Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Project Title:

Current and 2050 Planning Scenario Agricultural Diversion Demand

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Section 1: Introduction

This technical memorandum summarizes the analysis approach and results for the Technical Update Task 1: Agricultural Diversion Demand effort, including the current and 2050 agricultural diversion demand associated with each of the Technical Update Planning Scenarios. The current agricultural diversion demand used in the Technical Update is defined as the amount of water that needs to be diverted or pumped to meet the full crop irrigation water requirements associated with the current levels of irrigated acreage assuming historical climate conditions continued into the future. The current agricultural diversion demand serves as the foundational "baseline" for the Technical Update analysis, and can be used to estimate the change from current to future conditions. Irrigated acreage, climatic conditions, and efficiencies in the current agricultural diversion demand are then adjusted by various factors to estimate the agricultural diversion demand associated with the five plausible 2050 Planning Scenarios (hydrologic and other drivers associated with the scenarios are shown in Figure 1) that were previously developed presented in Colorado's Water Plan.

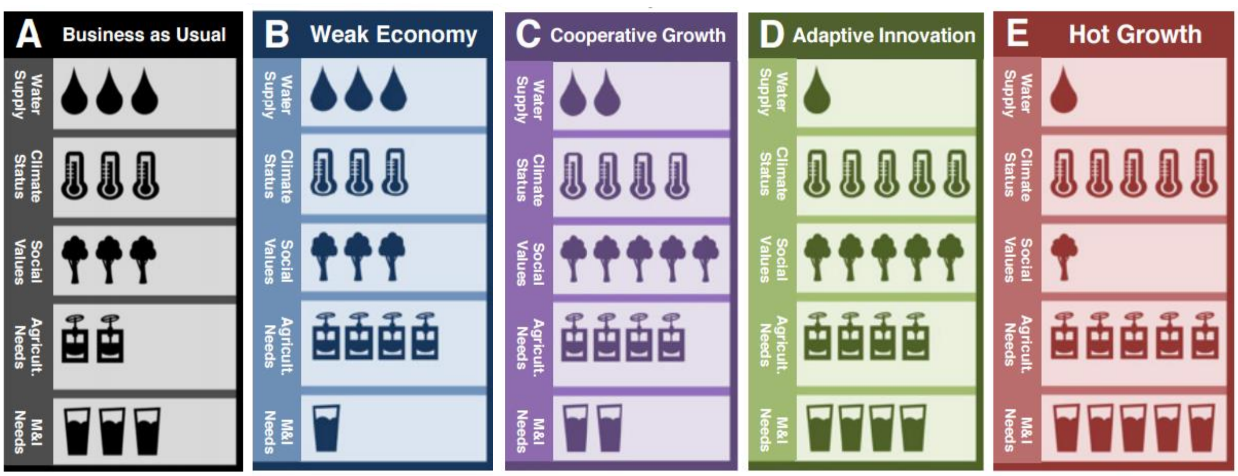

Figure 1: 2050 Planning Scenario Descriptions

This technical memorandum presents the approaches used to develop the current and 2050 agricultural diversion demand first, followed by basin-wide and statewide summaries of results. Basin-wide results were aggregated based on the river basin boundaries provided in Figure 2. Note that once developed, the agricultural diversion demands (along with other non-agricultural demands) will be incorporated into the Colorado Decision Support System (CDSS) water supply models, which will be used to determine how much water is available to meet the demands. Shortages to the agricultural diversion demands in the water supply modeling efforts will define the "agricultural gap". The *Technical Update Current and 2050 Planning Scenario Water Supply and Gap* documentation, available on the Colorado Water Plan website, can be referenced for more information on how the demands were implemented in the water supply models and how the "agricultural gap" was estimated.

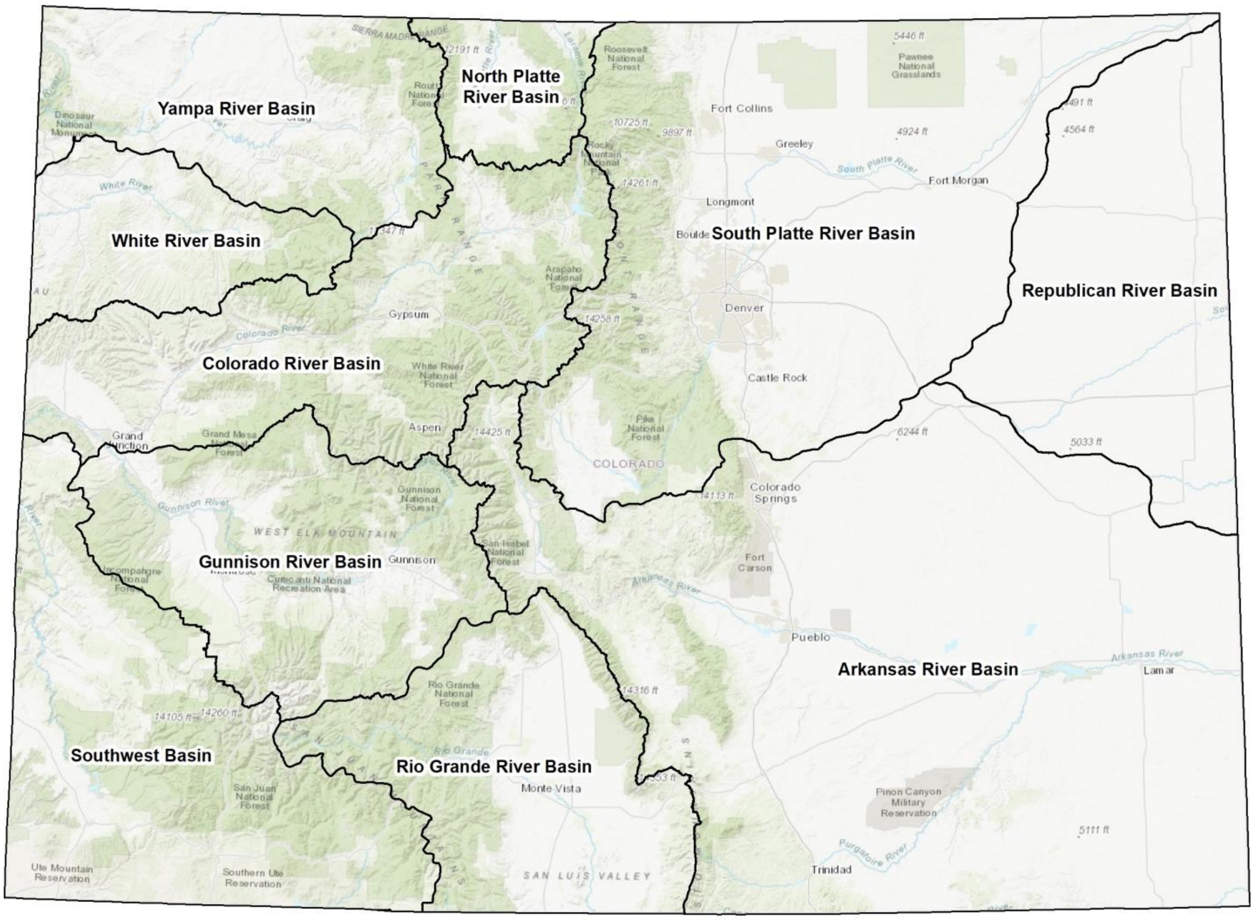

Figure 2: River Basin Boundaries

Section 2: Definitions/Terminology

This section summarizes the definitions and terminology used to discuss agricultural components in the Technical Update effort. As discussed in more detail below, there are differences in definitions and terminology between the SWSI 2010 and the Technical Update, particularly regarding the definition of "agricultural demand". The summaries below the definitions note legacy definitions from SWSI 2010 as applicable.

- Agricultural Diversion Demand: The amount of water that needs to be diverted or pumped to meet the full crop irrigation water requirement.
    - *SWSI 2010 defined agricultural demand as the amount of water currently consumed by the crops; not the amount of water that needs to be diverted to meet the current levels of agricultural production.*
- Irrigation Water Requirement (IWR): The amount of water that must be applied to the crop to meet the full crop consumptive use, also referred to as the crop demand. IWR provides an estimate of the maximum amount of applied water the crops could consume if it was physically and legally available.

- **Applied Water:** Water that is diverted from the river, pumped from ground water, or released from reservoirs for irrigation purposes; also referred to as irrigation supplies. Applied water does not include or reflect precipitation that is consumed by crops.
- **Water Supply Limited (WSL) Consumptive Use:** The amount of applied water consumed by the crop; also referred to as actual crop consumptive use. WSL is the minimum between the IWR and the amount of applied water that reaches the crops.
- **Irrigation System Efficiency:** The percent of diverted or pumped water consumed by the crops or stored in soil moisture; calculated by dividing the sum of WSL and water stored in soil moisture by the total applied water from all sources. System efficiency reflects the losses to applied water due to canal seepage and on-farm application losses.
- **Crop Shortages:** The difference between the amount of water the crops need to meet full crop consumptive use (IWR) and the amount of applied water the crops consumed (WSL).
- **Agricultural Gap:** The amount of additional water that would need to be diverted or pumped to meet the remaining crop shortages.
    - SWSI 2010 defined the agricultural gap as the crop shortages, although recognized that diversions and pumping would need to be much larger in order to meet the crop shortage.

Section 3: SWSI 2010 Methodologies

Agricultural "demands" in SWSI 2010 primarily reflected the consumptive use for the irrigation of crops[1]. Agricultural demands associated with irrigated crops were further defined as the Irrigation Water Requirement (IWR), Water Supply Limited Consumptive Use (WSL), and the difference between these two components was termed Shortages. As discussed throughout this documentation, the agricultural diversion demand developed for the Technical Update differ from the SWSI 2010 demands because the Technical Update estimates the amount of water that needs to be pumped or diverted at the headgate.

Note that the agricultural demands in SWSI 2010 reflected water consumptively used by the crops, not the greater demand of surface diversions and/or ground water pumping necessary to meet the crop consumptive use. It was recognized, however not quantified, that diversions and pumping are much larger in order to meet crop shortage.

3.1 SWSI 2010 IRRIGATED ACREAGE METHODOLOGY

The basis of the agricultural consumptive use was the quantification of currently irrigated acreage and an estimate of the irrigated acreage in 2050. Irrigated acreage mapping developed through the CDSS was used to determine current irrigated acreage in the West Slope Basins (Yampa, White, Colorado, Gunnison, and San Juan), the North and South Platte Basins, and the Rio Grande Basin. The CDSS mapping had not been completed in the remaining basins; therefore current irrigated acreage was determined using the following approaches:

[1] Additional smaller components of the agricultural demand included consumptive use associated with livestock production, stockpond evaporation, and losses incidental to delivering irrigation water. These non-irrigation demands were not included in the Technical Update effort; refer to the SWSI 2010 documentation for more information on how these demands were calculated.

- **Republican River Basin**: Groundwater irrigated acreage was obtained from the Republican River Compact Administration (RRCA) accounting spreadsheets for 2007.
- **Arkansas River Basin**: Irrigated acreage for the Lower Arkansas River basin was based on 2008 data obtained from the Irrigation Systems Analysis Model (ISAM), developed by Division 2 as a refinement of the Hydrological Institutional (HI) Model. Irrigated acreage in the Purgatoire River basin was obtained from 2008 mapping developed by Division 2 staff for the Purgatoire River Water Conservancy District (PRWCD). Irrigated acreage outside of these areas was developed by analyzing 2009 thermal imagery (Landsat 5 Thematic Mapper) with a vegetative index and removing non-agricultural and riparian areas.

2050 acreage estimates were developed by applying specific factors to the baseline Current acreage estimates. These factors included:

- Urbanization of existing irrigated lands
- Agricultural to municipal water transfers
- Water management decisions
- Demographic factors
- Biofuels production
- Climate change
- Farm programs
- Subdivision of agricultural lands and lifestyle farms
- Yield and productivity
- Open space and conservation easements
- Economics of agriculture

The first three factors were quantified based on future growth estimates, municipal water demand gaps that will be met by 2050, and interviews with water management agencies across the state. The urbanization of existing irrigated lands adjusted the current acreage by using 2050 population projections and estimation of future urban area size. The municipal water demand (M&I) gap was used in the analysis of irrigated acreage changes associated with agricultural to municipal water transfers. For each of the major river basins, the amount of the M&I gap was summarized on a low, medium, and high basis. For the purposes of estimating 2050 acreage, it was assumed that 70 percent of M&I gap would be met from agricultural to municipal transfers. Irrigated acreage needed for agricultural to municipal transfers to address M&I gaps was calculated by dividing the M&I gap by the historical consumptive use that may be transferred, increased by a 25 percent firm yield factor.

The remaining factors were qualitatively addressed based on information provided by the Colorado Water Conservation Board (CWCB) and the Colorado Department of Agriculture. CWCB interviewed entities within the South Platte, Rio Grande, and Republican River Basins to estimate what changes may occur in irrigated acres due to water management decisions affected by compact compliance or to maintain groundwater levels. For other factors (demographic factors, biofuels production, climate change, farm programs, subdivision of agricultural lands and lifestyle farms, yield and productivity, open space and conservation easements, economics of agriculture), CWCB identified trends that are expected to occur within each area over the next 40 years and then developed a qualitative assessment on whether each factor would cause a negative or positive impact on irrigated agriculture by 2050. Note that although climate change was listed as a factor, it was not quantitatively assessed or applied during the approach to developing 2050 acreage estimates.

Table 1 summarizes the irrigated acreage used for the Current scenario, the reduction in acreage associated with the factors discussed above, and the irrigated acreage used for the 2050 scenario in SWSI 2010.

Table 1: SWSI 2010 Current and 2050 Irrigated Acreage

Basin	Current Irrigated Acres	Decrease in Irrigated Acres Due to Urbanization		Decreases in Irrigated Acres Due to Other Reasons	Decreases in Irrigated Acres from Planned Agricultural to Municipal Transfers	Decreases in Irrigated Acres from Agricultural to Municipal Transfers to Address M&I Gap		Estimated 2050 Irrigated Acres	
		Low	High			Low	High	Low	High
Arkansas	428,000	2,000	3,000	–	7,000	26,000	63,000	355,000	393,000
Colorado	268,000	40,000	58,000	–	200	11,000	19,000	190,800	216,800
Gunnison	272,000	20,000	26,000	–	–	1,000	2,000	244,000	251,000
North Platte	117,000	–	–	–	–	–	–	117,000	117,000
Republican	550,000	300	600	109,000	–	–	–	440,400	440,700
Rio Grande	622,000	800	1,000	80,000	–	2,000	3,000	538,000	539,200
South Platte	831,000	47,000	58,000	14,000	19,000	100,000	176,000	564,000	651,000
Southwest	259,000	4,000	6,000	–	–	3,000	7,000	246,000	252,000
Yampa-White	119,000	1,000	2,000	–	–	3,000	64,000	53,000	115,000
Statewide Total	**3,466,000**	**115,100**	**154,600**	**203,000**	**26,200**	**146,000**	**334,000**	**2,748,200**	**2,975,700**

3.2 SWSI 2010 CONSUMPTIVE USE METHODOLOGY

The agricultural consumptive use associated with current irrigated acreage was reported in SWSI 2010 using both average IWR and WSL. As discussed in the Definitions section, WSL was considered to be the current "agricultural demand".

Where CDSS models were available, the results of the historical consumptive use analyses from the most recent 10-year period were averaged to develop the Current estimate of IWR and WSL. The analyses were performed in StateCU, the State's consumptive use model, using irrigated acreage and crop type information from the most recent CDSS acreage assessments and monthly climate data and water supply data available from HydroBase, the State's water resources database. The CDSS models used the Blaney-Criddle method described in the U.S. Soil Conservation Service Technical Report No. 21 (TR-21) for estimating potential consumptive use, and measured water supply data and historical irrigation practice efficiencies to determine WSL consumptive use. Additional details regarding the CDSS analyses are available in each basin's Historical Consumptive Use Report (cdss.state.co.us) and Appendix I of SWSI 2010.

Where CDSS models were not available, namely the Republican River Basin and the Arkansas River Basin, existing information used for accounting and administration in the basin was used to estimate IWR and WSL for the recent period.

- Republican River Basin: Values of "Annual Net IWR", as developed as part of the RRCA model, were averaged for the 1998 to 2007 period. The IWR values were calculated using the Hargreaves evapotranspiration equation calibrated to the Penman-Monteith equation as specified in the interstate settlement agreement in Kansas v. Nebraska and Colorado. Note that a portion of the IWR was assumed to be met by the accumulation of soil moisture over the winter. Current IWR for the basin was estimated by multiplying the RRCA irrigated acreage from 2007 by the Annual Net IWR. Current WSL was estimated as 75 percent of the Current IWR based on an assessment of ground water pumping from approximately 150 wells in the basin. Surface water diversions were being phased out in the basin; therefore no surface water supplies were considered during the development of WSL values.
- Arkansas River Basin: Current IWR and WSL for the Lower Arkansas River basin was obtained from ISAM and averaged over the 1997 to 2006 period. In the Purgatoire River basin, a StateCU scenario was developed specifically for the SWSI 2010 effort and results over the 1999 to 2008 period were averaged to estimate the Current IWR and WSL for the PRWCD area. The StateCU analysis was generally developed using CDSS modeling standards; refer to Appendix I of SWSI

2010 for specific modeling assumptions. Unit IWR for irrigated acreage outside of these areas was determined at representative climate stations over the recent period for the crops in the area, and multiplied by the Current acreage to determine the Current IWR. Current WSL was estimated by reviewing reported shortages, including information from ISAM, in several areas and applying that shortage percentage to the Current IWR. In general, shortage percentages ranged from 33 percent to 52 percent throughout the basin.

Table 2 summarizes the SWSI 2010 Current IWR, WSL, and resulting Shortages by basin. In general, the 2050 agricultural demand was developed by scaling the Current IWR and WSL values. The SWSI 2010 effort took this simplifying approach because:

- IWR is directly proportional to the change in irrigated acreage predicted for 2050
- The study intentionally avoided identifying specific water rights or ditches for change of use and therefore could not analyze the impact of these 2050 predicted changes to IWR or WSL on a structure basis
- The study did not analyze the change in water availability that may be caused by 2050 predicted changes and therefore could not determine changes in WSL due to water availability on a structure basis

Table 3 summarizes the 2050 IWR, WSL, and resulting Shortages by basin.

Table 2: SWSI 2010 Current Agricultural Consumptive Use

Basin	Irrigated Acres	Irrigation Water Requirement (AFY)	Water Supply-Limited Consumptive Use (AFY)	Shortage (AFY)
Arkansas	428,000	995,000	542,000	453,000
Colorado	268,000	584,000	485,000	100,000
Gunnison	272,000	633,000	505,000	128,000
North Platte	117,000	202,000	113,000	89,000
Republican	550,000	802,000	602,000	200,000
Rio Grande	622,000	1,283,000	855,000	428,000
South Platte	831,000	1,496,000	1,117,000	379,000
Southwest	259,000	580,000	382,000	198,000
Yampa-White	119,000	235,000	181,000	54,000
Statewide Total	**3,466,000**	**6,819,000**	**4,791,000**	**2,028,000**

Table 3: SWSI 2010 2050 Agricultural Consumptive Use by Basin

Basin	Irrigated Acres	Irrigation Water Requirement (AFY)	Water Supply-Limited Consumptive Use (AFY)	Shortage (AFY)
Arkansas	373,000	862,000	476,000	386,000
Colorado	204,000	443,000	366,000	77,000
Gunnison	219,000	573,000	457,000	116,000
North Platte	145,000	250,000	140,000	110,000
Republican	441,000	640,000	480,000	160,000
Rio Grande	537,000	1,108,000	739,000	369,000
South Platte	607,000	1,094,000	820,000	274,000
Southwest	249,000	558,000	367,000	191,000
Yampa-White	85,000	209,000	170,000	39,000
Statewide Total	**2,860,000**	**5,737,000**	**4,015,000**	**1,722,000**

3.3 METHODOLOGY ENHANCEMENTS FOR TECHNICAL UPDATE

The Technical Update will build on the approaches and information from SWSI 2010 to develop the agricultural diversion demand, however the application and use of the agricultural diversion demand in the Planning Scenarios in the Technical Update differs from the SWSI 2010 approach. SWSI 2010 reflected the "agricultural demand" in terms of IWR and WSL, not in terms of the irrigation diversions and pumping required to meet IWR. This led to ambiguous terminology in terms of "agricultural demand" and differed from the approach taken to determine the M&I demand, which was based on the amount of water needed to meet the per capita demand and not the M&I consumptive use. The Technical Update will define the "agricultural diversion demand" as the amount of diversions and pumping that would be required to meet the IWR demand.

The Technical Update will include the agricultural diversion demand as a component of the Planning Scenario models, which will look at existing water rights, operations, and supplies to estimate the agricultural gap. Incorporating the agricultural diversion demand into the Planning Scenario models also allows for future analysis of specific projects and methods to meet that demand. This differs from the SWSI 2010 approach whereby the analysis relied on historical diversions to estimate crop shortages.

In addition to the new approach to developing the agricultural diversion demand in the Technical Update, there have been several studies, models, reports, and datasets completed since SWSI 2010 that can be used to enhance the development of the agricultural diversion demand in the Technical Update.

- CDSS Irrigated Acreage Coverage Updates for more recent coverages in all basins, including revised assignment of water supply to irrigated acreage.
- Extended CDSS StateCU and StateMod models for the Western Slope basins, which include the 2010 irrigated acreage coverages and extend through 2013.
- South Platte StateCU and StateMod model for the 1950 to 2012 period, including current agricultural diversion demands and supplies.
- Republican River Compact Administration Resolution regarding the Compact Compliance Pipeline, including acreage and consumptive use reductions.

- Arkansas River Basin DSS development, including a StateMod model for acreage on the mainstem below Pueblo Reservoir and recent climate data developed to support daily consumptive use analyses throughout the basin.
- Rio Grande Subdistrict and DWR Rules and Regulations development, including current agricultural demands and supplies.

Section 4: Current Agricultural Diversion Demand Approach

The approach used to develop the current agricultural diversion demand for the Technical Update varied based on the available data and the type of supplies generally used to meet the demand in each basin. The Colorado Water Conservation Board (CWCB) has developed crop consumptive use datasets with the StateCU modeling platform for most basins in the state through the CDSS program, as reflected in Figure 3. Two consumptive use datasets have been developed for basins with full CDSS development:

1. **Historical Dataset**. This dataset calculates IWR and historical consumptive use associated with historical irrigated lands in each basin. It includes historical changes in irrigated acreage and crop types and contains historical diversions and pumping that reflect administrative and operational constraints on water supply as they occurred over time. It is an appropriate dataset to review the calibration of the model and for evaluating historical conditions in the basin over an extended period of time.
2. **Baseline Dataset**. This dataset calculates IWR associated with current irrigated acreage and historical climate variability, and estimates associated current agricultural diversion demand using average system efficiency. As it reflects current acreage, it is an appropriate dataset to use for “what if” planning scenarios.

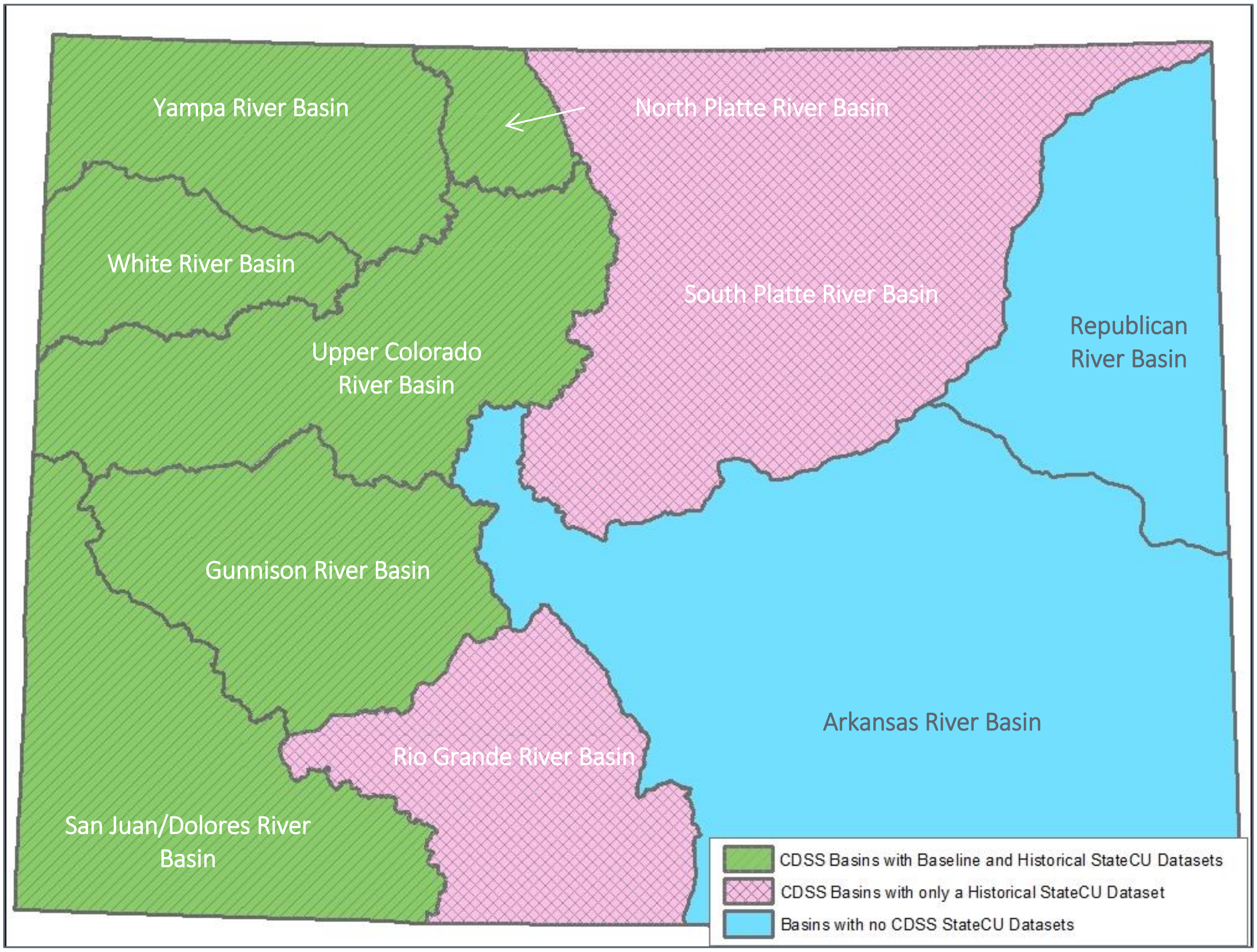

Figure 3: CDSS StateCU Model Availability

West Slope and North Platte Current Agricultural Diversion Demand Approach

The full CDSS program has been developed for the Western Slope basins (i.e. Yampa River, White River, Colorado River, Gunnison River, and Southwest Basins) and the North Platte River basin. The CDSS datasets for the Western Slope basins are available for the 1950 to 2013 period, and were recently revised to include irrigated acreage assessments through 2010. The Western Slope datasets are available on the CDSS website; minimal modifications were made to these datasets prior to their use in the Technical Update effort. These modifications include revisions to the total acreage and diversions in the Grand Valley Project area in the Colorado River Model and to Cimarron Canal area in the Gunnison River Basin model; removal of diversions for non-irrigation uses for aggregate structures in all datasets; and revisions to the Yampa River Basin to reflect recent modeling efforts undertaken by the Yampa/White/Green Basin Roundtable.

More significant revisions were required for the North Platte River datasets. The CDSS datasets for the North Platte River Basin only included irrigated acreage through 2001 and had not been updated since the previous SWSI effort; therefore the datasets in this basin were extended to include irrigated acreage through 2016 for this effort. During this effort, a total of six structures and irrigated acreage assessments from 2005 and 2010 through 2016 were added to the models. The North Platte River datasets are now available over the 1956 to 2016 period.

The Western Slope and North Platte River basins use minimal ground water supplies for irrigation. Therefore, the following approach was used to develop the irrigated acreage, IWR, system efficiencies, and current agricultural diversion demand attributable to surface water supplies:

1. Extract IWR, reflecting current acreage and crop types, from the most recent baseline StateCU datasets.
2. Develop a representative set of monthly system efficiency values[2] for wet, dry, and average year types[3] for each structure using information from the Historical StateCU datasets.
    a. Select a streamflow gage in each basin to serve as an "indicator" gage, and categorize each year type as wet, dry, or average based on annual natural flow.
    b. Divide the historical crop consumptive use by the total water diverted to determine monthly system efficiencies for each structure for every year in the dataset study period.
    c. Average the system efficiency information for each year type as determined by the indicator gage to develop a representative set of monthly system efficiencies for wet, dry, and average year types for each structure.
3. Divide the monthly Baseline IWR by either the wet, dry, or average monthly system efficiency values depending on the indicator gage year type to develop the current agricultural diversion demand.

South Platte and Rio Grande Current Agricultural Diversion Demand Approach

Only the Historical Dataset has been developed for the South Platte River and Rio Grande basins, therefore it was necessary to develop the Baseline Dataset prior to developing the current agricultural diversion demand.

- **South Platte River Basin**. The Historical Dataset in this basin was completed recently for the 1950 to 2012 period and includes irrigated acreage assessments through 2010. The Historical Dataset, however, excluded the Cache la Poudre basin (Water District 3) due to the ongoing permitting efforts for projects in the basin. Therefore, the Historical Dataset was first revised to include the agricultural demands and operations in Water District 3, then the Baseline dataset was developed using the 2010 irrigated acreage to calculate IWR.
- **Rio Grande Basin**. The most recent Historical Dataset in this basin was completed to support Phase 6 of the Rio Grande DSS Ground Water Modeling effort. The dataset, which includes irrigated acreage assessments through 2010 and extends over the 1950 to 2010 period, was used recently in the litigation to determine Rules and Regulations on ground water usage in the basin. The Baseline Dataset was developed using 2010 irrigated acreage from the Phase 6 dataset to calculate IWR.

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[2] System efficiencies generally developed based on the full model period; however a shorter period was used for structures that have experienced significant changes in irrigated acreage and/or diversions to be more representative of current conditions. Additionally, monthly system efficiencies were set to a minimum of 5 percent.

[3] Year types were calculated based on annual streamflow records for representative gages in each basin. Years with flow greater than the 25th percentile were categorized as wet; years with flow less than the 75th percentile were categorized as dry; and years with flow between the 25th and 75th percentile were categorized as average for the purposes of this effort.

An additional complication in these basins is the use of both surface and ground water as irrigation supplies. The total current agricultural diversion demand reflects the amount of water that needs to be diverted or pumped to meet a full crop demand, therefore it is necessary to partition the total demand into a surface water demand and a ground water demand.

Note that metered ground water pumping during the study period was generally not available in HydroBase for the South Platte and Rio Grande Basin Historical Datasets, therefore it was necessary to estimate ground water pumping. Pumping was generally estimated to meet the full crop IWR limited by known pumping restrictions such as well capacities or augmentation plan allocations. Actual ground water pumping is impacted by many factors including the irrigation practices, availability of surface water supplies, availability of recharge/augmentation supplies, aquifer levels, basin administration, crop types, and climate; and has changed significantly since the 2002 drought. These factors prove challenging when estimating the current and future agricultural diversion demand attributable to ground water supplies.

For the Baseline Dataset, it was necessary to make some general assumptions about how ground water supplies may be used to meet the agricultural diversion demand, particularly for ditches that irrigate with both surface and ground water supplies (i.e. co-mingled). Through discussions with ground water users and augmentation providers across the Eastern Slope basins, it was evident that ground water pumping levels on co-mingled lands would likely remain constant or decrease in the future due to declining aquifer levels and reduced augmentation supplies. As such, the pumping estimates from recent years (post-2002) reflect the maximum amount of co-mingled pumping that may be expected in the future.

This approach, summarized in more detail below, allows for pumping estimates to vary across hydrological conditions and limits pumping to current levels. Additionally, pumping estimates developed through this approach are a better indicator of the demand that may be met from co-mingled pumping in the future compared to other approaches such as attributing a static percentage to partition surface and ground water demand, or allowing surface water to meet full demand and estimate pumping from crop shortages which involves iterative modeling and could easily over or under estimate pumping depending on the seniority of the ditch or water availability. Refer to the Comments and Considerations section for additional discussion regarding estimates of well pumping information.

The following approach was used to determine the irrigated acreage, IWR, system efficiencies, and current agricultural diversion demand associated with surface and ground water supplies in the South Platte River and Rio Grande basins:

1. **Select a streamflow gage** in each basin to serve as an “indicator” gage, and categorize each year type as wet, dry, or average based on annual natural flow.
2. **Extract IWR**, reflecting current acreage and crop types, from the Baseline StateCU datasets.
3. **Divide the monthly Baseline IWR** for parcels only irrigated with ground water[4] (ground water only) by a static 80 percent system efficiency value (i.e. sprinkler application efficiency[5]) to develop the current ground water only agricultural pumping demand.
4. **Create a time series** of representative monthly pumping estimates for ditches that irrigate with both surface and ground water supplies (co-mingled) for wet, dry, and average year types using recent pumping estimates from the Historical StateCU datasets.
    a. Due to changes in administration and ground water pumping trends following the 2002 drought, select years to represent high, low, and average pumping values from post-2004

[4] Note structures that historically diverted surface water but now operate primarily with ground water supplies were treated as “ground water only” structures for the Technical Update effort.

[5] CDSS standard estimated efficiency for sprinkler systems; refer to South Platte DSS Technical Memoranda for more information on the development at use of system efficiency value.

co-mingled pumping estimates in the StateCU datasets. For example, 2009 was selected as the representative low pumping year for both basins.

   b. Create a time series of co-mingled pumping estimates by correlating low, high, and average pumping years to wet, dry, and average year types based on the indicator gage.

5. **Multiply the co-mingled pumping estimates** by a static 80 percent system efficiency (i.e. sprinkler application efficiency) to estimate the amount of IWR met by the co-mingled pumping.
6. **Subtract the IWR** met by co-mingled pumping from the Baseline IWR to determine the amount of IWR attributable to surface water supplies
7. **Develop a representative a set** of monthly system efficiency values for wet, dry, and average year types for each structure using information from the Historical StateCU datasets.
   a. Divide the historical crop consumptive use by the total water diverted and/or pumped to determine monthly system efficiencies for each structure for every year in the dataset study period.
   b. Average the system efficiency information for each year type from the indicator gage to develop a representative set of monthly system efficiencies for wet, dry, and average year types for each structure.
8. **Divide the IWR attributable to surface water supplies** by either the wet, dry, or average monthly system efficiency values depending on the indicator gage year type to develop the current agricultural diversion demand attributable to surface water supplies.

Arkansas Current Agricultural Diversion Demand Approach

A basin-wide consumptive use analysis has not yet been developed for the Arkansas River basin, although consumptive use analyses and other modeling efforts have been developed for portions of the basin. The primary source of agricultural consumptive use data available during the SWSI 2010 effort in the Arkansas River Basin was the Irrigation Systems Analysis Model (ISAM). ISAM is a refinement of the Hydrological Institutional (H-I) Model[6] to the individual farm level developed in support of the Arkansas Basin Agricultural Efficiency Rules. The ISAM and H-I models are limited to the irrigated acreage along the mainstem within the reach between Pueblo Reservoir and the Stateline (i.e. H-I Model area), therefore additional analyses are required to quantify the agricultural demand associated with acreage outside of this reach. There have been several efforts since SWSI 2010 to further the development of a basin-wide StateCU dataset in the Arkansas River Basin including:

- Development of a StateMod dataset reflecting historical diversions and irrigated acreage for the reach between Pueblo Reservoir and the Stateline.
- Development of a basin-wide daily and monthly climate dataset by DWR appropriate for use in an historical consumptive use analysis.
- Development of a basin-wide irrigated acreage coverage (2010 snapshot), assigned with water supply and crop types.

In addition, the State has embarked on the development of a complete Arkansas River DSS (ArkDSS), which includes a basin-wide StateCU and StateMod model in the basin. The ArkDSS project is running concurrently with this Technical Update effort. Information developed for the ArkDSS was used to the extent it was available.

[6] Colorado is required to use the HI Model for Compact accounting pursuant to settlement of the Kansas v. Colorado litigation; the model area includes irrigated lands served by canals that divert from the Arkansas River between Pueblo Reservoir and the Stateline

Using the basin-wide irrigated acreage coverage as the foundation, a Historical and Baseline StateCU dataset was developed for the Arkansas River Basin for the 1950 to 2017 period. Although Compact Accounting uses the Standardized ASCE Penman-Monteith equation to develop daily estimates of potential crop consumptive use, a monthly analysis using the Modified Blaney-Criddle equation was developed for this Technical Update effort. The monthly analysis under-estimates the potential crop consumptive use compared to the daily analysis, however the monthly approach provides estimates appropriate for this basin-wide planning level effort.

The following summarizes the general approach to developing the Historical Arkansas River StateCU dataset; refer to the StateCU documentation or other basin's historical consumptive use reports for more information on calculation methods or standard approaches.

- Historical irrigated acreage is available from the ISAM and H-I models for structures within the H-I Model area. Outside of the H-I Model area, the 2015 irrigated acreage coverage recently developed through the ArkDSS effort was used. Unfortunately, additional historical irrigated acreage coverages had not been developed at the time of the Technical Update and could not be incorporated into this analysis, however areas outside of the H-I Model area have not experienced as significant of changes in irrigated acreage.
- Climate station assignments are available from the ISAM and H-I models for structures within the H-I Model area. Climate stations were assigned to structures outside of the H-I Model area based on proximity to irrigated acreage, generally one climate station per Water District.
- Potential ET for all structures was determined using the SCS Modified Blaney-Criddle consumptive use methodology with TR-21 crop characteristics for acreage below 6,500 feet and the Original Blaney-Criddle consumptive use methodology with high-altitude crop coefficients developed for Denver Water for acreage above 6,500 feet. As recommended in the ASCE Manuals and Reports on Engineering Practice No. 70, Evapotranspiration and Irrigation Water Requirements (1990), an elevation adjustment of 10% adjustment upward for each 1,000 meters increase in elevation above sea level was applied to the Modified Blaney- Criddle method (i.e., for crops below 6,500 feet).
- The SCS effective rainfall method outlined in the SCS publication Irrigation Water Requirement Technical Release No. 21 (TR-21) was used for all structures to determine the amount of water available from precipitation.
- Conveyance loss is available from the ISAM and H-I models for structures within the H-I Model area, ranging from 34 to 6 percent. For structures outside of the H-I Model area, 10 percent conveyance loss was used. Maximum irrigation application efficiency for all structures was set to 65 and 85 percent for flood and sprinkler irrigated lands, respectively, based on the maximum efficiency in the H-I Model area.
- Historical diversions were obtained from HydroBase, with missing records filled using a wet, dry, and average pattern[7] at a nearby indicator gage. For lands irrigated with ground water, pumping was estimated to meet the full potential consumptive use. A majority of the pumping occurs within the H-I Model area, where records are available, however for areas outside of the H-I Model area, this approach likely over-estimates the amount of pumping. Additional analysis and

[7] Each month of the streamflow at the indicator gage was categorized as a wet/dry/average month through a process referred to as 'streamflow characterization'. Months with gage flows at or below the 25th percentile for that month are characterized as 'dry', while months at or above the 75th percentile are characterized as 'wet', and remaining months are characterized as 'average'. Using this characterization, missing data points were filled based on the wet, dry, or average pattern. For example, a data point missing for a wet March was filled with the average of other wet Marches in the partial time series, rather than all Marches.

potential supply limitations to this pumping are addressed in the *Technical Update Current and 2050 Planning Scenario Water Supply and Gap* documentation.

- Water supply-limited consumptive use was determined by including diversion records, conveyance efficiencies, application efficiencies, and soil moisture interactions. The model determined water supply-limited consumptive use by first applying surface water to meet irrigation water requirement for land under the ditch system. If excess surface water still remained, it was represented in the model as being stored in the soil moisture reservoir. Then if the irrigation water requirement was not satisfied, surface water stored in the soil moisture reservoir was used to meet remaining irrigation water requirement.
- System efficiency values for wet, dry, and average year types were estimated using the same approach outlined for other basins.

The Baseline StateCU dataset was then developed by revising the Historical StateCU dataset to reflect only the most current irrigated acreage over the entire study period. This dataset was simulated to estimate the IWR for the full study period, and the steps outlined for other basins was then used to estimate the current agricultural diversion demand. As with the South Platte and Arkansas River basins, ground water serves as a significant irrigation supply in the Arkansas basin. Therefore, the current agricultural diversion demand was partitioned into surface water and ground water demands in the Arkansas River basin using the same approach outlined for other basins with ground water.

Republican Current Agricultural Diversion Demand Approach

Agricultural diversion demand information in the Republican River basin is available from the most recent Compact accounting and model (RRCA), therefore a Historical or Baseline StateCU analysis was not developed for this basin. Irrigation in the Republican River basin is supplied primarily from ground water pumping. As such, the limited surface water diversions were not represented, and the current agricultural diversion demand was assumed to be attributable to ground water supplies. The following approach was used to develop the irrigated acreage, IWR, system efficiencies, and current agricultural diversion demand in the Republican River basin:

1. **Develop current irrigated acreage**, reflecting crop types and irrigation application type, using the CDSS 2016 irrigated acreage assessment. Parcels delineated in the CDSS 2016 assessment were compared to pumping records to determine which parcels were actively irrigated in 2016; parcels within the Compact boundary[8] with no active pumping records were excluded.
2. **Extract crop-specific monthly unit IWR** from the RRCA summary, available over the 2007 to 2016 period. Extend the period or record for unit IWR using previously published IWR values from the original SWSI effort back to 1998.
3. **Multiply the current acreage** by the unit IWR to develop the monthly Baseline IWR.
4. **Divide the monthly Baseline IWR** for acreage served by flood/furrow by a static 65 percent and divide the monthly Baseline IWR for acreage served by sprinklers by a static 80 percent to develop the current agricultural pumping demand attributable to ground water supplies.

[8] Note that the Republican River Compact boundary does not extend over the entire Republican River watershed (i.e. Water Districts 65 and 49) as reflected in Figure 10, therefore acreage totals from the RRCA were not representative of the total acreage in the watershed

Section 5: Current Results

There are currently 3.28 million acres of irrigated agricultural land in the State of Colorado. This acreage supports a wide network of agribusiness in Colorado from producers of agricultural goods to those that process and deliver those goods to the consumer. Agricultural production in the State of Colorado is a large part of the state's economy, with agribusiness contributing $41 billion annually and directly employing nearly 173,000 people[9].

As shown in Figure 4, over a quarter of the irrigated acreage in Colorado is located in the South Platte River Basin. The Arkansas River, Rio Grande, and Republican River Basins also have significant acreage. Grass pasture is the predominant crop grown in the state, particularly in the West Slope basins, however irrigators also grow alfalfa, wheat, cereals/grains, fruits, and vegetables. Much of the irrigated acreage supports ranching operations, either through grass hay production for livestock operations or grazing of irrigated pastures. The basin summaries below provide more information on crops grown in each basin.

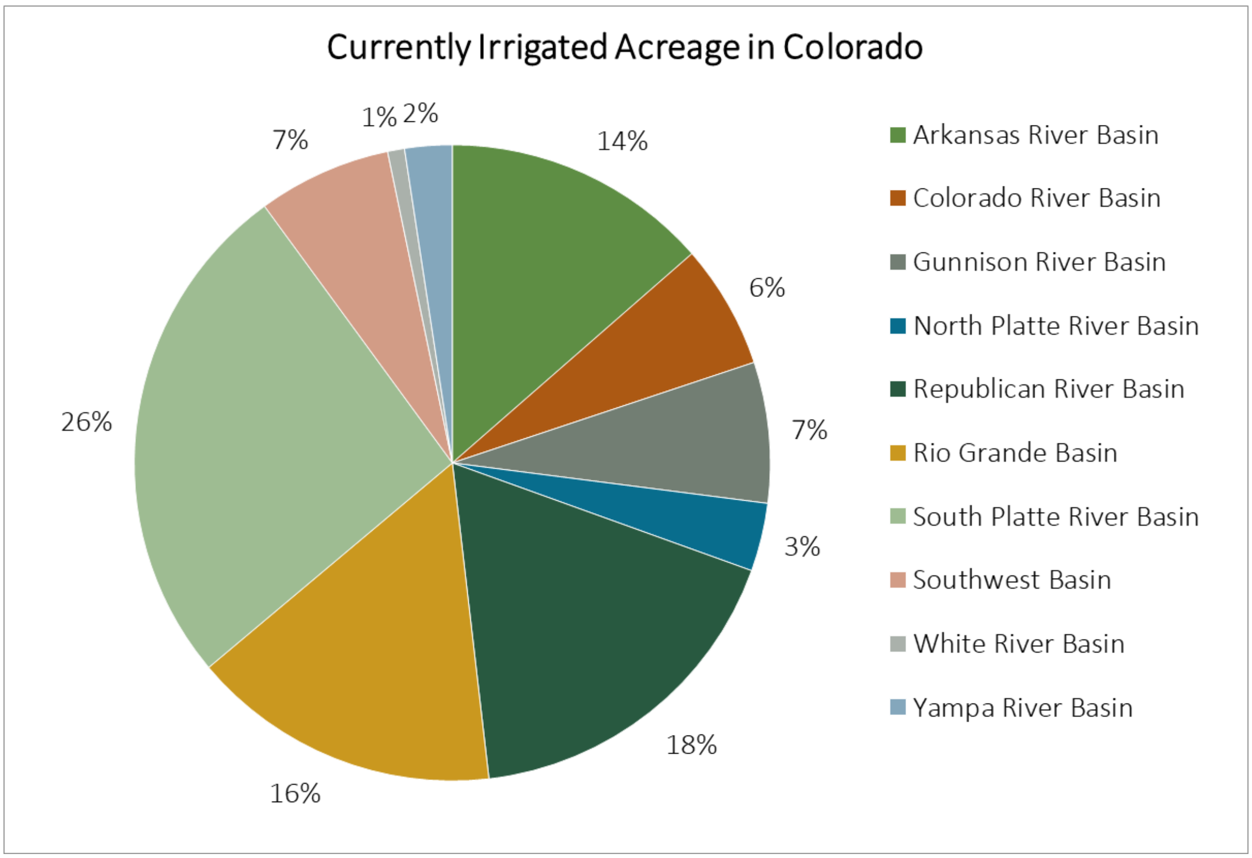


Figure 4: Currently Irrigated Acreage in Colorado

The following graphics and tables reflect the agricultural diversion demand for surface and ground water supplies summarized by basin for wet, dry, and average hydrological year types compared to average IWR. Results are provided over a range of hydrological year types to reflect how demands and system

[9] Source: Contribution of Agricultural to Colorado's Economy (January 2012, Colorado State University Extension)

efficiencies change under different climatic/hydrological conditions and to show how different types of supplies are used. As discussed in Section 4, the agricultural diversion demand is calculated by dividing the IWR by system efficiency. In dry years, for example, surface water irrigation supplies are reduced due to lower precipitation and streamflow and irrigators are more efficient with the surface water irrigation supplies that are available, resulting in a lower dry year diversion demand. For irrigators with supplemental ground water supplies, the ground water demand generally increases in response to decreased availability of surface water supplies. System efficiencies range across basins and year types for reasons other than supply including irrigation methods (i.e. sprinkler or flood applications), on-farm conditions such as ditch/lateral alignments, soil types, and field topography. The basin summaries below provide more information on conditions that impact the system efficiency and the agricultural diversion demand.

Table 4 shows the current irrigated acreage, average IWR and unit IWR by basin. Average IWR is driven by both climate conditions and crop type. For example, although climate conditions may be similar the row crops grown on the eastern plains of Colorado require less water than some of the perennial crops grown in the Grand Valley area of the Colorado River basin.

As reflected in Table 5 and Table 6, the statewide total agricultural diversion demand is currently approximately 13 million acre-feet; over 80 percent of that demand is from surface water supplies. The total diversion demand represents the amount of water that would need to be diverted or pumped to meet the full crop IWR, and does not reflect historical irrigation supplies. Irrigators often operate under water-short conditions resulting in an agricultural gap. Refer to the *Technical Update Current and 2050 Planning Scenario Water Supply and Gap* documentation for more information on how the demands were implemented in the water supply models and how the agricultural gap was estimated.

Table 4: Current Irrigated Acreage and Average Annual IWR

Basin	Acreage	Average IWR (acre-feet)	Unit IWR (feet)
Arkansas	445,000	980,000	2.20
Colorado	206,700	456,500	2.21
Gunnison	234,400	528,200	2.25
North Platte	113,600	191,100	1.68
Republican	578,800	837,000	1.45
Rio Grande	515,300	1,021,000	1.98
South Platte River	854,300	1,500,000	1.76
Southwest	222,500	474,900	2.13
White	28,100	46,400	1.65
Yampa	78,900	150,600	1.91
Total	**3,280,000**	**6,190,000**	**1.89**

Table 5: Current Agricultural Diversion Surface and Ground Water Demand

			Surface Water Demand			Ground Water Demand		
Basin	Acreage	Average IWR (acre-feet)	Wet Year (acre-feet)	Average Year (acre-feet)	Dry Year (acre-feet)	Wet Year (acre-feet)	Average Year (acre-feet)	Dry Year (acre-feet)
Arkansas	445,000	980,000	1,567,000	1,497,000	1,501,000	327,000	375,000	461,000
Colorado	206,700	456,500	1,640,000	1,608,000	1,538,000	-	-	-
Gunnison	234,400	528,200	1,824,000	1,814,000	1,716,000	-	-	-
North Platte	113,600	191,100	548,000	555,000	489,000	-	-	-
Republican	578,800	837,000	-	-	-	913,000	1,056,000	1,241,000
Rio Grande	515,300	1,021,000	1,237,000	1,172,000	1,195,000	564,000	628,000	654,000
South Platte	854,300	1,500,000	2,078,000	2,186,000	2,108,000	349,000	403,000	524,000
Southwest	222,500	474,900	980,000	1,025,000	1,007,000	-	-	-
White	28,100	46,400	250,000	243,000	242,000	-	-	-
Yampa	78,900	150,600	387,000	402,000	403,000	-	-	-
Total	3,280,000	6,190,000	10,511,000	10,502,000	10,199,000	2,153,000	2,462,000	2,880,000

Table 6: Total Current Agricultural Diversion Demand

			Total Water Demand		
Basin	Acreage	Average IWR (acre-feet)	Wet Year (acre-feet)	Average Year (acre-feet)	Dry Year (acre-feet)
Arkansas	445,000	980,000	1,894,000	1,872,000	1,962,000
Colorado	206,700	456,500	1,640,000	1,608,000	1,538,000
Gunnison	234,400	528,200	1,824,000	1,814,000	1,716,000
North Platte	113,600	191,100	548,000	555,000	489,000
Republican	578,800	837,000	913,000	1,056,000	1,241,000
Rio Grande	515,300	1,021,000	1,801,000	1,800,000	1,849,000
South Platte	854,300	1,500,000	2,427,000	2,589,000	2,632,000
Southwest	222,500	474,900	980,000	1,025,000	1,007,000
White	28,100	46,400	250,000	243,000	242,000
Yampa	78,900	150,600	387,000	402,000	403,000
Total	3,280,000	6,190,000	12,664,000	12,964,000	13,079,000

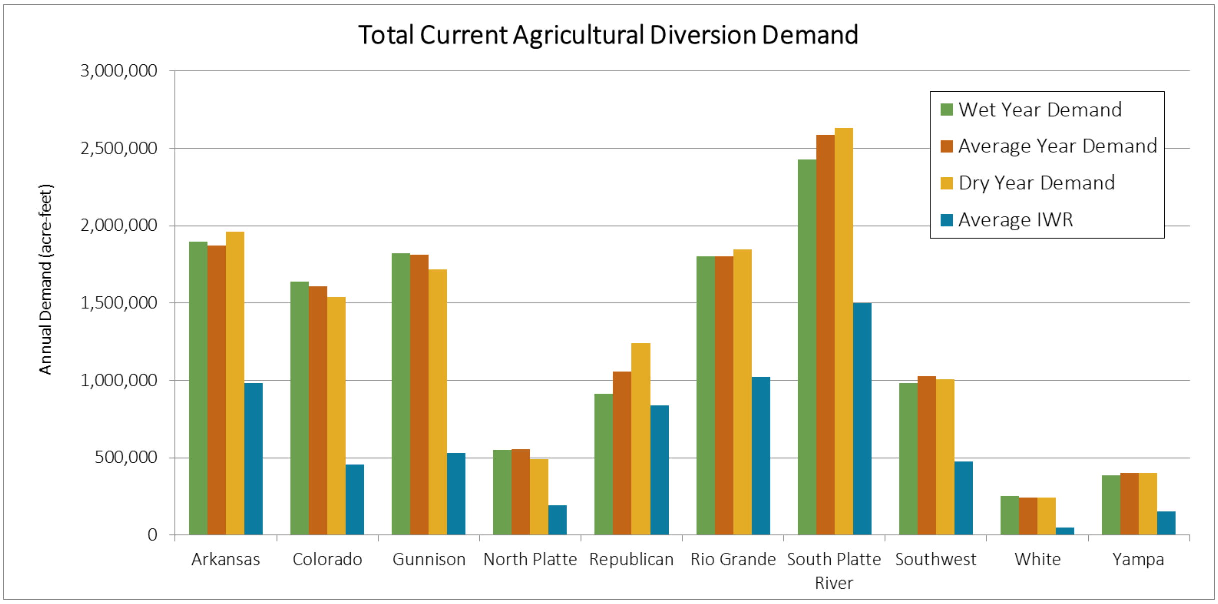


Figure 5: Total Current Agricultural Diversion Demand

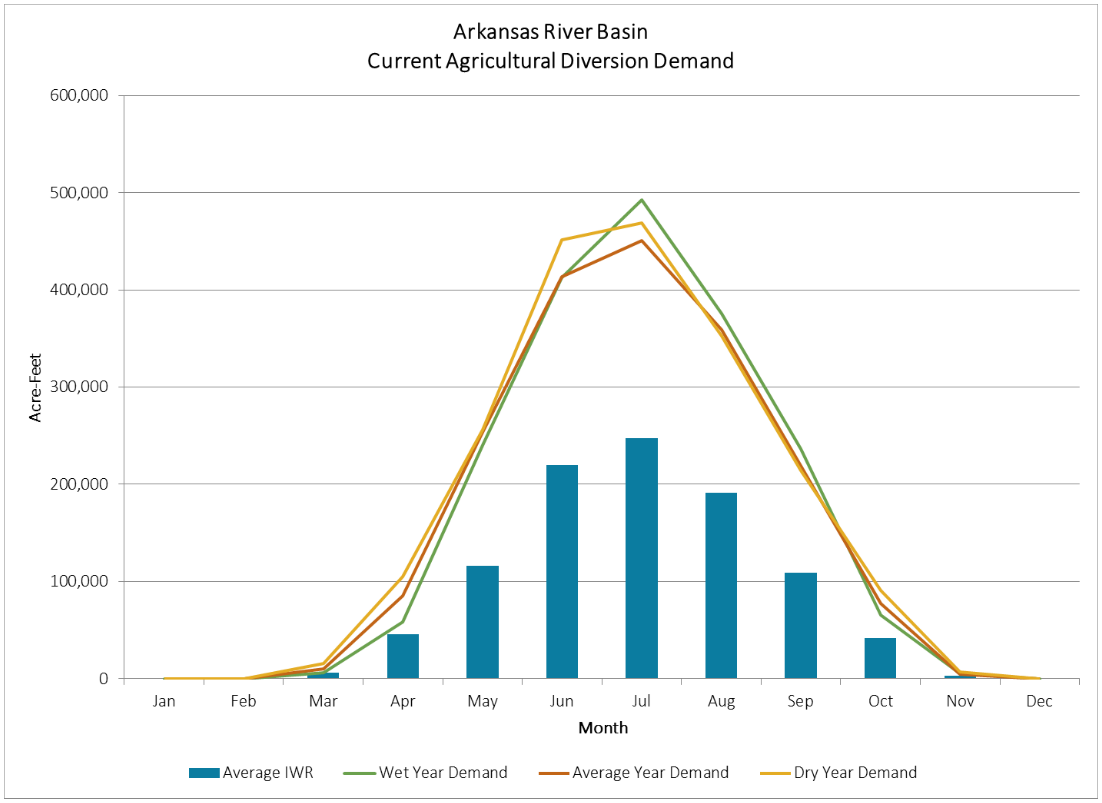


Figure 6: Arkansas River Basin Currently Agricultural Diversion Demand

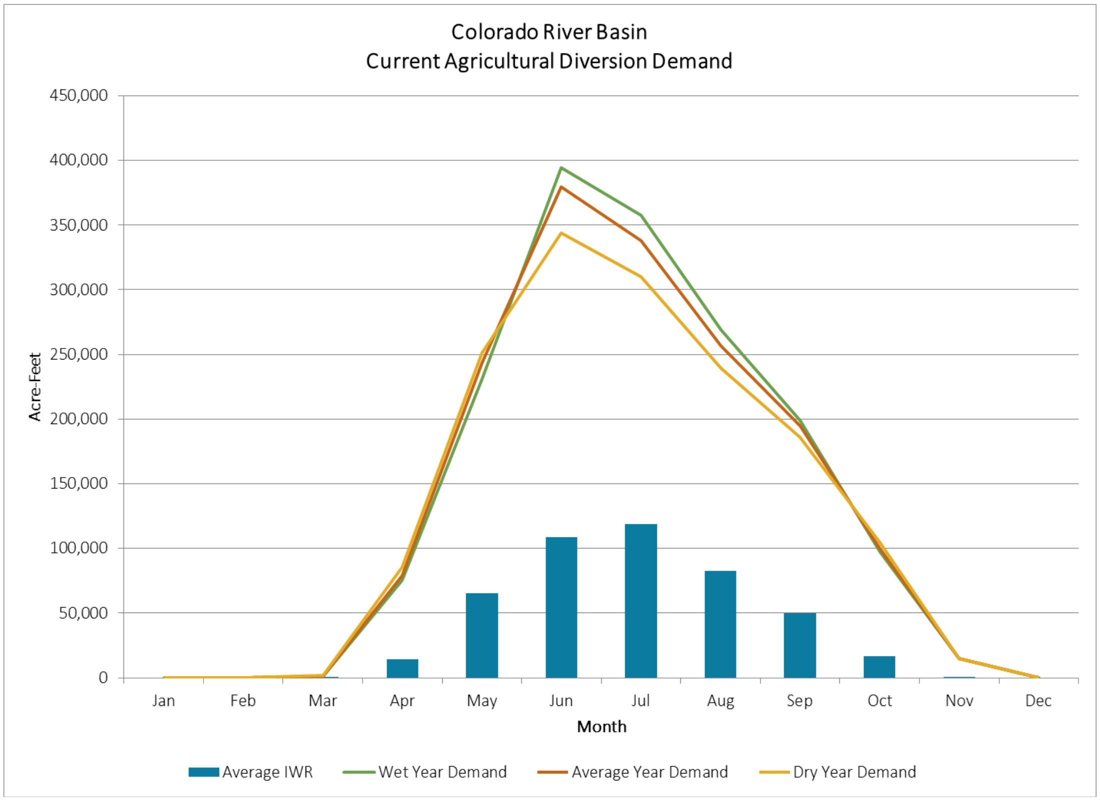


Figure 7: Colorado River Basin Current Agricultural Diversion Demand

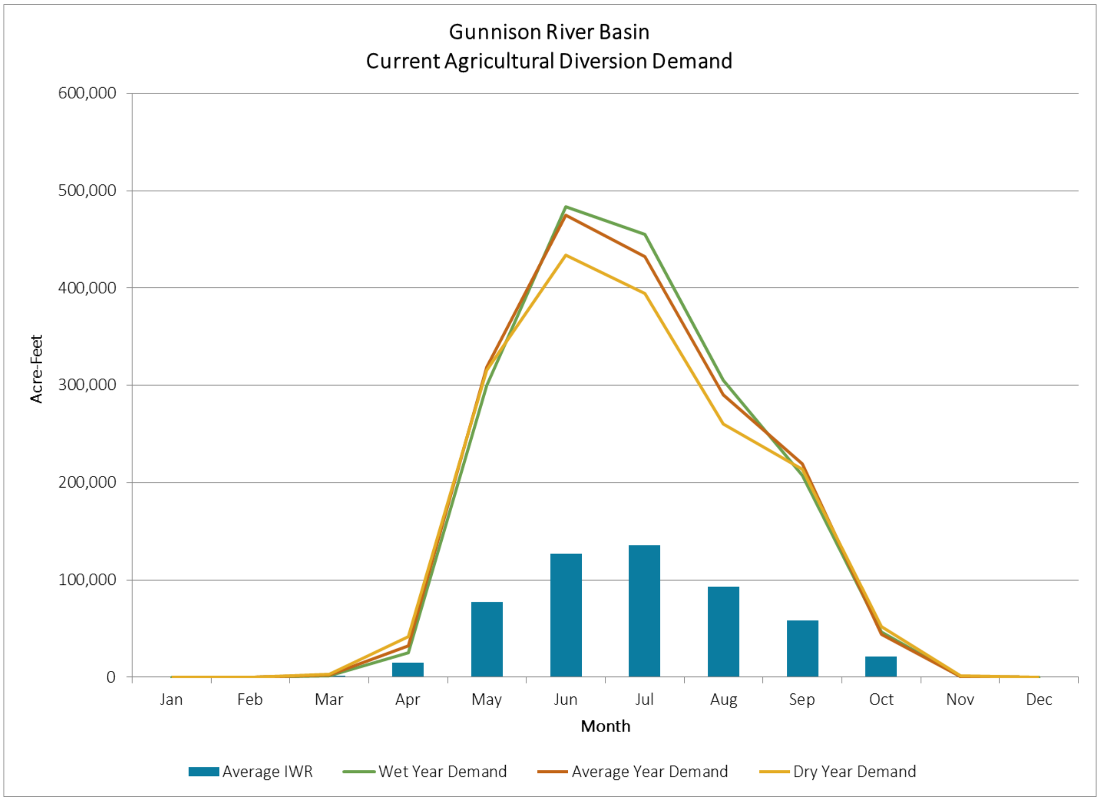


Figure 8: Gunnison River Basin Current Agricultural Diversion Demand

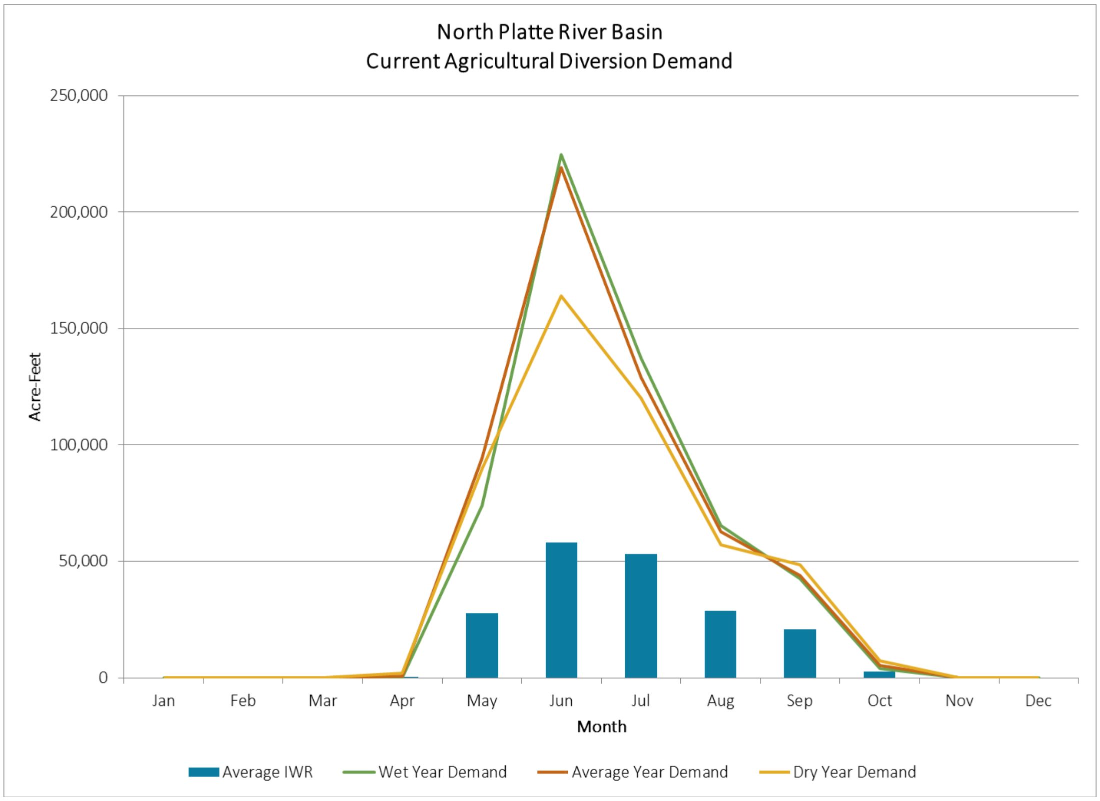


Figure 9: North Platte River Basin Current Agricultural Diversion Demand

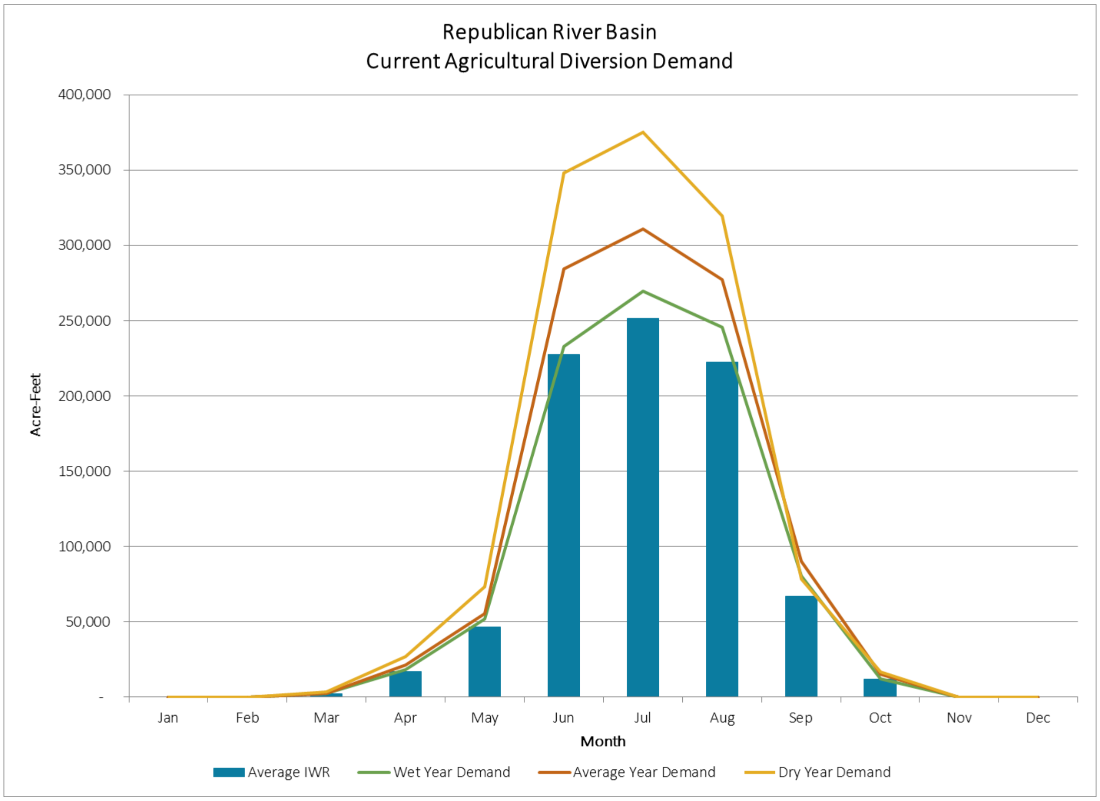


Figure 10: Republican River Basin Current Agricultural Diversion Demand

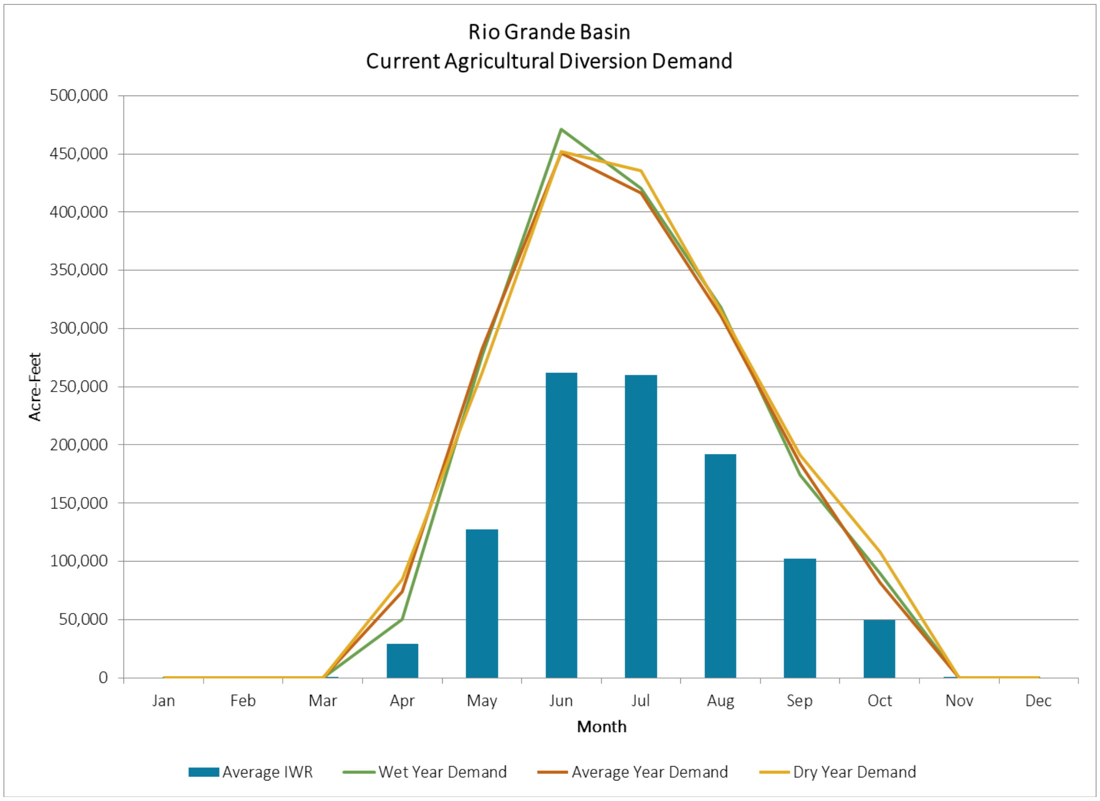


Figure 11: Rio Grande Basin Current Agricultural Diversion Demand

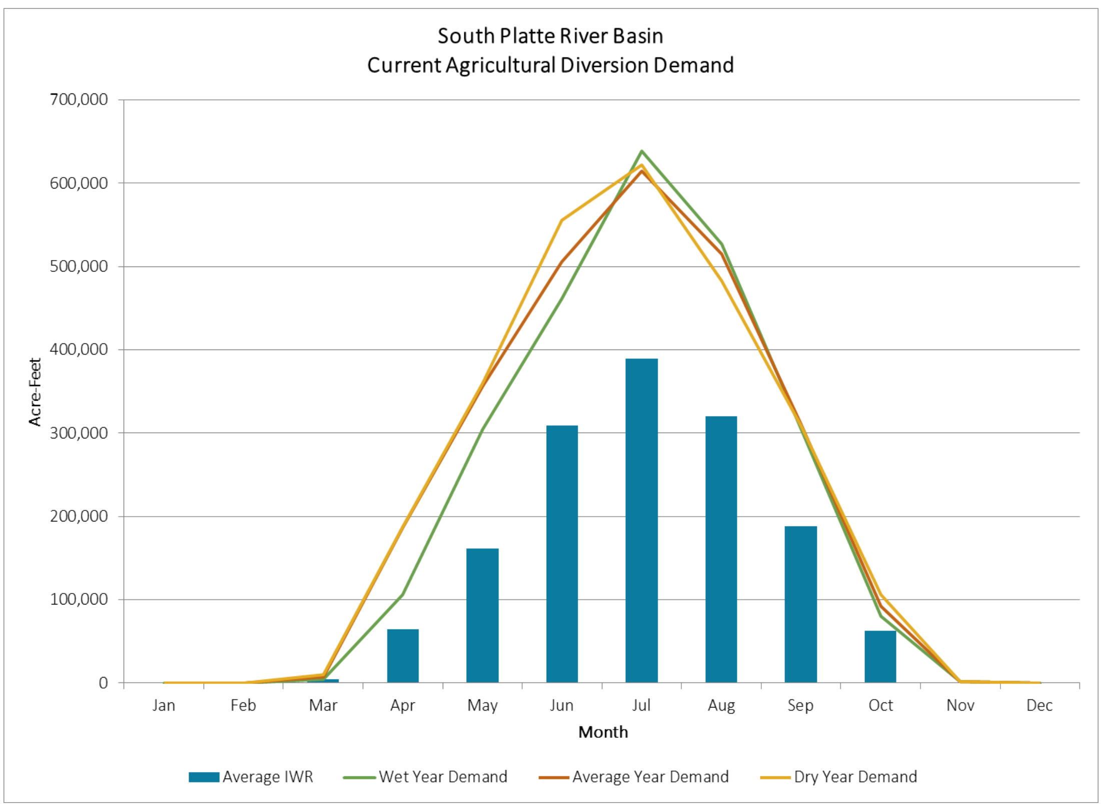


Figure 12: South Platte River Basin Current Agricultural Diversion Demand

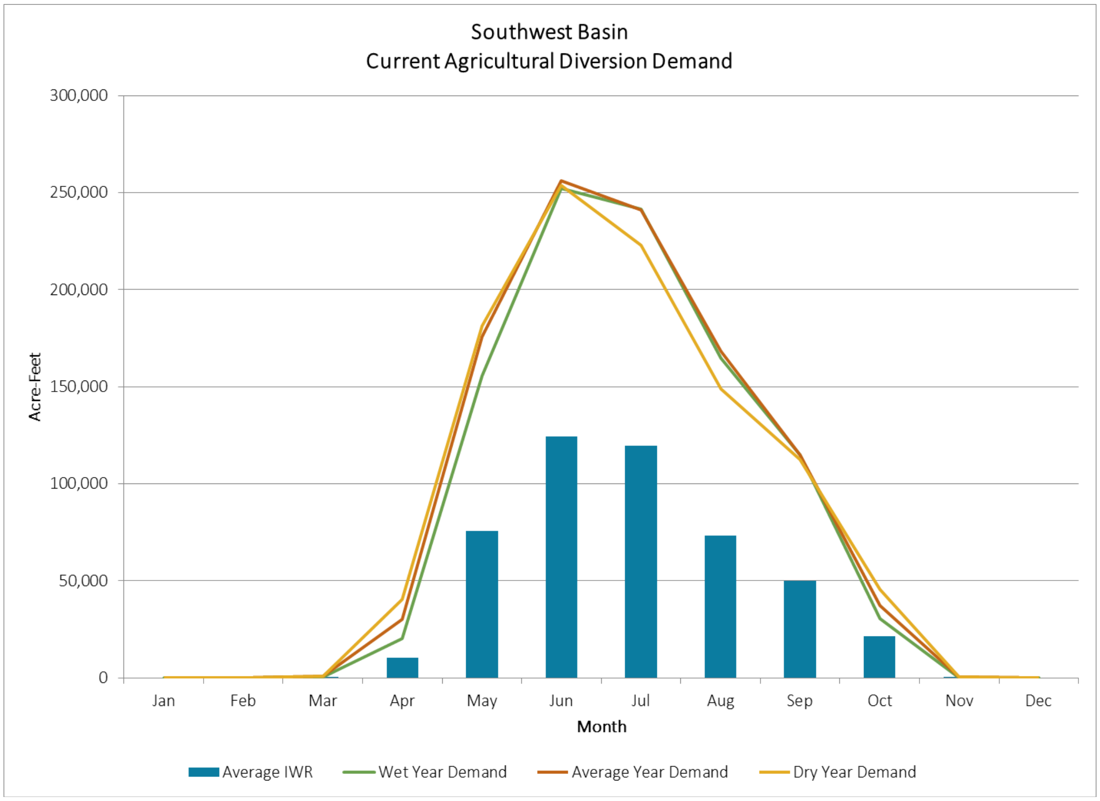


Figure 13: Southwest Basin Current Agricultural Diversion Demand

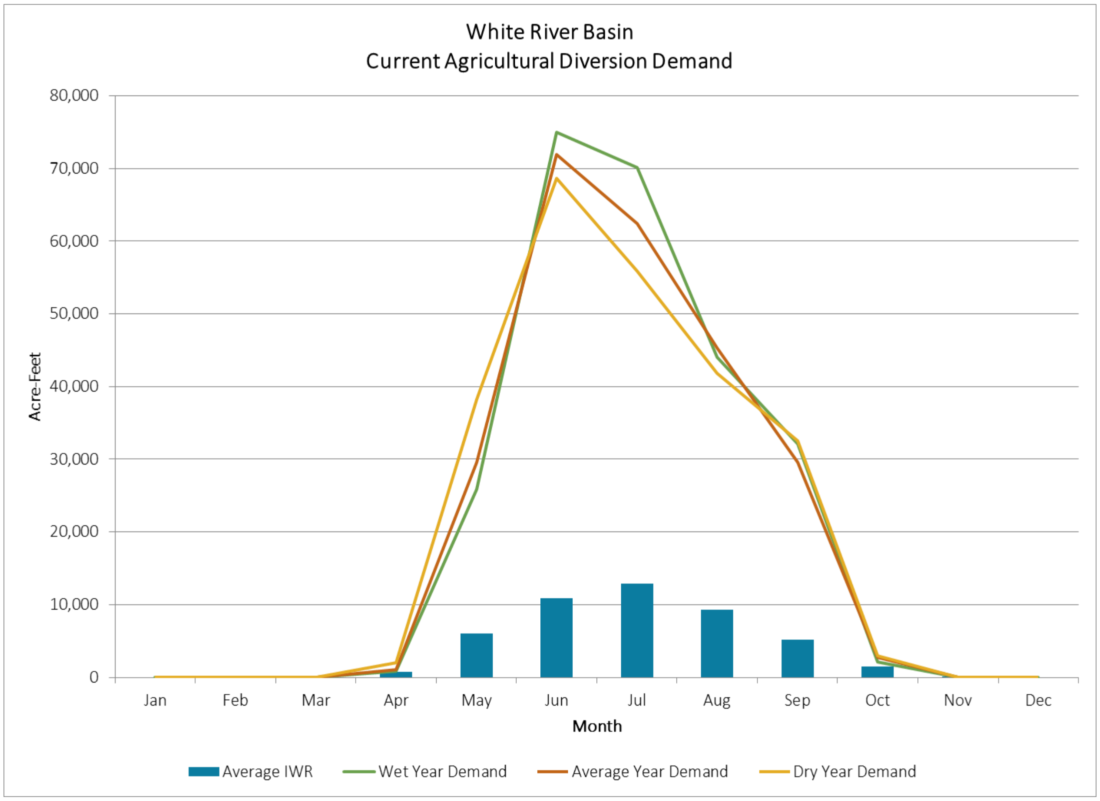


Figure 14: White River Basin Current Agricultural Diversion Demand

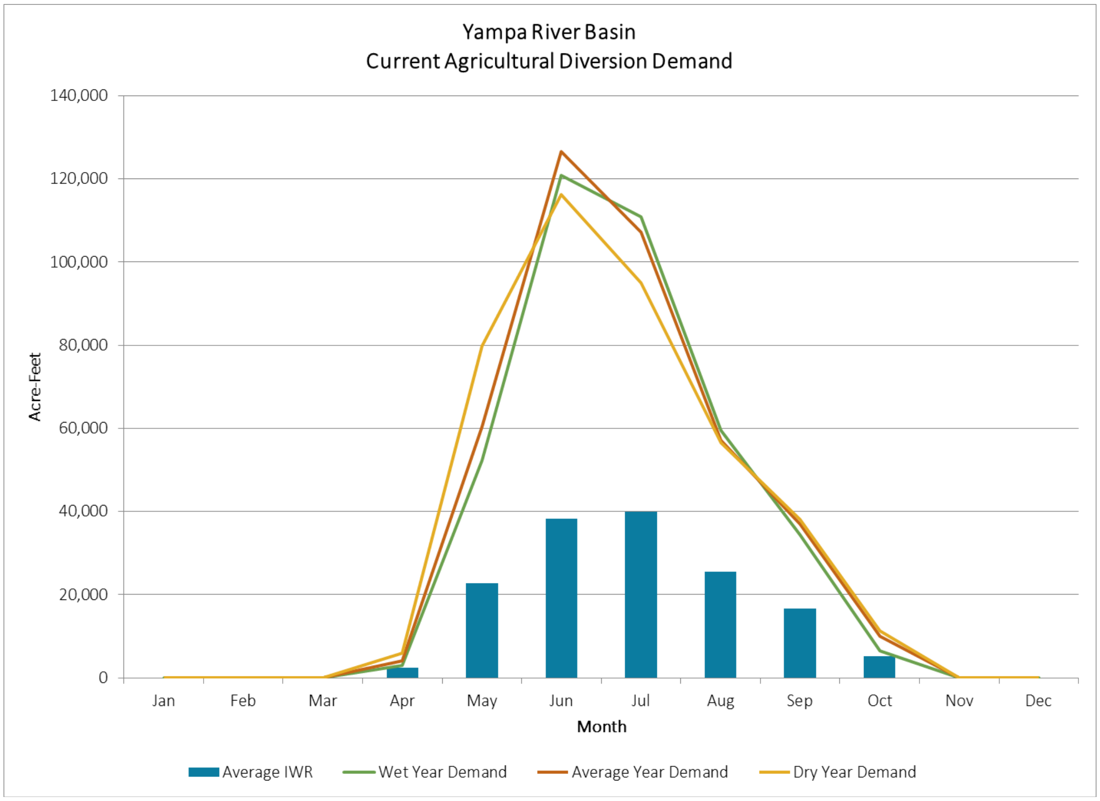


Figure 15: Yampa River Basin Current Agricultural Diversion Demand

Section 6: Planning Scenario Adjustments

Many different factors will impact the future of agriculture in the State of Colorado, including changing climatic conditions, increased demand for food, new irrigation and seed technologies, environmental regulations, and agricultural market fluctuations. Although these factors will all play a part in shaping the future of agriculture, the impact from many of these factors is difficult to quantify or predict. As such, the Technical Update focused on the following factors that can be consistently and quantitatively applied to adjust the agricultural diversion demand in each Planning Scenarios.

- Urbanization
- Planned Agricultural Projects
- Ground Water Acreage Sustainability
- Climate
- Emerging Technologies

Note that this section provides general descriptions of the Planning Scenario adjustment factors; refer to *Planning Scenario Agricultural Diversion Demand Approach* section for discussion on the general approach for applying each factor and the basin-wide summaries for specific information regarding how the factors were reflected in each basin.

6.1 URBANIZATION

As many municipalities are expected to grow in the 2050 Planning Scenarios, it is anticipated that some of the municipal growth will occur into currently irrigated agricultural lands. For this effort, this growth is referred to as "urbanization" and reflects the amount of irrigated acreage that will likely be converted for municipal uses under each Planning Scenario. Additional non-irrigated land may also be urbanized to accommodate projected population growth but non-irrigated lands were not considered or quantified for this factor since development on those lands would not impact the amount of projected irrigated acres.

The *Technical Update Agricultural Diversion Demand Methodology* outlined an approach to account for the impact of urbanization of irrigated acreage in the 2050 Planning Scenarios. The originally contemplated approach relied on estimates of population growth and urbanized acreage from a recent period (i.e. 1997 – 2015), and assumed that growth onto irrigated acreage would occur at the same rate. Applying this "urbanization rate" using the 2050 projected population, however, resulted in estimates of urbanized acreage greater than the available irrigated acreage in and around the municipal boundaries. This indicates that growth, at least with respect to urbanization of irrigated acreage, will look different in the future and a revised approach was developed.

The revised approach relies on current irrigated lands, current municipal boundaries, and basin-wide population projections to determine the amount of irrigated acreage that would likely be dried up and urbanized within each basin by 2050. First, a geo-spatial analysis was performed to identify currently irrigated lands within and directly adjacent to existing municipality boundaries. No assumptions or considerations were made to forecast how any individual municipality may expand or change boundaries in the future (direction or distance) or forecast changes in density of future growth. Second, population projections were reviewed to determine if the basin was projected to experience growth in each Planning Scenario. If so, then it was assumed the irrigated acreage from the spatial analysis would be urbanized and removed from production by 2050. If population was projected to decline in a basin by 2050 in a specific Planning Scenario, no changes to irrigated acreage were made. This approach results in a conservative estimate of urbanized acreage, however, it can be consistently applied statewide and does not require specific knowledge of future municipal growth or direction of expansion.

Table 7 reflects the amount of projected urbanized acreage by basin, historical urbanization, and also current levels of irrigated acreage for context. This approach estimates approximately 153,500 irrigated acres will be dried up and taken out of production due to urbanization by 2050, approximately 5 percent of the total irrigated acreage statewide. The largest impact is expected in the South Platte River basin, with dry up projected to exceed 12 percent of the irrigated acreage in basin.

Table 7: Projected Loss of Irrigated Acreage Due to Urbanization

Basin	Historically Urbanized Irrigated Acreage (1)	Projected Urbanized Irrigated Acreage (2)	Currently Irrigated Acreage
Arkansas	N/A (3)	7,240	445,000
Colorado	6,060	13,590	206,700
Gunnison	2,380	14,600	234,400
North Platte	2	40	113,600
Republican	0	1,410	578,800
Rio Grande	N/A (3)	4,010	515,300
South Platte/Metro	49,400	105,900	854,300
Southwest	100	3,800	222,500
White	-15 (4)	360	28,100
Yampa	135	1,500	78,900
Total	**58,060**	**152,450**	**3,277,600**

1) Irrigated acreage dried up between 1987/1993 and 2015 within current municipality boundaries. Based on CDSS irrigated acreage assessments and 2018 DOLA municipality boundaries.

2) 2015 irrigated acreage within or shares boundaries with 2018 municipality boundaries.

3) Neither a 1987 nor a 1993 basin-wide acreage assessment has been developed.

4) The White River basin showed a slight decline in irrigated acreage within municipal boundaries from 1993 to 2015.

Population estimates for some Planning Scenarios show a population decline in some basins; therefore, it is reasonable to assume no urbanization of irrigated acreage will occur in these basins under these Planning Scenarios. As a result, urbanization in basins with projected losses to population in 2050 Planning Scenarios will be set to zero. Table 8 shows a matrix of urbanized acres by basin and Planning Scenario.

Table 8: Urbanization of Irrigated Acreage by Planning Scenario

Basin	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Arkansas	7,240	7,240	7,240	7,240	7,240
Colorado	13,590	13,590	13,590	13,590	13,590
Gunnison	14,600	14,600	14,600	14,600	14,600
North Platte	-	-	-	40	40
Republican	1,410	-	1,410	1,410	1,410
Rio Grande	4,010	-	4,010	4,010	4,010
South Platte/Metro	105,900	105,900	105,900	105,900	105,900
Southwest	3,800	3,800	3,800	3,800	3,800
White	360	-	360	360	360
Yampa	1,500	1,500	1,500	1,500	1,500
Total	**152,410**	**146,630**	**152,410**	**152,450**	**152,450**

In specific basins, additional irrigated acreage was removed to account for irrigation water rights that are currently being transferred for municipal uses, or rights that have been purchased and will be transferred for municipal uses in the future. Estimates of this acreage, termed *Municipal Transfers* in the basin summaries below, were provided by stakeholders in the basin. Note *Municipal Transfers* reflect acreage that is currently *planned* to be dried up and their water rights transferred for municipal purposes, not acreage that may be dried up in a future transfer as part of an Identified Project and Process (IPP) or in response to meeting a future 2050 Planning Scenario municipal gap.

The total acreage projected to be urbanized or part of a planned municipal transfer for the Technical Update is similar to the High Scenario estimates in SWSI 2010 (Table 1); however the distribution across the basins differs. Specifically, the Technical Update analysis reflected much lower urbanized acreage estimates in Colorado River basin and much higher estimates in the South Platte River basin, as compared to the SWSI 2010 effort. This difference may be a result of more current population projections and identifying potential urbanized parcels in the Technical Update approach, compared to a more regional or basin-wide approach taken in SWSI 2010.

6.2 PLANNED AGRICULTURAL PROJECTS

The Basin Implementation Plans (BIP) developed by each of the Basin Roundtables (BRT) outlined the current agricultural needs in each basin, as well as the basin's future agricultural goals and approaches to meeting those goals. All of the BIP indicated water shortages occur on existing agricultural demands, cited concern over the current trend of converting agricultural water supplies to municipal uses, and proposed solutions to address the agricultural gap. Two basins, the North Platte and Yampa River basin, also included a goal to increase agriculture in the basin by putting new lands under production. Planned agricultural projects in the North Platte River basin totaled 10,576 acres and projects in the Yampa River basin totaled 14,805 acres. Refer to the basin summaries below for more information on implementation of this factor in these basins.

SWSI 2010 efforts identified a total increase of 42,000 acres by 2050, with 14,000 acres in the Yampa River basin and 28,000 acres in the North Platte River basin. The Technical Update estimates correlate closely in the Yampa River basin as the estimates are generally based on the same source data. The Technical Update estimates for increased irrigated acreage in the North Platte Basin are approximately 10,500 acres and were based on planned agricultural projects identified by stakeholders in the basin. The SWSI 2010 effort relied on maximum irrigated acreage increases allowable under the Three States Agreement of the Platte River Recovery Implementation Plan and the North Platte Equitable Apportionment Decree (rev. 1953).

6.3 GROUND WATER ACREAGE SUSTAINABILITY

A large portion of the currently irrigated acreage in Colorado relies on ground water supplies, primarily in the South Platte, Republican River, Arkansas River, and Rio Grande basins. Sustaining these ground water supplies, both in terms of physical and legal availability, is necessary for maintaining irrigated acreage supplied by ground water into the future. If ground water levels or augmentation supplies cannot be sustained, irrigated acreage served by ground water in these basins will likely decrease in the future.

Meetings were held with several stakeholders in these basins to determine the primary considerations regarding the sustainability of ground water supplies in the future. The following provides a summary of these considerations and the general level of impact in each basin; refer to the basin summaries below for more information of implementation of this factor in these basins.

- **Republican -** Essentially all of the 578,800 acres in the Republican River Basin are served only by ground water supplies. Sustainability of this irrigated acreage is impacted by two primary issues;

achieving compliance with the 1942 Republican River Compact (and the 2002 Settlement) and declining levels in the High Plains Aquifer System. Discussions with Republican River Water Conservation District (RRWCD) Board Members yielded potential reductions to irrigated acreage across the counties within the basin; a total of 135,420 acres, or nearly 25 percent, is estimated to be taken out of production by 2050 in response these issues.

- South Platte - Sustainability of continued irrigation on acreage served by ground water in South Platte River Basin is vulnerable to the availability of augmentation supplies. Central Colorado Water Conservancy District, which operates two of the largest well augmentation plans in the South Platte River basin, provided information on current augmentation supplies and insight into the availability of projected augmentation supplies. In short, up to 20 percent of the irrigated acreage currently served solely by ground water may not have access to sufficient augmentation supplies to continue farming. Discussions with the Lower South Platte Water Conservancy District focused on the current and future trends in taking irrigated acreage out of production and converting those water rights over to municipal uses. While Colorado is making strides towards reducing the occurrence of permanent agricultural to municipal water transfers (e.g. buy and dry), the practice will likely continue in the future to some degree. In addition, even if permanent transfers are eliminated, reductions in irrigation demand will occur as a consequence of municipal uses pursuant to alternative transfer methods. Although augmentation shortages and water transfers are two distinctly different and unrelated drivers for reduction in irrigated lands, the impact of this issue is the same – the amount of irrigated acreage in the South Platte will decline in the future.

- Arkansas - Nearly 85,000 acres in the southeast corner of the Arkansas River Basin is solely irrigated with ground water pumped from the Southern High Plains aquifer system. DWR has measured aquifer levels in this area over the past two decades and has noted declines in all aquifers layers. Increasing IWR due to projected climate conditions will likely lead to increased pumping and more aggressive declines in aquifer levels than recently measured. This, in turn, will likely result in acreage reductions in this area in the future.

- Rio Grande - The Rio Grande Basin has already experienced a reduction to irrigated acreage as a result of declining aquifer levels, and administrators and stakeholders in the basin indicated additional reductions can be expected in the future. Pumping of the unconfined aquifer, which serves as the primary supply for irrigated acreage in the San Luis Valley, has depleted the aquifer by more than 1.1 million acre-feet since the early 1990s. The Rio Grande Water Conservation District (RGWCD) is tasked with managing the ground water depletions through the creation of Groundwater Management Subdistricts and recovering nearly 700,000 acre-feet of aquifer storage in the next 13 years. Although 20,000 acres have already been taken out of production, the stakeholder group indicated additional reductions will be needed to recharge the aquifer.

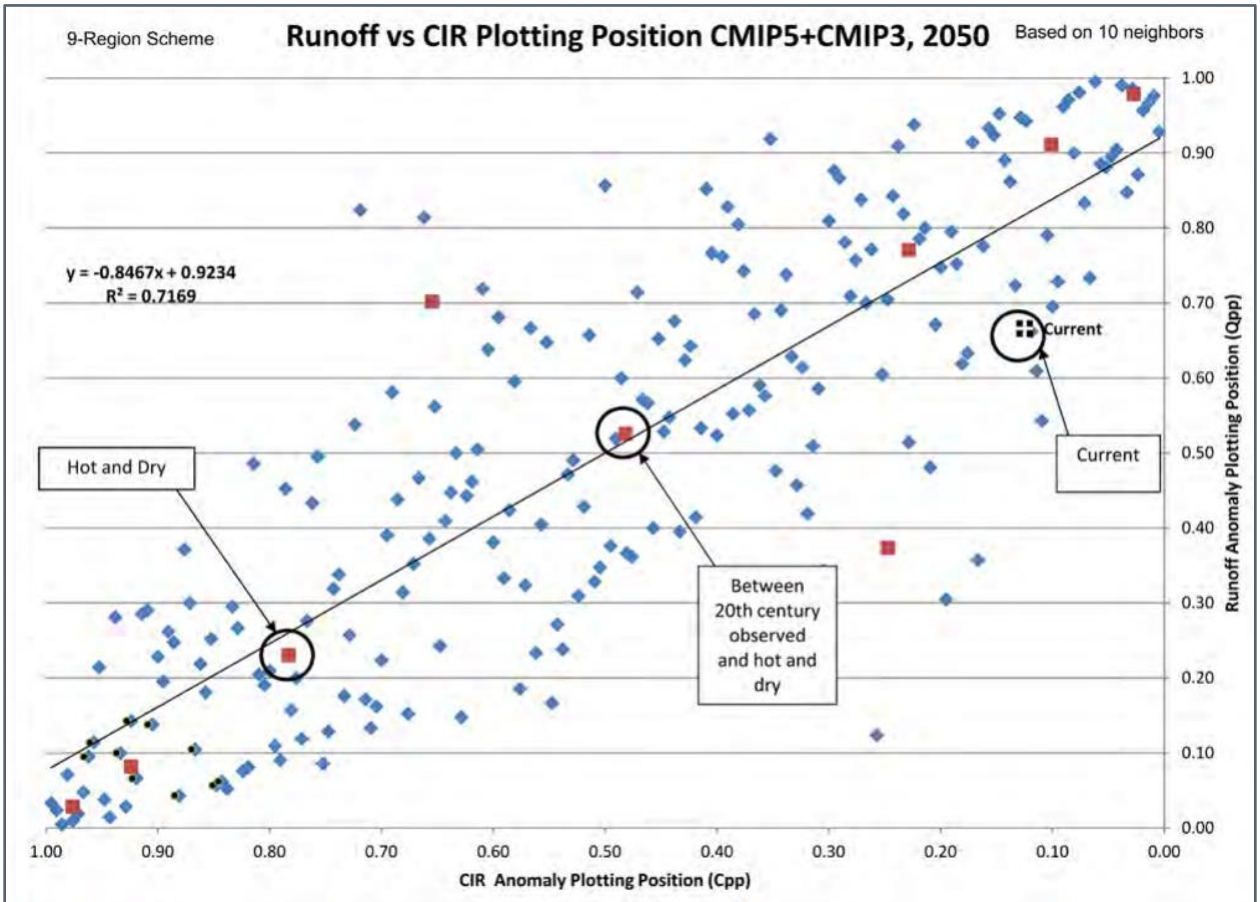
6.4 CLIMATE

CWCB has undertaken several studies and investigations on the potential impact of climate change and its effect on the future of water supply and use in Colorado. Most notably was the development of the Colorado Climate Plan (CCP), which focuses on observed climate trends, climate modeling, and climate and hydrology projections to assist with the planning and management of water resources in Colorado. The CCP discusses the most recent global climate projections (CMIP5) and recommends the integration of these results with the previous global climate projections (CMIP3) to provide a representative range of potential future climate and hydrological conditions.

Supported by the information from the CCP, Colorado's Water Plan identified two future potential climate projections for incorporation into the 2050 Planning Scenarios; a group of climate projections representative of "Between 20th Century Observed and Hot and Dry" conditions and another group of projections representative of "Hot and Dry" conditions, as reflected in Figure 16.

- "Hot and Dry" is defined as the 75th percentile of climate projections for crop irrigation requirements (water use), and the 25th percentile for natural flows. In other words, only 25 percent of projections have lower natural flows and 25 percent of projections have higher crop irrigation requirements.
- "Between 20th century-observed and hot and dry" (referred to as "In-Between") is defined as the 50th percentile for both natural flows and crop irrigation requirements. This scenario represents the middle of the range in terms of severity.

For comparison, historical or current conditions, which represent no change in runoff or in crop irrigation requirements, fall at roughly the 9th and 67th percentiles; meaning that 91 percent of individual projections show increases in crop irrigation requirements and 67 percent show reductions in runoff.



"Hot and dry" is defined as the 75th percentile of climate projections for crop irrigation requirements (water use), and the 25th percentile for natural flows. In other words, only 25 percent of projections have lower natural flows and 25 percent of projections have higher crop irrigation requirements. "Between 20th century-observed and hot and dry" is defined as the 50th percentile for both natural flows and crop irrigation requirements. This scenario represents the middle of the range in terms of severity. Historical or current conditions, which represents no change in runoff or in crop irrigation requirements, fall at roughly the 9th and 67th percentiles; this means that 91 percent of runs show increases in crop irrigation requirements and about two-thirds show reductions in runoff.

Figure 16: Colorado's Water Plan Selected Climate Projections

The effort associated with processing the projected climate data and downscaling the information for use at the Water District level was completed through the Colorado River Water Availability Study Phase II (CRWAS-II) project. This effort resulted in a time series of factors for each Water District reflecting the relative change in IWR under each climate projection. Refer to the *Technical Update Temperature Offsets and Precipitation Change Factors Implicit in the CRWAS-II Planning Scenarios* memorandum for more information on the development of the climate-adjusted factors. These factors were then limited to the 95th percentile of change factors in their river basin to eliminate large outliers that occurred due to the down-scaling process. The North Platte and Arkansas River Basin consumptive use analyses extend beyond 2013. Change factors for these additional years (e.g. 2014 – 2017) were developed by using a climate change factor from a year that most closely matched the monthly and annual IWR from the additional year.

Figure 17 reflects the annual IWR factors averaged over the West Slope and East Slope basins for the Hot and Dry and In-Between scenarios. The "pool" of climate scenarios used to develop the overall Hot and Dry and In-Between conditions over historical years in which climate projections were applied generally show a greater summer warming effect in basins at higher elevations, therefore the West Slope factors are generally greater than those developed for the East Slope basins. Additionally, the scenarios tend to show greater warming effects during years that were historically cooler and/or had higher precipitation, inversely resulting in lower factors during drought periods (i.e. periods that, historically, were already hot and dry).

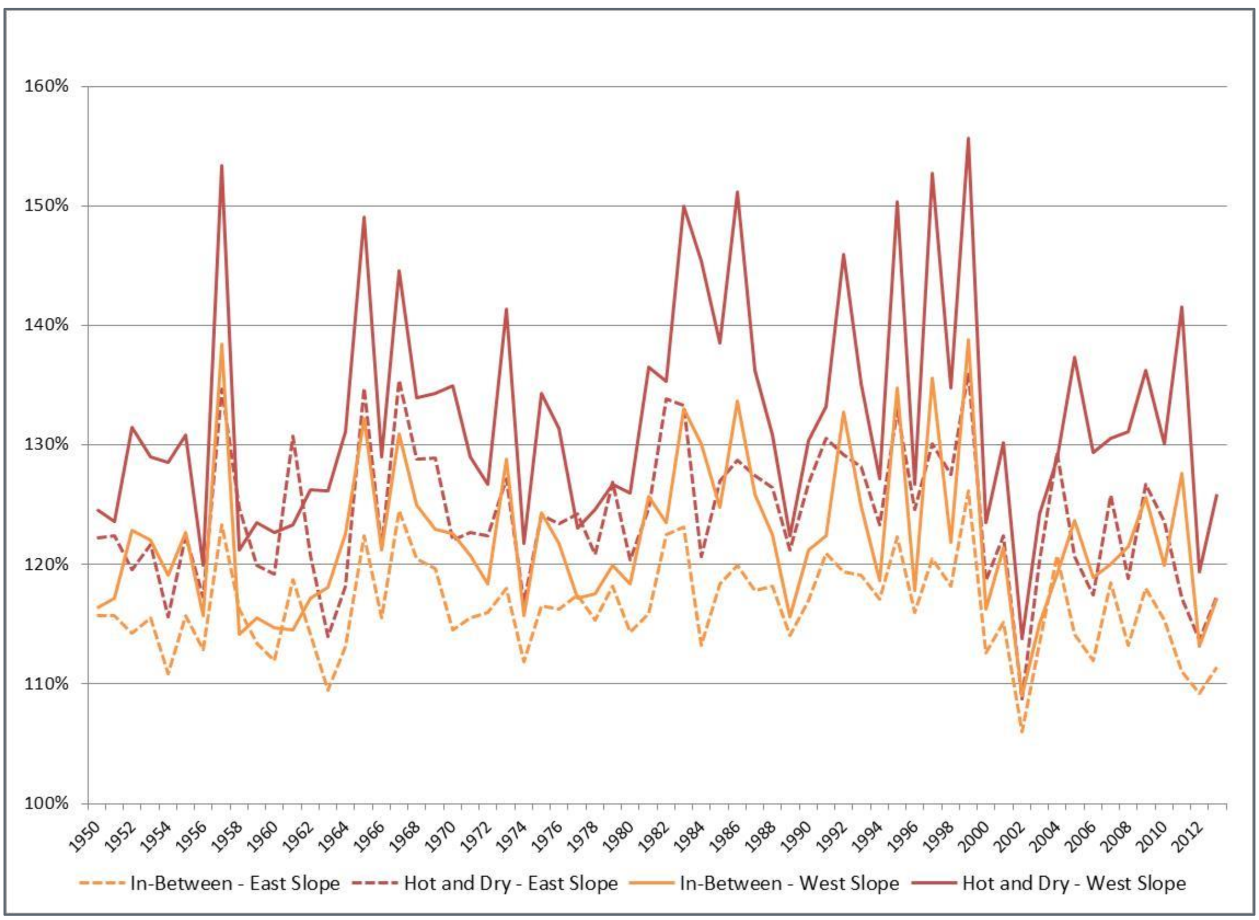


Figure 17: Average IWR Change Factors

It is important to note that factors must be applied to estimates of IWR, which also reflect monthly and annual variability due to changes in temperatures and precipitation. As an example, Figure 18 reflects the average annual unit IWR for irrigated acreage in the White River Basin; the In-Between and Hot and Dry IWR factors for the basin; and the resulting unit IWR after the application of the IWR factor. For this basin, the factors have the effect of significantly increasing the IWR during historically cooler periods and only slightly increasing the IWR during drought periods. Over the 1950 to 2013 period, the average annual unit IWR is projected to increase approximately 20 percent in the Cooperative Growth scenario compared to historical climate conditions and 35 percent compared to historical conditions in the Adaptive Innovation and Hot Growth scenarios.

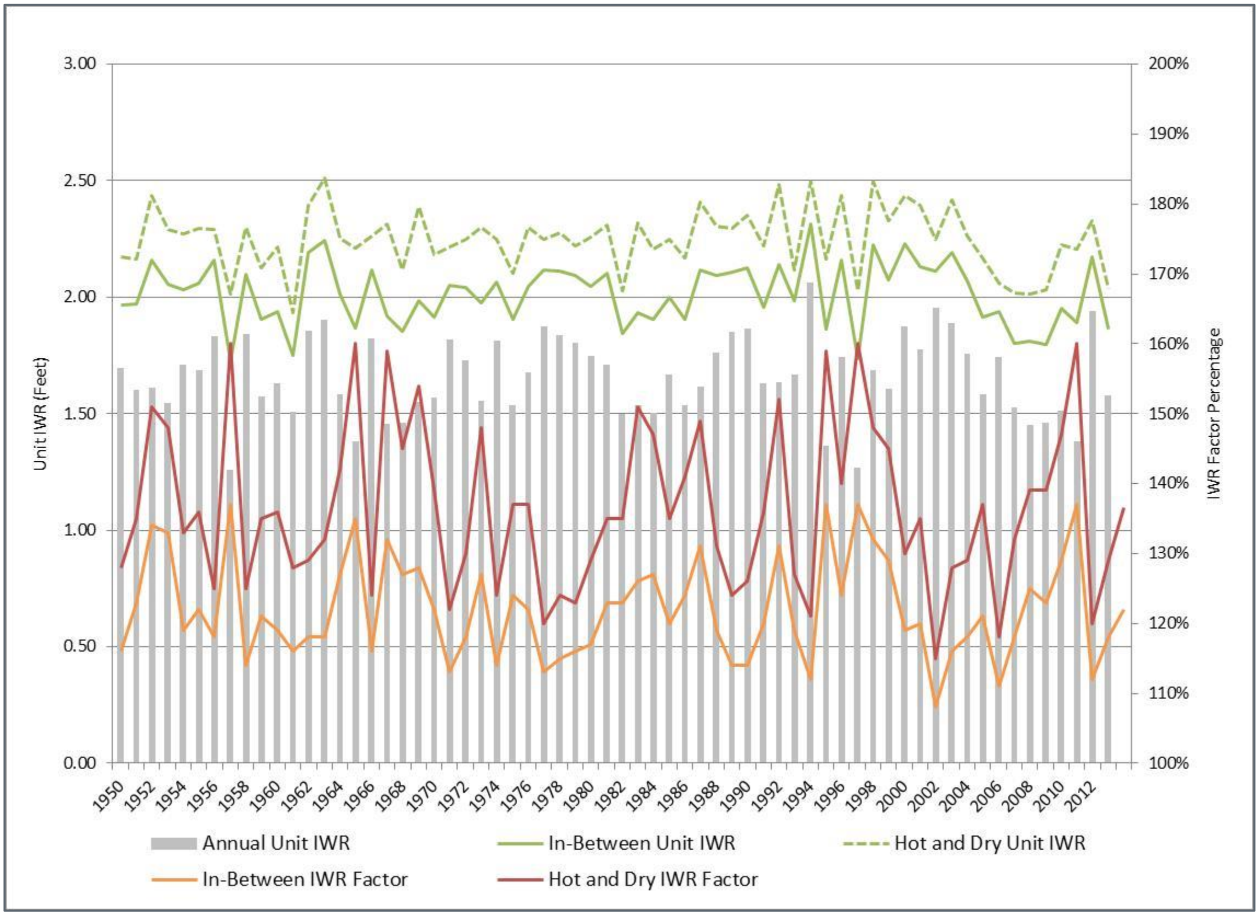


Figure 18: White River Basin Unit IWR and Planning Scenario Factors

Using the "Climate Status" driver under each Planning Scenario as a guide, Table 9 reflects the assignment of projected climate conditions for 2050 Planning Scenarios.

Table 9: Climate Factors by Planning Scenario

Planning Scenario	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Climate Factor	Current	Current	In-Between	Hot and Dry	Hot and Dry

6.5 EMERGING TECHNOLOGIES

Emerging agricultural technologies will continue to play a significant role in water use by 2050. Instrumentation, automation, and telemetry have improved irrigation efficiency and scheduling in many areas of Colorado and will likely continue to improve into the future. Improvements to the efficient delivery and application of water, through new drip irrigation or sprinkler technologies (or additional adoption of these practices), may reduce water supply shortages and/or reduce the amount of water diverted or pumped. Innovations in seed technologies have resulted in more drought-tolerant hybrids and seed varieties that require less water to produce the same or greater crop yield. In order to capture the potential effect of these emerging technologies in the 2050 Planning Scenarios, two specific adjustments will be made under this Technical Update effort.

1. Sprinkler Development. The South Platte River basin has experienced significant conversion of flood irrigation practices to center-pivot sprinklers for the past several decades, effectively increasing the efficiency of the irrigated land. Based on the CDSS Irrigated Acreage Assessments, approximately 28 percent of the acreage in the South Platte River basin was irrigated using sprinklers in 1997; the percentage increased to 44 percent by 2010. The percentage is significantly higher when analyzing irrigated acreage served only by ground water; 43 percent in 1997 up to 59 percent by 2010. Discussions with stakeholders in the South Platte River Basin indicated a continued likelihood of this development to varying degrees in the Planning Scenarios. Ultimately, stakeholders agreed to assume 85 percent of total acreage served by ground water only will be under sprinklers by 2050 in the Business as Usual and Weak Economy Planning Scenarios, and 90 percent in the remaining Planning Scenarios. Stakeholders also contemplated sprinkler development in certain areas of the Arkansas River Basin in the future. Approximately 20 percent of the irrigated acreage between Pueblo Reservoir to the stateline is irrigated with sprinkler or drip systems. Stakeholders indicated that doubling the current amount of irrigated acreage supplied by more efficient systems would be feasible by 2050, even with Compact administration requiring mitigation of changes in return flows. Additional sprinkler development in the southeastern portion of the Arkansas River basin was also considered feasible; all of the irrigated acreage is to be supplied to sprinklers in the Cooperative Growth, Adaptive Innovation, and Hot Growth Planning Scenarios in this area. Sprinkler development has occurred in other basins but there are limitations preventing significant development in the future. Examples include limited amounts of irrigated land suitable for operating sprinklers, limitations to augmentation supplies required to offset irrigation improvements, or economic factors. As such, this adjustment is applicable only in the South Platte River and Arkansas River basins. Refer to Section 7.1 and Section 7.7 for additional information on how this adjustment will impact system efficiency and future agricultural diversion demand.

2. Adaptive Innovation. The Adaptive Innovation Planning Scenario narrative contemplates future technological innovations that mitigate the increased agricultural demand due to climate adjustments. In order to implement this narrative in the agricultural diversion demand methodology, the impact of these contemplated technological innovations is translated as reductions to IWR and improved system efficiencies in the methodology calculation. Because these contemplated innovations and technologies have yet to be developed; current trends or existing efficiency values were not evaluated to determine the adjustment factors. Rather, the irrigation water requirement will be reduced 10 percent Statewide to reflect increased use of drought-tolerant hybrids and changed agronomic management practices brought on by drier conditions. Additionally, system efficiency will be increased by 10 percent in select basins to

reflect improvements to conveyance/application efficiencies or irrigation/tillage practices in the future. The system efficiency adjustment will be applied in the Western Slope, North Platte River, and South Platte River basins. The adjustments will not be applied in the Arkansas River, Republican River, and Rio Grande basins due to limitations on the feasibility of significantly improving irrigation efficiencies in these basins or limitations of improving efficiencies due to Compact restrictions. Refer to each basin summary in Section 7 for additional information on how these adjustments to irrigation water requirement and efficiency are applied to the future agricultural diversion demand.

Section 7: Planning Scenario Adjustments – Basin Summaries

This section provides an overview of the current state of agriculture in each basin; opportunities and constraints that may affect agriculture in the basin by 2050; and how the Planning Scenario adjustments were implemented within each basin. The resulting Planning Scenario agricultural diversion demand by basin is provided in the next section.

7.1 ARKANSAS RIVER BASIN

Producers irrigate over 472,000 acres in the Arkansas River Basin, with nearly half of these acres located along the river between Pueblo Reservoir and the stateline (Figure 19). The fertile soils in the river valley support a wide variety of crops, including pasture grass, alfalfa, corn, grains, wheat, fruits, vegetables, and the renown Rocky Ford melons. Many of the large irrigation systems in this area rely on surface water diversions from the mainstem Arkansas River, supplemented with ground water and Fryingpan-Arkansas Project[10] deliveries. Pasture grass is the predominant crop grown outside of the Arkansas River Valley, with concentrated areas of irrigated acreage under the Trinidad Project on the Purgatoire River; along Fountain Creek downstream of Colorado Springs; and in the southeastern corner in the Southern High Plains ground water management area.

The basin also provides water to three of the fastest growing municipalities in the state, Colorado Springs, Aurora, and Pueblo, and competition for water is high. An over-appropriated basin coupled with the constraints of developing new water supplies under the Arkansas River Compact have historically led municipalities to purchase and transfer irrigation water rights to municipal uses to meet their growing needs. In the 1980s, large transfers of irrigation water rights in the Twin Lakes Reservoir and Irrigation Canal Company resulted in the dry up of 45,000 acres in Crowley County alone. More recently, however, the basin has been proactive at looking for solutions to share water supplies and has been one of the front-runners in developing alternative transfer methods, lease/fallow tools, and interruptible supply agreements in which irrigation rights can be temporarily leased to municipalities for a limited number of years (e.g. 3 years out of every 10 years).

[10] The Fryingpan-Arkansas Project is a transmountain diversion project that diverts an average of 69,000 acre-feet annually from the Colorado River Basin and delivers water for municipal, industrial, and supplemental irrigation purposes in the Arkansas River Basin.

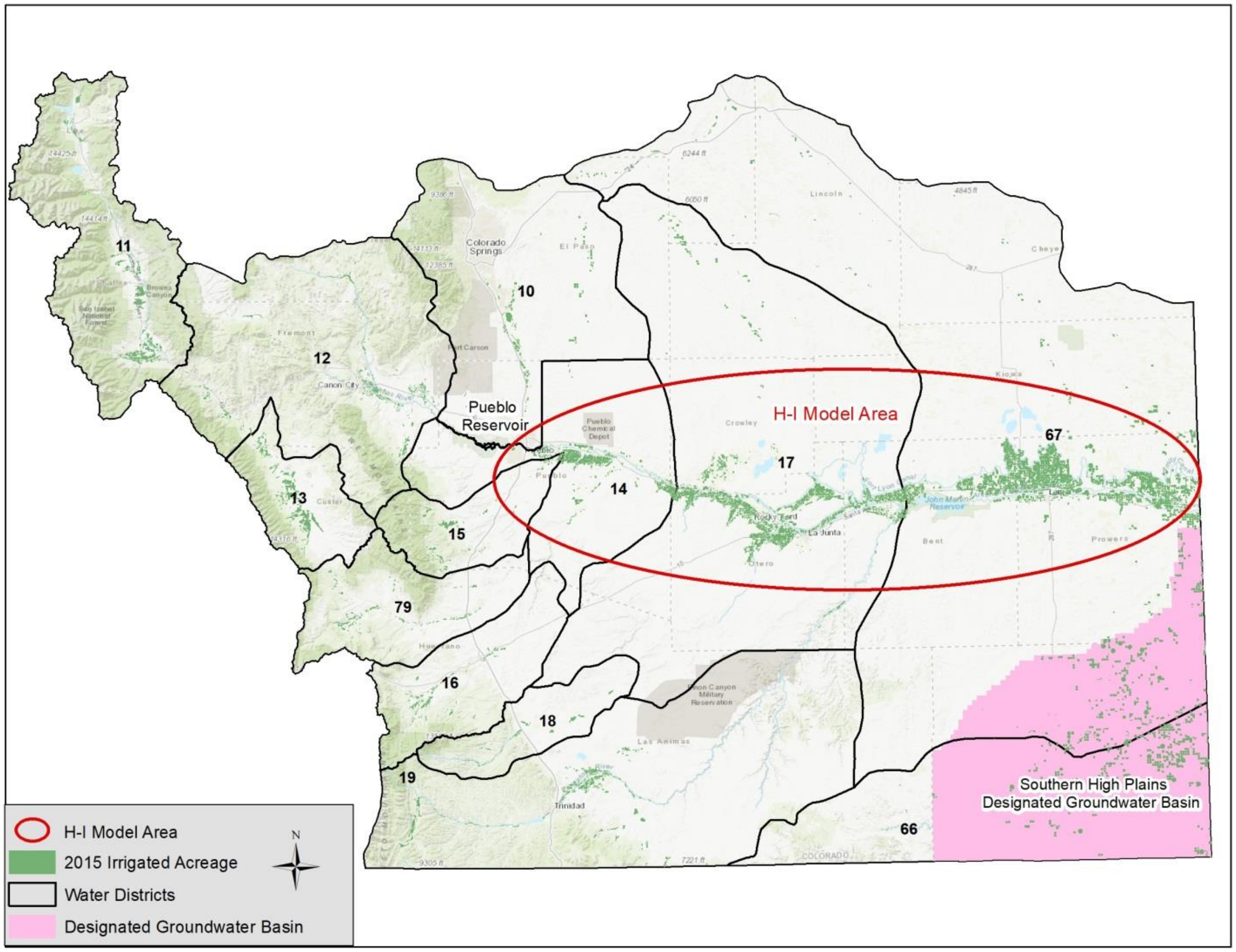


Figure 19: Arkansas River Basin Irrigated Acreage

Discussions with stakeholders in the basin regarding what agriculture in the basin may look like by 2050 focused on three major areas; additional dry up of acreage for municipal purposes, declining ground water aquifer levels in the Southern High Plains region, and irrigation practices. As discussed in more detail below, dry up of acreage and declining aquifer levels impacts the amount of projected 2050 irrigated acreage and irrigation practices effects projected 2050 efficiencies.

Population projections by 2050 in the basin reflect significant increases for Colorado Springs and Pueblo. The impact of that growth from urbanization, however, is tied to the proximity of existing municipality boundaries to agricultural operations. With limited acreage in close proximity, there is expected to be a smaller amount of irrigated acreage urbanized by their growth compared to urbanization that may occur around smaller agricultural towns such as Salida, Cañon City, and Lamar. Stakeholders in the basin noted that some of these smaller municipalities are inherently tied to the agricultural production and community that surrounds them, and if additional acreage is dried up, these municipalities will decline instead of grow as projected.

Currently portions of two irrigation ditches, Fort Lyon Canal and Bessemer Ditch, have been purchased by municipalities and their water rights are in the process of being transferred for municipal uses. It is anticipated that the portions of these ditches, totaling 12,600 irrigated acres, will be dried up by 2050. Although additional purchase of irrigation water rights is expected, the stakeholders in the basin are hopeful that leasing agreements or other solutions may limit the permanent dry up of irrigated acreage in the future.

From a ground water sustainability perspective in the basin, over 85,000 acres in the southeast corner of the basin are irrigated by ground water pumped from a series of deep aquifers, including the Ogallala, Dakota/Cheyenne, and Dockum aquifers. This area is largely disconnected from the mainstem of the Arkansas River and is managed as the Southern High Plains Designated Ground Water Basin (SHPDGWB). DWR has monitored and recorded well levels in these aquifers over time and annually reports their observations[11] . The 2018 report results are summarized in Table 10 and indicate a general downward trend over the past decade. The report notes that several monitoring wells showed rising water levels in 2018, however based on the annual well records, this is likely a temporary improvement.

Table 10: Southern High Plains Aquifer Levels (2018)

Aquifer	2018 Water Level Range (ft below ground)	Avg. Water Level Change 2017-2018 (ft)	Avg. Water Level Change 2013-2018 (ft)	Avg. Water Level Change 2008-2018 (ft)
Ogallala	94 to 305	0	-3.5	-21.2
Dakota/Cheyenne	58 to 321	0	-4.1	-13
Dockum	31 to 289	0.8	-4.2	-11.5

After review of the ground water reports, discussions with stakeholders, and conversations with landowners in the area, the acreage in this area was reduced between 10 and 33 percent across the 2050 Planning Scenarios. This range reflects the uncertainty associated with estimating the future water availability in the basin and the potential for increased pumping as projected climate change increases crop demands in the area.

The climate change conditions in the Arkansas River Basin project the largest increases to IWR in the southwest region of the basin, including the Purgatoire, Huerfano, Cucharas, and Apishapa River basins, averaging 32 percent for the In-Between climate conditions and 44 percent for the Hot and Dry conditions. Projected increases in the Upper Arkansas River Basin were slightly lower, averaging 24 percent for the In-Between conditions and 33 percent for the Hot and Dry conditions. The Lower Arkansas River Basin and Fountain Creek are projected to experience more moderate increases, averaging 5 percent and 9 percent for the In-Between and Hot and Dry conditions, respectively. As in other basins, IWR is reduced by 10 percent in the Adaptive Innovation planning scenario to account for technological innovations that may mitigate the increased agricultural demand due to climate adjustments.

The Arkansas River Basin has a unique constraint with respect to irrigation practices that improve the irrigation efficiencies. The 1948 Arkansas River Compact limits the use of irrigation return flows that were historically delivered to Kansas and therefore cannot be consumed by crops through the use of improved irrigation practices[12]. As such, any improvements to irrigation practices (e.g. methods that reduce seepage from canals, conversion from flood to sprinkler or drip irrigation systems) on acreage in the Lower Arkansas River Basin require analysis through the ISAM model to quantify the change in return flows. Any reductions to return flows must then be provided through alternative supplies, such as an augmentation plan. This limits the potential for wholesale sprinkler development in the basin (i.e. substantial conversion of flood irrigated fields over to sprinklers), however the stakeholders indicated it

[11] Source: Colorado Division of Water Resources, Groundwater Levels in the Southern High Plains Designated Groundwater Basin 2018

[12] Source: Summary of Irrigation Improvement Rules in the Arkansas River Basin by Tracy Kosloff, DWR

was feasible for the basin to experience more moderate sprinkler development in the future. Approximately 20 percent of the irrigated acreage in the H-I Model area is currently irrigated with sprinklers or drip systems. This percentage was doubled under all 2050 Planning Scenarios, resulting in 20 percent more acreage in the basin irrigated using sprinklers.

There is mixed potential for sprinkler development outside of the H-I Model area. Additional substantial sprinkler development is less likely in the Upper Arkansas River Valley and southwest tributary basins due to the topography/terrain of many fields and/or economic factors that are not conducive to the large capital investment needed for sprinkler equipment. Down in the southeast corner of the basin, however, nearly 90 percent of the irrigated acreage in the SHPDGWB area is currently under sprinkler irrigation and there is potential to fully develop the remaining 10 percent. Stakeholders indicated that in the Cooperative Growth, Adaptive Innovation, and Hot Growth Planning Scenarios, it is feasible that all of the acreage could be converted to sprinkler irrigation. Note that only adjustments to acreage irrigated by sprinklers were implemented as an Emerging Technology factor, no adjustments were made to the flood or sprinkler efficiency.

Table 11 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 11: Arkansas River Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization & Municipal Transfers	19,840 Acre Reduction	19,840 Acre Reduction	19,840 Acre Reduction	19,840 Acre Reduction	19,840 Acre Reduction
GW Acreage Sustainability	10% Acre Reduction (SHPDGWB)	15% Acre Reduction (SHPDGWB)	20% Acre Reduction (SHPDGWB)	33% Acre Reduction (SHPDGWB)	33% Acre Reduction (SHPDGWB)
IWR Climate Factor	-	-	18%	26%	26%
Emerging Technologies	20% Increased Sprinkler Use (H-I Area)	20% Increased Sprinkler Use (H-I Area)	20% Increased Sprinkler Use (H-I Area) 100% use of Sprinklers (SHPDGWB)	20% Increased Sprinkler Use (H-I Area) 100% use of Sprinklers (SHPDGWB) 10% IWR Reduction	20% Increased Sprinkler Use (H-I Area) 100% use of Sprinklers (SHPDGWB)

7.2 COLORADO RIVER BASIN

There is great diversity in the irrigated agriculture industry across the Colorado River Basin. Large ranching operations dominate agriculture in the higher elevations of the basin, particularly around the Towns of Kremmling, Collbran, and Rifle. Farming regions focused on the cultivation of fruits, vegetables, and alfalfa are more prevalent in the lower basin due to a longer growing season and warmer summer temperatures. The largest of these farming operations, the Grand Valley Project (Figure 20), irrigates about a quarter of the 206,700 acres irrigated in the entire basin. Mixed between these agricultural operations are many growing municipal communities, including Grand Junction and resort towns such as Aspen and Vail. Future irrigated agriculture in the Colorado River Basin will be affected by urbanization of irrigated acreage, climate change, and technological improvements in the industry.

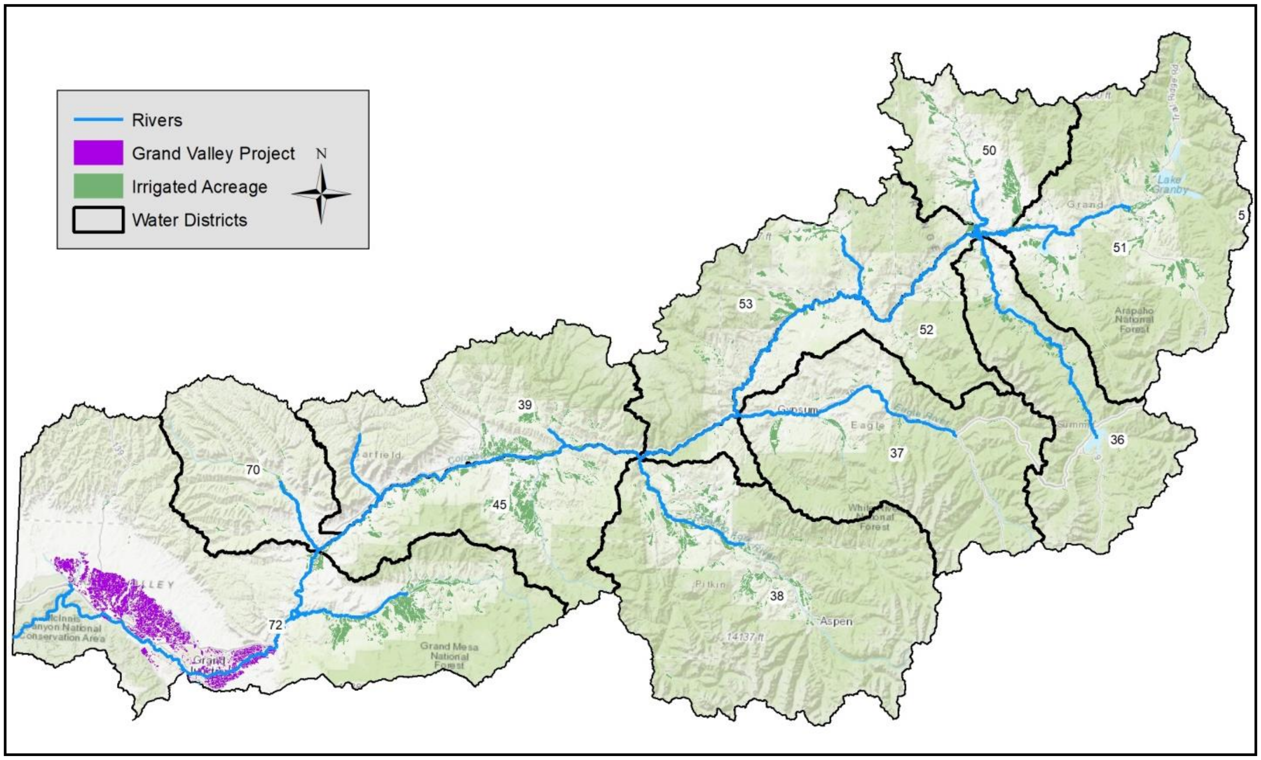


Figure 20: Colorado River Basin Irrigated Acreage

2050 population projections reflect significant increases for counties across the Colorado River Basin. The impact of urbanization, however, is tied to the proximity of existing municipalities to agricultural operations. As such, the impact of urbanization to resort communities such as the Towns of Winter Park, Breckenridge, Snowmass Village, Vail, and Avon is limited due to lack of adjacent irrigated acreage to urbanize. The impact of urbanization is expected to be much larger in agricultural-based communities such as Fruita, Grand Junction, Palisade, Eagle, and Rifle. In total, nearly 14,000 acres of irrigated land is expected to be urbanized, with one-third of that expected to occur in municipalities located in and around the Grand Valley Project.

In the Colorado River basin as a whole, IWR is projected to increase due to climate change by 20 percent and 31 percent on average for the In-Between and Hot and Dry climate conditions, respectively. Irrigated acreage upstream of the confluence of Plateau Creek with the Colorado River mainstem near Palisade is projected to experience an average increase of 21 percent for the In-Between climate conditions and 33 percent for the Hot and Dry conditions. The Lower Colorado River basin downstream of the Plateau Creek confluence, where approximately 40 percent of the irrigated acreage in the basin is located, could experience smaller projected increases in IWR of 3 percent for the In-Between conditions and 7 percent in the Hot and Dry conditions. As in other basins, IWR is reduced by 10 percent in the Adaptive Innovation planning scenario to account for technological innovations that may mitigate the increased IWR due to climate adjustments.

In addition to assuming reduced IWR, the average irrigation efficiency was assumed to increase by 10 percent in Adaptive Innovation scenario. Irrigation system efficiencies range across the Colorado River basin depending upon irrigation practices and irrigation infrastructure, averaging just under 30 percent for the basin as a whole. System efficiencies were improved by 10 percent for ditches that provide water solely for irrigation purposes in the Adaptive Innovation scenario; structures that carry water both for irrigation and for other purposes (e.g. power operations) were not adjusted.

Table 12 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 12: Colorado River Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization	13,590 Acre Reduction	13,590 Acre Reduction	13,590 Acre Reduction	13,590 Acre Reduction	13,590 Acre Reduction
IWR Climate Factor	-	-	20%	31%	31%
Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

7.3 GUNNISON RIVER BASIN

Agriculture in the Upper Gunnison River Basin, above Blue Mesa Reservoir, is defined by large cattle and sheep ranches located along the tributaries and mainstem river. Ranchers generally rely on flood irrigation to fill the alluvium during the runoff season, as supplies are typically scarce later in the irrigation season. Gravelly soils lead to large diversions and lower efficiencies in the basin, a fact captured in the high duty of water (i.e. water decreed as reasonably necessary to grow and mature a valuable crop) in many of the irrigation decrees. Irrigation in the Lower Gunnison River basin was shaped by several Bureau of Reclamation Projects, which provide supplemental irrigation supplies for much of the irrigated acreage in the area. The most notable irrigation projects in the area include the Uncompahgre Project, Paonia Project, Smith Fork Project, Fruitland Mesa Project, Bostwick Park Project, and the Fruitgrowers Dam Project, as reflected in Figure 21. Due to lower elevations and warmer temperatures, irrigators in the Lower Gunnison River basin cultivate a variety of fruits, vegetables, corn grain, and root crops on over 185,000 acres of the total 234,400 acres irrigated in the basin.

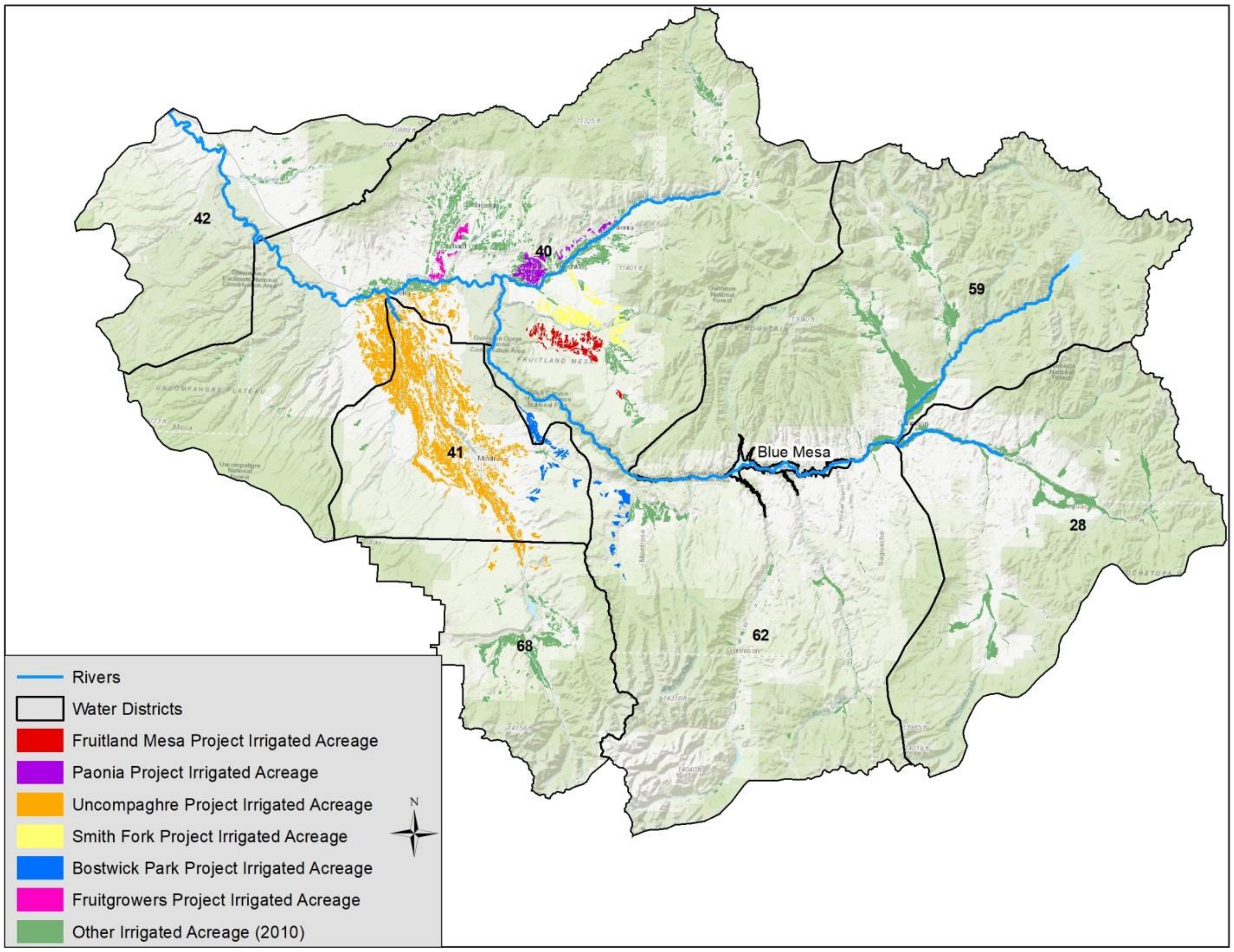


Figure 21: Gunnison River Basin Irrigated Acreage

Reflective of the importance of agriculture in the basin, many of the municipal communities in the area are surrounded by or in close proximity to irrigated acreage. Many counties in the basin are projected to have significant population increases by 2050. The resulting urbanization of irrigated acreage from this growth was estimated to be approximately 14,600 acres, primarily around Gunnison, Montrose, Delta, and the corridor between Cedaredge and Orchard City.

In the Gunnison River basin as a whole, IWR is projected to increase due to climate change by 22 percent and 33 percent on average for the In-Between and Hot and Dry climate conditions, respectively. A 32 percent and 43 percent average increase to IWR was projected for the In-Between and Hot and Dry conditions, respectively, for the Upper Gunnison River and the Upper Uncompaghre River (Water District 68). More moderate increases to IWR of 9 percent and 12 percent were estimated for irrigated lands at lower elevations. As in other basins, IWR is reduced by 10 percent in the Adaptive Innovation scenario to account for technological innovations that may mitigate the increased IWR due to climate adjustments.

In addition to assuming reduced IWR, the average irrigation efficiency was assumed to increase by 10 percent in the Adaptive Innovation scenario. Due to the prevalence of flood irrigation, system efficiency improvements have a moderate effect in the basin as a whole, increasing average system efficiency in the Adaptive Innovation scenario from 30 percent to 40 percent.

Table 13 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 13: Gunnison River Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization	14,600 Acre Reduction	14,600 Acre Reduction	14,600 Acre Reduction	14,600 Acre Reduction	14,600 Acre Reduction
IWR Climate Factor	-	-	22%	30%	30%
Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

7.4 NORTH PLATTE RIVER BASIN

Ranchers in the North Platte River and Laramie River Basins irrigate over 113,000 acres of grass and hay to support numerous calf/cow operations throughout the basin. These high mountain meadows are generally flood irrigated, and with limited storage in the basin, irrigators rely on diversions of spring and summer runoff for supplies. With low future population projections for the basin, the future agricultural diversion demands in the basin will be most impacted by the ability to maintain and even increase irrigated acreage and potential impacts from climate change.

The North Platte BIP identified seven planned agricultural projects (Table 14, Figure 22) throughout the basin, including delineation of a total of 10,576 irrigable acres and descriptions as to what structures will likely serve the new acreage. Due to the prevalence of irrigated pasture grass related to ranching operations in the basin, it is reasonable to assume that the planned agricultural projects will also be operated for hay and cattle ranching. The North Platte BRT consistently emphasizes the importance of maintaining and increasing irrigated acreage in the basin allowable under the Nebraska v. Wyoming Equitable Apportionment Decree and foresees implementation of the planned agricultural projects in all 2050 Planning Scenarios.

Table 14: North Platte River Basin Planned Agricultural Projects

Project Name	Project Description
Hanson and Wattenberg Ditch Acreage	Irrigable acreage (1,612 acres) potentially served by rehabilitated Hanson and Wattenberg Ditch (4702030) or new North Platte diversion
Lost Creek Ditch Acreage	Irrigable acreage (1,646 acres) potentially served by existing or enlarged Darcy Reservoir or new Willow Creek pipeline (WDID 4700737)
Cumberland Ditch Acreage	Irrigable acreage (544 acres) potentially served by rehabilitation of existing Cumberland Ditch siphon under Canadian River (WDID 4700577)
Independence Ditch Acreage	Irrigable acreage (5,215 acres) potentially served by enlarged Independence Ditch and/or rehabilitated Big Creek Reservoir (WDID 4700683)
Cleveland Ditch Acreage	Irrigable acreage (1,097 acres) potentially served by rehabilitated Cleveland Ditch or new Spring Creek diversion (WDID 4700559)
Wolfer Ditch Acreage	Irrigable acreage (431 acres) potentially served by existing Wolfer Ditch (WDID 4700961) or existing or enlarged Butte Reservoir (WDID 4703598)
Bona Fide Ditch Acreage	Historically irrigated acreage (31 acres) served by rehabilitated Bona Fide Ditch (WDID 4700515)

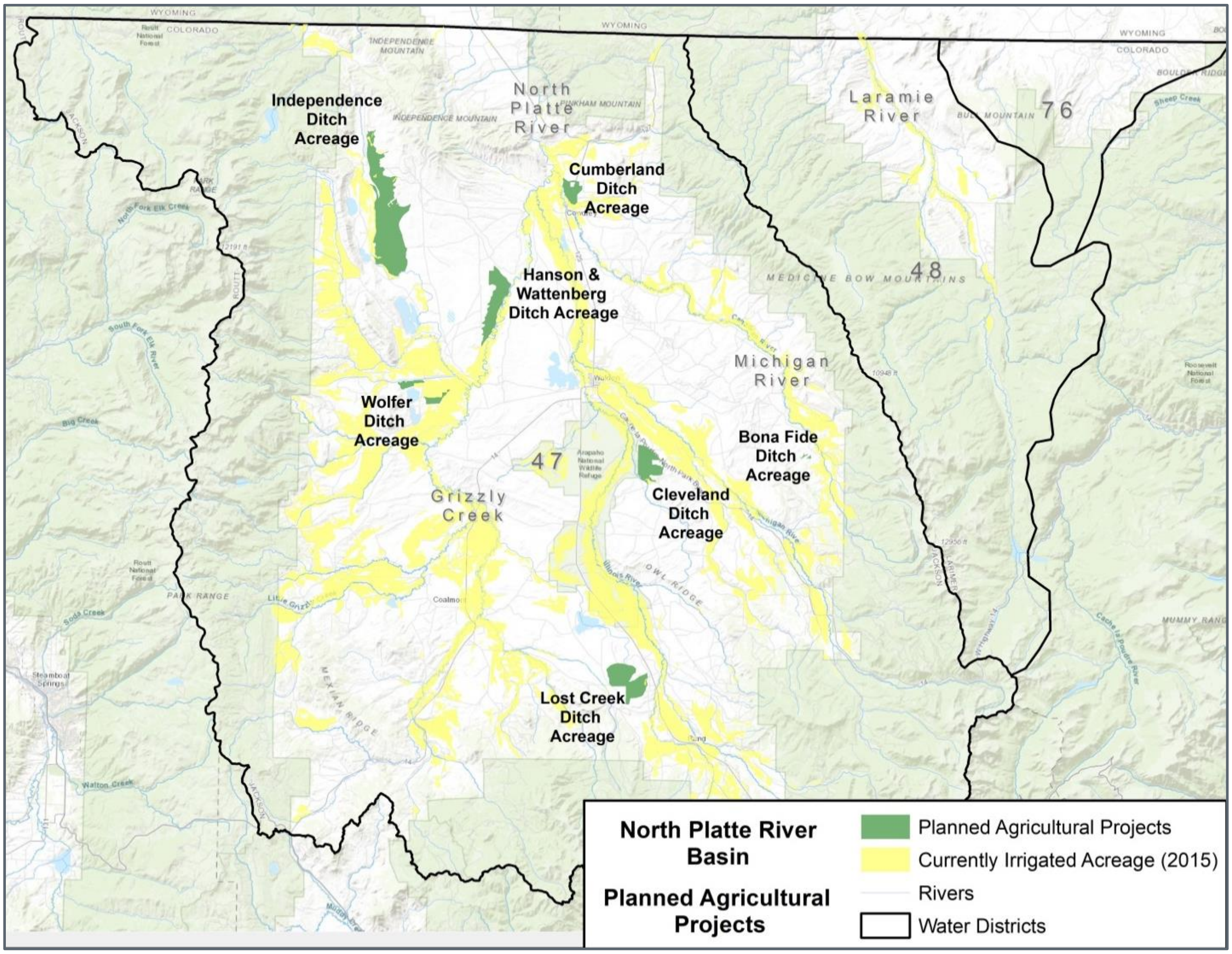


Figure 22: North Platte River Basin Planned Agricultural Projects

Based on modest projections of population increases for the basin in the Adaptive Innovation and Hot Growth scenarios, urbanization of approximately 40 acres of irrigated land was estimated to occur in and around the Town of Walden. The remainder of the Planning Scenarios reflected either no change or decreases to population in Jackson County, therefore urbanization is set to zero for these scenarios.

The climate change scenarios project modest increases to IWR in Jackson County relative to projections in adjacent basins, reflecting a 16 percent increase for the In-Between climate conditions and 26 percent for the Hot and Dry climate conditions. Higher increases to IWR are projected for the Laramie River basin, resulting in a 31 percent increase for the In-Between conditions and 49 percent for the Hot and Dry scenario. IWR is reduced by 10 percent in the Adaptive Innovation scenario to account for technological innovations that may mitigate the increased IWR due to climate adjustments.

In addition to assuming reduced IWR, the average irrigation efficiency was assumed to increase by 10 percent in the Adaptive Innovation scenario. As with other basins that primarily flood irrigate, system efficiency improvements have a moderate effect in the basin as a whole, increasing average system efficiency in the Adaptive Innovation scenario from 33 percent to 43 percent.

Table 15 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 15: North Platte River Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization	-	-	-	40 Acre Reduction	40 Acre Reduction
Planned Agricultural Projects	10,576 Acre Increase	10,576 Acre Increase	10,576 Acre Increase	10,576 Acre Increase	10,576 Acre Increase
IWR Climate Factor	-	-	25%	39%	39%
Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

7.5 REPUBLICAN RIVER BASIN

The Republican River Basin has nearly 580,000 irrigated acres, making it one of the highest producing basins of irrigated crops in the State. The basin has very limited surface water supplies and as such, there are virtually no surface water diversions left in the basin. To irrigate crops, water users rely on ground water supplies from the High Plains Aquifer (also known as the Ogallala Aquifer). Approximately 10 percent of total pumping is subject to the Republican River Compact with the remaining 90 percent pumped from “storage” in the High Plains Aquifer. Ground water pumping is managed by the several Ground Water Management Districts in the basin, as reflected in Figure 23.

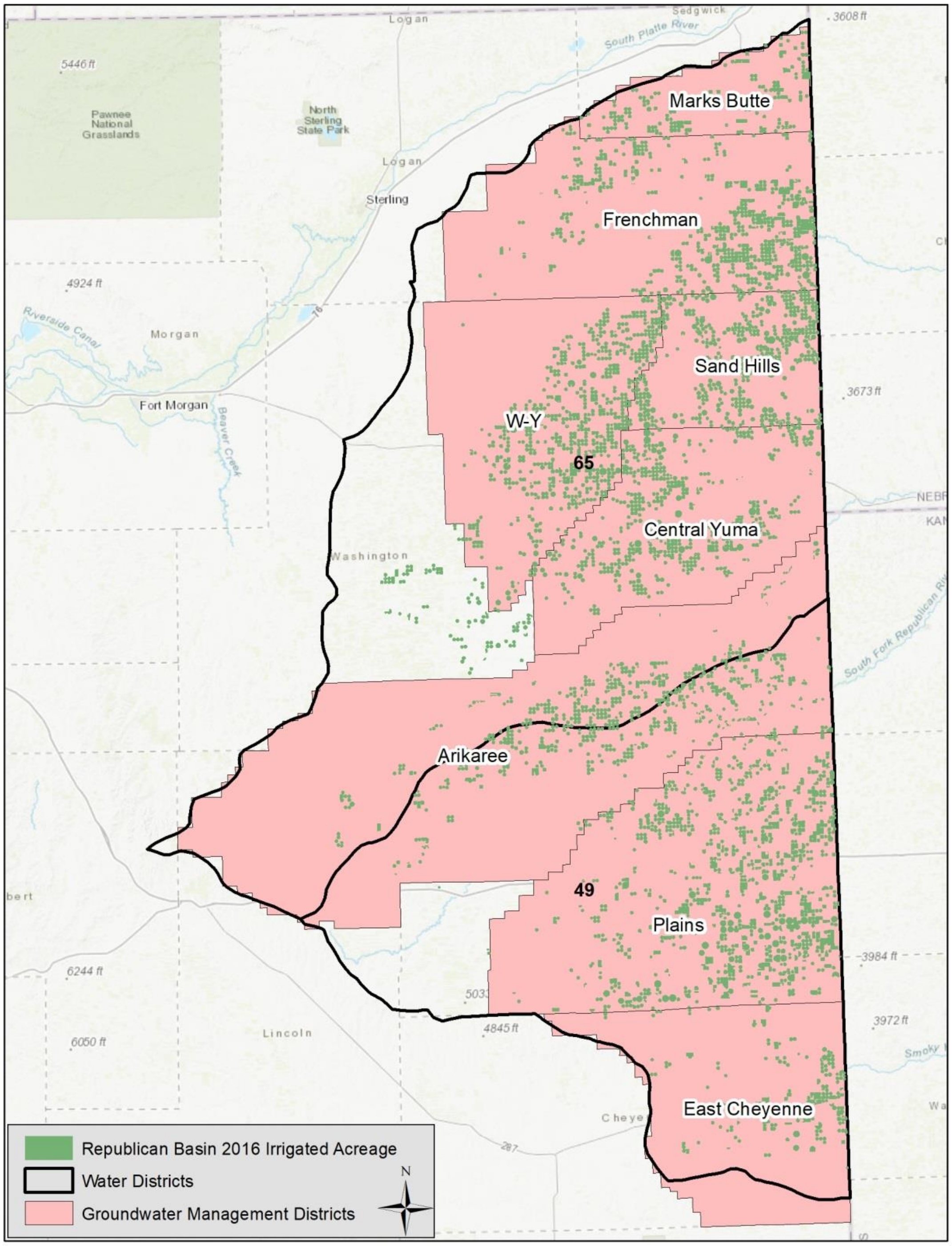


Figure 23: Republican River Basin Ground Water Management Districts

Large capacity (>50 gpm) irrigation and commercial wells developed in the basin after 1942 are subject to the Republican River Compact. Since 2002, when the Republican River Compact Final Settlement Stipulation was approved, water users in the basin have changed how water is managed to better assist the State of Colorado reach and maintain compact compliance. Efforts include establishment of the Republican River Water Conservation District (RRWCD) in 2004, voluntary retirement of more than

30,000 irrigated acres[13] , and construction of the Compact Compliance Pipeline to deliver pumping ground water from wells purchased by the RRWCD to downstream states. Bonny Reservoir was also drained in 2011 to reduce evaporative and seepage losses.

In addition to Compact compliance, the basin is also experiencing declining thickness of the High Plains Aquifer. Ground water modeling supporting the Republican River Compact Accounting reflects thinning aquifer levels, particularly in the southern and western areas of the basin, and if current pumping rates were to continue into the future the aquifer would be depleted such that irrigation in many of these areas could not continue. The future of agriculture in the basin will be dictated by the sustainability of High Plains Aquifer and Compact compliance.

Through discussions with RRWCD of these issues, stakeholders in the basin indicated that the current levels of irrigation will decline by 2050. Stakeholders noted that the recent resolution by the Republican River Compact Administration (August 24, 2016) called for the retirement of 25,000 irrigated acres in the South Fork Republican River basin by 2027 through Conservation Reserve Enhancement Program (CREP) or other voluntary acreage reduction programs. Additionally, the RRWCD has investigated purchasing and changing the use of additional ground water rights to increase deliveries through the Compact Compliance Pipeline. These reductions to acreage for compact compliance resulted in the removal of 35,000 acres for the Technical Update effort, however this removal may not be sufficient for long-term compliance and additional acreage may have to be retired.

Stakeholders also discussed inevitable reductions to irrigated acreage in the basin due to declining High Plains Aquifer (i.e. Ogallala Aquifer) levels. Guided by ground water modeling results performed for the RRWCD and considering reductions for Compact Compliance, stakeholders estimated the percent change of total acreage in each Ground Water Management District that could be expected by 2050. Stakeholders estimated reductions to acreage in all Ground Water Management Districts except the Sandhills District, as reflected in Table 16. A modest 5 percent increase was estimated for the Sandhills District as it may be one of the last areas with sufficient aquifer thickness to support irrigation pumping.

Table 16: Changes to Republican River Basin Irrigated Acreage by 2050 - Ground Water Sustainability

Ground Water Management District	Current (2016) Acreage	% Change	Estimated Dry-up	2050 Irrigated Acreage
Plains	134,640	-45%	-60,590	74,050
Frenchman	79,500	-15%	-11,925	67,575
Marks Butte	23,200	-15%	-3,480	19,720
Y-W	93,900	-20%	-18,780	75,120
Sand Hills	67,040	5%	3,350	70,390
Central Yuma	76,330	-10%	-7,630	68,700
Arikaree	78,760	-30%	-23,630	55,130
East Cheyenne	25,470	-50%	-12,735	12,735
Total	**578,840**	**-24%**	**-135,420**	**443,420**

In addition to these reductions, current population projections for the basin indicated that municipal growth may occur in all scenarios except for the Weak Economy scenario. The small agricultural communities in the basin are surrounded by irrigated acreage, and any population growth may result in

[13] Estimated reduction to irrigated acreage from 2004 to 2016; sourced from RRWCD

the urbanization of irrigated land. A total of 1,410 acres was projected to be urbanized in the basin for this effort. The economy in the basin, however, has historically been heavily reliant on agriculture and to the extent groundwater levels decline and land comes out of production, populations of local communities may also decline over time.

Modest increases to IWR are projected for the Republican River basin, relative to other areas of the State. For the northern portion of the basin (Water District 65), IWR is projected to increase by 4 percent for the In-Between climate conditions and 10 percent for the Hot and Dry conditions. The southern portion of the basin (Water District 49) is projected to experience a 5 percent and 13 percent increase to IWR in the In-Between and Hot and Dry climate conditions, respectively. IWR is reduced by 10 percent in the Adaptive Innovation scenario to account for technological innovations that may mitigate the increased IWR due to climate adjustments.

Over 95 percent of the acreage in the basin is currently irrigated by sprinklers. Very few flood operations remain in the basin, and stakeholders indicated that areas irrigated by flood practices are likely not suitable for conversion to sprinkler operations. As such, no adjustments for system efficiency improvements will be applied in the Planning Scenarios in the Republican River basin.

Table 17 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 17: Republican River Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization	1,410 Acre Reduction	-	1,410 Acre Reduction	1,410 Acre Reduction	1,410 Acre Reduction
GW Acreage Sustainability	135,420 Acre Reduction	135,420 Acre Reduction	135,420 Acre Reduction	135,420 Acre Reduction	135,420 Acre Reduction
IWR Climate Factor	-	-	4%	11%	11%
Emerging Technologies	-	-	-	10% IWR Reduction	-

7.6 RIO GRANDE BASIN

Irrigated acreage in the Rio Grande basin, and particularly in the San Luis Valley, is inherently tied to the basin's unique surface and ground water supplies. Surface water supplies diverted from streams fed by snowmelt are highly variable from year to year, with annual runoff in high flow years yielding up to eight times[14] more than in drought years. Ground water supplies are available from stacked aquifers located in the Valley floor; the upper unconfined aquifer and the deeper confined aquifer. Ground water withdrawals (i.e. pumping and artesian supplies) provide for a more consistent irrigation supply. Although recharge to the unconfined aquifer occurs relatively quickly, decades of withdrawals greater than recharge have it severely depleted. The deeper confined aquifer supplies fewer wells than the unconfined aquifer due to its depth, however also experiences greater withdrawals compared to recharge. Daily administration of the Rio Grande Compact, which primarily restricts surface water diversions through

[14] Source: Rio Grande Basin Implementation Plan (April, 2015)

curtailment to meet Compact deliveries, further impacts water availability in the basin. These surface and ground supplies combined currently support the irrigation of approximately 515,000 acres in the basin, predominately in grass, alfalfa, small grains, and potatoes, however the future of agricultural in the basin is threatened by more frequent periods of drought and declining aquifer levels.

Spurred by the early 2000s drought, declining levels of the unconfined aquifer in the Closed Basin along with reduced confined aquifer pressure Valley-wide, and passage of Senate Bill 04-222 mandating the promulgation of ground water rules and regulations by the Division of Water Resources (DWR), the Rio Grande Water Conservation District (RGWCD) created the first Special Improvement District of the Rio RGWCD (Subdistrict No. 1) in 2012. Through management of ground water withdrawals and recharge, Subdistrict No. 1 operates on an annual basis to replace injurious stream depletions caused by the Subdistrict wells; recover aquifer levels; and maintain a sustainable irrigation supply from the aquifers for the long term. The impacts to streams covered by the Subdistricts are derived from a basin-wide ground water model, developed through the Rio Grande Decision Support System (RGDSS)[15].

The first Subdistrict formed, Subdistrict No. 1, began operations in 2012 and encompasses approximately 174,000 irrigated acres in the Closed Basin area. Additional Subdistricts located throughout the basin, as reflected on Figure 24 from the RGWCD, are currently in various stages of formation.

- Subdistrict No. 2 covering the Rio Grande Alluvium and Subdistrict No. 3 covering the Conejos area began operating in 2019.
- Subdistricts No. 4, No. 5 and No. 6 covering the San Luis Creek, Saguache, and Alamosa/La-Jara Creek areas, respectively, are under development.

Due to the large amount of acreage in the Subdistrict areas, management of these Subdistricts will likely shape how irrigated agriculture will look by 2050.

[15] RGDSS represents groups of wells with similar hydraulic characteristics as a “response area”, and their combined impact to streams is represented as a “response function”. Each Subdistrict represents the geographic area reflected in the RGDSS “response area”.

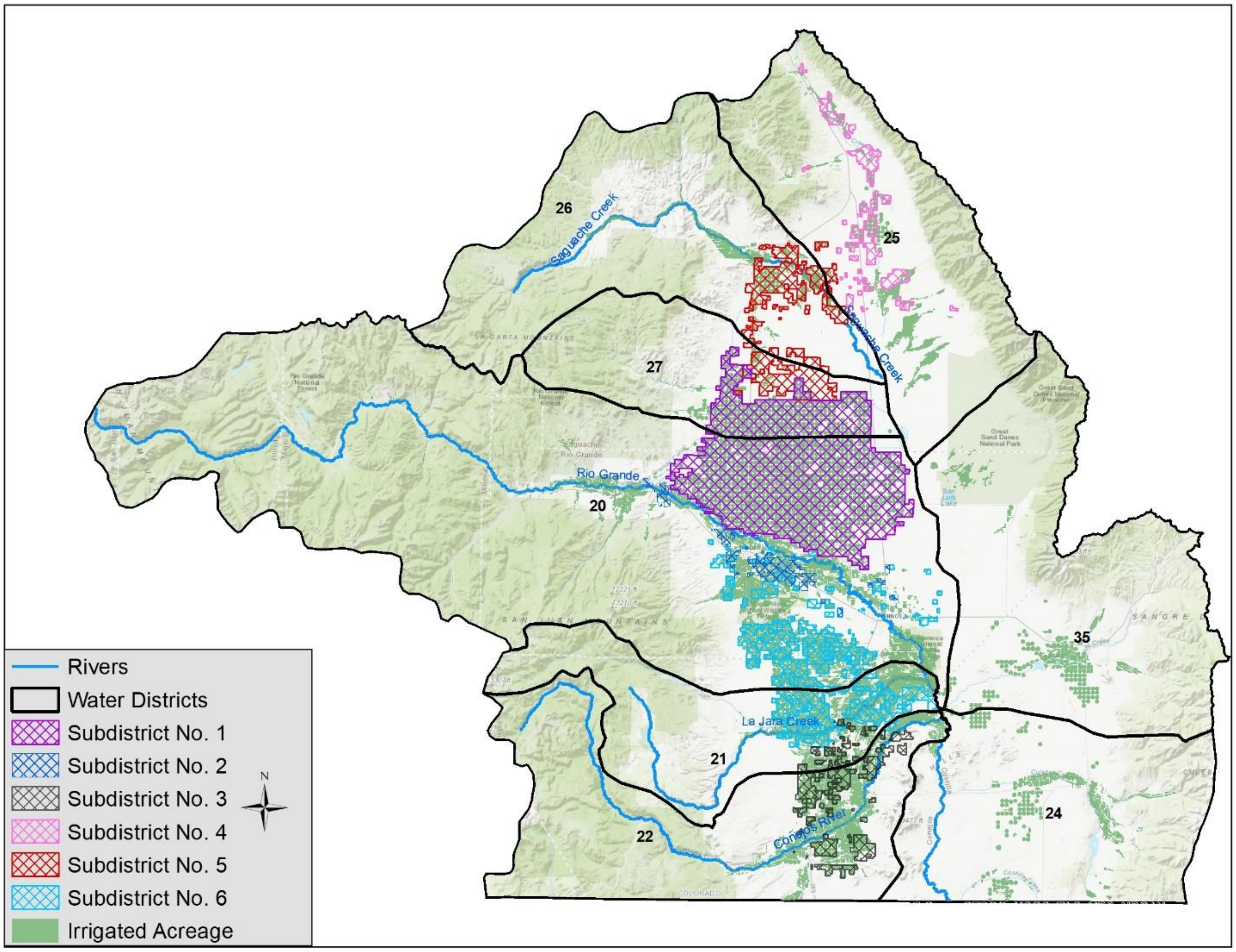


Figure 24: Rio Grande Basin Irrigated Acreage and Groundwater Management Subdistricts

Discussions with RGWCD, San Luis Valley Water Conservancy District (SLVWCD), Conejos Water Conservancy District (CWCD), stakeholders in the basin, and DWR staff for the Technical Update effort indicated that irrigated acreage will likely decline by 2050 in the basin. The group noted three primary reasons for this decline, discussed in more detail below:

1. Acreage already taken out of production in recent years
2. Reduction in pumping to mitigate declining unconfined aquifer levels
3. Reduction in pumping to mitigate declining confined aquifer levels

Analysis of the agricultural diversion demand for this Technical Update effort relied on data and modeling efforts completed by DWR in support of Rules and Regulations promulgation in the basin. The most recent irrigated acreage assessment available was developed for 2010 conditions. Between 2010 and 2018, approximately 20,000 irrigated acres were taken out of production in Subdistrict No. 1. Approximately 10,000 acres of the 20,000 acres have been enrolled in USDA's Conservation Reserve Enhancement Program (CREP) since 2012.

As reflected in Figure 25 below, a graphic available from RGWCD, storage in the unconfined aquifer in the West Central San Luis Valley has declined over 1.1 million acre-feet since the early-1990s. When the plan to create Subdistrict No. 1 was approved, the plan called for recovery of groundwater levels in the unconfined aquifer of the Closed Basin such that by the end of 2031 groundwater levels will have recovered to within 200,000 to 400,000 acre-feet below the January 1, 1976 storage levels . Based on the current unconfined aquifer storage, RGWCD and water users in Subdistrict No. 1 have thirteen years to overcome a minimum 700,000 acre-foot deficit in the unconfined aquifer. The stakeholder group estimated that it would need a reduction of 20,000 acres in the Subdistrict No. 1 area to refill the aquifer. This estimation is based on current hydrology; if drier conditions persist in the future more acreage may need to be removed.

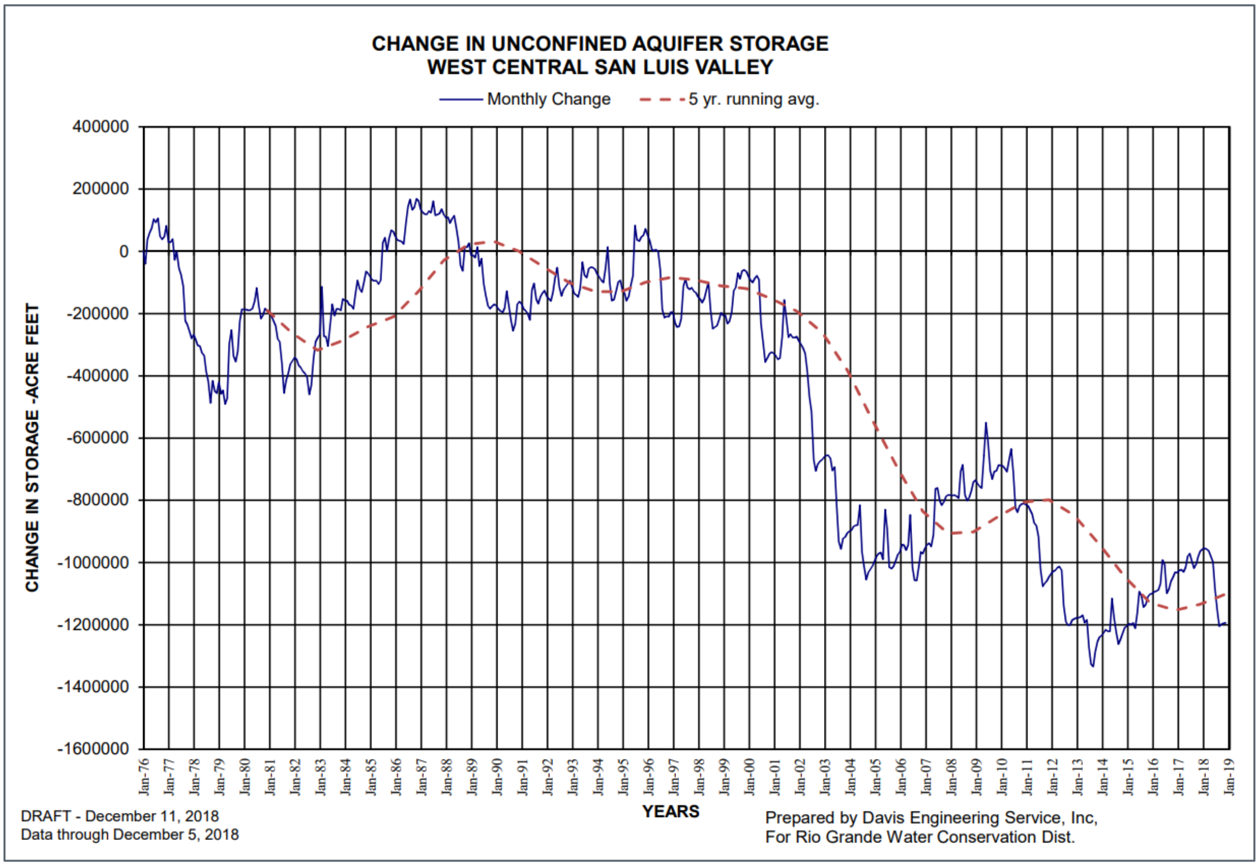


Figure 25: Change in San Luis Valley Unconfined Aquifer Storage

The stakeholder group also indicated that approximately 5,000 acres will need to come out of production to mitigate depletions in the confined aquifer. Metered ground water withdrawals from the confined aquifer in the Conejos, Alamosa/La-Jara, San Luis, and Saguache Creek areas over the most recent five years is compared to average withdrawals over the historical 1978 to 2000 period by DWR. Areas in which the five year average is greater than the historical average indicate an unsustainable level of withdrawals. The most recent reporting available from DWR[16] indicated that recent withdrawals were approximately 10,000 acre-feet greater than the historical average. This value led the stakeholders to estimate a 5,000 acre reduction across the basin to reach sustainability. As with the unconfined aquifer mitigation, this estimation is based on current hydrology; if drier conditions persist in the future more acreage may need to be removed. In total, 40,000 irrigated acres were removed from the Subdistrict No.1 area and 5,000

[16] Source: *Five Year Average Ground Water Withdrawals in Confined Aquifer Response Areas in Division 3: July 2018 Requirement of Division 3 Ground Water Rules Section 8.1.5* (DWR website)

irrigated acres were removed across the basin in all 2050 Planning Scenarios for the Ground Water Sustainability factor.

IWR in the Rio Grande Basin is projected to increase on average by 15 percent for the In-Between climate conditions and 18 percent on average for the Hot and Dry conditions. Water District 24 in the southeastern part of the basin is projected to have the largest increase in IWR in the basin with 17 percent and 20 percent under In-Between and Hot and Dry conditions, respectively. Faced with this information, the stakeholder group discussed what the ultimate effects on the basin may be if IWR increases to these levels, particularly in light of the Rio Grande Compact. The group ultimately decided that as the Compact will continue to limit surface water availability, any increase in IWR would likely lead to irrigated acreage being taken out of production because there would not be sufficient surface water supplies to meet these increased demands.

To account for this future potential outcome, it was assumed that the percent increase in IWR by Water District would result in the same percent decrease in irrigated acreage. With basin-wide unit IWR historically averaging 2 acre-feet per acre and crop consumptive use in the basin historically averaging 1.3 acre-feet per acre, this is potentially an underestimate of the total acreage that may come out of production under potential future climate conditions. Using this approach, however, does account for this impact and resulted in the removal of approximately 70,000 acres in the Cooperative Growth scenario and approximately 81,000 acres in the Adaptive Innovation and Hot Growth scenarios across the basin. Note that IWR is still reduced by 10 percent in the Adaptive Innovation scenario to account for technological innovations that may mitigate the increased IWR due to climate adjustments.

Modest population projections for the basin indicate that under all scenarios besides the Weak Economy scenario, the basin's population will increase and municipal water demands will grow. Irrigated acreage surrounding small towns in the basin is vulnerable to urbanization. It was estimated that approximately 4,010 acres would come out of production due to urbanization of irrigated lands in the basin.

The stakeholder group did not envision any adjustment in irrigation efficiency in the basin; current levels of sprinkler development in the basin are expected to stay relatively steady. The stakeholder group indicated that any improvement to irrigation efficiencies in the future may be used as a solution to help meet the agricultural gap.

Table 18 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 18: Rio Grande Basin Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization	4,010 Acre Reduction	-	4,010 Acre Reduction	4,010 Acre Reduction	4,010 Acre Reduction
GW Acreage Sustainability	45,000 Acre Reduction	45,000 Acre Reduction	45,000 Acre Reduction	45,000 Acre Reduction	45,000 Acre Reduction
IWR Climate Factor	-	-	15% 70,000 Acre Reduction (Basin-wide)	18% 81,000 Acre Reduction (Basin-wide)	18% 81,000 Acre Reduction (Basin -wide)
Emerging Technologies	-	-	-	10% IWR Reduction	-

7.7 SOUTH PLATTE RIVER BASIN

The South Platte River Basin is expected to experience the largest municipal growth in the state by 2050, straining already limited water supplies in the basin between municipal, industrial, agricultural, environmental and recreation users in the basin. By 2050, agriculture in the South Platte Basin will likely experience increased urbanization of irrigated lands; pressures of increased municipal needs to "buy and dry" irrigated acreage with senior water rights; limited augmentation supplies; and higher crop demands due to climate change.

There are approximately 854,300 acres of irrigated land currently in the South Platte River Basin. Urbanization of irrigated lands alone is projected to remove nearly 106,000 acres in and around existing municipalities in the basin by 2050. The majority, over 60 percent, of these 106,000 urbanized acres are projected to occur in the St. Vrain River, Big Thompson River, and Cache La Poudre River basins. This is partly driven by the projected population increases in Larimer and Weld Counties; however these basins also have some of the highest concentrations of irrigated acreage in close proximity to municipalities. Although large population increases are also anticipated in and around the Denver Metropolitan area, there is little to no irrigated acreage around the area that could potentially be urbanized. As such, urbanized acreage in Denver, Jefferson, Adams, and Arapahoe Counties totals less than 10,000 acres, or less than 10 percent of the total urbanized acreage in the basin.

For municipalities that are anticipated to grow onto existing irrigated acreage by 2050, it is reasonable to assume they will go through the process of "buy and dry". This process involves acquiring and changing the irrigation water rights associated with the irrigated acreage in Water Court in order to use the changed water as a supply to meet future municipal demands, and drying up the irrigated parcel. Growth onto existing irrigated acreage by 2050 depends on many factors, including but not limited to the seniority of the water rights; type of supply (e.g. surface/ground water, storage); ability to treat the supply which is impacted by location or quality; and/or legal restrictions on the change of use. The process of "buy and dry", however, is not limited to municipalities that urbanize irrigated acreage. Many municipalities throughout the basin have purchased irrigation water rights and ultimately dried up the acreage served by the rights; and ditches with the most senior water rights often experience the highest rates of "buy and dry".

The prevalence and impact of this practice in the South Platte River basin was discussed with respect to the sustainability of irrigated agriculture in the basin with the Lower South Platte Water Conservancy District (LSPWCD) and Central Colorado Water Conservancy District (Central) staff. These entities have observed first-hand the amount of irrigated acreage that has gone through "buy and dry", particularly under irrigation ditches that divert from the lower South Platte River in Water Districts 1 and 64 (Figure 26). LSPWCD indicated that although efforts are taking place to find flexible and innovative solutions to sharing water between agriculture and municipalities, irrigated acreage in the basin will likely continue to decrease due to "buy and dry" practices in the future. Based in part on recent trends in water rights purchases in the area, it was estimated that irrigated acreage served by surface water will decrease between 10 and 30 percent in Water Districts 1 and 64, depending on the Planning Scenario. A lower number of acres are anticipated in collaborative Planning Scenarios; and conversely a higher number of acres are anticipated in more aggressive Planning Scenarios, as reflected in Table 19. The values presented in the table below may underestimate the amount of acreage taken out of production by 2050 due to "buy and dry" as the practice is likely to occur in other areas in the South Platte River basin. Estimates of the amount of acreage however, were not readily available for this effort.

Table 19: Reduction to Irrigated Acreage Supplied by Surface Water (Water Districts 1 and 64)

Planning Scenario	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Reduction to Surface Water Acreage	20%	20%	10%	10%	30%
	42,500 acres	42,500 acres	21,200 acres	21,200 acres	63,700 acres

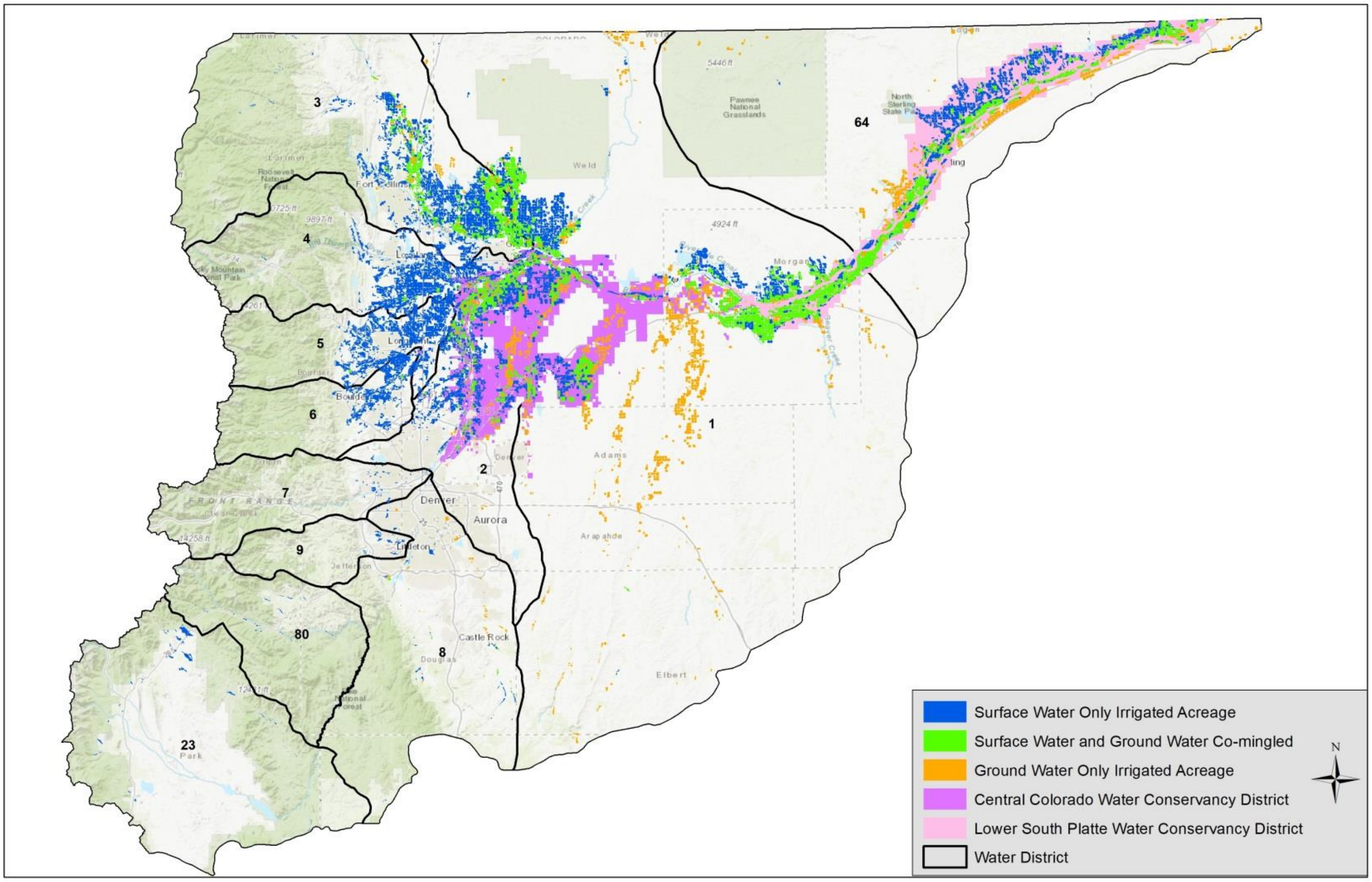


Figure 26: South Platte River Basin Irrigated Acreage

Another challenge to sustaining irrigated agriculture in the basin is the ability to maintain augmentation supplies in the future. Augmentation is the process of replacing well depletions in time and location as they impact the river flows and water supplies for senior water right holders. Irrigated acreage supplied only by junior ground water rights rely on augmentation supplies in order to pump when there is a senior call on the river and their resulting depletions are out-of-priority. The type of water used for augmentation supplies varies across the basin, however they primarily consist of water diverted under junior water rights for storage and recharge; water available from senior irrigation water rights changed for augmentation purposes; and leased reusable effluent from municipalities. As municipal entities seek opportunities to reuse more of their effluent, less effluent will be available to lease for augmentation uses. Additionally, when senior irrigation rights become available on the market, augmentation providers often compete against municipal entities to purchase these rights. These conditions put current augmentation supplies at risk and also make it difficult to obtain new augmentation supplies in the future. In response to these conditions, it was estimated that 20 percent of the irrigated acreage served only by ground water supplies within the Central service area are vulnerable and may come out of production due to a lack of augmentation supplies in 2050. This adjustment equated to approximately 4,800 acres of irrigated land removed from each of the Planning Scenarios.

Although water availability will be a limiting factor to sustaining current levels of irrigated acreage by 2050, innovative and emerging technologies will benefit the industry. As noted in the Emerging Technologies section above, 59 percent of the acreage in the South Platte River basin served only by ground water supplies was irrigated using sprinkler technologies in 2010. Stakeholders in the basin, including LSPWCD and Central, believe that sprinkler development will continue at a relatively fast pace as new technologies become available. By 2050, it is expected that between 85 to 90 percent of the acreage served only by ground water will be irrigated with sprinklers or a similar efficient form of irrigation application. This adjustment will impact system efficiency for irrigated lands located primarily in Designated Groundwater Basins and along the Lower South Platte River. In addition to the sprinkler adjustment, average system efficiency in the basin as a whole was increased by 10 percent, from 60 to 70 percent, in the Adaptive Innovation scenario. This adjustment is applicable to both flood and sprinkler irrigated lands across the basin.

In the South Platte River basin as a whole, IWR is projected to increase due to climate change by 15 percent and 24 percent on average for the In-Between and Hot and Dry climate conditions, respectively. The climate change scenarios projected relatively high increases to IWR for the headwaters of the South Platte River basin, averaging 49 percent and 73 percent for the In-Between and Hot and Dry conditions, respectively, for irrigated acreage upstream of Cheesman Lake. Projections, however, significantly decrease moving downstream in the basin. Projected increases to IWR in the Clear Creek, Cherry Creek, and Bear Creek basins are similar, averaging 13 percent for the In-Between conditions and 21 percent for the Hot and Dry conditions. Projections for basins downstream of the Boulder Creek confluence with the South Platte River reflect more moderate increases, averaging 7 percent and 12 percent, respectively, for the climate conditions. The lowest projected increases in IWR correspond to the basins with the greatest amount of irrigated acreage, muting the impact of the projected increases in the headwaters for the basin as a whole. Additionally, the Adaptive Innovation scenario contemplates that future technological innovations mitigate the increased agricultural demand due to climate adjustments anticipated by the Hot and Dry conditions. As such, the projected increases to IWR in this Planning Scenario are reduced by 10 percent.

Table 20 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 20: South Platte River Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization & Municipal Transfers	105,900 Acre Reduction 20% SW Acre Reduction (WD 1 & 64)	105,900 Acre Reduction 20% SW Acre Reduction (WD 1 & 64)	105,900 Acre Reduction 10% SW Acre Reduction (WD 1 & 64)	105,900 Acre Reduction 10% SW Acre Reduction (WD 1 & 64)	105,900 Acre Reduction 30% SW Acre Reduction (WD 1 & 64)
GW Acreage Sustainability	20% GW-Only Acre Reduction (Central)	20% GW-Only Acre Reduction (Central)	20% GW-Only Acre Reduction (Central)	20% GW-Only Acre Reduction (Central)	20% GW-Only Acre Reduction (Central)

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
IWR Climate Factor	-	-	15%	24%	24%
Emerging Technologies	85% GW Only Acreage in Sprinkler	85% GW Only Acreage in Sprinkler	90% GW Only Acreage in Sprinkler	90% GW Only Acreage in Sprinkler 10% IWR Reduction 10% System Efficiency Increase	90% GW Only Acreage in Sprinkler

7.8 SOUTHWEST BASIN

The Southwest Basin is made up of a series of nine sub-basins, each with their own unique hydrology and demands. The basin, as shown in Figure 27, is home to a diverse set of demands; several small towns founded primarily due to either mining or agricultural interests, two Native American reservations (Southern Ute Indian Tribe and Ute Mountain Ute Tribe), one major transmountain diversion (San Juan - Chama Project), and four major Reclamation Projects (Pine River Project, Dolores Project, Florida Project, and the Mancos Project) that both brought new irrigated acreage under production and provided supplemental supplies to existing lands. For areas outside of the Reclamation Projects, producers generally irrigate grass meadows for cattle operations aligned along the rivers and tributaries and rely on supplies available during the runoff season. Producers under the Reclamation Projects irrigate a wider variety of crops, such as alfalfa and row crops, due to lower elevations, warmer temperatures, and supplemental storage supplies during the later irrigation season.

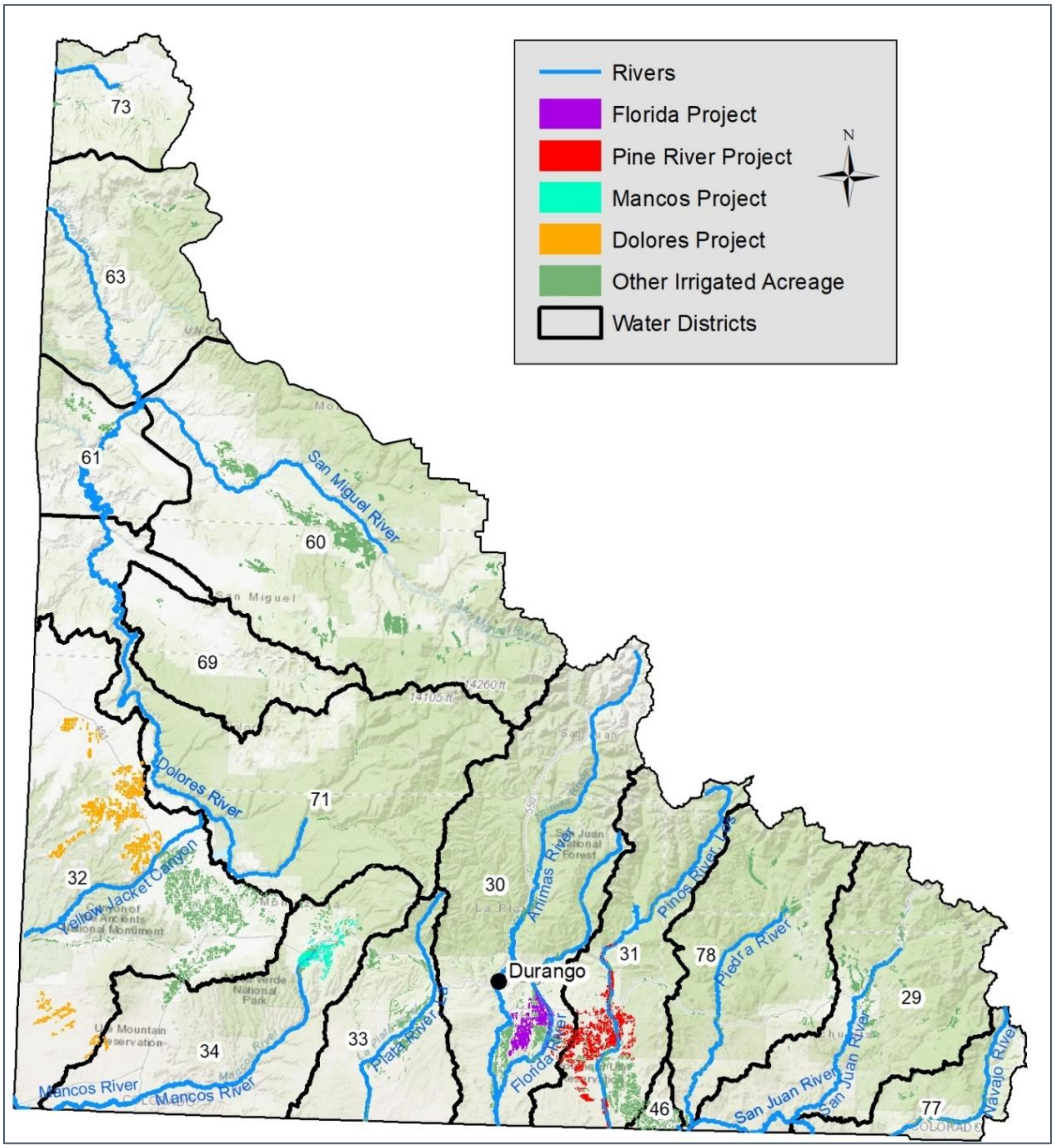


Figure 27: Southwest Basin Irrigated Acreage

Urbanization in the overall basin will likely have a limited impact on agriculture in the future, as 4,080 acres of irrigated land basin-wide were estimated to be urbanized by 2050. The larger towns of Durango, Cortez, and Pagosa Springs do not have significant areas of irrigated acreage located within or directly adjacent to the current municipal boundaries; therefore, urbanization of acreage in these areas is projected to be low in the future. Smaller towns in the basin, such as Norwood, Nucla, Bayfield, and Mancos are surrounded by irrigated agriculture, which may lead to some urbanization of irrigated lands by 2050.

In the Southwest basin as a whole, IWR is projected to increase due to climate change by 26 percent and 34 percent on average for the In-Between and Hot and Dry climate conditions, respectively. IWR is projected to increase by 42 percent and 53 percent on average for the In-Between and Hot and Dry conditions, respectively, on the ranches in the Upper San Juan, Navajo River, and Piedra River basins. More moderate increases of 22 percent and 29 percent on average for the In-Between and Hot and Dry conditions, respectively, are projected for the remainder of the basin. The sub-basin with the largest amount of irrigated acreage is the McElmo Creek basin (Water District 32) with nearly 20 percent of the total acreage in the basin. Increases of 11 percent and 15 percent to IWR on average are projected for the two climate change conditions for this sub-basin. As in other basins, IWR is reduced by 10 percent in the Adaptive Innovation scenario to account for technological innovations that may mitigate the increased IWR due to climate adjustments. In addition to assuming reduced IWR, the average irrigation efficiency was assumed to increase by 10 percent in the Adaptive Innovation scenario. System efficiency was increased from 47 to 57 percent in the Adaptive Innovation scenario basin-wide in this scenario.

Table 21 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 21: Southwest River Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization	3,800 Acre Reduction	3,800 Acre Reduction	3,800 Acre Reduction	3,800 Acre Reduction	3,800 Acre Reduction
IWR Climate Factor	-	-	26%	34%	34%
Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

7.9 WHITE RIVER BASIN

The majority of irrigated acreage in the White River Basin, approximately 60 percent of the total 28,100 acres in the basin, is concentrated along the mainstem river near the Town of Meeker (Figure 28). The remaining acreage is found along tributaries and lower mainstem spread throughout the basin. Grass pasture is the predominant crop grown in the basin to support the cattle grazing and ranching operations in the basin, with smaller areas growing alfalfa. Cattle ranching is a major economic driver in the basin, however mining and oil and gas extraction are also important elements of the basin’s economy.

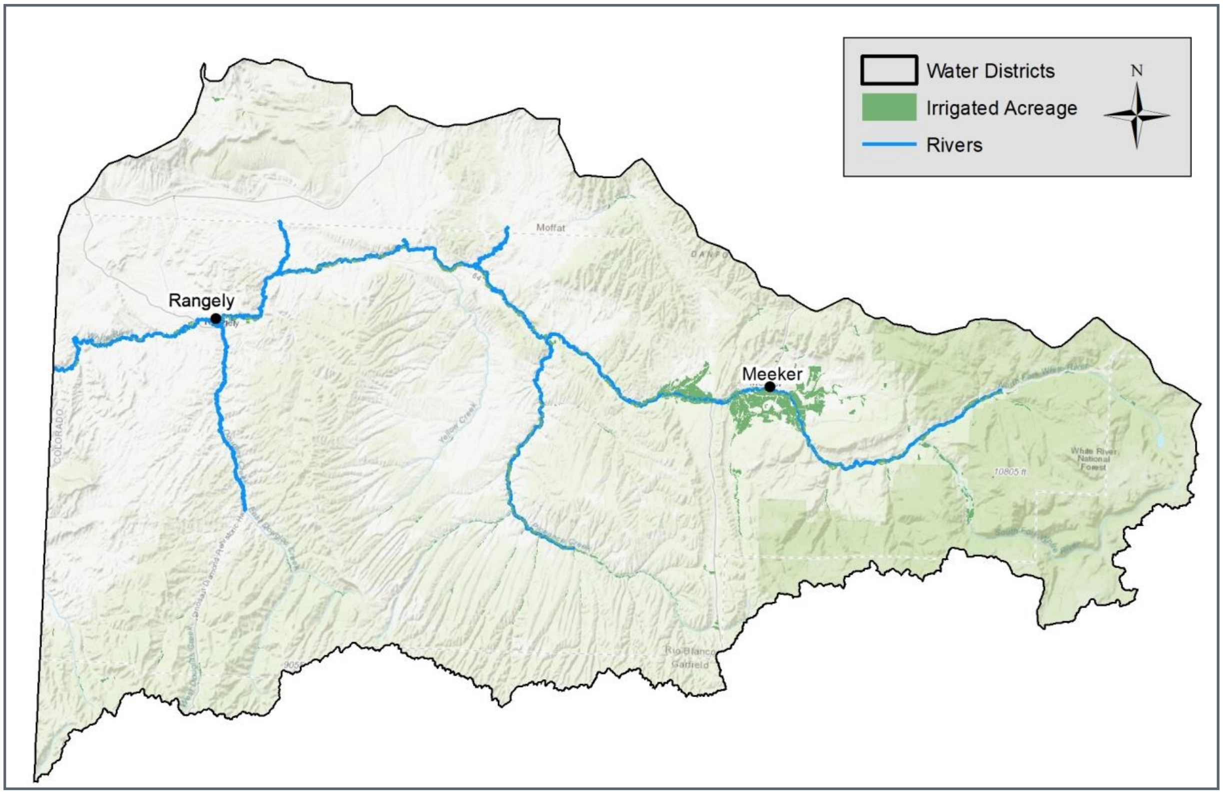


Figure 28: White River Basin Irrigated Acreage

Urbanization of irrigated lands is expected to be limited in the basin, with 360 acres total in and around the towns of Meeker and Rangely projected to be urbanized. Population projections in Rio Blanco County are expected to decline in the Weak Economy scenario, therefore urbanization in the White River Basin for this scenario was set to zero.

As reflected in the Planning Scenario Adjustment section above, IWR is projected to increase by approximately 22 percent and 37 percent on average under the In-Between and Hot and Dry conditions, respectively. IWR is reduced by 10 percent in the Adaptive Innovation scenario to account for technological innovations that may mitigate the increased IWR due to climate adjustments. Additionally, system efficiency will increase by 10 percent, from 35 to 45 percent in the Adaptive Innovation scenario to account for the impact of improved technologies that may more efficiently convey supplies to irrigated lands.

Table 22 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 22: White River Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization	360 Acre Reduction	-	360 Acre Reduction	360 Acre Reduction	360 Acre Reduction
IWR Climate Factor	-	-	22%	37%	37%
Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

7.10 YAMPA RIVER BASIN

Irrigated acreage in the Yampa River Basin consists primarily of high mountain meadows and cattle ranches in the upper reaches of the basin along Elk Creek and the Yampa River. Water users also irrigate acreage along the Little Snake River as it meanders between Colorado and Wyoming. The Yampa River Basin is an agricultural-focused basin; producers in the basin desire to maintain and increase irrigated acreage along the Yampa River mainstem. The basin also has recreational industries with a top ski destination at Steamboat Springs and the canyons along the Yampa and Green Rivers in Dinosaur National Monument.

The Yampa/White/Green River Basin Roundtable completed an Agricultural Water Needs Study in 2010. Among other objectives, the study sought to better define the location of up to 40,000 acres of potentially irrigable land within the oxbows of the Yampa River mainstem originally identified by National Resource Conservation Service (NRCS) mapping. Though the NRCS mapping was lost in a fire, the Needs Study performed a spatial analysis and identified 14,805 acres of potentially irrigable land along the Yampa River Basin between the Fortification Creek and Little Snake Creek confluences, primarily in Water District 44 (Figure 29)[17].

[17] Sourced from the Agricultural Water Needs Study (2010), Yampa/White/Green River Basin Roundtable

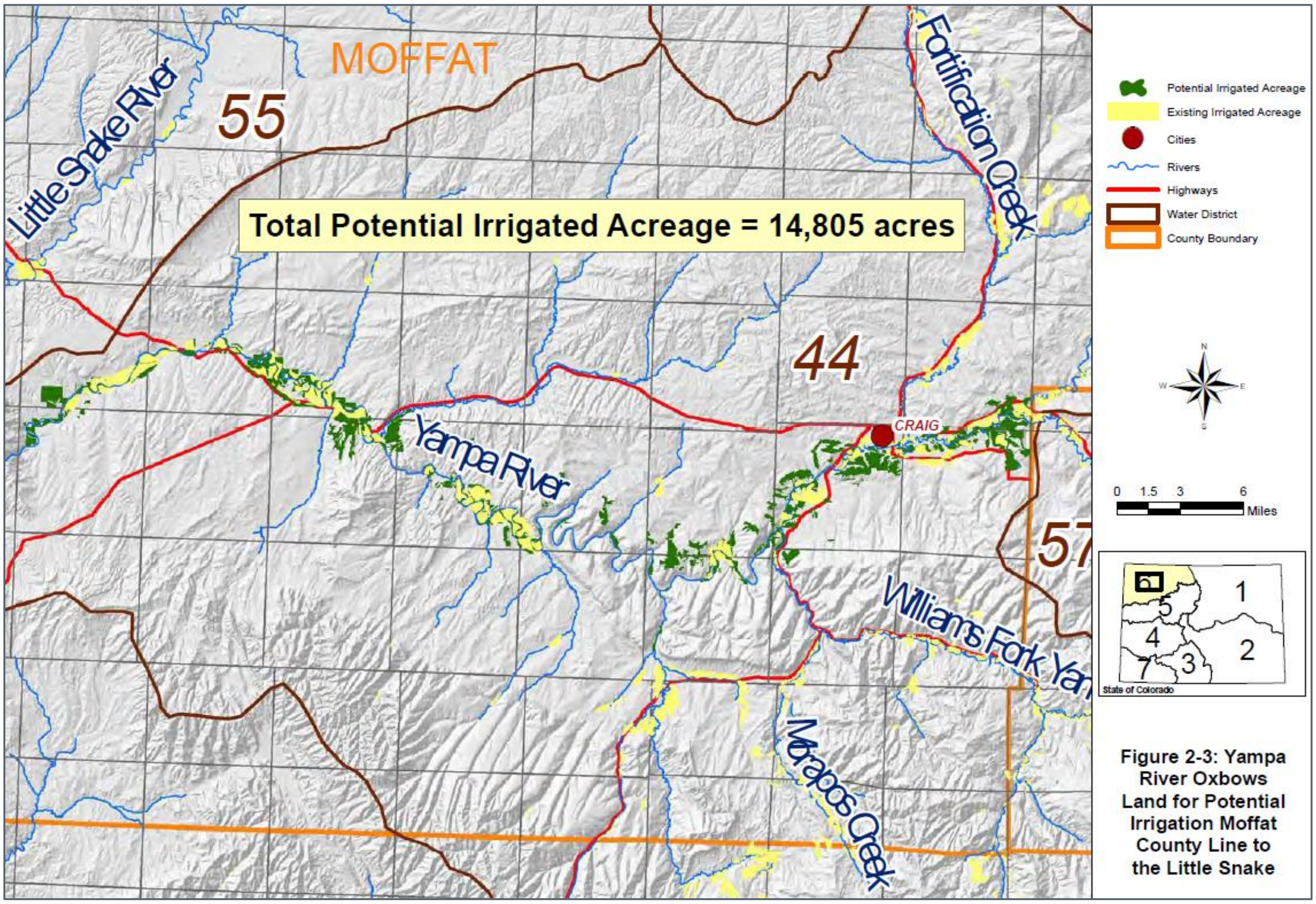


Figure 29: Yampa River Basin Planned Agricultural Projects

For the Technical Update effort, Yampa/White/Green BRT contemplated how the planned agricultural projects may be developed under the Planning Scenarios, recognizing that there may be variable growth depending on the future demand and economics for hay crops and cattle production. As such, the stakeholders in the basin provided a varying amount of acreage and crops types for the Planned Agricultural Projects in each Planning Scenario in the Yampa River basin as reflected in Table 23.

Population projections anticipate significant growth in the Yampa River Basin. The impact to irrigated areas, however, will be limited because the three largest municipal centers in the basin (Steamboat Springs, Hayden, and Craig) are not surrounded by irrigated agricultural areas. Approximately 2 percent of the irrigated acreage in the basin, or 1,500 acres, is estimated to be urbanized by 2050.

IWR in the basin is expected to increase a 19 percent on average under the In-Between climate conditions and 34 percent for the Hot and Dry conditions. These estimates are only slightly greater for the basins where there is planned irrigated acreage, projected as 21 percent and 36 percent under the two climate change conditions respectively. Estimates of IWR will be reduced by 10 percent in the Adaptive Innovation scenario, in which technological innovations mitigate the increased agricultural demand due to climate adjustments anticipated by the Hot and Dry conditions. Additionally, irrigation operations will experience a 10 percent increase to average system efficiency over the irrigation season, from 34 to 44 percent, in the Adaptive Innovation scenario.

Table 23 provides a summary of the adjustments discussed above; refer to the Planning Scenario Results section below for agricultural diversion demand summaries.

Table 23: Yampa River Planning Scenario Adjustments

Adjustment Factor	A: Business as Usual	B: Weak Economy	C: Cooperative Growth	D: Adaptive Innovation	E: Hot Growth
Change in Irrigated Land due to Urbanization	1,500 Acre Reduction	1,500 Acre Reduction	1,500 Acre Reduction	1,500 Acre Reduction	1,500 Acre Reduction
Planned Agricultural Projects	1,000 Acre Increase 100% Alfalfa	1,000 Acre Increase 100% Alfalfa	5,000 Acre Increase 50/50 Grass Pasture/Alfalfa	14,805 Acre Increase 50/50 Grass Pasture/Alfalfa	14,805 Acre Increase 50/50 Grass Pasture/Alfalfa
IWR Climate Factor	-	-	19%	34%	34%
Emerging Technologies	-	-	-	10% IWR Reduction 10% System Efficiency Increase	-

Section 8: Planning Scenario Agricultural Diversion Demand Approach

In general, the factors discussed in the previous sections impact the acreage, efficiency, or IWR components of the agricultural diversion demand analyses. The following general approach was used to integrate the factors into the agricultural demand process:

1. **Adjust current acreage by the Urbanization, Planned Agricultural Projects, and Ground Water Acreage Sustainability factors**. Using the current irrigated acreage as a starting point, irrigated acreage was increased or decreased in each basin using the acreage values associated with each factor. Some factors reflect an acreage adjustment to a regional area (e.g. Ground Water Acreage Sustainability factor in the South Platte River basin), whereas other factors were applied to acreage at a more specific location (e.g. Urbanized Acreage). In general, adjustments to acreage (e.g. Planned Agricultural Projects, Urbanized Acreage) were applied first, then adjustments based on percent of total acreage were applied. Note that total acreage was adjusted based on the factors; however, in general, crop types and irrigation methods were maintained. The only exception to this is the adjustment for sprinkler development in the South Platte River basin. For the South Platte, the Emerging Technologies factor was increased - effectively increasing the percent of acreage served by sprinklers under each irrigation system in the South Platte River basin.

2. **Calculate adjusted IWR**. Revise the consumptive use datasets developed for the current agricultural diversion demand effort with the adjusted acreage and simulate the models to calculate the adjusted IWR for each Planning Scenario in each basin. Note that the consumptive use datasets will reflect historical climate data; climate adjustments are applied to the IWR in Step 3.

3. **Adjust the IWR by the Climate factor**. Multiply the adjusted IWR from Step 2 by the CRWAS-II climate change data associated with the specific climate projection in each Planning Scenario. The CRWAS-II effort provided a time series of climate change factors for each Water District for both the "In-Between" and "Hot and Dry" projections. These Water District factors are multiplied by IWR to apply the effect of the climate projections on the crop water requirement. Note that in many basins, IWR is reduced by 10 percent in the Adaptive Innovation scenario to account for technological innovations that may mitigate the increased IWR due to climate adjustments. Additionally, note that the North Platte River, Republican River, and Arkansas River basin consumptive use datasets extend beyond the climate change factor dataset developed through the CRWAS-II effort. Climate change factors in recent years were filled from the available factors (i.e. 1950 – 2013) by correlating the IWR from recent years to historical years with similar IWR.

4. **Adjust the system efficiency by the Emerging Technologies factor**. Using the historical wet, dry, and average monthly system efficiencies as a starting point, increase the system efficiency of each ditch by 10 percent. For example, a monthly system efficiency of 40 percent would be increased to 50 percent. Note that is adjustment is only implemented in the Adaptive Innovation scenario; the remaining scenarios rely on the historical system efficiencies.

5. **Develop the 2050 Planning Scenario Agricultural Diversion Demand**. Divide the climate-adjusted IWR from Step 3 by system efficiency values to develop the agricultural diversion demand for each Planning Scenario. Note that wet, dry, and average year types used to assign the appropriate system efficiency in this step reflects climate-adjusted hydrology at the indicator gage, if specified for the Planning Scenario. As the climate-adjusted hydrology will be drier, this approach resulted in more dry-year efficiencies being used to develop the agricultural diversion demand. For basins that use both surface and ground water supplies, partition the total demand using the same method outlined in Section 4.

Section 9: Planning Scenario Results

The following graphics and tables summarize the acreage, IWR, and the agricultural diversion demand attributable to surface and ground water supplies in each basin calculated for the 2050 Planning Scenarios based on the adjustment factors and approach discussed above. From a statewide perspective, the agricultural diversion demand ranged from 10 million acre-feet in the Adaptive Innovation scenario to 13.5 million acre-feet in the Hot Growth scenario. For basins with limited acreage adjustments, such as the Colorado, Gunnison, and Southwest basins, the agricultural diversion demand in the Business as Usual and the Weak Economy scenarios was similar to the Current demand. In these basins, climate change projections and efficiency adjustments had a significant impact resulting in more variable demands in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios.

For basins with significant acreage reductions, such as the South Platte River and Republican River basins, demands in all Planning Scenarios are lower than the Current demand. The largest variation in a majority of the basins occurred in the Adaptive Innovation scenario due to 10 percent reduction in IWR and 10 percent increase to system efficiency. In some basins, such as the Southwest basin, the combined impact of the Adaptive Innovation scenario adjustments resulted in an agricultural diversion demand that is lower than the Current demand.

As discussed above, agricultural diversion demands will be incorporated into the Planning Scenario models, which will be used to determine how much water is available to meet the demands. Shortages to the agricultural diversion demands in the Water Supply modeling efforts will define the agricultural gap. Refer to the *Technical Update Current and 2050 Planning Scenario Water Supply and Gap* documentation for more information on how the demands were implemented in the water supply models and how the agricultural gap was estimated.

Table 24: Arkansas River Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Total Water Demand Wet Year (acre-feet)	Total Water Demand Average Year (acre-feet)	Total Water Demand Dry Year (acre-feet)
Current	445,000	980,000	1,894,000	1,872,000	1,962,000
A	417,700	921,000	1,775,000	1,751,000	1,834,000
B	413,600	915,000	1,767,000	1,743,000	1,826,000
C	409,500	970,000	1,907,000	1,844,000	1,914,000
D	398,900	889,000	1,764,000	1,686,000	1,741,000
E	398,900	987,000	1,965,000	1,880,000	1,942,000

Planning Scenario	Surface Water Demand			Ground Water Demand		
	Wet Year (acre-feet)	Average Year (acre-feet)	Dry Year (acre-feet)	Wet Year (acre-feet)	Average Year (acre-feet)	Dry Year (acre-feet)
Current	1,567,000	1,497,000	1,501,000	327,000	375,000	461,000
A	1,466,000	1,394,000	1,392,000	309,000	357,000	442,000
B	1,466,000	1,394,000	1,392,000	301,000	349,000	434,000
C	1,585,000	1,473,000	1,483,000	322,000	371,000	431,000
D	1,477,000	1,340,000	1,353,000	287,000	346,000	388,000
E	1,653,000	1,509,000	1,528,000	312,000	371,000	414,000

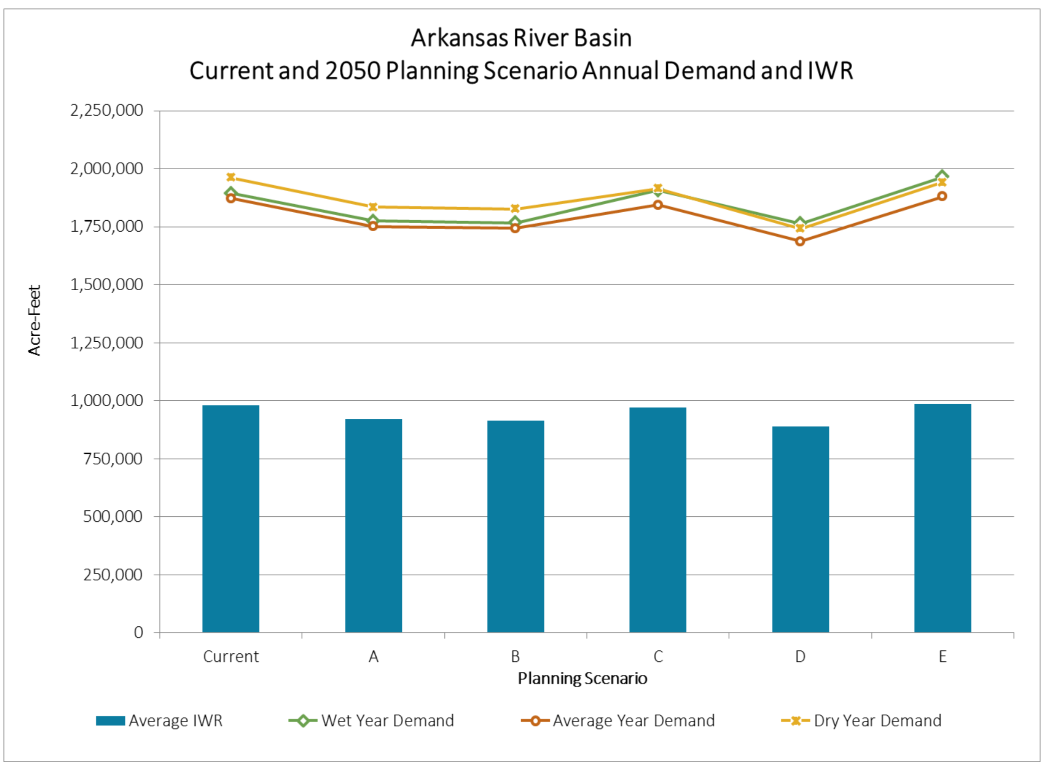


Figure 30: Arkansas River Basin Planning Scenario Results

Table 25: Colorado River Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Surface Water Demand Wet Year (acre-feet)	Surface Water Demand Average Year (acre-feet)	Surface Water Demand Dry Year (acre-feet)
Current	206,700	456,500	1,640,000	1,608,000	1,538,000
A	193,100	426,000	1,515,000	1,485,000	1,420,000
B	193,100	426,000	1,515,000	1,485,000	1,420,000
C	193,100	480,000	1,729,000	1,666,000	1,571,000
D	193,100	463,000	1,336,000	1,306,000	1,253,000
E	193,100	514,000	1,866,000	1,786,000	1,657,000

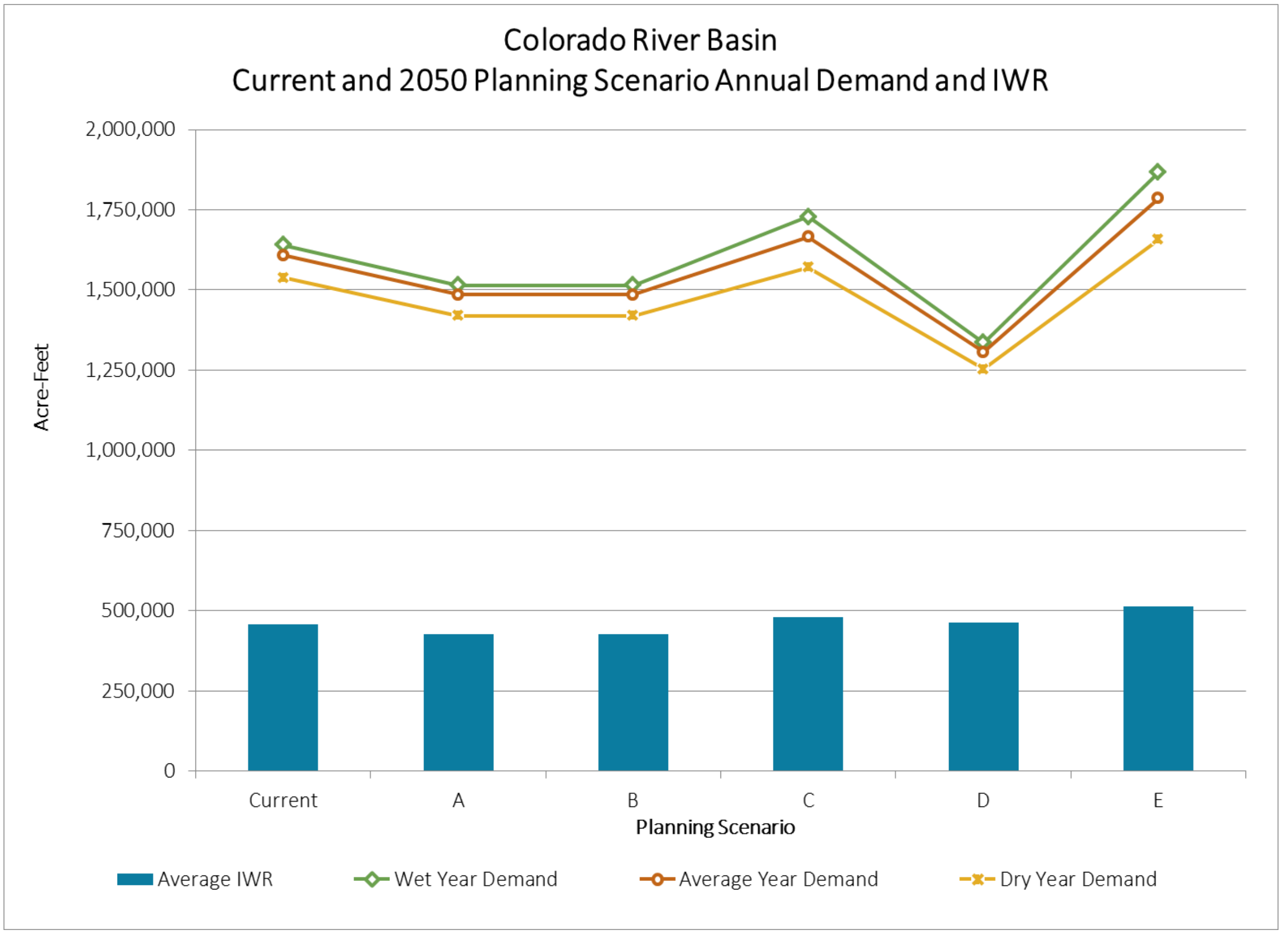


Figure 31: Colorado River Basin Planning Scenario Results

Table 26: Gunnison River Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Surface Water Demand: Wet Year (acre-feet)	Surface Water Demand: Average Year (acre-feet)	Surface Water Demand: Dry Year (acre-feet)
Current	234,400	528,200	1,824,000	1,814,000	1,716,000
A	219,800	494,000	1,699,000	1,688,000	1,596,000
B	219,800	494,000	1,699,000	1,688,000	1,596,000
C	219,800	573,000	2,050,000	1,973,000	1,845,000
D	219,800	541,000	1,361,000	1,315,000	1,253,000
E	219,800	601,000	2,194,000	2,074,000	1,914,000

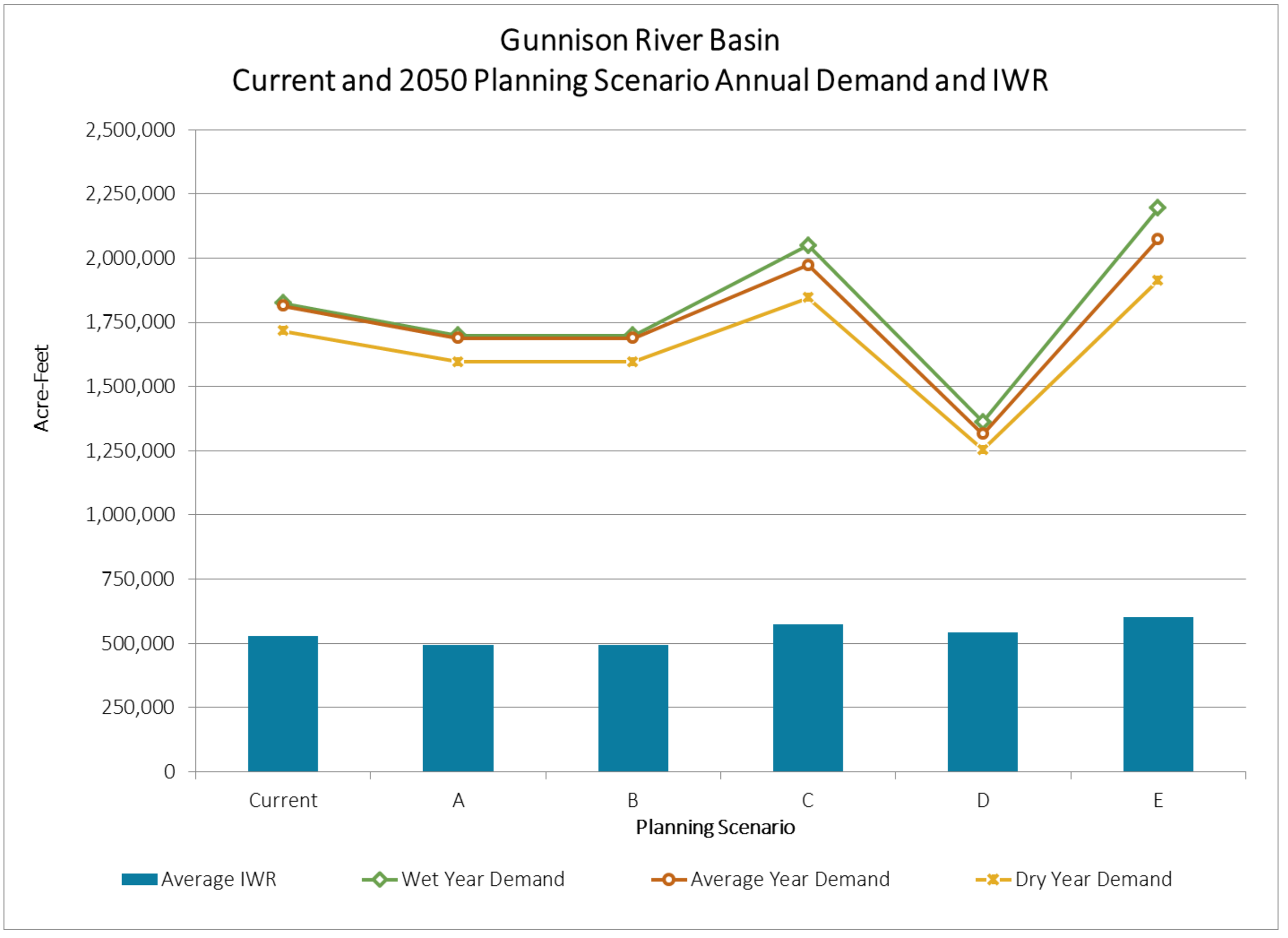


Figure 32: Gunnison River Basin Planning Scenario Results

Table 27: North Platte River Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Surface Water Demand Wet Year (acre-feet)	Surface Water Demand Average Year (acre-feet)	Surface Water Demand Dry Year (acre-feet)
Current	113,600	191,100	548,000	555,000	489,000
A	124,200	208,000	623,000	640,000	546,000
B	124,200	208,000	623,000	640,000	546,000
C	124,200	243,000	736,000	754,000	619,000
D	124,200	236,000	530,000	531,000	476,000
E	124,200	263,000	801,000	806,000	665,000

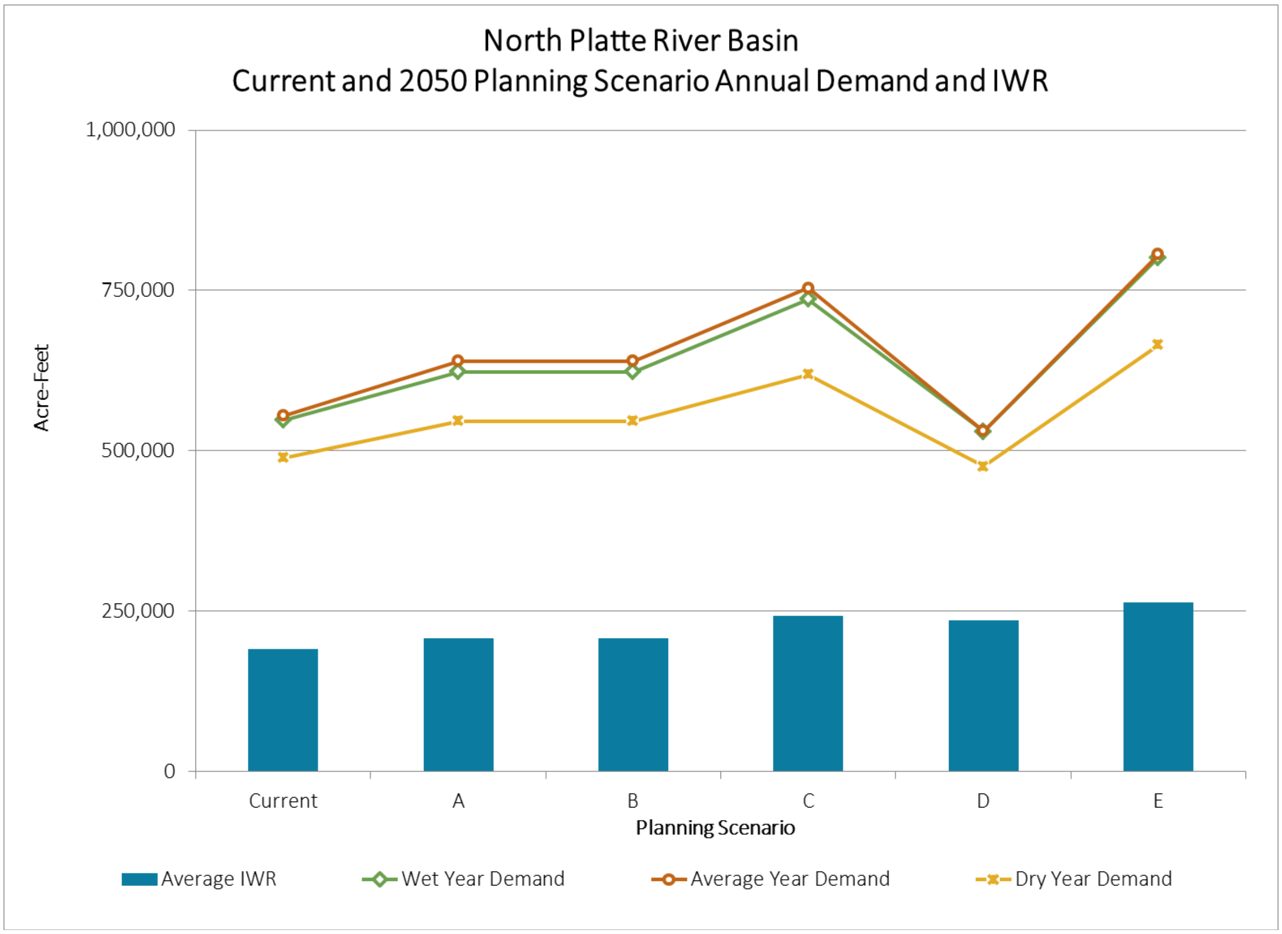


Figure 33: North Platte River Basin Planning Scenario Results

Table 28: Republican River Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Ground Water Demand Wet Year (acre-feet)	Ground Water Demand Average Year (acre-feet)	Ground Water Demand Dry Year (acre-feet)
Current	578,800	837,000	913,000	1,056,000	1,241,000
A	442,000	635,000	681,000	800,000	941,000
B	443,400	636,000	683,000	802,000	943,000
C	442,000	661,000	714,000	833,000	960,000
D	442,000	649,000	695,000	799,000	896,000
E	442,000	721,000	772,000	888,000	995,000

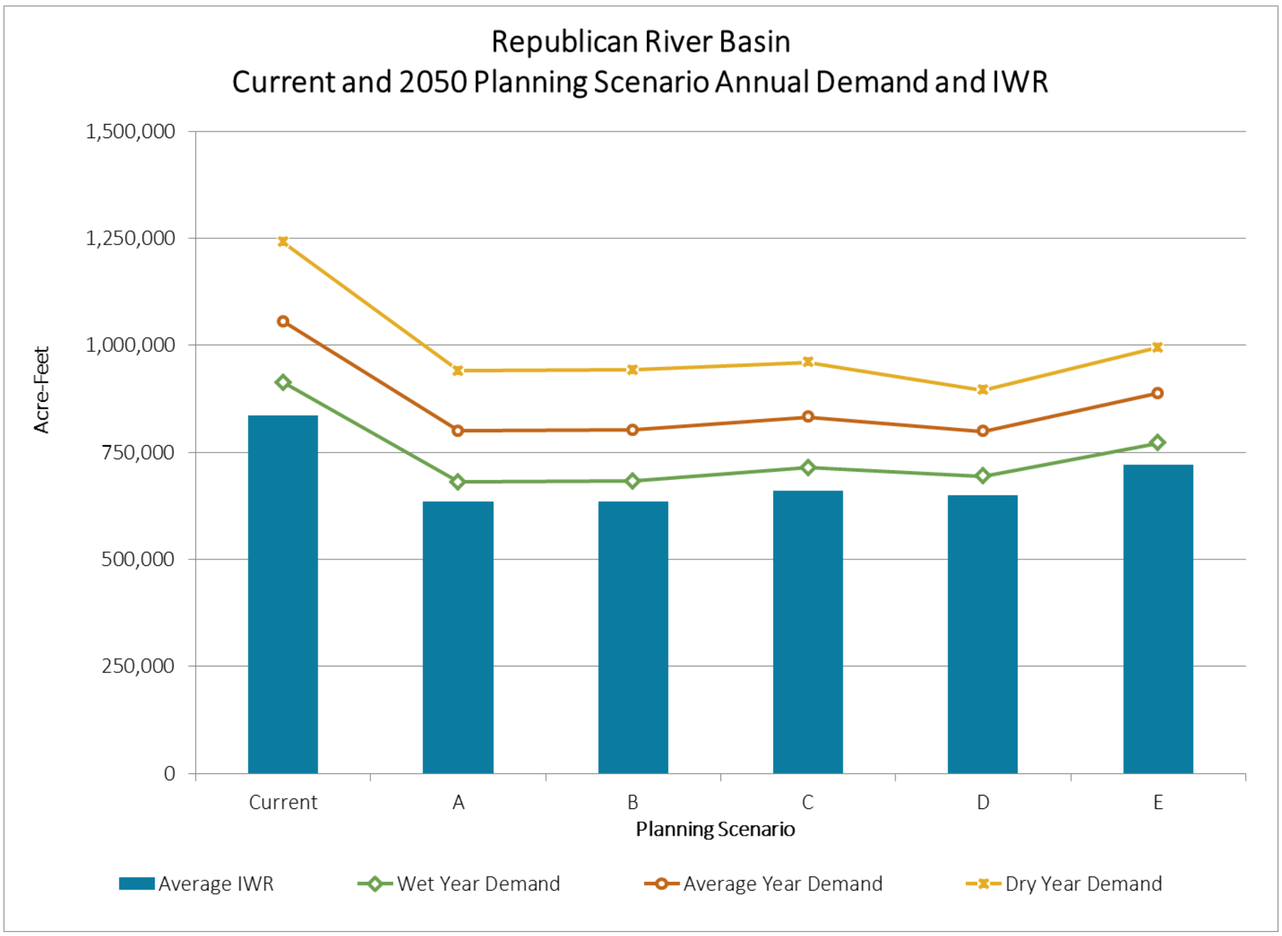


Figure 34: Republican River Basin Planning Scenario Results

Table 29: Rio Grande Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Total Water Demand Wet Year (acre-feet)	Total Water Demand Average Year (acre-feet)	Total Water Demand Dry Year (acre-feet)
Current	515,300	1,021,000	1,801,000	1,800,000	1,849,000
A	466,300	940,000	1,695,000	1,694,000	1,735,000
B	470,300	949,000	1,712,000	1,712,000	1,754,000
C	396,500	913,000	1,635,000	1,652,000	1,647,000
D	385,200	818,000	1,468,000	1,465,000	1,458,000
E	385,200	909,000	1,635,000	1,632,000	1,625,000

Planning Scenario	Surface Water Demand			Ground Water Demand		
	Wet Year (acre-feet)	Average Year (acre-feet)	Dry Year (acre-feet)	Wet Year (acre-feet)	Average Year (acre-feet)	Dry Year (acre-feet)
Current	1,237,000	1,172,000	1,195,000	564,000	628,000	654,000
A	1,221,000	1,156,000	1,178,000	474,000	538,000	557,000
B	1,237,000	1,173,000	1,196,000	475,000	539,000	558,000
C	1,182,000	1,139,000	1,120,000	453,000	513,000	527,000
D	1,048,000	999,000	968,000	420,000	466,000	490,000
E	1,186,000	1,135,000	1,104,000	449,000	497,000	521,000

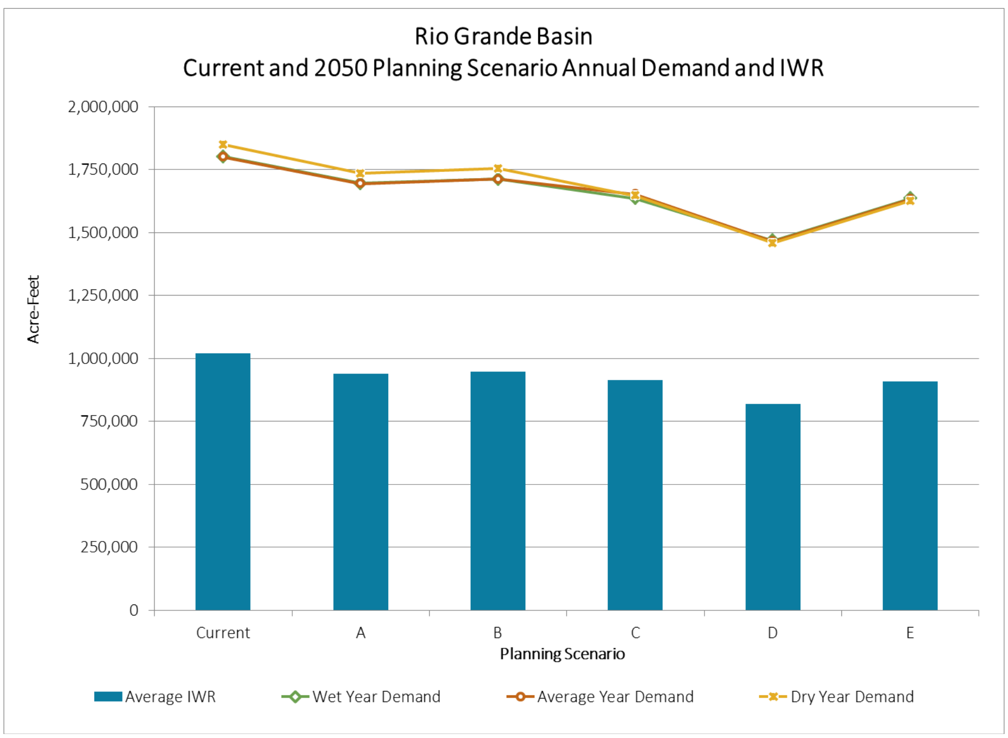


Figure 35: Rio Grande Basin Planning Scenario Results

Table 30: South Platte River Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Total Water Demand Wet Year (acre-feet)	Total Water Demand Average Year (acre-feet)	Total Water Demand Dry Year (acre-feet)
Current	854,300	1,500,000	2,427,000	2,589,000	2,632,000
A	701,100	1,225,000	1,959,000	2,081,000	2,128,000
B	701,100	1,225,000	1,959,000	2,081,000	2,128,000
C	722,400	1,341,000	2,186,000	2,268,000	2,286,000
D	722,400	1,264,000	1,707,000	1,771,000	1,797,000
E	679,900	1,323,000	2,123,000	2,202,000	2,191,000

Planning Scenario	Surface Water Demand Wet Year (acre-feet)	Surface Water Demand Average Year (acre-feet)	Surface Water Demand Dry Year (acre-feet)	Ground Water Demand Wet Year (acre-feet)	Ground Water Demand Average Year (acre-feet)	Ground Water Demand Dry Year (acre-feet)
Current	2,078,000	2,186,000	2,108,000	349,000	403,000	524,000
A	1,634,000	1,704,000	1,632,000	325,000	377,000	496,000
B	1,634,000	1,704,000	1,632,000	325,000	377,000	496,000
C	1,842,000	1,872,000	1,777,000	344,000	396,000	509,000
D	1,415,000	1,432,000	1,358,000	292,000	339,000	439,000
E	1,768,000	1,796,000	1,681,000	355,000	406,000	510,000

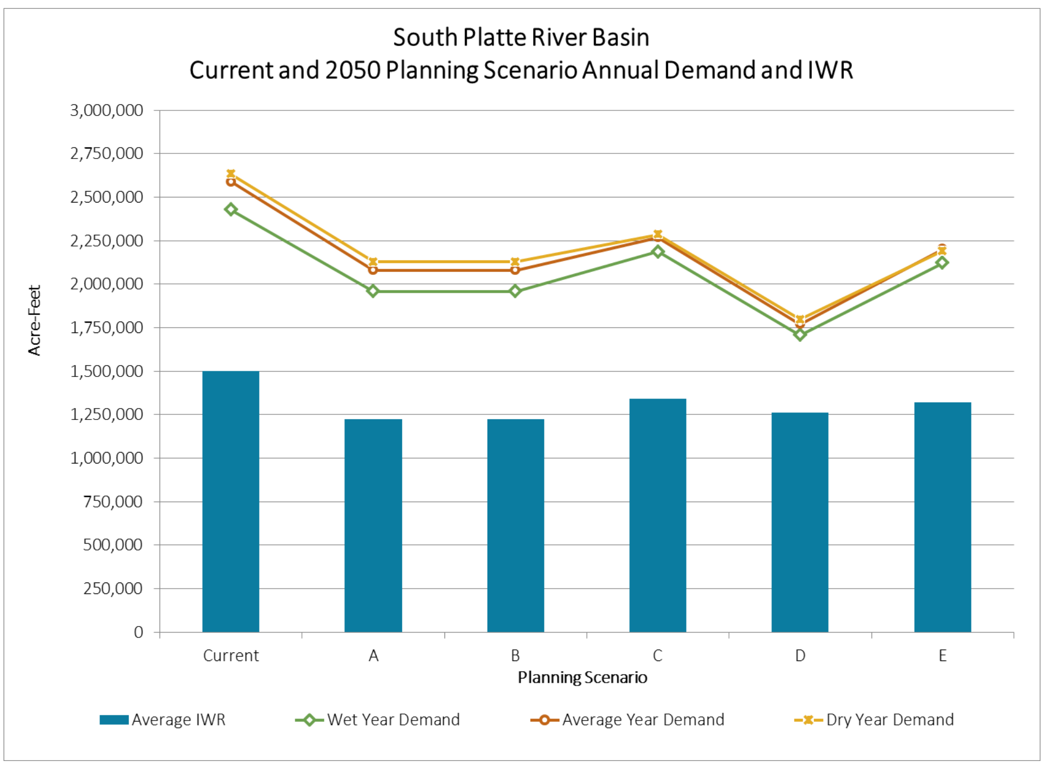


Figure 36: South Platte River Basin Planning Scenario Results

Table 31: Southwest Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Surface Water Demand		
			Wet Year (acre-feet)	Average Year (acre-feet)	Dry Year (acre-feet)
Current	222,500	474,900	980,000	1,025,000	1,007,000
A	218,800	467,000	962,000	1,005,000	987,000
B	218,800	467,000	962,000	1,005,000	987,000
C	218,800	569,000	1,279,000	1,211,000	1,162,000
D	218,800	537,000	958,000	933,000	883,000
E	218,800	597,000	1,345,000	1,290,000	1,210,000

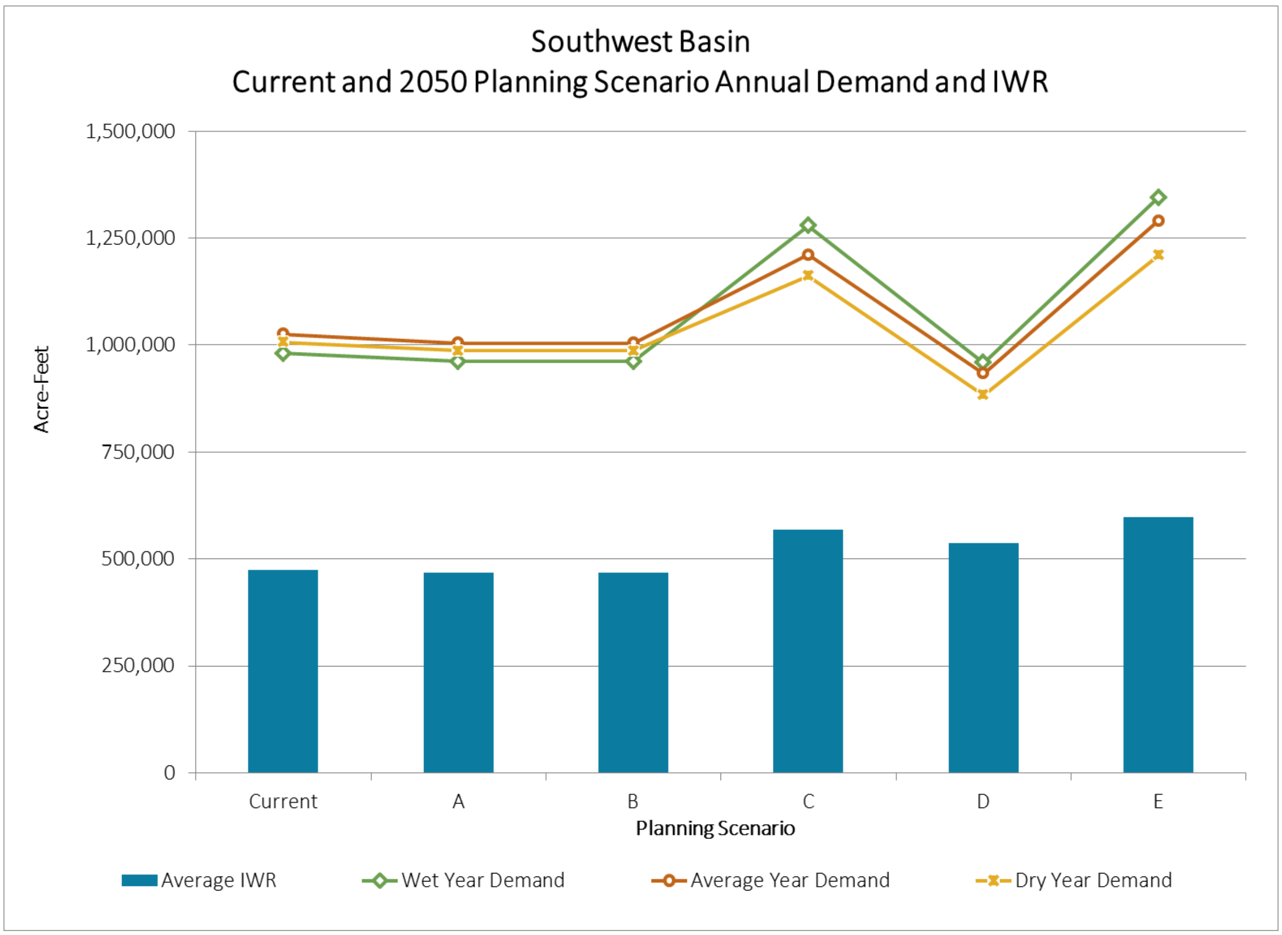


Figure 37: Southwest Basin Planning Scenario Results

Table 32: White River Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Surface Water Demand: Wet Year (acre-feet)	Surface Water Demand: Average Year (acre-feet)	Surface Water Demand: Dry Year (acre-feet)
Current	28,100	46,400	250,000	243,000	242,000
A	27,700	45,800	246,000	239,000	238,000
B	28,000	46,400	250,000	243,000	242,000
C	27,700	55,700	305,000	293,000	278,000
D	27,700	55,900	186,000	180,000	173,000
E	27,700	62,100	344,000	324,000	306,000

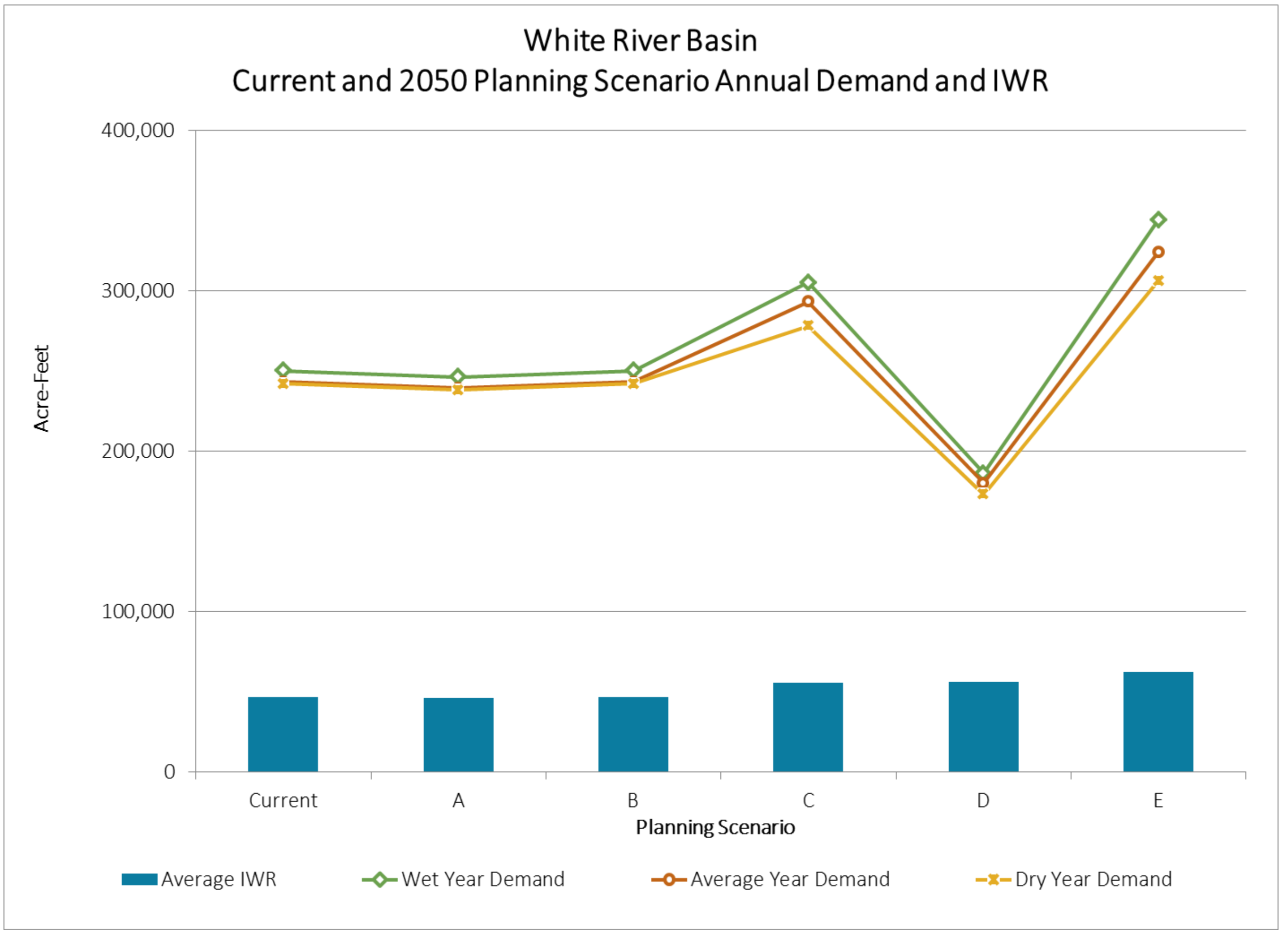


Figure 38: White River Basin Planning Scenario Results

Table 33: Yampa River Basin Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Surface Water Demand		
			Wet Year (acre-feet)	Average Year (acre-feet)	Dry Year (acre-feet)
Current	78,900	150,600	387,000	402,000	403,000
A	78,400	150,000	389,000	403,000	404,000
B	78,400	150,000	389,000	403,000	404,000
C	82,400	188,000	518,000	518,000	514,000
D	92,300	209,000	460,000	456,000	447,000
E	92,300	232,000	691,000	679,000	658,000

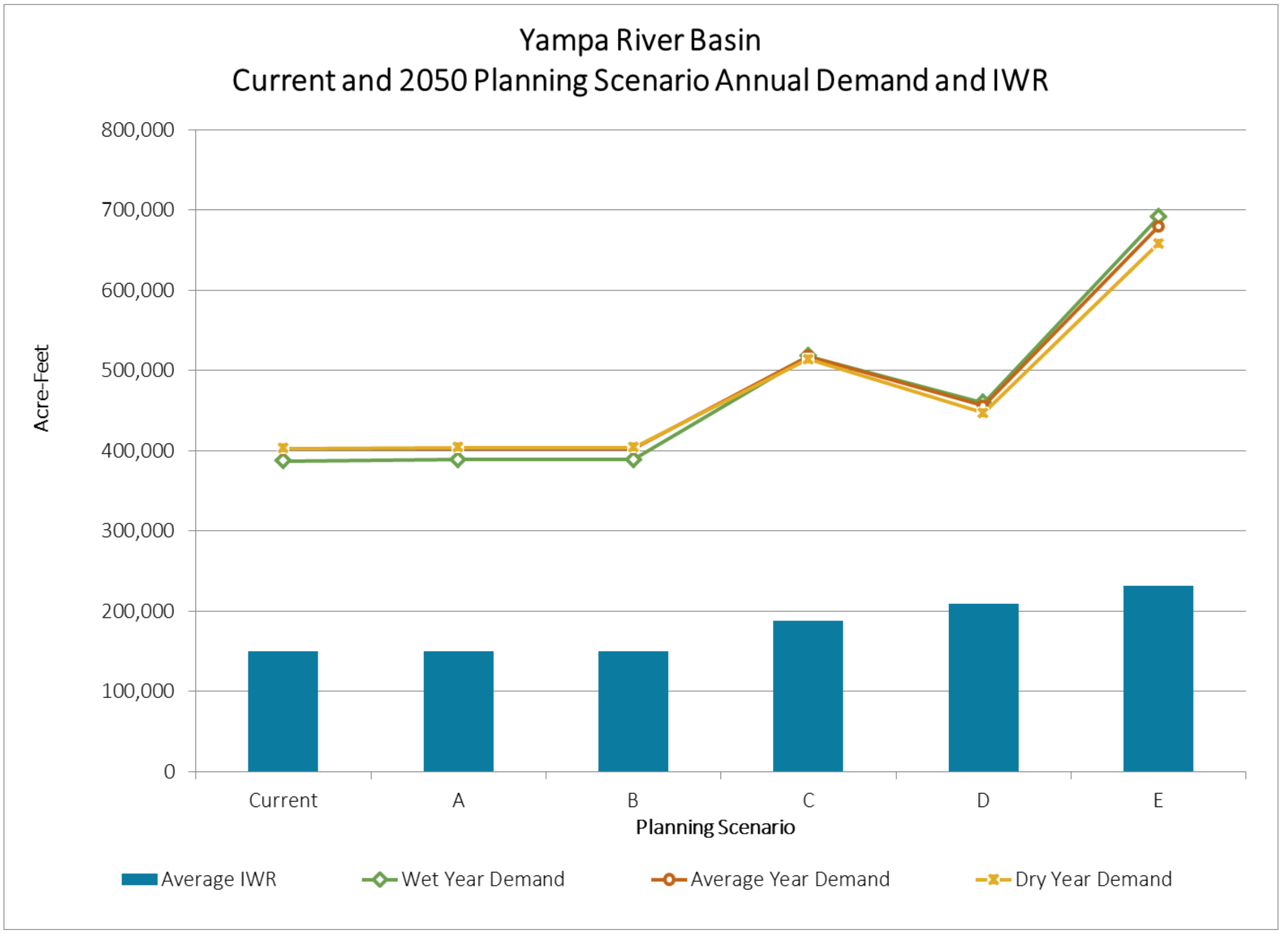


Figure 39: Yampa River Basin Planning Scenario Results

Table 34: Statewide Planning Scenario Results

Planning Scenario	Acreage	Average IWR (acre-feet)	Total Water Demand: Wet Year (acre-feet)	Total Water Demand: Average Year (acre-feet)	Total Water Demand: Dry Year (acre-feet)
Current	3,280,000	6,190,000	12,664,000	12,964,000	13,079,000
A	2,890,000	5,510,000	11,544,000	11,786,000	11,829,000
B	2,890,000	5,520,000	11,559,000	11,802,000	11,846,000
C	2,840,000	5,990,000	13,059,000	13,012,000	12,796,000
D	2,820,000	5,660,000	10,465,000	10,442,000	10,377,000
E	2,780,000	6,210,000	13,736,000	13,561,000	13,163,000

Planning Scenario	Surface Water Demand: Wet Year (acre-feet)	Surface Water Demand: Average Year (acre-feet)	Surface Water Demand: Dry Year (acre-feet)	Ground Water Demand: Wet Year (acre-feet)	Ground Water Demand: Average Year (acre-feet)	Ground Water Demand: Dry Year (acre-feet)
Current	10,511,000	10,502,000	10,199,000	2,153,000	2,462,000	2,880,000
A	9,755,000	9,714,000	9,393,000	1,789,000	2,072,000	2,436,000
B	9,775,000	9,735,000	9,415,000	1,784,000	2,067,000	2,431,000
C	11,226,000	10,899,000	10,369,000	1,833,000	2,113,000	2,427,000
D	8,771,000	8,492,000	8,164,000	1,694,000	1,950,000	2,213,000
E	11,848,000	11,399,000	10,723,000	1,888,000	2,162,000	2,440,000

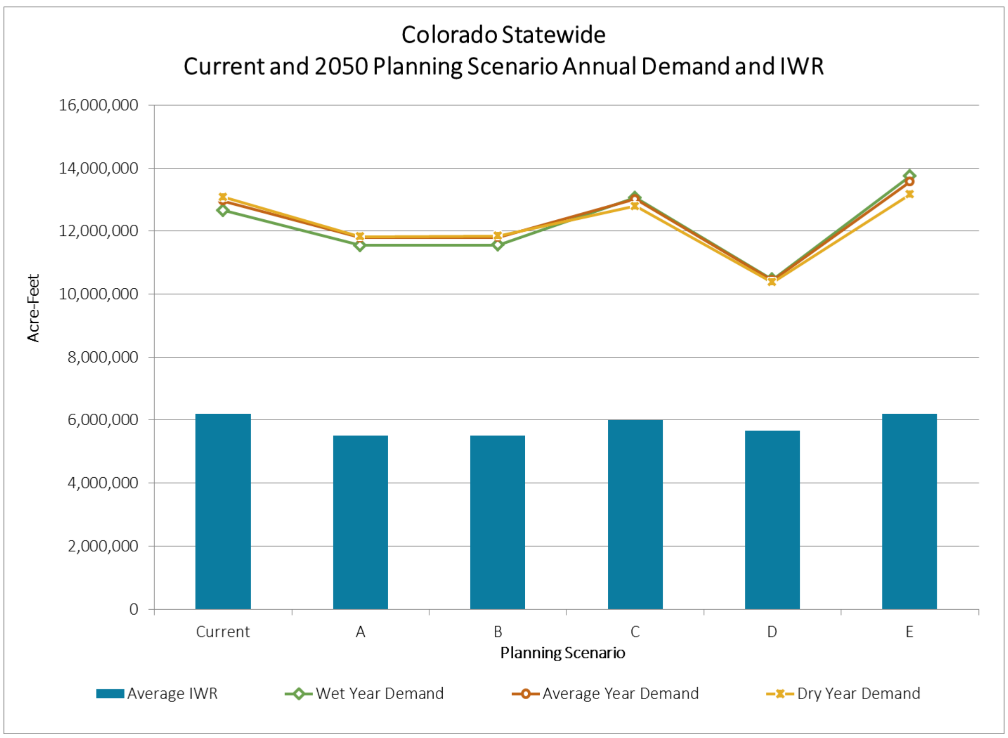


Figure 40: Statewide Planning Scenario Results

Section 10: Comments and Considerations

The following reflects observations and comments that should be considered when reviewing the current and 2050 Planning Scenario agricultural diversion demand results.

- **Comparison to Historical Diversions**. The current agricultural diversion demands are not directly comparable to the historical diversions as the historical diversions reflect changing irrigation practices, crop types, and acreage, as well as physical and legal water availability shortages. A comparison to recent average diversions (2005-2012) can, however, provide perspective on the amount of shortages experienced in a specific area and provide a high-level check on the demand results. In consistently water short basins, such as the Rio Grande basin, the historical diversions are generally significantly less than the diversion demands as reflected in Figure 41.

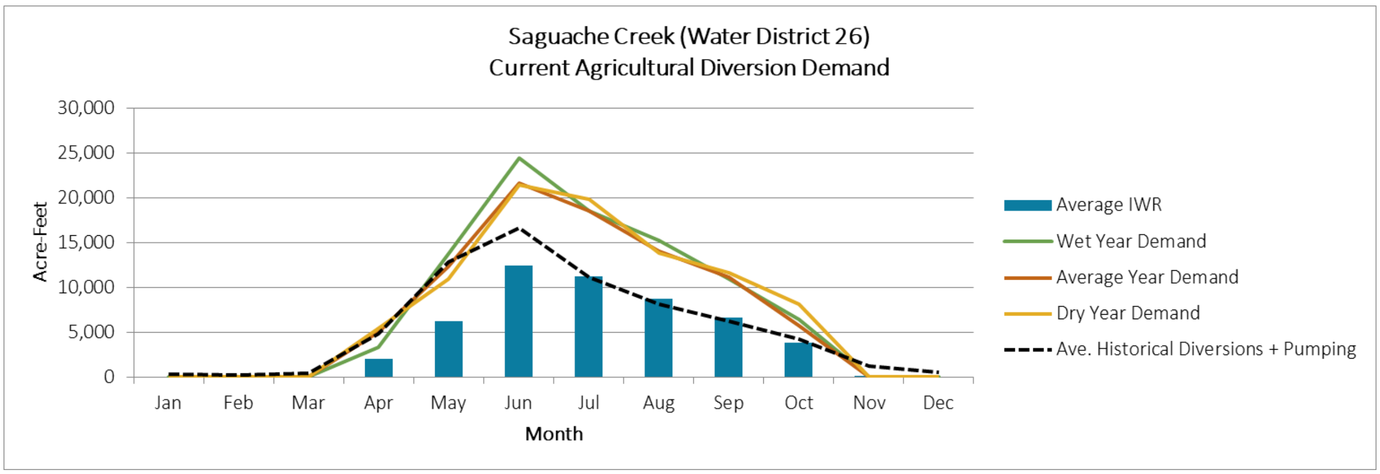


Figure 41: Saguache Creek Current Agricultural Diversion Demand

Conversely, in tributaries with more consistent native supply or supplemental supplies available from storage, the historical diversions more closely match the diversion demands. As reflected in Figure 42, irrigators in the Upper Uncompahgre River basin still experience shortages; however historically diverted supplies more closely mimic the agricultural demand.

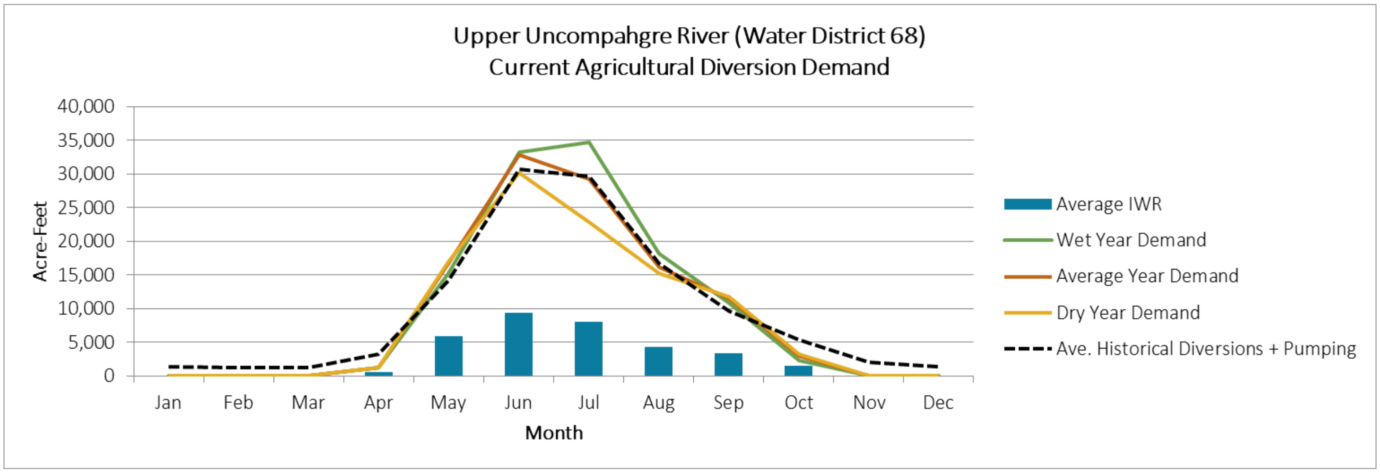


Figure 42: Upper Uncompahgre River Current Agricultural Diversion Demand

In areas that have experienced significant urbanization of irrigated lands including the transfer of water rights from irrigation to municipal uses, the historical diversions are generally larger than the agricultural diversion demand values because the demand values are based on the current (reduced) acreage. This impact is reflected in the Clear Creek River basin agricultural diversion demand results illustrated in Figure 43, where irrigated acreage has been reduced due to water transfers to municipalities and urbanization of crop land.

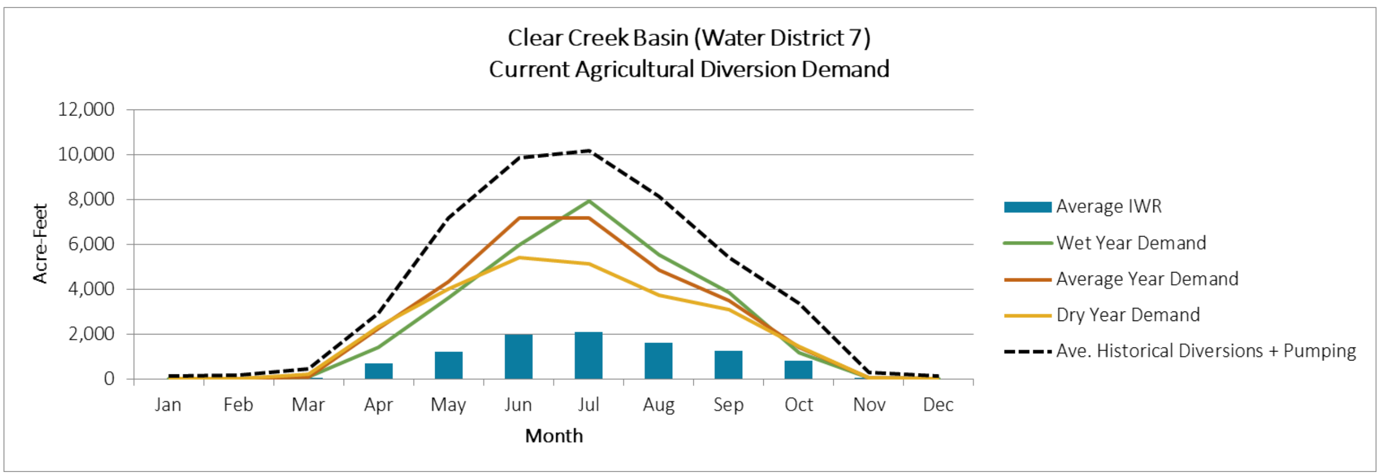


Figure 43: Clear Creek Basin Current Agricultural Diversion Demand

- **Irrigated Acreage Assessments**. The current agricultural diversion demand analysis relies on the irrigated acreage assessments developed by the CWCB and DWR. The assessments are generally performed every 5 years and more frequently in basins where annual acreage assessments are required for Compact reporting or DWR administration. CWCB and DWR staff have continually improved the delineation of parcels, crop assignments, and water supply assignments in these assessments, however there remains areas with acreage delineation inconsistencies.

- The irrigated acreage assessments are generally not intended to delineate municipal or commercial irrigated parcels. Therefore, parks, cemeteries, golf courses, or small pasture areas (hobby farms) are not delineated in the acreage assessments. Overall, this irrigated acreage is a small component of the basin-wide acreage totals, however, if concentrated in a specific area (e.g. Clear Creek basin or Grand Valley area), it can have a more significant local impact. This acreage was not accounted for or delineated under this Technical Update effort, therefore the current acreage and agricultural diversion demands may be lower in these areas for this analysis.

- Approximately 20,000 irrigated acres on the Western Slope do not have recent diversion records available in the Historical Dataset and, therefore, system efficiency information could not be calculated. As this acreage represents around 2 percent of the total acreage on the Western Slope, it was not accounted for in the Technical Update effort.

- Recharge Demands. There are a small number of irrigation systems in the Rio Grande basin that have decrees allowing preferential use of ground water supplies while diverting surface water for on-farm aquifer recharge. The RGDSS Phase 6 – Historical Consumptive Use Analysis documentation identified six structures in the basin that operate under this preferential practice, including three of the largest irrigation systems in the basin; Rio Grande Canal, Farmers Union Canal, San Luis Valley Canal Company. The approach outlined above for developing the current agricultural diversion demand for co-mingled structures double-accounted the demand for these structures. Therefore the agricultural diversion demand for these structures was developed using the ground-water only approach outlined above and designated as a ground water demand in the results. Although the structures are legally allowed to use either surface or ground water supplies on their acreage, designating their agricultural diversion demand as a ground water demand for the Technical Update efforts is consistent with their current irrigation practices.

- Shoulder Season Irrigation Practices. The agricultural diversion demand approach outlined above relies on IWR and historical system efficiencies from wet, dry, and average year types to capture the variability of irrigation practices across variability hydrological conditions. As reflected in the summary graphs above, the dry year demand is often greater in the early spring months. This can be attributed to both a higher IWR in the early season due to generally warmer temperatures in dry year types and irrigation practices that reflect higher diversions during the runoff with the knowledge that supplies may not be available later in the irrigation season during dry years.

  Although this approach allows for the estimation of demands that can vary based on IWR, it may not fully capture the agricultural diversion demand associated with irrigation practices during months when the IWR is very low or zero. This issue is generally limited to lower elevation basins with limited water availability (i.e. rely primarily on supplies during runoff, no significant supplemental reservoir supplies or ground water) that rely on filling their soil early in the season. Figure 44 for the La Plata River basin illustrates the issue between the historical diversions in March and April and the resulting current agricultural diversion demand.

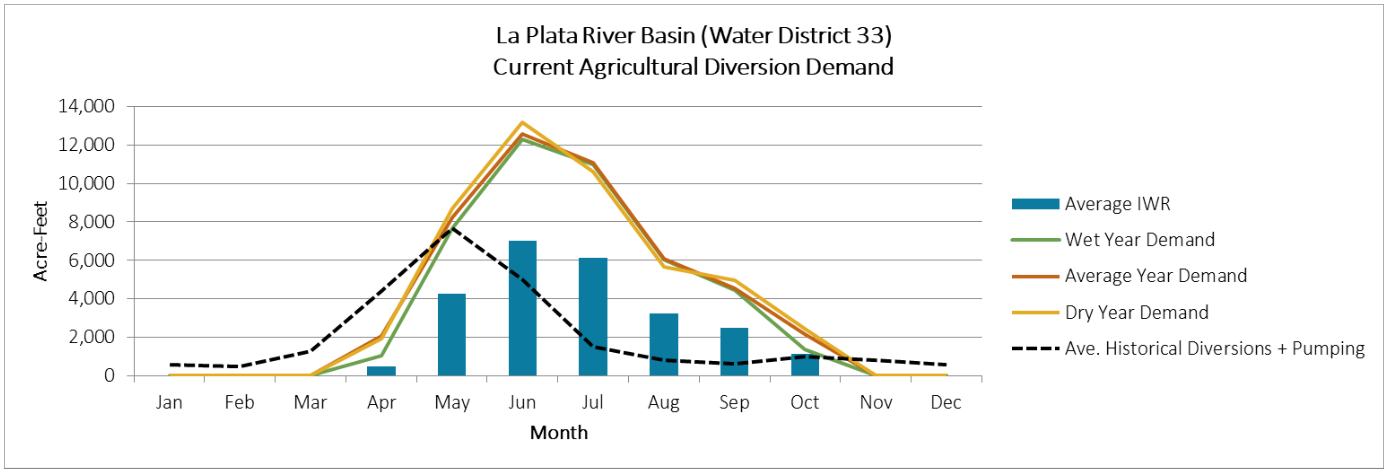


Figure 44: La Plata River Basin Current Agricultural Diversion Demand

- **Agricultural Diversion Demands**. The agricultural diversion demand is defined as the amount of water that would need to be diverted or pumped to meet the full crop irrigation demand. The tables provided herein reflect a summation of agricultural diversion demand across major river basins. The tables do not reflect nor consider the common practice of re-diverting irrigation return flows many times within a river basin. As such, it is not appropriate to assume the total demand reflects the amount of native streamflow that would need to be diverted to meet the full crop irrigation demand.

- **Pumping Estimates**. Ground water withdrawals have been metered and recorded in recent years, but records are generally not available over a long historical period. With rare exceptions, pumping records in the Rio Grande basin have only been available since 2009, and even more recently in the South Platte River basin. As such, it is necessary to estimate ground water only and supplemental irrigation (co-mingled) supplies over a longer period of record. For CDSS basin-planning efforts, pumping is initially estimated based on IWR in the StateCU datasets and then adjusted to account for historical restrictions to pumping. For irrigated lands served by ground water only, pumping is estimated by dividing the IWR by system efficiency, which is usually 80 or 85 percent due to sprinkler application methods. For irrigated lands served by both surface and ground water supplies, the surface water irrigation supplies are applied to the land first and any remaining IWR is assumed to be met by ground water supplies. This remaining IWR is then divided by system efficiency to estimate the supplement pumping supply. Pumping estimates are limited by well development (i.e. estimates are limited historically when fewer wells were developed) and account for the change in sprinkler development over time within the StateCU process. Additionally restrictions to historical pumping vary by basin:
    - Pumping estimates in the Rio Grande basin are adjusted based on historical season of use and calibrated to metered pumping when available.
    - In the South Platte River basin, pumping estimates were limited based on historical quotas imposed by augmentation providers due to lack of augmentation supplies.
    - Pumping within the H-I Model area in the Arkansas River basin was estimated back to 1950 in support of the Arkansas River Compact, and accounted for well development and changes to irrigated acreage due to municipal transfers.

For the Technical Update effort, it was necessary to estimate Current and 2050 Planning Scenario pumping demands. These baseline demands needed to reflect current conditions, without imposing water supply shortages, and respond to changing IWR demand. As outlined above, baseline pumping estimates for irrigated lands served by ground water only were estimated based on Current and 2050 Planning Scenario IWR divided by system efficiency. The process was more difficult for supplemental pumping supplies due to the ability of surface water supplies to meet a portion of the IWR. Stakeholders in basins with ground water pumping indicated both declining ground water availability and declining augmentation supplies, indicating pumping would not likely increase in the future. As such, supplemental pumping estimates that reflected low, high, and average pumping conditions in recent years (i.e. post-2005 to account for administrative changes spurred by the 2002 drought) were selected and correlated to wet, dry, and average year types to create a longer time series of supplemental/co-mingled pumping supplies for the Current and 2050 Planning Scenarios. Years selected for each basin are:

- Arkansas River Basin: 2012 for High, 2013 for Low, 2006 for Average
- Rio Grande Basin: 2006 for High, 2009 for Low, 2010 for Average
- South Platte River Basin: 2006 for High, 2009 for Low, 2011 for Average

This approach holds supplemental/co-mingled pumping to current levels, leaving any change of agricultural diversion demand (positive or negative) in the 2050 Planning Scenarios to be a change in surface water agricultural diversion demand. Refer to the *Technical Update Current and 2050 Planning Scenario Water Supply and Gap* documentation for more information on how the ground water agricultural gap was estimated.

- Planning Scenario Adjustments. The Planning Scenarios presented by Colorado's Water Plan describe five plausible futures that each include several adjustments to agricultural diversion demand. Although the individual adjustments are discussed in the Basin Summaries above, it is difficult to completely isolate the impact of a specific adjustment because the adjustments tend to compound within a Planning Scenario. For example, urbanized acreage in the South Platte River basin was removed first, and the acreage adjustments for ground water sustainability were applied to the remaining acreage. These adjustments would have resulted in slightly different values had the adjustments been applied in a different order. If water resources planners are interested in the impact of an individual adjustment, they are encouraged to obtain the consumptive use datasets and implement the adjustments in a step-wise fashion, analyzing the results after each adjustment is implemented.

Section 11: References

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