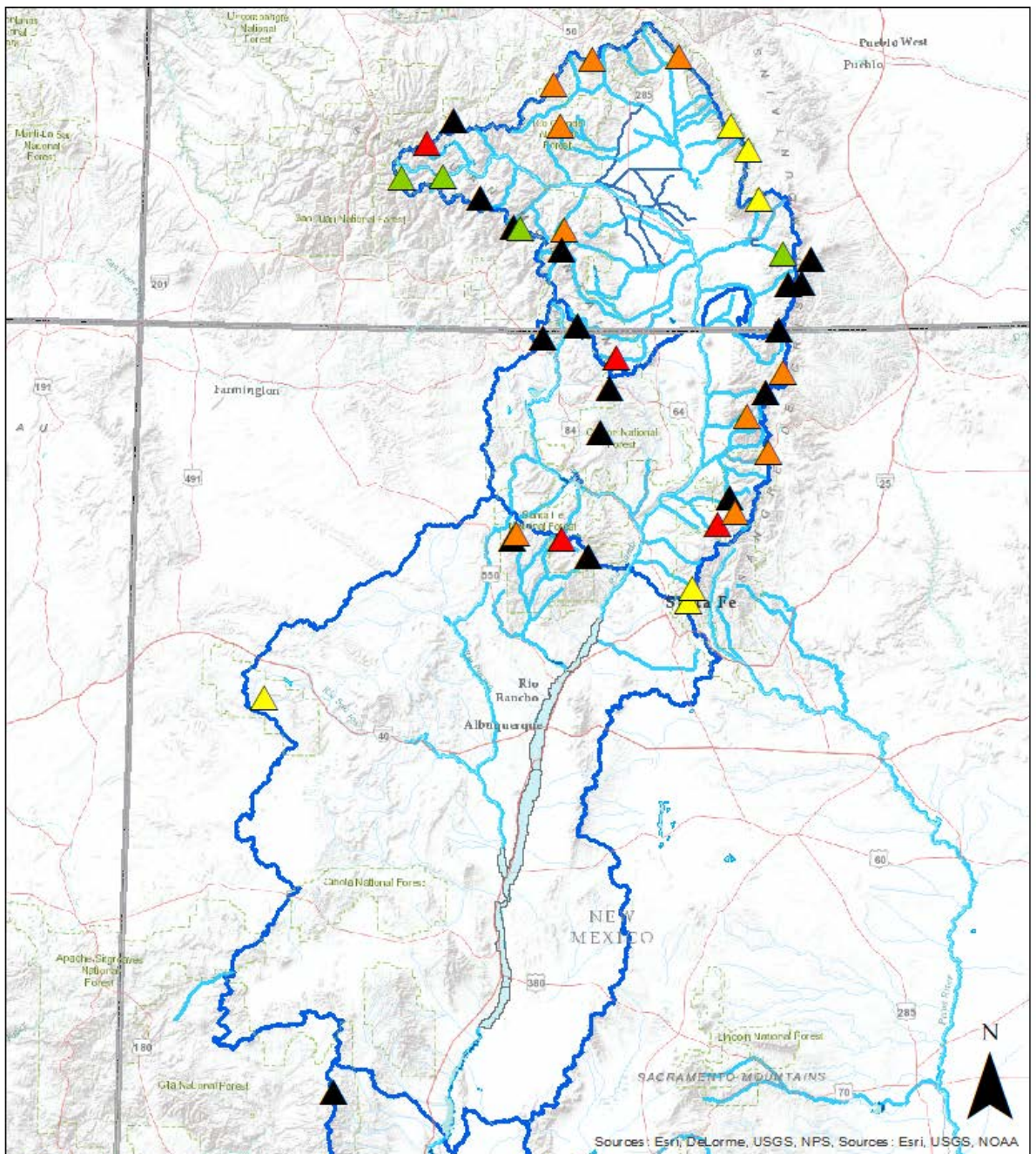
Figure 6: Normal annual precipitation (inches) based on PRISM dataset

Table 12: Reservoirs in the Rio Grande Basin

Name	State	ID	County	Elevation (ft)	HUC
Abiquiu Reservoir	NM	08108010	Rio Arriba	6180	130201021006
Beaver Reservoir	CO	08219000	Rio Grande	8794	130100011104
Bluewater Lake	NM	08341400	Cibola	7346	130202070206
Caballo Reservoir	NM	08108020	Sierra	4180	130301010411
Cochiti Lake	NM	08108040	Sandoval	5350	130202010209
Continental Reservoir	CO	08008170	Hinsdale	10260	130100010201
Costilla Reservoir	NM	08108050	Taos	9380	130201010103
El Vado Reservoir	NM	08108060	Rio Arriba	6900	130201020406
Elephant Butte Reservoir	NM	08108070	Sierra	4350	130202110806
Heron Reservoir	NM	08108080	Rio Arriba	7150	130201020305
La Jara Reservoir	CO	2103582	Conejos	9700	130100020402
Mcclure Reservoir	NM	08315500	Santa Fe	7790	130202010102
Mountain Home Reservoir	CO	MTNRESCO	Costilla	8198	130100020603
Nambe Falls Reservoir	NM	08294200	Santa Fe	6798	130201011201
Platoro Reservoir	CO	08008120	Conejos	9980	130100050103
Rio Grande Reservoir	CO	08008130	Hinsdale	9450	130100010106
Sanchez Reservoir	CO	08008140	Costilla	8260	130100020802
Santa Maria Reservoir	CO	08008150	Mineral	9500	130100010205
Terrace Reservoir	CO	08008160	Conejos	8550	130100020305

### Snow water equivalent (SWE)

Automated SNOTEL sites monitor precipitation, temperature, barometric pressure, relative humidity, soil moisture and temperature, wind speed and direction, snow depth, and SWE. Data is transmitted on an hourly basis to a central location where it is made available to end-users via the internet. Multiple sites in New Mexico and southern Colorado are used to forecast streamflow by the USDA-NRCS. Streamflow data will be prioritized in the definition of drought indicators due to the advantages mentioned in the streamflow session. SNOTEL data will likely not be used in the definition of the drought indicator. However, if necessary, this dataset can be used to evaluate current trends in snow cover and volume and snow melt. Figure 7 highlights the SNOTEL sites that present a starting date before 1981. These sites would be used if trend analysis of snow data is necessary.



**SNOTEL site start date**

- |               |               |                    |          |                       |
|---------------|---------------|--------------------|----------|-----------------------|
| ▲ 1978 - 1981 | ▲ 2001 - 2010 | ▭ States           | — Canal  | — Canal Intermittent  |
| ▲ 1982 - 1990 | ▲ 2011 - 2016 | ▭ Rio Grande Basin | — Dam    | — Stream Intermittent |
| ▲ 1991 - 2000 |               |                    | — Stream |                       |

0 25 50 100 Miles

Figure 7: SNOTEL sites color-coded by starting date

### 3 Water demand

Ideally water demand is used as a parameter to define drought severity. However, as it will be shown in this section, no dataset provides accurate and a long enough time series of water demand data as required to define drought indicators. The longest record is provided by the ET Toolbox, and only covers the period of 2000-2018. This is a common problem, and as an alternative to water demand, data temperature or potential evapotranspiration are used to quantify demand due to its cause and effect relationship with water consumption. Even though no water demand dataset reached the necessary requirements to be included in the analysis, in this section we present a summary of the available datasets for future references and comparisons.

#### Evaluation of water demand by the New Mexico Office of the State Engineer

A complete evaluation of drought conditions should take into consideration possible changes in water demand. The Rio Grande water demand includes water for consumptive use, the delivery obligations under the Water Compact, Native American pueblos and reservations with “Prior and Paramount” rights, and requirements to protect endangered species.

Evaluation of water use for 1990, 1995, 2000, 2005, and 2010 are provided by the New Mexico Office of the State Engineer. Based on the 2010 report, water use in the whole state of new Mexico constitutes: 3,000,155 AF (78.62%) for irrigated agriculture, 317,410 AF (8.32%) for public water supply, 262,216 AF (6.87%) for evaporation, 58,339 AF (1.53%) for power generation, 54,693 AF (1.43%) for commercial use, 41,559 AF (1.09%) for mining, 40,180 AF (1.05%) for livestock, 28,952 AF (0.76%) for self-supplied domestic, and 12,440 AF (0.33%) for industrial use.

Estimates are also provided by county or by watershed. Estimates for the Rio Grande Watershed include the whole area of the Rio Grande Watershed in New Mexico. Therefore, these estimates cover an area larger than the area of interest of this project. Water withdrawal from the surface and groundwater for each category for the Rio Grande watershed for 1990 and 2010 are shown in Table 13. A total of 1,163,929 acre-feet in surface water and 602,592 acre-feet of groundwater was withdraw from the basin. The values shown in Table 13 correspond to withdrawals only. Depletions have not been quantified in this report. Some portion of diverted water returns to the surface or to the groundwater. This is common with agricultural runoff or seepage and discharge from wastewater treatment plants.

Table 13: Water withdrawal in the Rio Grande Basin in New Mexico in 1990 and 2010

Category	1990			2010		
	WSW	WGW	TW	WSW	WGW	TW
Commercial (self-supplied)	511	11,309	11,820	351	41,376	41,727
Domestic (self-supplied)	0	18,617	18,617	0	18,727	18,727
Industrial (self-supplied)	25	1,269	1,294	1	7,547	7,548
Irrigated Agriculture	978,334	345,259	1,323,593	954,247	345,731	1,299,979
Livestock (self-supplied)	1,269	7,535	8,804	1,055	8,740	9,795
Mining (self-supplied)	908	39,725	40,633	8,012	14,669	22,681
Power (self-supplied)	28	5,917	5,945			
Public Water Supply	12,376	201,462	213,838	55,185	165,679	220,864
Reservoir Evaporation	206,083	0	206,083	145,078	0	145,078
<b>River Basin Totals</b>	<b>1,199,534</b>	<b>631,093</b>	<b>1,830,627</b>	<b>1,163,929</b>	<b>602,469</b>	<b>1,766,399</b>

WSW=withdrawal, surface water; WGW=withdrawal, groundwater; TW=total withdrawal

### Regional Water Plan (2000-2050)

Current water demand and no-action future water demand are also provided in the Regional Water Plan (2000-2050) for each New Mexico region. The current water demands provided in the report follow the same values as provided by the 2010 New Mexico Office of the State Engineer report.

The following regions are of interest for this study:

- Rio Chama: The Rio Chama encompasses portions of Rio Arriba County. The region is bounded on the north by Colorado, on the west by the continental divide, on the south by the northern boundary of Santa Clara Pueblo and the City of Espanola, and on the east by Santa Fe and Taos counties.
- Middle Rio Grande: The water planning region encompasses Valencia County, Bernalillo County, and most of Sandoval County. The principal river basin is the Rio Grande. The region is bounded on the north by Los Alamos and Rio Arriba counties, on the west by McKinley and Cibola counties, on the south by Socorro County and on the east by Torrance and Santa Fe counties.
- Socorro-Sierra: The water planning region encompasses Socorro and Sierra counties. The principal river basin in the Rio Grande. The region is bounded on the north by Torrance, Valencia, and Cibola counties, on the west by Catron and Grant counties, on the south Luna and Doña Ana counties, and on the east by Torrance and Otero counties.
- Lower Rio Grande: The water planning region encompasses Doña Ana County and that portion of Sierra County comprised of the boundaries of the Elephant Butte Irrigation District. The principal river basin is the Rio Grande River. The region is bounded on the north by Sierra County, on the west by Luna County, on the south by Mexico and Texas, and on the east by Otero County.

Unfortunately, the definition of these regions do not follow the delineation of the watershed, and therefore the direct application of the data provided in The Water Plan is limited. The description presented in this section focuses on the middle Rio Grande region.

### **Map of irrigated agriculture in the United States**

A geospatial modeling approach was applied to generate consistent irrigated agriculture maps across the conterminous United States for 2002, 2007 and 2012 (Brown and Pervez 2014; Pervez and Brown 2010; Brown et al. 2009). Model inputs included the National Land Cover Dataset resampled to 250m, USDA Census of Agriculture irrigated area statistics, and annual maximum vegetation index (VI) calculated from NASA Moderate Resolution Imaging Spectroradiometer (MODIS) imagery.

### **Irrigation demand and reservoir evaporation projections**

The USBR (2015) has conducted an analysis of the potential changes in crop irrigation demand and projections of evaporation for 12 reservoirs considering observed and projected impacts of climate change. This study included projections for the Rio Grande Basin and for the Elephant Butte Reservoir. The analysis was based on the WCRP Coupled Model Intercomparison Project3 (WCRP CMIP3) climate projections that were bias-corrected and spatially downscaled (BCSD). CMIP3 climate projections were used since they represented the best available collection of climate projections when the project started. CMIP3 has since been replaced by CMIP5.

Monthly temperature and precipitation climate projections for 112 GCMs are available. Since it was not practical to run the evapotranspiration demand model for all these scenarios, the 112 climate projections were used to inform a set of five climate-change scenarios using precipitation and temperature changes defined for five conditions: (1) warm-dry (WD); (2) warm-wet (WW); (3) hot-dry (HD); (4) hot-wet (HW); and (5) central tendency. For each of the five climate change scenarios, assessments of changes to irrigation demands were determined at three future periods labeled 2020s (for years covering the period 2010–2039), 2050s (2040–2069), and 2080s (2070–2099) from the baseline period, 1950–1999.

The evapotranspiration demands model is based on a common reference evapotranspiration crop coefficient approach, where the reference evapotranspiration is multiplied by time-varying crop coefficients to estimate the actual evapotranspiration of a vegetated area. The evapotranspiration and irrigation demands model was developed at the spatial resolution of a hydrologic unit code eight (HUC8). Irrigation demands in this study do not account for changing crop patterns, changes in irrigation practices, and other socio-economic considerations that cannot be determined without stakeholder participation.

Open water evaporation was estimated using an energy balance model referred to as the Complementary Relationship of Lake Evaporation (CRLE), which has been widely applied for estimating operational reservoir and lake evaporation with limited climatic and heat storage information.

## **USBR ET (Evapotranspiration) Toolbox**

For operational and management purposes, the ET Toolbox provides high-resolution daily rainfall and water depletions (crop and riparian vegetation evapotranspiration, and open water evaporation) within specified river reaches in the region between Cochiti and Elephant Butte Reservoir. The river reach locations are described in

Table 14 and shown in Figure 8. Estimates for the years of 2000 to 2018 were downloaded from <https://www.usbr.gov/uc/albug/water/ETtoolbox/rg/newreaches/>.

The data and methods used in the calculations of consumptive uses are documented in Brower (2015). Consumptive use is calculated for each day based on daily potential evapotranspiration rates for each vegetation class, and vegetation and open water coefficient. The data and the method to calculate daily reference evapotranspiration has been modified and therefore this data should not be used to evaluate trends in evapotranspiration. The modified Penman method was used to calculate evapotranspiration until 2011. Beginning January of 2012, the 1985 Hargreaves method for calculating reference evapotranspiration was used. Operational weather stations were used as input to the toolbox until January of 2016. Since no operational weather stations were available after that year, forecast weather data at a 5-km resolution was used.

Crop and vegetation acreages are multiplied by their respective evapotranspiration rates to calculate total daily consumptive use for each cell, and cells are summed to provide reach totals. In the calculation employed by the USBR for the ET Toolbox, time-invariant crop coefficients and vegetation acreages are employed, but climatic parameters are varied according to the climatic record.

Before 2004, crop and vegetation acreages were based in part on the 1992 condition, calculated by the USBR utilizing aerial photography and 1992 Landsat TM satellite imagery, in coordination with a program of field verification. The acreages derived from this work were compiled by the USBR into a GIS database and are commonly referred to as the 1992 LUTA (land use trend analysis). After 2004 a combination of the July 2000 IKONOS satellite imagery at a 4-meter spectral resolution land use data set and the year 2001 Utah State University (USU) aerial photography at a .5-meter resolution was used. Usually the following crops are included in the calculations: alfalfa, pasture, oats-barley, corn, trees-fruit, trees-nursery, vegetables, row crops, garden, and yard.

Evapotranspiration estimates for the period of 1975 to 2010 were also obtained by personal communication (2018) with Lester Brower, the main developer of the ET Toolbox. However, as informed by Brower, water consumptive use for this period is not available.

Through personal communication Lester Brower informed that “ET Toolbox began in the Middle Rio Grande in 1998, and the consumptive use component started in 2000”. Moreover, according to Lester Brower, “the 2000-2018 consumptive use data you have downloaded are rough estimates, especially in the early years, and should be used with caution”.

Table 14 Definition of river reaches in the ET Toolbox

Reach	2000	2011 to present
1	Cochiti to San Felipe gauge	Same
2	San Felipe to Alameda gauge	Same
3	Alameda to Central Ave. gauge	Same
4	Central Ave. to Isleta gauge	Same
5	Isleta to Bernardo gauge	Isleta to State Hwy. 346 near Bosque, NM gauge
6	Bernardo to San Acacia gauge	State Hwy. 346 near Bosque, NM to San Acacia gauge
7	San Acacia to San Marcial gauge	Same
8	San Marcial to Elephant Butte	Same

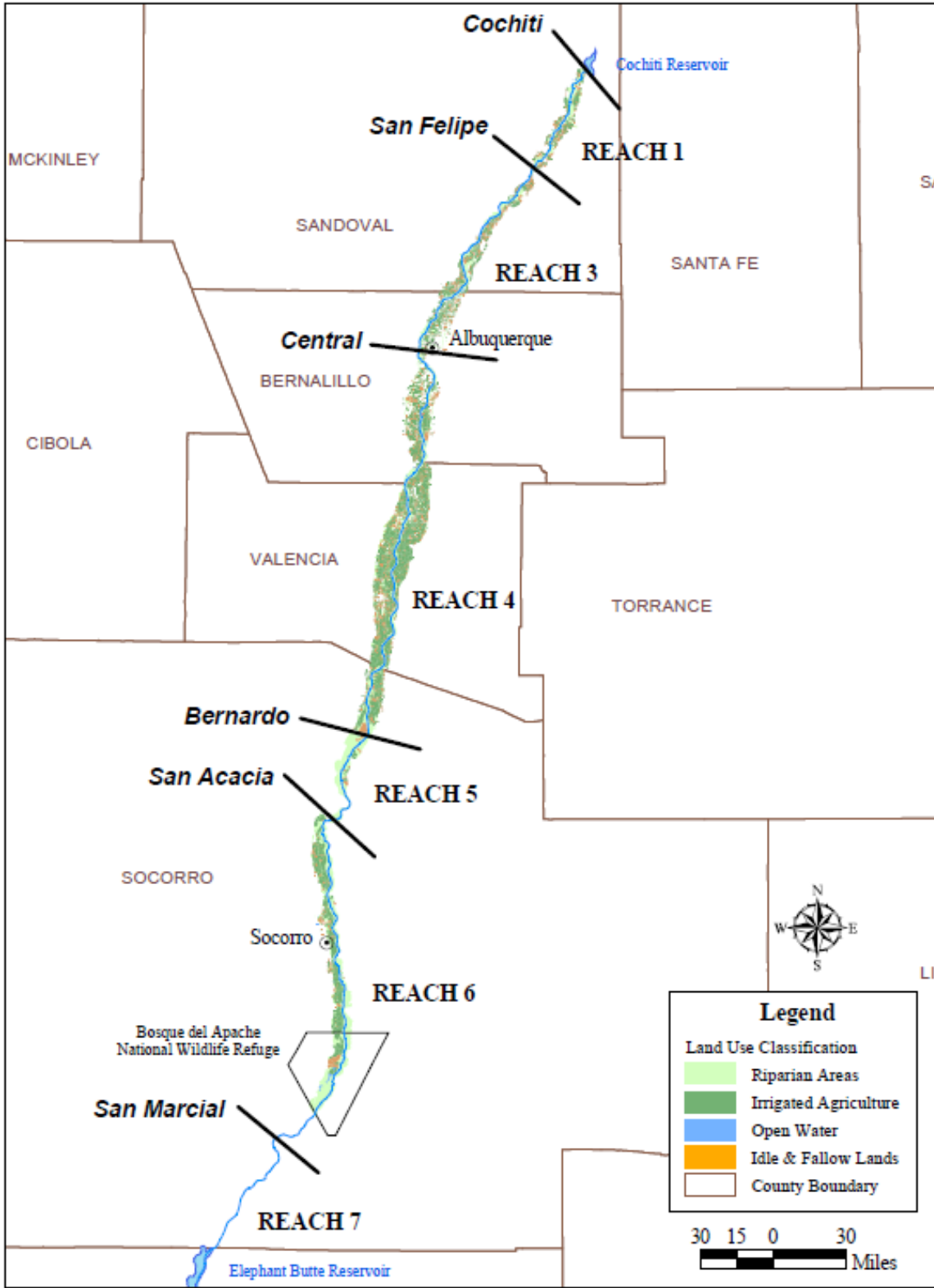


Figure 8: ET Toolbox River reaches definition (Source USACE Albuquerque District and NMISC, 2004)

## Temperature

A recent study evaluated the effects of climate change in the Upper Rio Grande using multiple GCMs. The study concluded that precipitation changes, coupled with temperature-driven increases to evapotranspiration demands within the system, are expected to cause significant changes in the available water supply and demand. Therefore, it is important to account for these changes in the quantification of drought.

Temperature observations are provided by several networks in the United States, including the Global Historical Climatology Network (Menne et al., 2012). However, gauge datasets, especially for the western part of the United States, are limited to a very short period of record (usually less than 50 years). Substantial effort has been put on collecting, quality controlling, and interpolating gauge data to generate grid-based temperature datasets. Here we focus on describing these datasets. Table 15 lists relevant grid-based temperature datasets available for the study area. Table 15 compares the different datasets based on spatial resolution (y-axis) in kilometers, and temporal coverage (x-axis). Some of the temperature records date back to the mid-19<sup>th</sup> century. The dataset that presents the longer time series of monthly data is the BEST: Berkeley Earth Surface Temperature (Rohde, 2013). However, these datasets usually present coarse spatial and/or temporal resolution. The PRISM and the TopoWx datasets (Oyler, et. al., 2016) present the best spatial resolution (800 meters). Since the PRISM dataset is recommended for precipitation analysis, for consistency **the monthly series of PRISM dataset is also recommended for this project**. A map of normal mean temperature based on the PRISM dataset is shown in Figure 9.

Table 15: List of grid-based, multi-sensor temperature datasets

Datasets	Areal Coverage	Grid Size*	Time Frequency	Start date
Modis 11/ Temperature and Emissivity	Global	1km	5 min	2002
PRISM gridded climate data (daily)	CONUS	800 m and 4 km	Daily	1985
PRISM gridded climate data (monthly)	CONUS	800 m and 4 km	Monthly	1895
Livneh daily CONUS	CONUS	0.06°	Daily	1915
North American Regional Reanalysis (NARR)	Northern Hemisphere	32 km	3 hours	1979
NOAA MLOST	Global	1.0°	Daily	1940
GFS Model Output	Global	2.5°	12 hours	1979
NOAA-CIRES 20th Century Reanalysis	Global	2.5°	6 hours	1851
NCEP/NCAR Reanalysis	Global	2.5°	6 hours	1948
U. of Delaware Air Temperature	Global	0.5°	Monthly	1901
Daymet	North America	1 km	Daily	1980
NLDAS - forcing	CONUS	1/8°	Hourly	1979
GHCN-Daily Temperature and Precipitation Dataset, Version 1	U.S.	5 km	Monthly	1895
GPCC Global Precipitation Climatology Centre	Global	0.5°	Monthly	1895
BEST: Berkeley Earth Surface Temperature	Global	0.25° (USA)	Daily	1750
TopoWx (“Topography Weather”)	U.S.	800 m	Daily	1880

\* Units are meters (m), kilometers (km), and degrees (°). If only one value is shown, the vertical and horizontal resolutions are the same.

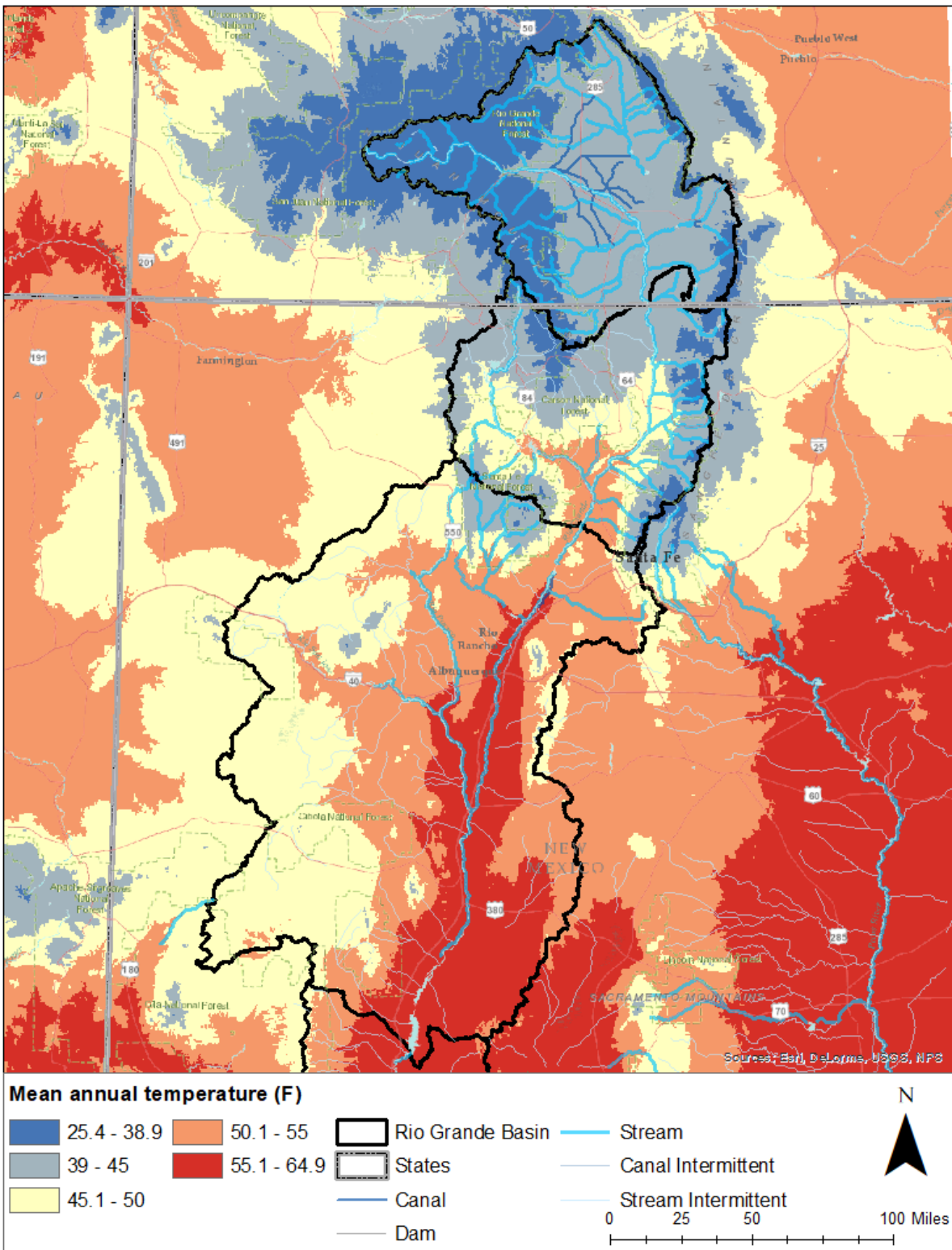


Figure 9: Normal annual temperature (F) based on PRISM dataset

## 4 Past drought impacts and operations

The following datasets will be applied to identify past droughts:

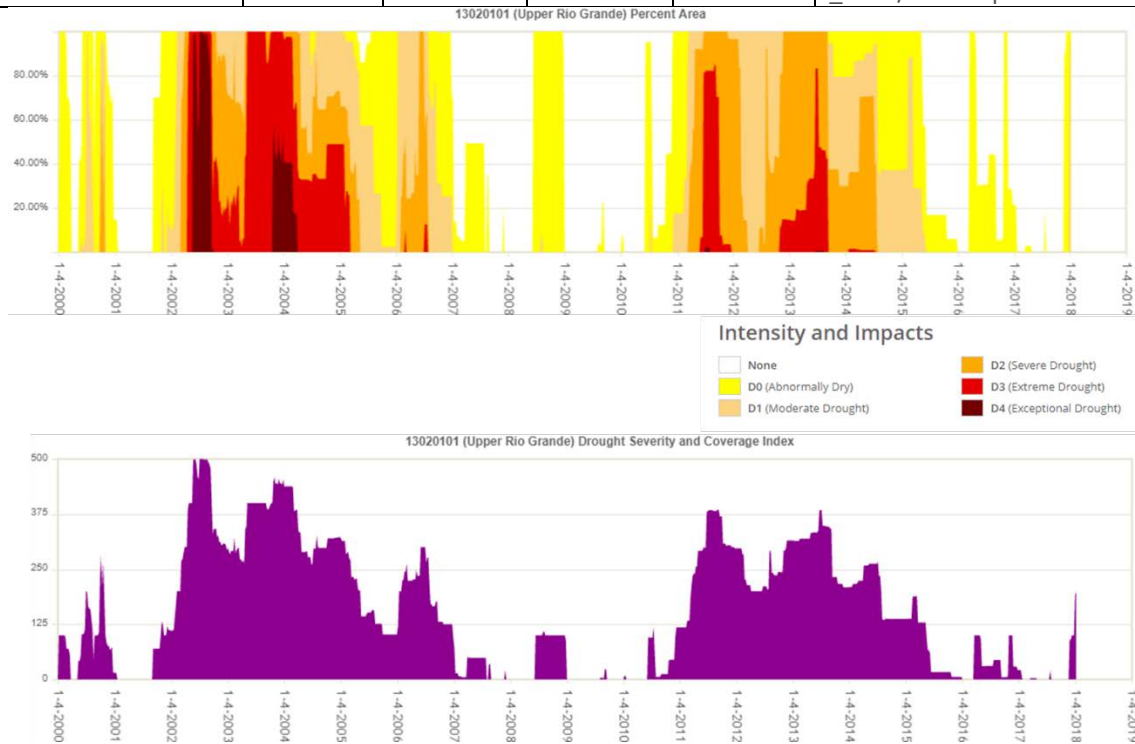
- **District board minutes:** MRGCD provided historic board minutes for the following years: 1951, 1954, 1958, 1959, 1963, 1964, 1965, 1966, 1968, 1971, 1972, and 1977. These years correspond to dry periods and the minutes contain information about how operational decisions were taken during periods of drought.
- **Historical climate data:** The historical climate data as described in the water supply and water demand section of this report will be applied to conditions that surrounded periods of reduced supplies to identify what factors have historically been indicators of drought.
- **Meteorological and agricultural drought indicators:** Meteorological drought results from a shortage of precipitation; agricultural drought is identified by a shortage of available water for plant growth (World Meteorological Organization (WMO), 1975); and hydrological drought is caused by a deficiency in the volume of water supply (streamflow, reservoir storage, and/or groundwater depths). Table 16 lists available meteorological and agricultural grid-based drought severity index datasets with their main characteristics. The first four listed datasets represent drought indices based on climatological data, while the last two represent drought indices based on measurements of vegetation characteristics. Examples of the information provided by these datasets are presented in Figure 10 and Figure 11. These indicators are useful for identifying agricultural and meteorological drought, but they cannot be applied for reservoir management, since they do not take into consideration reservoir storage. Moreover, these indicators are usually based on current available information and are not used to predict droughts.
- **Hydrological drought indicators as defined in this project:** See discussion in following section.
- **Rio Grande Compact Cumulative Departures:** New Mexico cumulative departure from the Rio Grande Compact can provide indications of the years for which demand exceeded supply in the Middle Rio Grande Watershed. Figure 12 shows the New Mexico cumulative departures from the Rio Grande Compact from 1940 to 2016. Rio Grande Annual reports of the Rio Grande Compact Commission were provided to WEST for the period of 1942 to 2016.
- **Local reports and news articles:** Some of the reports to be considered:
  - Drought Watch on the Rio Grande produced by the TEXAS A&M AGRILIFE RESEARCH (example: <http://agrilife.org/el Paso/files/2014/04/Drought-Watch-Press-Release-and-Graphics-2014-04-21.pdf>)
  - Drought Along the Rio Grande Highlights Water Management Complexities, by Lucero Radonic, WRRRC Graduate Outreach Assistant (<https://wrrc.arizona.edu/drought-rio-grande>)
  - Despite Rain, South Texas Crop Losses Could Hit \$100 Million, Santa Ana, 2013. (<https://today.agrilife.org/2013/05/01/south-texas-crop-losses-could-hit-100-million/>)

Unfortunately, not a lot of information is available in terms of the economic impacts of droughts in the Middle Rio Grande. Drought events can have large impacts on the economies of rural communities, not

only directly impacting producers, but also having an indirect effect on enterprises and institutions throughout the supply chain (Bauman et al. 2013).

**Table 16: List of grid-based drought severity index datasets**

Drought severity	Areal Coverage	Grid Size	Time Step	Time Coverage	Source
PDSI from NCAR	Global	2.5° x 2.5°	Monthly	1850-2014	<a href="http://www.cgd.ucar.edu/cas/catalog/climind/pdsi.html">http://www.cgd.ucar.edu/cas/catalog/climind/pdsi.html</a>
SPI from NCAR	Global	1.0° x 1.0°	3, 6, 12 Months	1949-2012	<a href="http://rda.ucar.edu/datasets/ds298.0/">http://rda.ucar.edu/datasets/ds298.0/</a>
SPEI	Global	0.5° x 0.5°	Monthly, Seasonal, Annual	1901 - 2014	<a href="https://digital.csic.es/handle/10261/104742">https://digital.csic.es/handle/10261/104742</a>
WestWide Indices (PDI, PZI, PDSI, sc-PDSI, SPI, SPEI)	U.S.	0.04° x 0.04°	Monthly	1895 - current	<a href="http://www.wrcc.dri.edu/wwdt/">http://www.wrcc.dri.edu/wwdt/</a>
The National Integrated Drought Information System	U.S.	Multiple	Multiple	Real time maps	<a href="http://gis.ncdc.noaa.gov/map/drought/US.html#app=cdo">http://gis.ncdc.noaa.gov/map/drought/US.html#app=cdo</a>
Wildland Fire Assessment Vegetation Index	U.S.	1.1 km	Weekly	January 1989 to present	<a href="http://wfas.net/data/ndvi/nd">http://wfas.net/data/ndvi/nd</a> (NDVI, Greenness map, Relative Greenness map)
MODIS Vegetation Indices 16-Day L3 Global 250m	Global	250 m x 250 m	16-day	2000 to present	<a href="https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mod13q1">https://lpdaac.usgs.gov/dataset_discovery/modis/modis_products_table/mod13q1</a>



**Figure 10: United States Drought Monitor for the Upper Rio Grande Basin**

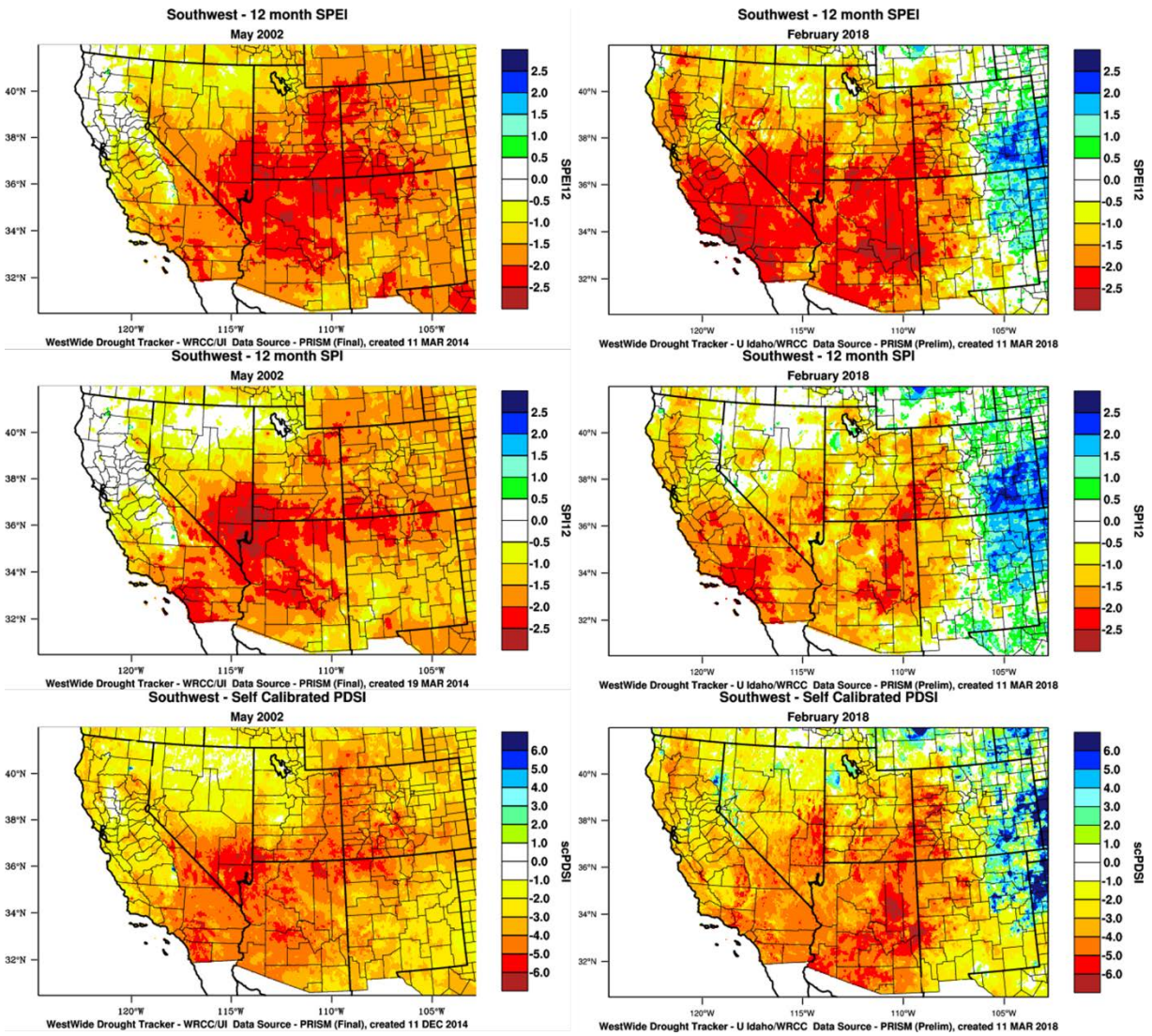
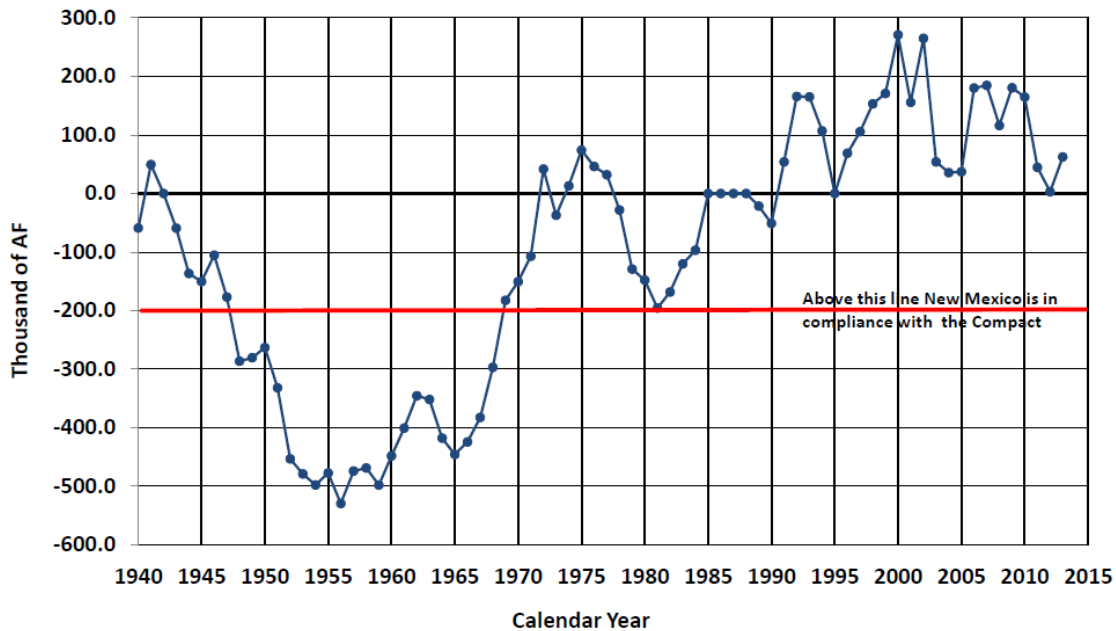


Figure 11: Drought severity indices maps for May 2002 and February 2018. The index is shown at the top of each map. Source: WestWide Drought Tracker - UIdaho (<http://www.wrcc.dri.edu/wwdt/>)

### Rio Grande Compact Cumulative Departures 1940 to 2013



Note: The Compact Commission has not approved annual accounting since 2011. Values in the chart since that time are those calculated and proposed by the New Mexico Engineer Adviser as described in annual reports to the Compact Commission

Figure 12: Rio Grande Compact Cumulative Departures

Source: <http://www.ose.state.nm.us/Compacts/RioGrande/compactAccounting.php>

### Hydrological drought indicators

The severity of past droughts will be evaluated based on hydrological drought indicators. Online resources to identify drought only evaluate meteorological and agricultural drought conditions. These indicators are usually not appropriate for reservoir management, since they do not take into consideration reservoir storage. Moreover, these indicators are usually based on current available information and are not used to predict droughts. Drought Contingency Plans require drought indicators that are capable of identifying hydrological drought at the basin scale. As part of this project, hydrological drought indicators for the MRGCD area will be identified and developed. The following components will be accounted for in the development of the Middle Rio Grande drought indicator:

- All dominant hydrological processes should be explicitly or implicitly taken into consideration.
- Indicators need to take into consideration likely effects of natural and man-induced climate variability.
- Indicators should reflect the balance between water supply and demand.
- Indicators need to capture the inherent memory of the hydrological system (snow accumulation and subsequent runoff) which can be used in a predictive form.

- Datasets used to calculate indicators should have a long and continuous period of historical record, and need to be guaranteed to be readily, consistently, and easily available in the future.
- Indicators should be fast to calculate in an operational environment.
- The process should be easy to implement and maintain.

Drought detection and estimation can be based on a single indicator, multiple indicators, or hybrid indicators.

Table 17 presents the list of hydrological drought indicators that are most appropriate for the MRGCD. The Aggregate Dryness Index (ADI) is a comprehensive drought indicator that can be used to identify all types of droughts. It was developed and tested for three regions in California, including the San Joaquin Valley (Keyantash and Dracup, 2004). ADI takes into consideration all water resources by assessing standardized anomalies of hydrologic data, including precipitation, evaporation, discharge, reservoir storage, and soil moisture content. Snow data can also be included if available. The method is flexible and just the variables that affect the hydrology of the area of interest need to be included. The disadvantages of the indicator are that it does not take into account temperature and water demands. Moreover, the indicator has only been tested in a limited number of cases. Even though this indicator has many important elements to describe drought, more tests are required before applying it operationally.

The Surface Water Supply Index (SWSI) is an extension of the PDSI which was discussed in the previous section (Columbia River Water Management Group, 2000). The SWSI characterizes multiple water supply components, including snow accumulation, snowmelt and runoff, and reservoir data. The index captures the memory of the hydrological system and can forecast drought. Different formulations of the SWSI can be applied to represent water supply for different periods of the year. For example, Colorado SWSI uses snowpack during the period of December through May and streamflow for the months of June to November. The Columbia River Forecasting Service<sup>2</sup> (CRFS) uses SWSI instead of PDSI as a main indicator since the latter fails to account for many items such as mountain snowpack, snowmelt, water demand, recreation, navigation, and hydropower.

The Reclamation Drought Index is an extension of the SWSI that accounts for temperature which allows the implicit consideration of climate change effects. The index was created by the USBR to be used as a trigger for drought emergency. It can be used to define drought severity and duration. It can also be used to predict the onset and end of drought periods. The RDI is a function of supply (including precipitation, streamflow, reservoir storage, and groundwater), demand (which is computed as a function of temperature due to its cause and effect relationship with water consumption), and duration (allowing individual months, such as those that overlap the growing season, to be “weighted” according to their importance to supply/demand factors).

The SWSI and the RDI will be considered in the definition of drought indicators for the MRGCD based on hydrological and meteorological characteristics and data availability for the area of interest. The RDI

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<sup>2</sup> The CRFS is formed by an agreement between the Northwest River Forecast Center (NWRFC), the USACE, and Bonneville Power Administration and is coordinated with the USBR.

application normally requires monthly precipitation, snowpack, reservoir levels, streamflow, and temperature.

Table 17: List of appropriate drought indicators to identify hydrological drought

Indicator	Main characteristics / reference	Input variables	Advantages	Disadvantage
Aggregate Dryness Index (ADI)	A multivariate regional drought index that accounts for all water resources. (Keyantash and Dracup, 2004)	P, EVPT, SF, RS, SM, SWE	Looks at the total amount of water in a climate regime. Takes into account water stored in reservoirs, as snow, or in the soil.	More complex formulation and large data requirement. Not extensively validated. Developed to be used across uniform climate regimes.
Standardized Reservoir Supply Index (SRSI)	An extension of the SPI that accounts for reservoir storage data. (Gusyev et al., 2015)	SF, RS	Easy to compute, as it mimics SPI calculations using a standard gamma distribution of the probability distribution function.	Does not take into account snow and losses due to evaporation.
Standardized Snowmelt and Rain Index (SMRI)	An extension of the SPI that accounts for frozen precipitation and its contribution to runoff. (Staudinger, M., K. et al. 2014)	SF, P, T and SC/SWE (if available).	Accounts for snow and its future contributions to streamflow, ability to use temperature, and precipitation to model snow or snow amounts.	Does not account for reservoir volume. Not using actual snow depths and associated snow water equivalency can lead to errors in runoff projections.
Surface Water Supply Index (SWSI)	Based on PDSI but accounts for water supply data. Calculated at basin level. (Doesken et al. 1991)	RS, SF, SWE and P.	Provides a good indication of the overall hydrology of a particular basin or region.	As data sources change or additional data are included, the entire index has to undergo recalculation. Does not account for changes in temperature.
Reclamation Drought Index (RDI):	Developed to define drought severity, duration and to predict the onset and end of drought periods. Similar to the SWSI, but contains a temperature component.	P, T, S, RS, SF	Flexibility to add only the variables that are dominant for the area, or season. It accounts for temperature and consequent climate change effects. It was created to trigger drought emergency relief.	Calculations are made for individual basins, so comparisons are hard to make. Having all the inputs in an operational setting may cause delays in the production of data.
P=Precipitation; T=temperature; AWC=available water content; EVPT=evapotranspiration; SF=streamflow; RS=reservoir storage; SM=soil moisture; SWE=snow water equivalent (content), S=snowpack				

Different indicators will be defined as a function of the hydrological characteristics of each season. For August to December, water supply contributions are mainly provided by rainfall in the incremental basin and reservoir storage (Drought Indicator Type I). For the period of January to March, the estimated water deliverable from Colorado will be calculated based on USDA-NRCS forecasted streamflow data. Streamflow for the locations used to calculate the Conejos Index Supply and the Rio Grande Index Supply, and deliverable estimation tables provided in the compact, will be used to predict flow at the Otowi Bridge gauge for following months. For the period of April to July a similar method will be used, but different forecast periods are provided by USDA-NRCS (current month to July). The drought indicators and variables that will likely be used in the project, with possible mitigation responses are listed in Table 18. Figure 13 shows the relationship between the seasonal drought indicators, monthly water demand variability between the years 2000 and 2018 for reach 5, and New Mexico planting and harvesting dates (New Mexico Annual Bulletin, 2016).

Table 18: List of recommended drought indicators for MRGCD  
RDI or SWSI are the main recommended indicators for operational purposes

Time	Data source	Possible example of drought mitigation measures
August 1 <sup>st</sup> to December 31 <sup>h</sup>	<p><b>Drought Indicator Type I</b></p> <p><b>Calibration data:</b> Storage, observed temperature, and observed precipitation in incremental watershed</p> <p><b>Forecast data:</b> Storage, forecasted seasonal temperature, and forecasted seasonal precipitation in incremental watershed</p>	<p>Irrigation schedules</p> <p>Rotation of water delivery</p> <p>Water conservation subsidies</p> <p>Water banks/water lease</p>
January 1 <sup>st</sup> to March 31 <sup>st</sup>	<p><b>Drought Indicator Type II</b></p> <p><b>Calibration data:</b> Storage, observed temperature, observed precipitation, and <i>Otowi<sub>C</sub></i></p> <p><b>Forecast data:</b> Storage, forecasted seasonal temperature and forecasted seasonal precipitation in incremental watershed, and Otowi estimated delivery from Colorado based on USDA-NRCS forecasted streamflow and the Water Compact (March to July)</p>	<p>Reservoir management (alternative water use)</p> <p>District water allocation</p> <p>Water conservation subsidies</p> <p>Create incentives for farms to switch to water efficient crops</p> <p>Water banks/water lease</p>
April 1 <sup>st</sup> to July 31 <sup>st</sup>	<p><b>Drought Indicator Type II</b></p> <p><b>Calibration data:</b> Storage, observed temperature, observed precipitation, and <i>Otowi<sub>C</sub></i></p> <p><b>Forecast data:</b> Storage, forecasted seasonal temperature and forecasted seasonal precipitation in incremental watershed, and Otowi Bridge USGS estimated delivery from Colorado based on USDA-NRCS forecasted streamflow and the Water Compact (current month to July)</p>	<p>Reservoir management (alternative water use)</p> <p>District water allocation</p> <p>Water conservation subsidies</p> <p>Water banks/water lease</p>

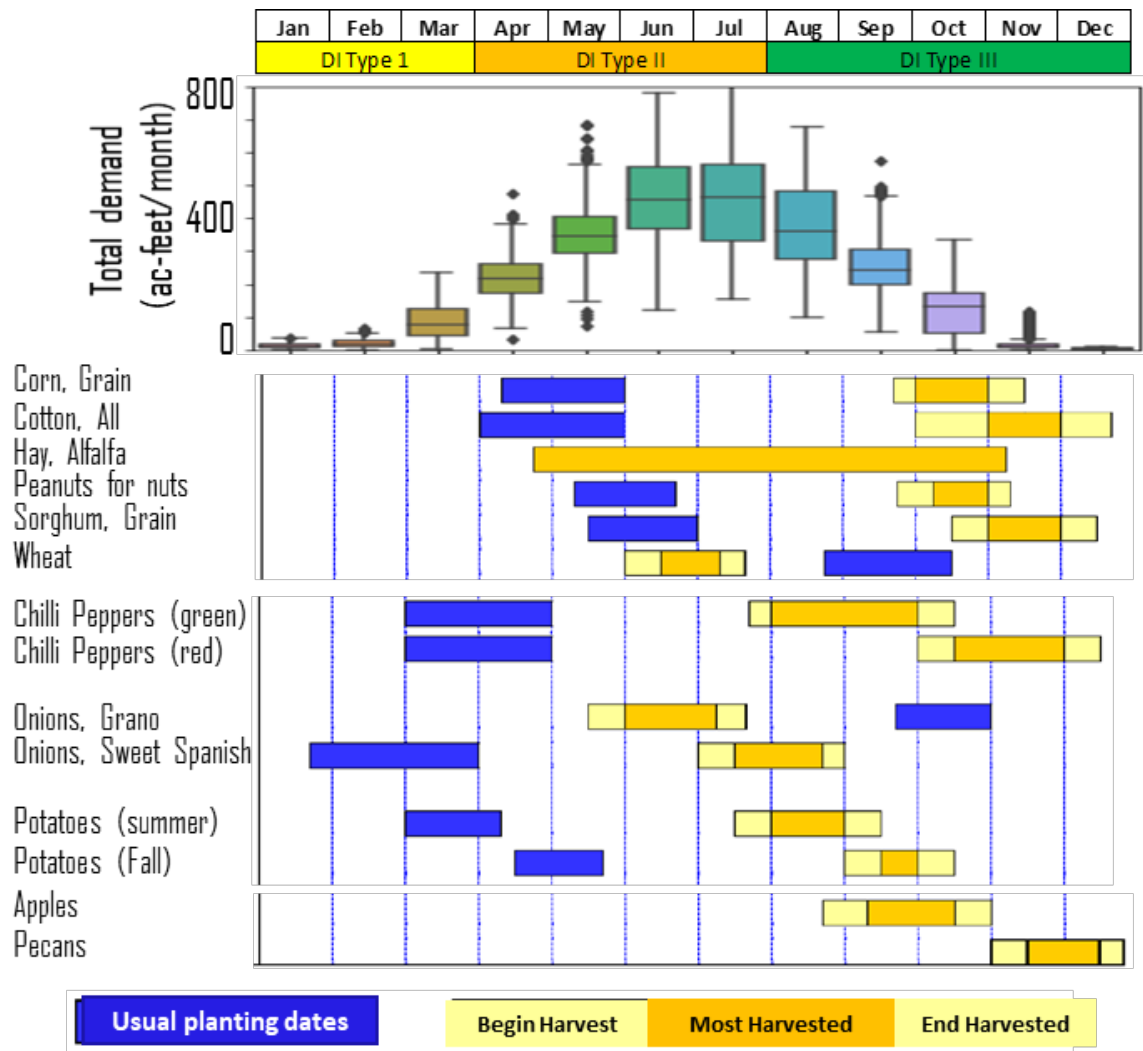


Figure 13: Drought indicators, total water demand monthly variability (Source: ET Toolbox, reach 5), and New Mexico planting and harvesting dates (Source: New Mexico Annual Bulletin, 2016)

## 5 Possible drought responses

As part of the study, a set of drought responses will be prepared for each drought trigger. Drought responses will be evaluated taking into consideration the District regulations and authority, including:

- The Water Compact of 1938 and its amendments;
- Policies and procedures of the MRGCD, revised in April 04, 2007;
- Water Bank Revised Rule No 23 of May 29, 2009;
- Water Service Charges resolution of the Board of Directors of the MRGCD of September 26, 2011;
- Policy of the MRGCD revised in March 12<sup>th</sup>, 2012;
- Resolution of the Board of Directors of the MRGCD adopting revised rule 23 water bank policy and appendix, November 12<sup>th</sup>, 2012; and

- Resolution of the Board of Directors of the MRGCD of September 26, 2011 allowing for water deliveries to water bank lessees for water that has been previously scheduled up to five days after curtailment conditions are in effect, May 13th 2013.

Alternatives for drought response and conservation include:

- Rotation of water delivery: Optimal water delivery schedules should be generated based on water rights, district divisions, and crop types/needs. Modifying the rotation schedule in critical growth periods saves water and minimizes yield losses. A hierarchical scheme of water rotation should be established depending on the severity and duration of the drought. Higher order canals should only be included in the rotation if the water deficit is severe.
- Following/leasing programs: Establish a leasing program that allows water-rights owners, including tribes and farmers, to lease their water for periods of time. The leasing price would follow market values, and therefore would be a measure of water scarcity.
- Water banking: The MRGCD has already established a water bank for its members. Water banking allows farmers to buy and sell water on a short-term basis at prices set administratively by the water bank. An owner who is conserving water or not using it could deposit that water for use by a borrower without being subject to the state's forfeiture rules.
- Create water conservation subsidies to motivate conservation: The benefits of conservation need to be evaluated taking into consideration accurate measurement of water use at different scales, including better estimates of return flows and evapotranspiration (Huffaker, 2008). Farms that adopt subsidized irrigation systems should be mandated to keep the conserved water in underground water tables or streams. The saved water should not be used to expand irrigation or grow crops that demand higher volumes of water.
- Create incentives for farms to switch to water efficient crops: Alfalfa, for example, requires 86% more irrigation water than water-use efficient crops.
- Provide technical assistance and financial incentives: These incentives can help farms decrease water waste, such as with the use of laser field leveling and more precise control of water applications.
- Implement methods to improve the accuracy of predicting daily water allocation.
- Establish conservation water agreements for alternative reservoir storage use: Such as the one established for Abiquiu reservoir under the Conservation Water Agreement in 2001- 2003 and the Emergency Drought Water Agreement of 2003.
- Best management practices: Lining Canals (process of reducing seepage loss of irrigation water by adding an impermeable layer to the edges of the trench) and Tailwater Reuse thorough the implementation of pickup ditches, sumps, pits, and pipelines.
- Intra-compact and interstate water markets: Using a model that maximizes the total regional economic benefits for each of the three compact states. Booker et al (2005) demonstrate that drought damagers could be reduced by 20 to 33% per year by the implementation of intra-compact and interstate markets.

## 6 Recommendations

Recommendations will be provided based on each project task. To evaluate natural climate variability the reconstructed streamflow dataset of Connie Woodhouse (2014) will be used to quantify natural climate variability for Rio Grande Basin Headwaters and the reconstructed precipitation dataset of Stahle et al (2009) will be used to quantify natural climate variability in intermediate watersheds.

To investigate the impact of climate change on water supply and demand, previous studies that focus on climate change impacts on the Middle Rio Grande will be reviewed. To complement available results from these studies, the most recent downscaled GCM datasets will be evaluated in this project. Analysis will focus on the BCSD-CMIP5 climate and hydrology projections (USBR, 2014), including time series of streamflow projections for points of interest. Only GCMs selected for California water resources planning (CCTAG, 2015) will be included in the analysis. If necessary, observed time series of streamflow measured by the USGS, monthly temperature and precipitation as provided by the PRISM dataset, and SWE provided by SNOTEL will be used to evaluate model results for the observed period of data.

In order to investigate the hydrological conditions that resulted in limited water variability for MRGCD, multiple datasets will be applied, including district board minutes, historical climate data, meteorological, agricultural and hydrological drought indicators, and Rio Grande Compact status.

Data used to monitor and predict droughts should be readily available, accessible for a long period of record, reliable, cost effective to collect, and, ideally, should be easily accessible by stakeholders. The period of data availability is a key factor for the definition of drought indicators. This criterion limits the use of many available datasets for the definition of drought indicators. The focus on this project is to define drought indicators that account for all water supply and demand for the Middle Rio Grande using readily available information.

Current reservoir storage is used in the definition of drought indicators for all seasons. To quantify water supply contributions from Rio Grande Basin Headwaters, observed streamflow at Otowi Bridge gauge corrected by the SJC contribution will be used. The advantage of using this gauge instead of the SWE provided by SNOTEL sites is that streamflow is an integrated measure of the system that accounts for multiple processes that occurred upstream from the site (snow melt, evapotranspiration, runoff generation and transport). Streamflow forecasts taking into consideration observed SWE at selected measurement sites is available through the USDA-NRCS for the period of January to July. The streamflow forecast will be used to estimate the deliverables from Colorado to New Mexico and it will allow the use of drought indicators in a predictive form. Drought indicators will vary with season and will be defined on a monthly basis.

To quantify the water supply contributions for the incremental basin, as well as soil moisture conditions, observed precipitation will be considered for the period of August to December. The PRISM monthly precipitation dataset that covers the period of 1895 to today will be used in this analysis.

Ideally, water demand is considered in the definition of hydrological drought indicators. However, no water demand database presents an accurate and long enough period of record to be used as one of the

parameters in the drought indicator. A common approach, especially for irrigated areas, is to use temperature or potential evapotranspiration as a proxy for water demand. The PRISM monthly temperature dataset (1985 to today) will be used in this analysis. To calculate potential evapotranspiration as a function of temperature and latitude, the Hargreaves (Hargreaves and Samani, 1985) or the FAO-56 Penman-Monteith (Allen et al 1998) will be used.

The results of the previous tasks will allow the development of drought triggers. Triggers and actions are directly linked to drought severity measured by the drought indicator. For each trigger, a set of drought responses will be defined with the goal of minimizing the effects of the drought. In the definition of the drought responses, the general policies and the authority of the MRGCD will be taken into consideration.

A range of possible future drought conditions will be developed based on the analysis of the past and future climate. This analysis will also provide information on the types of risks that the district faces in terms of changes in water supply and water demand, and changes in the seasonality of runoff. Changes in the hydrological and meteorological regime impose threats to the MRGCD water supply and demand, but also present opportunities to adapt the management of existing infra-structure to efficiently use the water. These risks and opportunities will be investigated in this project. For these tasks all the results from previous analysis will be applied. Table 19 summarizes all the datasets that will be applied in the project.

Table 19: Datasets recommended for the project

<b>Natural climate variability</b>			
<b>Datasets</b>	<b>Record Begin</b>	<b>Record End</b>	<b>Application</b>
Connie Woodhouse (2014) Rio Grande at Otowi, NM – USGS 08313000 (1450-2012)	1450	2012	Quantify natural climate variability for Rio Grande Basin Headwaters
Cool- (November–May) and early-warm season (July) precipitation	137 BC	2002	Quantify natural climate variability in intermediate watersheds
<b>Climate change impacts on droughts and future condition range</b>			
BCSD-CMIP5 climate and hydrology projections	1950	2100	Quantify the impacts of climate change on water supply and water demand
BCSD-CMIP5 streamflow projections for points of interest	1950	2100	Quantify the impacts of climate change on water supply
USBR’s “Upper Rio Grande Impact Assessment” (2013)			Quantify the impacts of climate change
Auxiliary: Observed time series of streamflow and SWE			
<b>Drought indicator</b>			
Potential evapotranspiration calculated based on Temperature, PRISM gridded climate data (monthly)	1895	2015	Quantify water demand
Precipitation, PRISM gridded climate data (monthly)	1895	2015	Quantify water supply (contributions from incremental basin)
Streamflow, 8313000, Rio Grande at Otowi Bridge	1895	2017	Quantify water supply (contributions from Rio Grande Basin Headwaters)
Abiquiu Reservoir	1964	2017	Quantify current storage (up to 170,000 ac-ft)
El Vado	1952	2017	Quantify current storage
Heron	1970	2017	Quantify current storage
Cochitti	1973	2017	Quantify current storage (up to 50,000 ac-ft)
USDA-NRCS streamflow forecast and Water Compact	1995	2017	Will be used to forecast drought
<b>Past drought impacts and operation</b>			
District board minutes			
Historical climate data			
Multiple meteorological drought indicators			
Rio Grande Compact Cumulative Departures			
<b>Possible drought responses</b>			
Middle Rio Grande policies			

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Appendix 3:  
Climate Change Analysis

Prepared by

WEST Consultants

For the

Middle Rio Grande Conservancy District

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## **Executive summary**

Droughts in the Middle Rio Grande Conservancy District (MRGCD) are expected to become more severe due to man induced and natural climate variability. In this report instrumental observations, paleoclimatic time series, and downscaled climate model projections were applied to quantify the severity, frequency, duration, and persistency of past and future droughts for the area of interest of the MRGCD.

The results presented in this report should be applied to examine MRGCD's vulnerability to future droughts. In this report, the effects of climate change were evaluated for the period of 2000 to 2049 and 2050 to 2100. However, for drought planning and mitigation purposes, the MRGCD is focusing on the first half of the century. Evaluations were performed based on 10 Global Climate Models (GCMs) that best represent the climatology in the area for two greenhouse gas emission scenarios: the Representative Concentration Pathways 4.5 (RCP 4.5) and the Representative Concentration Pathways 8.5 (RCP 8.5). Hydrologic Unit Code six (HUC6) was used to delineate different areas of interest.

The analyses were performed separately for the Hydrologic Unit Code six (HUC6) listed in

Table 23 and shown in Figure 19. The HUC 130100 sub-Basin covers the Rio Grande Headwaters up to the Rio Grande near the Lobatos gauge (HUC name: *Rio Grande Headwaters*; area equal to 19,705 km<sup>2</sup>). The HUC 130201 goes from the Rio Grande near Lobatos gauge to the Rio Grande near Otowi Bridge gauge (HUC name: *Upper Rio Grande*; area equal to 16,606 km<sup>2</sup>). The HUC 130202 covers the main area of the MRGCD from the Rio Grande near the Otowi Bridge gauge to the Rio Grande at Elephant Butte Dam (HUC name: *Rio Grande-Elephant Butte*; area equal to 53,620 km<sup>2</sup>). The HUC 140801 covers the watershed from where water is transposed to the San Juan Chama (SJC) system (HUC name: *Upper San Juan*). Evaluations were performed for the area that comprise the Rio Grande Basin up to the Rio Grande-Elephant Butte Reservoir, plus the area of the Upper San Juan, which is referred to as the “combined area”. Streamflow projections were evaluated in multiple locations in the watershed, including the Rio Grande near the Lobatos gauge, the Rio Grande near Abiquiu, the Rio Grande near the Otowi Bridge gauge, and the Rio Grande at Elephant Butte dam.

The following changes are expected for the MRGCD areas of interest for the period of 2000 to 2049:

- **Temperature** increases are identified by all locations, GCMs, RCPs, and months of the year. Minimum and maximum temperatures are projected to increase on average by 1.8°C (3.2 °F).
- **Snow Water Equivalent (SWE)** is projected to decrease for all basins and months for which snow occurs. Changes are relatively higher for the Upper Rio Grande Basin, but the loss of water volume is most significant for the headwaters, where the volume of water stored as snow is higher. Projected changes are most significant for the month of May. For the Rio Grande Headwaters, the May SWE is projected to decrease on average by 14 mm (20%, 0.57 inches) for RCP 4.5 and RCP 8.5. For the Upper Rio Grande Basin, the May SWE is projected to decrease on average by 8.1 mm (36.1%, 0.32 inches) for RCP 4.5 and by 8.6 mm (0.33 inches) for RCP 8.5. Changes in SWE for the Upper SJC are also significant and might affect the delivery of water to the Upper SJC system.
- **Annual Potential Evapotranspiration** for the area irrigated by MRGCD is expected to increase on average by approximately 5% for both RCPs. Significant increases occur mainly from March to November. Assuming irrigation techniques, crops, and served areas are kept constant, this percentage increase corresponds to expected relative increases in irrigation demand.
- **Actual Evapotranspiration** increases for some of the winter and fall months, but actually decreases for June and July for both RCPs. This decrease is caused by the decrease in soil water availability during these months.
- **Soil Moisture** is projected to decrease for all months for the combined area for both RCPs. Soil moisture in the combined area is the lowest for the period of July to October, when irrigation is mostly needed.
- The magnitude and direction of projected changes in **Annual Runoff** vary significantly among all models.
- Changes in **Runoff Seasonality** occur in snow dominant basins. For the Rio Grande Headwaters, May runoff increases while June runoff decreases. For the Upper Rio Grande, March and April runoff increases while May and June runoff decreases. Changes for the Rio Grande-Elephant

Butte are much less significant, since snow is not predominant in the basin and average runoff volumes are lower than the ones observed in the upper watersheds. For the period of July to October, when localized storms can alleviate droughts in the region, no significant trends in runoff are detected.

- Model ensemble average **Streamflow** indicates decreasing trends in mean annual streamflow for all scenarios and locations, but changes occur mainly in the second half of the 21<sup>st</sup> century. The range of projections provided by the different GCM models is very large and both positive and negative trends are identified for the first part of the century.
- Changes in **the Seasonality of Streamflow** are clear in the Rio Grande Basin. Monthly streamflow variability increases for the projected period. Streamflow on the Rio Grande at the Otowi Bridge gauge increases for the months of March and April, and decreases for the months of May, June, and July. The major loss in streamflow volume for the Rio Grande near the Otowi Bridge gauge location occurs in June. Negative trends in streamflow volumes also occur for the summer and fall months, which is likely the result of higher evaporation caused by higher temperatures resulting in drier soils and higher hydrologic losses. Streamflow change patterns for the Rio Chama and the Rio Grande at Albuquerque are similar to the ones observed for the Rio Grande at the Otowi Bridge gauge, with exception of the month of April for the Rio Chama, for which no increase in streamflow is projected.
- **The Intensity, Frequency, Duration, and Persistency of Droughts** are also evaluated. The frequency of dry years (below average mean annual streamflow) increases for the projected period for all sites. However, increases are more significant for the period of 2050 to 2099. For the Rio Grande Otowi Bridge gauge, the frequency increases by 4.6% for a 1-year window, 7.9% for a 2-year window, 10.4% for a 3-year window, and 17.7% for a 30-year window for the period of 2000 to 2049.
- Projected changes in **Drought Persistency** are also evaluated. The number of consecutive dry years also increases for the projected period for all observed locations, with larger changes occurring from 2050 to 2099. For the observed period, a maximum of 12 consecutive years with streamflow are observed at the Rio Grande at the Otowi Bridge gauge. This number increases to 16 for the period of 2000 to 2049. For the Vallecito in the Colorado River Basin, a maximum of 9 consecutive dry years are observed, and this number increases to 18 from 2050 to 2099. The percentage of mean annual streamflow observed for shorter duration droughts (2 to 10 years) also decreases for the projected periods for all sites.
- **Reduction in Supply:** Considering only the water supply provided by the upper Rio Grande Basin (through Otowi gauge), the frequency of years with 10% reduction in supply increases from 44% to 49%, with 25% reduction in supply from 28% to 34%, and with 40% reduction in supply from 12% to 19%. Even more significant increases are projected to occur during the second half of the 21<sup>st</sup> century, when 40% reduction in supply is project to be observed for one third of years.

## 1 Climate variability

The Rio Grande Basin is a large and complex catchment. Runoff at the basin headwaters is controlled by alpine snow melt, while the low elevation desert regions in the downstream parts of the basin depends on runoff generated as the result of short duration scattered convective rainfall events that occur mainly during summer.

The Upper and Middle Rio Grande Basin climate is characterized by strong inter-annual variability, and long periods of persistent wet and dry conditions. For context, it is important to understand how much more variable the New Mexico climate is compared to the climate observed in the eastern parts of the United States. Figure 14, reproduced from Dettinger et al. (2011), shows the coefficient of variation of total annual precipitation at long-term monitoring stations across the continental United States.

Variability in precipitation, in general, increases from east to west. Inter-annual variation in precipitation for the Middle Rio Grande is up to four times higher than the variation observed in the eastern parts of the country.

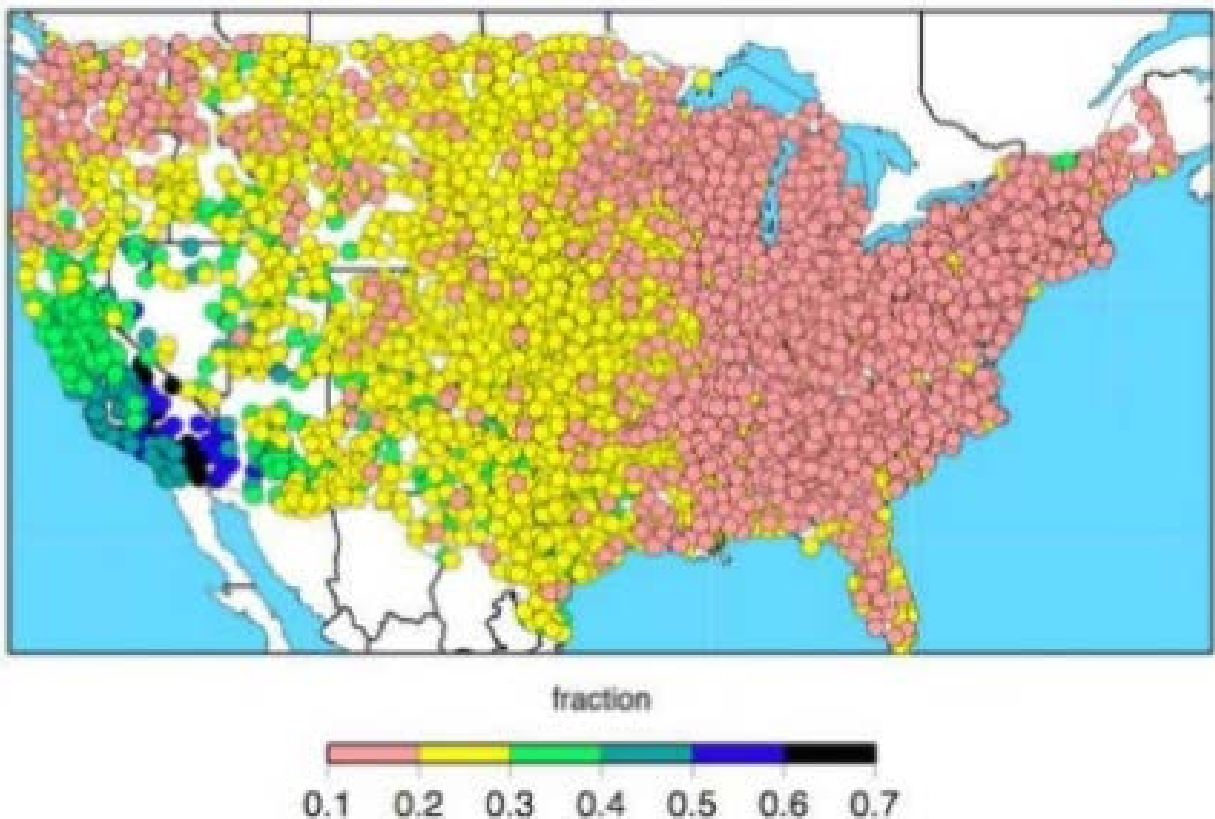


Figure 14: Coefficients of variation of water-year precipitation at long-term monitoring stations across the conterminous US, from water year 1951–2008 (reproduced from Dettinger et al., 2011)

## 2 Review of recent climate studies

Climate in the Rio Grande Basin is expected to change and the evidence of the changing climate and its impact for water management has been discussed by numerous organizations and researchers (Hurd and Coonrod, 2012; Hurd 2012, Chavarria and Gutzler, 2017; Stewart et al. 2005, Rango et al. 2003, Rango 2006, U.S. Bureau of Reclamation {USBR}, 2011). The major changes expected for the Rio Grande Basin include:

- **Warmer temperatures:** Over the period of 1971 through 2011, average temperatures in the Upper Rio Grande Basin increased approximately 0.18 °C (0.7 °F) per decade, which is two times the average global rate of temperature rise (Rahmstorf et al. 2012).
- **Changing precipitation:** The detection of precipitation trends in the region is challenging due to high precipitation inter-annual variability. In all parts of Colorado, including the northern portion of the Upper Rio Grande Basin, no consistent long-term trend in annual precipitation has been detected (Ray et al. 2008). The USBR (2011) did not consistently project changes in annual average precipitation. Chavarria and Gutzler (2018) detected small increases in precipitation.
- **Changing soil moisture:** The Climate Change Impacts in the United States: The Third National Climate Assessment (IPCC 2007) report shows a decrease in the average soil moisture content compared to 1971–2000, as projected for the middle of this century (2041–2070) and late this century (2071–2100) under two emission scenarios: a lower scenario (B1) and a higher scenario (A2). The future drying of soils is consistent with future projections of increasing drought severity.
- **Changing magnitude, timing, and variability of inflows:** Chavarria and Gutzler (2018) used observed streamflow and climate data to show that winter and spring season temperatures in the basin have increased significantly. The April 1 SWE decreased by approximately 25%, and streamflow declined slightly in the April–July snowmelt runoff season. Trends are more apparent in the changing ratios of precipitation to streamflow and in the declining fraction of runoff attributable to snowpack or winter precipitation. According to the USBR (2011) supplies of all native sources to the Rio Grande are projected to decrease on average by about one third, while flows in the tributaries that supply the imported water of the San Juan-Chama Project are projected to decrease on average by about one quarter. Inflow seasonality is projected to change, with snowmelt happening earlier in the season. Projections indicate that this basin might experience a decrease in summertime flows and less of a decrease (or potentially even an increase) in wintertime flows. Month to month and inter-annual variability of flows will also increase, which might result in an increase in the frequency, intensity, and duration of both droughts and floods.

It is important to also highlight the contributions of water use and management on the Rio Grande flow regime. Blythe and Schmidt (2018) recently estimated natural flows at daily time step resolutions for the

northern branch of the Rio Grande, upstream from the Rio Conchos. Their results highlight the significant deviation from natural conditions that occurred during the 20th century likely driven by largescale changes in climate or land use. The magnitude of the changes in the total annual flow are shown in Figure 15, reproduced from Blythe and Schmidt (2018). According to the author the total annual flow of the northern branch is 95% lower than it would be in the absence of human use.

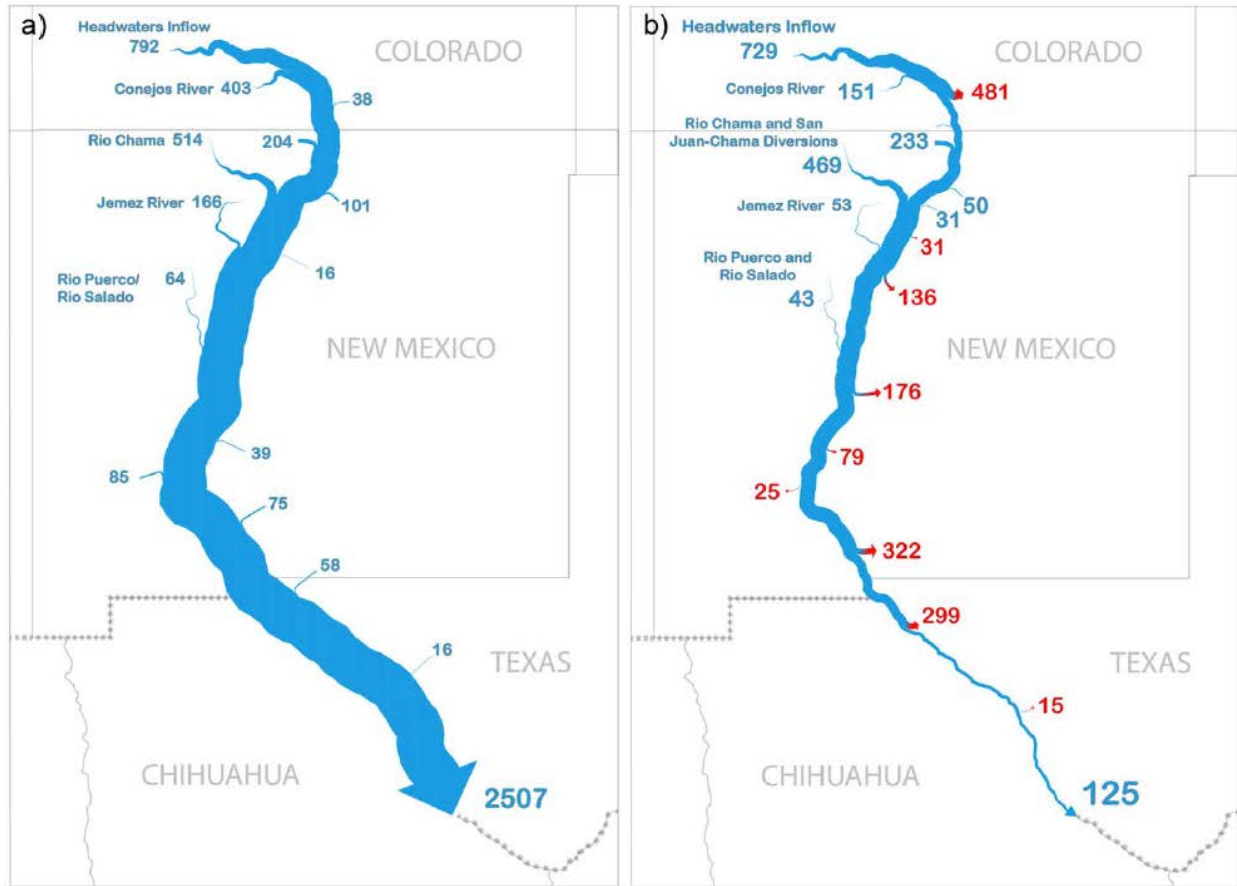


Figure 15: Scaled line diagram showing average annual inflows (blue lines) and consumptive losses (red arrows) of the northern branch in million cubic meters for (1) estimated natural conditions between 1900 and 2010; and (b) modern conditions during the latter half of the 20th century (1950–2010)

### 3 Paleoclimatic records

Instrumental records of precipitation and streamflow usually date back about 100 years. This period of record does not provide a complete picture of the full range of variability in climate. Tree-ring datasets extend back hundreds and even thousands of years and therefore provide valuable additional information on the length and severity of past droughts. This data should be applied to put current droughts into a more comprehensive perspective.

Past droughts were evaluated based on reconstructed time series of streamflow and precipitation for the Rio Grande Basin based on tree-ring data. Water supply in the Middle Rio Grande is composed mainly of inflow from the Colorado headwaters and by runoff generated in minor and major (Rio Chama and Jemez) tributaries in New Mexico. Annually a total of 20,900 acre-feet of water from the SJC Project is also allocated for the MRGCD. Each one of these components is evaluated individually.

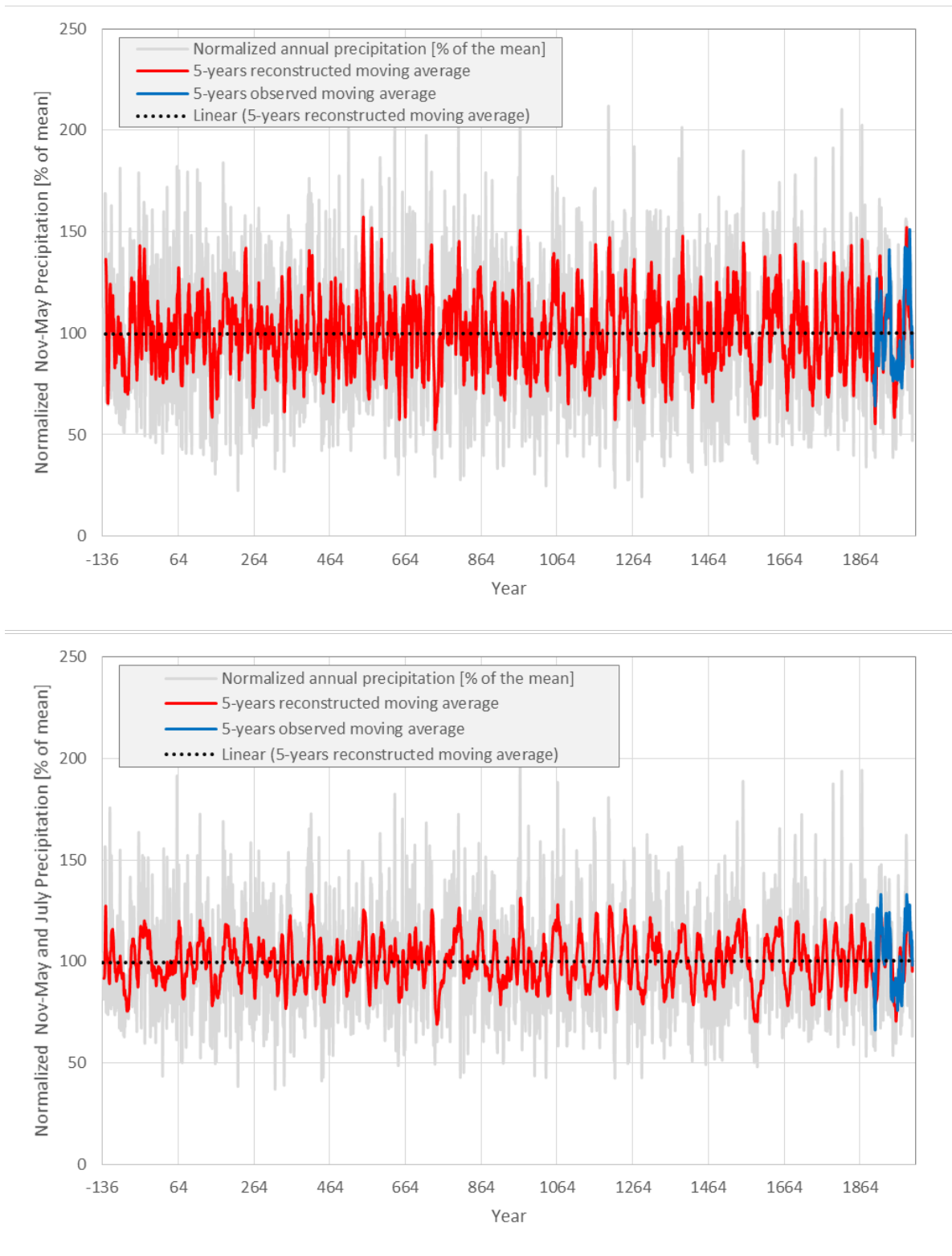
Due to the lack of more localized paleoclimatic data to evaluate water supply in the incremental basin between the Otowi Bridge gauge and Elephant Butte Dam and contributions from the SJC Project, time series of reconstructed precipitation generated based on the El Malpais tree-ring data are applied (Stahle et al 2009). While the El Malpais data refers to a unique location, the dataset is correlated with seasonalized precipitation (November to May and July, respectively) for all divisions in New Mexico. Figure 16 shows the annual time series of reconstructed November to May and November to May plus July precipitation in New Mexico. The time series covers the period of 136 B.C. to 2002 A.D., and therefore the latest drought that occurred around the year of 2012 is not included in this dataset. November to May precipitation varies between 19% and 211% of the long-term precipitation while the November to May plus July time precipitation varies from 37% to 194%. While co-occurrence of droughts in the cool and warm seasons can intensify droughts during specific years, in general the worst droughts were alleviated by the warm season precipitation.

The 5-year moving average shows strong swings between dry and wet periods, clearly demonstrating the variability of New Mexico climate. The wettest 5-year period occurred between 963 and 968 A.D. when the 5-year average of November to May plus July precipitation was 31% higher than the long-term average. The driest period occurred between 742 and 747 A.D. when the 5-year average November to May and July precipitation was 31% lower than the long-term average. The driest 10-year period in the 20<sup>th</sup> century occurred from 1954 to 1959 when the 5-year average November to May precipitation was 29.5% lower than the long-term average. No significant trend was observed for these time series.

The driest 1, 5, 10, 20 and 30-year periods that occurred during the period for which precipitation measurements are available (1895 to 2002) are shown in Table 20. The short duration (5 years or less) driest periods occurred mainly in the first half of the twentieth century, while longer droughts were more common in the second half of the century. The driest 1-, 5-, and 10-year periods ended in 1904, when only 34%, 64%, and 70%, respectively, of the long-term average precipitation was observed in the basin. The driest 20-year and 30-year periods ended in 1972, when approximately 80.5% and 81.5% of the average were observed, respectively.

The probability of non-exceedance for each event is also included in Table 20. This probability was calculated based on a gamma distribution fitted to the observed (P1) and the paleoclimatic record (P2).

The probability of non-exceedance shows the expected chance of an observation not exceeding a specific value. For example, there is a 0.6% probability that a value equal to or lower than 81.5% of the 30-year long term average will occur. This value was observed during the period of 1942 to 1972. Note that the non-exceedance probabilities calculated based on both time series are not significantly different, but P1 is usually smaller than P2 for the short duration droughts and larger than P2 for the longer duration droughts. Therefore, the observed record (P1) underestimates the probability of short duration droughts and overestimates the probability of longer droughts in relation to the paleoclimatic record (P2).



**Figure 16:** Normalized reconstructed November to May and November to May plus July precipitation time series for New Mexico

Table 20: Driest 1-, 5-, 10-, 20- and 30-year periods that occurred during observed record and the probability of non-exceedance based on the observed (P1) and the paleoclimatic time series (P2)

Window	Rank	End Year	Obs. Value [% average]	P1 [p<=pobs] <sup>1</sup>	P2 [p<=pobs] <sup>2</sup>
1	1	1904	34.80	0.23	1.38
	2	1950	44.40	2.44	3.36
	3	1959	44.51	2.49	3.39
	4	1971	46.22	3.22	3.90
	5	2002	46.44	3.33	3.97
5	1	1904	64.64	0.20	1.73
	2	1902	69.12	1.80	3.46
	3	1903	70.94	3.10	4.47
	4	1974	73.09	5.17	5.93
	5	1900	75.12	7.63	7.61
10	1	1904	70.12	0.24	1.44
	2	1959	77.63	4.53	5.13
	3	1951	79.47	6.80	6.72
	4	1956	79.49	6.83	6.74
	5	1964	79.80	7.26	7.04
20	1	1972	80.53	3.01	1.98
	2	1964	81.58	4.08	2.60
	3	1961	81.95	4.51	2.86
	4	1977	82.05	4.63	2.93
	5	1962	82.16	4.76	3.01
30	1	1972	81.49	1.84	0.59
	2	1977	82.35	2.37	0.83
	3	1974	82.62	2.56	0.92
	4	1975	82.67	2.60	0.94
	5	1971	82.85	2.73	1.00
1: P1 is equal to the probability of not exceeding the observed value calculated based on the observed period (1895 to 2002) 2: P2 is equal to the probability of not exceeding the observed value calculated based on the paleoclimatic record (-136 to 2002)					

	First half of the twentieth century
	Second half of the twentieth century
	Twenty first century

The supply from the Colorado headwaters is evaluated based on the updated reconstructed time series of natural streamflow of the Rio Grande Basin at the Otowi Bridge (Woodhouse, 2006 and 2012). This dataset was updated at the request of the New Mexico Interstate Steam Commission (NMISC) and encompasses the period of 1450-2012. The time series of normalized annual flow is shown in Figure 17. Annual inflow was normalized based on the 1950 to 1999 streamflow to simplify the comparison with the GCM results that are discussed in subsequent sections.

Annual inflow varies between 22% and 242% of the 1950 to 1999 average streamflow. The 5-year moving average shows significant variability. The wettest 5-year period occurred between 1982 and 1987 A.D. when the 5-year average inflow was 73% higher than the long-term average. The driest period occurred between 1621 and 1626 when the 5-year average inflow was 48.5% lower than the long-term average. The period of 1999 to 2004 was also extremely dry with average inflow 46% lower than the long-term average. No clear trend is observed during the period of data.

The driest 1-, 5-, 10-, 20-, and 30-year periods that occurred during the observed period of data (1940 to 2012) are shown in

Table 21. Even though the time series of record for the Otowi Bridge gauge dates back to 1895, the author of the study applied unregulated flows from 1940 to 2012. The probability of non-exceedance for each event was calculated based on a gamma distribution fitted to the observed (P1) and the paleoclimatic records (P2). The non-exceedance probabilities calculated based on both time series are significantly different probably due to the short period of the observed time series. The driest 1 and 5 years ended in 2002 and 2004, which presented approximately one fourth and one half of the long-term average. The long duration (20 years or more) driest years occurred in the 70's. The 20-years inflow average observed in 1972 has a probability of occurrence of 0.37% based on the observed period of observed data and 6.34% based on the paleoclimatic record.

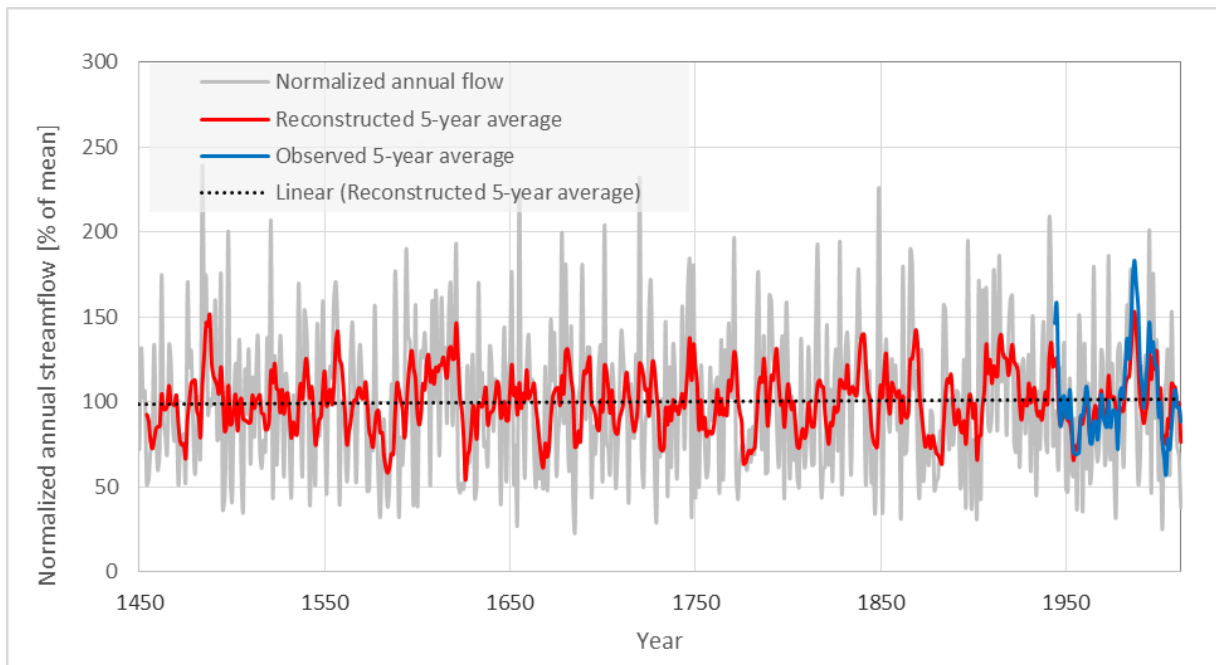


Figure 17: Normalized reconstructed November to May precipitation time series for New Mexico

Table 21: Driest 1-, 5-, 10-, 20- and 30-year period that occurred during observed record and the probability of non-exceedance based on the observed (P1) and the paleoclimatic time series (P2)

Window	Rank	Year	Obs. Value [% average]	P1 [p<=pobs] <sup>1</sup>	P2 [p<=pobs] <sup>2</sup>
1	1	2002	26.4	0.30	0.31
	2	1977	30.7	1.93	1.77
	3	1951	37.1	6.02	7.30
	4	1956	37.2	6.14	2.81
	5	1964	40.9	9.03	20.56
5	1	2004	54.1	0.25	7.33
	2	2003	63.6	4.15	12.59
	3	1955	65.7	5.90	6.13
	4	1956	65.7	5.93	4.76
	5	1957	66.8	6.94	11.19
10	1	1956	75.7	0.00	4.85
	2	1955	76.2	7.84	7.35
	3	2007	76.6	11.76	31.82
	4	1959	76.9	14.52	2.07
	5	1972	77.3	17.37	22.83
20	1	1972	79.0	0.37	6.34
	2	1978	79.8	2.06	17.38
	3	1964	80.8	4.81	1.19
	4	1969	81.1	5.60	2.76
	5	1968	82.0	8.55	2.95
30	1	1978	82.0	4.26	4.88
	2	1972	83.2	5.41	1.70
	3	1974	83.9	6.18	5.48
	4	1979	83.9	6.25	4.91
	5	1977	84.1	6.45	3.15

1: P1 is equal to the probability of not exceeding the observed value calculated based on the observed period (1940 to 2012)

2: P2 is equal to the probability of not exceeding the observed value calculated based on the paleontological record (14.50 to 2012)

## 5 Climate projections

### Global Climate Models (GCMs)

Future climate variability induced either by natural recurring cycles, human activities, or both are expected to significantly affect the intensity and duration of future droughts. New Mexico climate is naturally characterized by strong inter-annual variability, multi-decadal periods of persistent wet and dry conditions, and abrupt changes between those periods. The U.S. Global Climate Research Program, for example, concluded in a 2009 assessment report that the Southwest will likely experience increased water scarcity as a result of the combined impacts of projected temperature increases and substantial reductions in rain and snowfall in the spring months. The USBR's "Upper Rio Grande Impact Assessment" (2013) demonstrated that man-induced climate change will affect drought in New Mexico as a result of increasing temperatures that will lead to lower snowpack, earlier runoff (more runoff during winter and early spring), lower stream flows during the summer, and higher water demand for irrigation.

GCMs are important tools for understanding potential effects of climate change and variability. However, the results of GCMs should be used with caution due to their coarse spatial resolution, high uncertainties, and the lack of agreement between different models. Limitations and uncertainties in GCMs are especially high with the predictions of extremely dry or wet events.

Not all available GCMs are included in the analysis. Focus is given to the models that best represent climate in the region. The GCMs listed in

Table 10 are included in the analysis. These models were selected by the California Department of Water Resources' (DWR's) Climate Change Technical Advisory Group (CCTAG), created to advise the DWR on the scientific aspects of climate change and variability to support water resources management in California.

A technical document (CA DWR, 2015) was prepared containing the preliminary findings. The report included recommendations on which GCMs are most appropriate for California water resources projects. The document serves as a guide for accounting for both man-induced and natural climate variability for water resources management in California. While the model selection was performed for California, a lot of the criteria adopted in the study also apply for New Mexico. The first two steps of the process evaluated historical GCM simulations at the global scale and at the Western region of the United States. The evaluation defined the models that best represent past observed data. Some of the regional metrics included in the evaluation are correlation and variance of mean seasonal spatial patterns, amplitude of seasonal cycle, diurnal temperature range, annual- to decadal-scale variance, long-term persistence, and Western United States regional precipitation teleconnections to El Niño Southern Oscillation (ENSO). Guaranteeing that the applied models are able to represent well the variability across different space and time scales is essential for the construction of realistic extreme drought scenarios.

CCTAG also considers model genetics in model selection. GCMs are numerical codes that solve the fundamental conservation and process equations, so to some extent they are all related (Knutti et al. 2013; Swanson 2013). Some are very closely related because they share common numeric or physical components. The CCTAG screening exercise tried to avoid redundancy by not selecting more than two GCMs from the same modeling group.

**Table 22: GCMs selected for California water resources planning (CCTAG, 2015)**

<b>Model No.</b>	<b>Model Name</b>	<b>Model Institution</b>	<b>Model Resolution*</b>
1	ACCESS-1.0	CSIRO (Commonwealth Scientific and Industrial Research Organisation, Australia), and BOM (Bureau of Meteorology, Australia)	192 x 14.5 (165 km, 63 mi)
2	CCSM4	National Center for Atmospheric Research	288 x 192 (110 km, 42 mi)
3	CESM1-BGC	National Science Foundation, Department of Energy, National Center for Atmospheric Research	288 x 192 (110 km, 42 mi)
4	CMCC-CMS	Centro Euro-Mediterraneo per I Cambiamenti Climatici	192 x 96 (165 km, 63 mi)
5	CNRM-CM5	Centre National de Recherches Meteorologiques / Centre Europeen de Recherche et Formation Avancees en Calcul Scientifique	256 x 128 (123 km, 47 mi)
6	CanESM2	Canadian Centre for Climate Modeling and Analysis	128 x 64 (247 km, 94 mi)
7	GFDL-CM3	Geophysical Fluid Dynamics Laboratory	144 x 90 (219 km, 84 mi)

8	HadGEM2-CC	Met Office Hadley Centre	192 x 14.5 (165 km, 63 mi)
9	HadGEM2-ES	Met Office Hadley Centre (additional HadGEM2-ES realizations contributed by Instituto Nacional de Pesquisas Espaciais)	192 x 14.5 (165 km, 63 mi)
10	MIROC5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology	256 x 128 (123 km, 47 mi)

\* Indicates the size of the model's atmospheric grid (number of columns by number of lines) and the resolution of the grid in km

## Representative Concentration Pathways (RCPs)

The Intergovernmental Panel on Climate Change defined four RCPs for CMIP5 models. These scenarios represent a wide range of potential worldwide greenhouse gas emissions and sequestration for the coming century. The scenario numbers (2.6, 4.5, 6, and 8.5) are based on the expected Watts per square meter, a measure of how much heat energy will be trapped by the end of the 20th century: RCP 2.6 (260 parts per million), RCP 4.5 (538 ppm), 6.0 (670 ppm), and RCP 8.5 (936 ppm). The projected greenhouse gas concentrations for the four different emission pathways are shown in Figure 18. The current carbon dioxide concentration in the atmosphere is around 400 parts per million, up from less than 300 parts per million at the end of the 19th century. Therefore, the RCP 2.6 scenario is a low greenhouse-gas emission scenario given current conditions. The RCP 4.5, RCP 6.5, and RCP 8.5 are reasonable choices to represent low and high emission scenarios, given current rates of global fossil fuel consumption and economic development. In this report we investigate the RCP 4.5 and RCP 8.5 scenarios since downscaled GCM datasets for RCP 6.5 are not available for all models. Note that all scenarios start to really divert from each other around 2030, and become considerably different by the end of the century.

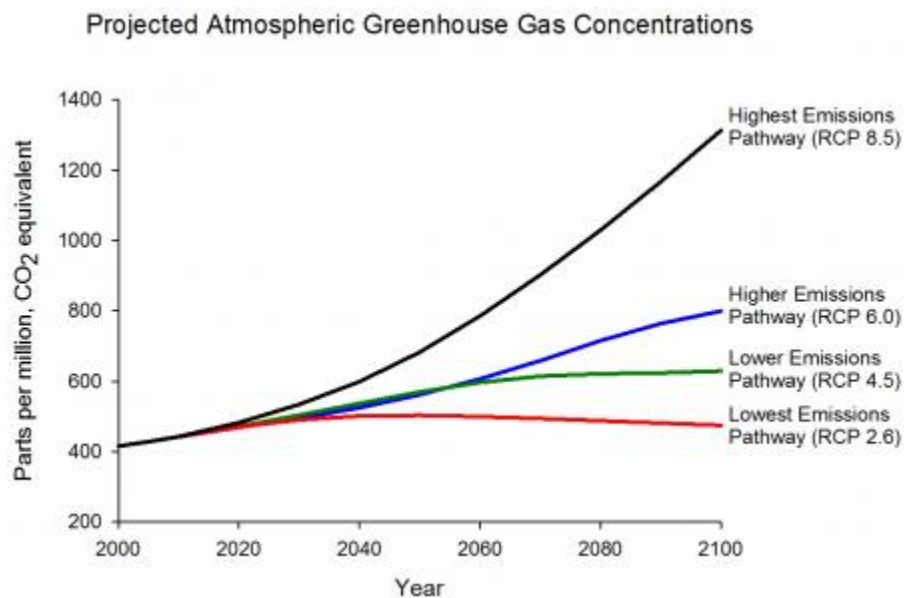


Figure 18: Projected greenhouse gas concentrations for four different emission pathways Source: Graph created from data in the RCP Database (Version 2.0.5) <http://www.iiasa.ac.at/web-apps/tnt/RcpDb>

## Downscaled Global Climate Models (GCMs)

Downscaling techniques are used to increase the resolution of GCM results. Downscaling techniques include methods to transform output at the GCM scale (e.g. 50 km or 19 mi or more) to higher resolution scales (e.g., 5 km or 2 mi). The downscaled results are intended to be more representative of watershed scale processes. Since GCM results must be interpreted with caution, downscaled results must also be used with caution as the GCM output is used as input in the downscaling procedure.

The USBR (2013) evaluated the potential hydrologic impacts of climate change in the Upper Rio Grande Basin. The 2013 study was based on the World Climate Research Programme (WCRP) Coupled Model Inter-comparison Project Phase 3 (CMIP3) (Meehl et al. 2007). The coarse resolution GCM projections

were downscaled using the statistical method Bias Correction and Spatial Disaggregation (CMIP3-BCSD) technique of Wood et al. (2002). These downscaled GCMs were then used as input to the variable infiltration capacity (VIC) hydrological model to generate projections of runoff across the United States, including the state of New Mexico (USBR, 2014). The projected runoff was used as input to an operation model to determine modification in streamflow across the Rio Grande Basin. The results of the USBR (2013) study are also be evaluated in this report.

The USBR (2013) concluded that climate change will cause a decrease in water availability with implications for water management, human infrastructure, and ecosystems. According to the study, simulated average supplies of all native sources to the Upper Rio Grande Basin would decrease on average by about one third, while flows in the tributaries which supply the imported water of the San Juan-Chama Project would decrease by about one quarter. Increases in temperature will also cause an increase in water demand, which would enlarge the gap between supply and demand. The study also concludes that the timing and spatial distribution of flows will change and that the month to month or year to year runoff volume variability will increase.

All the conclusions from the USBR (2013) study are based on the WCRP CMIP3-BCSD climate projections. The WCRP develops global climate projections through its Coupled Model Inter-comparison Project roughly every 5 to 7 years. During 2012-2013, WCRP released the CMIP phase 5 (CMIP5) global climate projections (Taylor et al., 2011), which informed the IPCC Fifth Assessment. Since the publication of the report, other downscaled climate datasets have also become available, including:

- BCSD-CMIP5 Climate monthly Projections: monthly bias-correction and spatial disaggregation based on the most updated WCRP-CMIP5. The approach is a quantile mapping technique operated on a monthly scale and at a location-specific basis to identify and remove bias from the projection datasets.
- BCCAv2-CMIP5 Climate daily Projections: daily bias-correction and constructed analogs (BCCA) (Maurer et al., 2007; USBR, 2011; USBR, 2013; USBR, 2014).
- LOCA-CMIP5 Climate daily Projections: Statistical downscaling using Localized Constructed Analogs (LOCA) is a statistical scheme used to produce downscaled estimates based on a multi-scale spatial matching scheme that picks appropriate analog days from observations (Pierce, D et al., 2014).

The LOCA model has been proven to provide the best downscaling results. However, hydrologic projections based on the LOCA model are still not available. Therefore, BCSD-CMIP5 climate and hydrologic projections were evaluated in this project. Climate projections include all variables of the hydrological cycle, without the streamflow routing component. Streamflow projections include the routing component and provide streamflow at certain interest locations in the basin. Reservoir operations were not considered in this analysis.

## **BCSD-CMIP5 Hydrologic Projections**

Since hydrologic projections based on the LOCA model are still not available, BCSD-CMIP5 climate and hydrologic projections were evaluated in this project. Hydrologic projections using VIC were generated based on the BCSD-CMIP5 Hydrology Projections.

The analyses were performed separately for the Hydrologic Unit Code six (HUC6) listed in

Table 23 and shown in Figure 19. The HUC 130100 sub-basin covers the Rio Grande Headwaters up to the Rio Grande near Lobatos gauge (HUC name: *Rio Grande Headwaters*; area equal to 19,705 km<sup>2</sup>). The HUC 130201 goes from the Rio Grande near Lobatos gauge to Rio Grande near Otowi Bridge gauge (HUC name: *Upper Rio Grande*; area equal to 16,606 km<sup>2</sup>). The HUC 130202 covers the main area of the MRGCD from Rio Grande near the Otowi Bridge gauge to Rio Grande at Elephant Butte Dam (HUC name: *Rio Grande-Elephant Butte*; area equal to 53,620 km<sup>2</sup>). The HUC 140801 covers the watershed from where water is transferred to the SJC system (HUC name: *Upper San Juan*). Evaluations were also performed for the area that comprises the Rio Grande Basin up to the Rio Grande-Elephant Butte Reservoir plus the area of the Upper San Juan, which is referred as the “combined area”. For each HUC 6 basin average values were calculated for the time period of 1950 to 2100 for the following variables: total precipitation (mm), minimum surface air temperature (°C), maximum surface air temperature (°C), soil moisture (mm) (state, 1st day of month, summed across the three VIC soil layers), snow water equivalent (mm), total runoff depth (mm), potential evapotranspiration (mm), and actual evapotranspiration (moisture limited and summed over all vegetation classes and also over all snow bands, mm). In this section each variable are evaluated independently. All evaluations were performed for the following periods: (1) observed period that goes from 1950 to 1999; (2) mid-century which corresponds to the period from 2000 to 2049, and (3) late-century which correspond to the period of 2050 to 2099. The water year (November -October) is used in this analysis to represent annual values.

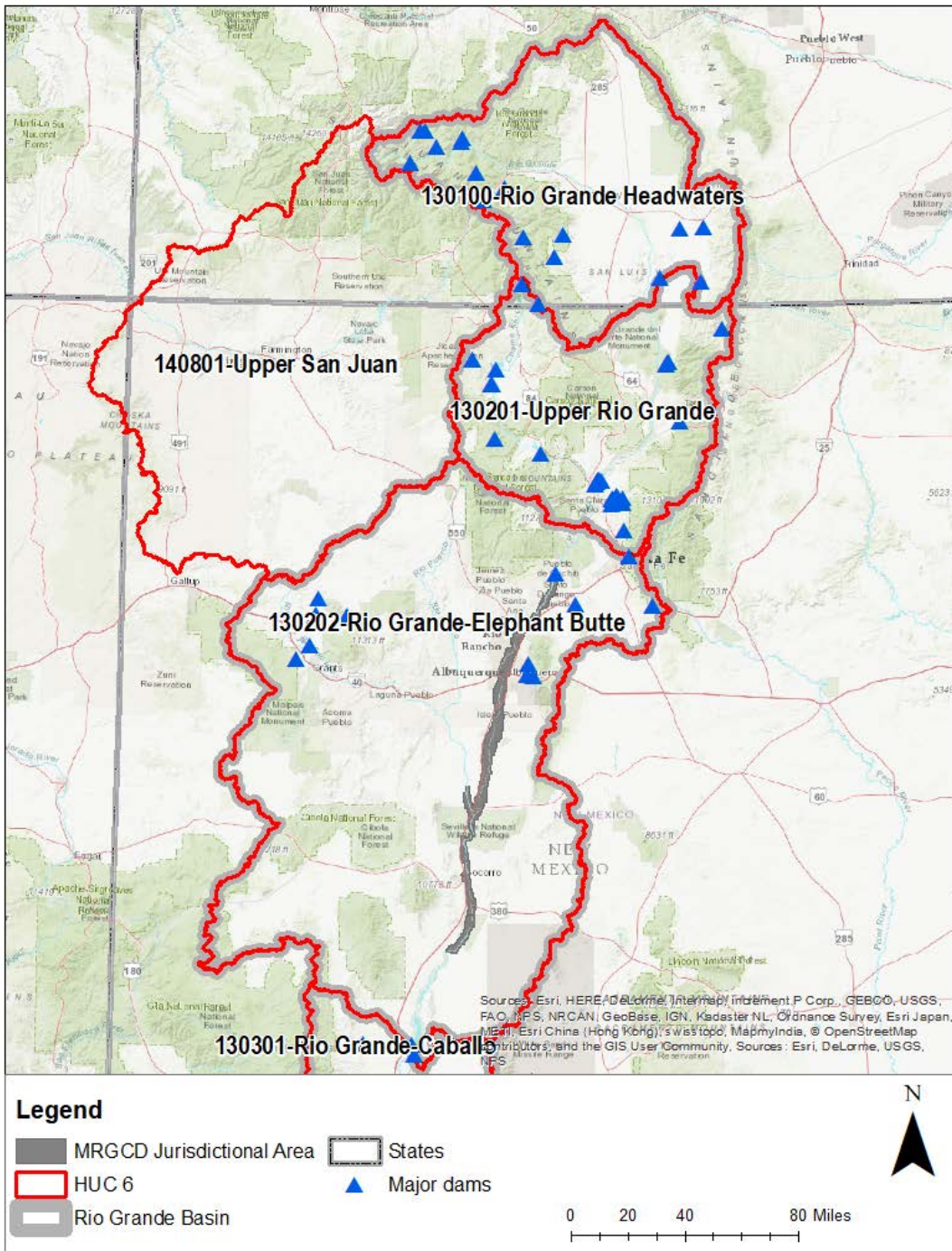


Figure 19: HUC 6 areas

Table 23: HUC 6 sub-watersheds

HUC6	Name	Contributing-Area (km <sup>2</sup> )*	Incremental-Area (km <sup>2</sup> )	States
130100	Rio Grande Headwaters	12,526	12,526	CO
130201	Upper Rio Grande	29,895	17,368	NM, CO
130202	Rio Grande-Elephant Butte	69,736	39,841	NM
140801	Upper San Juan	37,593	37,594	CO, NM
130301	Rio Grande-Caballo	89,403	20,742	MX, NM
130100+130201+130202+140801	Combined	107,329		MX, NM

\*Contributing areas are based on contributing areas for USGS gauges. Total areas might be larger. For area in mi<sup>2</sup> multiply by 0.38.

### Precipitation

Figure 20 shows the projected annual precipitation time series for all 10 selected models and the two emission scenarios evaluated in this project (RCP 4.5 and RCP 8.5) for the combined HUC area. Blue shaded areas include simulations for the 10 selected GCM models for the RCP 4.5 scenario, and yellow shaded areas for the RCP 8.5 scenario. The ensemble average is shown in blue and yellow lines and observed values are shown in red.

The p-value was used to evaluate the null hypothesis that the overall rate of change (slope) is zero, and therefore no temporal trend is observed. The p-value represents the probability that randomly selected points would result in a regression line as far from horizontal (or further) than the observed one. The higher the p-value, the higher the likelihood that a slope different than zero was obtained by chance. The p-value corresponds to the significance level of the hypothesis test. Normally, for trends analysis significant levels of 5% or 10% are applied. A significant level of 10% means that there is a 10% probability that a slope different than zero, which represents a trend, was identified by chance. In this project, trends are considered significant if the p-value is lower than 10%. Based on this criterion, significant (NS) trends are not detected for annual precipitation totals based on model ensemble averages.

Trends at the monthly scale were evaluated for all sub-watersheds. Figure 21 (a) shows the monthly average precipitation for the Rio Grande Headwaters for all models for the RCP 8.5 scenario and for the three different periods of evaluation. Figure 21 (b) shows the projected monthly precipitation rate of change (slope) for the Rio Grande Headwaters for all months, models, and scenarios. The slope represents the average change per year. For example, a slope of -0.1 mm/year (0.004 inches/year) corresponds to a reduction in precipitation of 5 mm (0.2 inches) in 50 years and 10 mm (0.4 inches) in 100 years. Only significant changes are shown (p-value < 10%) in the plot. If p-value is larger than 10% then the slope is set to zero for the purpose of generating the figure. In the figure the box center lines represent the median (Q2), the bottom of the box represents the first quantile (Q1) and the top of the

box represents the third (Q3) quantile. The whiskers are defined by  $Q1-1.5(IQR)$  and  $Q3+1.5(IQR)$ , where IQR is the interquartile range ( $Q3-Q1$ ). Individual points beyond the whisker are considered outliers. Outliers are not necessarily erroneous data. Often apparent outliers represent extremes in the dataset.

Significant trends occur only for the RCP 8.5 scenario. For this scenario, February precipitation is projected to increase, while April, May, and June precipitation are expected to decrease. Precipitation is projected to decrease for April and May for all watersheds evaluated in this study. For the combined area, May precipitation is projected to decrease up to 21% for the first half of the century and up to 43% for the second half of the century.

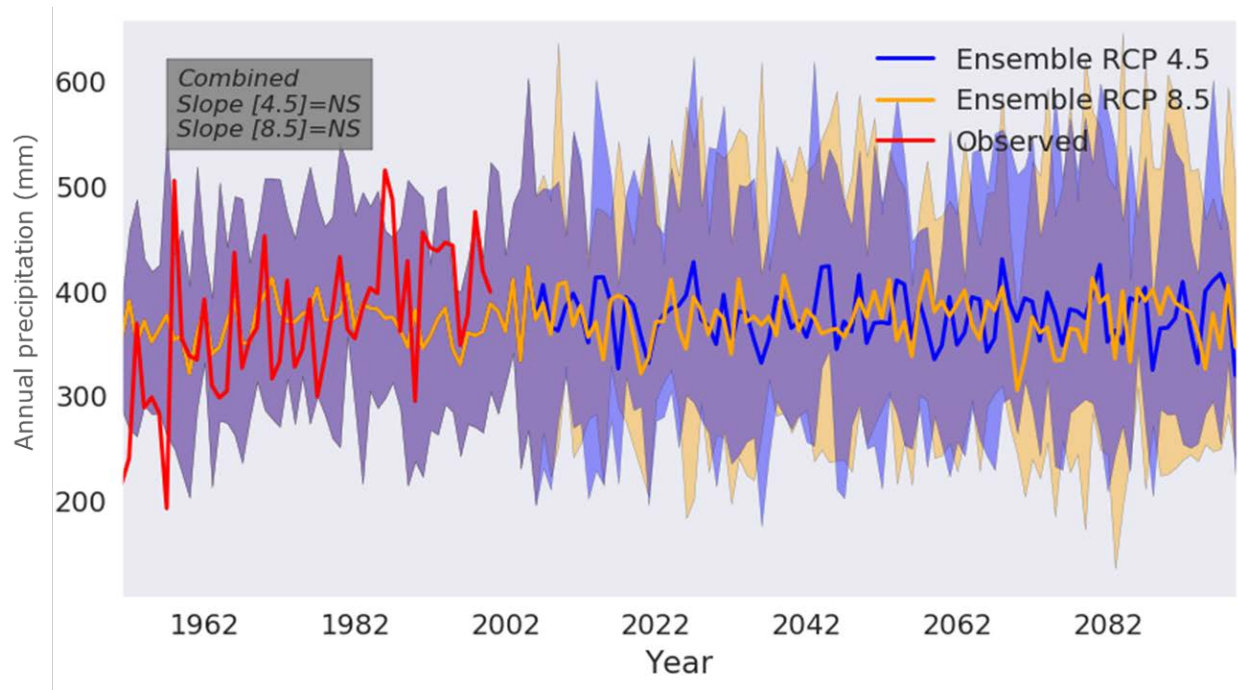


Figure 20: Projected annual precipitation time series - no significant (NS) trend is detected for annual precipitation

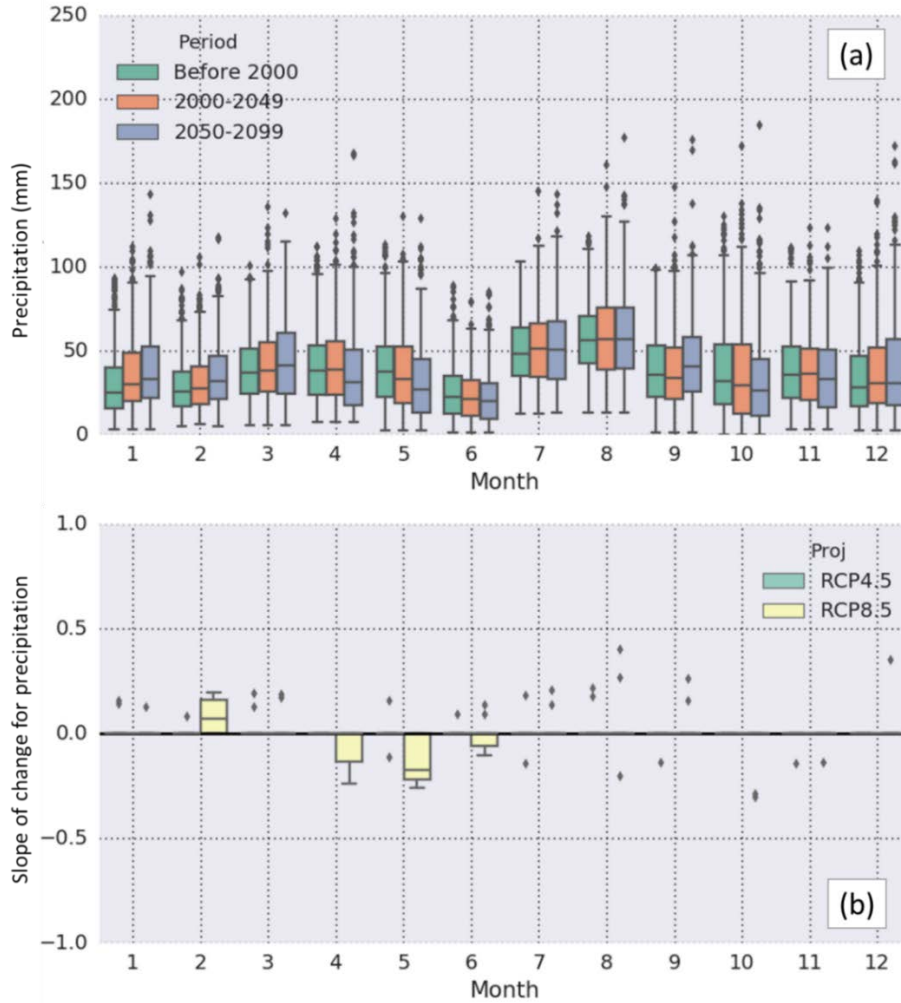


Figure 21: (a) Monthly average precipitation for the Rio Grande Headwaters for all models and evaluation period for the RCP 8.5 scenario (b) Slope of projected change in monthly precipitation for the Rio Grande Headwaters for all months, models, and scenarios  
Only significant changes are shown (p-value < 10%)

### Maximum and minimum temperature

Minimum and maximum temperatures are projected to increase for all months of the year and all sub-watersheds. Table 24 shows the projected mean annual maximum temperature for different HUCs for RCP 4.5 and RCP 8.5 for the period of 2000 to 2049 and 2050 to 2099.

Table 25 shows the same for projected mean annual minimum temperature. All sub-watersheds present similar patterns of changes in minimum and maximum temperatures. Mean annual maximum temperatures are projected to increase on average by approximately 1.8°C (3.2 °F) for RCP 4.5 and 1.9 °C (3.4 °F) for RCP 8.5 by the middle of the century. By the end of the century mean annual maximum temperature are projected to increase on average 3.5°C (6.3 °F) for RCP 4.5 and 5.2 °C (9.3 °F) for RCP 8.5.

As shown in Figure 22, significant changes in temperature are detected for all months, scenarios, and models. This significant increase in temperature is expected to increase potential evapotranspiration, and consequently, increase water demand requirements for irrigation. Higher temperatures will potentially affect soil moisture conditions, the ratio between rainfall and snow for higher altitudes, and the timing of snow melt.

**Table 24: Projected (2000-2049 and 2050-2099) mean annual maximum temperature relative (%) and absolute (°C, multiply by 1.8 to obtain values in °F) change in comparison to observed data for the period of 1950-1999 for RCP 4.5 and RCP 8.5**  
The model ensemble minimum, maximum, and average are included

Relative to observed (%)						
Temp Max	RCP 4.5 (2000-2049)			RCP 8.5 (2000-2049)		
	Min	Max	Average	Min	Max	Average
<b>130100</b>	109.0	120.1	114.5	108.6	121.2	115.8
<b>130201</b>	107.1	116.3	111.8	106.6	117.1	112.8
<b>130202</b>	105.5	112.0	108.8	104.8	112.6	109.6
<b>140801</b>	106.6	114.8	110.9	106.6	115.6	111.8
<b>Combined</b>	106.3	114.0	110.2	105.7	114.7	111.1
Temp Max	RCP 4.5 (2050-2099)			RCP 8.5 (2050-2099)		
	Min	Max	Average	Min	Max	Average
<b>130100</b>	121.1	138.6	128.8	133.9	155.2	143.8
<b>130201</b>	117.8	130.7	123.3	128.5	144.1	135.2
<b>130202</b>	113.5	123.0	117.3	121.7	133.6	126.1
<b>140801</b>	116.3	128.2	121.4	126.1	140.6	132.1
<b>Combined</b>	115.4	126.7	120.1	124.7	138.7	130.3
Absolute change (°C, multiply by 1.8 to obtain values in °F)						
Temp Max	RCP 4.5 (2000-2049)			RCP 8.5 (2000-2049)		
	Min	Max	Average	Min	Max	Average
<b>130100</b>	1.1	2.4	1.8	1.0	2.5	1.9
<b>130201</b>	1.1	2.4	1.8	1.0	2.5	1.9
<b>130202</b>	1.1	2.3	1.7	0.9	2.5	1.9
<b>140801</b>	1.1	2.4	1.8	1.1	2.6	1.9
<b>Combined</b>	1.1	2.4	1.7	1.0	2.5	1.9
Temp Max	RCP 4.5 (2050-2099)			RCP 8.5 (2050-2099)		
	Min	Max	Average	Min	Max	Average
<b>130100</b>	2.5	4.6	3.5	4.1	6.6	5.3
<b>130201</b>	2.6	4.6	3.5	4.2	6.6	5.2

<b>130202</b>	2.6	4.5	3.4	4.2	6.5	5.1
<b>140801</b>	2.7	4.7	3.5	4.3	6.7	5.3
<b>Combined</b>	2.6	4.5	3.4	4.2	6.6	5.2

Table 25: Projected (2000-2049 and 2050-2099) mean annual minimum temperature relative (%) and absolute (°C, multiply by 1.8 to obtain values in °F) change in comparison to observed data for the period of 1950-1999 for RCP 4.5 and RCP 8.5  
The model ensemble minimum, maximum, and average are included

Relative to observed (%)						
Temp Min	RCP 4.5 (2000-2049)			RCP 8.5 (2000-2049)		
	Min	Max	Average	Min	Max	Average
<b>130100</b>	167.0	179.0	175.0	165.7	178.3	171.8
<b>130201</b>	138.2	165.7	153.5	136.0	165.3	147.8
<b>130202</b>	183.3	250.4	209.8	192.4	258.2	223.9
<b>140801</b>	126.0	202.8	158.5	133.8	214.5	176.0
<b>Combined</b>	102.7	159.0	120.8	101.6	166.2	133.9
Temp Min	RCP 4.5 (2050-2099)			RCP 8.5 (2050-2099)		
	Min	Max	Average	Min	Max	Average
<b>130100</b>	136.9	164.5	150.9	109.8	141.1	123.6
<b>130201</b>	100.9	139.9	115.0	107.3	169.3	142.1
<b>130202</b>	258.7	377.3	316.1	369.3	512.6	439.2
<b>140801</b>	221.9	373.4	305.0	368.7	543.6	469.0
<b>Combined</b>	169.7	292.1	232.8	284.8	436.6	364.6
Absolute change (°C, multiply by 1.8 to obtain values in °F)						
Temp Min	RCP 4.5 (2000-2049)			RCP 8.5 (2000-2049)		
	Min	Max	Average	Min	Max	Average
<b>130100</b>	1.3	2.1	1.6	1.4	2.2	1.8
<b>130201</b>	1.1	2.0	1.5	1.1	2.0	1.7
<b>130202</b>	1.1	1.9	1.4	1.2	2.0	1.6
<b>140801</b>	1.3	2.1	1.6	1.4	2.2	1.8
<b>Combined</b>	1.1	2.0	1.5	1.2	2.1	1.6
Temp Min	RCP 4.5 (2050-2099)			RCP 8.5 (2050-2099)		
	Min	Max	Average	Min	Max	Average
<b>130100</b>	2.2	4.0	3.1	3.7	5.7	4.8
<b>130201</b>	1.9	3.7	2.9	3.4	5.4	4.6
<b>130202</b>	2.0	3.6	2.8	3.5	5.3	4.4
<b>140801</b>	2.3	3.8	3.1	3.7	5.5	4.8
<b>Combined</b>	2.1	3.6	2.9	3.5	5.4	4.5

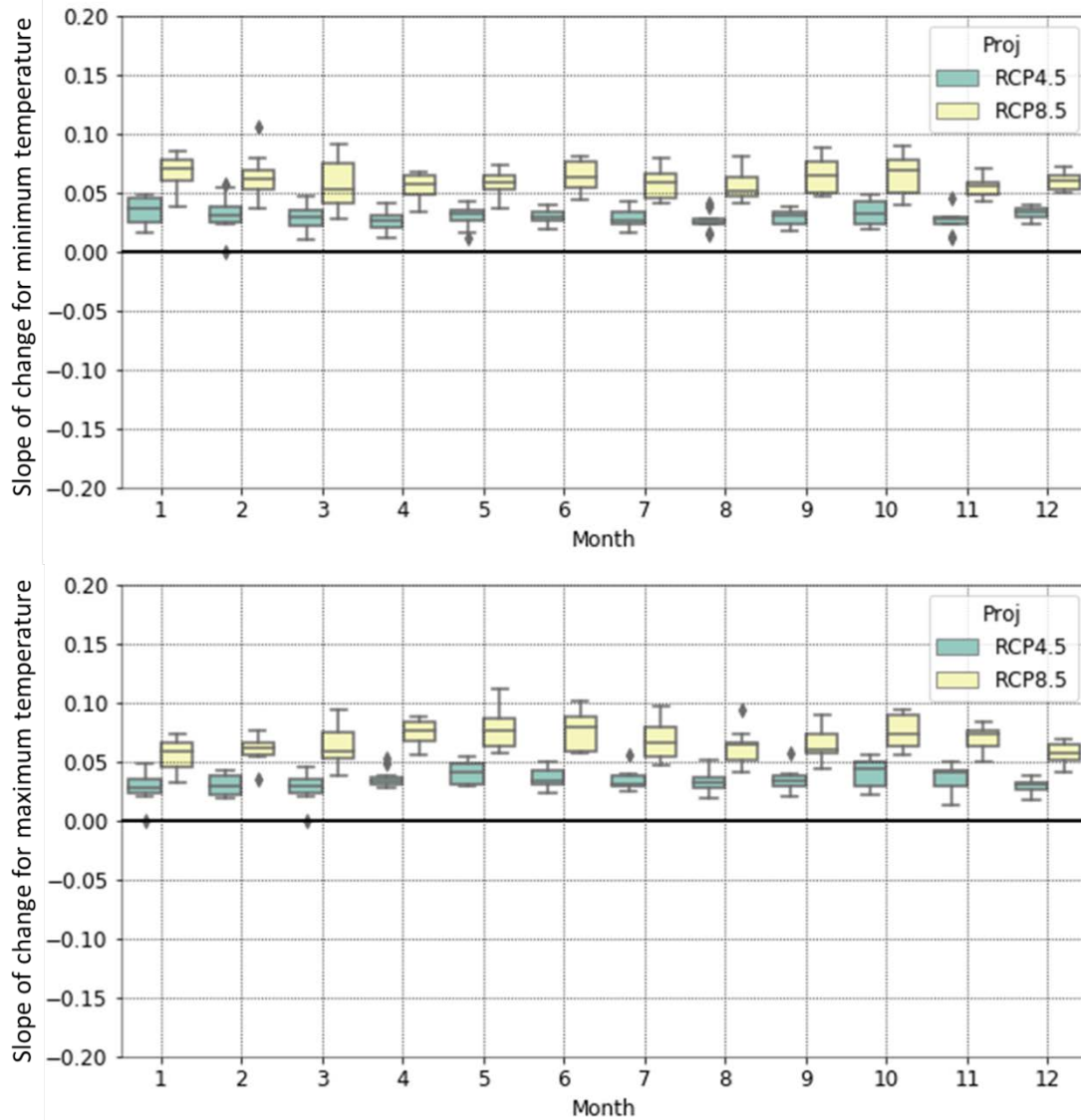


Figure 22: Slope of projected change in monthly minimum (a) and maximum (b) temperature for the Rio Grande Headwaters for all months, models, and scenarios  
Only significant changes are shown (p-value<10%)

### Snow Water Equivalent (SWE)

SWE is relevant for the Rio Grande Headwaters and upper basins, and for the Upper San Juan Basin. Table 26 shows the projected May snow water equivalent (mm, multiply by 0.039 to obtain values in inches) decrease in relation to the average snow water equivalent (1950-1999) for the period of 2000-2049 and 2050-2099 for RCP 4.5 and RCP 8.5. Figure 23 shows projected slope of change in monthly snow water equivalent for these three basins. Only significant changes are shown (p-value smaller than 10%). SWE is projected to decrease for all basins and months for which snow occurs. Changes are relatively higher for the Upper Rio Grande Basin, but the loss of water volume is most significant for the Rio Grande Headwaters, where the volume of water stored as snow is higher. Changes are most significant for the month of May.

For the Rio Grande Headwaters, the May SWE is projected to decrease on average by 14 mm (19.4%, 0.54 inches) for the first half of the century and 31.1 mm (42.8%, 1.21 inches) for the second half of the century for RCP 4.5, and by 13.5 mm (0.52 inches) for the first half of the century and 47.7 mm (1.86 inches) for the second half of the century for RCP 8.5. The maximum projected decrease for this basin for the first half of the century is 27.7 mm (1.08 inches) for the first half of the century and 67 mm (2.6 inches) for the second half of the century.

For the Upper Rio Grande Basin, the May SWE is projected to decrease on average by 8.1 mm (36.1%, 0.32 inches) for the first half of the century and 15.5 mm (69.1%, 0.6 inches) for the second half of the century for RCP 4.5, and by 8.6 mm (0.33 inches) for the first half of the century and 19.5 mm (0.76 inches) for the second half of the century for RCP 8.5. The maximum projected decrease for this basin for the first half of the century is 11.8 mm (0.46 inches) and 21.9 mm (0.85 inches) for the second half of the century.

Changes in the SWE for the Upper SJC are also significant and might affect the delivery of water to the SJC system.

Table 26: Projected (2000-2049 and 2050-2099) may snow water equivalent (mm, multiply by 0.039 to obtain values in inches) relative (%) and absolute (mm) change in comparison to data simulated by VIC using observed data for the period of 1950-1999 for RCP 4.5 and RCP 8.5 The model ensemble minimum, maximum, and average are included

<b>Relative to observed (%)</b>						
<b>May SWE</b>	<b>RCP 4.5 (2000-2049)</b>			<b>RCP 8.5 (2000-2049)</b>		
	<b>Min</b>	<b>Max</b>	<b>Average</b>	<b>Min</b>	<b>Max</b>	<b>Average</b>
<b>130100</b>	61.8	91.5	80.6	63.2	102.3	81.4
<b>130201</b>	51.6	76.5	63.9	47.4	85.3	61.7
<b>130202</b>	38.5	67.2	49.7	36.1	70.3	48.6
<b>140801</b>	61.4	94.3	82.8	64.9	96.3	82.2
<b>Combined</b>	59.4	85.9	76.6	59.8	98.2	76.8
<b>May SWE</b>	<b>RCP 4.5 (2050-2099)</b>			<b>RCP 8.5 (2050-2099)</b>		
	<b>Min</b>	<b>Max</b>	<b>Average</b>	<b>Min</b>	<b>Max</b>	<b>Average</b>
<b>130100</b>	22.2	79.7	57.2	7.6	57.1	34.3
<b>130201</b>	8.6	68.3	30.9	2.4	37.9	13.3
<b>130202</b>	1.3	48.6	17.7	0.0	18.3	6.5
<b>140801</b>	26.1	78.0	60.2	7.8	54.0	37.6
<b>Combined</b>	19.0	76.7	51.0	6.4	52.4	29.4
<b>Absolute change (mm, multiply by 0.039 to obtain values in inches)</b>						
<b>May SWE</b>	<b>RCP 4.5 (2000-2049)</b>			<b>RCP 8.5 (2000-2049)</b>		
	<b>Min</b>	<b>Max</b>	<b>Average</b>	<b>Min</b>	<b>Max</b>	<b>Average</b>
<b>130100</b>	-27.7	-6.1	-14.0	-26.7	1.7	-13.5
<b>130201</b>	-10.9	-5.3	-8.1	-11.8	-3.3	-8.6
<b>130202</b>	-0.5	-0.3	-0.4	-0.5	-0.2	-0.4
<b>140801</b>	-19.1	-2.8	-8.5	-17.4	-1.8	-8.8
<b>Combined</b>	-8.4	-2.9	-4.9	-8.4	-0.4	-4.8
<b>May SWE</b>	<b>RCP 4.5 (2050-2099)</b>			<b>RCP 8.5 (2050-2099)</b>		
	<b>Min</b>	<b>Max</b>	<b>Average</b>	<b>Min</b>	<b>Max</b>	<b>Average</b>
<b>130100</b>	-56.4	-14.7	-31.1	-67.0	-31.1	-47.7
<b>130201</b>	-20.5	-7.1	-15.5	-21.9	-13.9	-19.5
<b>130202</b>	-0.8	-0.4	-0.6	-0.8	-0.6	-0.7
<b>140801</b>	-36.6	-10.9	-19.7	-45.7	-22.8	-30.9
<b>Combined</b>	-16.8	-4.8	-10.2	-19.5	-9.9	-14.7

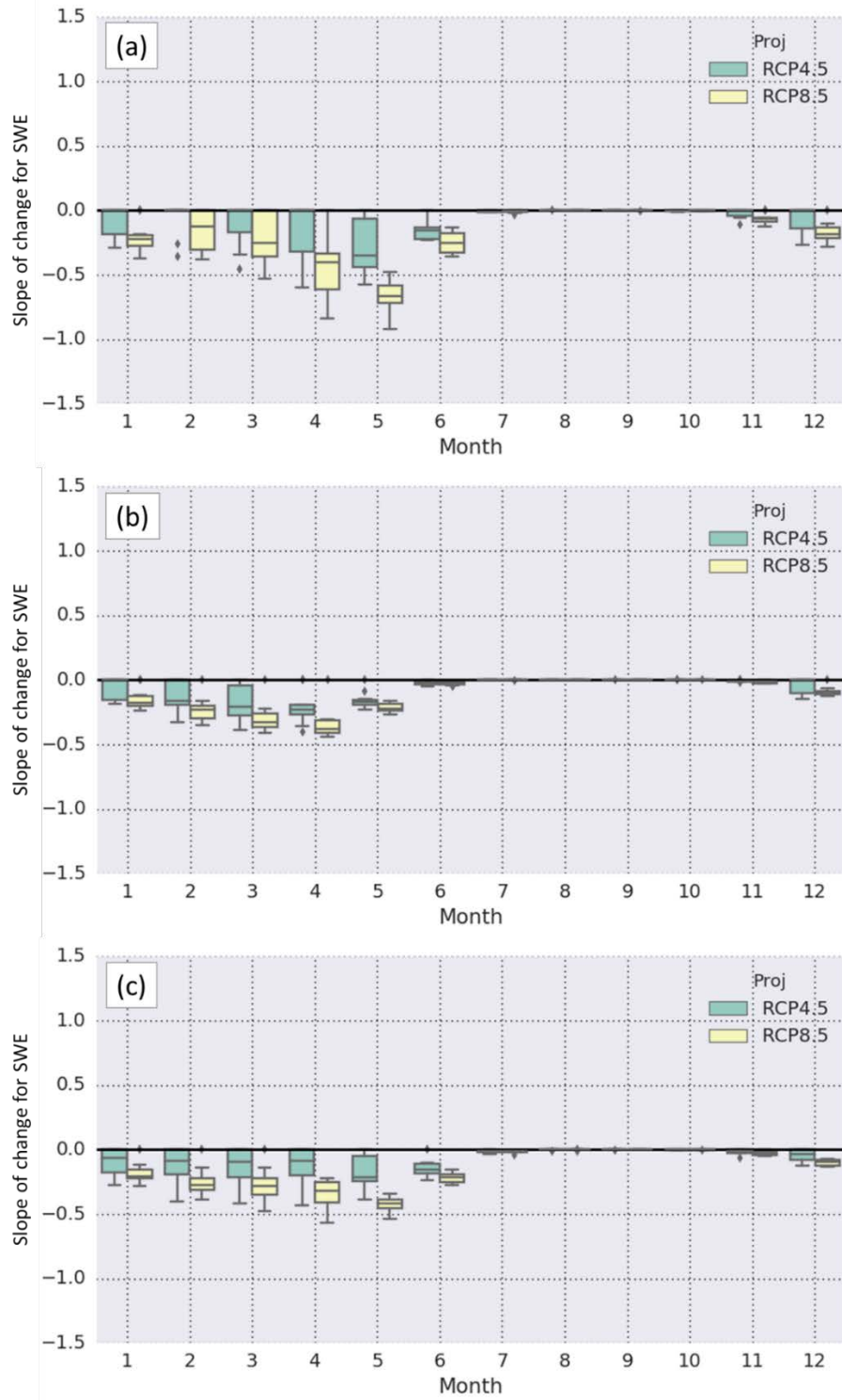


Figure 23: Slope of projected change in monthly snow water equivalent for the (a) Rio Grande Headwaters, (b) Upper Rio Grande, and (c) San Juan Basin for all months, models, and scenarios. Only significant changes are shown (p-value<10%)

### Potential and actual evapotranspiration

With increasing temperature, open water surface potential evapotranspiration is expected to increase. Higher evapotranspiration is expected to affect soil moisture and to increase irrigation requirements. Changes in annual potential evapotranspiration and actual evapotranspiration were evaluated for the area irrigated by MRGCD (HUC 130202).

Figure 24 (a) shows the slope of projected change in monthly open water potential evapotranspiration for the HUC area served by the MRGCD. Significant increases occur for both scenarios, mainly from March to November. Potential evapotranspiration increase have the potential to significant affect irrigation water demand. Annual potential evapotranspiration for the area irrigated by MRGCD is expected to increase on average by approximately 5% for both emission scenarios for the first half of the century. By the end of the century potential evapotranspiration is expected to increase on average by 10% for the RCP 4.5 and 15% for RCP 8.5. The maximum increase projected by a single model is 20%. Assuming irrigation techniques, crops, and served areas are kept constant, this percentage increase corresponds to projected increase in irrigation demand.

Figure 24 (b) shows the slope of projected change in monthly actual evapotranspiration for the HUC area served by the MRGCD. Actual evapotranspiration increases for some of the winter and fall months, but actually decreases for June and July. Decrease in actual evapotranspiration is caused by the decrease in soil water availability during these months.

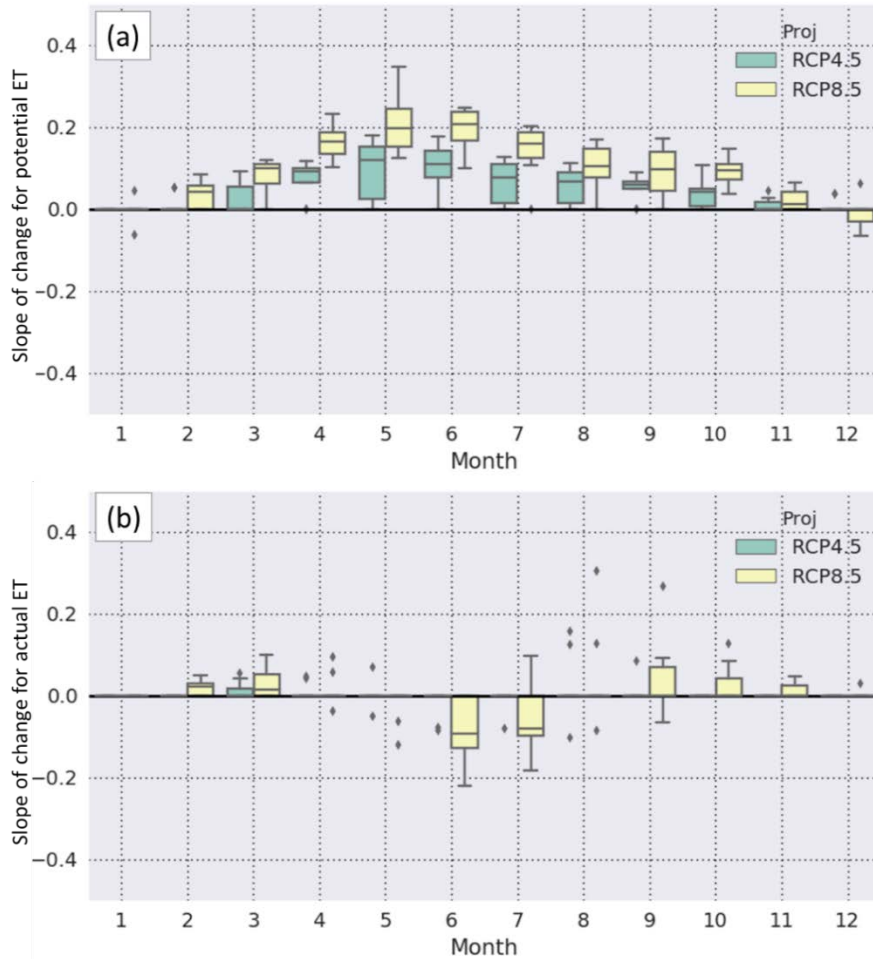


Figure 24: (a) Slope of projected change in monthly open water potential evapotranspiration for the HUC area served by the MRGCD for all months, models, and scenarios. (a) Slope of projected change in monthly actual evapotranspiration for the combined area for all months, models, and scenarios. Only significant changes are shown (p-value<10%)

### Soil moisture content

With increasing temperature and consequently potential evapotranspiration, soil moisture is projected to decrease for the combined area for all months of the year. Figure 25 (a) shows the seasonality of monthly average soil moisture for the combined area for all models and periods for the RCP 8.5 scenario. Soil moisture in the combined area is the lowest for the period of July to October, when irrigation is mostly needed. Figure 25 (a) shows the projected slope of change in monthly soil moisture for the combined area for all months, models, and scenarios. Only significant changes are shown (p-value<10%) in the plot. Significant decrease in soil moisture occurs for all scenarios and months, but rates of changes are higher for June and July. For agricultural production, lower soil moisture values will have to be compensated by increasing irrigation rates.

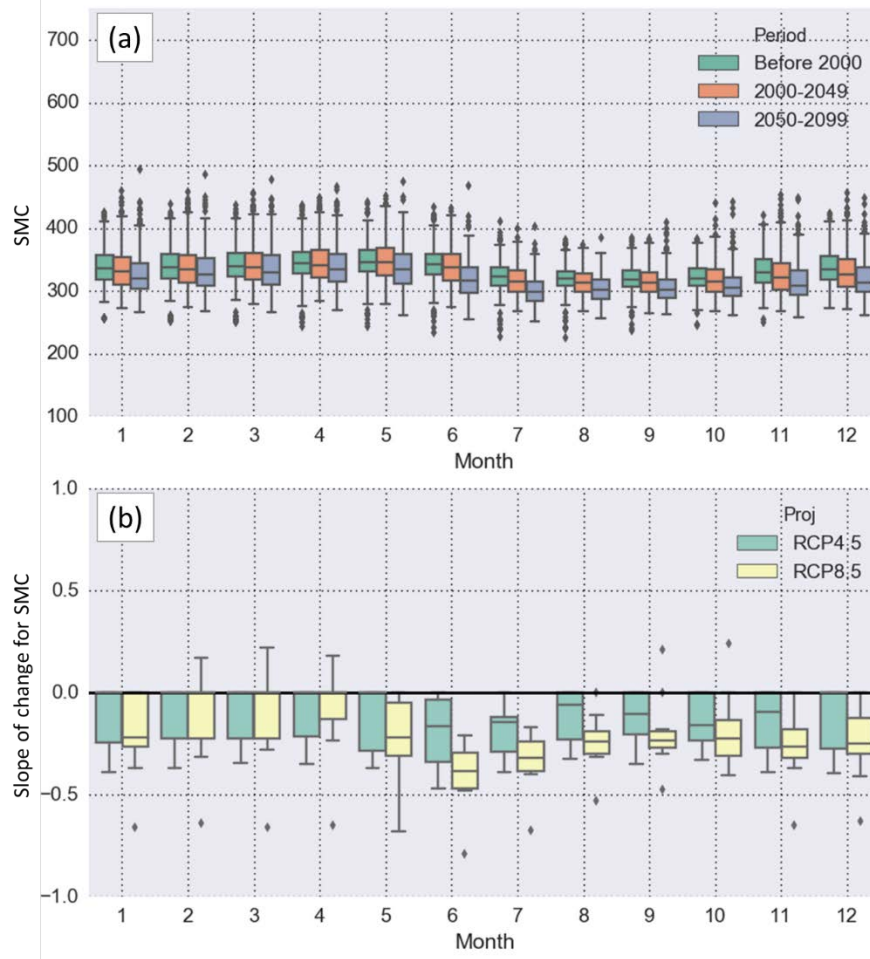


Figure 25: (a) Monthly average soils moisture for the combined area for all models and evaluation period for the RCP 8.5 scenario (b) Slope of projected change in monthly soil moisture for the combined area for all months, models, and scenarios Only significant changes are shown (p-value<10%)

### Runoff

With increasing evaporation and decreasing soil moisture, hydrological losses are expected to increase while runoff is expected to decrease. Runoff is also affected by other factors, including the temporal and spatial distribution of rainfall.

Table 27 shows the projected (2000-2049 and 2050-2099) annual runoff relative (%) and absolute (mm, multiply by 0.039 to obtain values in inches) change in comparison to values simulated by VIC using observed data for the period of 1950-1999 for RCP 4.5 and RCP 8.5. Note that there is a large difference between the models and on average changes in annual runoff are more significant in snow dominant basins. Even for these basins, projected changes in annual runoff can either be positive or negative depending on the model, but the ensemble average indicates a decrease in annual runoff.

While changes in annual runoff might not be consistent for all models, the changes in the seasonality of runoff in snow dominant basins are identified by all the models as shown in Figure 26. These changes are mainly caused by increasing temperatures and earlier snow melt. For the Rio Grande Headwaters (130100) during the period of 2000-2049, May runoff increases while June runoff decreases. Snowmelt for the For the Upper Rio Grande (130201) tends to occur earlier than for the Rio Grande Headwaters (130100). For the Upper Rio Grande (130201) during the period of 2000-2049, March and April runoff increases while May and June runoff decreases. Changes for the Rio Grande-Elephant Butte (130202) are much less significant, especially due to the fact that basin average runoff volumes observed in this basin are also much lower than the volume observed in the Rio Grande Headwaters and in the Upper Rio Grande.

Table 27: Projected (2000-2049 and 2050-2099) annual runoff relative (%) and absolute (mm, multiply by 0.039 to obtain values in inches) change in comparison to values simulated by VIC using observed data for the period 1950-1999 for RCP 4.5 and RCP 8.5

The model ensemble minimum, maximum, and average are included

Relative to observed (%)						
Annual runoff	RCP 4.5 (2000-2049)			RCP 8.5 (2000-2049)		
	Min	Max	Average	Min	Max	Average
<b>130100</b>	82.9	117.4	94.0	61.3	130.5	93.3
<b>130201</b>	98.2	134.5	113.8	83.6	154.2	112.1
<b>130202</b>	86.7	111.1	97.1	75.5	129.5	95.7
<b>140801</b>	82.4	112.8	93.4	67.8	123.6	92.8
<b>Combined</b>	87.8	120.3	99.6	71.6	136.2	98.5
Annual runoff	RCP 4.5 (2050-2099)			RCP 8.5 (2050-2099)		
	Min	Max	Average	Min	Max	Average
<b>130100</b>	55.6	105.0	84.1	44.1	108.7	75.2
<b>130201</b>	79.1	122.6	101.0	63.4	123.2	96.9
<b>130202</b>	83.5	110.5	91.8	74.5	116.2	92.1
<b>140801</b>	60.4	101.0	84.7	51.1	103.0	77.0
<b>Combined</b>	68.4	110.6	90.0	55.6	111.8	84.3
Absolute change (mm, multiply by 0.039 to obtain values in inches)						
Annual runoff	RCP 4.5 (2000-2049)			RCP 8.5 (2000-2049)		
	Min	Max	Average	Min	Max	Average
<b>130100</b>	-16.4	16.7	-5.7	-37.0	29.2	-6.4
<b>130201</b>	-1.0	18.6	7.4	-8.9	29.2	6.5
<b>130202</b>	-2.0	1.7	-0.4	-3.6	4.4	-0.6
<b>140801</b>	-13.1	9.5	-4.9	-23.9	17.5	-5.3
<b>Combined</b>	-4.9	8.2	-0.1	-11.4	14.5	-0.6
Annual runoff	RCP 4.5 (2050-2099)			RCP 8.5 (2050-2099)		
	Min	Max	Average	Min	Max	Average
<b>130100</b>	-42.4	4.7	-15.2	-53.5	8.4	-23.8
<b>130201</b>	-11.3	12.2	0.5	-19.8	12.5	-1.7
<b>130202</b>	-2.5	1.6	-1.2	-3.8	2.4	-1.2
<b>140801</b>	-29.4	0.8	-11.4	-36.3	2.2	-17.1
<b>Combined</b>	-12.7	4.2	-4.0	-17.8	4.8	-6.3

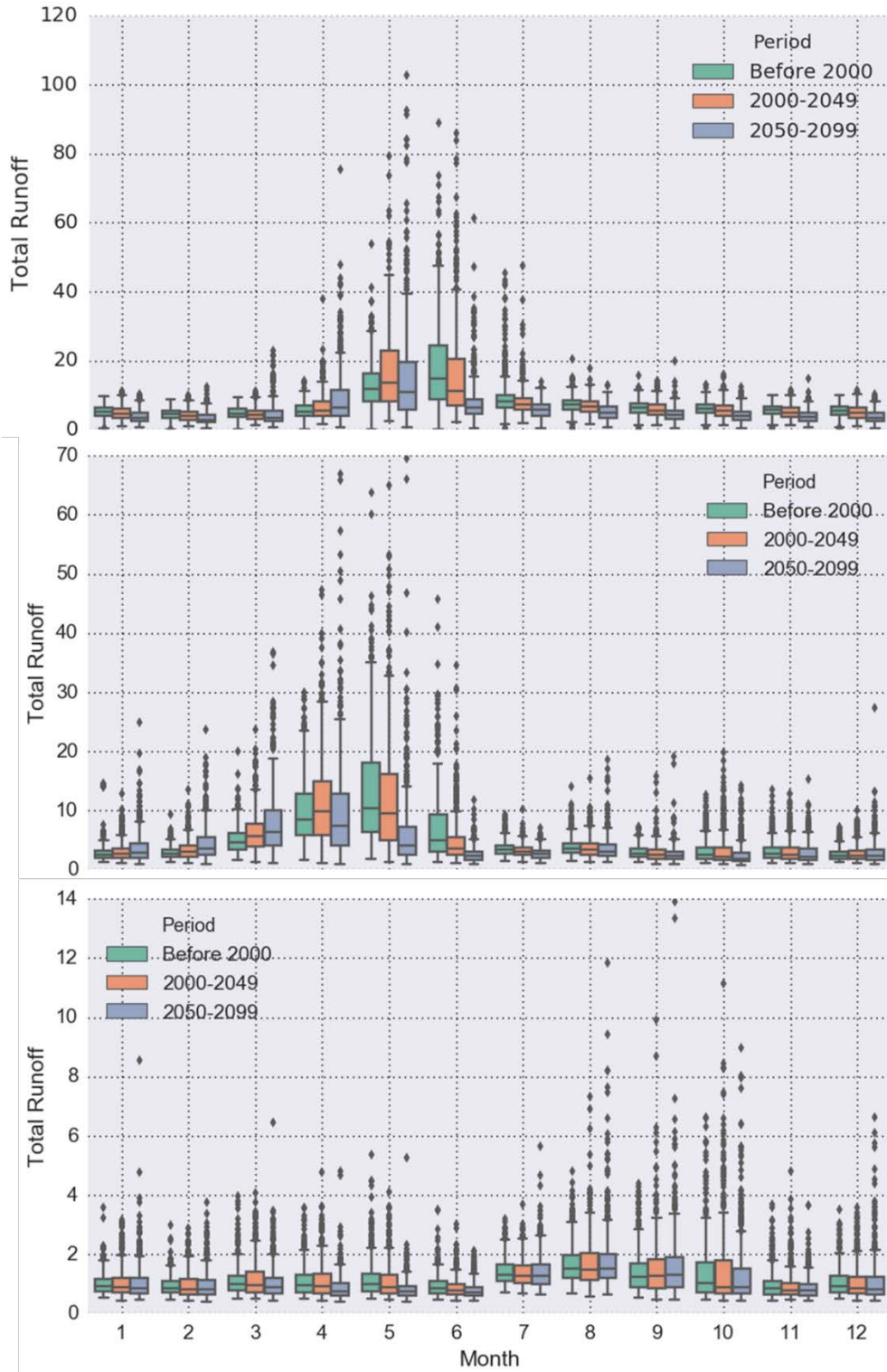


Figure 26: Monthly average runoff for all models and evaluation period for the RCP 8.5 scenario for the (a) Rio Grande Headwaters (130100), (b) Upper Rio Grande (130201), and (c) Rio Grande-Elephant Butte (130202)

## BCSD-CMIP5 streamflow projections

The effects of climate change on the different components of the hydrological cycle were evaluated in the previous section. In this section the effects of climate change on streamflow are evaluated. Streamflow is an integrated response of the watershed. Therefore, all components previously analyzed affect the streamflow response in an integrated way.

BCSD-CMIP5 streamflow projections are available for few locations of interest. Runoff produced by the gridded VIC model using observed or projected data were routed to generate streamflow based on the Lohmann et al (1996) routing model. The procedure consists of identifying the upstream basin tributary to a given downstream runoff location based on flow accumulation and flow direction classification from a digital elevation model. The VIC routing model is then applied to translate gridded surface runoff components above the runoff location into streamflow. Runoff, as evaluated in the previous section, relates to the amount of water that is transported to the river in each sub-watershed and how it is impacted by climate change locally. Streamflow is a response of the accumulated effect of climate change on upstream areas and how it affects the volume of water that is available in the channel.

Two sets of routing model implementations were used. The first set consists of the West-Wide Climate Risk Assessments (WWCRA) sites also used by the USBR (2013) study in the CMIP3 version. The second ensemble refers to the location points developed for the National Center for Atmospheric Research (NCAR, 2014). These datasets provide daily routed flow, surface runoff, and baseflow for the points of interest listed in Table 9 and shown in Figure 3.

**Table 28: NCAR and WWCRA sites with available BCSD-CMIP5 streamflow projections. Points highlighted in red are the focus of this report**

NCAR sites				
Side ID	Latitude	Longitude	Loc	Name
VLCTO	37.37800	-107.57300	COLO	Vallecito
NAVJO	36.80000	-107.61200	COLO	Navajo
LOBAT	37.07800	-105.75600	RIOG	Grande R nr Lobatos CO
CHAMA	36.07400	-106.11100	RIOG	Chama R nr Chamita NM
ALBUQ	35.08900	-106.68000	RIOG	Grande R at Albuquerque NM
DELNO	37.68900	-106.46100	RIOG	Grande R nr Del Norte CO
WWCRA sites				
Site ID	Latitude	Longitude		Site_name
28	37.07861	-105.756	RIOG	Rio Grande near Lobatos
29	36.31833	-106.597	RIOG	Rio Chama near Abiquiu
30	35.87624	-106.143	RIOG	Rio Grande near Otowi gauge
31	33.15634	-107.191	RIOG	Rio Grande at Elephant Butte Dam

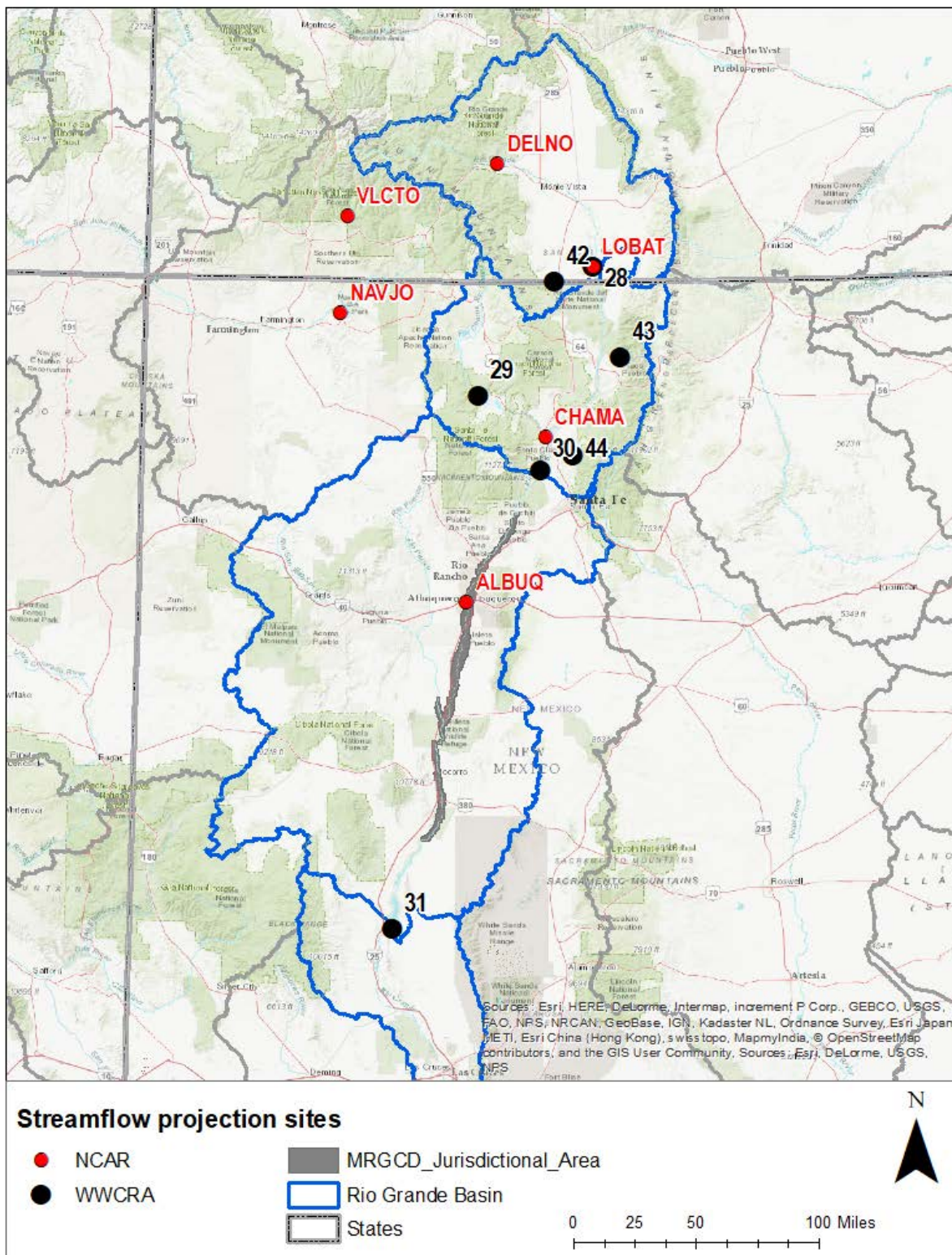


Figure 27: NCAR and WWCRA sites with available BCSD-CMIP5 streamflow projections

Figure 28 shows the projected annual streamflow time series for the sites highlighted in red in Table 9. Blue shaded areas include simulations for the 10 selected GCM models for the RCP 4.5 scenario, and yellow shaded areas for the RCP 8.5 scenario. The ensemble average is shown in blue and yellow lines and observed values are shown in red. The text box shows the site ID and the rate of change (slope) for both scenarios. Negative trends in streamflow are observed for all sites. Trends are higher for the RCP 8.5 scenario and for the period of 2050 to 2099. Negative trends become more significant for the second half of the 21st century.

Table 29 contains the projected (2000-2049 and 2050-2099) annual runoff relative (%) change in comparison to the average mean annual streamflow observed for the period of 1950-1999 for RCP 4.5 and RCP 8.5. The model ensemble average indicates decreasing trends in streamflow for all scenarios and sites. However, the range of projections provided by the different models is very large and both positive and negative trends are projected. For example, for the Rio Grande near the Otowi Bridge gauge location, projected mean annual streamflow for the RCP 8.5 scenario for the period of 2000 to 2049 varies between 68.1% (cmcc-cm5) to 138.1% (cnrm-cm5) of the observed mean annual streamflow for the period of 1950-1999. Only one model (cnrm-cm5) projected increase in annual streamflow. Five models predicted less than a 5% change in total annual streamflow. Discrepancies are high for all locations especially for the period of 2000-2049. For 2050 to 2099 decreasing trends are stronger as can also be seen in Figure 28.

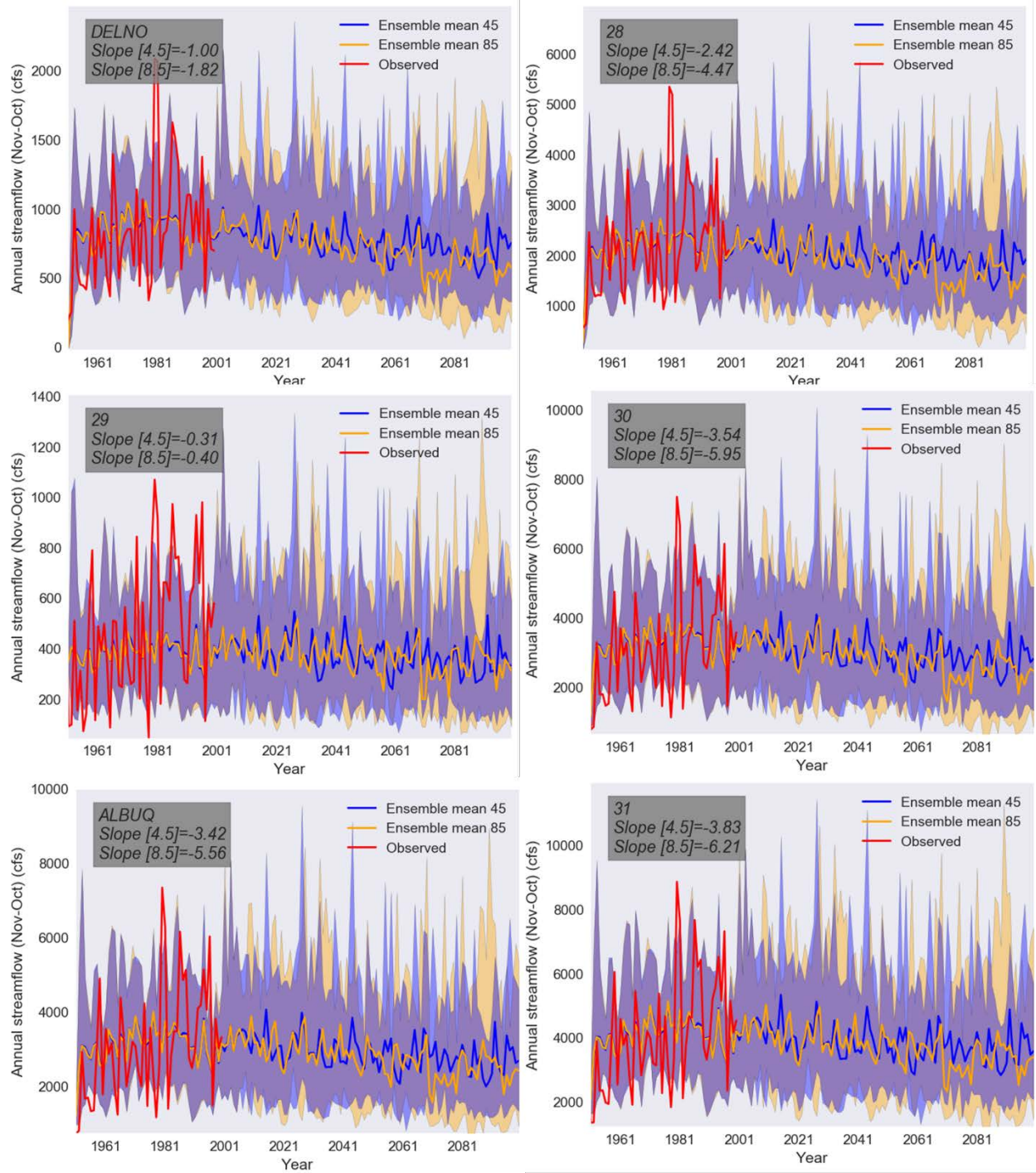


Figure 28: Projected streamflow time series. The slope of change for RCP 4.5 and RCP 8.5 are shown in the text box

Table 29: Projected (2000-2049 and 2050-2099) annual runoff relative (%) change in comparison to the average mean annual streamflow observed for the period of 1950-1999 for RCP 4.5 and RCP 8.5  
The model ensemble minimum, maximum, and average are included

Streamflow	RCP 4.5 (2000-2049)			RCP 8.5 (2000-2049)		
	Min	Max	Average	Min	Max	Average
<b>DELNO</b>	83.0	122.2	96.4	63.4	134.1	95.8
<b>LOBAT</b>	82.9	124.5	98.2	64.2	137.7	97.1
<b>CHAMA</b>	82.4	122.8	102.9	73.8	140.8	101.9
<b>28</b>	82.6	123.3	97.9	64.8	136.3	96.8
<b>29</b>	82.4	122.5	102.0	70.4	141.1	101.3
<b>30</b>	81.8	123.2	99.0	68.1	138.1	97.7
<b>ALBUQ</b>	81.4	124.0	99.3	68.6	140.2	98.0
<b>31</b>	83.1	121.9	99.7	72.0	138.1	98.4
<b>VLCTO</b>	80.7	115.4	94.0	69.7	123.6	93.2
<b>NAVJO</b>	79.7	116.3	95.3	65.4	129.8	94.4
Streamflow	RCP 4.5 (2050-2099)			RCP 8.5 (2050-2099)		
	Min	Max	Average	Min	Max	Average
<b>DELNO</b>	55.5	110.1	86.5	47.1	110.3	76.7
<b>LOBAT</b>	57.9	111.2	87.9	44.9	113.6	78.1
<b>CHAMA</b>	71.0	111.7	92.9	57.2	114.8	91.1
<b>28</b>	58.4	110.0	87.6	45.7	112.1	77.9
<b>29</b>	67.1	109.7	91.9	55.4	113.7	89.5
<b>30</b>	63.0	110.6	88.3	48.4	112.4	80.8
<b>ALBUQ</b>	63.9	111.3	88.3	48.5	112.9	81.3
<b>31</b>	69.2	111.9	90.0	54.3	112.5	84.2
<b>VLCTO</b>	60.7	105.2	85.8	50.8	104.9	76.2
<b>NAVJO</b>	58.2	102.2	85.4	48.8	103.2	77.2

Changes in the seasonality of streamflow caused by earlier snowmelt can aggravate drought conditions in the future. Even though the direction of change in total annual streamflow projected by different GCMs are not always consistent, changes in the seasonality of streamflow are projected by all the models. Figure 29 (a) shows the monthly average streamflow for the Rio Grande near the Otowi Bridge gauge location for all models and scenarios for the observed and projected periods. Often apparent outliers represent extremes in the dataset (e.g. dry or wet months). Based on these figure, monthly streamflow variability becomes much larger during the projection period. Streamflow at the Otowi Bridge gauge increases for the months of March and April, and decreases for the months of May, June and July.

Figure 29 (b) shows the slope of change in streamflow for the Rio Grande near the Otowi Bridge gauge location for all months and models, for the RCP 4.5 and RCP 8.5 scenarios. Based on the RCP 8.5 scenario, positive significant trends are projected for March and April. This increase is likely the result of earlier snowmelt. However, since streamflow volumes during these months are relatively low as shown in Figure 29 (a), the total gain in streamflow volume as a result of this projected increase is not substantial. Negative trends are also projected for January, and June to December for RCP 4.5 and January and May to December for RCP 8.5. The major loss in streamflow volume occurs in June. Negative trends in streamflow volumes also occur for the summer and fall months, which is likely the result of higher evaporation caused by higher temperatures which result in drier soils and higher hydrologic losses.

Figure 30 shows the slope of change in streamflow for the (a) Rio Chama near Chamita NM (CHAMA), (b) Rio Grande at Albuquerque NM (ALBUQ) and Navajo (NAVJO) in the Colorado River Basin. The patterns for the Rio Chama and Rio Grande at Albuquerque are similar to the ones observed for the Rio Grande at the Otowi Bridge gauge, with exception of the month of April for the Rio Chama, for which no increase in streamflow is projected. The pattern for Navajo in the Colorado Basin differs from the locations in the Rio Grande for the month of May. For this location streamflow is projected to increase for this month.

Figure 31 (a) shows the mean ensemble projected annual streamflow for the period of 2000-2049 and 2050-2099 for RCP 4.5 and RCP 8.5 expressed as the percentage of observed mean annual streamflow for the period of 1950-1999. Changes for the Colorado River locations are more accentuated with a maximum decrease of 23.8% on the total annual streamflow for the VLCTO Basin. The same plot is shown for the April (Figure 31 b) and June (Figure 31 c) monthly streamflows. For all the sites and scenarios an increase in monthly streamflow is projected for April, and a decrease is projected for June. For the period of 2050 to 2099, projected streamflow for June is less than half of what has been observed in the period of 1950 to 2000.

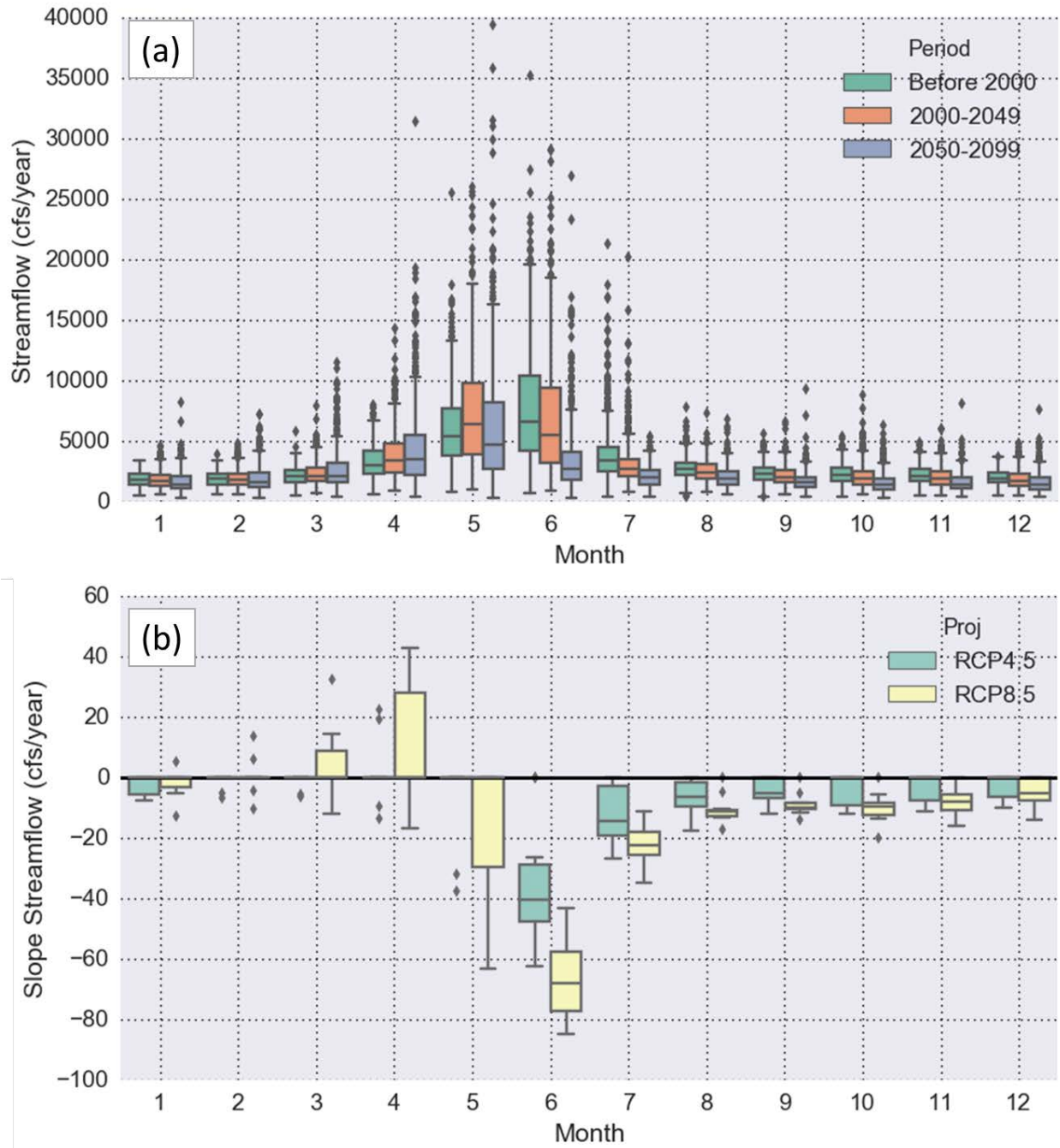


Figure 29: (a) Monthly average streamflow for the Rio Grande near the Otowi Bridge gauge location for all models for the RCP 8.5 scenario (b) Slope of projected change in streamflow for the Rio Grande near Otowi Bridge gauge for all months, models, and scenarios  
 Only significant changes are shown (p-value<0.1)

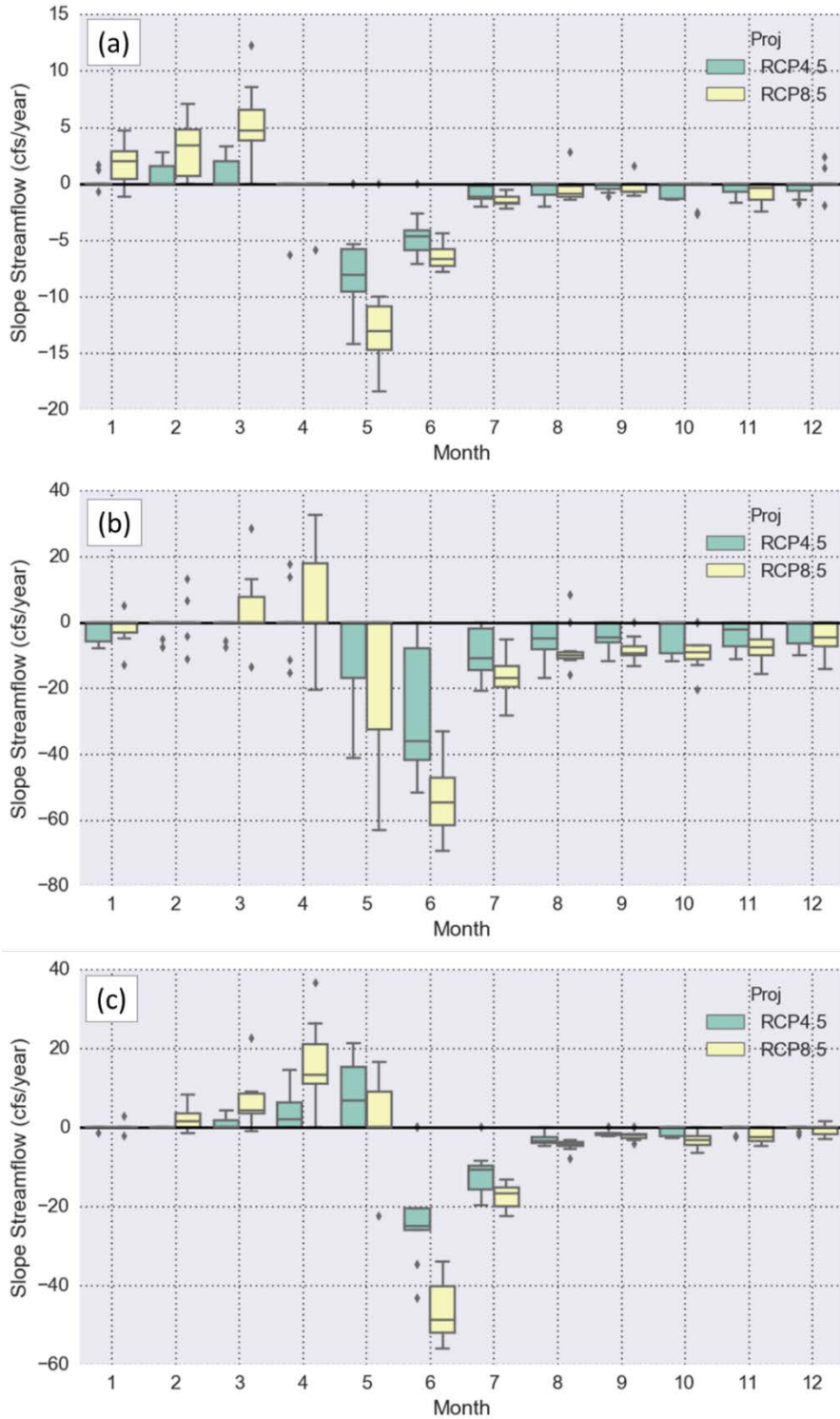


Figure 30: Slope of projected change in streamflow for the (a) Chama R nr Chamita NM (CHAMA), (b) Rio Grande at Albuquerque NM (ALBUQ) and Navajo (NAVJO) in the Colorado River Basin. Only significant changes are shown (p-value<0.1)

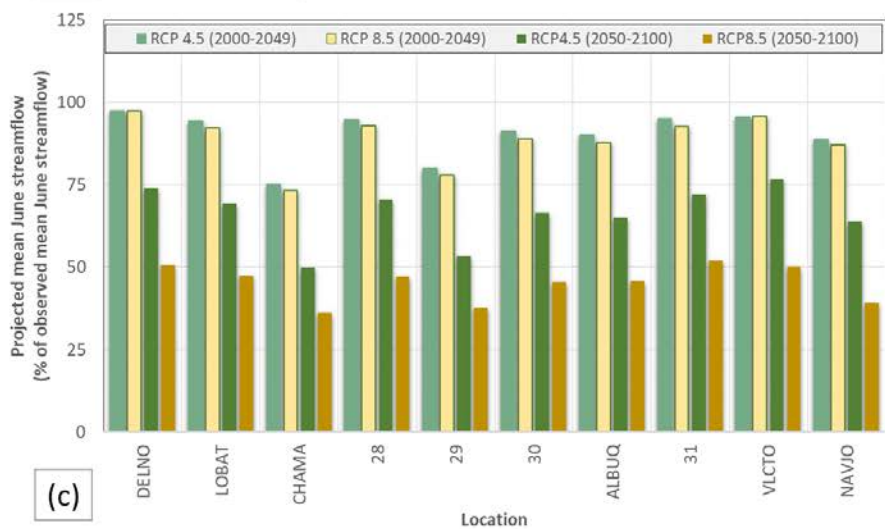
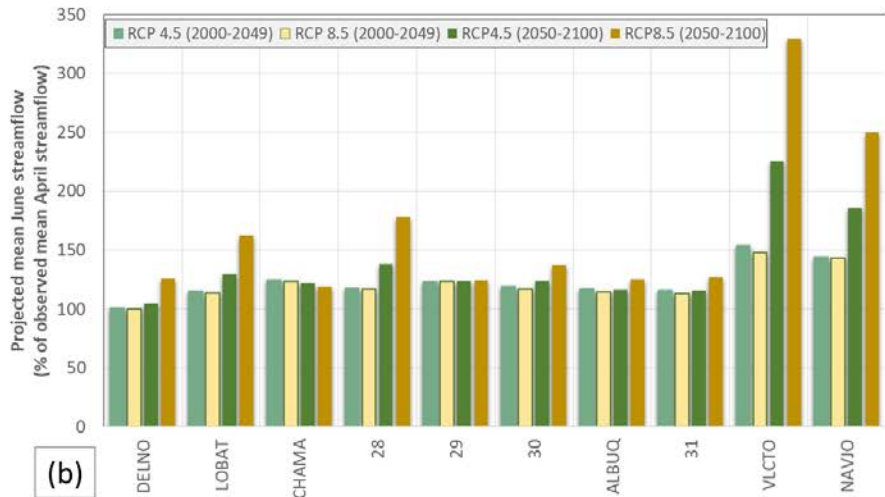
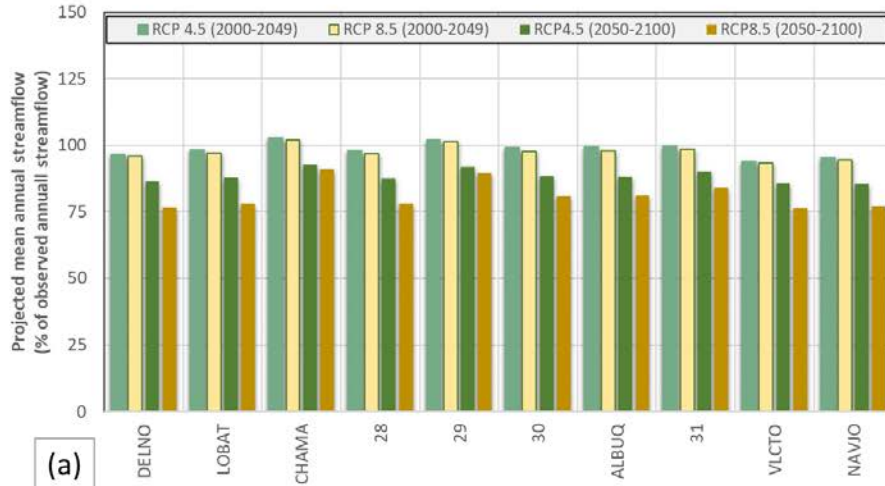


Figure 31: (a) Ensemble projected mean annual streamflow for the period of 2000-2049 and 2050-2099 for RCP 4.5 and RCP 8.5 expressed as a percentage of observed mean annual streamflow (b) the same for the month of April, and (c) the same for the month of June

It is important to investigate the cumulative effects of droughts to evaluate the potential of droughts becoming more persistent in time, with dry years occurring more frequently and in sequence. Figure 32 shows 1- to 30-year average mean annual flows for the Rio Grande near the Otowi Bridge gauge location as simulated by the 10 selected models for the two scenarios evaluated in this project (RCP 4.5 and RCP 8.5). Values are normalized by the simulated average mean annual flow for the observed period (1950-1999). Values for 1950-1999 are based on the GCM simulations results for that period, and not based on the observed data. The 1-year time series presents large variability with annual streamflow varying from 16.1 to 330% of the mean annual streamflow. This large annual variability is alleviated by the reservoir storage capacity in the basin. Low and high 1-year values occur during the observed and projected periods.

Years with streamflow values below average become more frequent for the projected period. Below average years occur 55.3% of the time during the observed period, 59.9% for the 2000-2049 period, and 71.2% for the 2050-2099 period. Note that the minimum values observed in the period of 1950 to 1999 and 2000 to 2049 are similar, but the minimum value decrease by more than 10% for the period of 2050 to 2099.

The results for one 30-year window average annual streamflow shows that dry years are becoming more intense and frequent during the projected period as compared to the observed period of data. For the 5-year period, inflow lower than the mean is observed 49.9% of the time during the observed period and it is projected to increase to 60.1% and 73.6% for the 2000-2049 and 2050-2099 periods. The minimum observed 5-year streamflow is 45.4% of the mean annual streamflow for the observed period. This value does not decrease significantly for the 2000 to 2049 period, but decreases to 28.8% for the 2050-2099 period. The most severe droughts are projected to happen in the second half of the 21st century.

Note that observed values are not included in Figure 32. The values for the 1950 to 1999 period were generated by the multiple GCMs. Considering that 10 models and 2 scenarios are included, 980 years of simulated data is available for the observed period. The lowest value of 5-year streamflow estimated based on the paleoclimatic data occurred between 1621 and 1626 when the 5-year average inflow was 51.5% of the long-term average. The period of 1999 to 2004 was also extremely dry with an average inflow of 54% of the long-term average. GCMs simulated a 5-year average inflow lower than the value registered in the observed period, with the lowest 5-year value simulated during the 1950-1999 period equal to 45.5%. The models predict that this value decreases to 44% for the period of 2000 to 2049 and to 28.8% during the second half of the century.

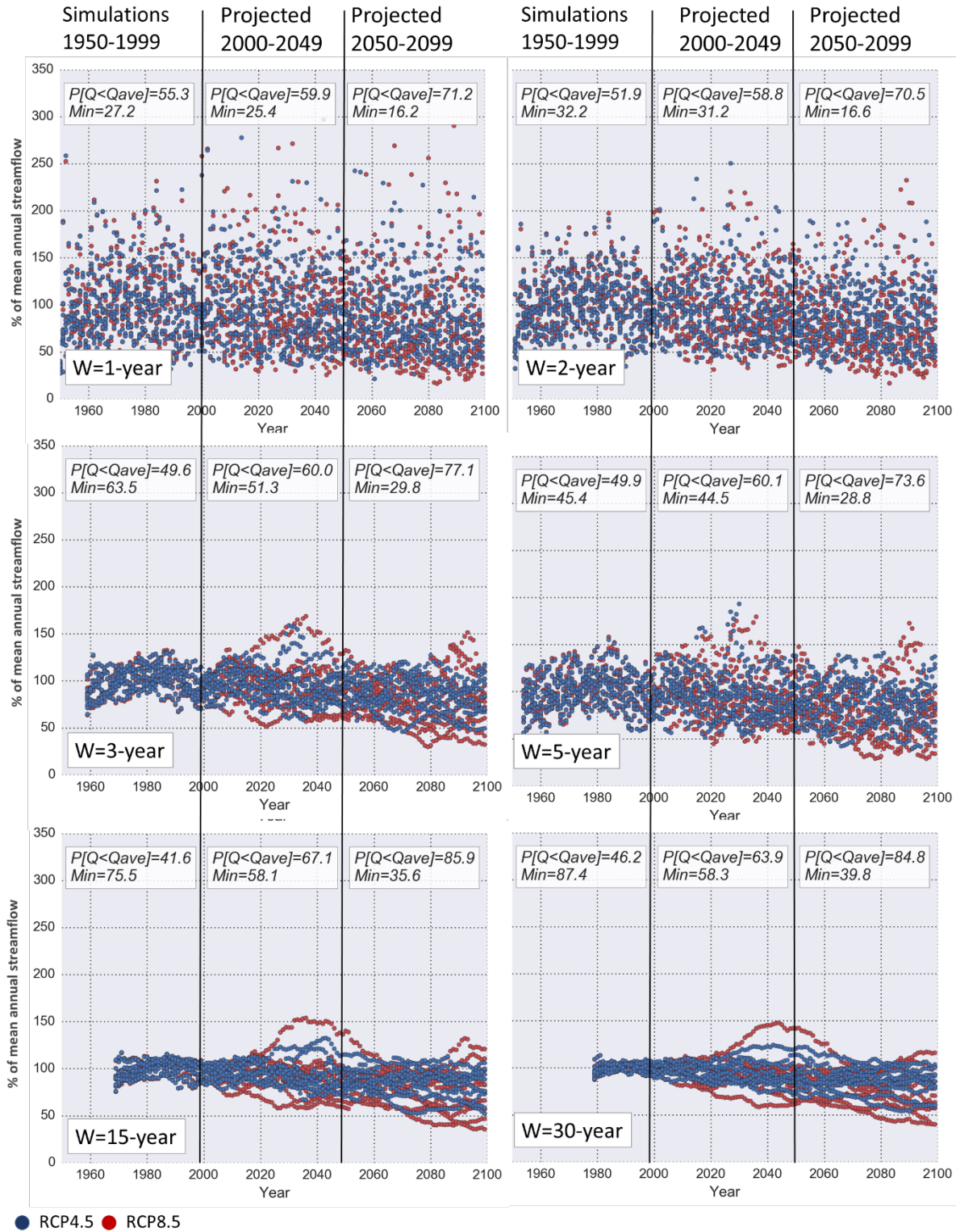


Figure 32: Projected 1-, 2-, 3-, 5-, 15-, and 30-year mean annual streamflow for all ten selected GCM models and scenarios (RCP 4.5 and RCP 8.5) for the Rio Grande near the Bridge gauge location (Site ID 30)

In Figure 32, the frequency of years with streamflow below average was evaluated. In Figure 33 drought persistency is evaluated. This figure shows the number of consecutive dry years and the percentage of streamflow observed during that period for (a) Rio Grande Gauge at the Otowi Bridge gauge and (b) Vallecito in the Colorado River Basin. Only dry periods that last more than 2 consecutive years are shown in the figure. Events that occurred during the 1950 to 1999 period are shown in Figure 33 a.1 and b.1, during the 2000 to 2049 period in Figure 33 a.2 and b.2, and during the 2050 to 2099 period in Figure 33 a.3 and b.3.

For the observed period the maximum number of consecutive dry years is 12 for Rio Grande at the Otowi Bridge gauge and 9 for the Vallecito in the Colorado River Basin. This number increases to 16 and 45 years for the Rio Grande at the Otowi Bridge gauge for the periods of 2000 to 2049 and 2050 to 2099. For the Vallecito in the Colorado River Basin the number of consecutive years with below average streamflow increases to 18 and 40 for the periods of 2000 to 2049 and 2050 to 2099. Note that the % of mean annual streamflow observed for shorter duration droughts (2 to 10 years) also decreases for the projected periods.

Considering only the water supply provided by the upper Rio Grande Basin (through Otowi gauge), the frequency of years with 10% reduction in supply increases from 44% to 49%, with 25% reduction in supply from 28% to 34%, and with 40% reduction in supply from 12% to 19%. Even more significant increases are projected to occur during the second half of the 21st century, when 40% reduction in supply is projected to be observed for one third of years.

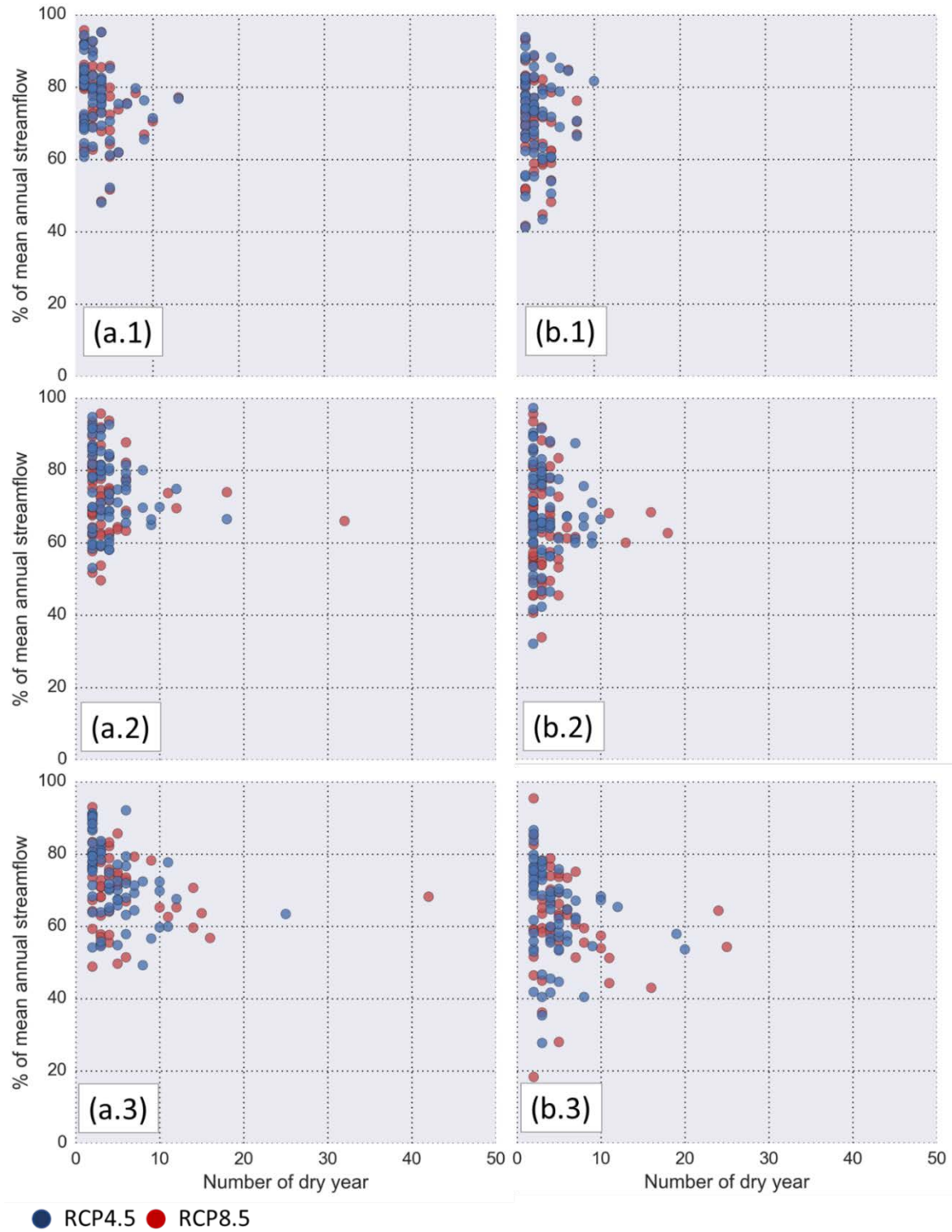


Figure 33: Number of consecutive dry years and % of mean annual streamflow for (a) Rio Grande at the Otowi Bridge gauge and (b) Vallecito in the Colorado River Basin for (1) 1950-1999, (2) 2000-2049 and (3) 2050-2099.

## Uncertainties

While it is important to understand how droughts can be affected by climate change, it is also important to take into consideration that climate change impact studies are subject to several sources of uncertainties, including uncertainties in the GCMs, emission scenarios, and downscaling methods. Despite uncertainties that are attributed to GCMs, there is consensus among models that droughts will increase in multiple regions in the United States by the end of the twenty-first century unless climate mitigation actions are taken. One of the regions is the Middle Rio Grande. Therefore, instead of disregarding GCM projections due to its uncertainties, the uncertainties should be taken into consideration when evaluating future projections. In this section uncertainties in the climate projections applied to the project were evaluated.

Figure 34 shows the comparison between the observed mean annual maximum temperature, annual precipitation, June streamflow, annual streamflow, and downscaled GCM VIC simulated values for the observation period (1950-1999) and the two projection periods (2000 to 2049 and 2050 to 2100). In red, observed values are compared to downscaled GCM VIC simulations using observed meteorological variables for the historical period (1950-1999) as input. If these points are over the reference line, it means that downscaled GCM simulations represent well the historical period. Note that this is true for the maximum temperature, precipitation, and annual streamflow. Downscaled GCM values for maximum temperature represent very well the historical period. All models are also consistent in predicting that there will be an increase in annual maximum temperature for all basins. The models might not agree on the magnitude of this increase, and in this case the ensemble average among all the models can be used as the best predictor.

Based on Figure 34, the representation of precipitation by the downscaled GCM is accurate for all watersheds analyzed. However, the models do not agree on the direction or intensity of changes, with some models predicting an increase in precipitation and other models predicting a decrease. In this case, caution should be taken into applying this value. The same characteristic is observed for the annual streamflow.

Bias exists on representing June streamflow for many of the sites, with simulated values being usually smaller than observed values. Although there is a negative bias on the representation of the June streamflow, a large majority of the models predict an even more significant decrease in streamflow. Therefore, it is fair to assume that the absolute value of change projected by the models might be biased, but that a decrease in June streamflow is very likely to happen.

Figure 35 shows the comparison between VIC simulated mean annual snow water equivalent, mean annual soil moisture, potential evapotranspiration, and actual evapotranspiration and downscaled GCM VIC simulations for the observation period (1950-1999) and the two projection periods (2000 to 2049 and 2050 to 2100). For all variables, GCMs represent reasonably well the observed period of data, with exception of soil moisture for one basin (Upper Rio Grande, 130201) for which GCM simulated values underestimate soil moisture in comparison with simulated values using observed data. For the SWE and potential evapotranspiration the direction of change is clear, with the SWE decreasing and potential evapotranspiration increasing for the projection periods. Projections for soil moisture changes and

actual evapotranspiration are not always consistent, even though the majority of the models project an increase in actual evapotranspiration.

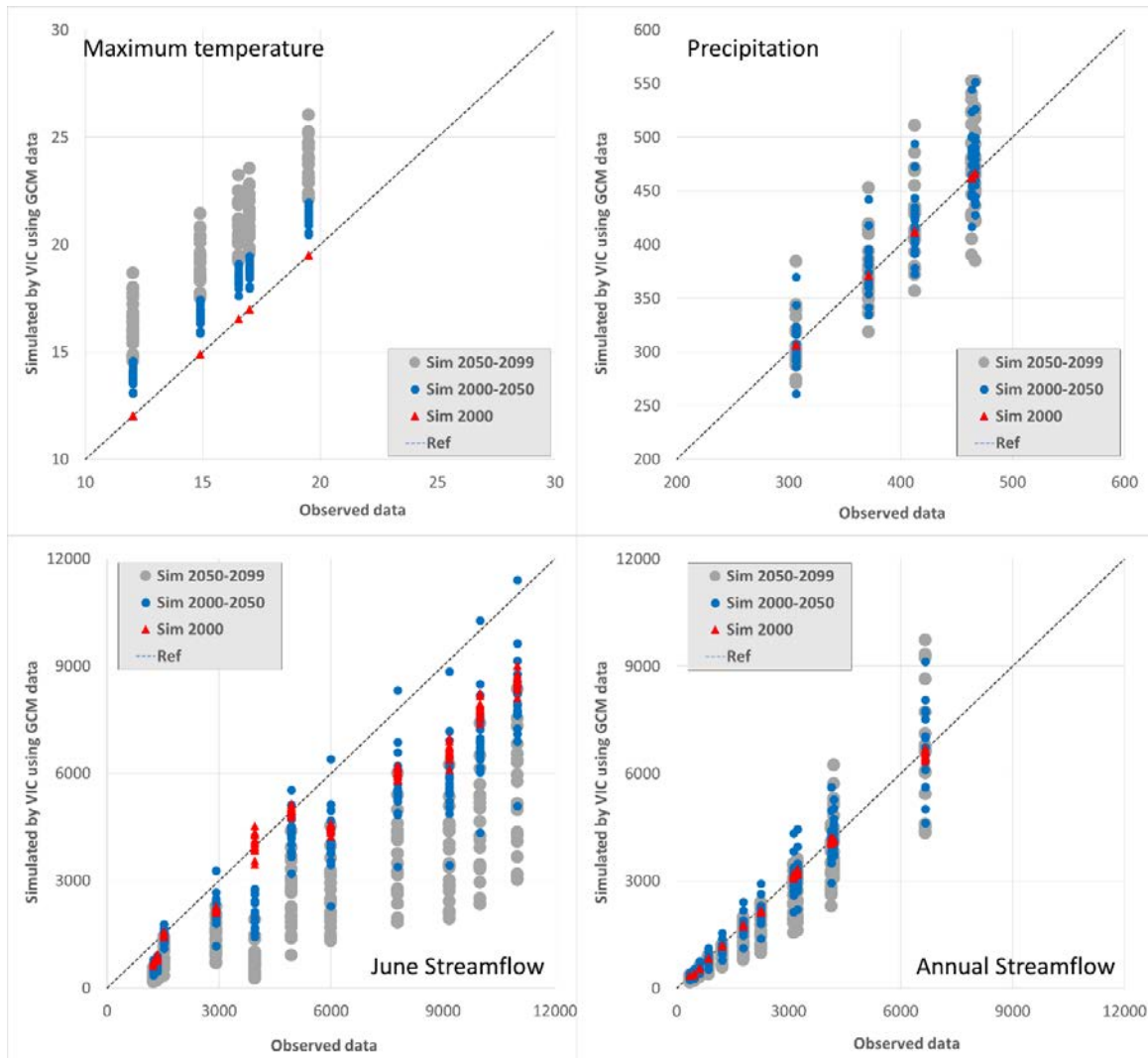


Figure 34: Comparison between observed mean annual maximum temperature, annual precipitation, June streamflow, annual streamflow, and downscaled GCM VIC simulated values for the observation period (1950-1999) and the two projection periods (2000 to 2049 and 2050 to 2100)

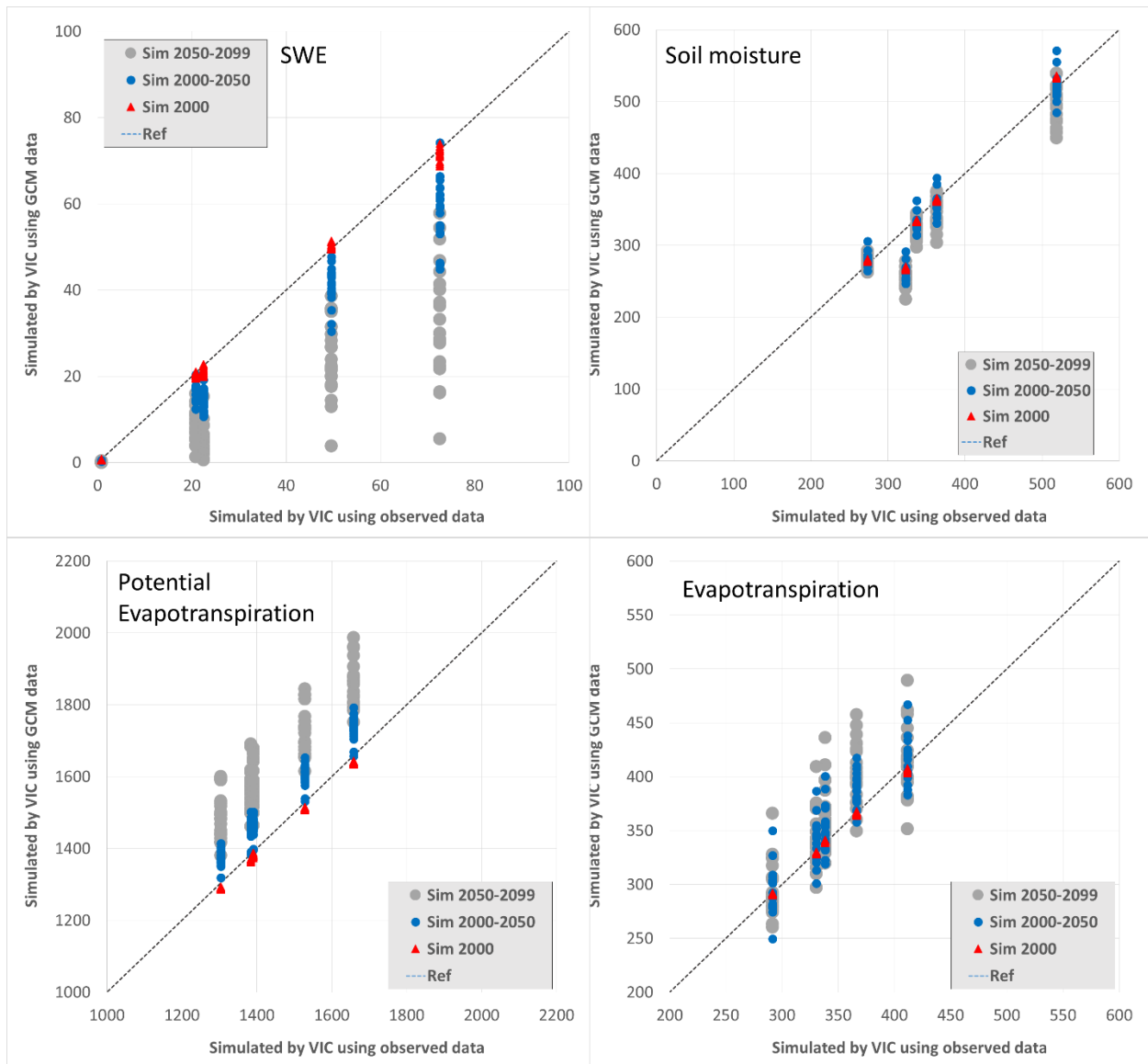


Figure 35: Comparison between VIC simulated mean annual snow water equivalent, mean annual soil moisture, potential evapotranspiration, and potential evapotranspiration and downscaled GCM VIC simulated values for the observation period (1950-1999) and the two projection periods (2000 to 2049 and 2050 to 2100)

## 6 inventory of possible range of impacts

Projected climate change effects for the Middle Rio Grande Watershed include:

- Precipitation
  - Model ensemble averages do not show significant trends for annual precipitation for any area (HUC6) or emission scenarios evaluated in this project.
  - Significant trends in monthly precipitation are only observed for the RCP 8.5 scenario. May precipitation is projected to decrease up to 21% for the first half of the century and up to 43% for the second half of the century.
- Temperature
  - Minimum and maximum temperatures are projected to increase for all months of the year and all areas.
  - Mean annual maximum temperature is projected to increase on average by approximately 1.8°C (3.2°F) for both RCP 4.5 and RCP 8.5 by the middle of the century. By the end of the century the mean annual maximum temperature is projected to increase on average 3.5°C (6.3°F) for RCP 4.5 and 5.2°C (9.3°F) for RCP 8.5.
- Snow Water Equivalent
  - The SWE is projected to decrease for all basins and months for which snow occurs. Changes are relatively higher for the Upper Rio Grande Basin, but the loss of water volume is most significant for the Rio Grande Headwaters, where the volume of water stored as snow is higher. Changes are most significant for the month of May.
  - For the Rio Grande Headwaters, the May SWE is projected to decrease on average by 14 mm (19.4%, 0.55 in) for the first half of the century and 31.1 mm (42.8%, 1.21 in) for the second half of the century for RCP 4.5, and by 13.5 mm (0.52 inches) for the first half of the century and 47.7 mm for the second half of the century for RCP 8.5. The maximum projected decrease for this basin for the first half of the century is 27.7 mm (1.1 inches) and 67 mm (2.6 inches) for the second half of the century.
  - For the Upper Rio Grande Basin, the May SWE is projected to decrease on average by 8.1 mm (36.1%, 0.32 inches) for the first half of the century and 15.5 mm (69.1%, 0.6 inches) for the second half of the century for RCP 4.5, and by 8.6 mm (0.34 inches) for the first half of the century and 19.5 mm (0.76 inches) for the second half of the century for RCP 8.5. The maximum projected decrease for this basin for the first half of the century is 11.8 mm (0.46 inches) for the first half of the century and 21.9 mm (0.85 inches) for the second half of the century.
  - Changes in the SWE for the Upper SJC are also significant and might affect the delivery of water to the SJC system.
- Potential Evapotranspiration and Evapotranspiration
  - Annual potential evapotranspiration for the area irrigated by MRGCD is expected to increase on average by approximately 5% for both emission scenarios for the first half of the century. By the end of the century potential evapotranspiration is expected to increase on average by 10% for RCP 4.5 and 15% for RCP 8.5. The maximum increase projected by a single model is 20%. Significant increases occur for both scenarios, mainly from March to November. Assuming irrigation techniques, crops, and served areas are kept constant, this percentage increase corresponds to projected increase in irrigation demand.

- Actual evapotranspiration increases for some of the winter and fall months, and actually decreases for June and July. Decrease in actual evapotranspiration is caused by the decrease in soil water availability during these months.
- Soil Moisture Content
  - With increasing temperature and the consequent potential evapotranspiration, soil moisture is projected to decrease for all months for the combined area.
  - Soil moisture in the combined area is the lowest for the period of July to October, when irrigation is mostly needed.
- Runoff
  - The magnitude and direction of projected changes in annual runoff vary significantly among all models.
  - Changes in the seasonality of runoff in snow dominant basins are identified by all the models.
  - For the Rio Grande Headwaters (130100) and for the period of 2000-2049, May runoff increases while June runoff decreases. Snowmelt for the Upper Rio Grande (130201) tends to occur earlier than for the Rio Grande Headwaters (130100). For the Upper Rio Grande (130201) and for the period of 2000-2049, March and April runoff increases while May and June runoff decreases.
  - Changes for the Rio Grande-Elephant Butte (130202) are much less significant, especially due to the fact that basin average runoff volumes observed in this basin are also lower than the volume observed in the upper watersheds. For the period of July to October, when localized storms can alleviate droughts in the region, no significant trend in runoff was detected.
- Streamflow
  - The model ensemble average indicates decreasing trends in mean annual streamflow for all scenarios and sites. Trends are higher for the RCP 8.5 scenario and for the second half of the 21st century.
  - The range of projections provided by the different GCMs is very large and both positive and negative trends are identified. For example, for the Rio Grande near the Otowi Bridge gauge location, projected mean annual streamflow for the RCP 8.5 scenario for the period of 2000 to 2049 varies between 68.1% (cmcc-cm) to 138.1% (cnrm-cm5) of the observed mean annual streamflow for the period of 1950-2000. Only one model (cnrm-cm5) projected increase in annual streamflow. Five models predicted less than 5% change in total annual streamflow. Discrepancies are high for all locations.
  - Changes in the seasonality of streamflow are significant in the Rio Grande Basin.
  - Monthly streamflow variability becomes larger during the projected period. Streamflow at the Otowi Bridge gauge increases for the months of March and April, and decreases for the months of May, June, and July.
  - The major loss in streamflow volume for the Rio Grande near the Otowi Bridge gauge location occurs in June. For the period of 2050 to 2099, projected streamflow for June is less than half of what has been observed in the period of 1950 to 2000.
  - Negative trends in streamflow volumes also occur for the summer and fall months, which is likely the result of higher evaporation caused by higher temperatures resulting in drier soils and higher hydrologic losses.

- Streamflow change patterns for the Rio Chama and Rio Grande at Albuquerque are similar to the ones observed for the Rio Grande at the Otowi Bridge gauge, with exception of the month of April for the Rio Chama, for which no increase in streamflow is projected. The pattern for Navajo in the Colorado Basin differs from the locations in the Rio Grande for the month of May. For this location streamflow is projected to increase for this month.
- Ensemble average changes for the Colorado River locations are more accentuated than the ones observed in the Rio Grande Basin, with an average decrease of 23.8% on the total annual streamflow for the VLCTO Basin.
- Changes in the Intensity, Frequency, and Persistency of Droughts
  - The evaluation of trends on the absolute values of annual streamflow might be misleading since both wet and dry events might become more extreme and frequent. Therefore, the frequency, the duration, and the persistency of droughts (dry years) were also evaluated. One- to 30-year window average annual streamflows show that dry years become more intense and frequent during the projected period as compared to the observed period of data. Increases are more significant for the period of 2050 to 2099. For the Rio Grande Otowi Bridge gauge, the frequency of dry years increases by 4.6% for a 1-year window, 7.9% for a 2-year window, 10.4% for a 3-year window, and 17.7% for a 30-year window for the period of 2000 to 2049. The minimum values observed in the period of 1950 to 1999 and 2000 to 2049 are similar, but the minimum value decreases by more than 10% for the period of 2050 to 2099.
  - Projected changes in drought duration were also evaluated. The number of consecutive dry years also increases for the projected period for all observed locations, with increases being more significant for the period of 2050-2099. For the observed period the maximum number of consecutive dry years is 12 for Rio Grande at the Otowi Bridge gauge. This number increases to 16 and 45 years for the Rio Grande at the Otowi Bridge gauge for the period of 2000 to 2049 and 2050 to 2099. For the Vallecito in the Colorado River Basin, a maximum of 9 consecutive dry years were observed, and this number increases to 18 and 40 years for the period of 2000 to 2049 and 2050 to 2099. The percentage of mean annual streamflow observed for shorter duration droughts (2 to 10 years) also decreases for the projected periods.
  - Reduction in Supply: Considering only the water supply provided by the upper Rio Grande Basin (through Otowi gauge), the frequency of years with 10% reduction in supply increases from 44% to 49%, with 25% reduction in supply from 28% to 34%, and with 40% reduction in supply from 12% to 19%. Even more significant increases are projected to occur during the second half of the 21<sup>st</sup> century, when 40% reduction in supply is project to be observed for one third of years.

## 7 Conclusions

In this report the effects of climate change on drought intensity, frequency, and duration were evaluated. Multiple hydrological and meteorological variables projected by GCMs, including precipitation, soil moisture, snow water equivalent, evapotranspiration, and streamflow were evaluated. An inventory of possible range of impacts for each variable was presented in the previous section. In this section, only the main aspects that influence drought management in the MRGCD area were listed.

The main source of water supply for the MRGCD is the streamflow from the Rio Grande Headwaters and upper basins. This flow is measured at the Rio Grande at the Otowi Bridge gauge. Based on this gauge, it is very likely that droughts will become more intense, more frequent, and more persistent in the future. More extreme changes are expected for the second half of the century. However, the changes that are expected to occur in the first part of the century should not be neglected.

While the range of streamflow projections provided by the different GCM models for the 2000 to 2049 period is large and both positive and negative trends are identified, it is clear that changes in the seasonality of streamflow will occur and are significant for the Rio Grande and Colorado basins. Monthly streamflow variability becomes larger during the projected period. Streamflow at the Otowi Bridge gauge increases for the months of March and April, and decreases for the months of May, June, and July. This change in seasonality is caused by an increase in temperature which results in earlier snowmelt.

Dry years (below average mean annual streamflow) become more frequent during the projected period. Below average years occur 55.3% of the time during the observed period, 59.9% for the 2000-2049 period, and 71.2% for the 2050-2099 period. For the 5-year period, inflow lower than the mean is observed 49.9% of the time during the observed period and it is projected to increase to 60.1% and 73.6% for the 2000-2049 and 2050-2099 periods, respectively. Minimum values observed in the periods of 1950 to 1999 and 2000 to 2049 are in general similar, but the minimum values projected for the period of 2050 to 2099 decrease significantly for all time windows.

Droughts also become more persistent during the projected period. For the observed period, a maximum of 12 consecutive years with streamflow were observed in the Rio Grande at the Otowi Bridge gauge. This number increases to 16 and 45 years, respectively for the periods of 2000 to 2049 and 2050 to 2099. The same behavior is observed for the other gauges in the Rio Grande Basin.

Water supply for the MRGCD also includes runoff generated in the intermediate basin (HUC 130202) and water transferred from the San Juan Basin to the SJC system. For the intermediate basin, annual runoff is not expected to change significantly. No changes have been projected for the months for which runoff from these areas are most relevant for the MRGCD (July to October) for the period of 2000 to 2049.

Streamflow generated in the San Juan in the Colorado Basin are expected to decrease significantly during the second half of the century, but for the first half of the century average decrease is approximately 7%. This basin also experiences significant changes in the seasonality of streamflow due to earlier snowmelt. Since the MRGCD only receives a small portion of this supply, it is not clear at this point how this decrease would affect the MRGCD operations.

Climate change is also expected to affect irrigation demands due to warmer temperatures. Potential evapotranspiration, which is directly related to irrigation demands, is expected to increase an average of 5% and 12%, respectively, for the area of interest of the MRGCD for the first and second half of the century. Maximum increases projected by GCM are 8% and 20% for the same periods. Assuming irrigation techniques, crops, and served areas are kept constant, this percentage increase would directly correspond to the expected increase in irrigation demand.

As a next step for this work, the MRGCD should consider the construction of scenarios for stress tests. Stress tests are used to characterize the range of climate-change extremes and to develop scenario-

based analyses that consider how a system would perform if an extreme drought occurred (Stern et al. 2013). This type of test is used to define ways to increase resilience. Although that was not in the scope of the project, the data evaluated in this report can be used to construct such scenarios. Stress tests focus on identifying weaknesses and breaking points in the water system that stem from different characteristics of extreme events (CA DWR, 2015). Stress tests are used to obtain plausible estimates of the impacts of unprecedented events utilizing climate modeling; to detect crucial thresholds for which specific sectors would be endangered, and to suggest new adaptation pathways to stay within bounds of tolerable risk levels (Swart et al. 2013).

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Appendix 4:  
Drought Indicator  
Prepared by  
WEST Consultants  
For the  
Middle Rio Grande Conservancy District  
October 2018



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## 1 Drought indices: selection

Droughts are a normal part of the climate; however, aridification in the southwest United States is redefining what a normal drought means, in terms of intensity and frequency, in this region. Droughts are one of the more costly natural hazards due to their spatial coverage and long duration, which impact many economic sectors and people at any one time (World Meteorological Organization and Global Water Partnership, 2016). Drought indices identify, forecast, and quantify droughts to support the design and implementation of relevant and timely drought mitigation actions.

To evaluate the applicability of drought indices for a location of interest, such as the Middle Rio Grande, the importance of drought parameters, the availability of data, and the developmental status of the indices must first be established.

### Drought Parameters

Drought parameters are current or forecast inputs used to calculate a drought index. Parameters can include meteorological (e.g. temperature or precipitation), hydrological (e.g. streamflow, snowpack, soil moisture or groundwater), land surface (e.g. land use or, vegetation indices), and other watershed (e.g. reservoir levels) parameters. Both the initial determination and subsequent reviews of a drought index should examine location-specific water operations and scientific watershed research to ensure that dominant parameters are accounted for. In simple cases, a drought index could account for the relative deviation from normal of a single parameter, such as precipitation; however, the Middle Rio Grande is not such a simple system.

MRGCD's management of the Middle Rio Grande system is, generally speaking, a balance between the water supply and the water demand. Therefore, a useful drought indicator for the MRGCD must have the capability to account for both the supply and demand.

In this initial determination of a suitable drought index for the MRGCD, important parameters, categorized by their primary impact on either water supply or water demand, include:

- Water supply
  - Precipitation
  - Streamflow
  - Snowmelt
  - Reservoir storage
  - Soil moisture
- Water demand
  - Temperature
  - Evaporation

### Availability of Data

To calculate a drought index, data must be available for all its drought parameters. Available data can be either current or forecast.

The methods to collect or model data should be sufficiently documented to provide the ability to evaluate the data for consistency and unintended uncertainties that may affect the characterization of water supply and demand. Documentation of data can be found elsewhere and therefore will only be referred to, as necessary, in the drought contingency plan. It will be important for future updates of this drought contingency plan to review the available data and note 1) changes regarding how it is collected or created and 2) research that may identify previously unrecognized uncertainties in the data.

Ideally, datasets for parameters used to calculate a drought index have:

1. A long and continuous historical record

In many cases, the value produced by a drought index represents the deviation from a normal value that can only be produced using the historical record. Evaluators and reviewers also use the historical record to validate and compare different drought indices.

2. Reliable up-to-date data and forecasts

Drought indices need real-time data to inform water management decisions in a timely and relevant manner that is reliably available to water managers.

3. Appropriate temporal resolution given the time scale of the drought

The required temporal resolution of the dataset will depend on the type of parameter and the type of process being model. Droughts are slow developing processes. Therefore, it is often appropriate to monitor droughts at longer time scales than other events, such as floods, that develop in a short period of time.

4. The ability to forecast future conditions.

The application of forecast as parameters in drought indices allow managers to predict drought conditions to better inform planning and adaptation strategies.

In this initial determination of a suitable drought index for the MRGCD,

1. The most appropriate available historical data was selected to represent each important drought parameter used to categorized water supply or water demand (Table 32). The parameters applied in this report might be re-evaluate in future versions of the indicator in case new datasets become available.
2. Real-time data is available for all the parameters, or proxies for the parameters, identified as important (above). Monthly temporal precision was requested by MRGCD for drought planning and mitigation decision making for the MRGCD. Moreover, the National Resource Conservation Service (NRCS) streamflow forecast, which is applied as one of the main parameters in the index, is updated monthly.
3. The only forecast data that is considered is the streamflow forecast for the snowmelt period, produced monthly by the NRCS.

## **Developmental Status of Drought Index**

To evaluate the developmental status of a drought index, two factors must be considered simultaneously: 1) acceptability and suitability and 2) complexity.

Acceptability refers to how extensively the index has been successfully applied in similar situations. Suitability refers to how well the index is reported to work in similar situations. It is not necessary to consider only indices with widespread application and in some cases, site-specific characteristics and requirements may favor the use of a novel index. However, the conceptual viability and the practicality of the index are important considerations for which a quick and informative, although general, assessment can be made by determining how many other use cases exist for the index and whether these use cases are comparable to this site.

In this initial determination of a suitable drought index for the MRGCD, the relative acceptance and suitability of drought indices was based off information from the Handbook of Drought Indicators and Indices (World Meteorological Organization and Global Water Partnership, 2016) and extensive previous experience from WEST Consultants Inc. (WEST). WEST has extensive experience in drought contingency plans (DCPs). For example, recently WEST reviewed 120 DCPs covering 266 projects for the Army Corps of Engineers. WEST wrote a report that summarized the findings in the DCPs including topics involving drought determination, drought actions, water law, potential surplus water availability, and drought history. On a project focus on the DCP for Pine Flat Reservoir on the Kings River, WEST proposed a methodology to allow the implementation of minor and major deviations from the Water Control Manual, including risk and uncertainty analysis that assess potential consequences of the deviation.

Complexity is affected by three factors: 1) the resources required to calculate the index (e.g. personnel required expertise level and computational resources), 2) the amount and availability of information needed to apply the index, and 3) the resources required to maintain the index. The importance of these factors depends on the available resources and intended users and audience of the index. Generally, a relative comparison between indices is sufficient when attempting to identify a drought index that is best in a given context. A detailed quantification of the accessibility of the drought index that is eventually chosen can be useful in the implementation and subsequent reviews and updates of the drought contingency plan.

In this initial determination of a suitable drought index for the MRGCD, focus was on applying a low complexity index that are quick to calculate, easy to implement, and easy to maintain. The drought index for the MRGCD must be ready to be implemented by MRGCD staff with minimal training and support upon the approval of this drought contingency plan and should be able to be presented with enough simplicity to the public to foster trust through transparency.

## **Drought Index Comparison for the MRGCD**

In this initial determination of a suitable drought index for the MRGCD, five drought indices are presented, two of those five are considered for recommendation to the MRGCD, and ultimately, a modified version of one of these two is recommended.

The five drought indices presented here are: the Aggregate Dryness Index (ADI), the Standardized Reservoir Supply Index (SRSI), the Standardized Snowmelt and Rain Index (SMRI), the Surface Water Supply Index (SWSI), and the Reclamation Drought Index (RDI). The Integrated Drought Management Programme's Handbook of Drought Indicators and Indices provides an overview for the five indices, which has been presented in Table 1.

### **Common Concepts**

All five indices employ a similar general concept, with individual variations that tailor them for certain situations.

The five indices use historic data to create distribution curves that classify the values of drought parameters as normal or some degree of wetter or drier than normal.

In the formulation of all five indices, the historic normal calculates to 0.00, while wetter than normal is positive and drier than normal is negative. This is not necessarily standard among every drought index available, but it is common among the five presented here.

Real-time drought identification and characterization is simply the comparison between real-time drought parameters and the historic normal, although equations may appear more complex and vary slightly to account for different methods of standardization. The advantage of using a drought index that compares drought parameters in a given year to the historical distribution of those same parameters in the same watershed is that it inherently calibrates the index to the watershed being evaluated. In the future, based on the experience acquire applying the current definition of the indicator, the MRGCD might re-define the baseline period for comparison (1953 to 2017). It is recommended that the selected period represents the average behavior of the basin, including the same number of wet and dry years.

Two different formulations of the drought indicator are proposed for the MRGCD:

- 1) Current: uses only current observed data (July to December). Apply to quantify and monitor current conditions;
- 2) Forecast: applies available forecast data (January to June). Apply to forecast droughts and therefore should be used to prepare and mitigate future effects of droughts.

Both current and forecast indices are calculated using the same equations, but the input to the equations are obtained from different data sources. Forecasting drought with these indices uses a similar process as real-time evaluation but produces values that should be interpreted differently, as described above.

### **Index-specific Characteristics**

The Aggregate Dryness Index (ADI) can be used to identify droughts that stem from drier than normal precipitation, streamflow, evaporation, reservoir levels, snowpack, and/or soil moisture levels. The ADI was developed and tested for three regions in California, including the San Joaquin Valley (Keyantash and Dracup, 2004). The disadvantages of the ADI are that it does not consider temperature and water demands apart from evaporation and it has only been tested in a limited number of cases. Although the

ADI uses many parameters to describe drought, this study determined that the development status of the ADI is insufficient: it does not have the level of acceptance desired for immediate use by the MRGCD and more tests are required before applying it operationally.

The Surface Water Supply Index (SWSI) characterizes multiple water supply drought parameters, including snow accumulation, snowmelt and runoff, and reservoir data. The formulation of the drought parameter for soil moisture in the SWSI captures the memory of the hydrological system. Different formulations of the SWSI can be applied to represent varying degrees of importance of water supply sources during different periods of the year. For example, Colorado's River Forecast SWSI uses snowpack during the period of December through May and streamflow for the months of June to November (Shafer and Dezman, 1982). As an indicator of the relatively advanced developmental status and general acceptance of the SWSI, the Columbia River Forecasting Service (CRFS) uses SWSI as their main index.

The Standardized Reservoir Supply Index (SRSI) and Standardized Snowmelt and Rain Index (SMRI) are both variations of the SWSI, detailed above. SRSI does not consider snow or evaporation. SMRI does consider snow but does not consider reservoir levels and evaporation. This study determined that the inability of these indices to capture important drought parameters makes them insufficient for further evaluation for use by the MRGCD.

The Reclamation Drought Index (RDI) is an extension of the SWSI that accounts for temperature which allows the implicit consideration of climate change effects. The RDI was created by the U.S. Bureau of Reclamation (Reclamation) to trigger drought emergencies, although it can be used to define drought severity and duration and predict the onset and end of drought periods. The RDI has three components: water supply, water demand, and drought duration. It uses precipitation, streamflow, reservoir storage, and groundwater to characterize water supply. It uses temperature, due to its impacts on water consumption, to characterize water demand. It uses temporal water supply and demand factors, such as the growing season, to define weights for individual months to characterize drought duration.

### **Two Drought Indices Considered for Recommendation**

The SWSI and the RDI are the two indices considered for recommendation to the MRGCD.

The major differences between the SWSI and the RDI are the drought parameters included and the developmental status.

SWSI, as it is currently formulated, does not consider water demand, including temperature. SWSI does have the capability to be modified to consider other parameters, such as temperature, although such a modification should consider how the added parameters relate to the existing ones. The RDI considers both water supply and water demand parameters. Importantly, the consideration of temperature provides a method to quantify the effects of a warming climate, which has been shown, in Appendix 2, to have important consequences in the Middle Rio Grande basin. However, RDI uses only temperature to characterize the water demand component, a method that might overestimate the effects of temperature on demand, since water availability also determines actual evapotranspiration, especially

in arid environments. This assumption is compounded further because the same weights are given to water supply and water demand.

A robust index that uses temperature as a proxy for water demand and that incorporates both water supply and water demand should include considerations for both issues. First, to correlate temperature to water demand, a coefficient should be derived to quantify the relative effect of temperature on evapotranspiration. If this process identifies other parameters that influence water demand, those parameters could reduce unexplained variability if they are added to the water demand component. Second, to integrate the relative effects of water supply and water demand on drought, a comparison should be made so that relative weights can be assigned. For example, a below average water supply might require more extensive drought triggers than a similarly anomalous above average water demand. Water managers may not be accustomed to the need to weight supply and demand separately because, generally, supply should equal demand in the absence of dry or wet conditions. But this weighting is necessary because the drought indices presented do not compare absolute amounts of water supply and demand, but instead they compare separate relative anomalies in supply and demand.

RDI has not been extensively applied in practice; the only reference available for this index is the original development work done by Reclamation (Weghorst, 1996). This index was not applied due to the difficulty of accessing existing references and due to the limited number of well-recognized and documented applications.

SWSI has been extensively applied operationally in the United States. Since it includes snowpack and reservoir storage, SWSI has been used in regions with mountainous terrain and complex regional microclimates, both of which also characterize the Middle Rio Grande basin and its headwaters. This index was not applied because it does not take into account in water demand. However, a modified version of SWSI is applied that accounts for the effect of temperature on water demand.

### **SWSI-Mod Recommended as Drought Index for MRGCD**

Given the strengths and weaknesses of the two indices evaluated, a hybrid method has been proposed. The proposed method, named SWSI-Mod, adapts the SWSI method to also consider the effect of higher temperature on drought, through its impacts on water demand. Therefore, the SWSI-Mod has multiple advantages that became evident through this study's analysis. The SWSI-Mod is as comprehensive in its consideration of drought parameters applicable to the MRGCD as any of the other five indices presented. Also, the datasets necessary to set up and use the SWSI-Mod for real-time evaluation and forecasting are readily available. Finally, in terms of developmental status, most of the major concepts and implementation in the SWSI-Mod benefit from the widespread use of the SWSI. Future review of the SWSI-Mod should further evaluate the impact of the modification to the SWSI by quantifying the relative effects of water supply and water demand on drought in the Middle Rio Grande, as described above.

**Table 30: Overview of Drought Indices Compared for the MRGCD, Provided by the Integrated Drought Management Programme's Handbook of Drought Indicators and Indices (World Meteorological Organization and Global Water Partnership, 2016)**

<b>Indicator</b>	<b>Main characteristics / reference</b>	<b>Input variables</b>	<b>Advantages</b>	<b>Disadvantage</b>
Aggregate Dryness Index (ADI)	A multivariate regional drought index that accounts for all water resources. (Keyantash and Dracup, 2004)	P, EVPT, SF, RS, SM, SWE	Looks at the total amount of water in a climate regime. Takes into account water stored in reservoirs, as snow or in the soil.	More complex formulation and large data requirement. Not extensively validated. Developed to be used across uniform climate regimes.
Standardized Reservoir Supply Index (SRSI)	Applies monthly inflows and average reservoir storage to provide information on water supply for a region. (Gusyev et al., 2015)	SF, RS	Easy to compute, as it mimics SPI calculations using a standard gamma distribution of the probability distribution function.	Does not take into account snow and losses due to evaporation.
Standardized Snowmelt and Rain Index (SMRI)	An extension of the SPI that accounts for frozen precipitation and its contribution to runoff. (Staudinger, M., K. et al. 2014)	SF, P, T and SC/SWE (if available).	Accounts for snow and its future contributions to streamflow. Has the ability to use temperature and precipitation to model snow or snow amounts.	Does not account for reservoir volume. Not using actual snow depths and associated snow water equivalency can lead to errors in runoff projections.
Surface Water Supply Index (SWSI)	Accounts for multiple components of the water supply data. Calculated at basin level. (Doesken et al. 1991)	RS, SF, SWE and P.	Provides a good indication of the overall hydrology of a particular basin or region.	As data sources change or additional data are included, the entire index has to undergo recalculation. Does not account for changes in temperature.
Reclamation Drought Index (RDI)	Developed to define drought severity, duration and to predict the onset and end of drought periods. Similar to the SWSI, but contains a temperature component.	P, T, S, RS, SF	Flexibility to add only the variables that are dominant for the area or season. It accounts for temperature and consequently climate change effects. It was created to trigger drought emergency relief.	Calculations are made for individual basins, so comparisons are hard to make. Having all the inputs in an operational setting may cause delays in the production of data.
P=Precipitation; T=temperature; AWC=available water content; EVPT=evapotranspiration; SF=streamflow; RS=reservoir storage; SM=soil moisture; SWE=snow water equivalent (content); S=snowpack; SC=snow cover				

## 2 MRGCD SWSI-mod

### Formulation

SWSI-Mod is composed of two components: (1) the Supply Component (SC) and (2) the Demand Component (DC). The SC represents the combined effects of the major water supplies to the MRGCD system. The DC represents the effect of temperature on water demand to the MRGCD system. The two components add together to produce the SWSI-Mod (*SWSIMod*):

$$SWSIMod = SC + DC$$

*SWSIMod* is set up to be calculated at a monthly timestep. An exception to the monthly timestep during part of the year due to the format of forecast data provided by the NRCS is described in detail later in this section.

SC and DC represent the relative deviation from normal of the water supply and the water demand, respectively. These relative deviations are quantified using the non-exceedance probability based on historical records. The non-exceedance probability represents the likelihood (%) that the value of a parameter will not be greater than the given value, based on the historic record. In theory, there is a 0% chance of having a drier year than the driest year on record and a 100% chance of having a drier year than the wettest on record. To maintain consistency of the *SWSIMod* with SWSI and produce intuitive index numbers for use as drought triggers, 50 is subtracted from the non-exceedance probability and the resulting number is divided by 12. This produces a range from -5.04 to 5.04 (unitless).

One caveat to note is that the meaning of the non-exceedance probability for water supply and demand are opposite for drought purposes (the wettest and hottest years have 100% chance of non-exceedance). To rectify this, the DC subtracts the non-exceedance probability from 50, essentially reversing the sign without adjusting relative values.

The SC combines multiple sources of water supply by combining the multiple non-exceedance probabilities into one value before re-adjusting to produce an intuitive index number. To do this, each source is given a unique weight (0.00 – 1.00) to multiply with the source's individual non-exceedance probability. The resulting weighted probabilities are added together, and the sum should range between 0 and 100. This does not apply to the DC because it consists of only one parameter.

The *SWSIMod* correlates temperature to water demand in the DC by adding a weighted coefficient to represent the effect of temperature on water demand in the Middle Rio Grande. This does not apply to the SC because the SWSI-Mod assumes that all major sources of water supply are accounted for.

As described above, the SC and DC equations are, respectively:

$$SC = [a * P(Otowi) + b * P(ElVado) + c * P(Heron) + d * P(Abiquiu) + e * P(Cochitti) + f * P(IntBasin_M) - 50] / 12$$

Equation 3

Where  $P(x)$  represents the non-exceedance probability (%) of the current or forecast volume relative to the historical records. *Otowi* represents the contribution from the upper Rio Grande Basin, based on the streamflow at the Otowi Bridge gauge. *ElVado*, *Heron*, *Abiquiu*, and *Cochiti* represent MRGCD's storage in each of the reservoirs. *IntBasin* stands for the amount of water supply generated in the Intermediate Basin (*IntBasin*) between the Otowi Bridge gauge and the Elephant Butte Reservoir. Streamflow measurements to adequately cover the contribution of precipitation to streamflow in the Middle Rio Grande are not available so this contribution will be defined based on the effect of the basin average precipitation on soil moisture. The variables a, b, c, d, e and f are weighted coefficients that represent the approximate contribution of each parameter to surface water supplies.

and

$$DC = g * [50 - (P(\text{Temperature}))]/12$$

*Equation 4*

Where *Temperature* represents the average temperature in the Middle Rio Grande during the previous twelve months. The coefficient *g* represents the effect of temperature on water demand in the Middle Rio Grande

### Calculating SWSI-Mod Parameters

The SWSI-Mod parameters, identified in the formulas above, are:

- Otowi
- ElVado
- Heron
- Abiquiu
- Cochiti
- IntBasin
- Temperature

As detailed in Appendix 2, Section 2, Subheading Streamflow, Otowi represents the natural streamflow at the USGS Otowi Bridge stream gauge as provided by the NRCS.

ElVado, Heron, Abiquiu, and Cochiti represent corresponding reservoir storage levels on the Rio Chama system (ElVado, Heron, and Abiquiu) and Rio Grande system (Cochiti). Although not all, and in some reservoirs none, of the stored water is available for use by the MRGCD, the parameter represents all storage in each respective reservoir. The section below (Calculating SWSI-Mod Weighted Coefficients) details the contribution of each reservoir to the overall MRGCD water supply, which is how the SWSI-Mod takes into account that not all reservoir storage is available to the MRGCD.

IntBasin represents the impact of precipitation that falls between the Otowi Bridge gauge and the Elephant Butte Reservoir over the MRGCD service area. Since observations or estimates for this variable are not available, precipitation was used in place of streamflow volumes. When using precipitation, the effect of previous precipitation in soil moisture and, consequently, in runoff generation should be taken

into consideration. The Antecedent Precipitation Index (API) (Kohler and Linsley, 1951) was used to capture the memory of the system in relation to soil moisture and runoff generation potential. The Antecedent Precipitation Index (API) is one of the most common index used as a soil moisture index for flood forecasting (Ali et al. 2010). For flood forecasting purpose the API is generally calculated at a daily timestep. In the SWSI-Mod implementation, API is calculated at a monthly timestep. For the SWSI-Mod,

$$API_{(t)} = k API_{(t-1)} + P_t$$

Where the time t represents the previous month (as API is calculated at the beginning of a month),  $P_t$  is precipitation during the month t,  $API_{(t-1)}$  is the antecedent precipitation index for month t-1 and k is an empirical decay factor that represents the weight given to the previous months' precipitation. Due to the lack of data for calibration, for this version of the indicator, the value of k was initially set to 0.81 based on trial and error and professional experience. The goal was to define a value for k that captures the memory of the system and the effects of previous rainfall on runoff, baseflow generation, as well as on how much water is available to plants. When k is applied to represent floods, the focus is on the water content on the most superficial layers of the soil, which controls fast runoff generation, which can cause floods. Drought is a slow-onset natural hazard that takes months and sometimes year to develop. In the case of droughts, the effects of deeper layers of soils and lower groundwater levels should be included. To represent this slowly moving processes, k is set to a high value, imposing higher weights for previous rainfall and accumulated deficit of rainfall.

Temperature represents the average temperature in the Middle Rio Grande during the previous twelve months. Similar to the IntBasin, Temperature is calculated at the beginning of a month, so the previous twelve months are represented by the t-13 month to the t-1 month, where t is the current month.

### **Special Considerations When Streamflow Forecast is Available**

The Natural Resources Conservation Service (NRCS) provides probabilistic water supply forecasts for the Otowi Bridge streamflow gauge and the El Vado Reservoir inflow. The forecasts represent total March – July streamflow. The forecasts are available near the beginning of the month in each month from January to July. The Otowi and ElVado parameters will be defined using the NRCS forecasts from January to June (Table 31).

As a forecast, the Otowi parameter still represents the natural streamflow at the Otowi Bridge stream gauge. The forecast will be obtained directly from monthly NRCS reports. Otowi streamflow forecast, regardless of the month, represents the sum of the total streamflow at Otowi Bridge stream gauge during March – July.

As a forecast, the ElVado parameter still represents the storage in El Vado Reservoir. The value for the forecast will be obtained from both the current reservoir storage and monthly NRCS reports. El Vado forecast, regardless of the month, represents the current reservoir storage plus the sum of the total streamflow at the inflow to El Vado Reservoir during March – July.

When the Otowi and ElVado parameters are forecast, all other parameters will continue to use current values since forecast is not available at this point. As a result, the SWSI-Mod for the months of January to June represents the forecast drought conditions for the subsequent irrigation season and should be used to plan and prepare for droughts. In contrast, the SWSI-Mod for the months of July to December represents the current drought conditions for the given month, and it is mainly applied to monitor and quantify droughts.

**Table 31: Parameters used in the SWSI-Mod**

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Otowi (Current)							X	X	X	X	X	X
Otowi (Forecast)	X	X	X	X	X	X						
Heron (Current)	X	X	X	X	X	X	X	X	X	X	X	X
ElVado (Current)							X	X	X	X	X	X
ElVado (Forecast)	X	X	X	X	X	X						
Abiquiu (Current) *												
Cochiti (Current) *												
IntBasin (Current)	X	X	X	X	X	X	X	X	X	X	X	X
Temperature (Current)	X	X	X	X	X	X	X	X	X	X	X	X

\* Abiquiu and Cochiti parameters do not contribute to the total MRGCD water supply. They are defined here because they could theoretically be used for MRGCD supply in the future, although current policies prohibit this practice. See the section “Calculating SWSI-Mod Weighted Coefficients” below for further details.

### Generating Historical Datasets for Non-exceedance Probability Calculation

The following steps are necessary for the development of historical datasets for SWSI-Mod parameters:

- Collect and review data for quality assurance
- Using the data, calculate IntBasin, and Temperature parameters
- Fit the data to statistical distributions to calculate non-exceedance probabilities for each parameter.

These steps are described in further detail below.

Data for the parameters is collected from the sources listed in

Table 32. WEST Consultants performed a quality control on the data collected by generating values for missing data. For further details regarding this quality assurance, please contact WEST Consultants. Data for the period of 1953 to 2017 was used in the definition of the indicator.

Table 32: Data Collected for SWSI-Mod Parameters

Parameter	Units	Available Time Period	Download Source
Otowi (Observed)	(Ac-ft)	<a href="#">1953 - current</a>	<a href="https://wcc.sc.egov.usda.gov/reportGenerator/view/customMultiTimeSeriesGroupByStationReport/monthly/start_of_period/08313000:NM:USGS%7Cid=%22%22%7Cname/POR_BEGIN,POR_END/stationId,name,SRVO::value?fitToScreen=false">https://wcc.sc.egov.usda.gov/reportGenerator/view/customMultiTimeSeriesGroupByStationReport/monthly/start_of_period/08313000:NM:USGS%7Cid=%22%22%7Cname/POR_BEGIN,POR_END/stationId,name,SRVO::value?fitToScreen=false</a>
Otowi (Forecast)	(Ac-ft)	<a href="#">1995 - current</a>	<a href="https://www.wcc.nrcs.usda.gov/ftpref/support/water/westwide/forecast_table/">https://www.wcc.nrcs.usda.gov/ftpref/support/water/westwide/forecast_table/</a>
ElVado (Forecast)	(Ac-ft)	<a href="#">1995 - current</a>	<a href="https://www.wcc.nrcs.usda.gov/ftpref/support/water/westwide/forecast_table/">https://www.wcc.nrcs.usda.gov/ftpref/support/water/westwide/forecast_table/</a>
Precipitation	(Inches)	<a href="#">1896 - current</a>	<a href="http://prism.oregonstate.edu/6month/">http://prism.oregonstate.edu/6month/</a>
Temperature	(Deg F)	<a href="#">1896 - current</a>	<a href="http://prism.oregonstate.edu/6month/">http://prism.oregonstate.edu/6month/</a>
Heron (Observed)	(Ac-ft)	<a href="#">1971 - current</a>	<a href="https://wcc.sc.egov.usda.gov/reportGenerator/edit/customMultipleStationReport/monthly/start_of_period/08108080:NM:BOR%7Cchuc=%2213*%22%20AND%20network=%22BOR%22%20AND%20outServiceDate=%222100-01-01%22%7Cname/POR_BEGIN,POR_END/stationId,name,RESC::value,RESC::average_1981,RESC::pctOfAverage_1981?fitToScreen=false">https://wcc.sc.egov.usda.gov/reportGenerator/edit/customMultipleStationReport/monthly/start_of_period/08108080:NM:BOR%7Cchuc=%2213*%22%20AND%20network=%22BOR%22%20AND%20outServiceDate=%222100-01-01%22%7Cname/POR_BEGIN,POR_END/stationId,name,RESC::value,RESC::average_1981,RESC::pctOfAverage_1981?fitToScreen=false</a>
ElVado (Observed)	(Ac-ft)	<a href="#">1953 - current</a>	
Abiquiu (Observed) *	(Ac-ft)	<a href="#">1965 - current</a>	
Cochiti (Observed) *	(Ac-ft)	<a href="#">1974 - current</a>	

Using the data collected in

Table 32, precipitation and temperature were pre-processed to calculate IntBasin, and Temperature parameters using appropriate methods. The calculation for IntBasin first requires an averaging of precipitation data throughout the geographic area, as described in the Excel spreadsheet “MRGCDIndexModCoeff\_5\_8\_20192”, sheet “BasinAve”. Next, the API is calculated, using the method described in the above section. The calculation for temperature requires an averaging of data throughout the geographic area, as described in the Excel spreadsheet “MRGCDIndexModCoeff\_5\_8\_20192”, sheet “BasinAve”.

Non-exceedance probabilities for each parameter are calculated by fitting the data for the respective parameter to a gamma distribution (Otowi, Heron, Abiquiu, Cochiti, IntBasin, Temperature) or a beta distribution (ElVado). Examples of gamma distributions are illustrated in Figure 36. Other statistical distributions (e.g. Rayleigh, Normal, and Pareto) were considered. Data for the period of 1953 to 2017 was used in the definition of the non-exceedance probabilities for the indicator.

**Examples of data and probability of non-exceedance time series are shown in Error! Reference source not found. Figure 37 for inflow at the Otowi Bridge gauge, El Vado reservoir storage, and API. Error! Reference source not found.**

Figure 38 shows the time series of 12-month precipitation and its probability of non-exceedance. Note that in the case of temperature, there is a positive trend in the time series.

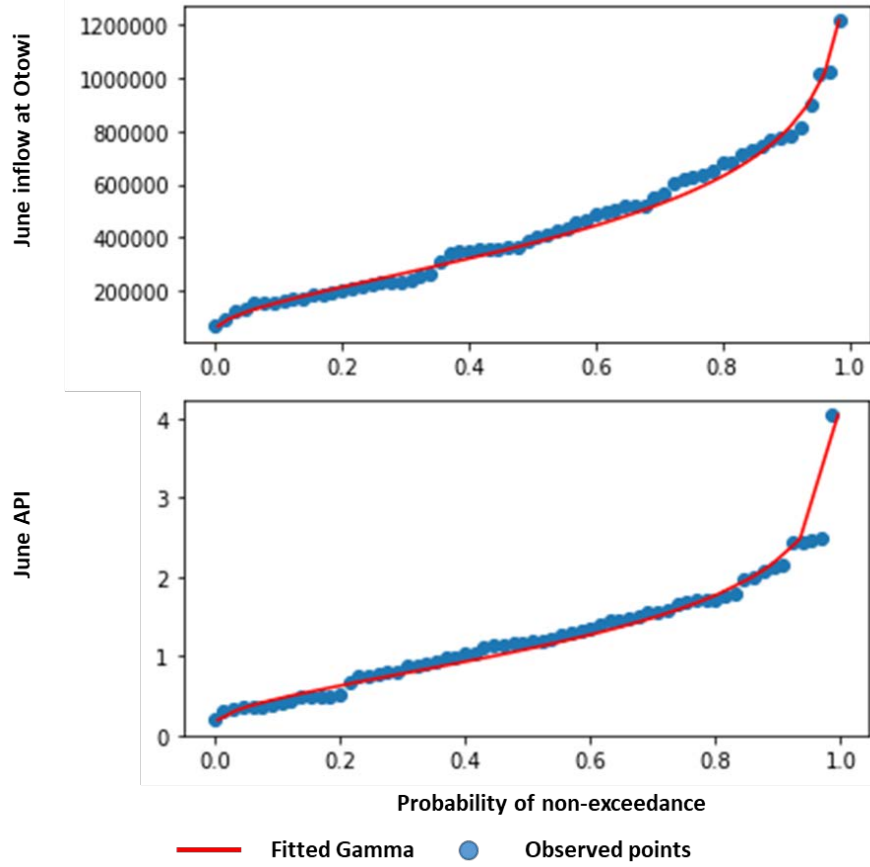
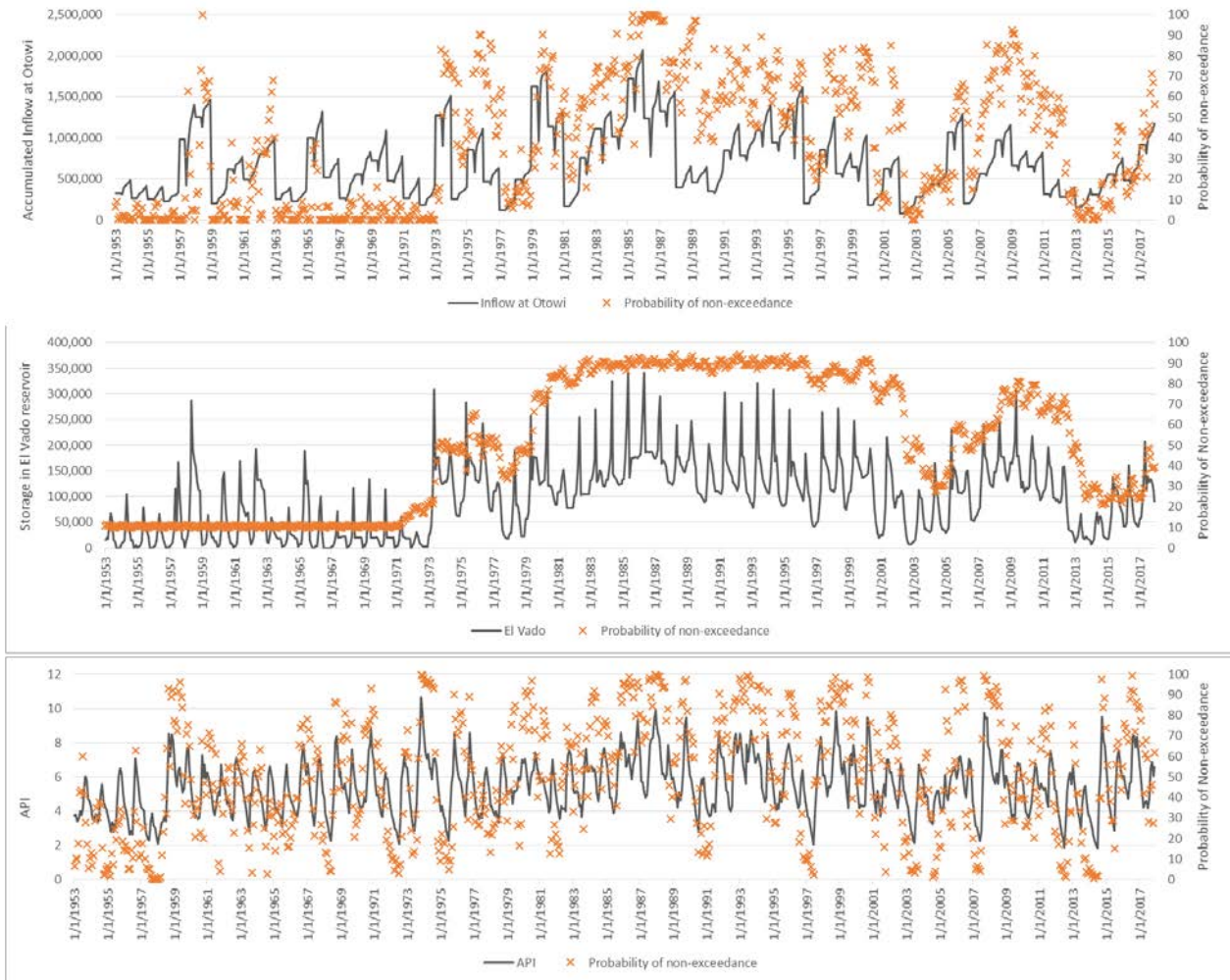
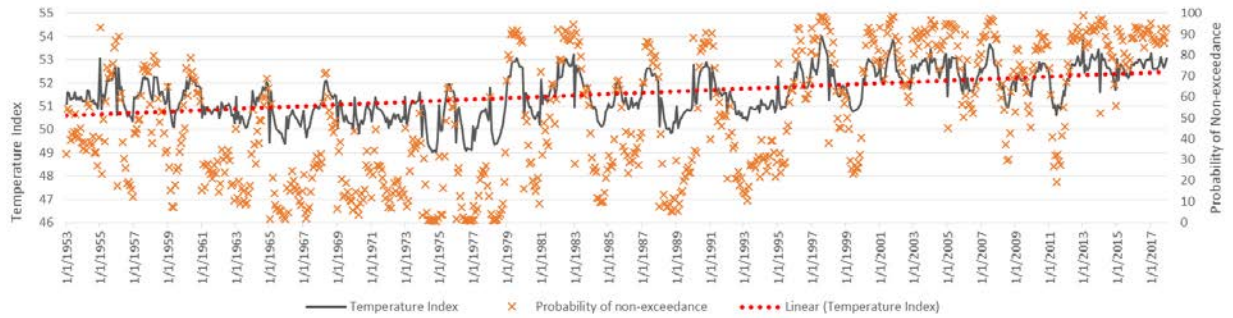


Figure 36: Fitted probability of non-exceedance based on the fitted gamma distribution and observed for the Otowi Bridge gauge inflow from March to May and API for June



**Figure 37: Time series of inflow at the Otowi Bridge gauge, El Vado Reservoir, and API; and their probability of non-exceedance**



**Figure 38:** Time series of 12-month average temperatures and their probabilities of non-exceedance. The red-dashed line shows increasing trend in Temperature

In the definition of the historical probabilities of non-exceedance for forecast values, the observed time series of inflow at the Otowi Bridge gauge and inflow to El Vado Reservoir were used. However, in an operational scenario, forecasts provided by the NRCS will be used. These forecasts are subject to uncertainties. **Error! Reference source not found.**4 shows the forecast and observed flow at the Otowi Bridge gauge and inflow at El Vado reservoir. Each point represents the observed and forecast values of flow for March to July as predicted on May 3rd by the current version of the model for a specific year. The plot shows that the forecast provided by the NRCS at the end of May accurately predicted flows in these two gauges. However, uncertainties will be higher for longer forecast lead times.

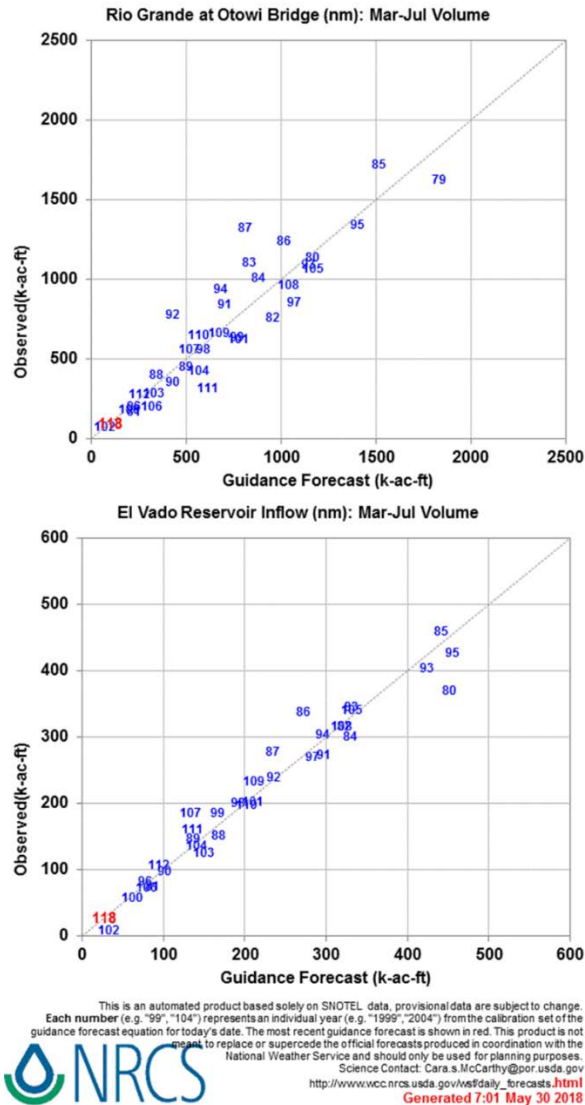


Figure 4: Guidance forecast versus observed flow at the Otowi Bridge gauge and inflow at El Vado reservoir for March to July (Source: [https://www.wcc.nrcs.usda.gov/wsf/daily\\_forecasts.html](https://www.wcc.nrcs.usda.gov/wsf/daily_forecasts.html))

## Calculating SWSI-Mod Weighted Coefficients

### SURFACE COMPONENT COEFFICIENTS

In the SC of the SWSI-Mod, the variables a, b, c, d, e and f are weighted coefficients that represent the approximate contribution of each parameter to surface water supplies. The SC of the SWSI-Mod assumes that the sum of the parameters defined above (Otowi, ElVado, Heron, Abiquiu, Cochiti, and IntBasin) equals the total water supply for the MRGCD. Therefore, the approximate contribution of each parameter to the surface water supply is simply the value of the parameter divided by the total water supply. Presented as an equation,

Otowi + ElVado + Heron + Abiquiu + Cochiti + IntBasin = Total Supply

Otowi/Total Supply = a

ElVado/Total Supply = b

Heron/Total Supply = c

Abiquiu/Total Supply = d

Cochiti/Total Supply = e

IntBasin/Total Supply = f

Where Otowi, ElVado, Heron, Abiquiu, Cochiti, and IntBasin represent the calendar year-to-date cumulative volume of water supplied to MRGCD from the corresponding source. Total Supply represents the calendar year-to-date cumulative volume of water supplied to the MRGCD from all the sources combined.

The supply provided by the headwaters of the Rio Grande was estimated by the monthly average inflow at Otowi Bridge gauge corrected by the San Juan-Chama contributions. However, not the entire supply from Otowi is available to the MRGCD, since the Rio Grande Compact requires that a certain amount of the water be kept in the river for downstream users. As shown in Figure 5, under the Compact the percent of native water available to the State of New Mexico varies depending on the total flow at Otowi. Based on the annual compact allocations provided by the Rio Grande Compact Commission (1948), when inflow is equal to the median annual inflow at the Otowi Bridge gauge (797,476 ac-ft), 42% of the inflow in Otowi can be used in New Mexico. Therefore, streamflow volume at Otowi is multiplied by 42% to estimate an approximate actual volume of water that can be used by the MRGCD under the Rio Grande Compact. For the purpose of the drought indicator, it is important to note that the percent of native water available to the State of New Mexico increases as the total flow at Otowi decreases. Therefore, the assumption of the 42% ratio is reasonably conservative.

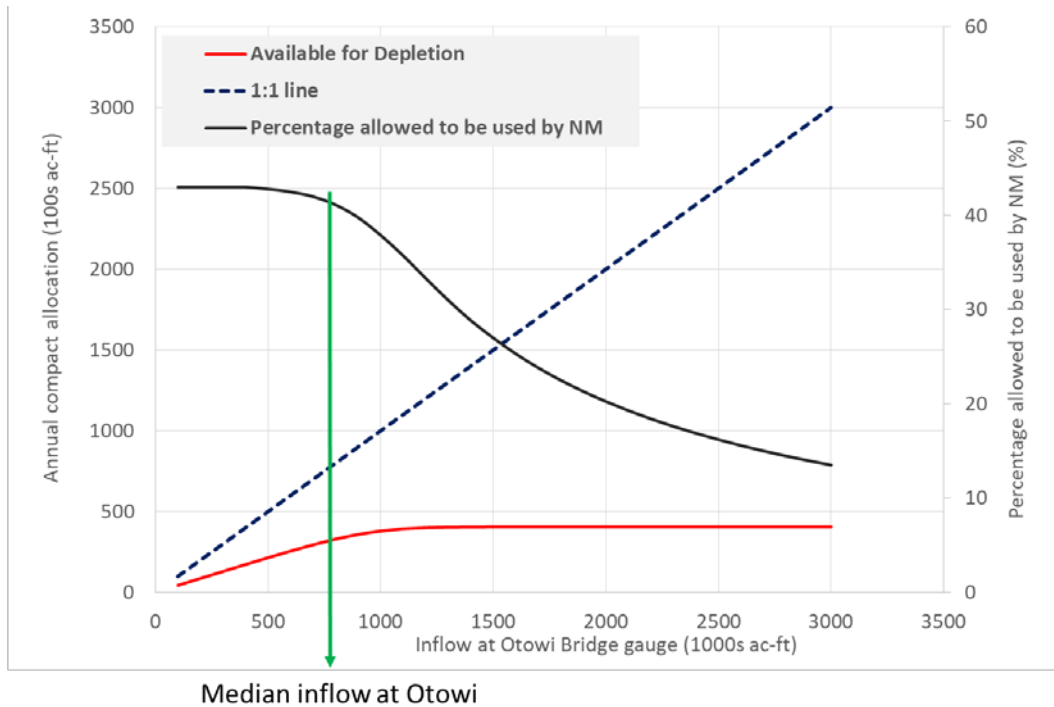


Figure 5: Annual NM compact allocation as a function of inflow at the Otowi Bridge gauge (left axis) and percentage allowed to be used by NM

The Heron parameter accounts for the MRGCD’s San Juan-Chama Project annual allocation of 20,900 acre-feet. Since the MRGCD only distributes water from March to October, water supply for each of these months for the Heron parameter is equal to 20,900 acre-feet divided by 8 months (2,612 acre-feet/month).

For the ElVado parameter, the supply was defined based on the median monthly outflow from the El Vado Reservoir.

Abiquiu Reservoir and Cochiti Reservoir are operated primarily for flood and sediment control. Currently, these reservoirs do not provide any contribution of water supply for the MRGCD. Therefore, the coefficients for these two reservoirs are zero. Even though no water for the MRGCD water supply can be currently stored in these reservoirs, this situation might change as droughts in the Rio Grande become more intense in the future. The two reservoirs were included in the conceptualization of the drought indices in case water can be stored in these reservoirs in the future or during extreme drought conditions.

For the IntBasin parameter, water supply equals the volume of precipitation that falls in the intermediate basin between Cochiti and Elephant Butte over areas served by the MRGCD. It is assumed that only precipitation that falls in the MRGCD jurisdiction areas is available to the district to support irrigation, since water that falls in upstream parts of the basin are expected to infiltrate locally especially during drought events. Basin-averaged precipitation was calculated for each month based on the gridded PRISM monthly average precipitation dataset, as described in the previous section. The monthly

precipitation was multiplied by the area covered by the Middle Rio Grande District to obtain a total volume of water that is available for infiltration or irrigation.

Figure 6 **Error! Reference source not found.** shows the monthly volume of water supply contributions for the three main supply components. In the figure the box center lines represent the median (Q2), the bottom of the box represents the first quantile (Q1) and the top of the box represents the third (Q3) quantile. The whiskers are defined by  $Q1-1.5(IQR)$  and  $Q3+1.5(IQR)$ , where IQR is the interquartile range ( $Q3-Q1$ ). Individual points beyond the whisker are considered outliers. Outliers are not necessarily erroneous data. Often apparent outliers represent extremes in the dataset (e.g. dry or wet months).

**Error! Reference source not found.** shows the high variability in the climate of the area. Flow at the Otowi Bridge gauge for the month of May varies from above 600 thousand acre-feet to almost zero. After June, flow at the Otowi Bridge gauge decreases and the main contribution to the area comes from the El Vado reservoir and runoff in the intermediate basin.

Table 33 presents calendar year-to-date cumulative water supply and the corresponding parameter coefficient values applied in the development of the drought indicator. Figure 7 shows the monthly weighted coefficients for the Otowi Bridge gauge, El Vado reservoir, and Intermediate Basin for  $SWSI_{f-Mod}$  (January to May) and  $SWSI_{o-Mod}$  (June to December). The accumulated relative contribution of the Otowi Bridge gauge is larger than El Vado and the intermediate basin runoff throughout the year. However, the relative contribution of the intermediate basin runoff starts to increase in July, when summer storms start, while the relative contribution of the Otowi Bridge gauge decreases. These values are consistent with water supply operation in the MRGCD.

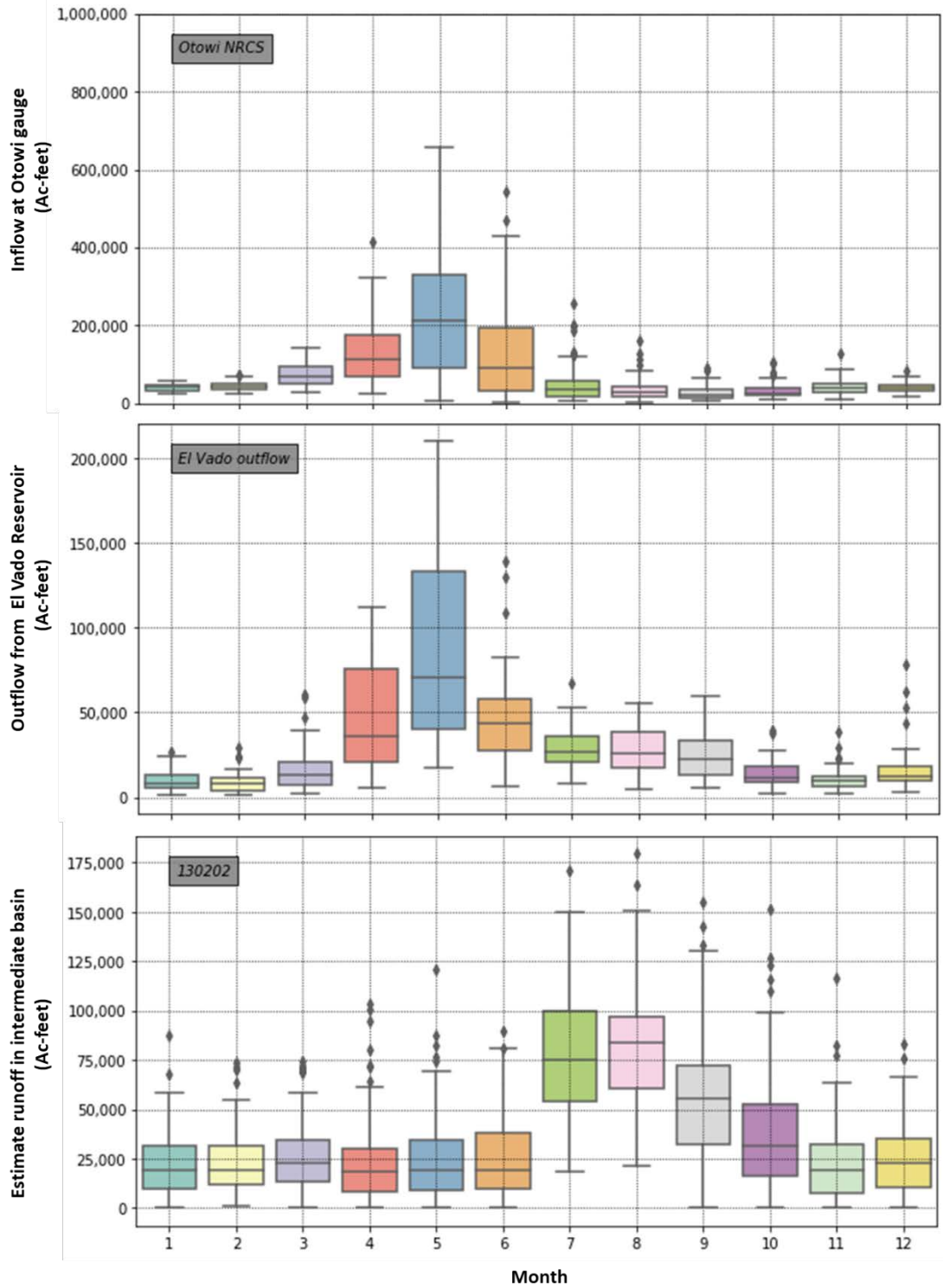


Figure 6: Monthly average values of inflow at Otowi Bridge gauge, storage in El Vado Reservoir, and estimated runoff in the Intermediate basin between Otowi Bridge gauge and Elephant Butte

Table 33: Accumulated yearly supply for the MRGCD and SWSI-Mod coefficients. Supply for Cochiti and Abiquiu are set to zero

Month	Supply (ac-ft)				Coefficients				
	Otowi	El Vado	Heron	IntBasin	Supply total	Otowi (a)	EVado (b)	Heron (c)	Intermediate Basin (f)
Jan-May	204051	160981	10450	29829	405311	0.50	0.39	0.03	0.07
Jun	193707	127985	10450	34113	366255	0.53	0.35	0.03	0.09
Jul	240079	166812	13062	44159	464112	0.52	0.36	0.03	0.10
Aug	263365	207433	15675	66568	553040	0.48	0.38	0.03	0.12
Sep	280604	238054	18287	93759	630704	0.44	0.38	0.03	0.15
Oct	287898	264126	20900	111058	683982	0.42	0.39	0.03	0.16
Nov	301629	274901	20900	122891	720321	0.42	0.38	0.03	0.17
Dec	318558	293408	20900	128680	761546	0.42	0.39	0.03	0.17

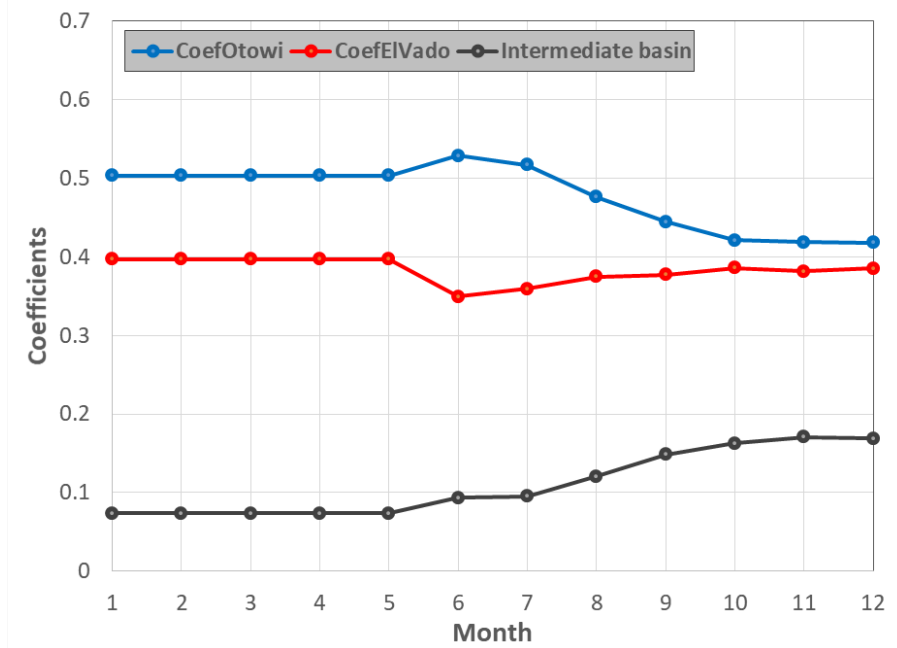


Figure 7: Monthly weighted coefficients for the Rio Grande at the Otowi Bridge gauge, El Vado reservoir, and the intermediate basin between the Otowi Bridge gauge and Elephant Butte reservoir. These coefficients are used in the estimation of SWSI-Mod

## DEMAND COMPONENT COEFFICIENT

In the DC component of the SWSI-Mod, the coefficient  $g$  represents the contribution of temperature to water demand in the Middle Rio Grande. The DC of the SWSI-Mod assumes that the sum of the parameter defined above (Temperature) and unidentified other water demands equals the total water demand for the MRGCD.

The Temperature parameter coefficient was estimated from the range of variability in potential evapotranspiration within the Middle Rio Grande. Potential evapotranspiration was calculated using temperature and the Thornwaite equation. The determination of the coefficient assumes that the range of variability in potential evapotranspiration is dependent on temperature, as illustrating in Figure 8. From Figure , the range of potential evapotranspiration is approximately 2.0 in. – 2.4 in. Because 2.4 in. is 20% greater than 2.0 in., the coefficient g is set to 0.2 for all months.

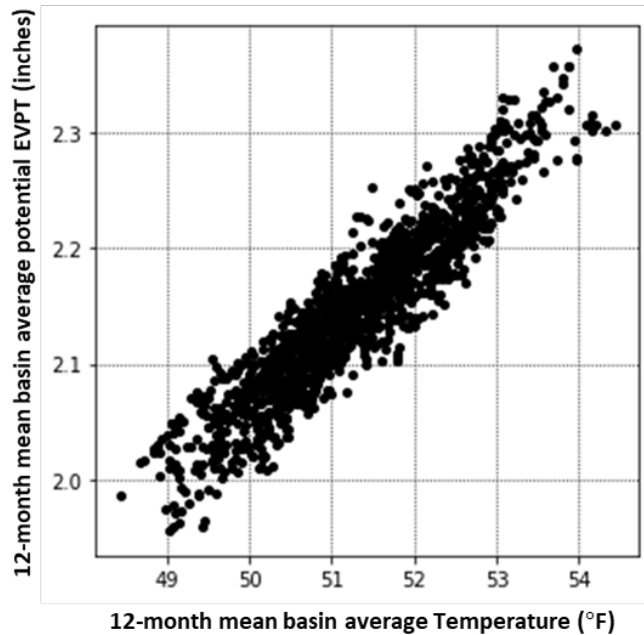


Figure 8: 12-month basin average temperature versus 12-month basin average EVPT

### Using the SWSI-Mod to Classify Current or Future Middle Rio Grande Drought Conditions

Recall that SWSI-Mod ranges from -5.04 to + 5.04. Based on SWSI-Mod, hydrologic conditions are classified as:

- SWSI-Mod  $\geq$  4: Extremely wet
- $3 \leq$  SWSI-Mod  $<$  4: Severely wet
- $2 \leq$  SWSI-Mod  $<$  3: Moderately wet
- $1 \leq$  SWSI-Mod  $<$  2: Slightly wet
- $-1 \leq$  SWSI-Mod  $<$  1: Near Normal
- $-2 \leq$  SWSI-Mod  $<$  -1: Slightly dry
- $-3 \leq$  SWSI-Mod  $<$  -2: Moderately dry
- $-4 \leq$  SWSI-Mod  $<$  -3: Severely dry
- SWSI-Mod  $<$  -4: Extremely dry

Drought conditions exist when SWSI-Mod is less than -1.

Figure 9 **Error! Reference source not found.** shows the SWSI-Mod time series for the period of 1953 to today. The thresholds for Normal to Extremely dry are also shown in the figure for reference. Extreme droughts ( $SWSI_{F-Mod} < -4$ ) are forecast for the years 1955 and 1956. Severe drought occurred from 1953 to 1956; in 1959, 1964, 1972, 2002, and 2003; and from 2012 to 2014. Table 34 shows the percentage of occurrence of each drought indicator class. Slightly wet to slightly dry classification occurs 56.3% of the time, and moderately dry to extremely dry conditions appears 27% of the time.

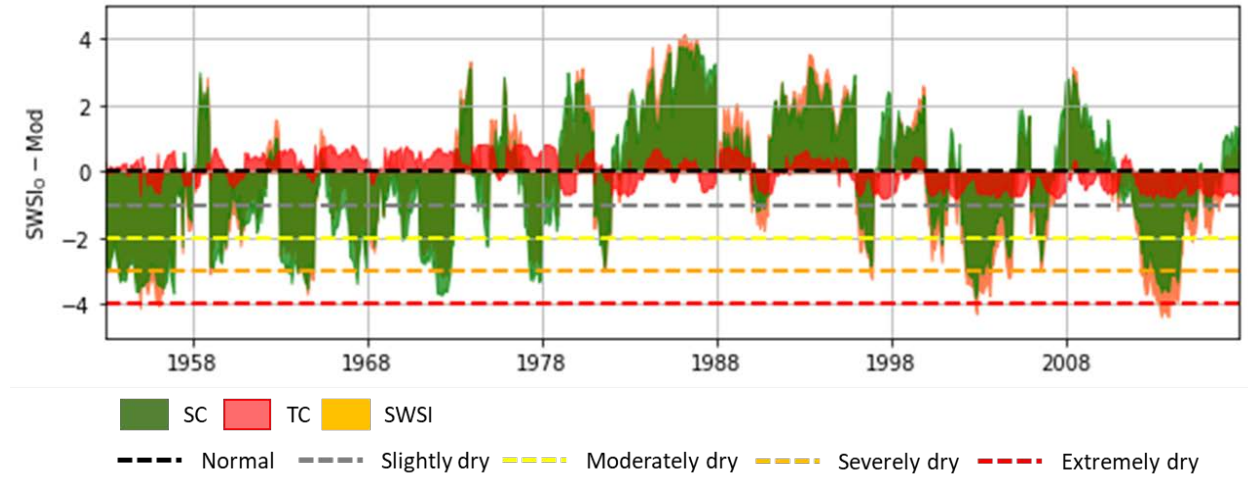


Figure 9: Supply component, temperature component, and SWSI-Mod ( $SWSI_{F-Mod}$  and  $SWSI_{O-Mod}$ ) time series

Table 34: Percentage occurrence of each drought indicator class ( $SWSI_{O-Mod}$ )

Month	Extremely wet	Severely wet	Moderately wet	Slightly wet	Near Normal	Slightly dry	Moderately dry	Severely dry	Extremely dry
Jun	0.0	4.6	9.2	16.9	29.2	13.8	15.4	9.2	1.5
Jul	0.0	3.1	15.4	15.4	27.7	9.2	16.9	10.8	1.5
Aug	0.0	4.6	13.8	12.3	32.3	9.2	15.4	10.8	1.5
Sep	0.0	3.1	12.3	15.4	32.3	9.2	18.5	7.7	1.5
Oct	0.0	3.1	10.8	20.0	23.1	16.9	16.9	7.7	1.5
Nov	0.0	4.6	12.3	15.4	26.2	16.9	10.8	10.8	3.1
Dec	0.0	4.6	15.4	13.8	21.5	16.9	13.8	10.8	3.1
<b>Average</b>		<b>16.7</b>		<b>56.3</b>			<b>27.0</b>		

### 3 Previous drought Records and SWSI-Mod validation

Ideally, quantitative economic and environmental data would be used to validate the drought indicator. However, this data was not available for the study area. Therefore, a subjective evaluation of the indicator based on qualitative drought records was performed. The following data was used to validate the drought indicator: water compact debit; MRGCD historic board minutes; and other literature including, news articles, and personal communication.

A summary of main drought records and the modified Surface Water Supply Index is shown in Figure 39. Historic board minutes provide only a limited picture of droughts. The minutes are only available from 1950 to 1977, and they are not always continuous. For example, in March 1954 the minutes indicated a continued shortage, which warned farmers about planting and stated that there would be no water available for irrigation after May 15<sup>th</sup>. The next board meeting minutes that mentioned drought conditions occurred in 1958. Consequently, it is not clear what kind of operation occurred during 1954 to 1956 when drought was severe. However, precipitation and flow at the Otowi Bridge gauge indicated that the drought persisted during those years.

A transition from severely dry to slightly dry occurred from 1956 to 1958. In 1958 the board debated if the water available in the El Vado reservoir should be used to alleviate drought conditions in the downstream part of the Rio Grande, where the Rio Grande was dry, instead of reserving water for later credit. The decision was made to operate El Vado on a yearly basis, and to release the water available in El Vado reservoir early in the season. Severe drought occurred again in the early season of 1964, when water rationing was planned to begin in the second week of June. The indicator again captured the drought condition well. Severe drought occurred again in July 1972, when the MRGCD decided that only Native Americans would get water after August 18, and there was a discussion about buying additional water from SJC.

From 1982 to 1995 a wet period was observed based on precipitation and flow records, and the drought indicator. In 1996 a period of dryness started that according to the MRGCD lasted until 2016. While 1996 was classified as slightly dry, 1997 to 1999 were normal to slightly wet. Severe dry conditions started again in 2002 and lasted until 2004. Based on the U.S. Drought Monitor, HUC 130202 (Rio Grande-Elephant Butte) was 97% under extreme drought and 3% under severe drought. The State Engineer's Office launched Active Water Resource Management (AWRM), which allows the State Engineer to actively manage the state's limited water resources during extreme droughts.

From 2007 to 2010 conditions in the MRGCD were near normal based on the indicator. According to a Reclamation employee in Albuquerque (personal communication), 2010 was an average year, while 2011 was worse than 2010 but not terrible. The Reclamation employee also pointed out that 2012 and 2013 were very dry years, as was captured by the indicator. By the end of September 2012, nearly all the surface water in the Lower Rio Grande (map) had been drained.

In 2013, NRCS forecast called for just 14% of the long-term average for spring runoff into Elephant Butte Reservoir. Drought at this point was classified as extreme. According to David Gensler, the MRGCD Water Manager, the MRGCD was expecting to run out of stored water in upstream dams sometime in late June. There were many consequences of the 2013 drought: farmers did not receive their full usual allocation for irrigation, pecan growers were forced to prune their trees to the trunk to help them survive, water levels at Elephant Butte fell to historic lows, Texas sued New Mexico over water shortages in the Mesilla Valley, and farmers turned to groundwater pumps (Frank Ward, 2014). In 2013, the shortest ever irrigation season for the federal Rio Grande Project ended a little more than a month after it started (USGS, 2013). The Rio Grande Project dates back to 1915.

**3/3/1954:** Expectation of a continued shortage.

**8/25/1959:** Extreme drought in the district. All irrigators north of Isleta would be curtailed to save perennial crops from destruction - not for a full crop, but so that they would not have to be replanted. Rain first time since May, which helped some.

**4/3/1963:** Notice of impending water shortage, rotating distribution of water will be imperative. Rationing of water required early in the season. Total loss is expected to be less than the past because of new infrastructure.

**7/22/1958:** Decision made to give short-term relief over the long term accumulation of credits.

**5/6/1964:** Severe water shortage would not be noticed until the end of June.

**6/9/1964:** Very little water. Water rationing within a week.

**7/14/1964:** Recent rains alleviated the severe water shortage temporarily, but much more rain is needed.

**8/25/1964:** No shortage at present time, but more rain needed to avoid shortage later.

**9/22/1964:** Water situation no longer alarming, probably enough to finish the season.

**3/9/1965:** Chief Engineer says no change in water conditions, shortage could be expected in late July or August due to lack of storage.

**4/13/1965:** USBR says water supply looking good. Chief Engineer says we could still run out.

**7/12/1965:** Potential for shortage is lowered.

**6/8/1971:** USBR published notice on water rotation due to storage, "...this is all that can be done at this time."

**7/25/1972:** Unless water supply improves, only Indians get water after August 18.

**8/22/1972:** Talk of purchasing additional San Juan-Chama water. MRGCD used its share due to drought.

**4/12/1977:** Reports of water shortage vary early in the season. Various complaints of water shortage by local farmers. Water rationing is started.

**1980-1990:** The 1980s and 1990s were years of plentiful rainfall by comparison. (David Gutzler, 2003)

**6/1/2002:** Stream flow during water year 2002 on the Pecos River was the lowest since 1850 and on the Rio Chama was the lowest since 1977 (Executive Order 2003-019). In a controversial ruling, a federal judge declared that water from the San Juan-Chama Project could be used to keep the river wet, although a later congressional rider neutralized the decision.

**7/9/2002:** Based on US Drought Monitor, HUC 130202 (Rio Grande-Elephant Butte) was 100% under extreme drought and 27% under severe drought.

**1996-2016:** Defined period of drought according to MRGCD.

**4/3/2003:** Emergency Drought Water Agreement approved by Interstate Stream Commission. Goal was to alleviate the effects of the ongoing drought in the summer of 2003 and in subsequent years, while providing water to sustain endangered species like the silvery minnow.

**3/2/2004:** Based on US Drought Monitor, HUC 130202 (Rio Grande-Elephant Butte) was 97% under extreme drought and 30% under severe drought. The State Engineer's Office launched Active Water Resource Management (AWRM), which allows the State Engineer to actively manage the state's limited water resources during extreme droughts.

**2005:** Over most of the State the wet period that began in late June had ameliorated the short-term drought that began in late October 2005. (New Mexico Drought Plan, 2006)

**7/5/2011:** Based on US Drought Monitor, HUC 130202 (Rio Grande-Elephant Butte) the MRGCD region was 63% under extreme drought and 34% under severe drought.

**2012:** NM counties declare drought emergency.

**10/1/2012:** By the end of September, nearly all the surface water in the Lower Rio Grande (map) had been drained. Back-to-back La Niña events during the 2010 and 2011 winters helped steer storms away from the Upper Rio Grande Basin in Colorado.

**2/25/2013:** Based on US Drought Monitor, HUC 130202 (Rio Grande-Elephant Butte) the MRGCD region was 100% under extreme drought and 51% under severe drought.

**4/1/2013:** Drought on the Rio Grande. "The worst year ever." (Albuquerque Journal, April 2013). According to David Gensler, the agency's water manager, the District will run out of stored water in upstream dams sometime in late June. After that farmers will depend on whatever meager supply comes from natural river flow.

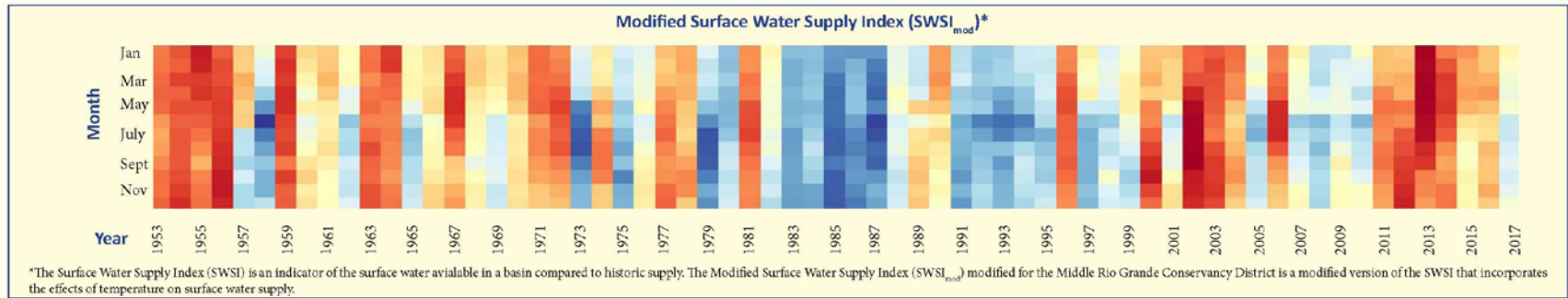


Figure 39: Summary of main drought records and the modified Surface Water Supply Index

## 4 Other SWSI applications

Many states in the United States apply SWSI to monitor droughts. The NRCS provides SWSI estimates for the following states: Colorado, Idaho, Montana, Oregon, and Wyoming. For Utah and New Mexico the NRCS creates the “New Mexico Basin Outlook Reports” which contain general information about the current state of hydrological components in the basin, including snowpack, precipitation, reservoir storage, and streamflow. A summary is provided for each watershed.

Statewide systems based on SWSI are available for the following states:

- Montana:  
[https://mslservices.mt.gov/geographic\\_information/maps/watersupply/statewide/StatewideSWSI.aspx](https://mslservices.mt.gov/geographic_information/maps/watersupply/statewide/StatewideSWSI.aspx)
- Colorado:  
<http://water.state.co.us/DWRDocs/Reports/Pages/SWSIReport.aspx>

The Colorado system includes the headwaters of the Rio Grande Basin. The data is available online from 2010 to today. To calculate the indicator for each basin, reservoir information, previous observed streamflow and forecast runoff are used. The Colorado SWSI for four HUC8 Rio Grande upstream watersheds is shown in Figure 401, together with the SWSI-Mod for comparison. The indicators for all watersheds captured the drought of 2013 well. The indicator for the Rio Grande Headwaters is more variable and indicates that the basin presented a fast recovery after the 2014 drought. The Colorado indicator that is most similar to SWSI-Mod is the indicator for the Conejos basin due to the proximity to the area of interest of MRGCD. This indicator applies Conejos River near Mogote observed and forecast inflow as the main component of SWSI, together with Platoro reservoir storage. SWSI-Mod showed slower recovery rate after the 2013 drought.

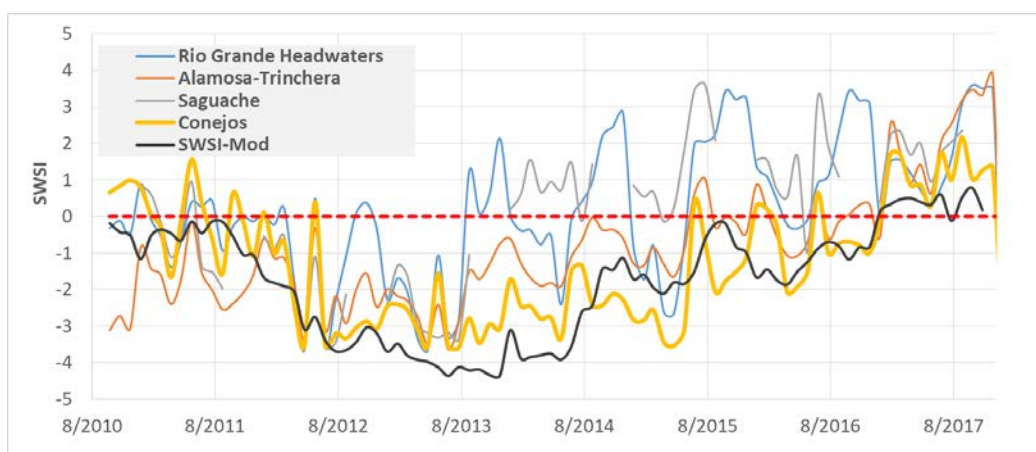


Figure 401: Comparison of SWSI-Mod and the Colorado Department of Water Resources SWSI for the Upper Rio Grande Basin

## 5 Drought indices: tool

A tool has been developed in excel that will enable the MRGCD to easily utilize the SWSI-MOD for the purpose of drought monitoring throughout the year. At the beginning of each month the tool may be used to either forecast the drought index for the upcoming irrigation season or to calculate the current drought condition, depending on the month.

## 6 Conclusions

In this report, the drought indicator developed for the MRGCD was described. To develop the drought indicator for the MRGCD the following components were taken into account: all dominant hydrological processes were taken into consideration; the effects of climate variability were accounted for in the formulation of the indicator; the indicator captured the inherent memory of the hydrological system (snow accumulation and subsequent runoff); all datasets used to calculate indicators were continuous and available for long periods of record, and were expected to be readily, consistently, and easily available in the future; the indicator was created to be capable of quickly calculating data in an operational environment and to be easy to implement and maintain.

The most common drought indicators used operationally were reviewed and a unique drought indicator that fit the needs of the MRGCD was proposed. A modified version of the Surface Water Supply Index (SWSI-Mod) was developed for the MRGCD that took into consideration the effects of temperature anomalies on water supply. The goal of the SWSI is to incorporate multiple hydrologic and climatological components into a single objective drought indicator that focus on surface water supplies, especially in areas where melting snow accounts for a big part of the annual supply. SWSI captures the memory of the hydrological system and can be used to forecast drought.

Two formulations of the SWSI were applied to take advantage of the streamflow forecast provided by the National Resources Conservation Service (NRCS). SWSI<sub>F</sub>-Mod covers the period of January to May, when streamflow forecast is available. NRCS has applied comprehensive statistical methods to estimate streamflow as a function of multiple variables, including SWE, water year to date precipitation, antecedent streamflow, and climate teleconnection index. This indicator will allow the early detection of the drought. SWSI<sub>O</sub>-Mod covers the period of June to December and is based on observed variables only. SWSI<sub>O</sub>-Mod can also be used in predictive mode if flow, precipitation and, temperature forecast are available.

The drought indicator represents past droughts well, highlighting for example the years of 2002 and 2013, which were marked by extreme droughts in the region. The indicator was also compared to the SWSI provided by the Colorado Department of Water Resources for the Upper Rio Grande Basin. SWSI-Mod follows the same patterns as the SWSI for the Conejos Basin.

WEST developed a tool to support the MRGCD on calculating SWSI-mod operationally.

Quantitative economic and environmental data were not available to perform a quantitative validation of the drought indicator. Therefore, it is recommended that the District continuously valid the indicator. If for a specific date the indicator differs from what is being observed, the indicator should be re-evaluated. Moreover, changes in policies, in the district operations, or in the operation of the reservoirs in the area of interest might also require the revision of the indicator.

## 7 References

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Appendix 5:  
Drought Preparedness and Response  
Actions

Prepared by

WEST Consultants

For the

Middle Rio Grande Conservancy District

October 2018



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## 1 MRGCD System Constraints

The following aspects limit the ability of the MRGCD to prepare and respond to droughts:

- ***The Rio Grande Compact and its accounting system:*** The Compact defines the obligation of New Mexico to deliver water in the Rio Grande at San Marcial. The Compact accounting system is based on annual observed flows, exclusive of the inflow during the months of July, August, and September. The Compact is evaluated on a yearly basis. During the irrigation season, there are no clear definitions of the water required to achieve the obligations with the Rio Grande Compact.
- ***Lack of adjudication:*** Currently, there are no legal determinations of who owns water rights, what quantity they are entitled to use, and how that right stands in the pecking order of priority use. Higher priorities are assigned to “Prior and Paramount” users (Pueblos) and for the Pre-1907 Water Rights, but all other users should receive water equally. This characteristic of water rights in New Mexico can be challenging, but also provides the opportunity for collaboration among users.
- ***Uncertain Water Demands:*** The Pueblos do not provide records to MRGCD on their water demands nor their water uses. Also, there are no clear definitions of the water requirements for endangered species for the Bosque del Apache National Wildlife Refuge (BDA) and for the Rio Grande Compact during the irrigation season. Irrigators also do not inform the MRGCD about their planting plans nor anticipated water demands for the season.
- ***Limited flexibility in operation due to limited storage and water control structures:*** MRGCD storage capacity is limited to El Vado reservoir. Additional regulating reservoirs that store small excesses and supply small deficits could benefit the system by minimizing fluctuations in the system and improving operational capacities. The MRGCD also is limited by a small amount of diversion works. Lack of conveyance works in some areas requires the water to be transported in the river, increasing hydrological losses. Water control is limited at most lateral canal sites. Improved water control structures could add more flexibility to operations.
- ***Rio Grande Compact Article VII:*** Article VII establishes that neither Colorado nor New Mexico shall increase the amount of water in storage in reservoirs constructed after 1929 whenever there is less than 400,000 acre-feet of usable water in project storage. In practice, with some exceptions, this article limits the ability of the MRGCD to use storage when it needs it the most (i.e. during extreme droughts). Under this restriction, even if more reservoirs are built, the ability of the MRGCD to use storage as a way to buffer the natural variability of the Rio Grande will be limited. New Mexico was out of Article VII restrictions from 1978 through July 2, 2002. Since then the state has gone in and out of the restrictions about 20 times, most recently from August 2017 to December 2017. With exceptions of a few months, the MRGCD was under the Article VII restrictions from 2002 to 2005, and from 2010 to 2016. In rare situations, and with the main focus of protecting the silvery minnows spawn, the Compact Commission allows Reclamation to temporarily store water while under Article VII restrictions.
- ***Uncertain volumes of water deliveries:*** The water volume delivered to a user is estimated based on acreage and experience. The duration of a water delivery is limited to no more than one hour per acre (i.e., a 20-acre field must be irrigated in 20 hours or less), but the flow rate is unspecified and not measured. This one hour per acre rule is a guideline and is not strictly enforced. With unquantified water deliveries, particularly under drought conditions, it is difficult to be equitable among users. Measurement systems can be used to increase the efficiency of the irrigation and to guarantee the equitability of the distribution for all users.

- **Informal water delivery scheduling:** No flow rate is specified when farmers request water deliveries from their ISO. The ISO accumulates upstream requests based on acreage and makes an estimation of flow rates needed at diversion canals. This estimate is uncertain due to the variable timing of irrigation, travel time in the channel, and the possibility of changes in the flow in the channel that might be performed by the water master. Inflow estimation and irrigation delivery is difficult because of fluctuations in the level of the canals caused, for example, by irrigators that interrupt the delivery before the expected time, changes in the operation, and diurnal fluctuations in wastewater and storm runoff outflows.
- **Multiple agencies have authority over the water:** The MRGCD maintains continuous communication among the multiple agencies at the operation and planning level. However, multiple interests and the definition of multiple contingency actions among agencies can generate conflict and require intensive negotiations. The agencies in the Middle Rio Grande region include:
  - NM Interstate Stream Commission (NMISC), which is responsible for meeting Rio Grande Compact requirements
  - U.S. Bureau of Reclamation (Reclamation), which is responsible for meeting federal requirements; endangered species (U.S. Fish and Wildlife Service {USFWS} Biological Opinion {BO}) and requirements of federal agencies (e.g., BDA)
  - U.S. Fish and Wildlife Service, which is responsible for endangered species protection.
  - U.S. Army Corps of Engineers (USACE), which is responsible for flood control and for maintaining the quality of rivers in the United States.
- **Increasing demands:** Irrigation demands are expected to increase due to projected increases in temperature and consequently in potential evapotranspiration. Irrigation demands are expected to increase, on average, by approximately 5% by the year 2050 (see Task 3: Climate Change report). By the end of the century potential evapotranspiration is expected to increase on average by 10% for the Representative Concentration Pathways 4.5 (RCP 4.5) and 15% for Representative Concentration Pathways 8.5 (RCP 8.5).
- **Decreasing snow water pack:** SWE is projected to decrease for months for which snow occurs. Changes are relatively higher for the Upper Rio Grande Basin, but the loss of water volume is most significant for the Rio Grande Headwaters, where the volume of water stored as snow is higher. For the Rio Grande Headwaters, the May SWE is projected to decrease an average of 19.4% for the first half of the century and 42.8% for the second half of the century for RCP 4.5.
- **Change in the seasonality of streamflow:** Even though climate model ensembles, on average, averages project a decrease in annual streamflow, the projections are highly uncertain with both positive and negative trends being projected by different models. However, projections of changes in the seasonality of streamflow are consistent and significant for all models. Streamflow at the Otowi Bridge gauge increases for the months of March and April, and decreases for the months of May, June and July. Streamflow at the Otowi Bridge gauge increases for the months of March and April, and decreases for the months of May, June and July. Ensemble averages change for the Colorado River locations are more accentuated than the ones observed in the Rio Grande Basin, and likely to affect the supply of water from the San-Juan Chama basin.
- **Change in the intensity, frequency, and persistency of droughts:** As shown in the “Task 3: Climate Change Impacts on Droughts” report developed during this project, due to the combined effects of hydro-meteorological changes induced by alterations in the climate, droughts in the MRGCD area are projected to become more intense, frequent, and persistent.

- **Increasing population:** Official population estimates indicate that the State of New Mexico population will reach 2.35 million by 2020 and hit the 2.5 million mark by 2025.
- **No long-term forecast:** At this point, The Natural Resources Conservation Service (NRCS) provides inflow forecast for the Rio Grande at the Otowi Bridge Gauge and inflows to El Vado from January to May. These forecasts are used in the definition of the drought indicator suggested in this work. While few studies have investigated the links between El Niño–Southern Oscillation (ENSO) and droughts in the U.S. Southwest, regional seasonal forecasts that focus on the MRGCD area of interest are still not available.

## 2 Opportunities

The intense droughts that have occurred in the MRG in the last two decades, and the projection that more intense, frequent, and persist droughts are expect to occur in the future, are strong catalysts for changes in the Rio Grande. The following opportunities should be consider by the MRGCD as ways to mitigate the effects of droughts:

- **Review existing Water Bank regulations and propose modifications:** the main goal of the existing water bank is to provide flexibility to users without increasing net depletions within the MRGCD boundaries. The water bank is composed of water that has been proven to be historically in beneficial use. The MRGCD should explore ways to expedite pre-1907 declarations and optimize approvals. The MRGCD should also assess the impacts of the current water bank, and investigate the possibility of expanding the water bank to a more comprehensive farmer-to-farmer negotiations systems that would count with appropriate administrative oversight. The goal is to strengthen the collaboration among users.
- **Water cost:** The MRGCD should study and implement a framework to determine the cost of water and fees in a way that rewards conservation during dry years.
- **The Strategic Water Reserve:** Evaluate the possibility of taking advantage of the New Mexico Strategic Water Reserve (SWR), created in 2005. SWR allows water or water rights in New Mexico to be designated for use for public purposes as specified in the statute. The New Mexico Interstate Stream Commission is authorized to implement and administer the Reserve. The Commission can acquire water or water rights for the reserve by purchase, lease, or donation. Water or water rights in the Reserve can be used to assist the State of New Mexico in complying with interstate river agreements, or compacts, and to benefit threatened or endangered species.
- **Take advantage of publicly available streamflow forecasts:** Based on the Upper RGB SNOWfall Measurement and streamFLOW 3(RIO-SNO-FLOW) Forecasting Improvement Project concluded in 2015, many recommendations have been proposed to improve forecast in the Upper RGB. Follow-on activities are currently in progress to improve forecasts in the region. The National Water Model operated by NOAA provides hourly short-range forecasts for 0 to 18 hours, 6 hours medium-range forecasts out to 10 days, and daily long-range forecast out to 30 days. These forecasts are invaluable resources for continuously monitor hydrological conditions during a drought, while seasonal forecasts provided by the National Resources Conservation Service (NRCS) will continue to play an important role on predicting the conditions for the irrigation season.

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<sup>3</sup> Gochis, D. J. et al. Upper Rio Grande Basin Snowfall Measurement and Streamflow (RIO-SNO-FLOW) Forecasting Improvement Project, RIO-SNO-FLOW Summary Report, January 2016.

- **Improve MRGCD operations and infrastructure:** Infrastructure improvements projects have been proposed to the MRGCD that can reduce hydrological losses in the system, including the addition of small reservoirs to capture flow fluctuations in the system, and the implementation of better connections from drains to supply canals for water reuse. Based on the part of this project, Infrastructure Recommendations for Drought Conditions, improved operations with a 10% reduction in supply can be accomplished with relatively minor infrastructure improvements; projects costing from \$1,000 to \$20,000. For a 25% reduction in supply can be achieved with projects on the range of \$20,000 to \$100,000. With a 40% reduction in supply, more aggressive measures are recommended, with costs ranging from \$100,000 to \$1,000,000 or more.
- **Improve water on-farm control and irrigation structures:** Subsidies, rebates, and giveaway programs can be used to incentivizes changes at the user property level;
- **Request users to inform MRGCD of their planting plan for the season:** A system that rewards users that inform their planting plan for the season should be designed and implemented to help the MRGCD estimate demands for the season. A web-based system where users could fill out a simplified form in the website, and the data would be directly saved in a database could be developed.
- **Improve scheduling methods:** Develop procedures to optimize irrigation scheduling. Develop and share with users a framework to help them coordinate scheduling with neighbors.
- **Improve on-farm monitoring and metering:** Develop automated procedures to monitor if farms are respecting irrigation procedures and to measure how much water is being delivered to each user.
- **Improve users education and increase public outreach:** Develop community-oriented training to instruct users on existing efficient irrigation practices (e.g., vegetative practices and mulching, and Residue and Tillage management), irrigation technologies, irrigation season planning including considerations about drought forecast, optimal delivery scheduling procedures, among others.

The regulations that limit the ability of the MRGCD and other stakeholders in the basin to efficiently manage and store water in the RGB have been established many decades ago, including the Rio Grande Compact, signed in 1938, and reservoir operation manuals and rules that were developed more than 60 years ago. These regulations were established based on limited data, and therefore limited knowledge about the basin’s climatic variability, and without any knowledge of possible climate change effects. Therefore, while regulations changes are challenging and long-lasting, they will likely be essential to minimize the impacts of future catastrophic drought with long during. Changes in regulation have the potential to benefits all stakeholders and water users in the RGB.

Opportunities to increase the MRGCD water operation flexibility during dry periods that will require coordination with multiple basin stakeholders and the modification of current regulations include:

- **Operation deviations:** During drought events, an increase of storage for water supply in USACE flood control storage can be approved under the “Guidance on the Preparation of Deviation from Approved Water Control Plans, Department of the Army South Pacific Division Corps of Engineer” published in 2014. The implementation of these deviations do not require the development of an updated reservoir operation manual.
- **Forecast-based reservoir operation (FIRO):** FIRO can improve the performance of reservoirs and increase water supply reliability. FIRO has already been implemented for USACE reservoirs in CA,

including Mendocino and Folsom Lake. The implementation of FIRO for Cochiti, Abiquiu, Jemez Canyon and Galisteo Reservoirs will decrease considerably the vulnerability of the region to droughts;

- **Review of the Rio Grande Compact rules:** The Rio Grande Compact was signed in 1938, and was developed based on a limited amount of data. A review of the Compact based on current system specification using data that have been collected during the last 80 years, and data that have been generated based on future predictions of climate change, will likely benefit all the users in the RGB.
- **Amendments to current Rio Grande Compact:** While a full review of the Compact will probably take decades to be developed and implemented, the Compact can be amended to include some considerations that are likely to benefit all users in the RGB. For example, carry over of water in upstream reservoirs should be allowed when it represents a considerable decrease in the expected losses. Even though the MRGCD focus on surface water, underground storage of surface water during times of surplus could also reduce the draft on groundwater aquifers and enhance the conjunctive use and management of surface and ground water resources.

### 3 Drought Preparedness

Due to the constrains highlighted in this report, preparing and responding to droughts in the area of the MRGCD can be challenging. Being a system mainly operated based on run-of-the-river, main preparedness and response actions depend on the coordination with multiple agencies and users. With a projected increase in the severity, frequency, and persistence of droughts due to climate change, the MRGCD will need to continuously work to explore new opportunities to reduce the effects of droughts in order to continue serving users appropriately.

Drought preparedness actions have the goal of minimizing the impact of droughts by the early implementation of actions that can decrease water demand or enhance water supply. Preparedness actions should be implemented continuously during periods of non-drought and drought. During non-drought periods, long-term actions should be study, designed, negotiated, and implemented by the MRGCD and other basin stakeholders based on current and projected drought vulnerabilities. Long-term actions include changes in regulations and policies, improvement or addition of new infrastructure, increase in the flexibility of operations, optimization of water distribution system, improvement or procedures and protocols to schedule and deliver water, and community awareness and education. The implementation of this kind of actions take several years, and even decades, and therefore proactive actions should start long in advance before the benefits can be achieved. Continuous long-term drought preparedness actions are listed in Table 35.

Table 35 actions that require coordination with multiple stakeholder are denoted by “C” and highlighted in blue, while actions that should be developed by the MRGCD in conjunction with its users and contractors are denoted by “M” and shown in black actions. According to Mary Carlson, Reclamation spokeswoman, Reclamation, the U.S. Army Corps of Engineers, the Middle Rio Grande Conservancy District, the six Middle Rio Grande pueblos and the U.S. Fish and Wildlife Service already coordinate during daily operations on river flows. Coordination is also a requirement for the development of long-term solutions. Stakeholders in the MRG include, but are not limited to:

- U.S. Bureau of Reclamation (Reclamation) is responsible for meeting federal requirements; endangered species (U.S. Fish and Wildlife Service {USFWS} Biological Opinion {BO}) and requirements of federal agencies (e.g., BDA)
- U.S. Fish and Wildlife Service is responsible for endangered species protection.
- U.S. Army Corps of Engineers (USACE) is responsible for flood control and for maintaining the quality of rivers of the U.S.
- NM Interstate Stream Commission (ISC) is responsible for meeting Rio Grande Compact requirements
- Colorado Department of Water resources manages the San-Juan Chama system and the Rio Grande deliveries to New Mexico
- Bureau of Indian Affairs (BIA)
- Albuquerque Bernalillo County Water Utility Authority (ABCWUA)
- City of Albuquerque
- City of Socorro
- Bernalillo County Public Works
- Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA)
- Southern Sandoval County Arroyo Flood Control Authority (SSCAFCA)
- Coalition of Six Middle Rio Grande Basin Pueblos
- New Mexico Acequia Association
- New Mexico State Forestry Division
- The Nature Conservancy New Mexico
- Audubon New Mexico
- Middle Rio Grande Water Assembly
- New Mexico Interstate Stream Commission (NMISC)
- Sandoval, Bernalillo, Valencia, and Socorro County
- Local and state fire response and prevention teams
- Rio Grande Compact Commission
- Office of the State Engineer
- Santa Ana Pueblo
- Elephant Butte Irrigation District (EBID)

Actions in Table 35 are also classify by type: Policy and Regulation (PR); Monitoring (M); Public Outreach (PO) and Resources Management (RM). Actions can have multiple classifications.

The evaluation of the actions proposed in Table 35 should be supported by the application of a hydrological model in conjunction with a water management model. Current and projected hydrological data is available through the BCSD-CMIP5 hydrologic and streamflow projections datasets described in “Task 3: Climate Change Impacts on Droughts” report developed during this project. The Upper Rio Grande Water Operations Model (URGWOM), developed by the US Army Corps of Engineer based on the RiverWare software developed by the University of Colorado at Boulder, if adequately modified, can be used to evaluate the benefits of policy and regulation changes, as well as, the effects of optimizing water collection, storage, and distribution systems.

Short-term preparedness actions occur when in the beginning of the season (January to May) reservoirs levels and hydro-meteorological conditions indicate that there will be a shortage of supply during the irrigation season. Short-term actions are triggered by values of the forecasted SWSI-Mod. Long-term

actions create the mechanisms necessary to allow the fast and efficient implementation of short-term preparedness actions. Many of the proposed actions will only become possible if they have been previously studied, proposed, negotiated, and if the legal and operational mechanisms to implement the actions are already in place.

Preparedness actions will depend on the drought intensity as classified by the forecasted SWSI, including Moderately Dry, Severely Dry and Extremely Dry. Stage zero corresponds to slightly dry periods. At this stage no goals are defined for reduction in water consumption. Actions recommended for Stage zero includes community outreaches, and continuously monitoring of the basin conditions. For the other drought stages, some level of reduction in water consumption is proposed. This reductions are based on expected decrease in supply observed for each drought severity level. Actions and water consumption reduction goals for each drought severity class are listed in Table 36.

Table 35. Continuous Long Term Drought Preparedness Actions

Enhancing supply
<p><b>(C.1)</b> Adjust legal and institutional framework to provide flexibility on the operation of existing reservoirs in advance of changes in hydro-meteorological conditions projected by climate change, including the shift on the seasonality of runoff and decreasing volumes of snow pack (PR and RM);</p> <p>Evaluate the possibility, the effects of, and develop financial, legal and institutional frameworks:</p> <p>(M.1) for adding regulating reservoirs to store small excesses to minimize fluctuations in the system and improve operation (PR and RM);</p> <p>(M.2) for improving infrastructure, including: addition of small reservoirs for flow regulation, increase connections from drains to supply canals for water reuse, and reduce losses from the system by reducing the use of the river to convey MRGCD (PR and RM);</p>
Decreasing demand
<p><b>(M.1)</b> Establish regulations that incentivize water conservation. For example, subsidies, rebates, and giveaway programs can be established for users that shift to less water-demanding crops (PR, PO, and RM);</p> <p>(M.2) Reduce losses through the implementation of more efficient transportation, diversion, and irrigation systems. Subsidies, rebates, and giveaway programs can be used to incentivizes changes at the user property level (PR, M, PO, and RM);</p> <p>(M.3) Create mechanisms and regulations to establish water conservation incentives, rebates, and giveaway programs to mobilize farms to conserve water (PR, M, PO, and RM);</p> <p>(M.4) Develop instructional materials and courses to orient users about existing methods to decrease water demand, including modern irrigation systems, alternative drought tolerant crops/species/genotypes, methods to adjust cropping calendars to avoid heat stress, adaptation to short growing seasons, and practices and techniques for conservation agriculture (PO);</p> <p>(M.5) Develop instructional materials and courses to orient users on how to interpret information provided by the MRGCD about the current conditions of the basin, and how to use this information to plan for the season. The user should be aware about the trade-offs between potential profits and risks on the advance of a drought in order to better plan for the season (PO);</p> <p>(M.6) Establish formal procedures for water delivery scheduling that allows a better monitoring, metering, and forecasting of water demands (PR and PO);</p>
<p><b>In Blue and denoted by C (Collaboration): Actions to be developed in coordination with other agencies including the USACE, Bureau of Reclamation, the Albuquerque Bernalillo County Water Utility Authority, The City of Santa Fe and other;</b></p> <p><b>In Black and denoted by M (MRGCD): MRGCD actions;</b></p>

Table 36. Drought Preparedness Actions – based on forecasted SWSI from January to May.

Stage 1: Moderately dry -3<SWSI<-2	Stage 2: Extremely dry -4<SWSI<-3	Stage 3: Severely dry SWSI<-4
*Goal: Reduce water consumption by 10 to 20% (15 TAF to 20 TAF)	*Goal: Reduce water consumption by 20% to 30 % (30 TAF to 45 TAF)	*Goal: Reduce water consumption by 30% to 40% (45 TAF to 60 TAF)
<p>C.1) Initiating drought awareness and conservation campaigns (PO). C.2) In coordination with multiple partners, continuously monitor water conditions and develop possible operation scenarios based on URGWOM (M, RM); M.1) Initiate community-oriented drought awareness with focus on community water use reduction goals and range of voluntary steps to accomplish savings (e.g., change in crops to conserve water). Landowners and farm operators should be informed about the possibilities of applying to the Environmental Quality Incentives Program (EQIP) (M and PO); M.2) Provide at least monthly updates to the public on drought and demand status. Weekly updates are preferred (M and PO); M.3) Reinforce with users existing irrigation practices to minimize the effects of droughts (e.g., vegetative practices and mulching, and Residue and Tillage management) (PO); M.4) Start inspection and maintenance work on the drains and diversions to guarantee they are in good condition for the year (RM).</p>	<p>Include continuation of Stage 1 shortage preparedness measures. C.1) Coordinate with basin stakeholders to quantify the need for water leasing, and to develop and implement a collaborative and integrated water management plan for the season. For example, water can be leased from the San-Juan Chama project supply (PO and RM); C.2) Request an authorization for temporary storage of native water released from El Vado in Cochiti Dam (PR and RM); (PO, M and RM); M.1) Implement water conservation incentive, rebate, and giveaway programs to mobilize farms to conserve. Among possible measures are changes to water efficient crops, reduction of planted acreage, or improvements on-farm irrigation efficiency. Low to moderate compensations for this actions might be provided at this stage. Compensations should increase as droughts become more intense (PR, M, PO, and RM); M.2) Determine the price for water bank leases according to drought conditions as a way to promote water conservation. Inform water bank contractors of change in the water price and possibilities of canceling the contract. This activity needs to be executed in January (PR, PO, and RM); M.3) Promote collaboration among users by notifying the users that requests made in coordination with neighbors are recommended and more likely to be attended in a timely matter (PO and RM); M.4) If allowed by regulation (Appendix to Water Bank Rule 23), restrict delivery to water bank contractors (PO and RM);</p>	<p>Include continuation of Stage 1 and 2 preparedness response measures. C.1) Collaborate with other agencies to negotiate water leasing agreements (PO and RM); M.1) Create subsidies (e.g., fee reduction) for users that adopt water efficient crops or reduce the cultivated area. Fee reduction and other subsidies should be created to incentivize users (PR and RM); M.2) Create subsidies (or rebates) for users to improve the efficiency of their irrigation system for the season (PR and RM);</p>
<p>In Blue and denoted by C (Collaboration): Actions to be developed in coordination with other agencies including the USACE, Bureau of Reclamation, the Albuquerque Bernalillo County Water Utility Authority, The City of Santa Fe and other;</p>		
<p>In Black and denoted by M (MRGCD): MRGCD actions;</p>		
<p>Type of measures: Police and Regulation (PR); Monitoring (M); Public Outreach (PO) and Resources Management (RM)</p>		

## 4 Drought Response

Due to limited flexibility on reservoir operation and limited storage capacity, the MRGCD has a restricted number of possible actions that can be taken to minimize the effects of droughts during the irrigation season. Table 37 lists the actions that can be taken by the MRGCD to minimize the effects of droughts during the irrigation season.

Table 37. Drought Response Plan Summary – based on observed SWSI from June to December.

Stage 1: Moderately dry -3<SWSI<-2	Stage 2: Extremely dry -4<SWSI<-3	Stage 3: Severely dry SWSI<-4
*Goal: Reduce water consumption by 10 to 20% (15 TAF to 20 TAF)	*Goal: Reduce water consumption by 20% to 30 % (30 TAF to 45 TAF)	*Goal: Reduce water consumption by 30% to 40% (45 TAF to 60 TAF)
<p>C.1) Initiating drought awareness and conservation campaigns (PO).</p> <p>C.2) In coordination with multiple partners, continuously monitor water conditions and develop possible operation scenarios based on URGWOM (M, RM);</p> <p>M.1) Continuously assess drought stage based on SWSI, observed and forecasted streamflow and precipitation, and evapotranspiration estimation (M and PO);</p> <p>M.1) Initiate community-oriented drought awareness with focus on community water use reduction goals and range of voluntary steps to accomplish savings during the irrigation season (proper diversion and irrigation techniques, techniques to monitor the soil, seasonal irrigation planning) (PO);</p> <p>M.3) Continuously monitor deliveries to guarantee users are following irrigation recommendations and mandatory irrigation procedures and to guarantee equitable distribution among users (M and RM);</p> <p>M.4) Predict if and when water delivery rotations will be necessary and inform the public (PO, M, RM);</p>	<p>Include continuation of Stage 1 shortage response measures.</p> <p>M.1) Imperative rotation of water delivery to guarantee shared shortage among all users (exception of Prior and Paramount and Pre-1907 Water Rights) (RM);</p> <p>M.1) Implement plan for water conservation subsidies, if available (PR, PO, RM);</p> <p>M.2) Continuously monitor water demand to decide on how to best allocate resources (M, and RM);</p> <p>M.3) If allowed by regulation (Appendix to Water Bank Rule 23), restrict deliver to water bank contractors (PR, M, PO, RM);</p> <p>M.4) Evaluate the need and possibility of curtailing supply to certain areas to save perennial crops (RM).</p>	<p>Include continuation of Stage 1 and 2 shortage response measures.</p> <p>M.1) Imperative deliver only for users with Prior and Paramount and Prior-1907 Water Rights (RM);</p> <p>M.2) Other users should prepare to rely only on supplies that come from natural river flows (RM);</p>
<p>In Blue and denoted by C (Collaboration): Actions to be developed in coordination with other agencies including the USACE, Bureau of Reclamation, the Albuquerque Bernalillo County Water Utility Authority, The City of Santa Fe and other;</p> <p>In Black and denoted by M (MRGCD): MRGCD actions;</p> <p>Type of measures: Police and Regulation (PR); Monitoring (M); Public Outreach (PO) and Resources Management (RM)</p>		

## 5 Conclusions

The MRGCD have done an amazing job operating the system under dry years. However, droughts are expected to become more intense, frequent and persistent, and therefore drought preparedness and response actions are proposed that can decrease water demand or enhance water supply. This report provides the base for the development of the MRGCD Drought Contingency Plan.

The purpose of this report is to list all potential drought preparedness and response actions that can minimize the impacts of drought for the Middle Rio Grande Conservancy District (MRGCD). Some of the proposed actions might not be applicable at this time, since their implementation requires in-depth evaluation of benefits and costs, and changes in operations (e.g. Reservoir Water Control Manual) and regulations. However, as droughts become more intense in the basin, and the negative impacts of droughts increase, actions that are harder to implement might need to be considered. One example is the implementation of Forecast-based reservoir operation (FIRO).

Drought preparedness actions have the goal of minimizing the impact of droughts by the early implementation of actions that can decrease water demand or enhance water supply. Preparedness actions should be implemented both during periods of non-drought and drought. During non-drought periods, long-term actions should be studied, re-negotiated, designed, and legally formalized by the MRGCD in coordination with all stakeholder and legal parties taking into consideration current and projected drought vulnerabilities. The goal of long-term actions is to increase resiliency to droughts by establishing the operational, educational, regulatory, and cooperative framework to allow the timely and efficient implementation of actions during periods of droughts.

The Surface Water Supply Indicator (SWSI) is used to forecast and monitor drought conditions, as well as, to estimate drought severity. Short-term preparedness actions are defined for the months of January to May based on forecasted  $SWSI_F$ -Mod. For the remaining months, response actions are defined based on observed  $SWSI_O$ -Mod, calculated based on observed properties of the water supply system. Due to the limited flexibility on reservoir operation and the limited storage capacity, the MRGCD has a restricted number of possible actions that can be taken to minimize the effects of droughts during the irrigation season.

For the final development of the MRGCD Drought Contingency Plan, the MRGCD should apply the SWSI-Mod in combination with current river flow observation. SWSI-Mod presents the advantage of combining in one indicator information about the state of all water supply components, as well as of allowing the prediction of the conditions for the irrigation season. Current streamflow measurements are essential for the MRGCD day-to-day operations.

Appendix 6  
Identification of  
Drought Performance  
Limitations Prepared by

WEST

Consultan  
ts For the

Middle Rio Grande  
Conservancy District October



2018

**This is a reduced version of this report that only includes detailed sections, without Introduction, etc.**

## Summary

WEST Consultants (WEST) and Davids Engineering (DE) performed an assessment of the operations and infrastructure of the Middle Rio Grande Conservancy District (MRGCD). The intent of this assessment was to identify those factors that influence MRGCD's ability to deal with drought. These factors included physical infrastructure, operational methods and operating rules. Water balances were computed for several years so that the team could understand how water flows through the MRGCD service area.

WEST also conducted a Vulnerability Assessment to identify drought conditions and develop drought triggers. In a separate report WEST provided recommendation on structural and operational methods to reduce the impact of drought.

The following factors were identified as having an influence on MRGCD's ability to deal with drought. Those factors that are thought to have to most influence are listed first.

- Limited storage exists downstream from El Vado Dam
- Water delivery scheduling is informal
- Water deliveries are not determined on a volume basis
- Water deliveries are not accurately measured and recorded
- Pueblo water use is uncertain
- Variable delivery timing and variable inflows cause flow rates in drains and the river to fluctuate diurnally
- Water losses occur in transporting water to points of diversion
- Water measurement and control are limited at lateral canal sites
- Water records are not sufficient for defining performance
- Water rights and allocations are not established on a volume basis
- Multiple agencies have authority over water in the river (for different purposes)

## Existing Conditions

WEST Consultants, Inc. (WEST) and Davids Engineering (DE) examined MRGCD records for water use (Appendix B). As water becomes more limited, the water available to ISOs for delivery may be reduced. To evaluate limitations for a 10%, 25%, and 40% reduction in the MRGCD's supply, one must first define the MRGCD supply. Here we assume that to be a normal or typical annual supply amount. The first step in evaluating this process is to define existing conditions.

WEST and DE examined the water supply and use for the years 2008 to 2015. Complete records were not available for all years. MRGCD provided records for inflow, outflows, and cropped acreage. Data on rainfall and reference evapotranspiration were provided on the Reclamation web site for the ETtoolbox. This site also includes estimates for water consumption from agriculture, phreatophytes, open water surfaces, and urban areas. The USGS provides flow measurement records for the Rio Grande and some of its tributaries extending from Cochiti Dam to San Marcial. All this data was compiled into water budgets for the years 2008-2015. A schematic of the water budgets is shown in Figure 1.

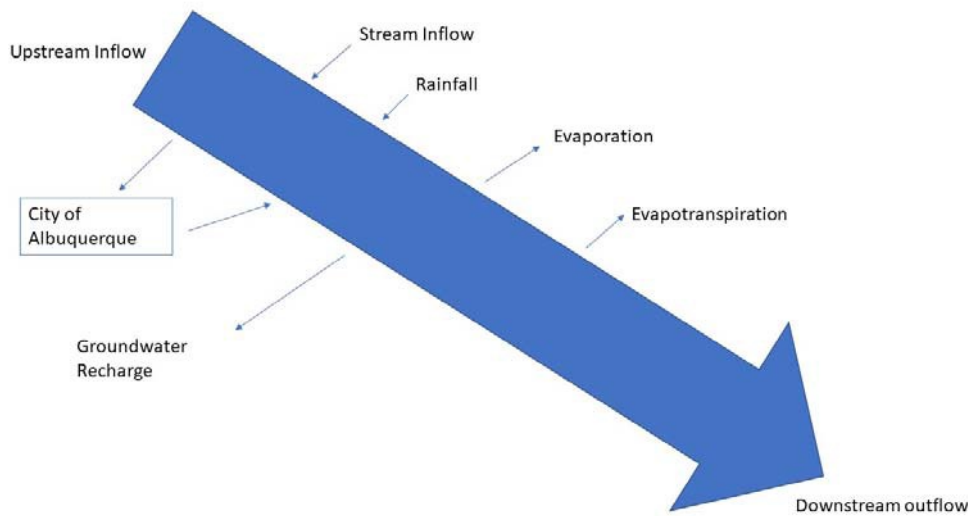


Figure 1. MRGCD water budget. Large arrow represents the MRGCD system including the Rio Grande and all MRGCD canals and drains.

Upstream, the inflow to the Rio Grande comes from releases at Cochiti Dam. Just downstream from the Dam, water is diverted into two MRGCD canals on either side of the river: the Sili Main Canal and the Cochiti Main Canal. Downstream from this diversion point, the flow rate is measured in the Rio Grande by the U.S. Geological Survey (USGS) and in these two canals by MRGCD. This is considered here as the upstream inflow. Essentially all surface water outflow

from the system is captured through measurement of the Rio Grande and Low Flow Conveyance Channel (LFCC) at San Marcial downstream from MRGCD. Flow passes downstream in the Rio Grande and in MRGCD canals and drains. This is all considered one system since the river, canals and drains all interact as water is diverted from and returned to the river. Groundwater inflow from upstream aquifers (for example, under Cochiti Dam) and outflow to downstream aquifers (for example, under the stream bed at San Marcial gages) were not included in the water budget.

In between, the river gains and losses water in a variety of ways. The City of Albuquerque diverts water for domestic and industrial use. The City returns water to the river from their wastewater treatment plant. Data from the City of Albuquerque was used in the water budgets for both diversions and returns. The City also pumps groundwater from below the City. The groundwater levels have declined significantly below the level of the river. This causes water from the river to recharge groundwater in the central Albuquerque area. This is estimated to occur at a rate of 60,000 ac-ft per year (MRGCD staff, 2018). Rain provides another major input to the system. This is an arid area, so light rainfall likely contributes little surface flow to the river. Larger storms provide runoff to streams and storm drains.

Those streams that are thought to contribute significant flows to the system are gaged by the USGS and included in the water budget. Data from the following USGS gages were used in the water budgets:

- Galisteo Creek, USGS gage 8317950
- Jemez River, USGS gages 8329000 and 8328950
- Albuquerque North Floodway Channel, 8329900
- Mariposa Division of San Antonio Arroyo, USGS gage 83299375
- San Jose Drain at Woodward Rd., USGS gage 8330200
- Albuquerque South Diversion Channel, USGS gage 8330775
- Tijeras Arroyo, USGS gage 8330600and
- Rio Puerco, USGS gage 8353000

One of the major outflows from the system is evaporation and evapotranspiration (ET). Reclamation has developed a tool for estimating the total loss from the system called the ETtoolbox. The ETtoolbox computes evapotranspiration from agricultural land and phreatophytes. It computes evaporation losses from open water surfaces. It also takes rainfall into consideration and determines the total losses (for example, ET minus rainfall). The details and assumptions are described in Brouwer, et al (2015). In 2012, the ETtoolbox began using agricultural acreage provided by MRGCD.

The water balance results are shown in Table 1 and Table 2. Table 1 provides the water budgets on an annual basis. Data is averaged over the calendar year so may not represent the irrigation season very well. MRGCD delivers irrigation water from March 1 to November 1 (i.e., the MRGCD irrigation season). Table 2 gives the water budgets during the irrigation season. Because there can be a lag time in return flows, outflow can be shifted relative to inflows during the irrigation season. This can be seen in the graph of annual water budgets, which show a negative balance in the late fall or early winter as agricultural return flows continue to pass through the system (Figure 2). The Vulnerability Assessment Drought Condition came from WEST (2018).

Table 1. MRGCD water budgets for calendar years 2008-2015, with water consumption estimates from ETtoolbox. The values are the average flow rates in cfs over the year. Note that these water balance tables do not include all inflows and outflows.

Year	Vulnerability Assessment Drought Condition	Upstream Inflow at Cochiti	Total ET-rain from ET-toolbox	Downstream Outflow at San Marcial	Annual Water Balance Remainder
		cfs	cfs	cfs	cfs
2008	Slightly wet	1,792	621	1,289	-54
2009	Near normal	1,395	540	961	-90
2010	Near normal	1,282	596	750	-35
2011	Slightly dry	888	396	426	14
2012	Severely dry	865	534	398	-54
2013	Extremely dry	714	474	418	-123
2014	Slightly dry	861	365	439	23
2015	Near normal	1,150	383	752	29
<b>Average</b>		1,118	489	679	-36

Table 2. MRGCD water budgets for irrigation seasons (March-October) 2008-2015, with water consumption estimates from ETtoolbox. The values are the average flow rates in cfs over the irrigation season.

Year	Vulnerability Assessment Drought Condition	Upstream Inflow at Cochiti	Total ET-rain from ET-toolbox	Downstream Outflow at San Marcial	Irrigation Season Water Balance Remainder
		cfs	cfs	cfs	cfs
2008	Slightly wet	2,330	771	1,553	-35
2009	Near normal	1,735	540	1,075	-79
2010	Near normal	1,543	870	797	-54
2011	Slightly dry	944	578	270	57
2012	Severely dry	968	771	304	-67
2013	Extremely dry	756	688	342	-168
2014	Slightly dry	933	525	325	70
2015	Near normal	1,224	557	646	56
<b>Average</b>		1,304	663	664	-28

The water balance remainder is the difference between inflow and outflow. The water budget does not include all of the rainwater inflow to the river because not all tributaries are gaged. Not including tributary inflow would cause the balance to be negative, which it is on average.

The Vulnerability Assessment evaluated the historical water supplies available to MRGCD and developed indices to define drought conditions (WEST 2018). The main indicators are the natural flow at the Otowi gage, the storage available in El Vado reservoir, temperature, and rainfall and other natural inflow

within the MRGCD service area. The natural flow at Otowi gage requires some explanation. This indicator was developed by the Natural Resources Conservation Service (NRCS). The indicator starts with the measured flow at Otowi gage, then subtracts the inflow resulting from the San Juan Chama project which brings in water from the Colorado River, then adjusts the inflow to account for water stored or released from the reservoirs along the Rio Chama. The water stored in El Vado prior to the irrigation season shows up as an increase in the natural flow at Otowi prior to the irrigation season. Using these indicators, the drought condition at the end of the irrigation season are included in Table 1 and in Table 2.

Further details on these water budgets are provided in Appendix A.

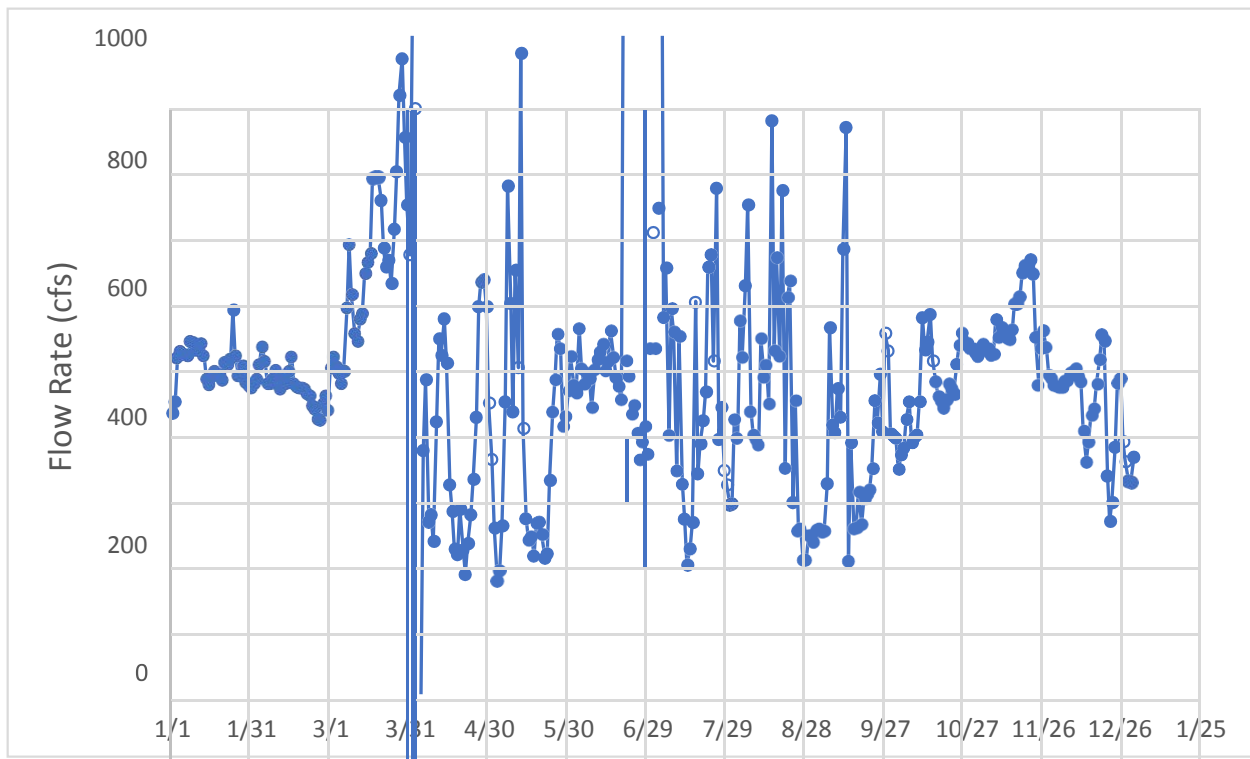


Figure 2. MRGCD water budget for 2012.

Water released from upstream is either removed from the system or it continues to flow downstream. All of the unused water from the upper three divisions (i.e., Cochiti, Albuquerque, Belen) end up at San Acacia Diversion; the upstream end of the Socorro Division. The water budgets shown in Table 1 and Table 2 show that even in low water supply years that there is a considerable amount of flow leaving the system at San Marcial. This implies that there is still some flexibility in managing this remaining supply if this water can be used within the Socorro

Division. For this reason, we chose to examine the water budgets in the Socorro Division more closely. This water budget has two inputs at the upstream end and two outputs at the downstream end, with only ET-rainfall in between. There are no other measured inflows or outflows in this part of the system. The Socorro water budgets are given Table 3 and Table 4 for calendar years and irrigation seasons, respectively. The annual water balance remainder is just over 5% of the supply amount (43/787). This is well within the accuracy of the water measurements and estimates. The large remainder in 2009 indicates that some of these measurements or estimates are in error. One possible reason for a negative remainder in the water budget is that net water consumption from ETtoolbox is overestimated. To better understand water consumption, or actual ET, in dry and wet years a remotely sensed water energy balance approach is recommended.

Table 3. Socorro Division water budgets for calendar years 2008-2015, with water consumption estimates from ETtoolbox. The values are the average flow rate in cfs over the year.

Year	Vulnerability Assessment Drought Condition	Upstream Inflow at San Acacia	Total ET-rain from ET-toolbox	Downstream Outflow at San Marcial	Annual Water Balance Remainder
		cfs	cfs	cfs	cfs
<b>2008</b>	Slightly wet	1463	196	1289	-23
<b>2009</b>	Near normal	947	171	961	-185
<b>2010</b>	Near normal	937	188	750	-29
<b>2011</b>	Slightly dry	521	115	425	-19
<b>2012</b>	Severely dry	499	150	398	-49
<b>2013</b>	Extremely dry	559	149	418	-8
<b>2014</b>	Slightly dry	528	92	440	-4
<b>2015</b>	Near normal	841	117	752	-28
<b>Average</b>		787	147	679	-43

Table 4. Socorro Division water budgets for irrigation seasons (March-October) 2008-2015, with water consumption estimates from ETtoolbox. The values are the average flow rate in cfs over the irrigation season.

Year	Vulnerability Assessment Drought Condition	Upstream Inflow at San Acacia	Total ET-rain from ET-toolbox	Downstream Outflow at San Marcial	Irrigation Season Water Balance Remainder
		cfs	cfs	cfs	cfs
<b>2008</b>	Slightly wet	1,818	279	1,553	-14
<b>2009</b>	Near normal	1,109	243	1,075	-209

<b>2010</b>	Near normal	1,034	272	797	-34
<b>2011</b>	Slightly dry	409	163	270	-25
<b>2012</b>	Severely dry	426	217	304	-95
<b>2013</b>	Extremely dry	490	215	342	-66
<b>2014</b>	Slightly dry	451	134	325	-8
<b>2015</b>	Near normal	791	168	645	-22
<b>Average</b>		816	211	664	-59

In the Socorro Division, there are three locations where the water in the LFCC is returned to MRGCD drains and eventually to MRGCD canals. Thus, drainage water from more than half of the Socorro Division is reused. Even in dry years, the water leaving the system is much greater than the total consumption of irrigation water in the Socorro Division. This suggests that on-farm irrigation efficiency in this division is relatively low. Based on experience in other irrigation districts, it seems reasonable to expect that significant improvement could be made in the operation of this division to reduce the overall water returned from the division to the system downstream. Similar to the full system budgets, the water budget remainder is negative in all years.

### Normal Supply Year

The Vulnerability Assessment (WEST 2018) evaluated the historical water supplies available to MRGCD and developed indices to define drought conditions (described in previous section). Using these indicators, the drought condition at the end of the irrigation season are shown in Table 4 for the years in which water budgets were evaluated.

Comparisons of the indicators to the data used in the water budgets are not very direct. The actual inflow to MRGCD from Cochiti Dam would approximately represent the natural flow at Otowi during the irrigation season plus the storage in El Vado reservoir at the start of the irrigation season. The contribution of rainfall considered in the MRGCD water budget (i.e., agricultural, phreatophyte, open water surfaces, and urban acreages) is given in Table 5.

Table 5. Drought conditions for years used for the MRGCD water budgets.

Year	Drought Indicator	Probability of Occurrence of lower flow from Vulnerability Assessment	Annual Average Upstream Inflow at Cochiti	Rainfall on MRGCD land during November to October
			cfs	cfs
2008	Slightly wet	0.80	1,792	138
2009	Near normal	0.59	1,395	150
2010	Near normal	0.57	1,282	153
2011	Slightly dry	0.23	888	112
2012	Severely dry	0.16	865	67
2013	Extremely dry	0.10	714	139
2014	Slightly dry	0.25	861	230
2015	Near normal	0.51	1,150	226

The Scope of Work required us to evaluate MRGCD operations under reductions in supply of 10%, 25% and 40%. In order to evaluate this, we chose to use the median inflow to Cochiti Dam as the supply amount. When the natural supply at Otowi for the years 1952 to 2018 were averaged to find the inflow in cfs, the resulting average flow was 1,376 cfs. The median value was 1,186 cfs. The median value should be more representative for our purposes since half the years have less flow and half the years have more flow. It also approximately matches the 50% probability that one might get from Table 4, for example 2015. So, for the purposes of this report 1,186 cfs inflow at Cochiti is considered a normal supply year. With this assumption for reductions of 10%, 25% and 40%, the resulting inflow at Cochiti are 1,086 cfs, 890 cfs, and 712 cfs, respectively.

Rainfall in Table 4 is from November to October. This is because rainfall after the irrigation season might not contribute to crop production but might contribute to soil moisture in the next season. One can see how the combination of lack of supply upstream and lack of rainfall contributes to the overall probability of drought conditions. Comparing 2011 to 2012, the supply is very similar but the rainfall is much lower in 2012. That is why 2012 shows up as a more severe drought condition according to the drought indicator. Note that the limited rain in 2012 may have made 2012 almost as bad as 2013. More rain in 2014 may have reduced the influence of the limited supply from Cochiti (for example, compared to 2012).

From Table 5, a 40% reduction in supply occurred during 2013 and a 25% reduction in supply occurred in 2011. Thus, MRGCD has recently operated successfully with all three levels of supply reduction (i.e., the 10%, 25%, and 40% reduction), likely because of significant in-season rainfall and because of key decisions made by experienced staff members. Even in 2013, average outflow from the tail end of the system was more than 300 cfs. The water supply is enough to

support the water consumption requirement, even with a 40% reduction in supply. Further reductions in supply are possible in future years, for example when both upstream supply and rainfall are low. Efforts to improve performance will allow MRGCD to handle these extreme events more effectively. Here performance has to do with adequacy, equity, efficiency, and uniformity of water delivery. Unfortunately, MRGCD records are not

sufficiently detailed to allow these performance factors to be evaluated. For this reason, the factors affecting performance are not organized by amount of supply reduction.

### Factors Affecting Performance

Some of the factors that likely influence performance are listed below. Some of these are based on experience in other irrigation districts (i.e., what other districts have done to improve performance), in addition to examination of MRGCD records. The water supply available influences the operation of MRGCD. In wet years, operation can be more flexible. The factors are listed in order of relative performance.

#### **Limited storage exists downstream from El Vado Dam.**

Fluctuations in the MRGCD system occur as far north as the middle of the Cochiti Division. Without regulating reservoirs to store small excesses and supply small deficits, these fluctuations tend to grow in the downstream direction. There is no effective storage in the MRGCD system to control these fluctuations. It takes several days for water to travel through the MRGCD service area. When rainfall events occur and farmers do not accept water, the water that has already been released cannot be captured and will end up downstream at Elephant Butte. The Rio Grande Compact does not allow reservoir storage on the Rio Grande. Small holding ponds for off-line storage are not restricted.

#### **Water delivery scheduling is informal**

Farmers request water deliveries from their ISO. No flow rate is specified. The ISOs accumulate these orders upstream and determine the flow rates needed at diversion canals. Some ISOs can estimate these flow rates with reasonable accuracy. Some have more difficulty quantifying flow rate. This accumulation of orders upstream is inexact due to the variable timing of deliveries and variable travel times. Different ISOs evaluate these needs differently. The estimated canal flow rates are requested by the ISOs to the water operations manager, who determines whether or not those needs can be met. The water operations manager may reduce the flow to any canal. This process requires the ISOs to adapt to their circumstances and to adjust on the fly. These complications make evaluation of ISO performance difficult. It also makes consistent water delivery scheduling for the project difficult.

#### **Water deliveries are not determined on a volume basis**

The need to deliver a volume of water is the basis for a water delivery. Currently, the water volume delivered to a user is estimated based on acreage and experience. The duration of a water delivery is limited to no more than one hour per acre (i.e., a 20-acre field must be irrigated in 20 hours or less), but the flow rate is unspecified and not measured. This one hour per acre rule is a guideline and is not strictly enforced. With unquantified water deliveries, particularly under drought conditions, it is difficult to be equitable among users. Most irrigation suppliers in the West have evolved to measure delivery volumes as the basis for equity.

## **Water deliveries are not accurately measured and recorded**

MRGCD collects data on water delivered to each user; typically, a duration and a rate of flow. This data is compiled at the end of the season. The flow rates are not accurately measured in many cases. MRGCD staff evaluations of compiled data indicate that the data is not complete and often not accurate.

Because of this, it is thought that not all ISOs maintain accurate records during the season. Collecting this data on a more timely basis would be useful for MRGCD to evaluate their operations during the season. It would also give the data more credibility and allow a more reasonable evaluation of performance (efficiency, equity, and adequacy) at the end of the irrigation season.

### **Pueblo water use is uncertain**

MRGCD provides water to the canals that serve the Pueblos. The Pueblos take water at their discretion to serve their needs. The Pueblos do not provide records to MRGCD on their water demands or their water uses. The water operations manager has to estimate how much net water use will occur in Pueblos, so that he knows how much water is needed in the canals that serve them, in addition to scheduled MRGCD water orders.

## **Variable delivery timing and variable inflows cause flow rates in drains and the river to fluctuate diurnally**

Fluctuations can be caused by irrigators turning irrigation off at night such that the water flows to the drains. Fluctuations can also be caused by diurnal fluctuations in wastewater outflows and storm runoff.

- Variable drain flow causes variable river flow causing flow at diversion points to fluctuate: Variable flows in the drains at the lower end of one division result in variable inflows to the next division downstream.
- Variable canal flow makes it difficult for ISOs to accurately deliver water: The intent of the operators is to keep the canal inflow constant. High flows can be diverted to the river or one of the drains for use further downstream. When flows are too low, deliveries somewhere downstream will suffer.
- Variable drain flows make it difficult for the water operations manager to accurately do the following:
  - Estimate return flows. The water operations manager uses the drain flows to monitor whether there is enough water for downstream diversion. Measurement of these flows tells him if his current inflow is appropriate.
  - Schedule reservoir releases: If the water operations manager does not know whether current inflow is appropriate, it is difficult to decide when flow adjustments from the reservoir are needed.

### **Water losses occur in transporting water to points of diversion**

Water is lost to evaporation, seepage, and evapotranspiration from phreatophytes as water travels from Cochiti Dam to other diversion structures along the river. These losses tend to be greater when the river is used to transport the water. Seepage losses are particularly significant in the central part of the Albuquerque Division because of groundwater overdraft which has occurred near the City of Albuquerque. In some stretches of the river, MRGCD has attempted to keep the water within MRGCD canals and drains rather than releasing it to the river. In other stretches, MRGCD does not have facilities that can keep water out of the river. In some of the stretches, losses are relatively minor. In others they are significant.

### **Water measurement and control are limited at lateral canal sites**

Discussion with ISOs in the field suggested that improved water control structures would improve operations at a few sites. Improved measurement is necessary to provide effective control and to provide consistent water deliveries to users. Further discussion with MRGCD staff would be required to identify those sites that might provide the best benefit-cost ratio.

## **Water records are not sufficient for defining performance**

MRGCD records were used to compute water budgets. Data was limited at some locations, which reduced the accuracy of the water budgets. Computing water budgets for MRGCD is problematic, which makes it difficult to evaluate project performance. Because of data limitations, primarily the unavailability of measured deliveries to farms, determining which factors contribute to MRGCD performance is somewhat subjective.

## **Water rights and allocations are not established on a volume basis**

Many districts adjust the volume of water a user is allocated for the year based on available water supply. MRGCD adjusts operations to share water through rotation when water is limited. It is not clear whether or not this provides an equitable distribution of available water. A volumetric water charge encourages conservation.

## **Multiple agencies have authority over water in the river (for different purposes)**

- NM Interstate Stream Commission (ISC) is responsible for meeting Rio Grande Compact requirements.
- U.S. Bureau of Reclamation (Reclamation) is responsible for meeting federal requirements; endangered species (U.S. Fish and Wildlife Service {USFWS} Biological Opinion {BO}) and requirements of federal agencies (e.g., BDA).
- U.S. Fish and Wildlife Service is responsible for endangered species protection.
- U.S. Army Corps of Engineers (USACE) is responsible for flood control and for maintaining the quality of rivers of the U.S.

## **Other Factors**

The WEST team examined other factors that were thought to influence performance, but now are considered to have no influence or a minor influence in rare conditions. The factors include

- Water required for endangered species;
- Water required for BDA; and
- Water required to satisfy compact requirements.

Under the current U.S. Fish and Wildlife Service Biological Opinion (BO), MRGCD and cooperators are required to maintain fish populations for endangered species. Prior strategies which required instream flows were found to not be effective. MRGCD works with cooperating agencies to help maintain fish populations.

BDA has a right to extract water that is available on site. MRGCD is not responsible for supplying water to BDA, nor to release water downstream so that BDA can extract it.

The Rio Grande Compact requires a certain volume of water to flow into Elephant Butte Reservoir based on the natural flow at Otowi gage. MRGCD can be in a deficit if the total annual supply is too low. This deficit can be erased in years when more water is supplied to

Elephant Butte. If MRGCD deficits accumulate over a number of years and exceeds a threshold, action could be taken against MRGCD to release more water downstream. For example, this could occur during a long, protracted drought, but does not affect MRGCD daily operations.

## Water Budget Recommendations

The WEST team recommends a complete energy balance remote sensing analysis (METRIC is the recommended algorithm) to better understand actual ET in dry and wet years. These ET results would provide a basis for:

- a. Improving the water budget;
- b. Calculating MRGCD performance indicators;
- c. Estimating actual ET in other years using the actual ET results from these two year types; and
- d. Improving estimates of Pueblo water use.

The suggested steps to complete this analysis include:

- First complete a dry year, preliminary recommendation is for 2013 (need to review availability of Landsat images before finalizing year selection) to determine actual ET for both agricultural land and phreatophyte vegetation in the MRGCD service area.
- Next complete a near normal year (the ET in a near normal year and a wet year are likely similar especially if the rainfall in the MRGCD service area is similar in those years), the preliminary recommendation is for 2015 (again need to review availability of Landsat images before finalizing year selection).

Cost for one year of METRIC analysis is roughly \$25,000 and for two years of METRIC analysis is roughly

\$50,000. Additional analysis would be required to complete the water budget, evaluate Pueblo water use, determine MRGCD performance indicators, and to determine how to adjust ETtoolbox results for other years.

## References

Brower, AI (2015) ET Toolbox Evapotranspiration Toolbox for the Middle Rio Grande, A Water Resources Decision Support Tool, Version 3.1, April 21, 2015. Water and Environmental Resources Division Technical Service Center, Bureau of Reclamation, US Department of the Interior, Denver, Colorado

WEST (2018). Vulnerability Assessment for MRGCD. Prepared for the Middle Rio Grande Conservancy District, Albuquerque, New Mexico. Draft July 2018. WEST Consultants, Inc.

# Appendix 7

## Infrastructure Recommendations for Drought Conditions

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Prepared by  
**WEST Consultants and Davids Engineering**  
For  
**Middle Rio Grande Conservancy District**

**August 2018**



## Introduction

The Middle Rio Grande Conservancy District (MRGCD) supplies water primarily to agricultural water users along the Middle Rio Grande, from Cochiti Reservoir to the Bosque del Apache National Wildlife Refuge (BDA) south of Socorro, NM. This is primarily a run-of-the-river system along the Rio Grande, with four major diversion works: Cochiti Dam, Angostura Diversion, Isleta Diversion, and San Acacia Diversion. Water in the Rio Grande is released by Colorado to New Mexico under terms of the Rio Grande Compact (Compact). New Mexico must supply water south of MRGCD to the Elephant Butte Reservoir as part of this Compact.

MRGCD utilizes the water in the Rio Grande, including that supplied by Colorado and water from the Rio Chama. The Rio Chama has several reservoirs including El Vado Reservoir where MRGCD can store water for the irrigation season. MRGCD releases water from El Vado Dam during the irrigation season (March 1 to October 31) to supplement water available from the Rio Grande. Water not used along the river ends up in Elephant Butte Reservoir, thereby satisfying Compact requirements. The City of Albuquerque also has water supplies that are available from the Rio Chama, including Colorado River Water supplied from the San Juan River. The City of Albuquerque water is comingled with water for MRGCD in the river. The City of Albuquerque pumps water from the river and supplies treated return flow water to the river from their wastewater treatment plant.

The U.S. Bureau of Reclamation (Reclamation) stores water in El Vado Reservoir for endangered species. In dry years, the Rio Grande becomes dry in certain reaches. This endangered-species water supply is used to keep water in the river over these reaches. While MRGCD is not under strict regulation, they cooperate with Reclamation and others to keep water flowing in the Rio Grande, when possible.

MRGCD supplies water to six Pueblos; Cochiti, Santo Domingo, San Felipe, Santa Ana, Sandia, and Isleta. These Pueblos have “Prior and Paramount” (PandP) water rights for 8,847 acres. In addition, they have roughly 12,600 acres of newly reclaimed land that can be irrigated. MRGCD also supplies water to historical irrigation areas know as Acequias. Other than those associated with Pueblos, all but La Joya Acequia are managed by MRGCD. The La Joya Acequia irrigates roughly 500 acres. The land irrigated other than La Joya Acequia and the Pueblo land averages about 46,000 acres. The total area irrigated is shown in Table 38.

**Table 38. Irrigated Land Area Served by MRGCD.**

Type	Irrigated Land Area	
<b>Pueblo Prior and Paramount</b>	8,847	ac
<b>Pueblo Newly Reclaimed</b>	12,600	ac (potential)
<b>La Joya Acequia</b>	512	Ac (average 2008-2016)
<b>MRGCD lands</b>	46,149	Ac (average 2008 to 2017)
<b>Total</b>	68,108	ac

The Pueblos are allowed to take water as they require it. All other water users request water from their Irrigation Service Operator (ISO). The ISO schedules their water delivery considering their request and the water that is available. The ISOs request water from the water operations manager who then schedules water from El Vado Dam if the Rio Grande supply is not sufficient. Early in the irrigation season, the water operations manager attempts to limit the water released from storage in El Vado Dam so that water will be available later in the season during the summer months. Summer storms (monsoons) provide additional water to the river and to El Vado Reservoir. Deciding how much water to release from storage early in the season is a balancing act: too much water released runs the risk that El Vado will run dry and not be able to provide water to crops later in the season; too little water released results in less production or less crop acreage and thus inability to utilize water from summer storms. The water operations manager generally assumes that there will be some summer rainfall and uses water at a rate that, should the summer monsoons not produce much rain, they are likely to run out of water late in the season. Over the last 10+ years that strategy has provided sufficient water late in the season. If El Vado storage is very low at the start of the season, the irrigation flow is limited and water is given to users in rotation, rather than as requested.

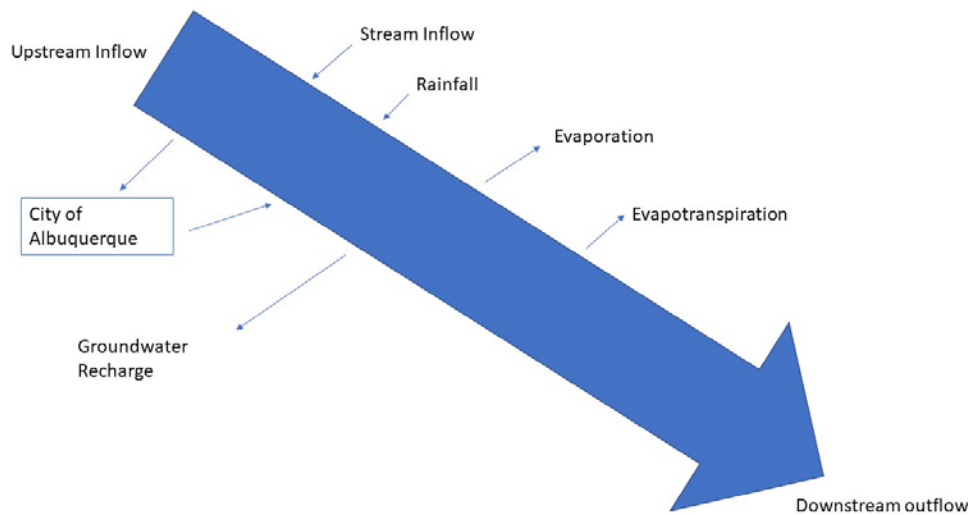
Irrigation water delivered to irrigated land and not stored in the soil for crop consumption returns to the river, either through drains to the river or subsurface flow to groundwater. Water that flows below the root zone is picked up by surface drains. These surface drains either flow back to the river or supply canals further downstream. Thus, most of the water not used for crop production ends up back in the system. One exception is in the Albuquerque area, where groundwater levels are much lower than the river due to a history of pumping which resulted in groundwater overdraft. In this area water seeps from the river to recharge groundwater. Water that seeps from drains also recharges groundwater and does not return to the river. At the tail end of the system water 1) is supplied to the Bosque del Apache National Wildlife Refuge (BDA), 2) enters the Low Flow Conveyance Channel (LFCC), or 3) flows down the Rio Grande.

The LFCC is a channel that was originally built to convey water from roughly San Acacia Dam to the river below MRGCD boundaries. The channel was meant to concentrate return flows so that there would be less conveyance losses in transferring water downstream to Elephant Butte. It has not been used for that purpose since sometime in the 1980s. Reclamation operates gates on the LFCC. In the summertime, these gates within MRGCD are closed so that water collected in the LFCC will flow into MRGCD drains, so that it can be used for irrigation further downstream. In the winter these gates are opened so that water will flow more quickly downstream. The gate on the LFCC at the south end of MRGCD and at the north end of BDA is regulated to provide water from the LFCC for BDA use.

## Normal Supply Year

WEST Consultants (WEST) and Davids Engineering (DE) examined MRGCD records for water use. As water becomes more limited, the water available to ISOs for delivery may be reduced. To evaluate limitations for a 10%, 25%, and 40% reduction in MRGCD's supply, one must first define the District supply. In this section, we define a normal or typical annual supply volume. The first step in defining a normal or typical annual supply is to define the existing conditions.

WEST and DE examined the water supply and use for the years 2008 to 2015. MRGCD provided records for inflows, outflows, cropped acreage, etc. Data on rainfall and reference evapotranspiration were available from the Reclamation web site ETtoolbox (<https://www.usbr.gov/uc/albug/water/ETtoolbox/riogrande.html>). This site estimates water consumption from agriculture, phreatophytes, open water surfaces, and urban areas. The USGS provides flow measurement records for the Rio Grande and some of its tributaries in the river from Cochiti Dam to San Marcial. All this data was compiled into water budgets for the years 2008-2015. A schematic of the water budgets is shown in Figure 41. These results are provided in the Infrastructure Assessment Identification of Drought Performance Limitations (WEST 2018b).



**Figure 41. MRGCD Water Budget** (large arrow represents the MRGCD system including the Rio Grande, all MRGCD canals and drains, the lands irrigated from the MRGCD system and Phreatophytes along the rivers and drains).

The Vulnerability Assessment (WEST 2018b) evaluated the historical water supplies available to MRGCD and developed indices to define drought conditions. The main indicators are the natural flow at the Otowi gage, the storage available in El Vado reservoir, temperature, and rainfall and other natural inflows within the MRGCD service area. The natural-flow-at-Otowi-gage indicator was developed by the Natural Resources Conservation Service (NRCS). The indicator starts with the measured flow at Otowi gage, then subtracts the inflow resulting from the San Juan Chama project which brings in water from the Colorado River, then adjusts the inflow to account for water stored or released from reservoirs along the Rio Chama. The water stored in El Vado prior to the irrigation season shows up as an increase in the

natural flow at Otowi prior to the irrigation season. Using these indicators, the drought conditions at the end of the Irrigation Season are shown in Table 39 for the years in which water budgets were evaluated. The indicator gives the probability that water supplies will be less than the value in that year. The rainfall presented in Table 2, column 5 is not used in the Vulnerability Assessment, but is a general indicator of additional downstream hydrologic contributions.

Rainfall in Table 39 is from November to October. This is because rainfall after the Irrigation Season might not contribute to production but might contribute to soil moisture in the next season. The combination of supply upstream and rainfall contributes to the overall probability of drought conditions. Comparing 2011 to 2012, the supply is very similar but the rainfall is much lower in 2012. That is why 2012 shows up as having more severe drought conditions. Note that the limited rain in 2012 may have made 2012 almost as bad as 2013. More rain in 2014 may have reduced the influence of the limited supply from Cochiti, for example compared to 2012.

Comparisons of the indicators to the data used in the water budgets are not very direct. The actual inflow to the district from Cochiti Diversion would approximately represent the natural flow at Otowi during the irrigation season plus the storage in El Vado reservoir at the start of the irrigation season. The contribution of rainfall to all lands in the MRGCD water budget (agricultural, phreatophyte, open water surfaces, and urban acreages) is also included in the budgets.

**Table 39. Drought conditions for years used for the MRGCD water budgets.**

Year	Drought Indicator	Probability of Occurrence	Average Upstream Inflow at Cochiti	Average Rainfall on MRGCD lands during November to October
			cfs	cfs
2008	Slightly wet	0.80	1,792	138
2009	Near normal	0.59	1,395	150
2010	Near normal	0.57	1,282	153
2011	Slightly dry	0.23	888	112
2012	Severely dry	0.16	865	67
2013	Extremely dry	0.10	714	139
2014	Slightly dry	0.25	861	230
2015	Near normal	0.51	1,150	226

The scope of work requires the team to evaluate MRGCD operations under reductions in supply of 10%, 25% and 40%, but does not quantify the supply. When the natural supply at Otowi for the years 1952 to 2018 were averaged to find the inflow in cfs, the resulting average flow was 1,376 cfs. The median value was 1,186 cfs. The median value should be more representative for our purposes and it more closely

matches the 50% probability as shown in Table 39, for 2015. So, for the purposes of this report 1,186 cfs inflow at Cochiti is considered a normal supply year. This does not consider rainfall contributions downstream. With this assumption for reductions of 10%, 25% and 40%, the resulting inflow at Cochiti are 1,086 cfs, 890 cfs, and 712 cfs, respectively.

From Table 39, a 40% reduction in supply occurred during 2013 and a 25% reduction in supply occurred in 2011. Thus, the district has recently operated successfully with all three levels of supply reduction. Even in 2013, outflow from the tail end of the system was more than 300 cfs. The water supply is enough to support the MRGCD agricultural water consumption requirement, even with a 40% reduction in supply. MRGCD was able to handle these supply reductions because of rainfall contributions during the irrigation season. Hydrologic probability suggests that there will be years when rainfall will not be sufficient to mitigate supply restrictions. The issue is not whether or not MRGCD can handle these supply reductions, but rather how they can maintain or improve operational performance under these conditions. Here performance has to do with adequacy, equity, efficiency, and uniformity of water delivery. Unfortunately, MRGCD records are not sufficiently detailed to allow these performance factors to be evaluated. For this reason, the factors affecting performance are not organized by amount of supply reduction.

Figure 42 on Page 7 shows a small image of New Mexico, with a zoomed-in image of the MRGCD as well as the general locations of the figures in this report. This figure was included to provide a broad geographic reference when looking at specific figures.

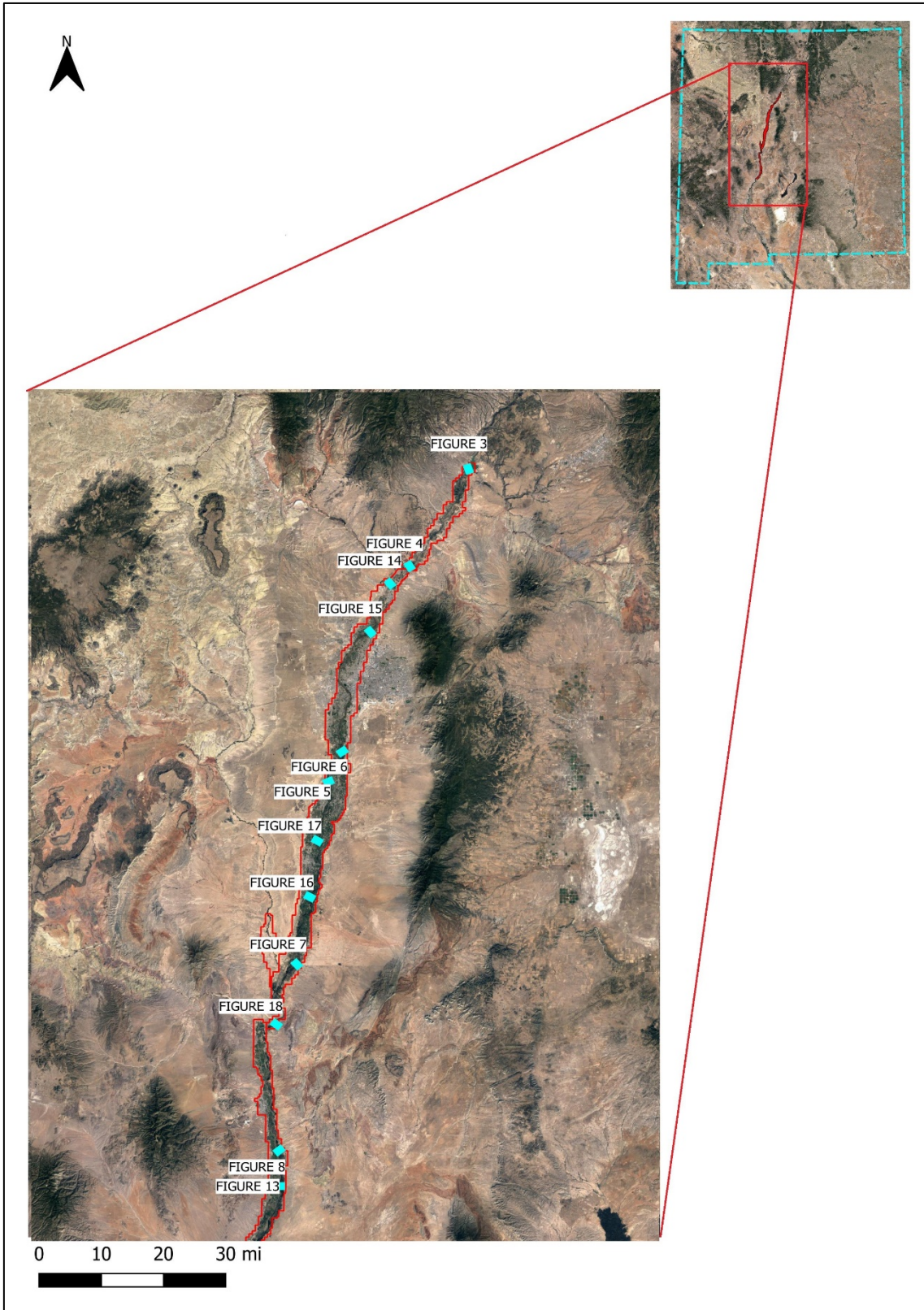


Figure 42. Location map for the general locations of report figures.

## Infrastructure Recommendations

The best way to handle drought limitations is to systematically develop better water control. The main method for improving water control are; infrastructure improvements and improved operational methods. When water is better controlled, it can be sent to the place where it is most needed, whether that is irrigation use, compact use, environmental use, or other use. The water balance indicates that additional water for supply during drought can be made available by reducing outflow from the downstream end of the system.

The main methods to reduce outflow and supply more water for irrigation when supplies are limited are:

- Capture flow fluctuations with the use of small reservoirs
- Increase connections from drains to supply canals for water reuse
- Reduce losses from the system by reducing the use of the river to convey MRGCD supply. This strategy keeps as much of the MRGCD supply as possible in the MRGCD conveyance and drain systems to:
  - Reduce evaporation
  - Reduce groundwater recharge
  - Reduce phreatophyte ET
- Increased use of drainage flows and groundwater in the Socorro Division

Changes in infrastructure can also assist MRGCD with improving their control of water. Water supply for irrigation is highly variable from year to year. Summer storms can add to the complexity of water control since water can enter the system for short periods. The scope of work requires infrastructure recommendations at different levels of flow reduction. The recommendations given below are organized around the 10%, 25% and 40% reduction in supply. All the methods presented will allow MRGCD to improve performance regardless of the amount of flow reduction.

Improved operations with a 10% reduction in supply can be accomplished with relatively minor infrastructure improvements; projects costing from \$1,000 to \$20,000. At this level of supply, fluctuations in canal flow can be minimized by sending the fluctuations to the river. With a 25% reduction in supply, more water can be provided to canals by pumping water from drains to supply canals. In some cases, this can also be used to minimize flow fluctuations. These projects are in the range of \$20,000 to \$100,000. With a 40% reduction in supply, more aggressive measures are recommended. These include methods to keep water out of the river, improved operations in the Socorro Division, and the use of reservoirs to capture drainage flows and flow fluctuations. These projects are in the range of \$100,000 to \$1,000,000 or more. If MRGCD's goal is to manage flow reductions of less than 40%, the addition of reservoirs would still assist the district in improving operations. These recommendations are presented in the sections that follow.

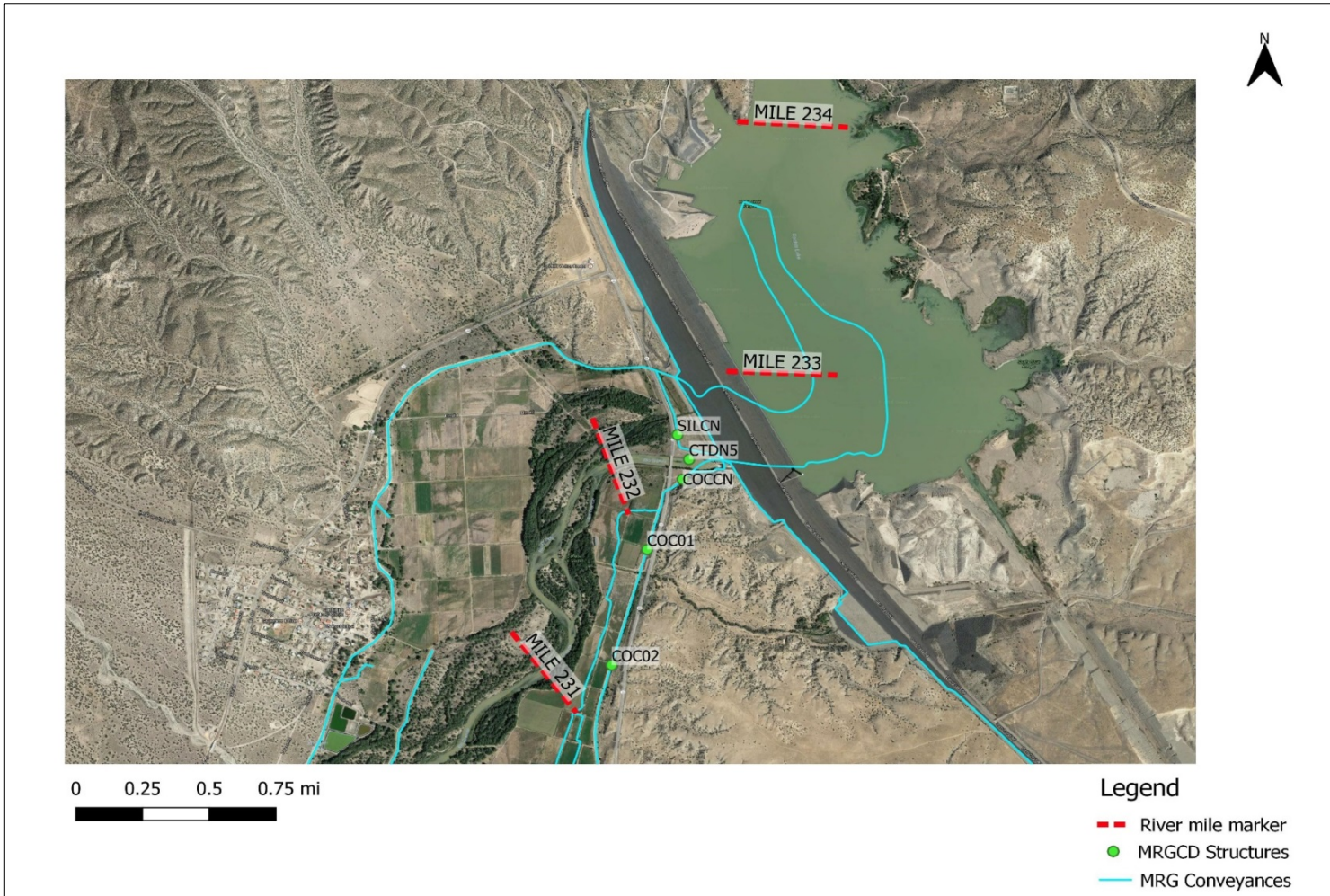


Figure 43. Cochiti Diversion and upper end of MRGCD system.

## Recommendations for a 10% reduction in supply

Two main improvements are recommended for a 10% reduction in supply: Improve flow control at the upstream diversion in each division and improve flow control at key locations in each division. These recommendations are described in the following sections.

**Improve flow control at upstream diversions into divisions:** These activities should help operations by maintaining steady canal flows.

The inflow at the upstream end of the Cochiti Division is controlled by the diversion structures. Surge waves were observed in the Sili Main Canal upstream from the measuring flume there (SILCN in Figure 43). These surge waves could be reduced and measurement accuracy increased by using a surface skimming weir. No additional improvements are needed here. Dotted red lines in figures are River Miles for Middle Rio Grande; defined as miles upstream from Elephant Butte Dam.

At the start of the Albuquerque Division, water is diverted from the river at the Angostura Diversion Weir (ANGDV) into the Angostura Sluiceway Channel, as shown in Figure 44. Water from the Algodones Riverside Drain (ALGDR) also enters the Angostura Sluiceway Channel. The flow in the drain fluctuates because of agricultural drainage flow from upstream. This causes the flow in the sluiceway channel to fluctuate. Since the flow into the sluiceway from the diversion is automatically controlled to keep a constant inflow, the control algorithm should be able to read the flow measured in the drain and adjust the flow from the diversion to keep the combined downstream flow constant. This will put the fluctuations in the river. This will help with moderate droughts but does not help if the intent is to keep water out of the river. For severe droughts, the flow in the sluiceway can be set such that the maximum flow possible is kept out of the river and passed on to the Belen division.

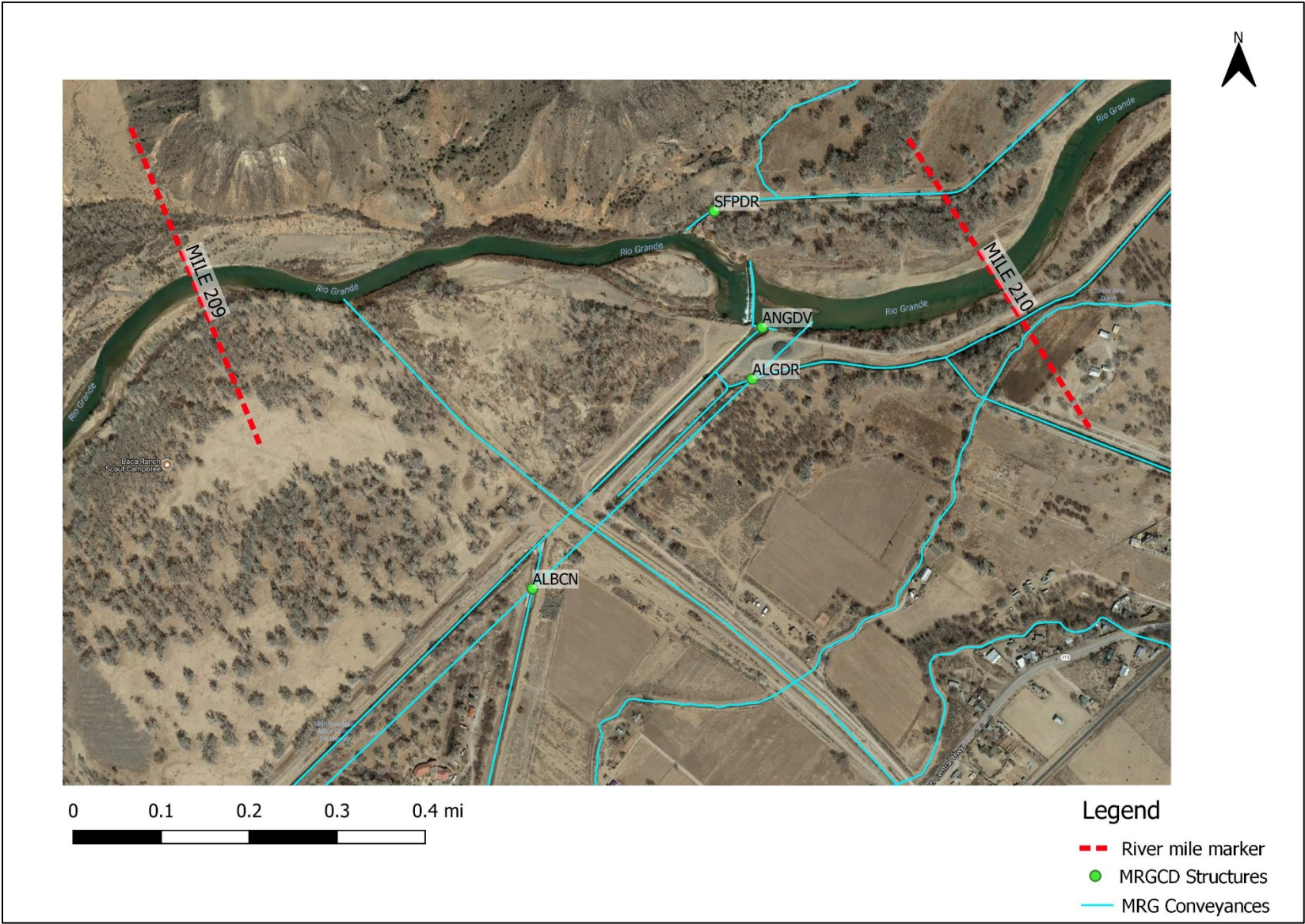


Figure 44. Angostura Diversion and associated MRGCD structures.

At the start of the Belen Division, fluctuations in flow can be sent to the river. When flow is limited, MRGCD staff already send the flow fluctuations from upstream down the Belen Highline Canal (BELCN in Figure 45). Further downstream, flow from the Isleta Interior Drain joins the Los Lunas Lateral where it connects to the Belen Highline Canal (near 240CN in the lower part of Figure 45). As such, most of the flow fluctuations from upstream end up here. Fluctuations at this point can be returned to the river or continue downstream.

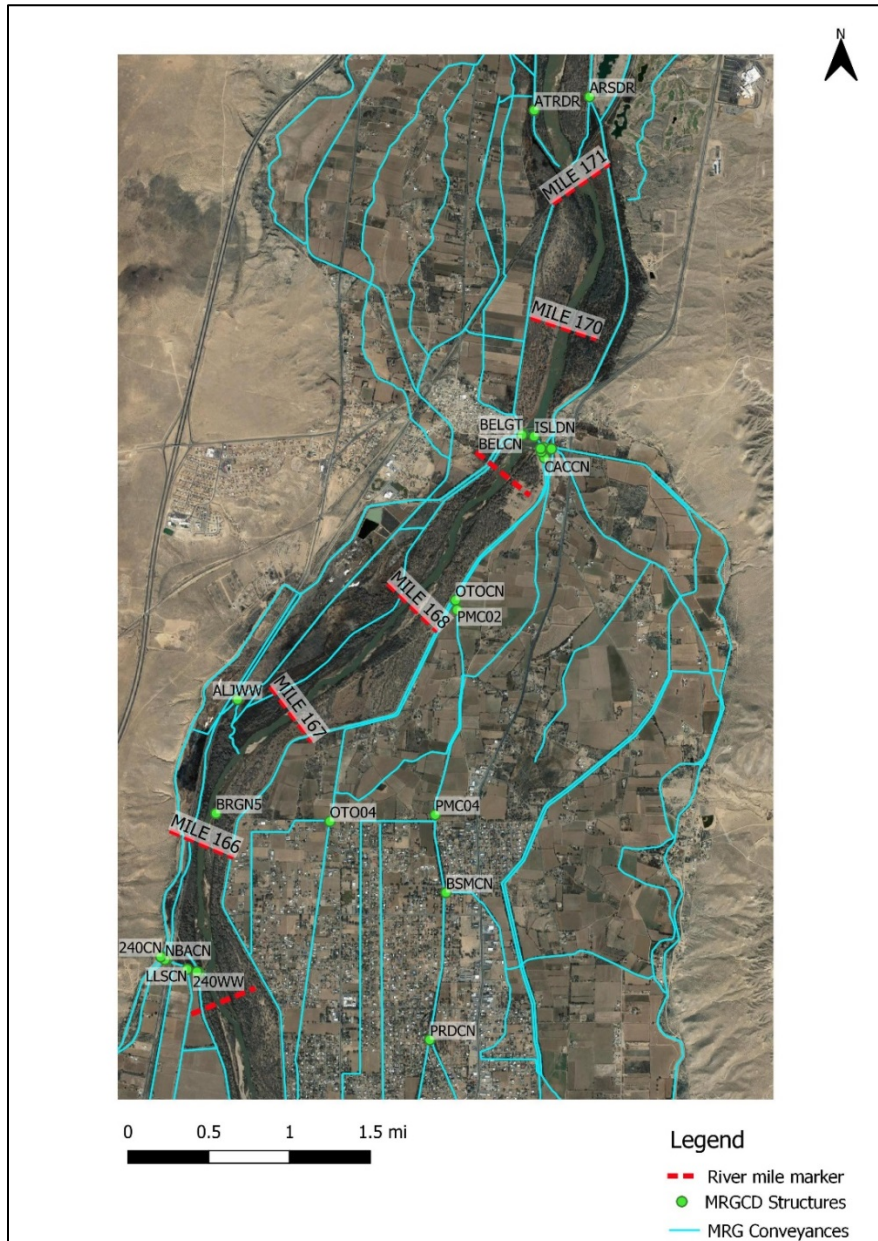


Figure 45. Start of Belen Division. Isleta Diversion is roughly at river mile 169.2.

At the upstream end of the Socorro Division, inflow to the Socorro Canal comes from the Unit 7 Drain and from the river (Figure 58). Any flow fluctuation at this location can be sent to the river or continue down the Socorro Main Canal. The inflow to the Socorro Main Canal from San Acacia Diversion could be automated to maintain constant flow into the Socorro Main Canal when the flow in the Unit 7 Drain fluctuates. Fluctuations in flow can be sent to MRGCD drains and to the Low Flow Conveyance Channel (LFCC). Flow in the LFCC eventually returns to the river below San Marcial. Reclamation has pumping stations along the LFCC where water can be pumped to the river for endangered species.

**Improve canal control with additional structure changes:** MRGCD staff discussed several sites where improved structures could assist operations and reduce spills. These sites are located at various points in the MRGCD service area. Additional assistance would be needed from MRGCD staff to identify and prioritize improvements.

### **Recommendations for 25% Reduction in supply**

In addition to the two improvements recommended for the 10% reduction in supply, adding more connections from drains to canals is recommended to improved performance during years with a 25% reduction in supply. The recommended drain-to-canal connections are described in the following section.

**Increase connections from drains to canals:** MRGCD has many locations where drains are connected to canals so that the drainage water can be used for irrigation. The MRGCD staff have not discussed salinity issues associated with drainage water reuse. No obvious signs of salinity were visible in the field tours. Therefore, it is assumed that salinity is not an issue. Three locations are considered where increased connections to drainage water could improve performance.

The Albuquerque Riverside Drain (ARSDR in Figure 6) is connected to the canals at the Isleta Diversion through the Barr-Chical Diversion Connection. It can be seen in Figure 6 on the east side of the river from roughly river mile 171.5 to Isleta Diversion at river mile 169.2. This connection does not work during the irrigation season since the slope of the water surface is too gradual to allow sufficient flow. Perhaps this connection could be re-examined or perhaps water would have to be pumped to make this a useful connection. The feasibility of this idea could be examined at low cost.

Water cannot be kept out of the river from the Atrisco Riverside Drain outfall (ATRDR on west side of river at river mile 171.5 in Figure 46 to Isleta Diversion. This is a relatively short reach, less than two miles. Records show flow in this drain at roughly 50 cfs. However, water from this drain could be pumped up to a canal to the west, such as Indian Ditch or Acequia Madre Canal, or to a drain such as Isleta Interior Drain. This would allow better regulation of those canals and keep water out of the river.

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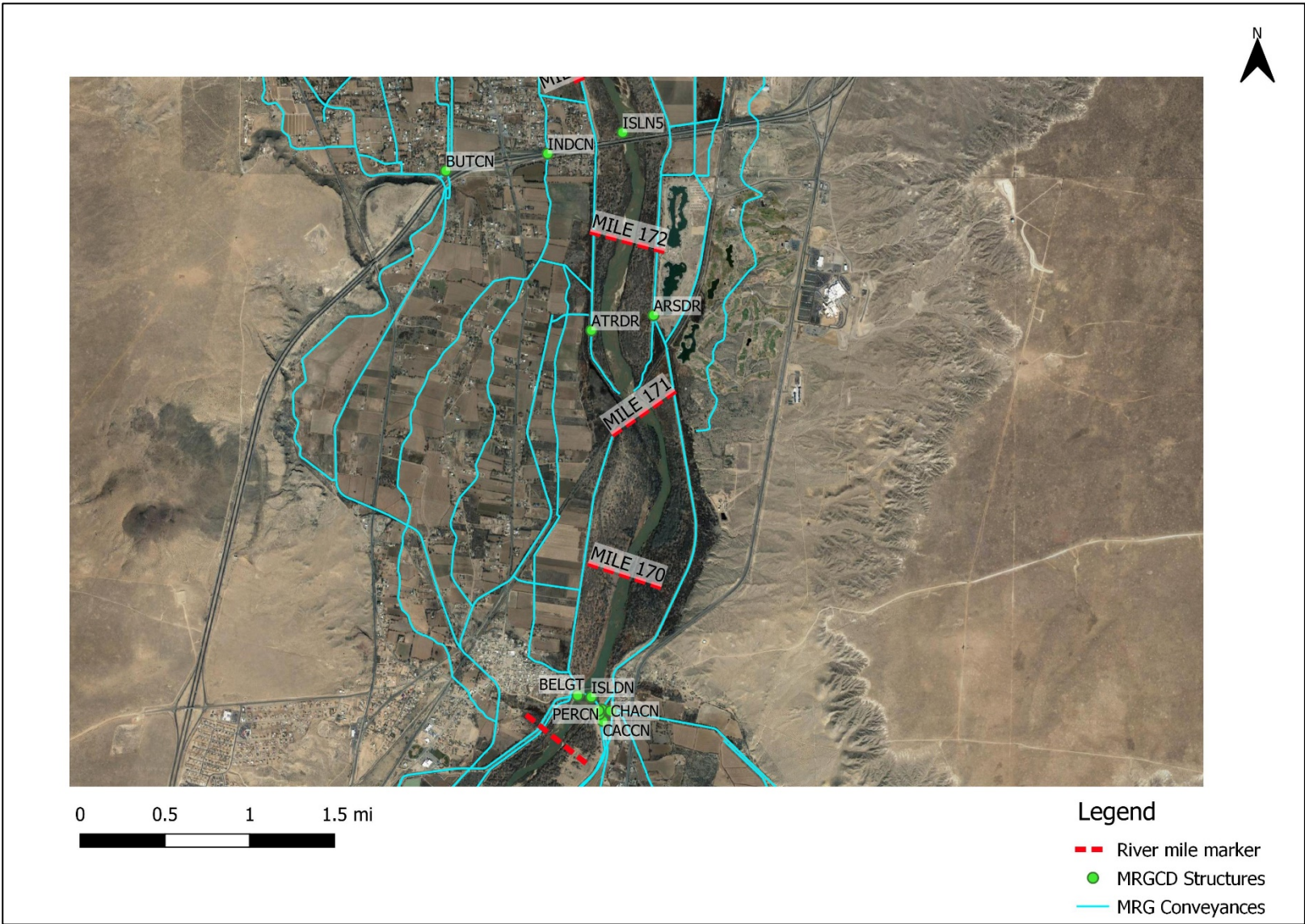


Figure 46. Drains above Isleta Diversion.

Water can't be kept out of the river from the San Juan Riverside Drain (LSJDR in Figure 47) to San Acacia. This drain is about 12 miles long and the drainage flow is roughly 100 cfs. The option discussed by MRGCD staff is to pipe this flow under the river to the Unit 7 drain. Constructing a channel to carry this water downstream to San Acacia diversion is not practical, and it would still be on the wrong side of the river from the Socorro Canal. One alternative option is to pump water from the San Juan Riverside Drain into the La Joya Acequia Canal (LJYCN) to maintain a more constant inflow rate to the Acequia land downstream. Another option is to pump water across the river to the San Francisco Riverside Drain, which flows into the Unit 7 drain and eventually goes to the Socorro Main Canal. This site is near the US-60 bridge which is about river mile 130.6.

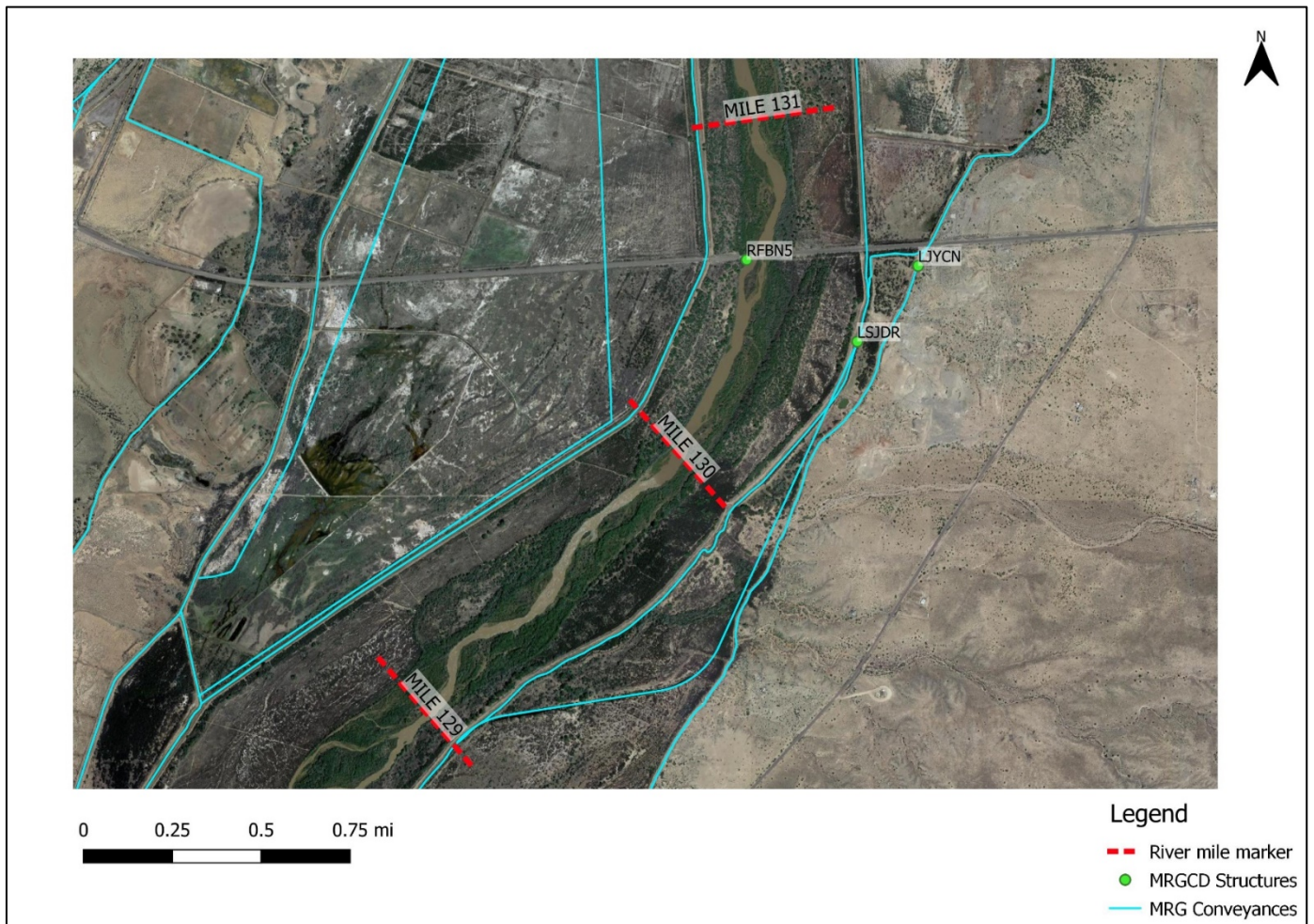


Figure 47. Location of San Juan Riverside Drain and La Hoja Acequia Canal.

MRGCD is currently in the process of installing a pumping station to pump water from one of their drains near the tail end of their system to a nearby canal (MRGCD Hub). This is located at the Neil Cupp Check of the LFCC (NCPCK in Figure 48). This could aid in the process of recovering some of the losses that flow out of the system downstream. Similar schemes are envisioned for the sites discussed in the previous paragraphs. Note the Reclamation pumping station to the river (NCPPS).

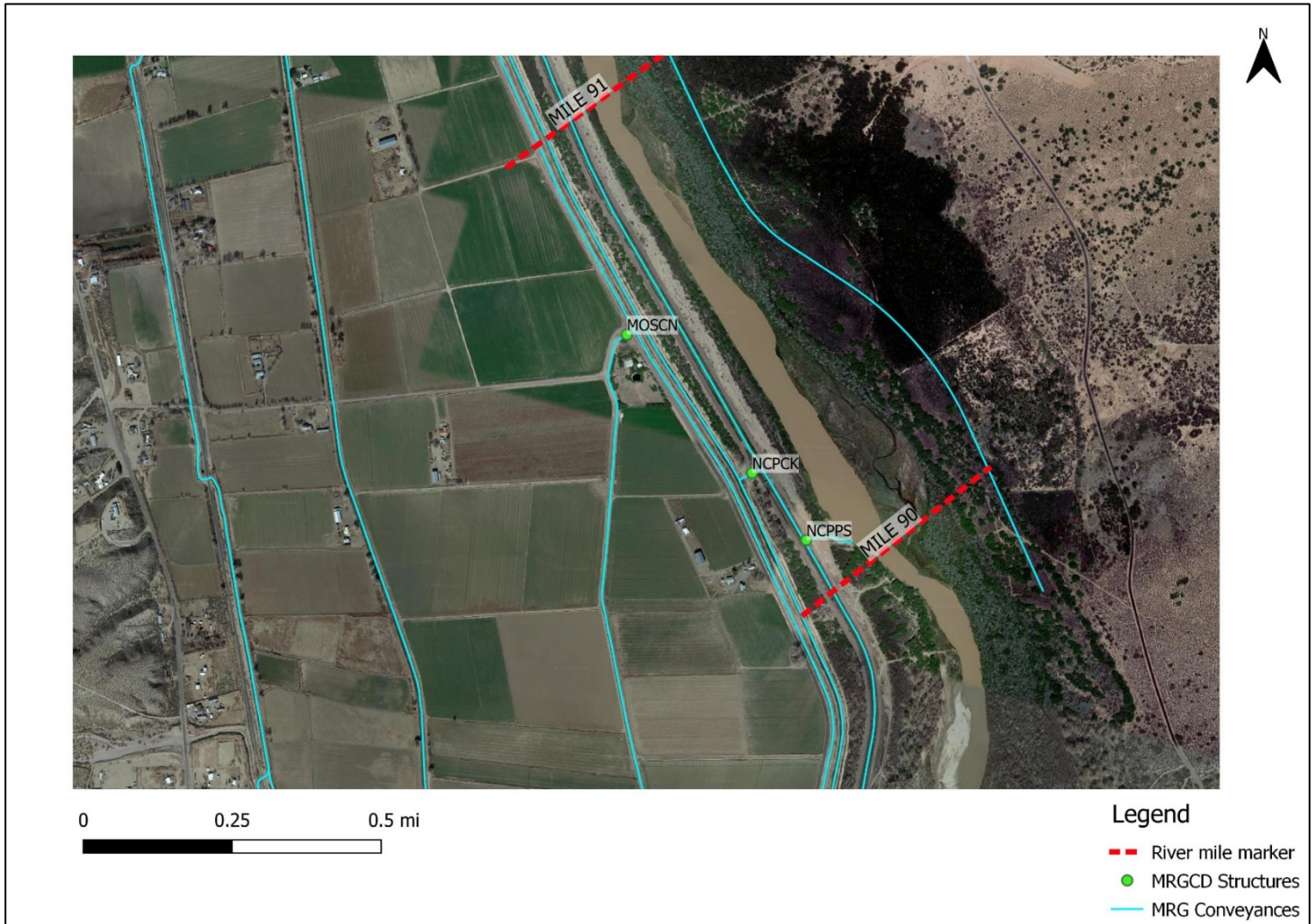


Figure 48. Location of MRGCD Hub.

## Recommendations for 40% Reduction in supply

At this level of reduction in supply, more aggressive measures are required. In addition to the three improvements recommended for the 10% and 25% reductions in supply, improving operations in the Socorro Division is recommended to improved performance during years with a 40% reduction in supply. The recommendations are described in the following section.

**Improve operations in the Socorro Division:** Efforts to reduce the losses from the downstream end of the system will require tightening up operations in the Socorro Division. The overall idea is to match supply and demand more closely. An understanding of the relative inflows to and outflows from the Socorro Division is useful for understanding how better operational control can be implemented.

A water budget was conducted within this division and extending south to the San Marcial Gages. Figure 49 shows the key features. Inflow measurements are Rio Grande (RG) at San Acacia and the Socorro Canal. Outflow gauges are the Low Flow Conveyance Channel (LFCC) at San Marcial and the RG at San Marcial. WEST (WEST 2018a) performed a seepage run over this reach of the river, which provided good relative data on inflow from the river to the LFCC. 2014 was chosen as a useful year for the water budget. The water supply for this year was such that there was a 74% chance that the water supply would be greater and a 26% of being drier. Thus, this year was drier than average but not so dry that the river ran dry for an extended period of time. There were a few days where the river ran dry, but not many. In contrast, 2013 has many more days when the river was dry. This would made seepage predictions less reliable for that year.

There are four check structure in the LFCC that influence how drainage water flows through the Socorro Division, as shown in Figure 49. The Lemitar Check gate on the LFCC (approximately river mile 107) is closed during the irrigation season. This causes the water in the LFCC to flow into the Lemitar Riverside Drain. The Lemitar Riverside Drain flows into the Socorro Main Canal approximately where it is joined by the Lemitar Lateral. Thus, all canal and drainage flows converge at this location (approximately river mile 105). Water can be diverted at this point into the LFCC and back to the river at roughly the Nine-Mile Outfall. The LFCC 1200 Station Check (also called Socorro Check) gate is also closed during the irrigation season (approximately river mile 99). Water in the LFCC flows into the Socorro Riverside Drain. The Socorro Riverside Drain joins the Socorro Main Canal South at approximately river mile 95. Most flows are in MRGCD canals at this site, although there may be some small drains. At about river mile 94, excess water can be sent to the LFCC.

The Neil Cupp Check structure on the LFCC (approximately river mile 90) is also closed during the irrigation season. Water in the LFCC flows into the San Antonio Riverside Drain. The water in the San Antonio Riverside Drain eventually leaves MRGCD and flows into the BDA at approximately river mile 84. The MRGCD Hub is planned to pump water from the LFCC at Neil Cupp Check into the Socorro Main Canal South. The LFCC check structure is regulated during the irrigation season to allow some water to enter drains into the DBA and some water to flow south in the LFCC. During the winter (non-irrigation) seasons, the Lemitar, 1200 Station and Neil Cupp check structure gates are open to allow water to pass downstream and to drain MRGCD drains. The Socorro Division can be divided into four parts, separated by the LFCC check structures, and can be seen in Figure 50.

For the purposes of the water budget, the area is divided into three parts; two sections of the MRGCD service area, divided at the 1200 Diversion (Socorro) Check; and one from the downstream end of MRGCD service area to the San Marcial gauges, including BDA. Figure 51 shows the area split into 3 parts based on the water budget. The evapotranspiration includes all sources; agricultural land, phreatophytes, and open water surfaces. ETtoolbox does not give separate estimates for ET within this area. It is assumed that 40% of the ET in this river reach is above the Socorro Check, 40% is between the Socorro Check and BDA and 20% is below MRGCD from BDA north boundary to San Marcial. The river miles below MRGCD are slightly more than the other reaches, but it is almost all riparian ET. Further analysis could be done to more accurately divide the ET contribution. This might change the flow values between segments, but would not change the overall concepts presented.

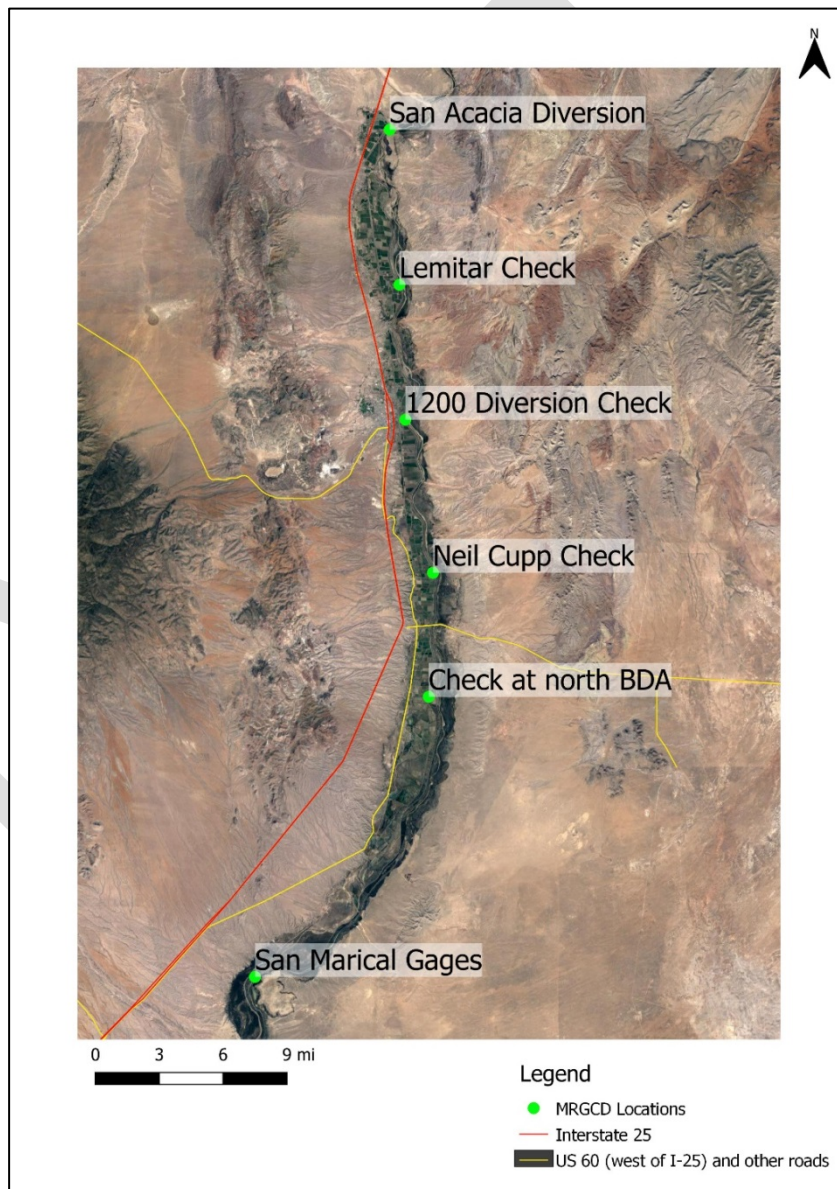


Figure 49. Key MRGCD locations in Socorro Division.

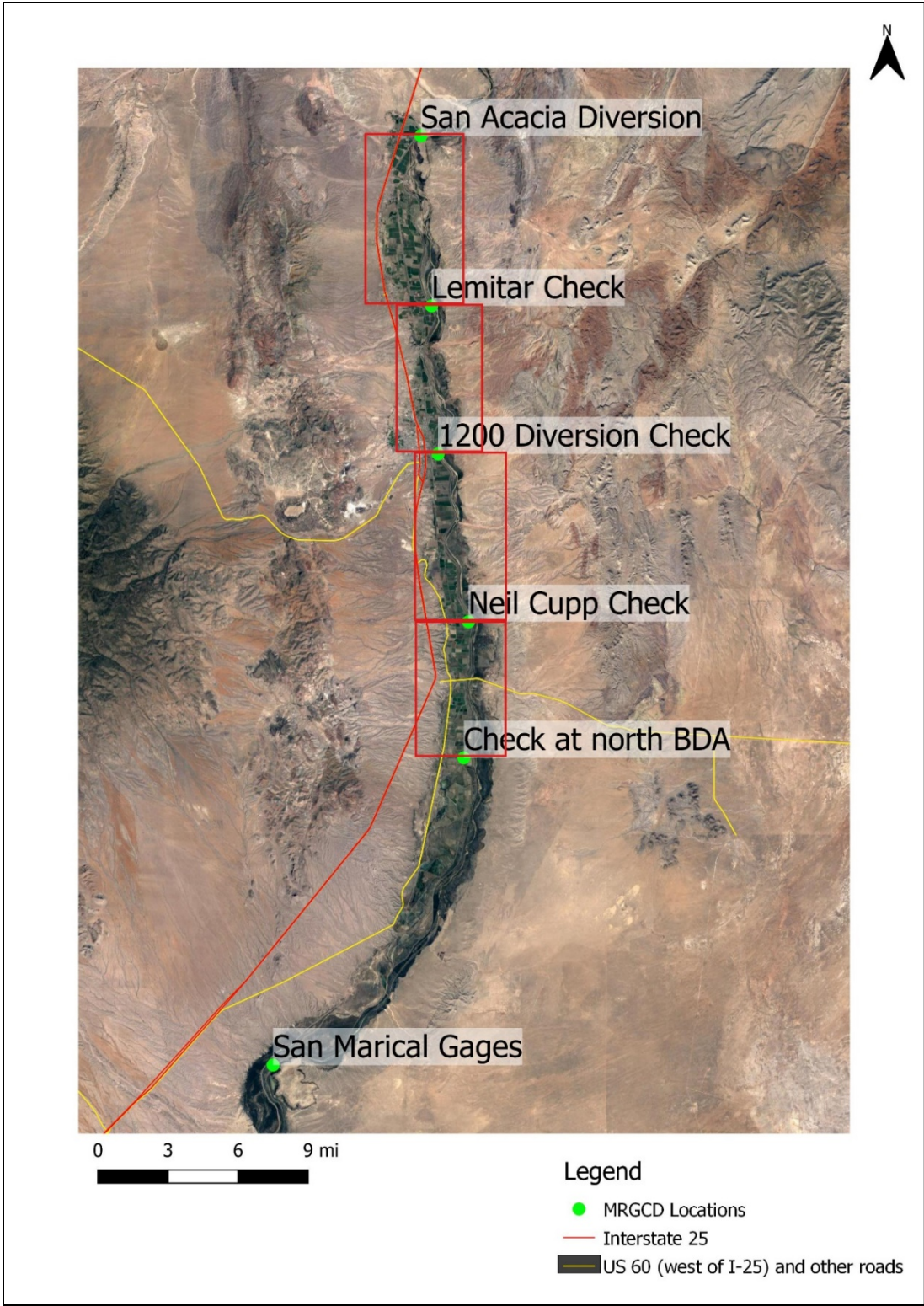


Figure 50. The Socorro Division, divided into four parts, separated by the LFCC check structures.

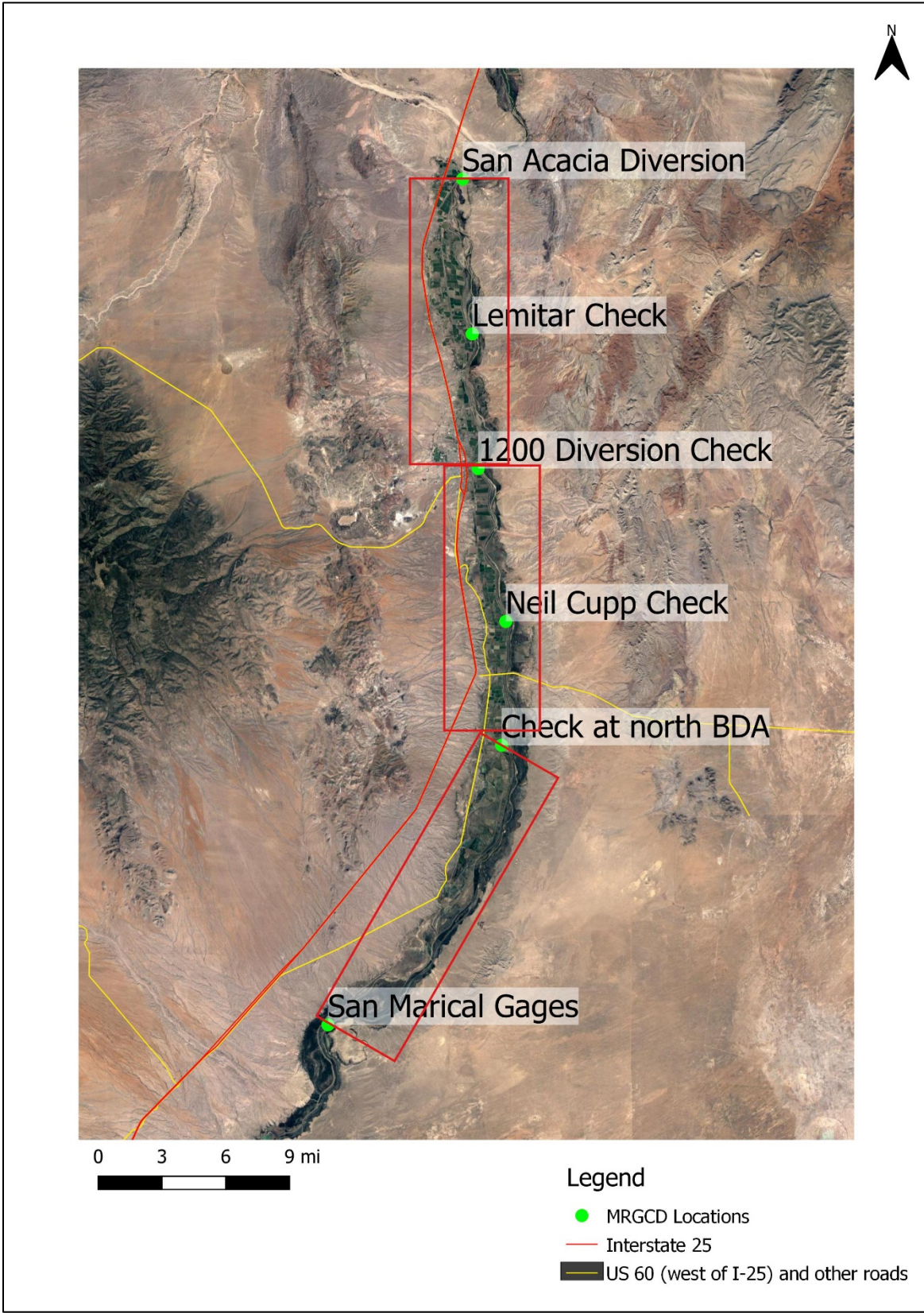


Figure 51. The Socorro Division, divided into 3 parts, for the purposes of the water budget.

The water budgets for 2014 for the three areas described are shown in Figure 52. The inflow at the Socorro Canal are based on MRGCD records. The RG San Acacia inflow and the outflows (RG and LFCC) at San Marcial are based on USGS records. Rainfall is based on Reclamations ETtoolbox. Evapotranspiration (ET) were based on ETtoolbox values, but reduced slightly (8 cfs) to balance the water budget. Seepage from RG to LFCC were based on seepage measurements in 2018, but reduced to match the total loss in the river for 2014. The flow at Socorro Check is roughly the flow between these two areas of the Division. Most is under the control of MRGCD, but some is in drains. Two seepage volumes are shown for the southern half of the division. The first part enters above the Neil Cupp Check, so might be controlled by the new MRGCD Hub. The second seepage volume is below the Neil Cupp Check and flows into the LFCC. It likely can't be controlled by MRGCD. Thus, about 96 cfs (119-23) of the 119 cfs that leaves the division could be controlled by MRGCD. So, the division has 132 cfs entering at the north end of the division and 119 cfs that is flowing out of the division with 96 cfs of outflow that could be reduced. Thus, there may be a lot of room for improvement. This 96 cfs can be broken down into; canal flow (this was 48 cfs in 2011, not available for 2014), seepage to the LFCC (roughly 38 cfs), and drainage from MRGCD lands. This all suggest that a reservoir in the middle of the Socorro Division (near the Socorro Check) may be useful for controlling outflows, since a lot of these flows are the result of fluctuations. Based on a preliminary analysis of flow fluctuations at the upstream end, a 40 - 50 ac-ft reservoir would be required. There are roughly 6,000 acres irrigated downstream from this location. Further analysis and discussion with MRGCD staff would be required to properly size this reservoir for improved operations. It may need to be as high as 100 ac-ft.

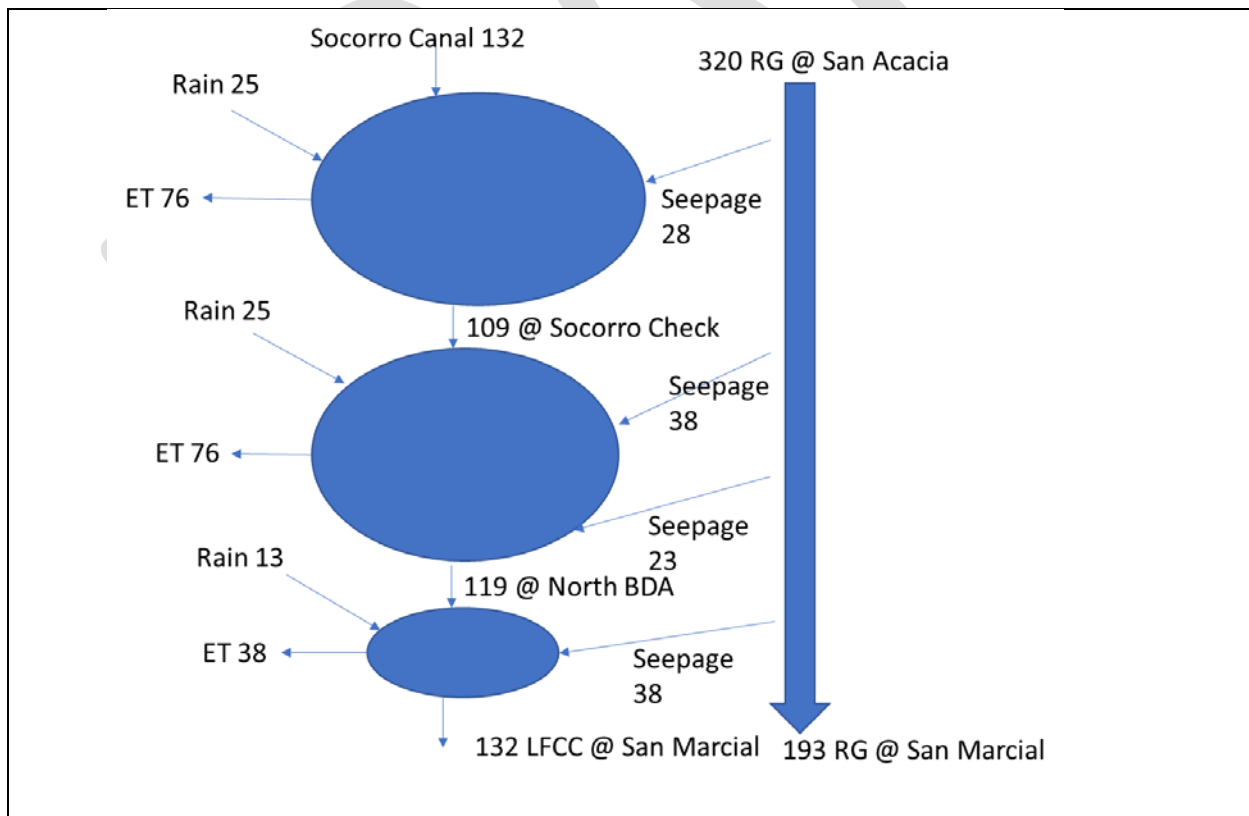


Figure 52. Socorro Division approximate Water Budget for 2014. Numbers are the average flow in cfs for the irrigation season.

A variety of operational and infrastructure improvements in the Socorro Division might include:

- A reservoir upstream to reduce the fluctuations reaching the Socorro Division, and to allow the inflow to be set more accurately to match demand.
- A system of water ordering and scheduling to define water use more precisely
  - Including volumetric water ordering and measurement
- More accurate recordkeeping of water deliveries
  - Including flow rate, time and volume
  - Including a comparison between water released to a canal and water delivered to users
- Better control structures at a few lateral canal sites
- Complete the MRGCD Hub to allow the use of drainage water

Currently this outflow serves the BDA and provides water to meet Compact requirements. The north boundary of BDA is roughly river mile 84.1 in Figure 53. BDA requires water during the growing season but MRGCD does not have the responsibility to supply them with water. BDA can use what when to crosses below the MRGCD service area. Under current operations, MRGCD has a hard time limiting these losses as indicated previously by >300 cfs drain outflow in 2013, which was considered a dry year.

The operational improvements described about could be applied to all Divisions. However, they would not be as effective in those divisions for several reasons. First, drainage water from the other three divisions ends up in the Socorro Division. If it is not utilized in the Socorro Division it is lost to the system. Second, there are no Pueblos and Acequia that take water in this division. Pueblos take water on demand, so excess water is routinely supplied so that their needs are satisfied. Improved operation of the rest of the Division may be more difficult. These two reasons make these improvements more cost effective in the Socorro Division. If MRGCD is interested in these types of operations improvements, they might try implementing them in the Socorro Division first.

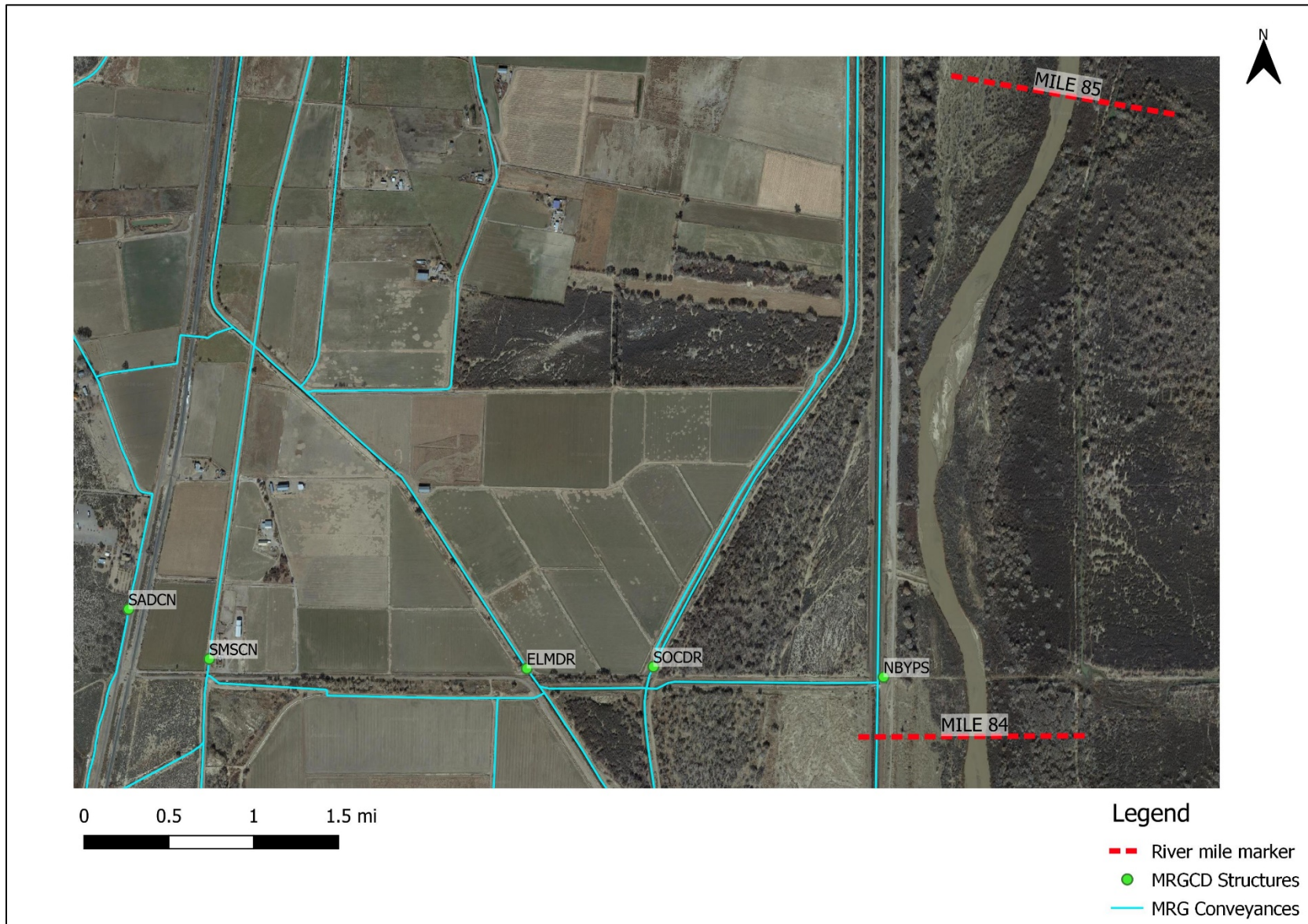


Figure 53. Downstream end of Socorro Division where flows leave the system. North boundary of Bosque del Apache.

**Reduce Losses from the system:** Reducing losses from the system mainly involves keeping water out of the river. All the losses listed above result from water in the river. It may be necessary for environmental needs to keep some water in the river, even in an extremely dry year. Groundwater recharge is probably the largest of these losses and that primarily occurs in the Albuquerque area. When necessary due to drought, MRGCD can keep MRGCD delivery water out of the river in this groundwater recharge area. In some cases, the use of reservoirs to minimize flow fluctuation can also help MRGCD in keeping its delivery water out of the river. Note that keeping water out of the river means keeping flow fluctuations within the canals and drains. Options for reducing canal flow fluctuations resulted in these fluctuations being sent to the river. Without reservoirs, keeping all flows in the canals rather than the river is difficult.

**Reduce flow fluctuations with the use of small reservoirs:** Several sites for reservoirs below Angostura Diversion were discussed during the field tour. Rough estimates of reservoir size were determined based on the magnitude of flow fluctuations. The size of these reservoirs should be examined in more details with MRGCD staff. Also, reservoirs placed upstream in the system may reduce the size of reservoirs further downstream. Reservoirs will increase surface-water evaporation. These additional losses must be weighed against the operations improvement resulting from the reservoirs. A more complete analysis would be needed to decide on reservoir sizes and locations. The sites are described below.

Water is lifted with pumps from the Albuquerque Main Canal to the Bernalillo Acequia Canal (BERCN). Water from flow fluctuations could be lifted at this site and stored in the Bernalillo Acequia Canal. This seemed to be a convenient location since the pumping station existed. However, this canal has insufficient storage. Expanding canal storage will be difficult and expensive at this site. This idea was abandoned at this site, but gave the team the idea to consider pumping to a reservoir at other sites.

There is sufficient drop in the Albuquerque Canal at heading on the Bernalillo Acequia Canal (BERCN) such that a reservoir could be constructed with water both entering and leaving the reservoir by gravity. The canal at this location is on Pueblo land (Santa Ana Pueblo). The Pueblo would have to be involved in any discussion about a small regulating reservoir at this location. While there is significant elevation drop along the Albuquerque Main Canal, there are no other sites where there is enough drop at one location to develop storage where water can both enter and leave the reservoir by gravity. The reservoir could be located just north of the Albuquerque Canal just across the canal from BERCN in Figure 54. The size of this reservoir should be in the range of 10 – 20 ac-ft.

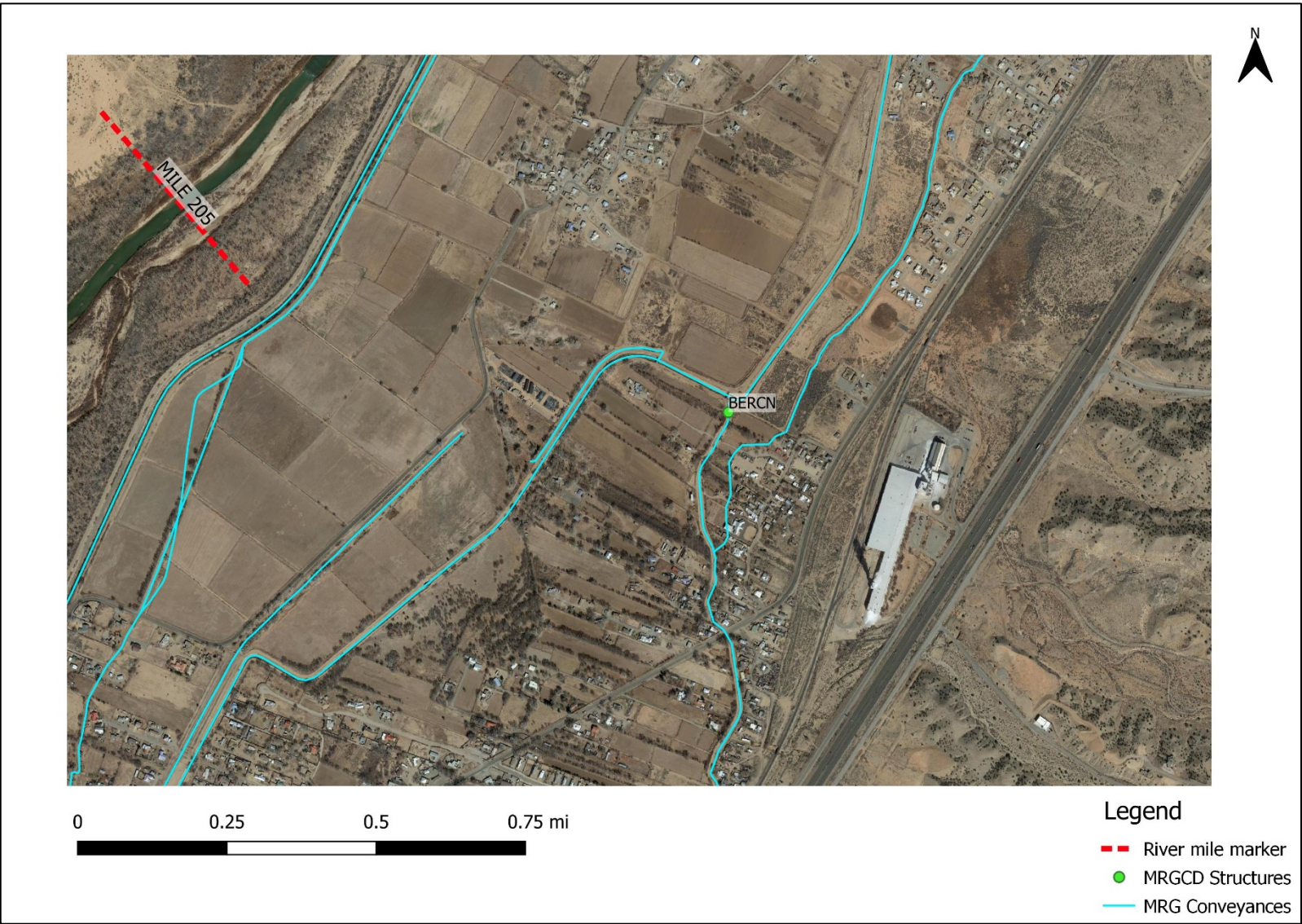


Figure 54. Bernalillo Acequia Canal site.

The next discussed was at Sandia Lake Recreation Area (below SANWW in **Error! Reference source not found.**). Several small reservoirs exist at this site. Water would have to be pumped either into or out of these reservoirs. A canal regulating reservoir sometimes has large water level changes which may not be convenient for recreation. Frequently, regulating reservoirs are fenced from public access to limit liability. All this makes this site unattractive.

The next site discussed was at the North Diversion Channel Outfall Sedimentation Basin (roughly at river mile 194.3 in Figure 15). Water could be pumped into this basin. A small erodible berm would be needed at the downstream end of this basin. The berm would hold water back for regulation. And could be designed to breach during a major flood event. Small storms could store water that could be used by MRGCD. Water would have to be pumped to get water into this basin, and could flow back to the canal by gravity. The berm would have to be reconstructed after large flood events. The size of this reservoir should be in the range of 10 – 20 ac-ft.

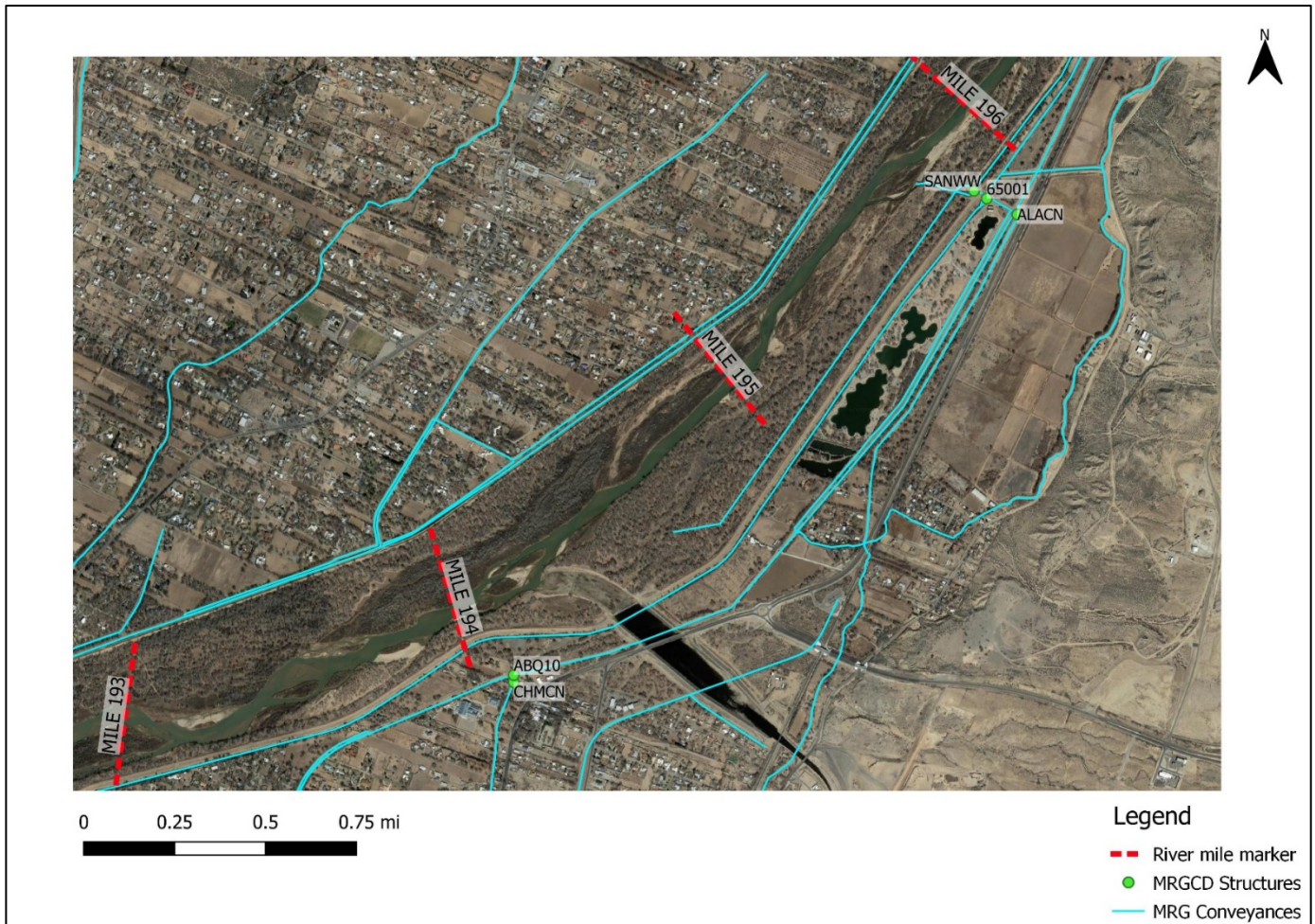


Figure 55. North Diversion Channel Outfall Si

Just upstream from Isleta Diversion, the Barr-Chical Diversion Connection attempts to bring water from the Albuquerque Riverside Drain (approximate river miles 170-171.5, see Figure 46). This connection does not work during the irrigation season. Perhaps water would have to be pumped into a reservoir that could feed the canals at this diversion. Flow in this drain is on the order of 100 cfs. There are already several lakes, a golf course and sufficient vacant land in this area. (Figure 46). A reservoir here might be used to supply water to pueblos via connections to the Chical Lateral and Chical Acequia Canal. This reservoir might more easily support daytime-only irrigation from these canals. The size of this reservoir should be in the range of 15 – 20 ac-ft.

There are several possible sites for a reservoir to store water from flow fluctuations within the Belen Division. MRGCD staff currently divert flow fluctuations into the Belen Highline Canal. One option for a regulating reservoir was from the Belen Highline Canal downstream from Feeder 3 Heading (FD3GT on center left of Figure 56, roughly river mile 143). The Belen Highline Canal is at a high elevation here, such that gravity in and out of a reservoir is possible. The Belen Highline canal has been abandoned downstream from this point (Note limited acreage below FD3GT (below river mile 143) in Figure 56), and the canal replaced with a pipeline to provide water to land downstream. There is adequate land in this area or further south to build a reservoir. This location is about 25 miles north of the San Acacia diversion. There is irrigated land for additional 15 miles along the river south of this point. Additional fluctuations in flow may occur in this area and this reservoir may not reduce the fluctuation related to water deliveries and drains further south in the Socorro Division. The size of this reservoir should be in the range of 10 – 15 ac-ft. Also, this deals only with fluctuation on the west side of the river. There is significant drainage on the east side as well.

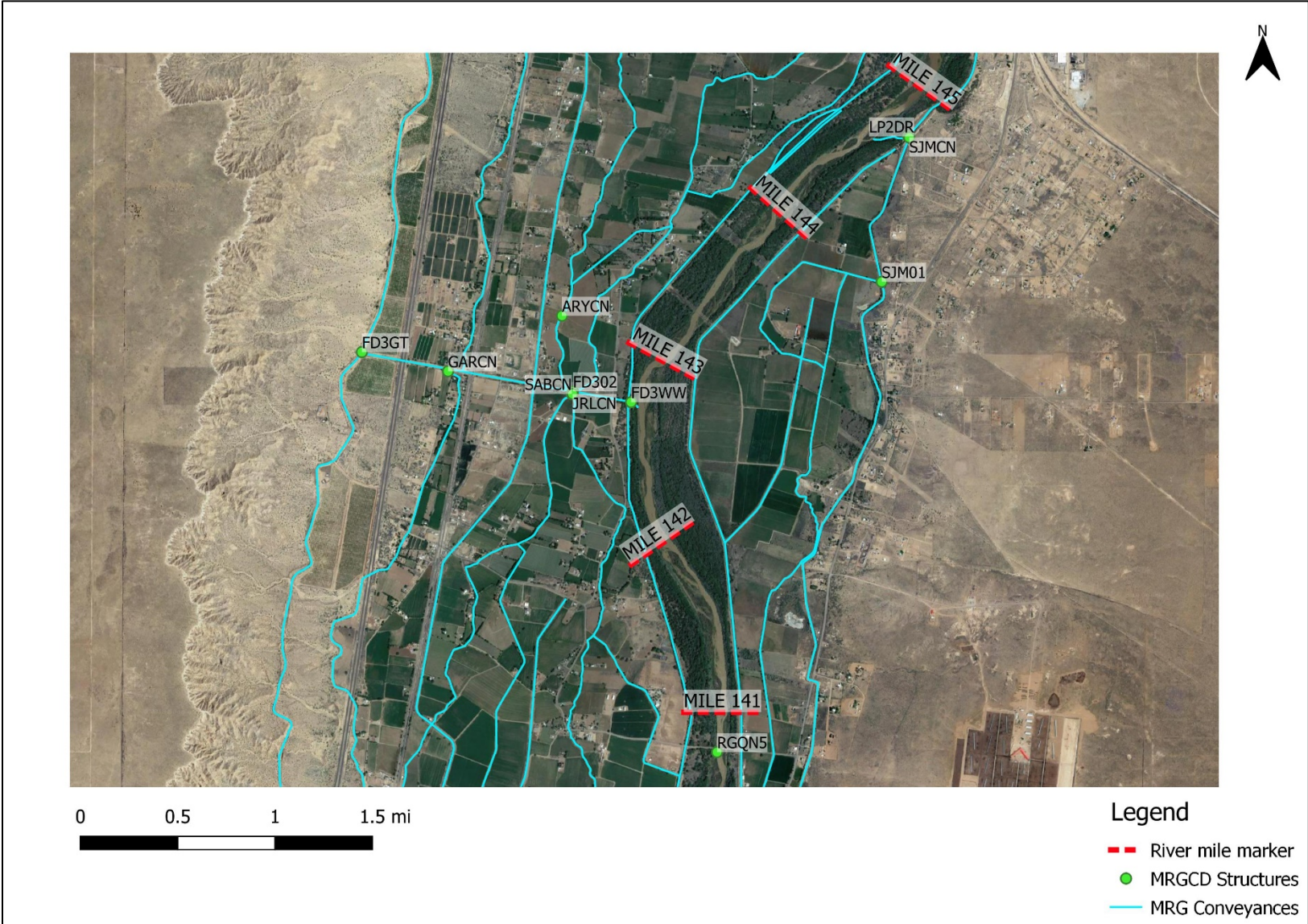


Figure 56. End of the Belen Highline Canal.

Additional regulation on the east side of the river within the Belen Division was discussed. The San Juan Feeder Canal connects irrigated areas that are separated by about 6 miles. This is a bottleneck since all canal and drainage water flows through this canal. A reservoir on either end of this canal would help operators deal with flow fluctuations. Two options were discussed; a reservoir near the end of the Peralta Riverside Drain at the head of the feeder canal (where a wasteway exists, PERWW near river mile 152.5 in Figure 57) and a reservoir near the San Juan Wasteway (near PL2DR at roughly river mile 144.8 in Figure 57) at the end of the feeder canal. A reservoir at either location would reduce the return flows to the river. More evaluation is needed to understand the impact these might have on performance here. The size of this reservoir should be in the range of 10 – 20 ac-ft.



Figure 57. Location of San Juan Feeder Canal.

In the previous section the site at the beginning of La Hoja Acequia was discussed as a possible site to locate pumps to regulate flow and to pump water from the east side to the west side of the river. This is also a potential site for a reservoir, for example at the head of the La Hoya Acequia Canal on the east side of the river. Water could be pumped from the San Juan Riverside Drain. This is roughly at where Highway US-60 crosses the Rio Grande (Figure 47). There appears to be vacant land at this site for a reservoir. A reservoir here would support daytime-only irrigation for the Acequia. The size of this reservoir should be in the range of 10 – 15 ac-ft.

The final site discussed in the Belen Division was near the Unit 7 drain about 3 miles upstream from San Acacia Dam where a gaging station exists (roughly river mile 119 in Figure 58). MRGCD staff discussed placing a reservoir between the drain and the river at this site. There is not enough drop in the drain elevation to allow water to flow both in and out by gravity. Water would have to be pumped either into or out of the reservoir. The main issue for this site are cost, land availability, and flooding from the river. The size of this reservoir should be in the range of 50 – 100 ac-ft.

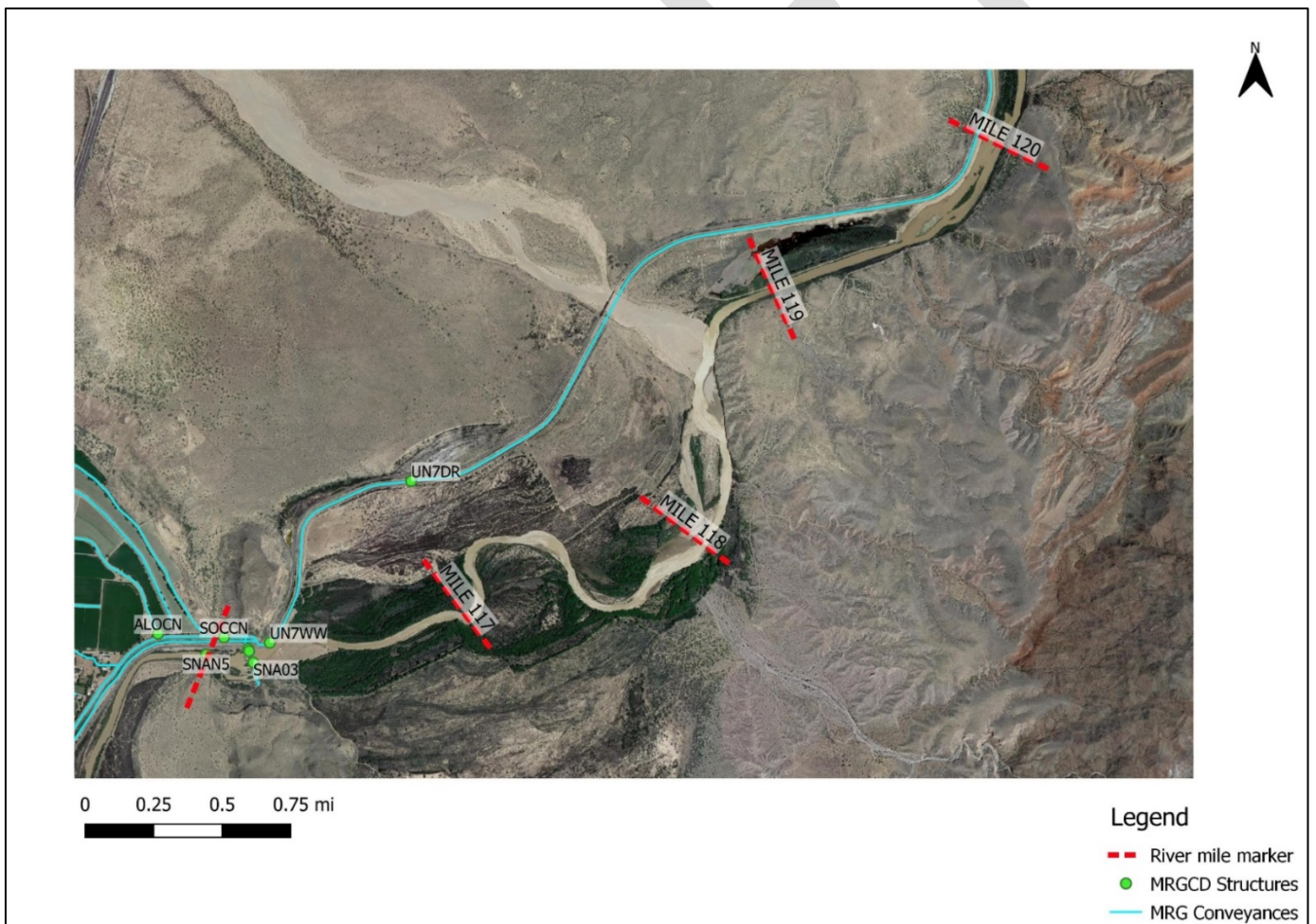


Figure 58. Potential reservoir site from Unit #7 Drain.

Two major washes enter the Rio Grande below the Belen Division and above the Socorro Division at San Acacia Dam; Rio Puerco and Rio Salado. Rio Puerco is gauged by USGS. Rio Salado was gaged for a short time, but sedimentation issues caused USGS to abandon the attempt to maintain a gage there. Storm flows entering the Rio Grande from these streams are not captured by MRGCD. There are no storage facilities to capture these flows. Even the reservoirs proposed here would not be able to capture a significant portion of these flows. These reservoirs are intended to capture flow fluctuations on the order of 10 to 50 cfs. The streams, when flowing, would provide flows on the order of 10's of 1000's of cfs. If a reservoir were constructed in the Socorro Division, high river levels during floods might result in increased seepage from the Rio Grande to the LFCC on the order of 10's of cfs. Excess river flow could be transported by the Socorro Canal on the orders of 10's of cfs. Thus, a reservoir may be able to capture up to a few hundred acre-feet of flood flows during storms, if properly sized and located.

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## Summary of proposed Recommendations

### Recommendation for 10% reduction in supply

#### Improve flow control at upstream diversions into divisions

- Surface skimmer at Sili Main Canal Flume (RM 232)
- Control of flow at Angostura diversion weir based on measured flow in Algodones Riverside Drain (RM 210)
- Send flow fluctuations to the river at head of Belen (RM 169) and Socorro Divisions (RM 116)
- Improved Canal Control with additional structure changes
- Control of flow from San Acacia Diversion to keep Socorro Canal Flow Constant

#### Improve canal control with additional structure changes

- Improved Canal Control with additional structure changes

### Recommendations for 25% reduction in supply

#### Increase connections from drains to canals

- Make Barr-Chical Diversion Connection function properly (RM 171)
- Pump to canal from Atrisco Riverside Drain (RM 171)
- Pump from San Juan Riverside Drain to La Hoja Acequia Canal and/or to San Francisco Riverside Drain (RM 130)
- MRGCD Hub at Neil Cupp Check (RM 90)

### Recommendations for 40% reduction in supply

#### Improve Operations System-wide (but initially focused on Socorro Division)

- A system of water ordering and scheduling to define water use more precisely
  - Including volumetric water ordering and measurement
- More accurate recordkeeping of water deliveries
  - Including flow rate, time and volume
  - Including a comparison between water released to a canal and water delivered to users

#### Improve Operations of the Socorro Division

- A reservoir upstream to reduce the fluctuations reaching the Socorro Division, and to allow the inflow to be set more accurately to match demand. (RM 119)
- Better control structures at a few lateral canal sites
- A reservoir in the middle of the division to control fluctuations and reduce downstream outflow
- Complete the MRGCD Hub to allow the use of drainage water

#### Reduce losses from the system by keeping water out of the river

#### Reduce flow fluctuations with the use of small reservoirs at or near:

- Albuquerque Canal at Bernalillo Acequia Canal (RM 205)

- North Diversion Channel Outfall Sediment Basin (RM 194)
- Barr-Chical Diversion Connection (RM 169)
- Belen Highline Canal near Feeder 3 Heading RM 143)
- San Juan Feeder Canal (either end) (RM 145-150)
- La Hoya Acequia Canal or San Juan Riverside Drain (RM 130)
- Unit #7 Drain just upstream from San Acacia (RM 119)
- Socorro Check (RM 99)

## References

Brower, AI (2015) ET Toolbox Evapotranspiration Toolbox for the Middle Rio Grande, A Water Resources Decision Support Tool, Version 3.1, April 21, 2015. Water and Environmental Resources Division Technical Service Center, Bureau of Reclamation, US Department of the Interior, Denver, Colorado

WEST (2018a). Seepage Measurements along the Rio Grande and Low Flow Conveyance Channel in the San Acacia Reach of the Middle Rio Grande, New Mexico, Winter 2018. Prepared for the New Mexico Interstate Stream Commission. June 2018. WEST Consultants, Inc.

WEST (2018b). Vulnerability Assessment for MRGCD. Prepared for the Middle Rio Grande Conservancy District, Albuquerque, New Mexico. Draft July 2018. WEST Consultants, Inc.

Appendix 8:

Drought

Task Force

April 2018

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## Introduction

In order to develop the MRGCD DCP, the MRGCD was required to identify key stakeholders to be members of the Drought Task Force. The MRGCD chose to change the name of the Drought Task force to the Drought Evaluation Team (DET) to avoid confusion with the existing state planning Drought Task Force. In this appendix the key stakeholders who would ideally be members of the DEC are identified. Several meeting of this entity occurred during the plan development, attached are the sign-in sheets from each of those meetings.

## 1 Key Stakeholders

Input from and communication with stakeholders in the planning area is necessary for the DCP to be successful. The following is a list of key stakeholder with whom the MRGCD will include in DET activities:

- U.S. Bureau of Reclamation (Reclamation) is responsible for meeting federal requirements; endangered species (U.S. Fish and Wildlife Service {USFWS} Biological Opinion {BO}) and requirements of federal agencies (e.g., BDA)
- U.S. Fish and Wildlife Service is responsible for endangered species protection.
- U.S. Army Corps of Engineers (USACE) is responsible for flood control and for maintaining the quality of rivers of the U.S.
- NM Interstate Stream Commission (ISC) is responsible for meeting Rio Grande Compact requirements
- Colorado Department of Water resources manages the San-Juan Chama system and the Rio Grande deliveries to New Mexico
- Bureau of Indian Affairs (BIA)
- Albuquerque Bernalillo County Water Utility Authority (ABCWUA)
- City of Albuquerque
- City of Belen
- Town of Bernalillo
- Village of Bosque Farms
- Village of Los Lunas
- City of Rio Rancho
- City of Socorro
- Albuquerque Metropolitan Arroyo Flood Control Authority (AMAFCA)
- Southern Sandoval County Arroyo Flood Control Authority (SSCAFCA)
- Coalition of Six Middle Rio Grande Basin Pueblos
- New Mexico Acequia Association
- New Mexico State Forestry Division
- The Nature Conservancy New Mexico
- Audubon New Mexico
- Middle Rio Grande Water Assembly
- Sandoval, Bernalillo, Valencia, and Socorro County
- Local and state fire response and prevention teams
- Pueblo De Cochiti
- Santo Domingo Tribe
- Pueblo De San Felipe

- Santa Ana Pueblo
- Pueblo of Sandia
- Pueblo of Isleta
- Elephant Butte Irrigation District (EBID)
- Soil and Water Conservation Districts

This list is not intended to be exhaustive and if there is a need to include additional entities the MRGCD may do so at their discretion.

## 2. Drought Evaluation Team Meeting Notes and Attendees

### 11/4/2016 Meeting

#### List of Attendees

DET 11/14/2016 meeting	
Name of Attendee	Affiliated Organization
Carolyn Kennedy	Coronado SWCD
Rose Jimenez	South Valley Acequia Association
Lynn Montgomery	Coronado SWCD
Bob Wessely	MRG Water Assembly
Sue Umshler	Business Water Task Force
Marvin Mendelow	Coronado SWCD
John McCathern	MRG Water Assembly
Jeff Goebel	Valencia SWCA
Ruben Lucero	Pueblo of Isleta
Ramona Montoya	Pueblo of Isleta
Mike Marcus	MRG Water Assembly
Virginia Nerochea	Center for Social Sustainable Systems
Martin Haynes	MRGCD Irrigator
Veronique Richardson	Pueblo of Sandia
Andrew Hautzinger	Valencia SWCA
Elaine Hebard	MRG Water Assembly
Sarah Hurteau	The Natue Conservancy
David Gensler	MRGCD
Janet Jarret	MRGCD Irrigator
Rick Billings	ABCWUA
Rolf Schmidt	NMISC
Ariane Pinson	USACE
Jessi Young	Pueblo of Santa Ana
Nylene Troxel Stowe	Socorro SWCD
Theresa Cardenas	Union of Concerned Scientists
Dagmar Llewellyn	Reclamation
Jeb Brown	USGs
Ian Colburn	Rio Grande Community Farm
Amy Galanter	USGS

## Meeting Notes

### **Middle Rio Grande Conservancy District Drought Contingency Planning Task Force Kick-off meeting**

**Bureau of Reclamation, Albuquerque Area Office, November 4, 2016**

#### Meeting start – Roundtable Introductions, and Expressions of Interest in This Process

David Gensler, MRGCD– The MRGCD is interested in potential infrastructure (such as re-regulating reservoirs) that can help the district be more resilient to drought. We are also interested in providing supplemental groundwater supply to MRGCD constituents.

Lynn Montgomery, Coronado SWCD – We are interested in public discussions leading to a community that is more responsible with its water. For example the spring I rely on has gone dry to overuse of groundwater for development.

Common theme- Many attendees expressed concern over climate change and how that translates to an uncertain water future. There was expressed concern over impacts of drought and private sector development on irrigation.

Jeb brown, USGS NM Water Science Center – We are available to provide science to support decisions and policy.

Rose Jimenez, South Valley Association- Our traditions are connected to water and land, our communities feel the impacts of drought and over development

Water Assembly –The state’s regional water plan did not deal with drought, there was one drought question but there were no gradations. Work needs to be done on balancing surface water and ground water.

Frank Chavez, Pueblo of Sandia- We want to try and ensure that New Mexico can sustain its people. There is a great amount of concerned about over-appropriation of water. We call it fully appropriated, but really we use more than we have – our use of the aquifer is not being replenished. There is risk in not honestly addressing these issues, or using good science. It is important to note that planning efforts are often conducted in silos, why is there not greater coordination in these efforts.

Veronique Richardson, Pueblo of Santa Ana (attorney) - I am here to protect the Pueblo’s interests and identify any impacts that this effort may have on the Pueblo.

Isleta Pueblo – There have been shared shortages recently and the Pueblo is interested looking at that. I also have concerns about official membership of the Drought Task Force, as I am here in my own and the Pueblo has agreed to participate in nothing.

Ariane Pinson, Army Corps-I am here as a partner, I am interested in impacts of climate change.

Rick Billings, ABCWU – We are interested in being responsible water stewards, and to addressing impacts of climate change.

Nylene Troxel Stowe – Socorro SWCD, I am here to learn about the program and how a plan will impact us, at the bottom of the MRGCD system.

Rolf Schmidt Peterson, ISC Rio Grande Bureau Chief– The ISC has many interests in this process, including Compact Compliance, storage restrictions, water operations, USGS gaging (ISC supports), partner with Reclamation and MRGCD on ESA Consultation.

#### Anne’s presentation – Brief Overview of the Program

Grant Agreement with Reclamation signed Sept. 30, 2016, 24 months to complete grant.

Drought Task Force is a required part of the program.

Drought Task Force will subdivide into smaller work groups; we will develop a governance structure.

Ramona Montoya- Pueblos have not officially signed on, and it might be easier if we don’t have a formal document and signatures.

Dagmar and David – We think that the program requirements don’t specifically require a signed document and commitments.

Public meetings – Public meetings will be held to inform the public of the efforts and findings of the contingency planning.

The public meeting should be a two way street. There needs to be a mechanism for the Drought Task Force to consider public input into this process.

The geographic extent is the confines of the MRGCD (Cochiti to Bosque del Apache), although there are entities outside the district who impact the MRGCD region. The Task Force will specifically address the benefited area only, due to the realities of operational authority.

The document from Middle Rio Grande Conservation Initiative needs to be reviewed. It was developed as part of the America’s Great Outdoors (which is still on the ESA Collaborative Program website).

David Gensler – There are already other drought task forces underway; we should coordinate with the other drought task forces within the basin.

#### Required elements:

Drought Monitoring – Discussion that there are many forms of drought monitoring going on already in the basin, including evaluations of snowmelt runoff and upstream storage, as well as soil moisture in the valley. The different types of drought need to be identified in this process; Hydrologic drought, operational drought, and Compact drought.

Definition of the triggers for the enactment of the plan would require a combination of the drought monitoring task and the Vulnerability Assessment task.

A requirement of the drought monitoring is that the triggers for enactment of the plan need to be identified; this will require a combination of the drought monitoring and the vulnerability assessment tasks.

David Gensler- We can lump the 6 tasks and divide these into 3 subgroups.

Bob Wessely – It is important that we define how serious of a problem we are worrying about.

David Gensler– We need to define drought in our Drought Monitoring Program.

Dagmar Llewelyn and Janet Jarrett – We will not consider just one kind of drought, and drought declaration will not be binary (either on or off) but instead we define different mitigation for different kinds of droughts, and different degrees.

Ariane Pinson – it seems that the vulnerability assessment should lead the way. Sort the vulnerabilities first, and then monitor the drought parameters related to those vulnerabilities.

Andrew Hautzinger– we need to focus our efforts really tightly. I second that we should use the vulnerability assessment to help us focus these efforts. And what are the vulnerability thresholds?

David Gensler- The Conservancy District has 3 jobs – irrigation, drainage, and flood control. Drought only affects the first one of these. Irrigation provides livelihoods, food, and a stable economic base for the region. Contingencies include what we do when El Vado is under rehab and may be unavailable to us for a period of years. What do we do when we don't have enough water in storage, or the Compact limits are ability to use the water that comes through the valley? I think that we need to take a long, hard look at what has happened in New Mexico's lower Rio Grande. Down there, whenever water has been short, they have turned on their pumps, and the cumulative impact of that action over time has built up to cause a problem.

Rolf Schmidt – The layers of planning going on is very helpful. The water authority has 70% of the permitted groundwater pumping rights in the MRG. It is important for the MRGCD to consider the impacts of that pumping over time on the MRGCD operations. The Water Authority's plan is quite different from any other I have seen in a while. It's remarkable to see the city's turnaround, including decreases in per-capita use and recovery of groundwater that has occurred in recent years.

David Gensler – One of our possible mitigation strategies could be to use groundwater during drought, but we need to do it carefully, and weigh all of the pros and cons, including the impact of other water users, such as the water authority.

Andrew Hautzinger– Yes, but we need to be cognizant that if we consider everyone's use, this process might get buried under its own weight.

David Gensler– At the moment, our policy is to have only 2 tiers of water delivery – Pueblos first, and all other irrigators second. The lowest tier is the water bank, most of the time.

### How to move forward

Someone suggested that David come up with the District’s list of possible “Response Actions” that the District will be considering. Other partners can then come forward with their own ideas to supplement.

Discussion about groundwater use. District is considering putting in wells that it could pump in times of short supply (so this is different from the irrigators pumping individually).

Ian Colburn, Rio Grande Community Farm –Most of the vegetables grown in this valley are done with groundwater, since the surface water is not suitable for drip irrigation. It’s also because you need to irrigate more often (every few days), and surface water is generally not available on that schedule.

Elaine Hebard, MRG Water Assembly – Many of the small-farm irrigators are also using domestic wells. These shallow wells might be impacted.

David Gensler– What happens on the Pueblo matters to all of the users downstream. So we expect 15% or so of our infrastructure improvements to be on Sandia Pueblo.

Janet Jarrett – The water for those shallow wells come from the ditches (70,000 af/year) – if we line those canals, the shallow groundwater will no longer be recharged, and those shallow wells will be impacted.

We should start with development of an outline for the plan, which can be distributed by email to this group for input. As we flesh things out, we will start to see some specific recommendations, and will need to include some fairly detailed design work.

Martin Haynes, MRGCD irrigator – There is a snowball’s chance in hell of my participation in this. I don’t have time to sit in so many meetings.

David Gensler – I do not expect the Water Authority to be a formal member of this process.

Dagmar Llewelyn– I think that the Water Authority is the key kind of member that Reclamation anticipated be part of the task force, since any actions the District takes in drought needs to be coordinated with the Water Authority, since the drought responses of both entities affect each other.

### Next Steps

Step 1 – formalize the process for membership in the Task Force, including a specific document that defines the process, so the tribal representatives can take it to their tribal authorities (Frank noted that the Pueblos want our community to thrive, and bringing this forward to our tribes is an opportunity for engagement).

Step 2 – develop outline and distribute it to the group for feedback. Try to get this distributed to group prior to the holidays.

Step 3 – get back together, form sub-teams, and get started fleshing out the plan.

## 1/27/2017 DET Meeting

### Attendee List

DET 1/25/2017	
Name of Attendee	Affiliated Organization
Ander Lunduhl	NMISC
Lynn Montgomery	Coronado SWCD
Carolyn Kennedy	Coronado SWCD
Chuck Thomas	SSCAFCA
Veronique Richardson	Santa Ana Pueblo
Ariane Pinson	USACE
Janet Jarret	MRGCD Assesment Payers Assocition
Mike Hamman	MRGCD
Amy Galanter	USGS
Dagmar Llewellyn	Reclamation
Elain Hebard	MRG Water Assemby
Antonio Griego	Rio Rancho
Rose Jimenez	South Valley Acequia Association
David Gensler	MRGCD
Sarah Hurteau	The Nature Conservacny
Page Pegram	NMISC
Jessica Tracy	Sandia Pueblo
Sean Woodson	Rio Grande Farmer coalition
Ian Colburn	Rio Grande Farmer Coalition
Zoe Economon	Ciudad SWCD

## Agenda

**Drought Task Force**  
**January 25<sup>th</sup>, 2017 9am-12pm**  
**Bureau of Reclamation San Juan Room**

Proposed Agenda:

Objectives: Establish a formalized process for membership in the Drought Task Force, identify sub-teams, begin plan development, and establish the next steps.

1. Introductions  
Attendees will introduce themselves and their affiliations
2. Drought Task Force Membership- Anne Marken, MRGCD  
Presentation and discussion of the commitment for membership in the Drought Task Force
3. Proposed framework of the Drought Contingency Plan-Anne Marken, MRGCD  
Discussion of framework that has been formed by the MRGCD
4. Identify subgroups  
Discussion by the group on how the subgroups should be organized
5. Discussion of next steps  
Identification of the next steps in the Drought Contingency Plan
6. Comments

## 8/10/2017 Meeting

### Attendee List

8/10/2019 DET Meeting	
Attendee Name	Affiliated Organization
P. Lucero	Coronado SWCD
George Sieber	USGS
Sarah Hurteau	The Nature Conservancy
Dagmar Llewellyn	Reclamation
Jerry Lovato	AMAFCA
David Gensler	MRGCD
Page Peegram	NMISC
Brooke Wyman	Pueblo of Sandia
Jame Aranda	Valencia County
Dave Park	Reclamation

### Agenda

**MRGCD Drought Task Force Meeting  
August 10<sup>th</sup>, 2017 9:30am-11:30am  
MRGCD General Office 1931 2<sup>nd</sup> St. SW, Albuquerque, NM, 87102**

1. Introductions
2. Brief description of the MRGCD Drought Contingency Plan- Anne Marken, MRGCD
3. Discussion:
  - Review of the statement of work for the Vulnerability Assessment
  - Review of the statement of work for the Infrastructure Assessment
4. Next Steps
5. Adjourn

Appendix 9:  
Supporting MRGCD Documents

April 2019

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# Water Distribution Policy of MRGCD



## WATER DISTRIBUTION POLICY OF THE MIDDLE RIO GRANDE CONSERVANCY DISTRICT



This Policy is established and adopted by the Middle Rio Grande Conservancy District (MRGCD) Board of Directors as of June 25, 2012. This Policy is intended to promote the effective, efficient, and equitable distribution of water to non-Pueblo irrigators within the boundaries of the MRGCD. It is not the intent of the MRGCD that this Policy or its enforcement, be used to make any determination of the status of land ownership, or ownership of a water right, or as a limitation of beneficial use, or as an indication of abandonment or forfeiture of a water right. It is also not the intent of the MRGCD that this Policy modifies the water, irrigation or property rights of the Six Middle Rio Grande Pueblos (the "Pueblos") nor does it modify the legal relationship between the MRGCD and any federal agency. In the event of a conflict between an applicable Federal or State law, regulation, or policy, or contractual obligation of the MRGCD and this Policy, such law, regulation, policy, or contractual obligation, shall control. In the event of a conflict between this Policy and a more specific MRGCD policy relating to another subject matter, such as the Water Bank Policy, the more specific provision shall control.

### 1. WATER DISTRIBUTION

Water that is available to the MRGCD will be distributed in proportion with the amount of land served. Water will be distributed to main canals, laterals, and ditches, considering local conditions, in proportion to and appropriate for acreage and crop scheduled for irrigation. The MRGCD distributes water to all users fairly and equitably without any preference. Water distribution and use within the MRGCD is subject to the following conditions:

#### a.) WATER TO PUEBLO LANDS

The MRGCD delivers water to six Middle Rio Grande Pueblos. The Pueblos occupy a unique position legally, historically, culturally, and physically within the Middle Rio Grande Valley. Scheduling of water deliveries to Pueblo lands is normally done by Pueblo majordomos, in cooperation with MRGCD staff. The MRGCD, to the greatest extent possible, will cooperate with the Pueblo majordomos to meet Pueblo water needs. Pueblo irrigators and majordomos are encouraged to follow scheduling of water delivery in a manner similar to non-Pueblo lands. Certain Pueblo lands have been designated by the US Congress as having "Prior and Paramount" water rights. During times of shortage, these lands will receive water preferentially over all other MRGCD lands and the MRGCD will coordinate with the Bureau of Indian Affairs Designated Engineer to assure Prior and Paramount water deliveries to the Pueblos. Allocations of water to all Pueblo Lands shall be carried out in strict conformance with the Act of February 14, 1927 (44 Stat. 1098), the Act of March 13, 1928 (45 Stat. 312) and the Act of August 27, 1935 (49 Stat. 887).

#### b.) WATER TO ALL OTHER LANDS

Irrigation water is available to lands within the boundaries of the MRGCD which are physically capable of receiving water via gravity. No water will be delivered to water users who are delinquent in the payment of MRGCD assessments, water service charges, or other fees. Water will not be delivered to lands from which water rights have been sold, severed, or transferred, according to New Mexico Office of the State Engineer records provided to the MRGCD, unless proof of either a leaseback agreement or enrollment in the MRGCD Water Bank program or alternate source of water is provided to the MRGCD.

**c.) IRRIGATION SCHEDULING**

All irrigation deliveries must be scheduled well in advance with the appropriate Ditch Rider for each service area. Water users will be provided advance notice of the schedule. A minimum of five (5) days advance notice is recommended for irrigation scheduling. To utilize available water supplies as efficiently as possible, it is essential that water users irrigate both day and night, seven days per week. Ditch Riders are normally available by phone between the hours of 7am and 6 pm Monday thru Saturday for scheduling water, and 24 hours per day for emergencies. In case a Ditch Rider cannot be reached, irrigators may call the appropriate Division Office for assistance.

**d.) IRRIGATION PERIOD**

When an irrigation delivery has commenced as scheduled, it will be continued without interruption; until completion. Turnouts should be opened fully to complete delivery as quickly as possible. Should an irrigator voluntarily cease irrigation before completion, delivery will be considered complete by the MRGCD, and the irrigator will be required to schedule a new delivery after a reasonable period of time has elapsed. If irrigation should be interrupted by causes beyond the irrigator's control, the Ditch Rider will re-schedule irrigation as quickly as possible for that irrigator, and in such a manner as to minimize impacts to other scheduled irrigators.

**e.) MAINTENANCE OF ON-FARM DELIVERY SYSTEMS**

It is the responsibility of the irrigator to maintain efficient On-Farm water delivery systems to lands irrigated. Water will not be delivered to silt-laden, vegetation-fouled, or otherwise obstructed On-Farm delivery systems (including community ditches). Where closed conduit systems are used, these must be appropriately sized for operating head and area served. On-Farm delivery systems should be capable, under normal irrigation conditions, of fully irrigating at least One (1) Acre/hour. Systems not capable of supplying this rate may be denied water if, in the opinion of the MRGCD, their use results in excessive use of water, or prevents other irrigators from receiving water in a timely manner.

**f.) OPERATION OF TURNOUTS AND STRUCTURES**

Turnouts, check structures, and other water control devices are the property of the MRGCD. Irrigators are permitted to open turnouts only for scheduled irrigation deliveries, and turnouts should remain closed and secured at all other times. Check structures on MRGCD facilities are generally to be operated by the Ditch Rider, and in some cases may operate automatically. Adjustment by irrigators of automatic control structures, diversion dams, or wasteway structures returning water to the Rio Grande are not allowed under any circumstance. Where necessary the Ditch Rider may permit irrigators to operate certain check structures, but this operation is to be precisely as specified by the MRGCD, and check structures are to be securely locked at all other times.

**g.) MODIFICATION OF IRRIGATION STRUCTURES**

Turnouts, check structures, and other water control devices are the property of the MRGCD. Irrigators may not alter, or cause to be altered, either temporarily or permanently, any MRGCD structure without the express permission of the MRGCD, and in the manner specified by the MRGCD. No modification will be allowed which results in a water surface elevation higher than the safe design capacity of the canal, or that reduces the safe design capacity of the canal, or results in changes to other associated hydraulic properties.

**h.) RECORD OF IRRIGATION**

Each Ditch Rider will keep an Irrigation Log for the purpose of documenting water use. The record will show date and time water was started and shut off for each irrigation delivery, place of use, irrigator using the water, and purpose of use (crop type). Notes shall be made of any special circumstances involving delivery or use of water. Any irrigation difficulties or violations of MRGCD rules/policies will be promptly reported to the Division Manager, and recorded in the Irrigation Log. The Irrigation Log will be in the format approved and specified by the MRGCD.

**i.) SMALL TRACT IRRIGATION**

Where a single turnout serves multiple small tracts (such as small community ditches), or where multiple small turnouts are aligned in close proximity along a canal and served by a single check structure, the Ditch Rider may request a single point of contact be designated for irrigation scheduling, so that all properties irrigate at a scheduled time to avoid repeated opening/closing of the turnout or check structure. Irrigators are encouraged to coordinate their irrigation requests with their neighbors to conserve water and efficiently manage the water delivery.

**j.) WASTE OF WATER**

If, in the opinion of the MRGCD a landowner or irrigator is wasting water, either willfully, negligently, or due to defective On-Farm delivery systems, and is unwilling to rectify the violation as outlined in this Policy in a manner acceptable to MRGCD, the MRGCD may refuse, discontinue, or limit the delivery of water until the wasteful practices are remedied. Wasteful irrigation practices include, but are not limited to the following:

- (1) Allowing water to leave land being actively irrigated, flowing onto lands not intended to be irrigated or not under the control of the irrigator, roads, ponds, drainage channels, vacant land, homes, buildings, livestock pens, etc.
- (2) Flooding land to an unreasonable depth, or using an unreasonable amount of water in order to inundate high elevation portions of land, or to compensate for inadequate On-Farm delivery systems.
- (3) Applying water to land that has been improperly prepared for efficient use of irrigation water.
- (4) Allowing excessive or unreasonable amounts of water to spill or drain to MRGCD drains or other channels; particularly while continuing to take delivery of water.
- (5) Applying water in such a manner as to result in ponded water remaining present on a property for an unreasonable amount of time, and inappropriate for crops being irrigated.
- (6) Applying water too frequently, and to soils already saturated or nearly saturated, such that the greater portion of the applied water cannot be stored for crop use and drains from the soil via surface or subsurface pathways, or evaporates.

**k.) WATER SHORTAGE**

The delivery of irrigation water within the MRGCD is highly dependent on flow of the Rio Grande. At times, this may be insufficient to supply all irrigator's needs. During such times, the MRGCD will practice "shortage sharing" in the distribution of water (please

note rule 1a. regarding delivery of water to Pueblo lands). At times, supplemental water may be available from El Vado reservoir to minimize the effect of low Rio Grande flows on the irrigation water supply. However, there may still occasionally be times when water is not available, and irrigators should be aware of that possibility. The MRGCD makes no guarantees regarding the availability of water; however, the MRGCD will keep irrigators informed as to the status of supplies and outlook for the future.

**l.) PUMPING FROM MRGCD DRAINS AND CANALS**

Pumping from MRGCD facilities is generally not permitted, except pursuant to a license in cases where it is not physically or financially feasible for water to be obtained from any other source. Water pumping is subject to the same regulations as water distributed through turnouts, including scheduling requirements and recordkeeping through Ditch Rider Log Book entries.

**m.) CONSERVATION PRACTICES**

The MRGCD supports and encourages the adoption and use of alternative water delivery systems and application techniques intended to promote water conservation and/or agricultural efficiency. To the greatest extent practical, the MRGCD will allow flexibility in its rules and regulations when needed to support conservation practices, with the exception that this flexibility may not result in water shortage, inequitable water distribution, or hardship to other irrigators. All water users are encouraged to laser-level their land and use other water conservation practices.

**n.) THE DITCH RIDER**

The Irrigation System Operator commonly known as the Ditch Rider, holds a key position and is responsible for proper coordination and operation of MRGCD facilities within his or her service area so that water is distributed equitably amongst all irrigators. Where conflicts arise between scheduling requests, or the operation of facilities, the Ditch Rider will determine what best meets the needs of all irrigators in an impartial manner. The Ditch Rider will show no partiality in distribution of water regardless of personal feelings, race, creed, relationship, political or social standing, or previous grievances. Any irrigator who is aware of any preferential treatment on the part of a Ditch Rider must report that information immediately to the MRGCD. The Ditch Rider is an employee of the MRGCD. Irrigators must not compensate Ditch Riders or any other MRGCD employee with monetary or other kinds of payments for any services rendered on behalf of the MRGCD.

**o.) RESOLVING DISPUTES**

Irrigation practices vary, and differences of opinion may naturally arise during the delivery of irrigation water. Irrigators must first attempt to resolve disputes directly with their Ditch Rider. If resolution cannot be attained, the Ditch Rider Supervisor may be contacted, followed by the Division Manager. If the dispute cannot be resolved locally with the assistance of the Supervisor or Division Manager, the MRGCD's Hydrology/Water Operations Department may provide assistance, followed if necessary by a decision of the Chief Engineer.

**p.) VIOLATION OF MRGCD IRRIGATION RULES/POLICIES**

Any irrigator found to be in violation of MRGCD rules/policies will be subject to loss or suspension of irrigation water delivery, and may be liable for damages resulting from those violations. Actions taken by MRGCD may include the following:

- (1) Securing turnouts to prevent operation using MRGCD locking devices, welding, burial, or removal.
- (2) Referral to local law enforcement authorities for prosecution, where appropriate.
- (3) Landowners, irrigators, or other persons who, by opening, closing, modifying, or otherwise interfering with the regulation of MRGCD facilities and structures cause any fluctuation on water flow or elevation that results in breaks or damage of any kind, will be responsible for the expense and damage caused and may be liable to others who are adversely affected.
- (4) All other remedies provided by law.

**q.) ILLEGAL IRRIGATION**

Irrigators determined to have been illegally irrigating lands from which water rights have been sold, severed, or transferred, according to New Mexico Office of the State Engineer records provided to the MRGCD will be provided with written notice that unless proof of either a leaseback agreement or enrollment in the MRGCD Water Bank program or alternate source of water is provided to the MRGCD within fifteen (15) days after the date of the notice, the head gate to the illegally irrigated property will be locked and all deliveries of water to the property will cease. The notice will explain to the irrigator that he/she may seek to resolve any dispute over the contents of the notice, first, with the Division Manager and/or MRGCD Engineering Department and if unsuccessful with the Chief Engineer. If no resolution is reached, the irrigator may assert remedies available as provided in paragraph 4 below. Following issuance of the notice, all Water Bank lease fees, including the annual administrative fee and the applicable lease fee, charged the illegal irrigator will be double the normal amount for the first year of any subsequent Water Bank lease, unless a resolution in favor of the irrigator is reached.

**2. DUMPING TRASH**

Dumping trash, waste, tree branches, grass clippings, animals, animal waste, or debris of any sort into MRGCD facilities, or on any MRGCD right-of-way is not allowed. Landowners, irrigators, and employees of the MRGCD are required to report to the MRGCD the description of the vehicle, license number, name of driver, if available, time and place of any observed dumping. Dumping will be referred to appropriate local law enforcement authorities for investigation and prosecution.

**3. CONTAMINATION OF WATER IN MRGCD FACILITIES**

Unauthorized discharge or wasting of water into MRGCD facilities from sources other than those associated with the normal delivery and management of irrigation water is not allowed. It shall be the duty of all MRGCD employees, landowners and irrigators to report promptly to the MRGCD any observations of unauthorized discharges. The MRGCD shall exercise best efforts to advise irrigators and the public as to regulations concerning contamination of waters conveyed by the MRGCD, and to advise as to water conditions should instances of contamination become known to the MRGCD.

**4. APPEAL OF MRGCD DECISIONS**

Notwithstanding any other language in this Policy to the contrary, if a dispute over any matter addressed in this Policy cannot be resolved administratively with the assistance of the Division Manager, the MRGCD's Engineering Department, or by a decision of the Chief Engineer, then the affected party may appeal to the Board. The affected party has the burden of providing specific evidence contradicting the position of staff regarding the matter. Otherwise, the Board must give deference to the factual determinations of its staff. The Board shall make a decision on the appeal no later than fifteen (15) days from the date of the presentation before the Board.

***FOR MORE INFORMATION, PLEASE CONTACT YOUR RESPECTIVE DIVISION OFFICE:***

**GENERAL OFFICE**

1931 Second Street S.W.  
Albuquerque, NM 87102 Phone:  
(505) 247-0234

**ALBUQUERQUE DIVISION OFFICE**

1930 Second Street S.W.  
Albuquerque, NM 87102 Phone:  
(505) 247-0234

**BELEN DIVISION OFFICE**

25 General Edward Baca Belen,  
NM 87002 Phone: (505) 864-  
7466

**COCHITI DIVISION OFFICE**

31 Carro de Caballos Pena  
Blanca, NM 87041 Phone: (505)  
465-2298

**SOCORRO DIVISION OFFICE**

2401 State Road One Socorro,  
NM 87801 Phone: (505) 835-  
1454

# 1 Revised Rule Number 23

MIDDLE RIO GRANDE CONSERVANCY DISTRICT  
POST OFFICE BOX 581, 1931 SECOND STREET S.W.  
ALBUQUERQUE, NEW MEXICO 87103-0581

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## REVISED RULE NO. 23 WATER BANK RULES

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### 23-1.00 PREAMBLE

The Board of Directors of the Middle Rio Grande Conservancy District, having adopted a Water Distribution Policy on June 25, 2012 and having previously resolved to form a Water Bank to promote the beneficial use of water for agriculture, "protect water rights of the landowners of the district" (NMSA 1978, § 73-14-47(B)) and the water supplies of the Middle Rio Grande Conservancy District, ensure adequate carriage water to irrigators and continue to support and promote aquifer recharge within the Boundaries of the Conservancy District, adopts the following Revised Rules to govern the operation of the Water Bank. The authority to enact these rules is conferred under the Conservancy District's statutory authority under NMSA 1978, §§ 73-14-1 through 73-18-43. They will be in effect twenty (20) days after they are adopted by the Conservancy District's Board of Directors. These Revised Rules will be adopted by the Conservancy District's Board of Directors pursuant to NMSA 1978, § 73-14-51 (1951), only after publication in two issues, one week apart, of a legal newspaper of general circulation in each county embraced within the Boundaries of the Conservancy District and after the posting of these revised Rules in the courthouse of each county within the Conservancy District. Public comment will be received on these rules after publication and before adoption. Once adopted, these Revised Rules will repeal and replace the preexisting Rule No. 23 previously adopted by the Conservancy District.

### 23-2.00 STATEMENT OF PURPOSE

#### A) Water Bank

- 1) It is the purpose of the Water Bank to support beneficial use and distribution of water for agriculture and related purposes within the Boundaries of the Conservancy District, to promote the welfare of the Conservancy District and of all the inhabitants and constituents thereof, pursuant to NMSA 1978, §§ 73-14-1 through 73-18-43. This welfare comprises the encouragement of agriculture and is conducive to the public welfare and the conservation of water within the state, including groundwater recharge, maintaining delivery of water to rights holders, and promoting food security, while secondarily providing incidental recreational uses and environmental benefits.

### 23-3.00 DEFINITIONS

For the purposes of the Water Bank Rules, the following definitions shall apply.

- A) BOARD OF DIRECTORS. The members of the Conservancy District Board elected under the provisions of NMSA 1978, §73-14-21 (1975).
- B) BOUNDARIES OF THE CONSERVANCY DISTRICT. The lands comprising the outer extent of the Conservancy District described in the order of the court establishing the Middle Rio Grande Conservancy District and any other lands lawfully designated as the boundaries.

- C) CONSERVANCY DISTRICT. The Middle Rio Grande Conservancy District, meaning the political subdivision created by the New Mexico Legislature with authority to manage water within its boundaries in accordance with the policies of its Board of Directors, acting through its designated agents and employees.
- D) CONSERVANCY WATER RIGHTS. All water rights owned by the Conservancy District acquired as permitted by law, including the Conservancy Act, NMSA 1978, §§ 73-14-1 through 73-18-43 and water rights acquired pursuant to contract, but not including water rights privately owned within the District.
- E) PERSON. A person, firm, partnership, cooperative, association, corporation, political subdivision, or governmental agency.
- F) PRE-1907 WATER RIGHTS. Water rights that were perfected by beneficial use prior to 1907 and that are exercised within the Boundaries of the Conservancy District.
- G) SAN JUAN CHAMA CONTRACT WATER. Water rights held by the Conservancy District pursuant to a contract between the Conservancy District and the United States Department of the Interior, Bureau of Reclamation.
- H) STATE ENGINEER. The New Mexico Office of the State Engineer.
- I) WATER BANK. The depository in which water rights are deposited and made available for lease to Persons wishing to apply Conservancy Water Rights, Pre-1907 Water Rights and/or San Juan Chama Contract Water to beneficial use within the Boundaries of the Conservancy District and for delivery within Conservancy District infrastructure.
- J) WATER BANK RECORD. The record containing all Water Bank deposits, lease withdrawals, and other Water Bank transactions.
- K) DEPOSITED WATER RIGHTS. The amount of Conservancy Water Rights, perfected Pre-1907 Water Rights and/or San Juan Chama Contract Water in the Water Bank that is available for lease at any given time. Water rights are perfected by approval of the New Mexico State Engineer or an adjudication court.
- L) WATER DEPOSIT. The transaction by which a person makes a water right available for lease at a given time by entering into an agreement with the Water Bank.
- M) WATER LEASE WITHDRAWAL. The transaction by which a water right becomes the subject of a lease agreement between a person and the Water Bank and is made unavailable for lease at a given time.

**23-4.00 WATER BANK OPERATIONS**

- A) It is the intent of the Water Bank to not increase net depletions within the District boundaries.
- B) Determination of Availability of Conservancy Water Rights under NMSA 1978, § 73-14-47(F) (1927).

Upon receipt of a Water Bank water lease application on a form approved by the Board of Directors, the Conservancy District will make a determination of the availability of Conservancy Water Rights and/or Pre-1907 Water Rights for lease.

To determine potential water availability, the Conservancy District will compare beneficial use of Conservancy Water Rights under historic conditions to current

beneficial use on specific acreage within the Boundaries of the Conservancy District, as well as other factors that could make water available for use by the Water Bank. If the Conservancy District finds a specific tract or tracts on which Conservancy Water Rights were placed to beneficial use under historic conditions, but that are no longer being placed to beneficial use, the water is available for leasing. Such tract is called the "Move From Tract". The tract to which the water is to be applied under the water lease is called the "Move To Tract". In evaluating the "Move From Tract" for the purpose of determining the availability of Pre-1907 Water Rights, the Conservancy District will certify that the State Engineer's records as of the date of the lease indicate that no water rights transfer of Pre-1907 Water Rights has previously removed water rights from that land. A water lease can only be issued if there are sufficient Conservancy Water Rights and/or Pre-1907 Water Rights available for leasing in sufficient quantities to meet the amounts requested in the Water Bank water lease application.

Upon approval of a Water Bank water lease application and execution of a Water Bank lease on a form approved by the Board of Directors, the Conservancy District will cause a record to be made within the Water Bank Record reflecting that Conservancy Water Rights and/or Pre-1907 Water Rights placed to beneficial use within a specific acreage within the Boundaries of the Conservancy District are currently under lease and are unavailable for further leasing during the term of the current lease. "Move From Tracts" shall not receive water from works of the Conservancy District. After termination of the lease, the Conservancy District may enter into a new lease for the use of said water rights on a different "Move To Tract".

The Conservancy District may also accept water from available San Juan Chama Contract Water Rights into the Water Bank for lease. In no case shall the existence of the Water Bank foreclose any current other user of water within the Conservancy District from exercising a right to continue using water as provided by law. Nor shall any actions of the Water Bank be considered an adjudication of the water rights of any Person or in any way affect vested rights within the Conservancy District.

C) Recording Transactions in the Water Bank Record.

The Conservancy District is responsible for assuring that all Water Bank transactions are recorded in the Water Bank Record. Transactions include water deposits and water lease withdrawals.

D) Lease of Pre-1907 Water Rights in the Water Bank.

Any person owning a Water Right appurtenant to lands within the Boundaries of the Conservancy District wherein the State Engineer has determined the tract or any portion of that tract has a pre-1907 priority date, or wherein a court having jurisdiction has made a comparable determination, such person may make a water deposit of this water right into the Water Bank for the purpose of obtaining revenue and so that others may place the Pre-1907 Water Right to beneficial use for a specific term. Each water deposit shall be recorded in the Water Bank Record with a description of the number of acre-feet per year and the appurtenant land.

Any person wishing to lease a Pre-1907 Water Right from the Water Bank shall enter into a Water Bank lease agreement on a form approved by the Board of Directors. The lease of Pre-1907 Water Rights shall not be subject to curtailment in times of shortage under this rule.

E) Lease Applications.

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Water Bank leases may be issued only for agricultural purposes and uses supporting such purposes. Any person wishing to lease Deposited Water from the Water Bank must submit a Water Bank water lease application to the Conservancy District. The lease application shall be submitted on a standardized form provided by the Conservancy District, which may be amended from time to time at the discretion of the Board of Directors. The lease application form shall require at least the following: the amount of water requested, the place water will be diverted using Conservancy District Infrastructure, the place water will be used, and a statement that the intended purpose of use is for agriculture and/or related purposes as determined by the Conservancy District.

F) Lease Agreement Required, Term of Lease, Termination of Lease.

If the Conservancy District accepts a Water Bank water lease application, the lessee shall be required to enter into a written water lease agreement with the Conservancy District. Lease periods may be up to a maximum of five years to be renewed annually. Upon expiration of a lease period, the Conservancy District may at its discretion renew the lease, provided that it has determined that sufficient water is available for lease.

The Conservancy District, at its discretion, may terminate water leases if the lessee is out of compliance with New Mexico Law or any Rules and Regulations of the Conservancy District. Prior to termination, the Conservancy District shall provide notice of the reason for termination. Notice shall be sent by first class mail to the address specified on the Water Bank water lease application. If the lessee does not come into compliance with New Mexico law or Conservancy District Rules and Regulations or otherwise remedy the reason provided in the notice of intent to terminate the lease within thirty days of mailing the notice, the Conservancy District shall terminate the lease.

G) Priority of Lease and Curtailment.

All Water Bank water leases for Conservancy Water Rights and San Juan Chama Contract Water shall have the same priority date. Each lease agreement shall specify that all leased Conservancy Water Rights or leased San Juan Chama Contract Water shall have a priority date junior to all other uses of Conservancy Water Rights and to all other water delivered via the MRGCD infrastructure, including privately held water rights. EACH LEASE AGREEMENT SHALL SPECIFY THAT WATER USE UNDER THE LEASE MAY BE CURTAILED IN TIMES OF SHORTAGE, PURSUANT TO THE CONSERVANCY DISTRICT'S AUTHORITY TO DISTRIBUTE AND ALLOCATE AVAILABLE WATER UNDER NMSA 1978, §§ 73-14-49 TO - 53 (1951). Water use under all Water Bank water leases, without exception, shall be automatically curtailed when natural flows in the river fall below the amount necessary to satisfy all irrigators and supplemental water reservoirs falls below a specified amount and when supplemental water designated for use in a particular year is insufficient, as determined by Conservancy District staff in accordance with the attached appendix of stream flow and storage volume. If these conditions occur, notice shall be provided by each Ditch Rider to water bank leaseholders that curtailment conditions are in effect. Once a curtailment order has been entered, the Ditch Rider having jurisdiction shall cease providing irrigation water to the Water Bank users until such time as the curtailment order is rescinded. Such curtailment shall apply equally to all leases, with the exception of local or transient conditions as noted in the appendix, which may allow deliveries to leases in certain areas if MRGCD staff determines that sufficient water is available. The Board of Directors may from time to time, after considering recommendations from Conservancy District staff, amend the attached appendix as necessary. Changes to the appendix shall be made to the greatest degree practicable at the same time as rates for the Water Bank are set.

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If a lease is curtailed, no refund or pro-rata reduction of lease amounts or fees shall be provided.

Any Water Bank lessee who illegally irrigates after a curtailment order has been entered shall be subject to the following penalties:

- (1) The first violation of a curtailment order will require the Water Bank lessee to pay double the normal annual administrative fee and applicable lease fee for the first year of any subsequent Water Bank lease.
- (2) A subsequent violation of a curtailment order will result in the termination of the Water Bank lease. Future Water Bank leases applied for by the violator will require approval by the Board of Directors.

H) Conservancy Water Rights, Lease Periods, Prices, Administrative Fees.

Applications for leases may be filed at any time during the irrigation season, provided that the annual lease fee shall be the same regardless of when application is made. The Conservancy District may lease available Conservancy Water Rights and/or San Juan Chama Contract Water at a rate determined by the Board of Directors. In setting lease rates, the Board of Directors shall consider the market value of water at that time, the capacity of agricultural water users to pay, and other related factors. Once determined, the rate shall be the same during that annual period for all lessees. The Board of Directors may charge the borrower a reasonable administrative fee to cover the administrative costs involved in administering the lease in addition to the lease fee. If the Conservancy District renews an existing lease, the Conservancy District shall have the authority to change any lease terms, including adjusting the lease rate. The price for water bank leases shall be determined on an annual basis by the Board at a special meeting called for that purpose no later than January 15 of each calendar year. In situations other than a curtailment of water, administrative fees may be refundable at the sole discretion of the Conservancy District.

I) Pre-1907 Water Rights, Lease Rates, Administrative Fees.

Leases of Pre-1907 Water Rights shall be at the rate determined by the owner of the Pre-1907 Water Right and the lessee. The Conservancy District shall act as the collector of all lease fees, and funds received from the lease of Pre-1907 Water Rights shall be delivered to the owner by the Conservancy District. The Board of Directors may establish an administrative fee to be paid by the owner to cover the reasonable costs of placing the Pre-1907 Water Right in the Water Bank and administering the lease.

J) Bank Fund.

All proceeds realized from Water Bank leases of Conservancy Water Rights and/or San Juan Chama Contract Water after the date of the Resolution adopting this Revised Rule No. 23 shall be deposited in the Conservancy District's general fund.

K) Financial Audit.

The Water Bank will be subject to an annual financial audit conducted by a qualified outside entity.

L) Violation of Water Bank Irrigation Rules/Policies.

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Any irrigator found to be in violation of Water Bank rules/policies will be subject to loss or suspension of irrigation water delivery, and may be liable for damages resulting from those violations. Actions taken by the Conservancy District may include the following:

- (1) Termination of the Water Bank lease;
- (2) Securing turnouts to prevent operation using Conservancy District locking devices, welding, burial, or removal.
- (3) Referral to local law enforcement authorities for prosecution, where appropriate.
- (4) Landowners, irrigators, or other persons who, by opening, closing, modifying, or otherwise interfering with the regulation of Conservancy District facilities and structures cause any fluctuation on water flow or elevation that results in breaks or damage of any kind, will be responsible for the expense and damage caused and may be liable to others who are adversely affected.
- (5) All other remedies provided by law.

M) Appeal of Conservancy District Decisions

Notwithstanding any other language in these Rules to the contrary, if a dispute over any matter addressed in these Rules cannot be resolved administratively with the assistance of the Division Manager, the Conservancy District's Hydrologist or Engineering Department, or by a decision of the Chief Engineer, then the affected party may appeal to the Board. The affected party has the burden of providing specific evidence contradicting the position of staff regarding the matter. Otherwise, the Board must give deference to the factual determinations of its staff. The Board shall make a decision on the appeal no later than the next regularly scheduled board meeting after the date of the presentation before the Board.

## APPENDIX TO WATER BANK RULE 23

### Water Bank Curtailment: Stream Flow and Storage Conditions

As provided in Water Bank Rule 23, attached to this table, delivery to Middle Rio Grande Conservancy District (MRGCD) Water Bank leases shall be curtailed under certain conditions. Curtailment shall occur based on the rates of natural flows in the river, as well as the amount of water in storage for irrigation use. Based on an analysis of these two variables, the general rule being followed is that curtailment should be expected when the natural flow of the Rio Grande drops below a level at which the MRGCD can no longer deliver water to all users within its system and supplemental storage is insufficient to complete the irrigation season. Under these conditions of limited water supply, water will be directed preferentially to persons who have not sold their pre-1907 water rights or who are relying on water rights of the MRGCD for irrigation. It should be noted, that this table is generic in scope and is designed to provide general information regarding circumstances likely to result in curtailment. However, natural flow sufficient to meet all users' needs varies, not only from year to year, but also throughout the course of the irrigation season.

### Stream Flow Conditions Resulting in Curtailment

The following schedule defines the natural flow requirement below which curtailment of water delivery to water bank leases could be expected:

Start Date	End Date	CFS
1-Mar	31-Mar	390
1-Apr	15-Apr	550
15-Apr	30-Apr	780
1-May	15-May	900
16-May	31-May	950
1-Jun	15-Jun	950
16-Jun	30-Jun	1030
1-Jul	15-Jul	1050
16-Jul	31-Jul	1000
1-Aug	15-Aug	920
16-Aug	31-Aug	850
1-Sep	15-Sep	660
16-Sep	30-Sep	600
1-Oct	15-Oct	410
16-Oct	31-Oct	310

This schedule defines the required natural flow in terms of cubic feet per second (cfs). The natural flow is calculated as the daily average of the combined total of flow as reported by USGS gauges for the following sites, less 100cfs (excluding March) to allow for consumptive use by the Rio Chama Acequia Association and main-stem users above Otowi, NM.

	Rio Grande at Embudo, NM	(USGS # 08279500)
	Rio Chama Near La Puente, NM	(USGS # 08284100)
	Rio Ojo Caliente at La Madera, NM	(USGS # 08289000)
+	Rio Jemez below Jemez Canyon Dam, NM	(USGS # 08328750)
	<u>Average Middle Rio Grande Inflow</u>	
-		100 cfs
=	<u>Natural flow</u>	

USGS Gauge information can be accessed online at:  
<http://www.usbr.gov/pmts/rivers/awards/Nm2/rg/riog/schematic/SCHEMATICmrgsjcopr.html>

#### **Storage Conditions Affecting Curtailment**

It should also be understood that the MRGCD may allow continued delivery of water to Water Bank leases at times when the natural flow is less than specified above. This can occur if MRGCD has sufficient supplemental water in storage to augment the natural flow of the Rio Grande for all users, with an expectation that sufficient water is present in storage to provide for all irrigators through the remainder of the current irrigation season. Reasonable expectations of sufficient supplemental water in storage to permit continued supply to water bank leases are described in the following schedule\* of supplemental water in storage at El Vado/Abiquiu/Heron reservoirs as of the listed dates, and designated for use in the then current irrigation season :

March 1:	91,000 AF**
April 1:	91,000 AF**
May 1:	91,000 AF**
June 1:	91,000 AF
July 1:	89,000 AF
August 1:	54,000 AF
September 1:	20,000 AF
October 1:	1,000 AF

These volumes are shown in Acre Feet (AF) (1 AF=325,850 gallons)

#### **Evaluation of Local or Transient Flow Condition**

Even though the above guidelines provide parameters for stream flow and storage, the Water Bank Rule recognized conditions may occur at certain points within the District which would make it possible to deliver water to MRGCD Water Bank leases; even though the natural flow and supplemental storage schedules indicate otherwise. Under these conditions deliveries to Water Bank leases would be the result of local conditions, often transient, which would provide additional water supply or reduce the demand on water supply for some users. These conditions could include, but not be limited to, precipitation in certain areas of the MRGCD, tributary inflows (ie: AMAFCA diversion channels, or Rio Puerco /Rio Salado), unusually cool temperatures or high humidity, a cessation of deliveries to portions of the MRGCD due to physical constraints (such as a major ditch break), or other causes. In some cases, these could affect the entire MRGCD service area, or in other cases could affect only limited areas. These will be evaluated by MRGCD staff if and/or when they occur, with the intent to maximize the beneficial use of water by irrigators within the MRGCD system, regardless of water right or Water Bank status.

\* Should Article 8 of the Rio Grande Compact (RGC) be in effect, the required storage volumes shown in the schedule will be increased by the amount of New Mexico's accrued RGC debits to the State of Texas.

\*\*Potential storage - In the early part of the season, storage may be noted as potential, so that the specified volume of water may not need to actually be present, but it is anticipated to be result from snowmelt runoff in the spring. The MRGCD must have physical space available to store this water and snowpack must be present to make it likely that the space will be filled before June 1 of the year in question. The USDA Natural Resource Conservation Services monthly New Mexico State Basin Outlook Reports will be used to determine the likelihood of acquiring that storage, based on the 70% "chance of exceedance" value for El Vado Reservoir Inflow, March-July. As provided in Article 7 of the RGC storage will not be allowed if Elephant Butte contains less than 400,000 acre feet of "usable water", unless MRGCD has acquired sufficient RGC storage credits to permit storage.

### 3 MRGCD Emergency Action Plan

The attached plan, drafted in 2017, has phone numbers and names removed but has included the agency and position (if available) of who would need to be coordinated with in an emergency.

# Middle Rio Grande Conservancy District Emergency Action Plan



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# MIDDLE RIO GRANDE CONSERVANCY DISTRICT

## EMERGENCY OPERATIONS PLAN



**PURPOSE:** This plan provides a framework for action in the event of an emergency, such as flooding, fire, drowning, ditch breaks, overflows, and any other unforeseen emergencies.

**MISSION** Operate MRGCD facilities to prevent loss of life and minimize property damage. Restore damaged facilities to operation as soon as possible. Assist City, County, State Highway Dept, AMAFCA, Pueblos and Private Organizations with available resources.

### I. OPERATIONS PLAN

#### a. Chief Engineer or his designee:

- Direct all MRGCD activities.
- Coordinate with City, County, State, AMAFCA and other organizations.
- Arrange State and Federal assistance when required.
- Inspect all critical facilities.
- Instruct Maintenance department as to priorities and provide technical guidance.
- Recommend emergency projects for contracting out if required.
- Prepare detail reports with photographs, videos, sketches, etc.

#### b. Field Operation: Division Managers, ISO Supervisors and Maintenance Foreman:

- Deploy men and equipment to ensure that MRGCD facilities are repaired, protected and operating as designed.
- Maintain communication (radio or telephone) with the Engineering Department and Division Office when possible, and communicate with appropriate authorities to facilitate and minimize damage to person(s) and or property.

#### c. Maintenance Crew:

- Report to field office.
- Follow instructions of Maintenance Foreman or Division Manager and authorized personnel.
- Prepare report of the situation attach photos when possible and submit to Field Engineer or Division Manager.

### II. RESPONSE TO PUBLIC:

- ✓ **Advise public** of potential health and safety hazards, i.e., but not limited to water contamination, flooding, etc.

- ✓ **Notify local relief** assistance agencies as requested.
- ✓ **Notify the District's Insurance Carrier** of the situation and provide some detail to extent of damages and possible claims that may be submitted.
- ✓ **Advise affected person(s)** to contact their personal Insurance Company and or Agent.

### **III. INCIDENT REPORTS & INVESTIGATION:**

- ✓ Following an emergency response, a formal incident report must be prepared within 72 hours of the incident.
- ✓ The investigation shall determine the root cause of the event, and identify corrective actions that shall be implemented to prevent a reoccurrence, including assignment of resources and completion dates if applicable.

### **IV. COMMUNICATION AND CONTROL:**

#### **MRGCD OFFICES:**

##### **GENERAL OFFICE**

##### **Physical Address**

1931 Second Street SW

Albuquerque, NM 87102

(505) 247-0234

##### **ALBUQUERQUE DIVISION OFFICE**

##### **Physical Address**

1930 Second Street SW

Albuquerque, NM 87102

(505) 247-0234

**COCHITI DIVISION OFFICE**

**Physical Address**

31 Carro De Caballos

Pena Blanca, NM 871041

(505) 465-2298

**BELEN DIVISION OFFICE**

**Physical Address**

25 General Edward Baca Road

Belen, NM 87002

(505) 864-7466

**SOCORRO DIVISION OFFICE**

**Physical Address**

2401 State Road One

Socorro, NM 87801

(575) 835-1454

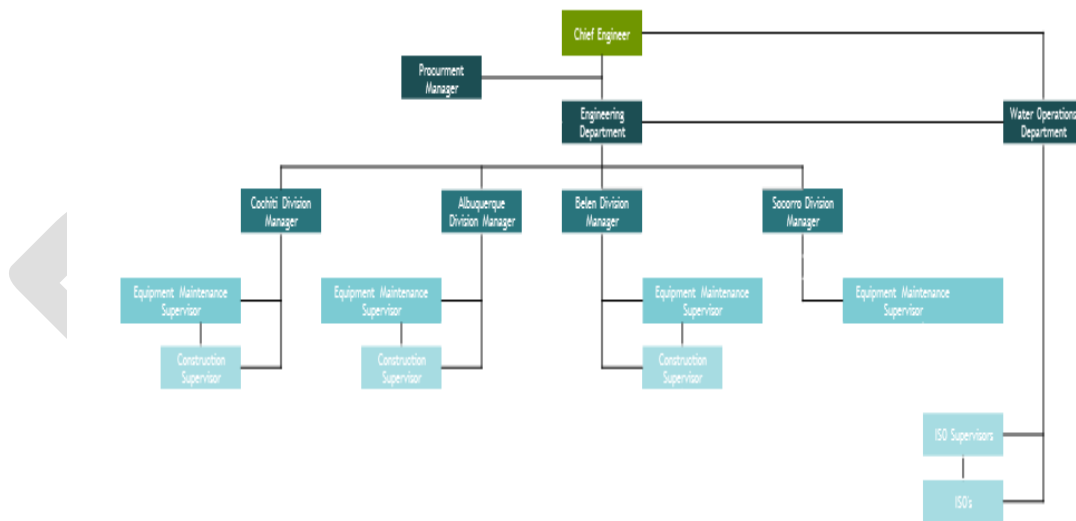
**RADIO FREQUENCY:**

Transmit

Receive

**FIELD AND MOBILE UNITS MAINTAIN RADIO CONTACT WITH DISTRICT OFFICES.**

**NORMAL CHAIN OF COMMAND APPLIES.**



**RED CROSS**

**HUMAN SERVICES DEPT.**

**SOCIAL SERVICES DIVISION:**

Albuquerque

Valencia

Socorro

**UNITED WAY**

**SOUTHERN PUEBLOS:**

Pueblo of Cochiti

Pueblo of Santo Domingo

Pueblo of San Felipe

Pueblo of Santa Ana

Pueblo of Sandia

Pueblo of Isleta

**BUREAU OF RECLAMATION**

Assistant Area Manager

Water Operations Supv.

**USACE**

(Res. Control Branch)

(Res. Control Branch)

(Emergency Management)

**NM DEPT. OF HOMELAND SECURITY  
& EMERGENCY MANAGEMENT**

Bureau Chief Preparedness Bureau

Recovery Unit Manager

Response and Recovery Bureau

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**EMERGENCY RESPONSE ALL COUNTIES 911**

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**LAW ENFORCEMENT AGENCIES**

- **MRGCD BOSQUE PATROL OFFICERS:**  
Socorro Division officer
  
- **SANDOVAL:**  
Police Department  
  
Sheriff's Dept. (Emergency)  
  
Sheriff's Dept. (Non-Emergency)  
  
Fire Department
  
- **BERNALILLO COUNTY:**  
Office of Emergency Management  
  
Bernalillo County Emergency  
    (Evacuation) Dispatch  
  
City of Albuquerque Police  
  
City of Albuquerque Fire Dept.  
  
Sheriff's Department  
  
Fire Department                      Call Specific Fire District
  
- **VALENCIA COUNTY:**  
Belen Police Department  
  
Belen Fire Department

Bosque Farms Police Department  
Bosque Farms Sheriff's Department  
Los Lunas Police Department  
Los Lunas Fire Department  
Emergency Management

- **SOCORRO COUNTY:**  
Police Department  
Sheriff's Department  
Fire Department (Emergency)  
Fire Department (Non-Emergency)  
Fire Department FAX

*EMERGENCY MANAGEMENT*

- **STATE OF NEW MEXICO:**  
Emergency Operations Center  
Daytime  
24 Hour
- **Flood Control Agencies**  
AMAFCA  
Field Engineer  
SSCAFCA  
Village of Bosque Farms
- **Resources**  
Rain For Rent (High Volume Pumps)  
Red Canyon Quarry (Rock Supply in Socorro)

<b>GENERAL OFFICE</b>
Chief Engineer

Water Operations Manager			
Engineer Supervisor			
Chief Procurement Officer			
<b>ENGINEERING DEPARTMENT</b>			
Professional Engineer			
Engineering Technician			
Construction Technician			
<b>EQUIPMENT REPAIR AND TRANSPORTATION DIVISION</b>			
ER&T Division Manager			
Transport Driver			
Oiler			
<b>ALBUQUERQUE DIVISION</b>			
Division Manager			
ISO Supervisor			
Equipment /Maintenance Supv.			
Equipment/ Maintenance Supv.			
Construction Supervisor			
Construction Supervisor			
ISO/Angostura Dam Keeper			
Division Manager			
ISO Supervisor			
Assistant ISO Supervisor			
Construction Maint. Supervisor			
Equipment Operations & Maintenance Supervisor			

ISO/Dam Keeper–Eastside B14			
<b>COCHITI DIVISION</b>			
Division Manager			
ISO Supervisor			
<b>SOCORRO DIVISION</b>			
Division Manager			
Equipment / Maintenance Supervisor			
ISO Supervisor			

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Appendix 10:  
Explanation of  
Work Plan

April 2019

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## **Introduction**

There are discrepancies between the MRGCD DCP and items described in the MRGCD work plan submitted to Reclamation in February of 2017. The work plan submitted reflected items that the MRGCD included in the Drought Contingency Plan proposal. The proposed items did not satisfy the requirements of Reclamation's drought planning program, and were not conducted for or included in the DCP. The following sections outline the discrepancies in from the work plan to the DCP, and an explanation of why these discrepancies exist.

### **Study of Sedimentation Impacts**

In the detailed work plan the MRGCD committed to include "impacts of sedimentation due to catastrophic wildfire" in the vulnerability assessment. There are vulnerabilities that face the MRGCD in connection with sedimentation impacts, but these were not included in the vulnerability assessment for drought. After the work plan was submitted there was a determination that the funds for the DCP would be better spent on developing items that would satisfy the requirements of Reclamation's drought planning program.

### **Plan for On-Farm Efficiencies**

In the work plan, the MRGCD committed to developing "a plan that will address on-farm efficiencies." The intent of this statement was to include as a mitigation recommendation that the MRGCD develop a plan to address on-farm efficiencies, not to develop an on-farm efficiency plan in the DCP.

### **Curtailment Matrix**

The MRGCD committed to develop a curtailment matrix for water bank users and a delivery schedule for all other users. As the Middle Rio Grande is not an adjudicated basin a delivery schedule for non-water bank users cannot be developed. A curtailment schedule of water bank users is already clearly laid out in the Water Rule Number 23 which is attached in Appendix 9.

### **Roles Matrix**

The MRGCD committed to develop a matrix that describes roles of implementation of actions in the DCP. This was not included in the DCP, as the roles and responsibilities in the DCP all belong to the MRGCD, as this is an MRGCD plan.

### **Drought Task Force will be Integral in the DCP**

The Drought Task Force, which was renamed the Drought Evaluation Team (DET) in the DCP, was utilized to receive input from stakeholders on several DCP items. A list of stakeholders who should be members on the DCP is listed in Appendix 8. Documents from the DET meetings held during the plan development can also be located in Appendix 8. How the DET will be utilized by the MRGCD in the future can be found in Section 7 of the DCP. Due to time constraints of plan development, not all documents were made available for the DET to review, but the MRGCD has clearly outlined how the DET will be able to have input into the efficacy of the DET and how it can be improved.

### **Decisions made in Conjunction with Reclamation**

This commitment is not a requirement of Reclamation's drought planning program and is not feasible as the MRGCD is an independent agency that can make decisions without consulting Reclamation. The MRGCD communicates in regards to many management decisions with Reclamation, as well as many other stakeholders in the study area. The MRGCD will continue to communicate certain decisions with the Middle Rio Grande stakeholders as appropriate.

### **DET Will Have a Webpage for Coordination**

The MRGCD did not develop a webpage for DET coordination. This was deemed unnecessary. The MRGCD DCP will be posted on the MRGCD website, once approved by Reclamation, along with the drought tool.

### **Interim Written Reports Integrated into the Final Plan**

Interim written reports were submitted to Reclamation. These reports were brief and do not provide any further insight into how the plan was developed or will be implemented. For this reason the reports were not included in the DCP.

### **In-Kind Contributions from DET Members/Budget Reconciliation**

Time spent by DET members in DET meetings was tracked by the MRGCD. These hours have been included as in-kind contributions, at the rate that the MRGCD and Reclamation agreed to. The hours estimated in the original budget did not equal what was contributed by DET members. This is due to the fact that the MRGCD utilized contractors to do much of the work initially intended to be conducted by DET members.

The hours that DET members contributed are in Table 1.

Additional budget discrepancies can be attributed to not having contracted a facilitator for the DET meetings due to fewer meetings being held than planned. A communications consultant was also not utilized by the MRGCD in the development of the DCP.

Entity	11/4/201 6 mtg	1/25/201 7Mtg	2/28/201 7 Mtg.
Coronado SWCD	3	5	4
South Valley AcequiaAssociati	3	5	
MRG Water Assembly	3	5	4
Business Water Task Force	3		
Valencia Soil and Water Conservation District	3		5
Isleta Pueblo	3		
Nm Acequias and Water Resources	3		
Martin Haynes	3		
Pueblo of Santa An	3	5	5
Pueblo of Sandia	3	5	
The Nature Conservancy	3	5	5
Valencia County Farm and Livestock Bureau	3	5	
Water Authority	3		
Socorro SWCD	3		
Union of Concerned Scientists	3		
NM ISC	3	5	5
MRGCD	3	5	5
RG Farmer Coalitio	3	5	
SSCAFCA		5	
Rio Rancho		5	
Ciudad SWCD		5	4
AMAFCA			5
Valencia County			5
NM Bureau of Geology			5
USACE	Attended	Attended	Attended
USBOR	Attended	Attended	Attended
USGS	Attended	Attended	Attended
Total Hours	54	65	52
Donated Time Value/ Mtg	2956.5	3558.75	2847
Running Total Donated Time	2956.5	6515.25	9362.25

Table 1: Donated time by DET members.