Analysis and Technical Update to the Colorado Water Plan

Technical Memorandum

Prepared for:

Colorado Water Conservation Board

Project Title:

Current and 2050 Planning Scenario Water Supply and Gap Results

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Section 1: Introduction

This technical memorandum summarizes the water supply and gap approach and results for the Technical Update effort. The water supply and gap results consider the current and projected 2050 agricultural, municipal and industrial demands associated with each of the Technical Update Planning Scenarios under current or climate-adjusted hydrological conditions. These water supply and gap results are then compared to Baseline results to compare and contrast how the projected water supply and gaps may change in the future under each Planning Scenario. Figure 1 shows the five plausible 2050 Planning Scenarios, as presented in Colorado's Water Plan.

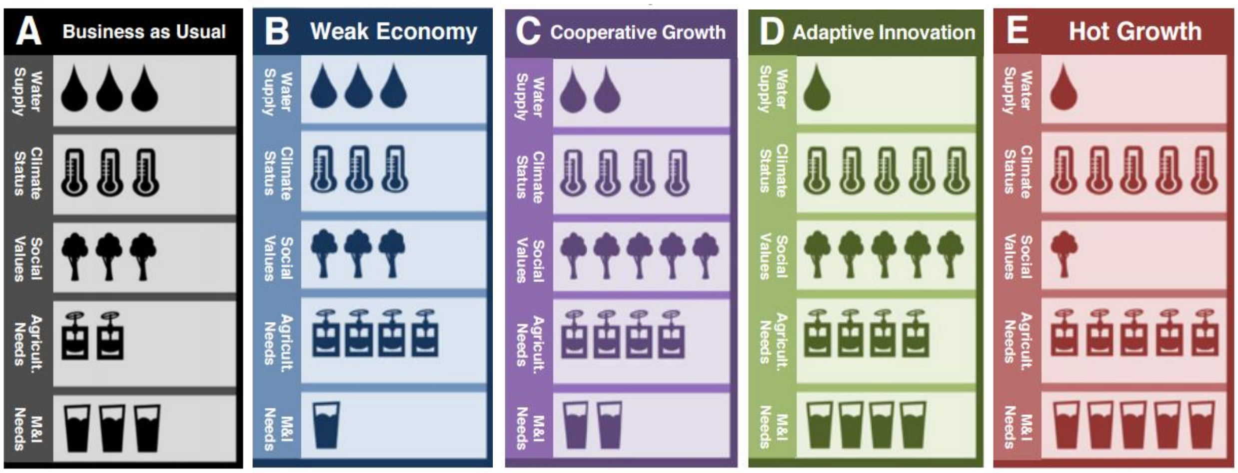


Figure 1: 2050 Planning Scenario Descriptions

The water supply and gap analyses rely heavily on information developed throughout the Technical Update effort, and documented in separate technical memoranda. The approach and resulting agricultural demands for the Baseline and 2050 Planning Scenarios are documented in the *Current and 2050 Planning Scenario Agricultural Diversion Demand* memorandum. Likewise, the approach and resulting municipal and self-supplied industrial (M&SSI) demands for the Baseline and 2050 Planning Scenarios are documented in the *Baseline and Projected 2050 Planning Scenario Municipal and Self-Supplied Industrial Water Demands* memorandum. Climate-adjusted hydrological information was developed through the Colorado River Water Availability Study Phase II (CRWAS-II) effort and documented in *Colorado River Availability Study Phase II Task 7: Climate Change Approach and Results*. The demand and hydrological information were brought together and analyzed using the Colorado Decision Support System (CDSS) water allocation modeling tools, where available. Using Prior Appropriation, these models are able to estimate the amount of water supply and gaps based on the changed demand and hydrology under each Planning Scenario.

This technical memorandum presents the water supply and gap information at a basin-level (Figure 2). Information presented herein generally includes a summary of agricultural and M&SSI demands and gaps by basin. Incremental increases in demand and gap are provided to understand how the results from each Planning Scenario compare relative to the Baseline results and other scenarios. Additionally, the results include projected changes in basin storage, physical streamflow, and water availability.

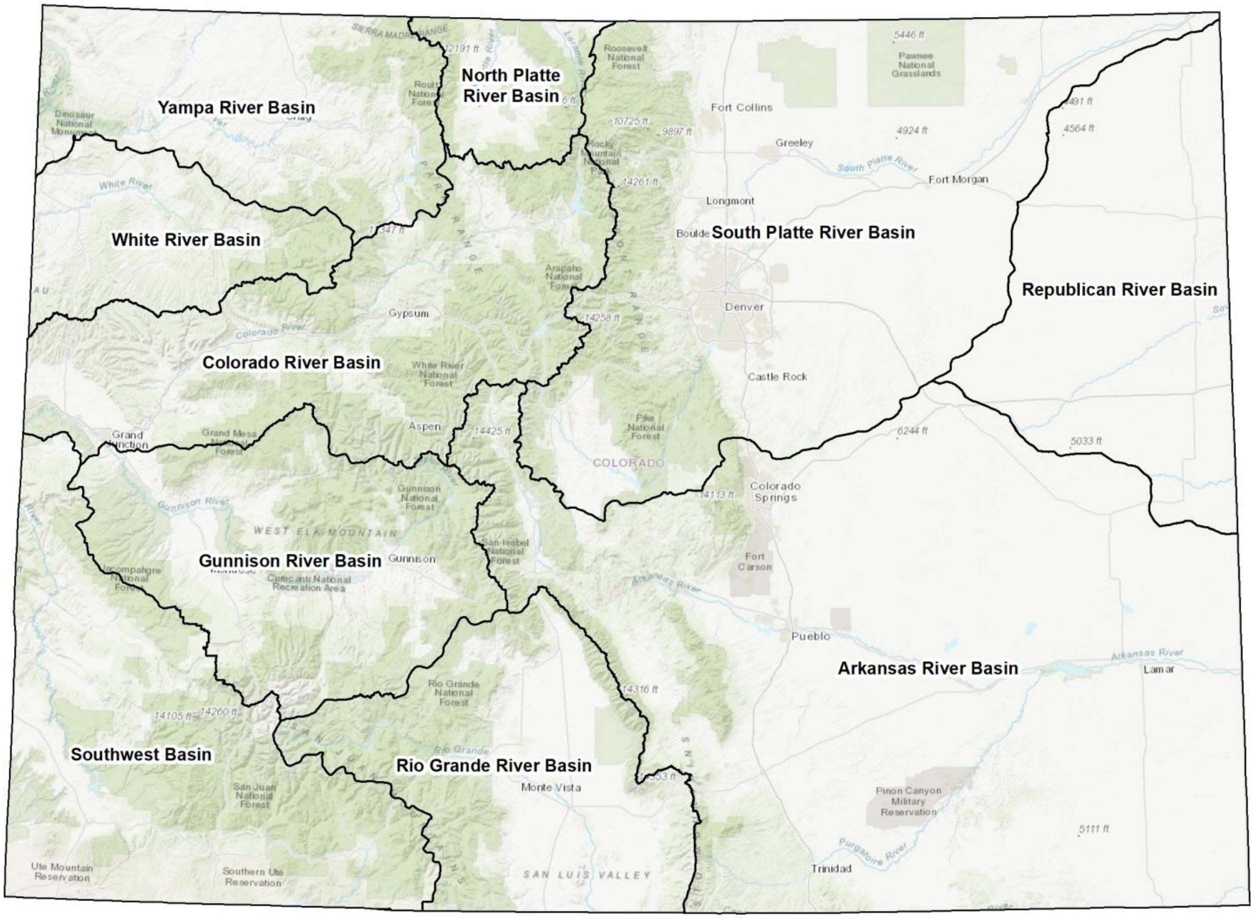


Figure 2: River Basin Boundaries

Section 2: Definitions and Terminology

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

- Water Supply Information: Collective term used to describe several pieces of data that characterize the total amount of water in a basin; data includes physical streamflow, reservoir contents, and agricultural and M&SSI gaps.
- Physical Streamflow: The amount of physical water in a stream at any given point in the river, either historical gaged streamflow or simulated streamflow from modeling results.
- Natural Flow: The amount of water supply absent the effect of man, serves as the foundation of the StateMod water allocation models.

- **Unappropriated Available Supply**: The amount of unappropriated streamflow at a specific location that could be developed under a future water right; also referred to as free river conditions.
- **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.
- **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.
- **Agricultural Gap**: The difference between the amount of water available to meet the agricultural diversion demand and the full agricultural diversion demand.
    - *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.*
- **Crop Demand Gap**: 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).
- **M&SSI Diversion Demand**: The amount of water that needs to be diverted or pumped to meet the full municipal and self-supplied industrial (M&SSI) demand.
- **M&SSI Gap**: The difference between the amount of water available to meet M&SSI diversion demand and the full M&SSI diversion demand.

Section 3: SWSI 2010 Water Supply Methodology

Basin-wide analyses on water supply and water availability were not completed in the SWSI 2010 effort. Rather SWSI 2010 discussed statewide surface and ground water availability by summarizing results of recent studies completed by CWCB and by individual Basin Roundtables. Additionally, SWSI 2010 summarized the major interstate compacts, decrees, and endangered species programs that impact water availability in each basin. Quantitative analyses completed for the original SWSI 1 effort in 2004 were not updated in the 2010 effort, with SWSI 2010 stating that “future SWSI updates will provide updated water availability analysis in each basin based on additional Colorado Decision Support System (CDSS) modeling tools”.

SWSI 2010 reported the following conclusions on water availability, which are consistent with conclusions developed during the SWSI 1 effort:

- There are no reliable additional water supplies that can be developed in the Arkansas and Rio Grande Basins, except in very wet years.

- The North Platte River Basin has the ability to increase both irrigated acres and some additional consumptive uses, consistent with the North Platte Decrees.
- The South Platte River Basin has water that is legally and physically available for development in wet years, although unappropriated water is extremely limited.
- Compact entitlements in the Colorado River Basins are not fully utilized and those basins (Colorado, Gunnison, Southwest, and Yampa-White) have water supplies that are legally and physically available for development given current patterns of water use.

The agricultural gap as defined in the Technical Update (i.e. the water required to meet the full IWR) was not analyzed in the SWSI 2010 effort. The SWSI 2010 effort calculated and reported shortages to the crops (i.e. crop demand gap) based on the most recent 10 years of historical information available, and noted that diversions and pumping would need to be much larger in order to meet the crop shortage.

The SWSI 2010 report provides an extensive summary of the M&SSI gap, defined as the amount of "future water supply need for which a project or method to meet that need is not presently identified". The SWSI 2010 municipal gap was developed by first calculating the 2050 M&SSI water needs corresponding to low, medium, and high growth scenarios; the current M&SSI use; and the anticipated yield from water providers' identified projects and processes (IPP). The gap could then be calculated using these components in the following equation, as documented in Section 5.3.1 of the SWSI 2010 report:

M&I and SSI Water Supply Gap = 2050 Net New Water Needs – 2050 IPPs

Where:

2050 Net New Water Needs =

(2050 low/medium/high M&I baseline demands – high passive conservation - current M&I use) + (2050 low/medium/high SSI demands – current SSI use)

2050 IPPs =

Water Provider Anticipated Yield from: Agricultural Transfers + Reuse + Growth into Exiting Supplies + Regional In-basin Projects + New Transbasin Projects + Firming In-basin Water Rights + Firming Transbasin Water Rights

Specific IPP and estimated yields were obtained from CWCB interviews and data collected from water providers throughout the State (2009-2010); the original SWSI effort (2004); and information from BRT (2008-2010). The overall IPP "success" was then adjusted to create varying levels of M&SSI gap based on the likelihood that a specific IPP would produce its full yield. Table 1 reflects the major categories of IPP and associated yield at 100 percent success rate.

Table 1: SWSI 2010 IPP Category and Yield by Basin

Basin	Agricultural Transfer (AFY)	Reuse (AFY)	Growth into Existing Supplies (AFY)	Regional In-Basin Project (AFY)	New Transbasin Project (AFY)	Firming In-Basin Water Rights (AFY)	Firming Transbasin Rights (AFY)	Total IPPs at 100% Success Rate (AFY)
Arkansas	9,200 – 11,000	23,000 – 32,000	2,300 – 2,600	37,000	0	6,100 – 7,300	10,000 – 11,000	88,000 – 100,000
Colorado	2,900 – 8,000	500	14,000 – 28,000	13,000 – 15,000	0	11,000 – 19,000	0	42,000 – 70,000
Gunnison	400 – 500	0	1,100 – 1,700	11,000 – 15,000	0	900	0	14,000 – 18,000
Metro	20,000 – 33,000	14,000 – 21,000	55,000 – 86,000	34,000 – 39,000	13,000 – 23,000	900 – 1,400	3,500 – 4,800	140,000 – 210,000
North Platte	0	0	100 – 300	0	0	0	0	100 – 300
Rio Grande	0	0	2,900 – 4,300	0	0	3,000 – 4,300	0	5,900 – 8,600
South Platte	19,000 – 20,000	5,000 – 7,000	20,000 – 30,000	37,000 – 39,000	0	22,000 – 26,000	18,000 – 21,000	120,000 – 140,000
Southwest	0	0	5,200 – 7,300	9,000 – 13,000	0	0	0	14,000 – 21,000
Yampa-White	0	0	3,500 – 4,900	6,600 – 9,000	0	0	0	10,000 – 14,000
Total	**51,000 – 73,000**	**43,000 – 61,000**	**100,000 – 160,000**	**150,000 – 170,000**	**13,000 – 23,000**	**44,000 – 58,000**	**32,000 – 37,000**	**430,000 – 580,000**

The SWSI 2010 reported the M&SSI gap ranging from 190,000 to 630,000 acre-feet by 2050, depending on the growth projection and the IPP success rate. This value assumes that the 1.16 million acre-feet of existing M&SSI supply annually will continue to be available into the future and that IPPs will yield between 350,000 and 430,000 acre-feet annually of additional supply to meet the increasedM&SSI demands.

Table 2 provides a summary of the projected 2050 M&SSI gap under the various growth and IPP success scenarios.

Table 2: SWSI 2010 M&SSI Gap

Basin	Increase in M&I and SSI Demand (AFY)			Estimated Yield of Identified Projects and Processes (AFY)			Estimated Remaining M&I and SSI Gap after Identified Projects and Processes (AFY)		
				100% IPP Success Rate	Alternative IPP Success Rates	Status Quo IPP Success Rates	Gap at 100% IPP Success Rate	Gap at Alternative IPP Success Rates	Gap at Status Quo IPP Success Rates
	Low	Med	High	Low	Med	High	Low	Med	High
Arkansas[2]	110,000	140,000	170,000	88,000	85,000	76,000	36,000	64,000	110,000
Colorado	65,000	82,000	110,000	42,000	49,000	63,000	22,000	33,000	48,000
Gunnison	16,000	19,000	23,000	14,000	14,000	16,000	2,800	5,100	6,500
Metro[3]	180,000	210,000	280,000	140,000	97,000	100,000	63,000	130,000	190,000
North Platte	100	200	300	100	200	300	0	20	30
Rio Grande	7,700	9,900	13,000	5,900	6,400	7,700	1,800	3,600	5,100
South Platte	160,000	180,000	230,000	120,000	78,000	58,000	36,000	110,000	170,000
Southwest	20,000	25,000	31,000	14,000	13,000	15,000	5,100	12,000	16,000
Yampa-White	34,000	48,000	95,000	10,000	11,000	13,000	23,000	37,000	83,000
Total	**590,000**	**710,000**	**950,000**	**430,000**	**350,000**	**350,000**	**190,000**	**390,000**	**630,000**

[1] Aggregated basin total values rounded to two significant digits to reflect increased uncertainty at larger geographic scales
[2] Arkansas gaps include additional 13,500 AFY for Urban Counties replacement of nonrenewable groundwater supplies.
[3] Metro gaps include additional 20,850 AFY for South Metro replacement of nonrenewable groundwater supplies.

Section 4: Technical Update Water Supply Methodology

As stated in SWSI 2010, the Technical Update provides a more in-depth analyses of historical and climate-adjusted hydrology and analyses of water availability to meet future projected agricultural and municipal diversion demands. The analyses, discussed in more detail below, relied primarily on water allocation models to simulate how climate-adjusted hydrology impacts future demands, and what unappropriated supplies may be available to meet the future projected demands. These Technical Update analyses will improve upon the SWSI 2010 effort by providing:

- Estimates of current and projected future physical streamflow at key locations.
- Estimates of how much the current and projected future agricultural and M&SSI diversion demands are satisfied on average and in a critically dry year; the remaining unmet diversion demand is considered to be the agricultural and M&SSI gap.
- Revised water allocation models in select basins reflecting the Planning Scenario demands and hydrology that can be used for future analysis of potential projects by Basin Roundtables (BRT) to meet the agricultural and M&SSI gap.

The Technical Update focuses on a basin's water supply under projected demands and hydrological conditions using the current municipal and agricultural operations and infrastructure. This differs from the SWSI 2010 effort because it will not look at the projected yield of a specific IPP or how effective that IPP would be in meeting the agricultural and M&SSI gap under the various Planning Scenarios. This approach is recommended because the BRT have taken on the role of looking at solutions to meet their basin needs through the Basin Implementation Planning effort. The BRT is a more appropriate forum to identify, fully vet, and ultimately analyze the ability of a specific IPP to meet demands in the basin under a variety of scenarios. The Technical Update, however, will provide the BRT with the data, tools, and analyses to support future analysis of an IPP.

The overall Technical Update water supply methodology can be separated into two steps. First, it is necessary to develop information for current conditions, providing a “baseline” comparison point for the Planning Scenario results. Next, the future demands and climate-adjusted hydrology are incorporated into the water allocation models. The Planning Scenario models are then simulated and results are used to develop water supply information, including estimates of physical streamflow and the agricultural and M&SSI gap for Planning Scenarios A through E.

4.1 CURRENT/BASELINE WATER SUPPLY METHODOLOGY

The water supply information for current conditions was developed using a “baseline” representation of the diversion demands and operations. A “baseline” representation means that the current agricultural and municipal diversion demands, operations, and infrastructure are in place as if the historical climatic and hydrological conditions will continue again into the future. Reflecting the current water supply in this way, as opposed to summarizing historical conditions over a recent period, was selected for the following reasons:

- It reflects current conditions over a long hydrologic period.
- It allows for a consistent methodology and comparison between the current and Planning Scenario water supply analyses.
- It is recommended by the CWCB as the starting point for “what if” Planning Scenario modeling.
- It has been previously implemented and vetted through the CDSS efforts.

The available data in each basin necessitates a slightly different methodology for analyzing the water supply information. The bulk of the analysis for the current water supply information relied on models and data developed under the CDSS program. In basins where the CDSS program has not been fully implemented, the methodology for those basins was modified based on water supply information that is available. This section discusses the specific methodologies that were used to develop the current “baseline” water supply information for each basin.

4.1.1 CDSS BASIN WATER SUPPLY METHODOLOGY

CWCB has developed water allocation datasets for use with the StateMod modeling platform for several of the basins in the State through the Colorado Decision Support System (CDSS) program. For basins with full CDSS program development, two water allocation datasets have been developed:

1. **Historical Dataset.** This dataset allocates water to meet the historical agricultural and municipal diversion demands in each basin. It contains historical diversions and pumping that reflect administrative and operational constraints on water supply as they occurred over time. This model is calibrated by comparing historical measured diversions, reservoir contents, and streamflow to simulated results; model adjustments are made until there is good correlation between the measured and simulated data. It is an appropriate dataset to look at historical conditions in the basin over an extended period of time.
2. **Baseline Dataset**. This dataset allocates water to meet the current agricultural and municipal diversion demands as if the historical climatic and hydrological conditions were to continue into the future. It reflects current administrative, infrastructure, and operational conditions over the entire study period (e.g. a reservoir constructed in 1985 would be operational for the 1975 – 2013 modeled period). It is an appropriate dataset to use for “what if” Planning Scenarios.

The State of Colorado's Water Allocation Model (StateMod) is a water allocation and accounting model capable of making comparative analyses for the assessment of various historical and future water management policies in a river basin. It is designed to be applied to any river basin through appropriate input data preparation. Note that information used in the modeling datasets is based on available data collected and developed through CDSS, including information recorded by the State Engineer's Office. The model datasets and results are intended for basin-wide planning purposes. Individuals seeking to use the model dataset or results in any legal proceeding are responsible for verifying the accuracy of information included in the model.

StateMod's operation, like the stream itself, is governed by its hydrology, water rights, demands for water, and infrastructure and operations used to deliver water. It recognizes four types of water rights (direct flow rights, instream flow rights, reservoir storage rights, well rights) and also user-specified operational "priorities or rights". Operational priorities or rights generally pertain to complex operations such as reservoir operating policies, exchanges, carrier ditch systems, augmentation or recharge, and changed water rights with associated terms and conditions. Each of the water rights is given an administration number (i.e. ranking) and location in the stream system. The model then sorts the water rights by priority and simulates their operation according to the Prior Appropriation Doctrine (i.e. first in time, first in right) allocating water until all the demands are satisfied or there is no longer physically or legally available streamflow to meet the demand.

The modeling platform is ideal for running "what-if" scenarios because, after it is properly calibrated, the user can include a "what-if" operation in the Baseline model (e.g. revised hydrology or a new demand) and simulate the model to see how the river regime responds with the future operation over a variable hydrology. The results of the changed model are compared to the results of the original Baseline model to assess the impact of the new operation. Figure 3 illustrates the availability of StateMod datasets in each basin.

Several of the CDSS datasets required refinement and/or extension prior to implementing revisions for the Technical Update effort. The following paragraphs summarize basin-specific revisions necessary to prepare the CDSS datasets for Technical Update modeling efforts.

West Slope Basins

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. 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.

North Platte River Basin

The North Platte River Basin model had not been updated and/or extended since the previous SWSI effort, therefore the Historical and Baseline datasets were extended through 2016 for this effort. During this effort, a total of six irrigation structures and irrigated acreage assessments from 2005 and 2010 through 2016 were added to the models.

South Platte River Basin

Only the Historical dataset was developed through the CDSS effort in the South Platte River Basin, therefore it was necessary to develop the Baseline StateMod dataset for the Technical Update effort. The Baseline StateMod dataset was developed by revising the Historical StateMod dataset to reflect the most current agricultural and municipal diversion demands, infrastructure, and operations over the entire study period. A significant complication in developing the Baseline dataset in South Platte River basin is the complexity of the municipal operations in the basin, both in terms of the municipalities' water portfolio and the flexibility in how the municipalities use their supplies. The Historical dataset in the basin reflects one representation of these operations, a representation that reflects the common municipal operations but may not capture the full operational flexibility that many municipalities have with their water supplies. The representation of the most current municipal operations, water rights, and infrastructure from the Historical model was implemented in the Baseline dataset[1] over the entire study period. The model extent was not expanded in this effort, however, and both the Historical and Baseline datasets exclude the Cache La Poudre River Basin (Water District 3) due to the on-going permitting efforts for projects in the sub-basin. Refer to the discussion below for more information on how the Cache La Poudre water supply information was developed and integrated into the overall South Platte River basin model.

[1] The South Platte River Historical model extends through 2012, and did not include representation of Aurora Water's Prairie Water Project. The Baseline model was revised to include this project, which increased the amount of return flows re-diverted by the project and used within Aurora Water's system in the model.

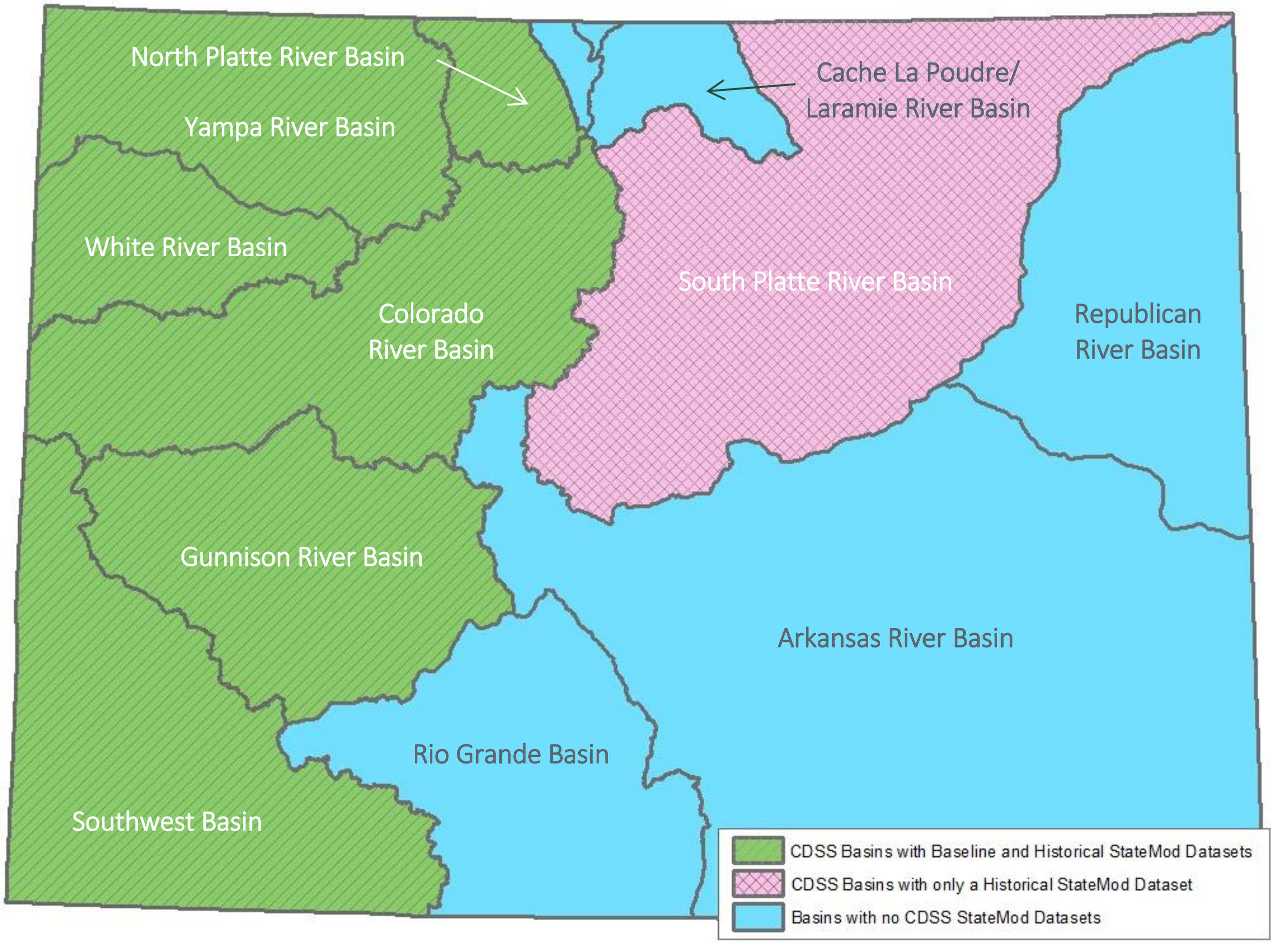


Figure 3: CDSS StateMod Model Availability

Once the CDSS models were refined for the Technical Update effort, the first step was to incorporate the Technical Update current agricultural demands and M&SSI demands into the Baseline Model. These demands were developed by the Technical Update consultant team and documented in the *Current and 2050 Planning Scenario Agricultural Diversion Demand* memorandum and the *Baseline and Projected 2050 Planning Scenario Municipal and Self-Supplied Industrial Water Demands* memorandum, respectively. Refer to Appendix A of this document for more information regarding how the agricultural and M&SSI demands were incorporated into the StateMod datasets. Note that transbasin imports and exports were not revised for the Current or Planning Scenario modeling effort and are represented with their historical records in the model datasets. Additionally, no environmental or recreational "demands" were added to the modeling dataset. The models represent many existing decreed minimum instream flow reach and recreational in-channel diversions (RICD) demands; however those demands were not revised for the Current or Planning Scenario modeling effort.

After incorporating the agricultural and M&SSI demands, the models were simulated over the period beginning in 1975 to the most current year available in the model. The Western Slope datasets extend through 2013, whereas the North and South Platte River Basin datasets extend through 2016 and 2012, respectively. The period of record in all of these basins provides for nearly 40 years of variable hydrology, including the critical drought years of the early and mid-2000s, over which to assess water supply conditions.

Results were extracted from the simulated model datasets and summarized using the standard CDSS data management tools (e.g. TSTool). The following information was extracted from the datasets to reflect current conditions:

1. Simulated monthly physical streamflow at key locations[2] in each basin.
2. Agricultural and M&SSI diversion demands on average and for a critically dry year summarized by Water District and by basin.
3. Agricultural gap and crop demand gap on average and for a critically dry year summarized by Water District and by basin.
4. M&SSI gap on average and for a critically dry year summarized by Water District and by basin.
5. Simulated monthly reservoir contents summarized by Water District and by basin.
6. Simulated unappropriated available supply at key locations in each basin, if the basin is not over-appropriated.

4.1.2 NON-CDSS BASIN WATER SUPPLY METHODOLOGY

There are four basins where a StateMod water allocation model has not been developed; the Arkansas, Republican, Rio Grande, and Cache La Poudre/Laramie River basins. These are also perhaps the four basins with the most limited water availability. As such, a full water allocation model is not necessary to understand the water availability in the basin; historical data can be used to estimate the current water supply information in the basin at a level sufficient for the Technical Update planning effort.

As with the CDSS Basin Water Supply Methodology, the agricultural and M&SSI demands in these basins were developed by the Technical Update consultant team and documented in the *Current and 2050 Planning Scenario Agricultural Diversion Demand* memorandum and the *Baseline and Projected 2050 Planning Scenario Municipal and Self-Supplied Industrial Water Demands* memorandum, respectively. The following sections summarize the approach used in each basin to develop the agricultural and M&SSI gap and water supply information for current conditions.

Republican River Basin

The Republican River basin is subject to the Republican River Compact of 1942, which governs the amount of beneficial consumptive use allowed in the basin. As the basin has almost no surface water diversions or reservoirs, the consumptive use in the basin is a result of irrigation from ground water supplies. Current levels of irrigation in the basin result in consumptive use that exceeds this allocation, therefore the basin is undergoing reductions to pumping and irrigated acreage, and the Compact Compliance Pipeline is being constructed to deliver ground water to the Stateline to bring the basin into compliance. As the basin is already over-appropriated, there is not consistent unappropriated surface or ground water available for a new water right in the basin. Current water supply information in the Republican River basin was developed primarily using historical information available from the Republican River Compact Accounting:

- Current agricultural gap was estimated to be the difference between the current agricultural diversion demand and historical pumping estimates.

[2] Key locations were selected in coordination with the Technical Update Environmental and Recreational consultant team to support analyses of projected streamflow in the Environmental Flow Tool. Refer to the Technical Update Environmental Flow Tool memorandum for more information on how the key locations were selected and environmental and recreational analysis of the resulting streamflow.

- Current crop demand gap was estimated as the difference between the historical IWR and WSL.
- The current M&SSI diversion demand was assumed to be fully satisfied and the current M&SSI gap was set to zero.

Arkansas River and Rio Grande Basins

Water availability in the Arkansas and Rio Grande basins is severely restricted by each basin's interstate agreements and compacts. In the Arkansas River basin the 1948 Arkansas River Compact restricts water use by post-1948 water rights to times when there would be no depletions to the usable Stateline flows. Those times only occur when flows are high enough to cause John Martin Reservoir to spill, which has only occurred 5 years since 1971.

The Rio Grande basin's compacts include the Rio Grande Compact of 1938, the Rio Grande, Colorado, and Tijuana rivers treaty of 1945 between the U.S. and Mexico, and the Amended Costilla Creek Compact of 1963. Although these compacts and agreements are complex, their administration effectively limits unappropriated water in the basin only to times when Elephant Butte Reservoir spills. This has occurred less than 10 times over the past 60 years.

Under these restricted conditions, there is not consistent unappropriated surface or ground water available for a new water right in either the Arkansas or Rio Grande basins. Current water supply information in these basins was developed primarily using historical information:

- Current agricultural gap was estimated to be the difference between the current agricultural diversion demand and the combined historical diversions and pumping.
- Current crop demand gap was estimated as the difference between the historical IWR and WSL.
- The current M&SSI diversion demand was assumed to be fully satisfied and the current M&SSI gap was set to zero.

Cache La Poudre and Laramie River Basins

The Cache La Poudre and Laramie River basins are located in north-central Colorado. The Laramie River basin flows north out of Colorado where it meets the North Platte River in Wyoming. The basin has a relatively small amount of irrigated acreage; however it does export a significant amount of water to the Cache La Poudre River via the Laramie-Poudre Tunnel. Diversions in the basin are limited by the Laramie River Decree of 1957.

The Cache La Poudre River flows southeast to its confluence with the South Platte River near Greeley. There is significant irrigation and municipal development in the basin, including several off-channel storage facilities. These basins were not included in the original South Platte River StateMod modeling effort due to the ongoing planning and permitting efforts of several large storage projects in the basin. Current water supply information in these basins was developed primarily using historical information:

- Current agricultural gap was estimated to be the difference between the current agricultural diversion demand and the combined historical diversions and pumping.
- Current crop demand gap was estimated as the difference between the historical IWR and WSL.
- The current M&SSI diversion demand was assumed to be fully satisfied and the current M&SSI gap was set to zero.

Although the methodologies for developing current water supply information in each of these basins differs from the CDSS basins, they provide an appropriate estimate of physical streamflow, water availability, and agricultural gap for current conditions for comparison to the Planning Scenario results.

4.2 PLANNING SCENARIO A-E WATER SUPPLY METHODOLOGY

The Colorado Water Plan presented five Planning Scenarios designed by the Interbasin Compact Committee (IBCC) to capture how Colorado's water future might plausibly look in 2050. The IBCC used five key drivers to adjust the relative demand and available water supply, as shown in Figure 4 below, to ultimately develop the five Planning Scenarios.

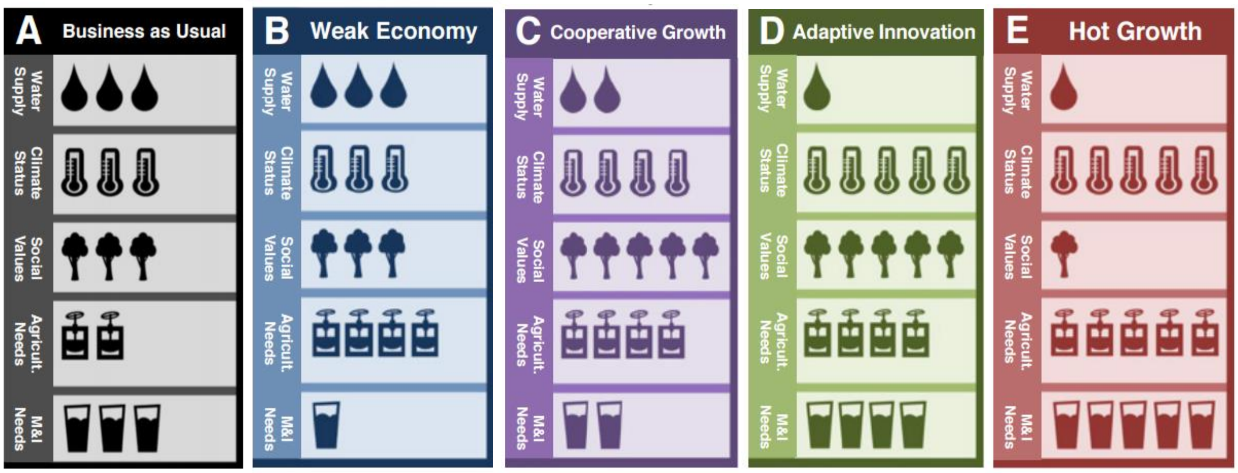


Figure 4: 2050 Planning Scenario Descriptions

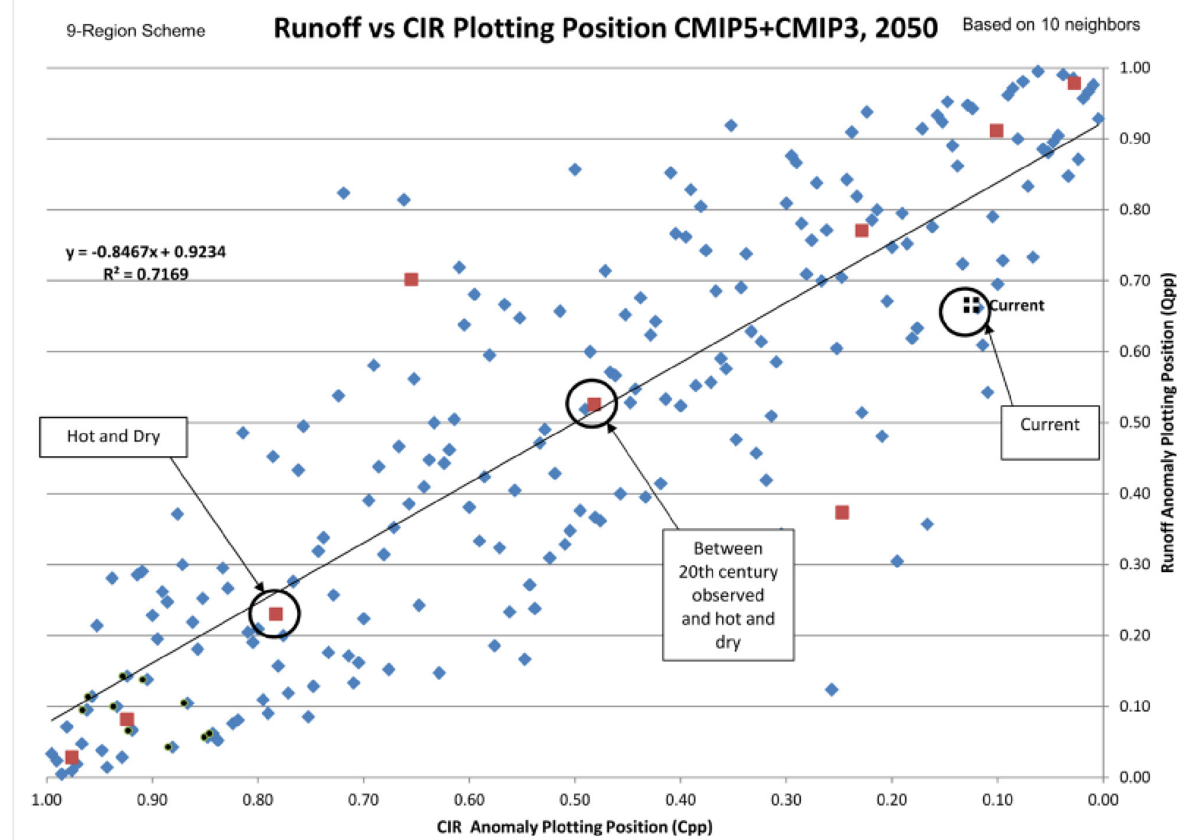
As depicted, "Water Supply" is a key driver in developing the overall Planning Scenarios, and the relative supply associated with this driver varies between each scenario (e.g. five water droplets reflects a larger water supply than two water droplets). Language associated with the graphics in the Colorado Water Plan provides information as to how the IBCC contemplated adjusting the water supply in the Planning Scenarios. The purpose of this section is to discuss how water supply was adjusted in each Planning Scenario and summarize the approach used in developing the projected 2050 water supply information for each Planning Scenario.

4.2.1 PLANNING SCENARIO WATER SUPPLY ADJUSTMENTS

CWCB has undertaken several studies and investigations on the impact of climate projections on the future of water 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, the IBCC chose to incorporate the impact of climate change and selected two future potential climate projections for the Planning Scenarios. As reflected in the graphic below from the Colorado Water Plan (Figure 5), the IBCC selected a group of climate projections representative of "Between 20th Century Observed and Hot and Dry" conditions (referred to as "In-Between") and another group of projections representative of "Hot and Dry" conditions. The climate projections included both projected changes to IWR and changes to hydrology.

Figure 5: Climate Projections selected by IBCC



"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.

The effort associated with processing the projected climate data and downscaling the information for use at the Water District level was completed through the CRWAS-II project. Refer to the CRWAS-II documentation, including the *Temperature Offsets and Precipitation Change Factors Implicit in the CRWAS-II Planning Scenarios* memorandum and *Colorado River Availability Study Phase II Task 7: Climate Change Approach and Results*, for more information on the projected climate conditions. The CRWAS-II effort resulted in a time series of climate-adjusted hydrology at over 300 streamflow gage locations statewide for each climate projection. The hydrology reflects "natural flow", which is the amount of water in the river absent the effect of man and serves as the foundation of the StateMod water allocation models. Although the impact of the climate projections varies across the state, natural flow under the climate projections generally show an overall decline and shift temporally to reflect earlier runoff periods.

Using the "Water Supply" driver under each Planning Scenario as a guide, Table 3 reflects the recommended assignment of projected climate conditions for Planning Scenarios A-E. The methodology for incorporating the climate-adjusted natural flow in the Planning Scenario allocation models is discussed in more detail below.

Table 3: Climate Projection Assignment to Planning Scenarios

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

4.2.2 CDSS BASIN PLANNING SCENARIO WATER SUPPLY METHODOLOGY

The Planning Scenario water supply information will be developed using an approach similar to that described in Section 4.1, which was used to develop the current water supply information. The Planning Scenario water supply information, however, will be developed using projected 2050 agricultural and M&SSI demands specific to each Planning Scenario and, in some scenarios, climate-adjusted hydrology. Once the Planning Scenario datasets are developed, they can be simulated and the results can be compared to the current water supply information to assess the impact of the projected demands and hydrology. This section outlines the approach that will be used to develop the Planning Scenario A through E StateMod models and water supply information.

The Baseline StateMod datasets developed for the current water supply analysis serve as the starting point for the Planning Scenario datasets. The following steps were taken to develop the Planning Scenario StateMod datasets and ultimately the water supply information:

1. Incorporate the appropriate 2050 Planning Scenario agricultural diversion demands into the Planning Scenario models.
2. Incorporate the appropriate 2050 Planning Scenario M&SSI diversion demands into the Planning Scenario models.
3. Incorporate the appropriate climate-adjusted natural flow into the Cooperative Growth, Adaptive Innovation, and Hot Growth Planning Scenario models; Business as Usual and Weak Economy reflect the current hydrology as if it were to occur again into the future.
4. Simulate the Planning Scenario models.
5. Extract the monthly physical streamflow and water availability at key locations in each basin.
6. Summarize the M&SSI gap by Water District and by basin on average and for critically dry years.
7. Summarize the agricultural gap and crop demand gap by Water District and by basin on average and for critically dry years.
8. Summarize total storage by Water District and by basin over the modeled period.

In select basins, additional information was extracted from the models to provide an estimate of how much water may be available from changed irrigation water rights associated with land undergoing urbanization, and an estimate of how much transbasin water may not be available to be delivered (i.e. transbasin import supply gap) due to changes in physically or legally available supplies in the exporting basin.

Note that the Planning Scenario StateMod datasets incorporate the projected hydrology and demands with the Baseline representation of the basins' infrastructure and operations. Adjustments to other modeling parameters, such as order of supplies used to meet municipal diversion demands or alternative methods for conveying water, were not be made in the Planning Scenario datasets under this effort. This effort will produce a set of Planning Scenario StateMod datasets that can be further refined in subsequent analyses to investigate future projects or operations that may help alleviate agricultural or M&SSI gaps or achieve other river basin goals.

4.2.3 NON-CDSS BASIN PLANNING SCENARIO WATER SUPPLY METHODOLOGY

The absence of basin-wide planning models in these basins limits the options to evaluate the projected demands and hydrology in the non-CDSS basins. Many models that have been created for these basins reflect historical conditions (i.e. point flow models); reflect only a portion of the basin; are proprietary models developed by water users and not available for use; have only been partially calibrated; or do not contain sufficient detail/resolution to evaluate the projected demands and hydrology. As such, these existing models are not conducive to implementing the "what-if" Planning Scenario conditions; however, they do provide information on the basin operations which can be used in developing the Planning Scenario water supply information. An additional consideration is that these basins are generally the most over-appropriated basins in the state. As such, any agricultural or M&SSI demands above and beyond current levels cannot be met from unappropriated supplies in the basin and are considered a gap. The following discussion summarizes how the water supply information was developed in these basins.

Republican River Basin

Development of Planning Scenario water supply information in the Republican River basin is unique in that the general absence of surface water diversions in the basin means that climate-adjusted hydrology will not impact the amount of surface water diverted for agricultural uses. Ground water supplies will be affected by the climate-adjusted hydrology; however, that interaction was not contemplated under this Technical Update effort. Due to the limited streamflow in the basin, specific climate-adjusted hydrology estimates were not explicitly developed for gages in the Republican River basin.

For the Republican River basin, the current levels of ground water supplies serve as the maximum available water supply in the basin into the future and it was assumed that no unappropriated surface or ground water supplies will be available in the future. As such, any projected demands in the basin greater than these supplies are reflected in the gap. Additionally, it was assumed that current irrigation practices, in which irrigators pump less than the full amount needed be the crops (i.e. deficit pumping) will continue into the future, as supported through discussions with stakeholders in the basin. Based on these assumptions, projected water supplies in the Republican River basin were estimated as follows:

- Planning Scenario unappropriated available supply was set to zero.
- Planning Scenario agricultural gap and crop demand gap was estimated as the difference between the Planning Scenario agricultural diversion demand and the current levels of agricultural pumping on average and for critically dry years.
- Planning Scenario municipal gaps were estimated as the difference between the Planning Scenario M&SSI demand and the current M&SSI demand on average and for critically dry years.

Arkansas River and Rio Grande Basins

Development of Planning Scenario water supply information in these basins relied heavily on historical water availability results in the basin, assuming that because the basins are over-appropriated, water availability would continue into the future at similar levels or decline under climate-adjusted Planning Scenarios. As such, agricultural gaps for the Business as Usual and Weak Economy Planning Scenarios were based on shortages experienced historically. For the remaining climate-adjusted Planning Scenarios, the change in hydrology at key locations was used to adjust the historical shortages. For example, the change in hydrology at the Alamosa River above Terrace Reservoir gage location was used to adjust (i.e. increase) the historical shortages to agricultural demands in the Alamosa River sub-basin for the climate-adjusted scenarios.

M&SSI gaps in Planning Scenarios were set equal to the incremental increase of the Planning Scenario demand compared to the Baseline demand, based on the premise no unappropriated supplies would be available in the basin to meet the increased demand.

Change in simulated flow and storage for the Planning Scenarios could not be accurately estimated, however the change in natural flow at key locations throughout the basin was provided to illustrate the potential impact of the changed hydrology to streamflow and storage conditions.

Cache La Poudre and Laramie River Basins

Although these basins do not have the full suite of CDSS modeling tools available, model results from neighboring sub-basins with similar levels of irrigated acreage, municipal demands, storage, and transbasin supplies, can be used to inform and adjust the Planning Scenario results in these basins. This approach allows the Planning Scenario results in these basins to be adjusted in response to the Planning Scenario adjustments, including increased M&SSI demands, reduced agricultural demands, and reduced hydrology, without simulated the full river operations. The following approach was used to develop water supply information in these basins:

- The Planning Scenario agricultural gap was based on the current agricultural gap, and then adjusted based on the gap results from neighboring sub-basins in each Planning Scenario.
- The Planning Scenario M&SSI gap was assumed to be similar to M&SSI gaps experienced in neighboring sub-basins, particularly in sub-basins in which the municipal supplies are similar (e.g. Colorado-Big Thompson supplies, changed water rights, storage).
- The outflow from the Cache La Poudre River to the South Platte River was based on historical streamflow for the Business as Usual and Weak Economy scenarios; and adjusted with the hydrology factors in Planning Scenarios with climate-adjusted hydrology.

The Planning Scenario water supply information from the Cache La Poudre and Laramie River basins was then incorporated into the overall South Platte River and North Platte River basin results, respectively.

4.3 EXPLANATION OF RESULTS

Water supply and gap results from the Baseline and Planning Scenarios are summarized by basin and Statewide in the sections below. The sections provide the results in both graphical and tabular format; additional discussion and observations on the results are also provided. The results are presented in the same order in each basin:

1. Agricultural results (green color-coding)
2. M&SSI results (orange color-coding)
3. Transbasin results (blue color-coding)

Agricultural and M&SSI demand and gap results presented in a tabular format in each section contain the following standard categories. Refer to the explanation for information on how the data in each category was calculated.

Result Table Category	Explanation
Average Annual Demand (ac-ft)	Total annual demand in the basin, averaged over model period of record
Average Annual Demand Increase from Baseline (ac-ft)	Planning Scenario average annual demand minus Baseline demand; set to zero if Planning Scenario demand is less than Baseline demand
Average Annual Gap (ac-ft)	Total annual gap in the basin, averaged over model period of record
Average Annual Gap Increase from Baseline (ac-ft)	Planning Scenario average annual gap minus Baseline gap; set to zero if Planning Scenario gap is less than Baseline gap
Average Annual Percent Gap	Average annual gap divided by the average annual demand
Average Annual CU Gap (ac-ft)	Only available for agricultural demands; average annual amount of shorted IWR; estimate of lost crop yield.
Demand In Maximum Gap Year (ac-ft)	Demand that occurred in the year with the largest gap; note that it may not represent the maximum demand for the entire period of record
Increase from Baseline Demand (ac-ft)	Planning Scenario demand in maximum gap year minus Baseline demand in maximum gap year; set to zero if Planning Scenario demand is less than Baseline demand
Gap In Maximum Gap Year (ac-ft)	Maximum gap volume by basin; may not occur in the same year statewide
Increase from Baseline Gap (ac-ft)	Planning Scenario maximum gap minus Baseline maximum gap; set to zero if Planning Scenario gap is less than Baseline gap
Percent Gap In Maximum Gap Year	Maximum gap divided by demand that occurred in the same year

Transbasin diversions, both imports and exports, are reflected in the model at their historical levels and were not assumed to vary across Planning Scenarios. Understanding how water providers may change their operations under the projected demands or climate-adjusted hydrological conditions was beyond the scope of this effort, therefore historical operations were maintained. The transbasin export demand is included in the total basin demands for basins that export transbasin supplies. In some instances, the full transbasin demand could not be diverted in the source basin due to a physical or legal limitation of water supply at the diverting location. This is caused by changes in water availability, increases in senior demands in the source basin, or a combination of both. When this occurs, the resulting shortage to the demand is reported as a transbasin import supply gap in the destination basin. Similar to the table above, the import supply gap results are summarized both on an average annual basis and for critically dry years. The import supply gap results are provided for informational purposes; the import supply gap would have the effect of increasing the overall gap in the destination basin, however this was not directly applied to the gap values.

All basins are projected to experience urbanization of irrigated acreage, or acreage that is projected to come out of production due to municipal growth, in at least one of the Planning Scenarios. Supplies used to irrigate the urbanized acreage could be considered a new municipal supply if the associated water rights were changed to municipal uses. To capture the amount of water associated with this potential new supply, the average annual consumptive use of the urbanized acreage was estimated and provided for each basin. There are several uncertainties as to whether the urbanized supply would or could directly be used to offset M&SSI demand, therefore the historical consumptive use values were not directly applied to the gap values.

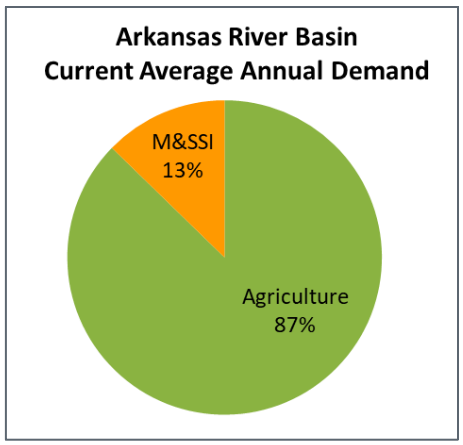
Time series information for the Baseline and Planning Scenarios is primarily presented either on a monthly basis over the model period of record (e.g. storage contents) or as average monthly values (e.g. simulated streamflow). The colors in these graphics used to represent Baseline and Planning Scenario results are consistent throughout the document. As discussed in the basin summaries below, results from the Weak Economy (green line) are often overlapping the Business as Usual (maroon line) and Baseline (black line) results. Note that natural flow information, as opposed to simulated streamflow information, is presented for the Arkansas River and Rio Grande basins. The graphics reflecting these natural flows only include results from the Current, In-Between, and Hot and Dry hydrological conditions and are displayed with a different color scheme.

Section 5: Water Supply and Gap - Basin Summary Results

This section summarizes the water supply and gap results for each basin; refer to Figure 2 for a map of each basin boundary. The total Statewide water supply and gap results are provided in Section 6.

5.1 ARKANSAS RIVER BASIN

The majority of the water in the Arkansas River basin is used to irrigate over 472,000 acres, with nearly half of these acres located along the river between Pueblo Reservoir and the stateline. 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[3] deliveries. 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).



The following sections describe the agricultural and M&SSI demands in the Arkansas River basin in more detail. Figure 6 reflects the basin outline, the administrative boundaries of

[3] The Fryingpan-Arkansas Project is a transbasin 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.

water districts, and the streamflow gages highlighted in the results section below.

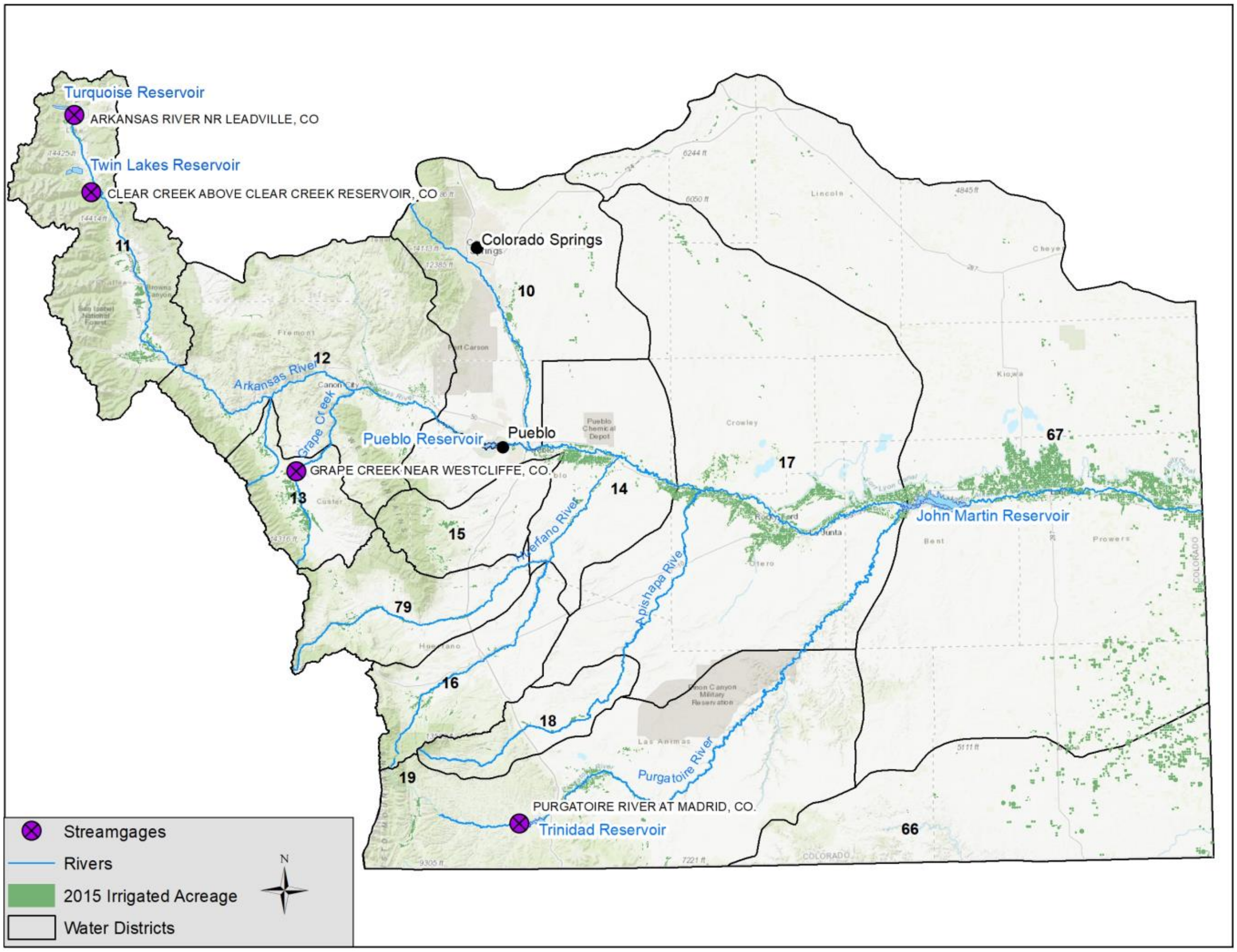


Figure 6: Arkansas River Map with Streamgage Locations

5.1.1 ARKANSAS RIVER BASIN AGRICULTURE WATER SUPPLY AND GAP

As mentioned above, a majority of the irrigated acreage in the basin is located between Pueblo Reservoir and the stateline. The fertile soils in this river valley support a wide variety of crops, including pasture grass, alfalfa, corn, grains, wheat, fruits, vegetables, and the renown Rocky Ford melons. Fields in the area are still predominantly flood irrigated, however producers are converting to drip and sprinkler irrigation methods. 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 resulting Arkansas River Basin agricultural diversion demands, demand gaps, and consumptive use gap results for the baseline and Technical Update Planning Scenarios are presented in Table 4. As discussed in the *Current and 2050 Planning Scenario Agricultural Diversion Demand* technical memorandum, 2050 agricultural diversion demands are influenced by a number of drivers, including climate, urbanization, and emerging technologies.

Table 4: Arkansas River Basin Agricultural Water Supply and Gap Summary

	Agricultural Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,899,894	1,778,323	1,770,230	1,878,883	1,721,160	1,918,022
	Average Annual Demand Increase from Baseline (ac-ft)	-	-	-	-	-	18,128
	Average Annual Gap(ac-ft)	617,289	586,445	585,246	701,659	734,783	819,461
	Average Annual Gap Increase from Baseline (ac-ft)	-	-	-	84,370	117,494	202,172
	Average Annual Percent Gap	32%	33%	33%	37%	43%	43%
	Average Annual CU Gap (ac-ft)	313,135	297,056	296,423	362,464	381,457	425,265
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	2,303,894	2,152,059	2,141,540	2,149,344	1,932,665	2,157,896
	Increase from Baseline Demand (ac-ft)	-	-	-	-	-	-
	Gap In Maximum Gap Year (ac-ft)	1,446,435	1,369,579	1,366,564	1,532,028	1,566,087	1,749,833
	Increase from Baseline Gap (ac-ft)	-	-	-	85,594	119,652	303,398
	Percent Gap In Maximum Gap Year	63%	64%	64%	71%	81%	81%

All of the Planning Scenarios reflect a reduction of approximately 20,000 irrigated acres due to the projected urbanization and/or municipal transfer of water rights; an additional reduction ranging from approximately 7,500 to 26,000 irrigated acres across the Planning Scenarios associated with projected ground water sustainability concerns; and projected sprinkler development in the Arkansas River Valley. These Planning Scenario adjustments lead to a 122,000 ac-ft reduction in average agricultural demand in the Business as Usual Planning Scenario, and an additional 8,000 ac-ft reduction in the Weak Economy scenario compared to the Baseline demand. The impact of reducing irrigated acreage is nearly offset by the climate adjustments to IWR and additional sprinkler development in the southeast corner of the basin in the Cooperative Growth scenario, resulting in an agricultural demand only 2 percent less than the Baseline scenario demand. The Adaptive Innovation Planning Scenario, however, is substantially less than the Baseline scenario despite the projected increase from climate-adjusted IWR factors because of the improved system efficiency adjustment attributable to Emerging Technologies. The combined impact from these factors leads to a 10 percent reduction to agricultural demand in the Adaptive Growth scenario compared to the Baseline scenario. The Hot Growth scenario reflects the largest demand due to the climate adjustments and is the only scenario in which the agricultural demand is greater than the Baseline scenario demand.

Development of the Arkansas River Decision Support System is currently underway and future Technical Updates will have the benefit of using the full suite of models to evaluate water availability in the basin. For this effort, a basin-wide historical and baseline consumptive use model were developed to better understand existing agricultural demands and shortages, however a surface water model was not available. As such, shortages from the consumptive use model were relied upon to inform the gap in the Baseline, Business as Usual, and the Weak Economy Planning Scenarios. The agricultural demands basin-wide have historically experienced a 32 percent gap on average. If current climate conditions occur again in the future as contemplated in the Baseline, Business as Usual and Weak Economy scenarios, the projected gaps for these scenarios are likely to be similar to the historical gap. The gap results for the critically dry year were developed in a similar fashion, however only using gap information for drought years in each Water District, resulting in a basin-wide average gap of 63 percent for the three scenarios.

For the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios that reflect a change in hydrology, the gap values needed to be further adjusted. In order to capture the combined impact of the climate adjustment in the basin, it would be necessary to simulate the basin operations with the climate-adjusted hydrology in a surface and ground water model. As that level of modeling was beyond the scope of this Technical Update, a simplified approach was developed that captured the change in hydrology and translated the change to a gap value. Refer to the Water Supply Methodology section above for more information on the approach; however, in short, the average decline in runoff at a representative streamflow gage was used to increase the projected gap for these scenarios. This approach assumes that irrigated acreage served by surface and ground water experience a similar shortage due to a decline in runoff volume because a reduction to surface water supplies would result in a reduction of diversions to irrigated land and diversions for augmentation and recharge to offset ground water pumping. On average, the decline in total runoff volume for the Cooperative Growth scenario increases the gap to 37 percent, and to 43 percent for the Adaptive Innovation and Hot Growth scenarios. The following bar graphs reflect the average and maximum gaps in critically dry years for each Planning Scenario. The gaps increase to 71 and 81 percent for the scenarios, respectively, in critically dry years as reflected in the annual agricultural gap time series below (Figure 9).

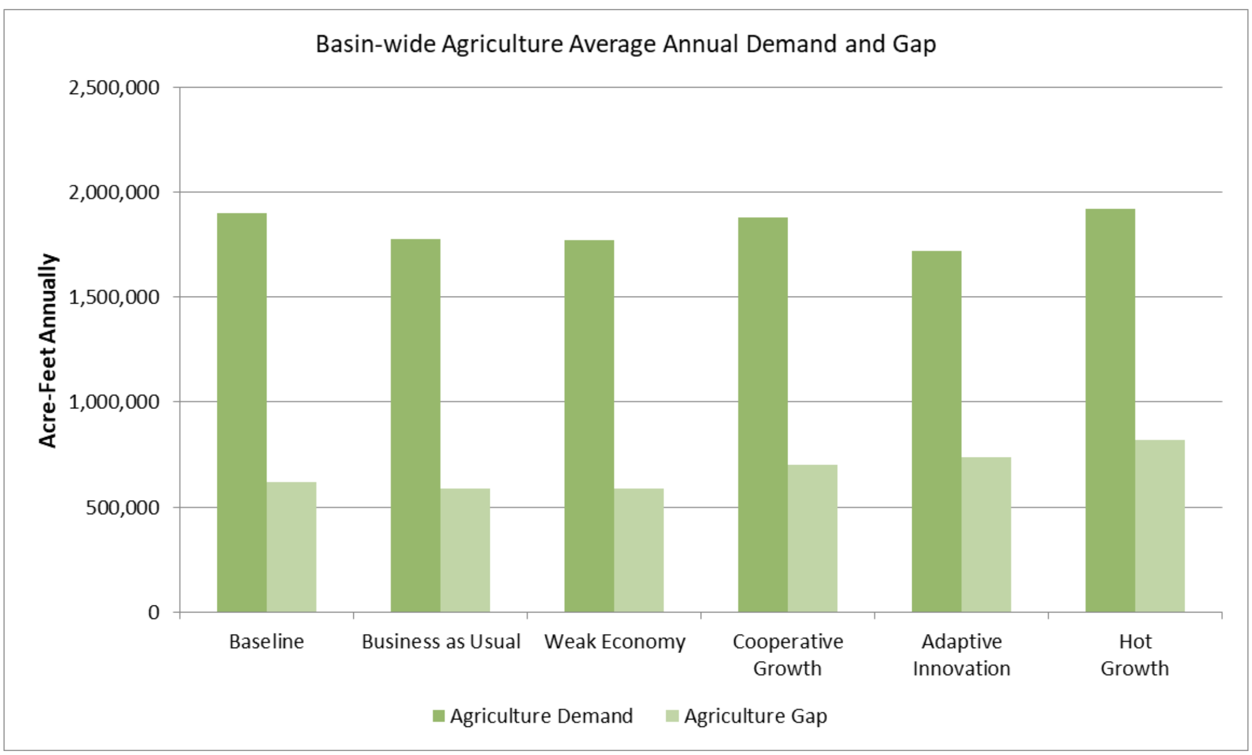


Figure 7: Arkansas River Basin Agriculture Average Annual Demand and Gap

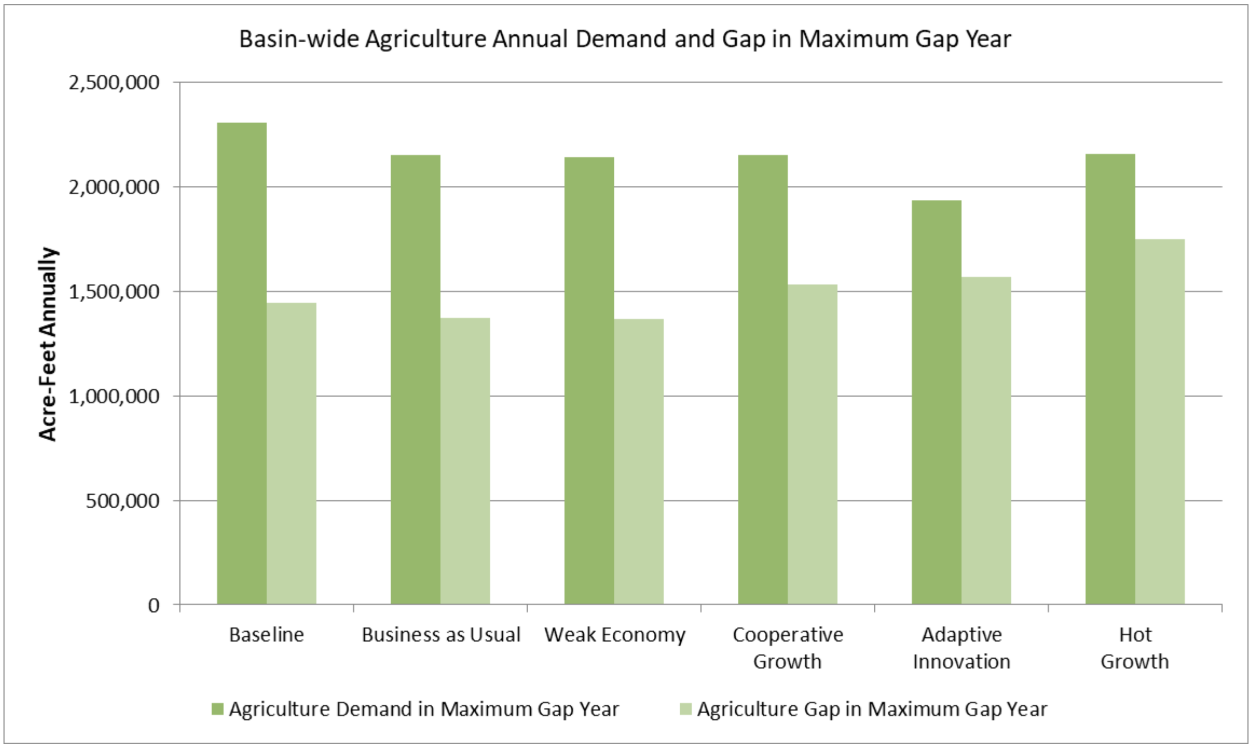


Figure 8: Arkansas River Basin Agriculture Annual Demand and Gap in Maximum Gap Year

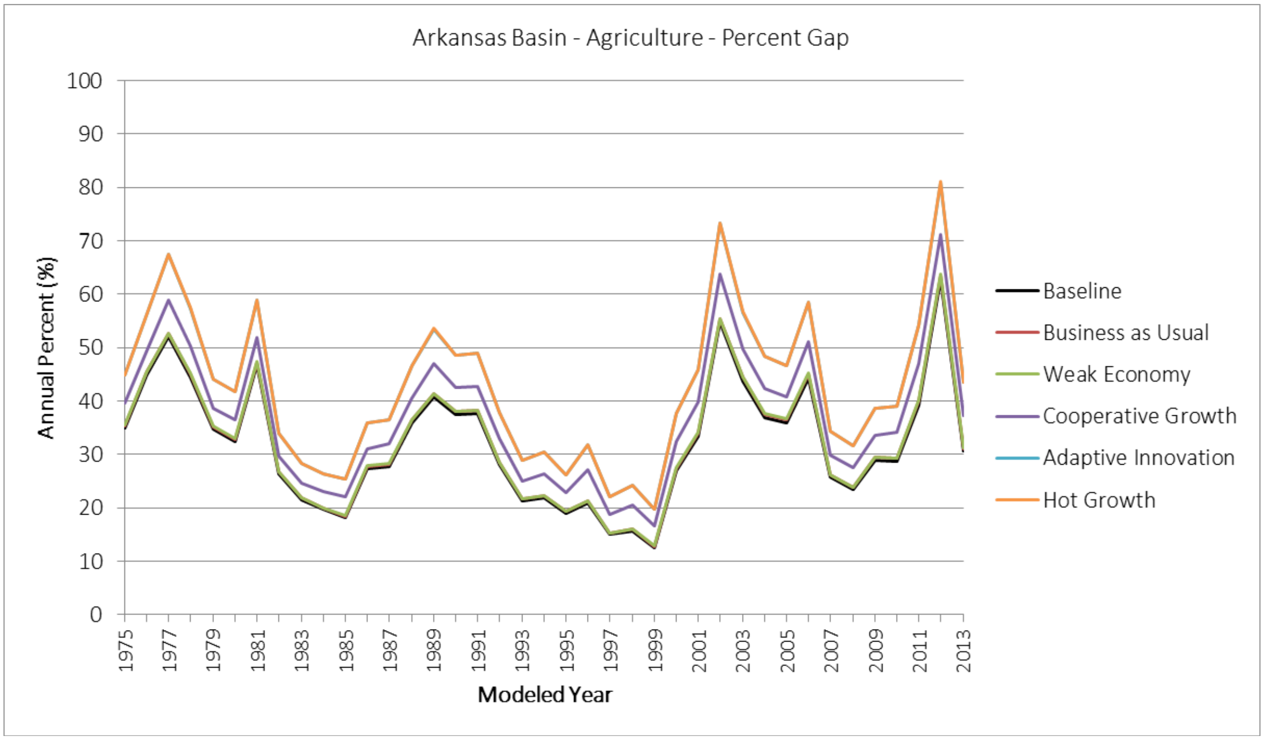


Figure 9: Arkansas River Basin Agriculture Percent Diversion Gap Times Series

5.1.2 ARKANSAS RIVER BASIN M&SSI WATER SUPPLY AND GAP

M&SSI demands in the Arkansas represent approximately 13 percent of the total demand in the basin, substantially lower than agricultural demand. Municipal demands currently account for approximately 80 percent of the total M&SSI demand, with the remaining portion attributable to Large Industrial and Energy Development SSI demands. Municipal demands are largest in El Paso and Pueblo County, and the municipal demand in these counties is projected to significantly grow in the future. Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin were developed. The water supply and gap results for M&SSI in the Arkansas River basin are summarized in Table 5, and graphically reflected in Figure 10 and Figure 11.

Table 5: Arkansas River Basin Municipal and Self Supplied Industrial Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	276,738	363,259	347,886	353,203	357,647	403,486
	Average Annual Demand Increase from Baseline (ac-ft)	-	86,521	71,148	76,465	80,909	126,748
	Average Annual Gap (ac-ft)	-	68,521	53,148	58,465	62,909	108,748
	Average Annual Gap Increase from Baseline (ac-ft)	-	68,521	53,148	58,465	62,909	108,748
	Average Annual Percent Gap	0%	19%	15%	17%	18%	27%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	276,738	363,259	347,886	353,203	357,647	403,486
	Increase from Baseline Demand (ac-ft)	-	86,521	71,148	76,465	80,909	126,748
	Gap In Maximum Gap Year (ac-ft)	-	68,521	53,148	58,465	62,909	108,748
	Increase from Baseline Gap (ac-ft)	-	68,521	53,148	58,465	62,909	108,748
	Percent Gap In Maximum Gap Year	0%	19%	15%	17%	18%	27%

Population is projected to increase in the Arkansas River basin in all Planning Scenarios, driven by the increase in population in the two most populous counties, El Paso and Pueblo County. Population is also expected to increase in the headwaters of the basin, but remain relatively constant or decline in counties on the eastern plains. Population increases for municipalities in the basin range from approximately 454,000 to 618,000 people across the Planning Scenarios, with the highest population projected to occur in the Adaptive Innovation scenario. Overall, the population and M&SSI Planning Scenario adjustments, including climate adjustments, captured in each county's projected per capita demand combine to increase the M&SSI demand compared to the Baseline demand.

A simplified approach to estimating the M&SSI gap was taken in the Arkansas River Basin. As neither surface nor ground water supplies are projected to be available to meet increases in demand in the future due to Compact administration and declining aquifer levels, for many M&SSI users the Baseline demand served as the maximum amount of demand expected to be met in the future. Larger M&SSI providers, such as Colorado Springs Utilities, may have additional existing supplies they can reasonably expect to grow into, however these are limited and projected M&SSI gaps in the Planning Scenarios remain. Therefore, any increases to the demand beyond growth into existing supplies[4] can reasonably be

[4] Colorado Springs' current demand was estimated for this effort to be approximately 77,000 ac-ft annually, calculated based on the municipality's current population as a percentage of the total El Paso County population multiplied by the total current El Paso County M&SSI demand. This is less than Colorado Springs Utilities' (CSU) estimated current demand of 88,000 ac-ft annually in the CSU Integrated Water Resources Plan (IWRP), as the assumptions for the IWRP demand differ from those used for the Technical Update. With this consideration in mind, the IWRP indicates CSU's current system can reliably meet 95,000 ac-ft of demand annually; resulting in an estimated 18,000 ac-ft of existing supplies that may be available to meet future demands. Pueblo Board of Water Works did not provide an estimate for growth into existing supplies, and therefore was not accounted for in the gap.

considered an M&SSI gap. This simplified approach does not take into consideration the shift of population and demand within the basin (i.e. decline of population in one county and an increase in population in another county), which may indicate a specific area may experience a larger gap in the future. Additionally, it also does not take into consideration the types of existing supplies that larger providers (e.g. storage, transbasin supplies, changed irrigation water rights) may grow into, and whether those supplies are available in critically dry years or in climate-adjusted Planning Scenarios. As such, the gap may be under-estimated based on this approach.

With this in mind, even the smallest basin-wide gap of approximately 53,000 ac-ft for the Weak Economy scenario is substantial. The M&SSI gaps increase moderately in the Business as Usual, Cooperative Growth, and Adaptive Innovation scenarios, but the M&SSI gaps double in the Hot Growth scenario compared to the Weak Economy scenario.

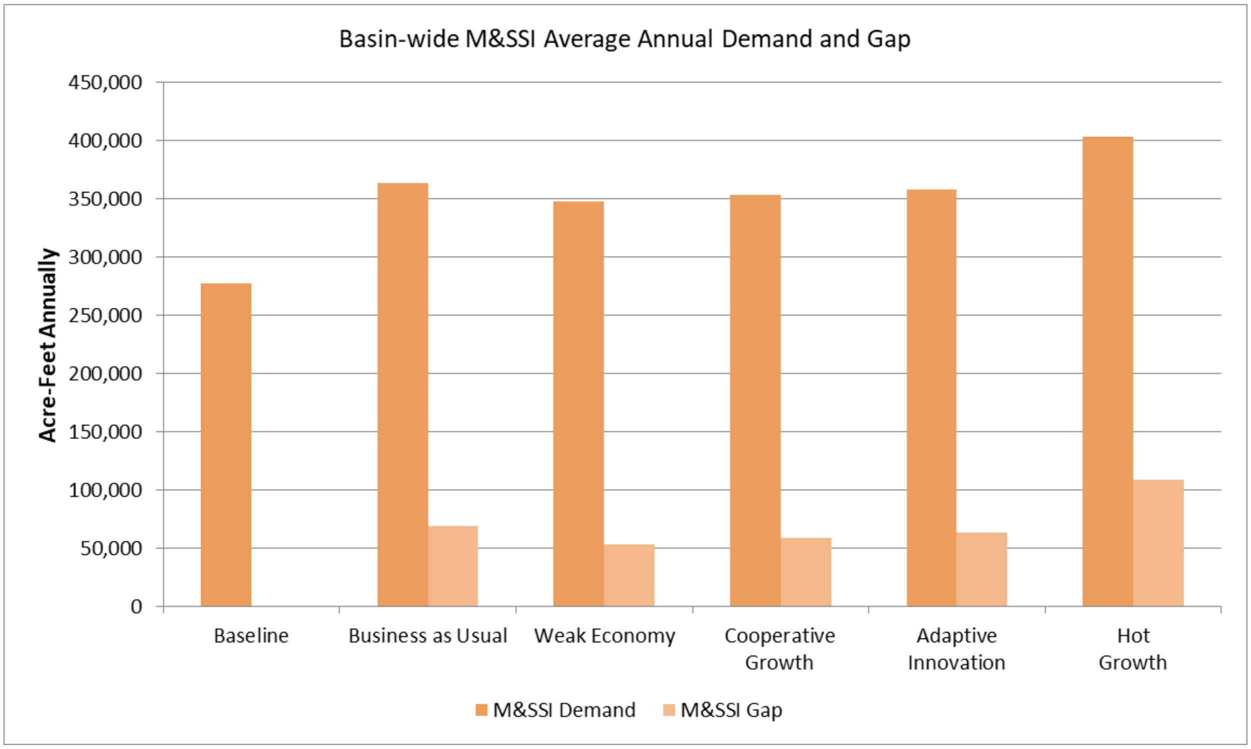


Figure 10: Arkansas River Basin M&SSI Average Annual Demand and Gap

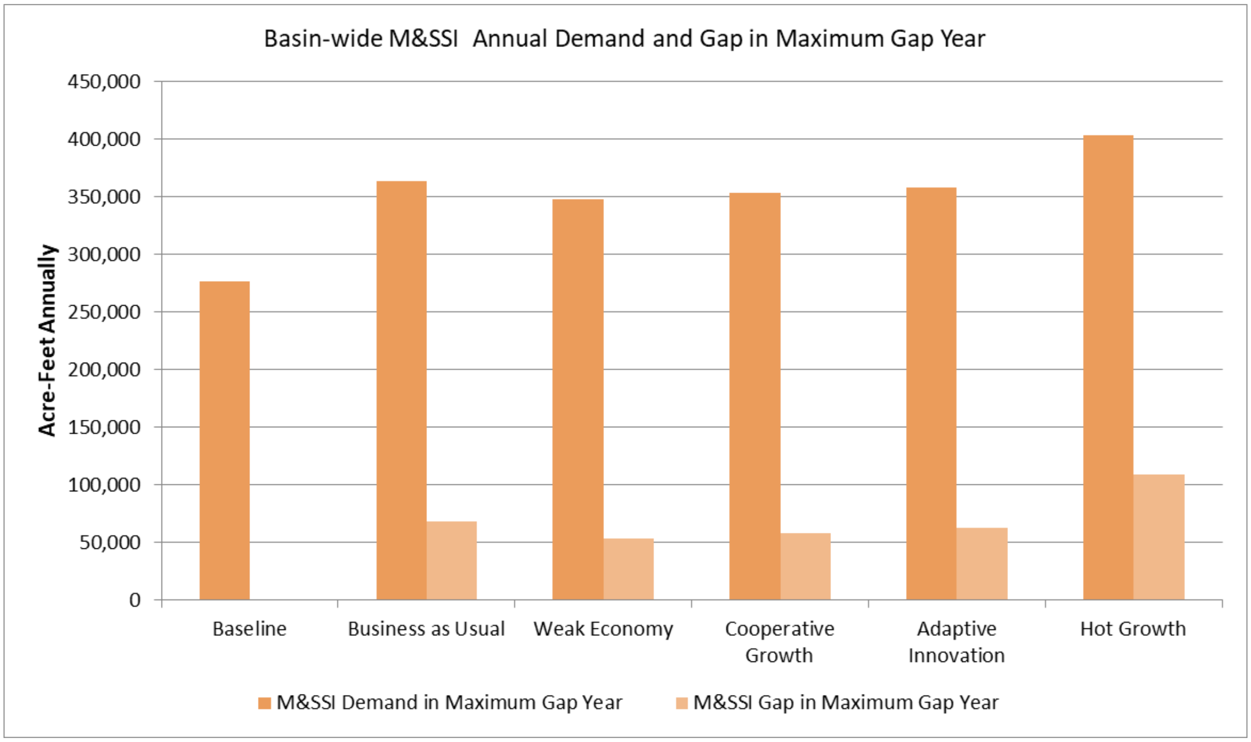


Figure 11: Arkansas River Basin M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

5.1.3 ARKANSAS RIVER BASIN TRANSBASIN EXPORT DEMAND

Aurora Water exports water from the Arkansas River basin into the South Platte River basin through the Otero Pump Station, which it shares with Colorado Springs Utilities. A majority of this water originates in the Colorado River basin and is carried through several tunnels (e.g. Homestake Tunnel, Twin Lakes Tunnel, Busk-Ivanhoe Tunnel, Columbine Ditch) into the Arkansas River basin before being delivered via the Otero Pipeline to Colorado Springs Utilities or exported from the Arkansas River. The transbasin demand for these diversions is included in the Colorado River basin demands. To a lesser degree, the Otero Pipeline also exports native Arkansas River basin water supplies; primarily water from changed irrigation rights on the Rocky Ford Ditch and Colorado Canal. Of the total Otero Pipeline diversions, only Aurora Water's changed irrigation share water can be considered an export demand from the Arkansas River basin, without double-accounting the Colorado River exports. As this amount is relatively small compared to the overall import and exports in the basin; varies depending on exchange potential and storage in Turquoise Reservoir, Twin Lakes, and Pueblo Reservoir; and is not explicitly measured separately by DWR (i.e. not available in HydroBase), the export demand was not developed nor provided for this Technical Update effort.

5.1.4 ARKANSAS RIVER BASIN SUMMARY

The combined agriculture and M&SSI demands and gap summary is provided in Table 6. The results are very similar to the agricultural results in Table 4, because water supplies in the Arkansas River basin are predominantly used for agriculture. Figure 12 reflects the relative size of the agricultural and M&SSI demands in the Arkansas River basin. Due to the projected decline in irrigated acreage and increase in population, the M&SSI demand is projected to increase from 13 percent of the total demand in the basin to 17 percent of the total demand in the 2050 Planning Scenarios. Following the graphic are summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage or transbasin import supply gaps.

Table 6: Arkansas River Basin Water Supply and Gap Summary

	Agricultural and M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	2,176,632	2,141,582	2,118,115	2,232,086	2,078,807	2,321,508
	Average Annual Gap (ac-ft)	617,289	654,967	638,394	760,125	797,692	928,209
	Average Annual Percent Gap	28%	31%	30%	34%	38%	40%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	2,580,632	2,515,318	2,489,426	2,502,547	2,290,312	2,561,382
	Gap In Maximum Gap Year (ac-ft)	1,446,435	1,438,100	1,419,712	1,590,494	1,628,996	1,858,581
	Percent Gap In Maximum Gap Year	56%	57%	57%	64%	71%	73%

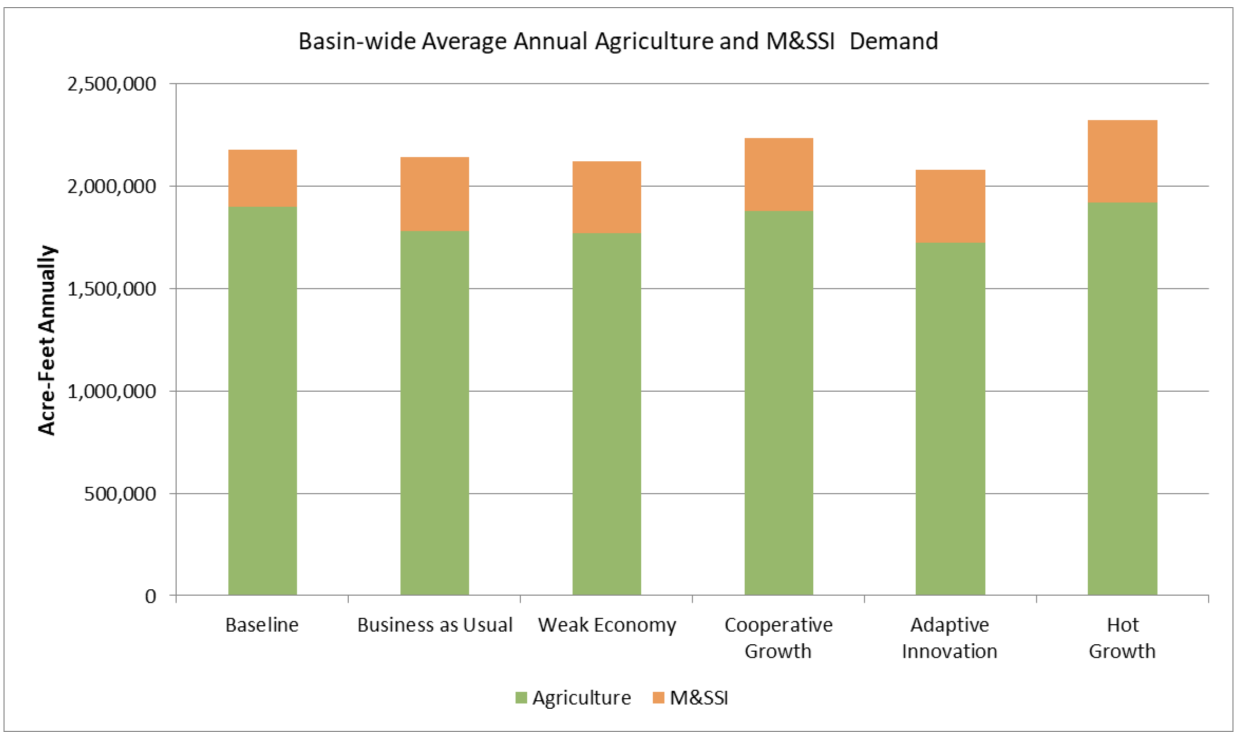


Figure 12: Arkansas River Basin Comparison of Average Agricultural and M&SSI Annual Demands

All scenarios project 19,840 acres of irrigated land will be taken out of production due to urbanization or due to municipal transfers (i.e. buy and dry). Acreage taken out of production for municipal transfers is intended to be used as a future municipal supply, and water used to irrigate the urbanized acreage could be considered a new municipal supply if the associated water rights were changed to municipal uses. To estimate this potential new supply, the average consumptive use of the urbanized acreage by Planning Scenario is reflected in Table 7.

With respect to urbanized acreage, it should be noted that the economy in the basin has historically been heavily reliant on agriculture and to the extent ground water levels decline and land comes out of production, populations of local agricultural communities may also decline over time. Additionally, if the urbanized acreage is supplied by ground water, it is less likely the supply would be used for municipal purposes and instead these supplies may remain in the aquifer for recovery purposes. Additionally, it is unknown if the water rights would be changed to municipal use or whether the supply could directly meet the future municipal demand.

With respect to municipal transfers, this estimate is not intended to replace or supersede any decreed estimates of consumptive use in a specific ditch. Nor is it known which farms and ranches will be directly impacted, or the crop type or specific irrigation practices on this acreage. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 7: Potential Water Supply from Urbanized Acreage in the Arkansas River Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage	19,840	19,840	19,840	19,840	19,840
Estimated Consumptive Use (ac-ft/year)	29,636	29,673	29,435	25,244	27,939

As noted above, the Arkansas River basin benefits from the delivery of several imported transbasin supplies from the Colorado River basin. These transbasin diversions include:

- The Continental Hoosier Project, or Blue River Project, delivers water from the headwaters of the Blue River for use by Colorado Springs Utilities.
- The Homestake Project delivers water to both the South Platte River Basin for use by Aurora Water, and to the Arkansas River Basin for use by Colorado Springs Utilities. Only the portion delivered to the Arkansas River Basin is accounted for in the results below.
- The Columbine Ditch delivers water from the East Fork of the Eagle River for use by Pueblo Board of Water Works.
- The Ewing Ditch delivers water from Piney Creek, a tributary to the Eagle River, for use by Pueblo Board of Water Works.
- The Wurtz Ditch delivers water from the South Fork of the Eagle River for use by Pueblo Board of Water Works.
- The Twin Lakes Tunnel delivers water from the headwaters of the Roaring Fork River to the Twin Lakes Reservoir and Canal Company in the Arkansas River Basin.
- The Boustead Tunnel, part of the Fryingpan-Arkansas Project, delivers water from the Fryingpan River to Turquoise Reservoir in the Arkansas River Basin.
- The Busk-Ivanhoe Tunnel delivers water to Busk Creek upstream of Turquoise Lake for use by Pueblo Board of Water Works and Aurora Water. Only the portion delivered to Pueblo Board of Water Works is accounted for in the results below.

Table 8 summarizes the total transbasin import volumes and associated import gaps. Note that transbasin imports are the same across the scenarios because they are represented in the model at historical levels, and no Planning Scenario adjustments were applied. A gap indicates that the historical import could not be diverted in the source basin due to a physical or legal limitation of water supply at the diverting location. This is caused by changes in water availability, increases in senior demands in the source basin, or a combination of both.

Ideally the import supply gap in the Baseline scenario would be zero; however the Baseline dataset represents current agricultural and M&SSI demands over the entire model period which can result in minor shortages to junior water rights, including transbasin diversions. With this in mind, the incremental increase in the import gap reflects the increase in gap due to the Planning Scenario adjustments. Under current hydrologic conditions, there was no projected increase in the gap for the Business as Usual and Weak Economy scenarios. The increased demands and changed hydrology in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios however resulted in more substantial gaps on average and during critically dry years.

If exports stay the same in the future, the reported import gaps could increase the total Arkansas River basin gaps in these scenarios. As transbasin imported supplies are able to be reused to extinction within the Arkansas River basin, the imported supply gap would have the effect of increasing the total Arkansas River basin gap by more than the values shown in the table.

Table 8: Summary of Transbasin Imports to the Arkansas River Basin

	Transbasin Import Supply Gap Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Import Supply (ac-ft)	123,244	123,244	123,244	123,244	123,244	123,244
	Average Annual Import Supply Gap (ac-ft)	1,434	1,405	1,412	15,566	27,399	27,632
	Average Annual Import Supply Gap Increase from Baseline (ac-ft)	-	-	-	14,132	25,965	26,198
	Average Annual Import Supply Percent Gap	1%	1%	1%	13%	22%	22%
Critically Dry Maximum	Import Supply In Maximum Gap Year (ac-ft)	154,756	154,756	154,756	154,756	126,528	126,528
	Import Supply Gap In Maximum Gap Year (ac-ft)	8,086	8,086	8,086	35,979	49,602	48,639
	Increase from Baseline Import Supply Gap (ac-ft)	-	0	0	27,893	41,516	40,553
	Import Supply Percent Gap In Maximum Gap Year	5%	5%	5%	23%	39%	38%

Although detailed surface water modeling was not completed in the basin, it is important to understand the potential impact the climate conditions may have on the volume and timing of runoff in the basin.

Figure 13 through Figure 20 reflect the average monthly and time series of annual natural flow runoff at following four gaged locations[5]:

- Arkansas River near Leadville (07081200)
- Clear Creek above Clear Creek Reservoir (07086500)
- Grape Creek near Westcliffe (07095000)
- Purgatoire River at Madrid (07124200)

Note that the graphics reflect *natural flow* or the amount of water in the river absent the effects or impact of man, not simulated streamflow. These streamflow gages are generally located in the headwaters with limited impact from upstream irrigation or municipal uses; however any man-induced effects (e.g. transbasin diversions, irrigation, reservoirs) above the gage locations have been removed so that the climate adjustments could be applied. Additionally, the annual natural flow graphics reflect a stacked volume of runoff compared to the volume of runoff for current conditions. The green band in these graphs reflects the incremental increase in runoff under the In-Between climate conditions compared to the runoff under the Hot and Dry conditions in the blue area.

As reflected, natural flow at the Leadville gage is projected to experience the smallest reduction in volume compared to the other gaged locations, with the In-Between conditions projecting a 6 percent decrease on average and the Hot and Dry conditions projecting a 15 percent reduction on average. There is however a pronounced shift in the peak runoff, projected to occur a month earlier than current conditions, and a reduction to late season flows.

Larger reductions are projected for the Clear Creek gage, which provides nearly the same amount of natural flow runoff as the headwaters of the Arkansas River. Natural flow on Clear Creek is projected to decline by approximately 15 percent on average under the In-Between conditions and 26 percent on average under the Hot and Dry conditions. As reflected in the graph, the reduction to streamflow is projected to occur during years with average and above-average runoff, with smaller reductions projected for years with lower flows. Although there is a projected shift in the runoff, it is not as pronounced as projected shifts at other locations.

Grape Creek and Purgatoire River are projected to have the largest declines in runoff under the climate-adjusted hydrology conditions. Grape Creek is projected to decline 29 percent on average and 38 percent on average under the In-Between and Hot and Dry conditions, respectively. From a volumetric perspective, this is projected annual decline of approximately 12,000 ac-ft and 16,000 ac-ft of runoff in the basin, respectively, compared to the current average annual runoff of 43,000 ac-ft. As reflected in the Figure 18, the decline is projected to occur fairly consistently across several hydrological year types, with only the wettest year projected to have less than average declines.

Hydrology in the Purgatoire River is projected to have the largest decline out of the four gages. Under the In-Between conditions, Purgatoire River is projected to decline 34 percent on average, or approximately 17,000 ac-ft of runoff annually. Under the Hot and Dry conditions, the Purgatoire River is projected to decline 44 percent on average, or approximately 22,000 ac-ft of runoff annually. The average monthly results for May and June indicate a substantial decline in snowpack runoff volume and a shift in the runoff earlier in the year. These inflows can serve as a predictor to the amount of water supplies that may be available in the future for storage in Trinidad Reservoir and irrigation under the Trinidad Project.

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[5] A majority of the streamflow results presented in this memorandum reflect information from gages selected to support the Environmental Flow Tool. These gages differ from those selected for the Flow Tool; the streamflow results from these gages are provided to better reflect the impact of climate-adjusted hydrology on the native streamflow in the basin.

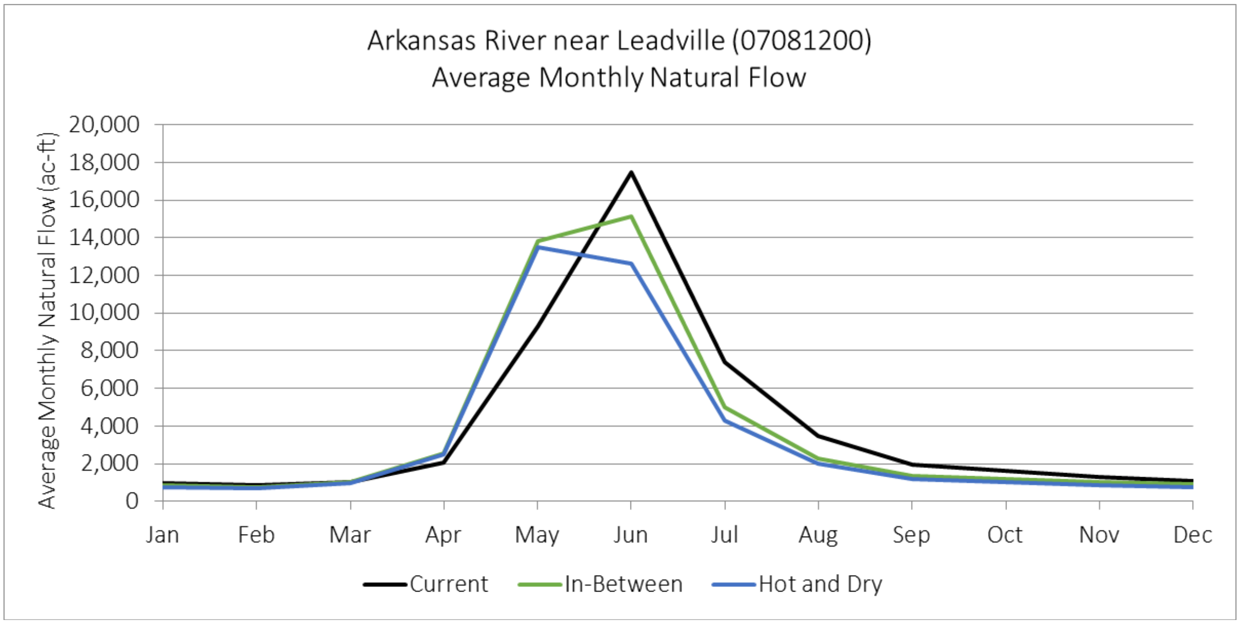


Figure 13: Average Monthly Natural Flow at Arkansas River near Leadville

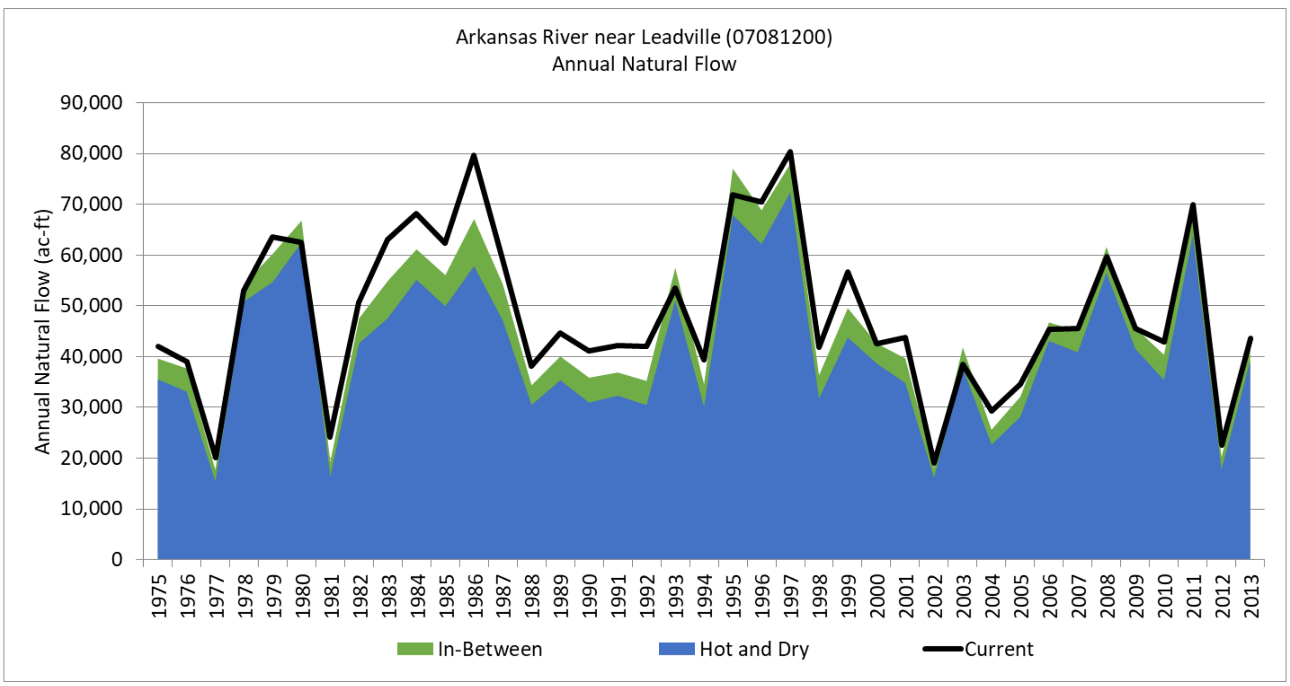


Figure 14: Annual Natural Flow at Arkansas River near Leadville

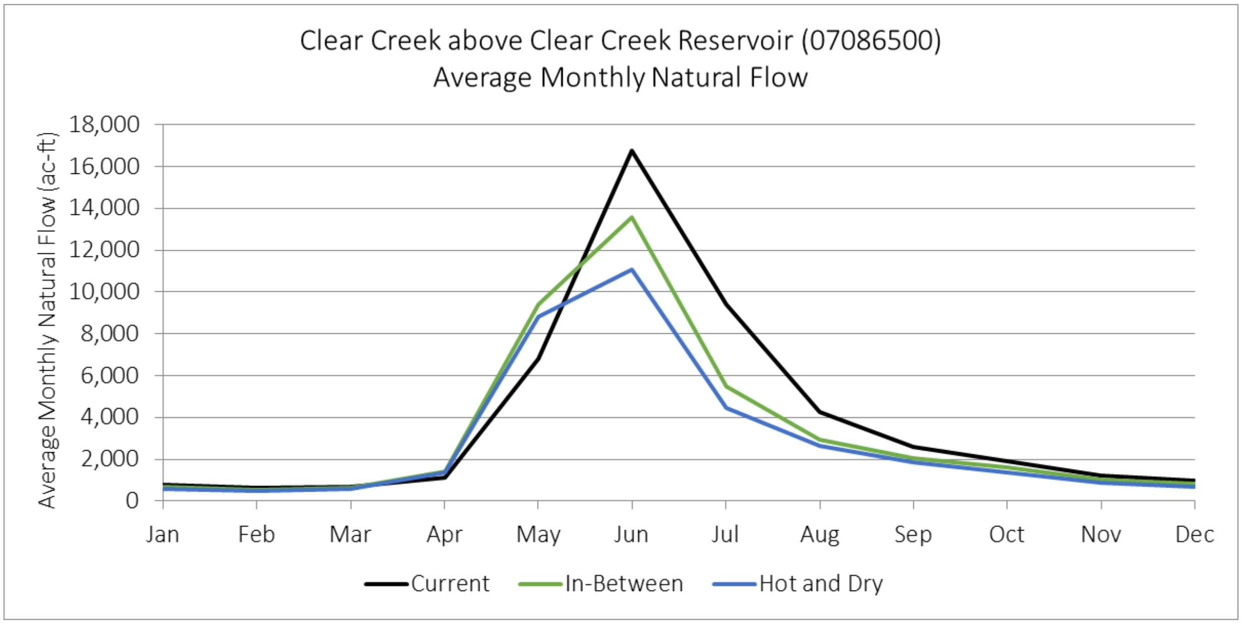


Figure 15: Average Monthly Natural Flow at Clear Creek above Clear Creek Reservoir

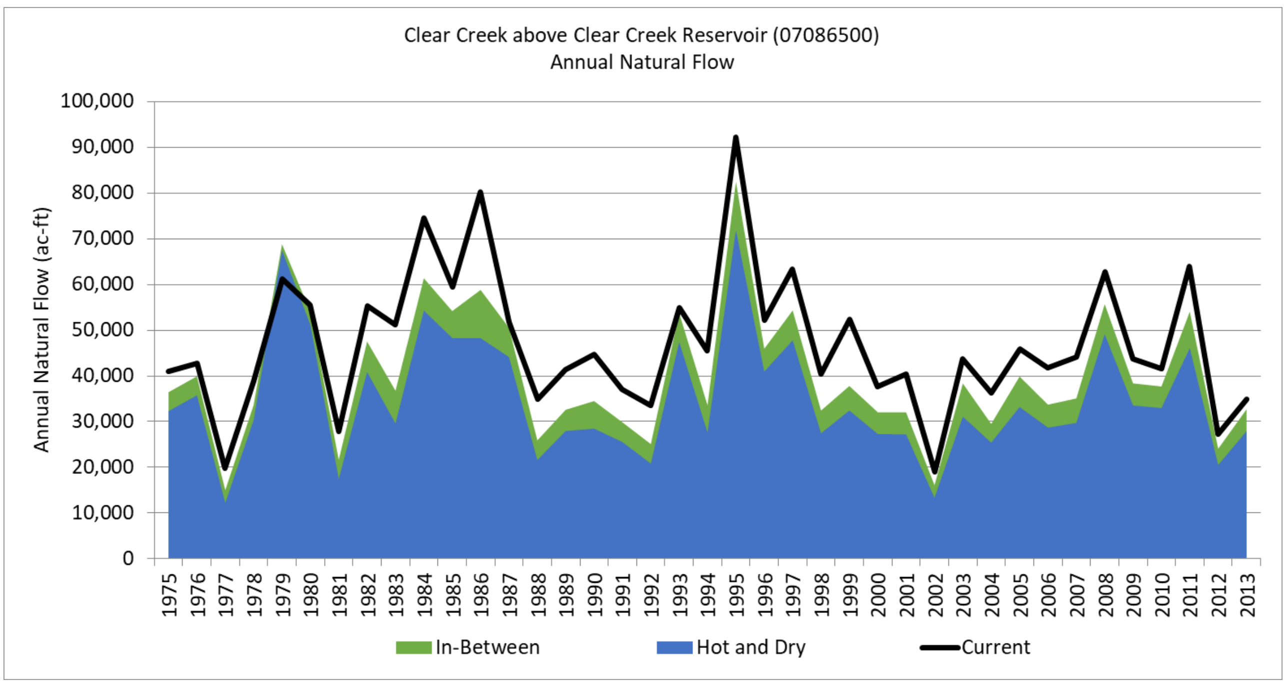


Figure 16: Annual Natural Flow at Clear Creek above Clear Creek Reservoir

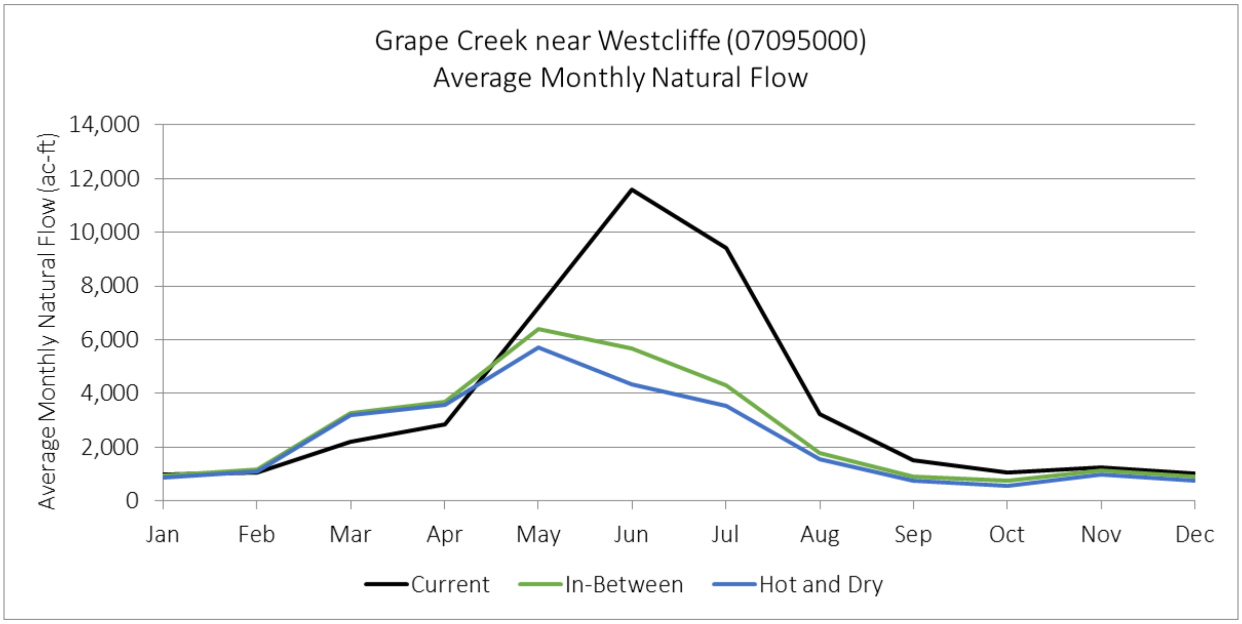


Figure 17: Average Monthly Natural Flow at Grape Creek near Westcliffe

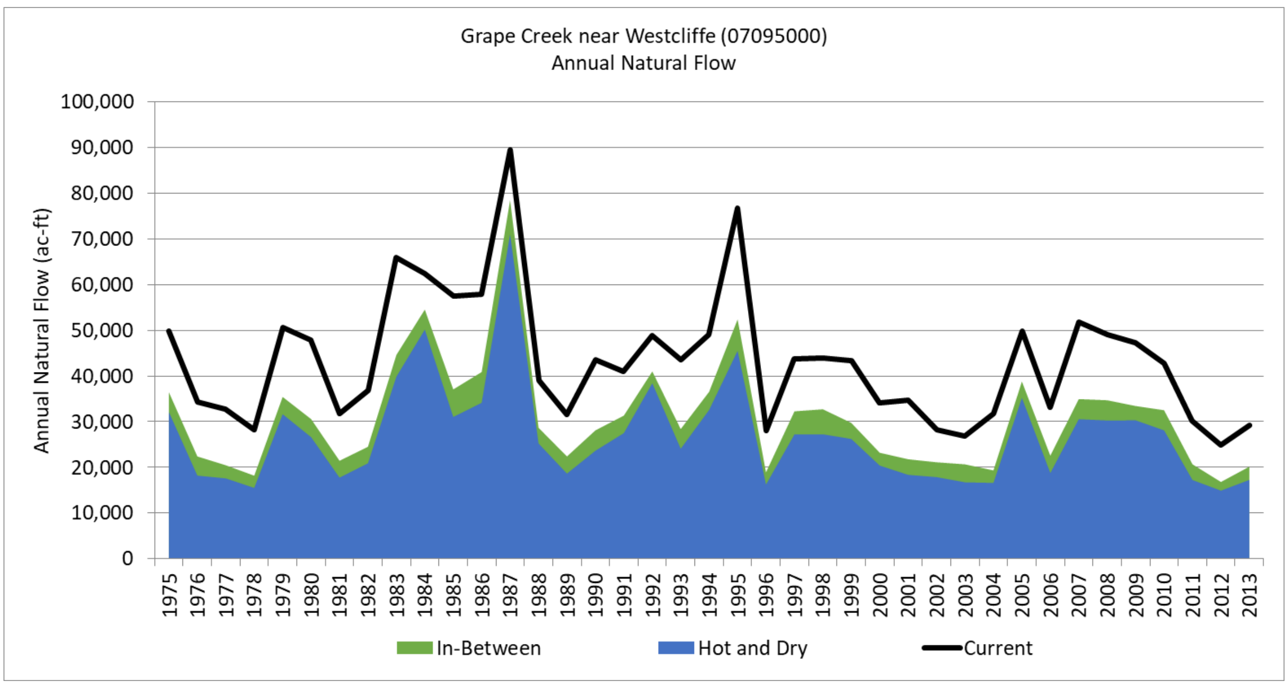


Figure 18: Annual Natural Flow at Grape Creek near Westcliffe

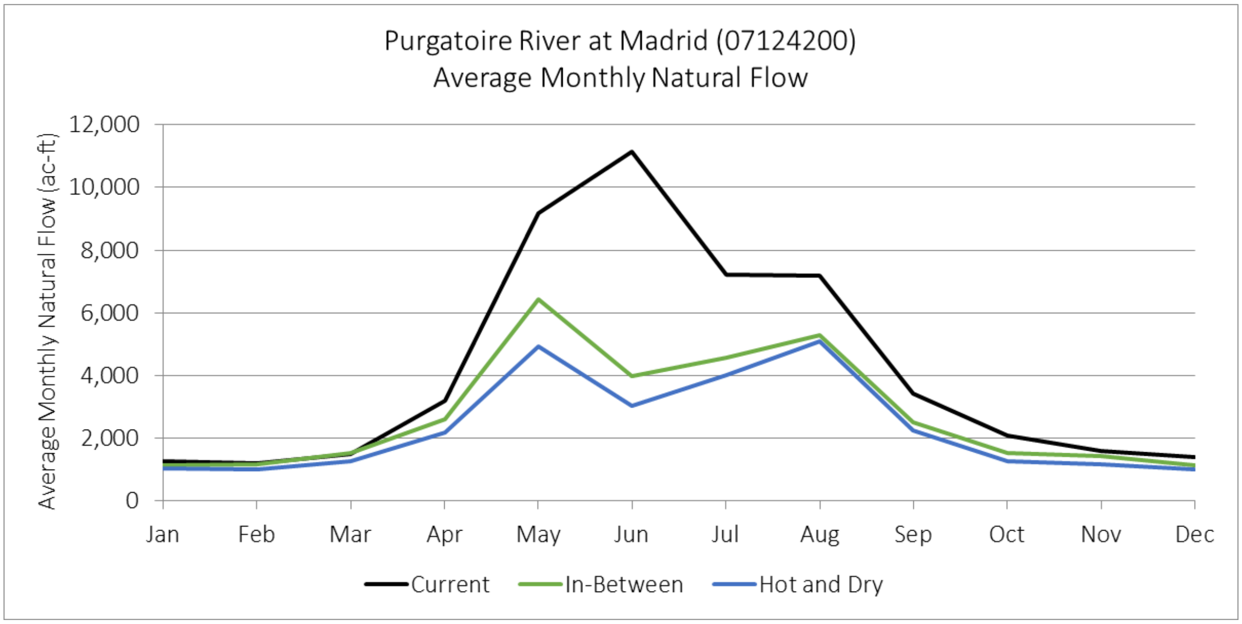


Figure 19: Average Monthly Natural Flow at Purgatoire River at Madrid

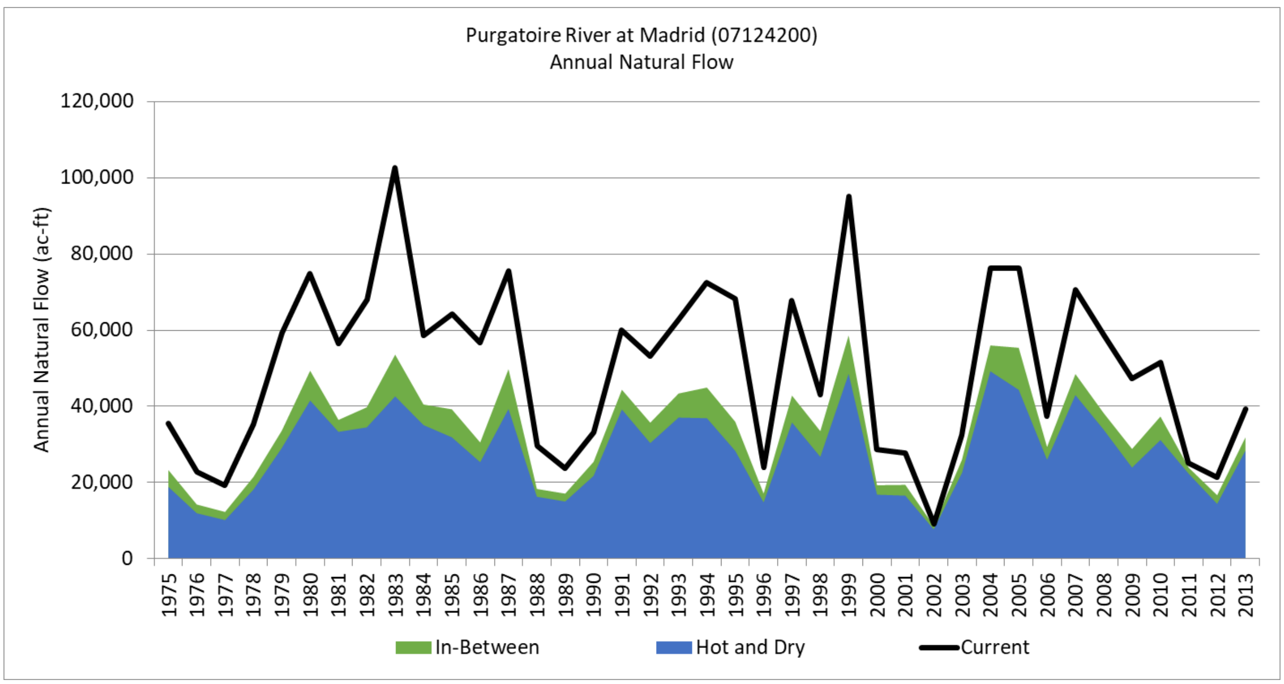
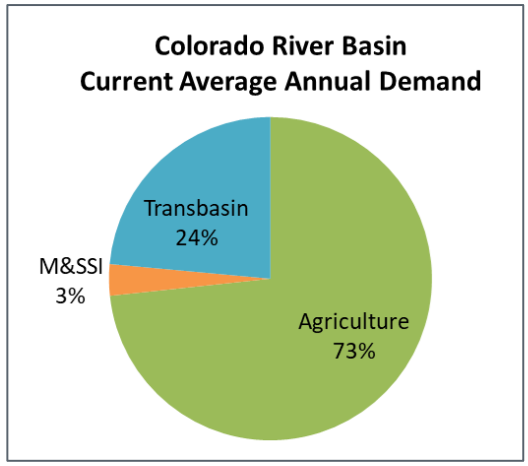


Figure 20: Annual Natural Flow for Purgatoire River at Madrid

5.2 COLORADO RIVER BASIN

The majority of the water in the Colorado River basin is used to irrigate over 206,000 acres, with nearly a quarter of these acres irrigated in and around Grand Junction by the Grand Valley Project. The next largest demand for water supplies in the basin is for transbasin exports. These diversions move water from the headwaters of the Colorado River basin to M&SSI and agricultural users in the South Platte and Arkansas River basins.

Smaller demands are associated with M&SSI uses in the basin. There are a number of growing municipal communities mixed between the agricultural operations. Resort towns such as Aspen, Avon, Breckenridge, Glenwood Springs, Snowmass Village, Winter Park, and Vail are located in the mountains and have economies primarily based on tourism. Agricultural-based communities include Eagle, Fruita, Grand Junction, Palisade, and Rifle. As with other parts of Colorado, people who come to visit the Colorado River Basin enjoy skiing, hiking, camping, rafting, fishing, hot springs, and other outdoor adventures.



The following sections describe the agricultural, M&SSI, and transbasin export demands in the Colorado River basin in more detail. Figure 21 shows the basin outline, the administrative boundaries of water districts, and the streamflow gages highlighted in the results section below.

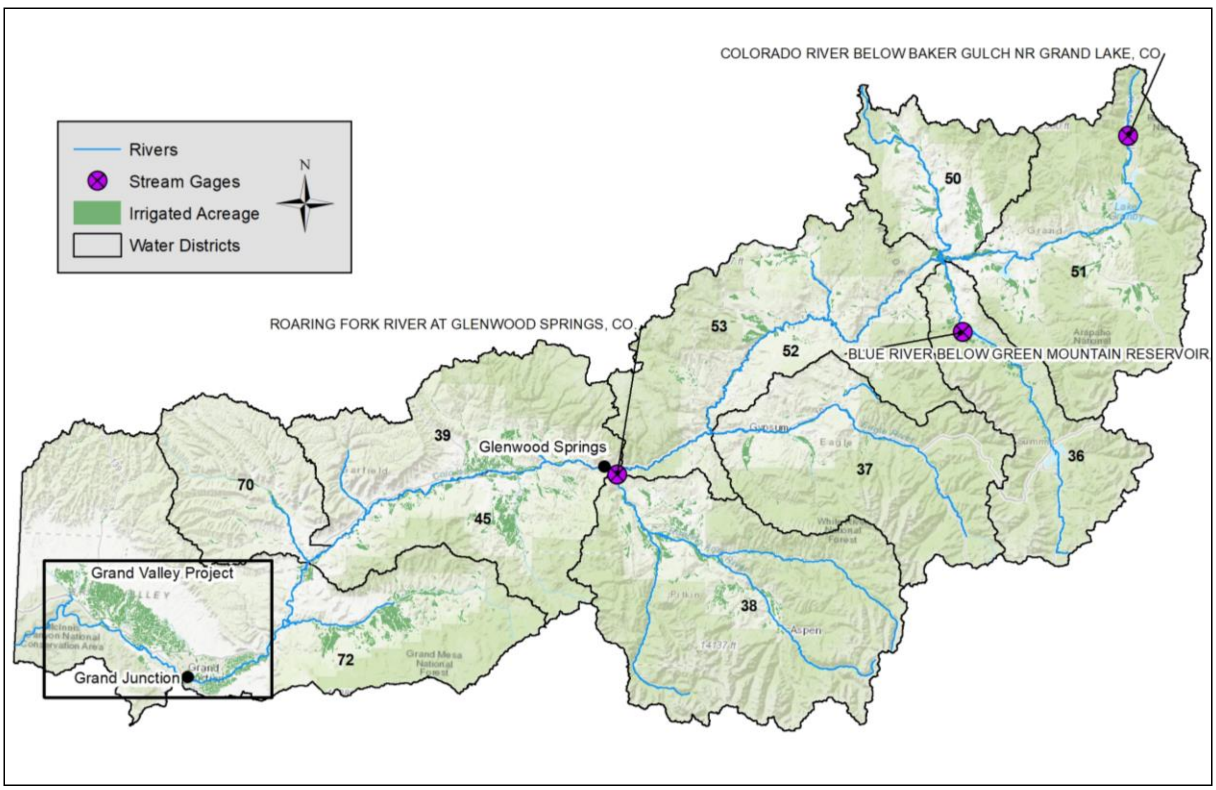


Figure 21: Colorado River Map with Streamgage Locations

5.2.1 COLORADO RIVER BASIN AGRICULTURE WATER SUPPLY AND GAP

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. Large scale irrigation projects built by Reclamation and other entities provide infrastructure and storage facilities to better serve agricultural lands and provide supplemental supplies. The biggest example is the Grand Valley Project and the Grand Valley Irrigation Company, located at the bottom of the Colorado. Together, they irrigate over a quarter of the 206,700 acres irrigated in the entire basin.

The Colorado River Basin agricultural diversion demands, demand gaps, and consumptive use gaps results for the baseline and Technical Update Planning Scenarios are presented in

Table 9. As discussed in the *Current and 2050 Planning Scenario Agricultural Diversion Demand* technical memorandum, 2050 agricultural diversion demands are influenced by a number of drivers[6], including climate, urbanization, planned agricultural projects, and emerging technologies.

Table 9: Colorado River Basin Agricultural Water Supply and Gap Summary

	Agricultural Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,598,908	1,476,827	1,476,827	1,663,820	1,294,883	1,751,552
Average	Average Annual Demand Increase from Baseline (ac-ft)	-	-	-	64,911	-	152,644
Average	Average Annual Gap (ac-ft)	45,288	43,994	43,985	76,208	61,498	103,782
Average	Average Annual Gap Increase from Baseline (ac-ft)	-	-	-	30,920	16,209	58,494
Average	Average Annual Percent Gap	3%	3%	3%	5%	5%	6%
Average	Average Annual CU Gap (ac-ft)	25,105	24,400	24,395	42,381	40,368	57,772
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	1,598,822	1,477,522	1,477,522	1,587,174	1,258,020	1,668,295
Critically Dry Maximum	Increase from Baseline Demand (ac-ft)	-	-	-	-	-	69,473
Critically Dry Maximum	Gap In Maximum Gap Year (ac-ft)	147,979	141,118	141,049	166,477	131,445	210,423
Critically Dry Maximum	Increase from Baseline Gap (ac-ft)	-	-	-	18,498	-	62,444
Critically Dry Maximum	Percent Gap In Maximum Gap Year	9%	10%	10%	10%	10%	13%

The average annual agricultural demand decreases from the Baseline to the Business as Usual and Weak Economy Planning Scenarios due to the projected reduction of 13,590 irrigated acres due to urbanization of irrigated lands. As reflected in the table, irrigators in the basin currently experience a relatively small agricultural gap on average and during critically dry years.

[6] As noted in the technical memorandum, structures that carry water both for irrigation and for other purposes (e.g. power operations), such as those within the Grand Valley Project, were not adjusted across Planning Scenarios for changes in system efficiency or increases in agricultural demands.

Demand for the Cooperative Growth scenario incorporates the urbanized acreage as well as the increase in climate change adjustments to IWR, leading to an increase of 187,000 ac-ft of demand basin-wide compared to the Business as Usual scenario. Climate adjustments to hydrology in the Cooperative Growth scenario reduce the magnitude, shift the peak runoff generally from June to May, and reduce the amount of late season supplies. These changes lead to approximately 32,000 ac-ft of increased gap basin-wide on average compared to the Business as Usual and Weak scenarios. Agriculture located on smaller tributaries throughout the basin often has limited or no access to supplemental irrigation supplies from reservoir storage. Increased demands in these areas must be met using water supplies available only during runoff. As such, agricultural demands in this scenario, particularly on smaller tributaries, are often shorted more than the average basin-wide gap.

For the Adaptive Innovation scenario, the average annual demand is less than the Baseline demand, despite reflecting the same reduction to irrigated lands for urbanization and incorporating climate adjustments to IWR under the Hot and Dry conditions. To offset the impact of climate change, the Adaptive Innovation scenario assumes that emerging technologies decrease the IWR and increase irrigation system efficiency for the entire basin. Agricultural demands are highly sensitive to changes in IWR and system efficiency, so the two adjustments result in a net decrease of nearly 182,000 ac-ft of agricultural demands on average compared to the Business as Usual scenario. The average annual gap and the CU gap in the Adaptive Innovation scenario is smaller than the Cooperative Growth scenario, but larger than the Business as Usual scenario, indicating the two adjustments did not fully mitigate the effects of Hot and Dry climate conditions.

Finally, the Hot Growth scenario produces the largest agricultural gaps in the Colorado River Basin. Average annual demands are projected to increase while the runoff is projected to decrease. The annual percent gap is 6 percent on average and 13 percent during critically dry years. These are larger than those currently experienced in the basin on average, but still relatively small compared to gaps projected in other areas in the State.

In general, the Colorado River Basin is projected to experience relatively low agricultural gaps in 2050. The difference between the average annual gap and gaps during critically dry years are highlighted in Figure 22 and Figure 23, which show the relative size of the agricultural demands and gaps. As noted above, agricultural water users are not impacted evenly throughout the basin, depending on the available water supply and the relative seniority of the agricultural water rights. For example, Water District 45 (Divide Creek) has a gap of 47 percent in a critically dry year in the Hot Growth scenario. In contrast, Water District 72 (Lower Colorado River) has a gap of 8 percent in a critically dry year. Irrigation in Water District 45 depends on smaller tributaries to the Colorado River, such as Divide Creek, Beaver Creek, and Battlement Creek, and has no access to storage. In the Hot Growth scenario, runoff declines and is not able to meet the agricultural demand in the late season. Irrigation in Water District 72, primarily under the Grand Valley Project, have senior water rights and are supported by large diversion infrastructure directly from the Colorado River.

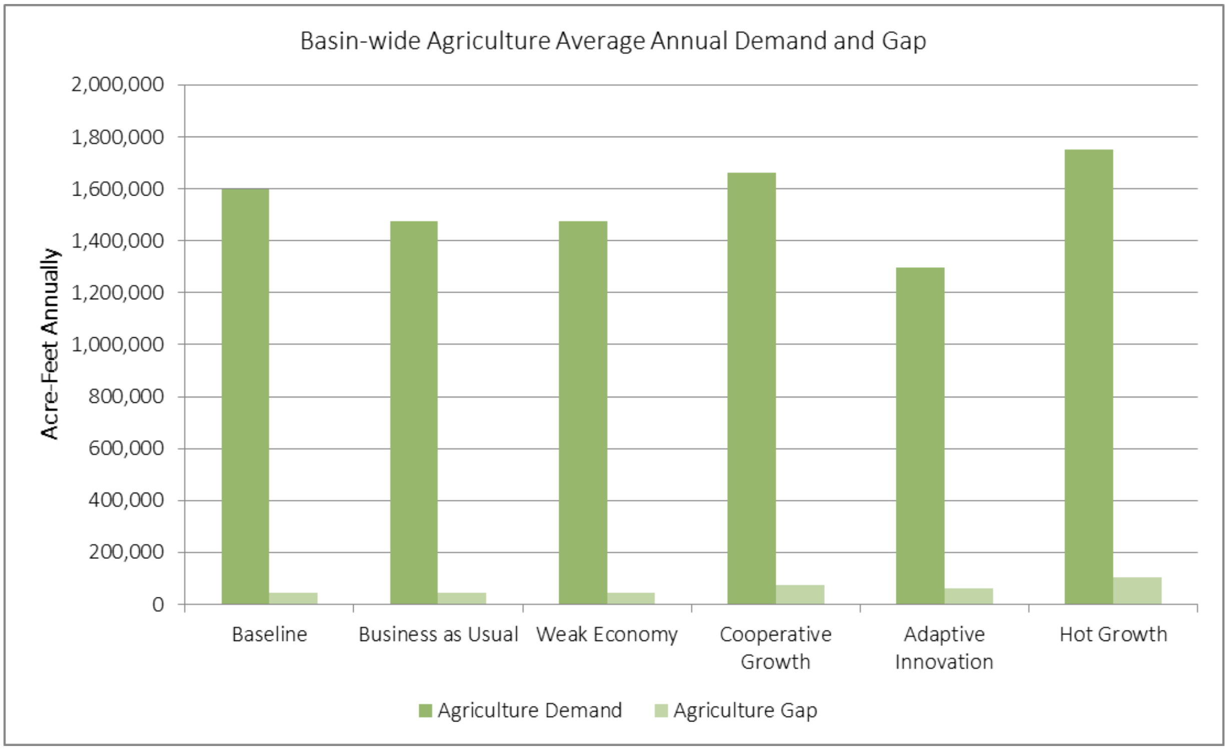


Figure 22: Colorado River Basin Agriculture Average Annual Demand and Gap

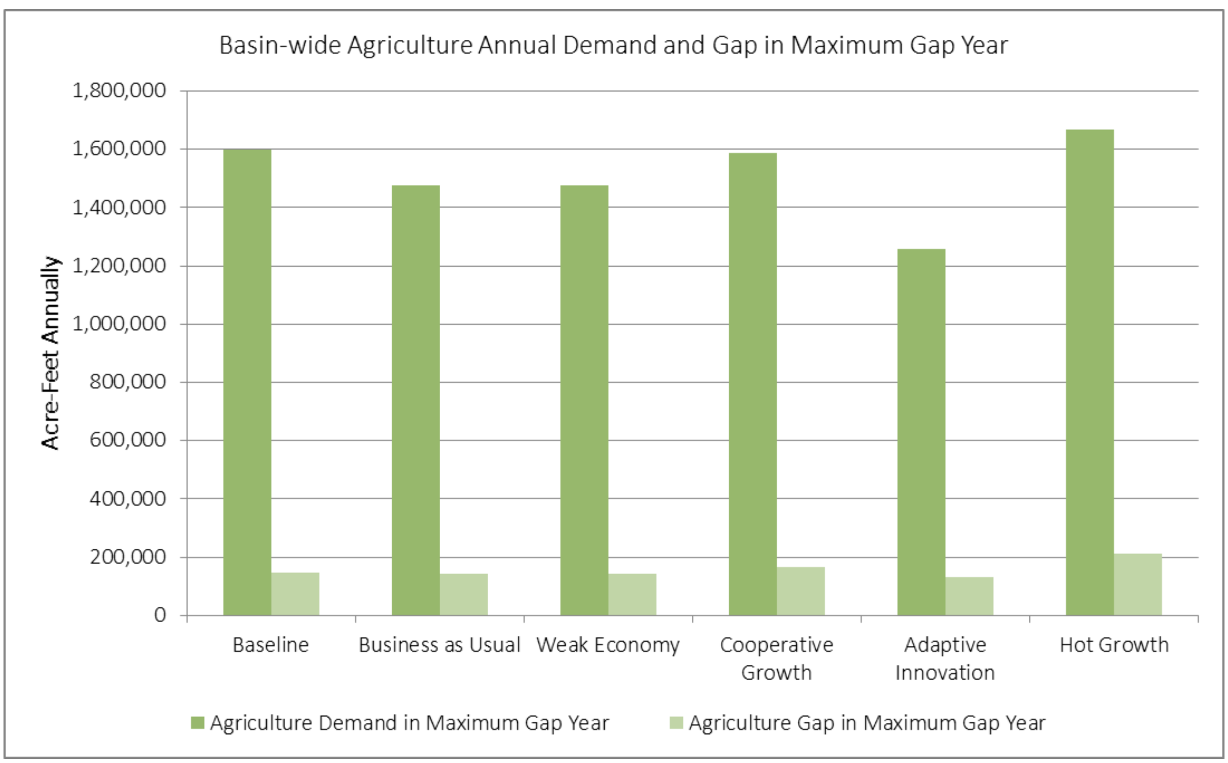


Figure 23: Colorado River Basin Agriculture Annual Demand and Gap in Maximum Gap Year

In addition to the average annual summary, it is important to consider the variability of gaps across wet, average, and dry year types. Figure 24 reflects the average annual percent gap for the modeled years (1975 – 2013). The dry hydrology years of 1977, 2002, and 2012 stand out as the largest gaps in the basin, followed by 1981 and 1990. The Baseline, Business as Usual, and Weak Economy scenarios all produce very similar results, which are often overlapping in the graphic. The Cooperative Growth and the Adaptive Innovation scenarios generally trend together, indicating the emerging technologies adjustments had the effect of partially mitigating the impact of Hot and Dry climate conditions. The Hot Growth scenario consistently produces the largest gaps.

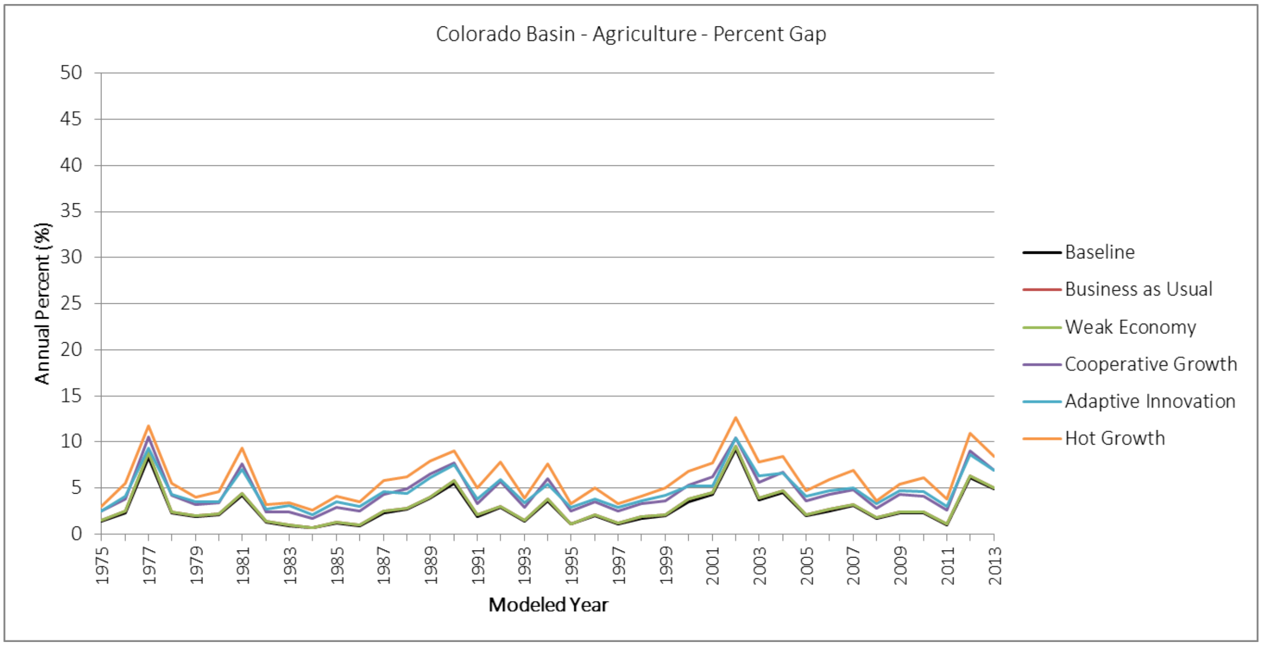


Figure 24: Colorado River Basin Agriculture Percent Diversion Gap Times Series

5.2.2 COLORADO RIVER BASIN M&SSI WATER SUPPLY AND GAP

M&SSI demands are small relative to the other demands in the basin, consisting of approximately 3 percent of the total demands. Of the total M&SSI demand, approximately 90 percent are attributable to municipal demands and the remaining 10 percent are attributable to SSI operations.

The municipal demands are largest in Mesa, Garfield, and Eagle counties, which encompass the municipalities along the I-70 corridor. Population is projected to increase in all Planning Scenarios, driving an increase in municipal demands by 2050. Of the total municipal demands, approximately half are represented in the model at grouped locations and the other half are represented in the model using the municipalities' individual demands, water rights, and operations. Entities represented individually in the model include:

- Aspen
- Breckenridge
- Carbondale
- Dillon Valley Water and Sanitation District

- Glenwood Springs
- Grand Junction
- Keystone
- Rifle
- Snowmass
- Ute Water Conservancy District

The SSI[7] in the basin is predominantly snowmaking; large industry and energy development demands vary depending on the Planning Scenario. Similar to the municipal demands, the SSI demands can be modeled individually or at grouped locations. SSI operations represented individually in the model include:

- Breckenridge Snowmaking
- Copper Mountain Snowmaking
- Henderson Mine
- Keystone Snowmaking
- Ten Mile
- Vail Snowmaking

There are several reservoirs in the Colorado River Basin that currently lease water to M&SSI water providers from contract pools/accounts. These reservoirs include Green Mountain, Wolford Mountain, and Ruedi. For purposes of the Technical Update, it was assumed that these current lease agreements would continue in the future, therefore the model was revised to include releases of contract supplies to grouped M&SSI demands in the basin.

Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin were developed. The water supply and gap results for M&SSI in the Colorado River basin are summarized in

[7] Note that water used for hydropower, such as those operations at the Shoshone Power Plant, are represented in the model but are not included in the SSI demand summaries (i.e. non-consumptive) and are not adjusted between Planning Scenarios.

Table 10, and graphically reflected in Figure 25 through Figure 27.

Table 10: Colorado River Basin M&SSI Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	68,485	98,415	85,793	95,383	94,490	121,433
Average	Average Annual Demand Increase from Baseline (ac-ft)	-	29,930	17,308	26,898	26,005	52,948
Average	Average Annual Gap (ac-ft)	498	1,207	813	1,865	2,344	4,677
Average	Average Annual Gap Increase from Baseline (ac-ft)	-	709	315	1,368	1,846	4,179
Average	Average Annual Percent Gap	1%	1%	1%	2%	2%	4%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	68,485	98,415	85,793	95,383	94,490	121,433
Critically Dry Maximum	Increase from Baseline Demand (ac-ft)	-	29,930	17,308	26,898	26,005	52,948
Critically Dry Maximum	Gap In Maximum Gap Year (ac-ft)	2,339	4,238	3,348	5,306	6,595	15,849
Critically Dry Maximum	Increase from Baseline Gap (ac-ft)	-	1,899	1,008	2,967	4,256	13,510
Critically Dry Maximum	Percent Gap In Maximum Gap Year	3%	4%	4%	6%	7%	13%

As reflected in the table, there is an M&SSI gap in the Baseline scenario. Ideally, the Baseline scenario would have no M&SSI gaps because the current conditions in the basin fully satisfy the existing M&SSI demands. This small amount of gap is likely a result of minor calibration issues in the model during low flow years on tributaries supplying small water providers.

The Colorado River Basin is projected to increase in population in 2050; therefore all of the Planning Scenarios reflect an increase to the average annual demands above the Baseline scenario. For the Business as Usual scenario, the average annual demand increase is primarily driven by the increase in municipal demands, although industrial demands also increase modestly. The average annual gap doubles from the Baseline scenario, but still represents about 1 percent of the total demand. The gap during critically dry years is slightly larger; however still only 4 percent of the total M&SSI demand.

The Weak Economy scenario has similar results. The average annual gap increases from the Baseline scenario, but still represents about 1 percent of the total demand. The gap in a critically dry year increases from 3 to 4 percent, compared to the Baseline scenario. These are relatively small gaps and show that under current hydrology, future M&SSI demand increases can generally be met from unappropriated flows in the basin supplemented with contract releases from reservoirs.

The Cooperative Growth and Adaptive Innovation scenarios have a similar increase in demand as the Business as Usual scenario, however have slightly larger gaps. This is due to the climate-adjusted hydrology in these scenarios, which causes the annual streamflow volume to decline and reduces the water available to meet the increased demands. On average, gaps in both scenarios are approximately 2 percent of the total demand, with critically dry years reflecting more substantial gaps of 6 and 7 percent, respectively.

The demands and the gaps are the largest in the Hot Growth scenario. While the average annual gap is a moderate 4 percent on average, the gap is 13 percent of total demand in critically dry years. As noted above with agricultural demands, the average basin-wide gap under-estimates gaps projected for M&SSI water providers reliant on water supplies from smaller tributaries without the benefit of storage.

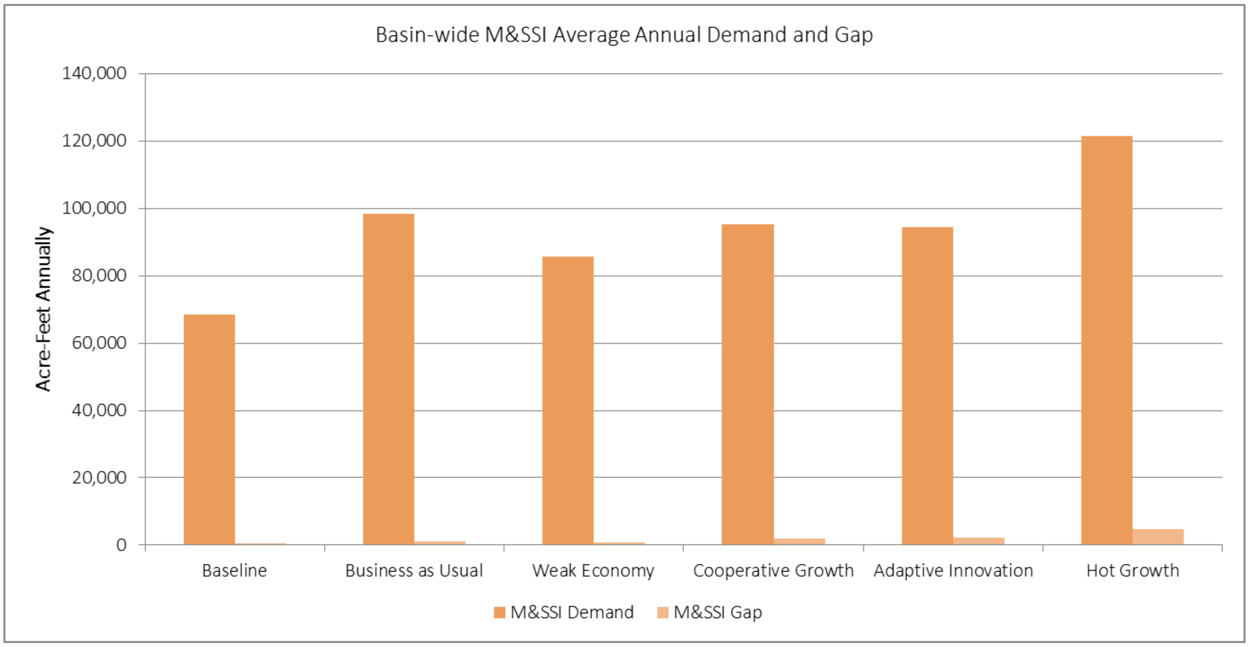


Figure 25: Colorado River Basin M&SSI Average Annual Demand and Gap

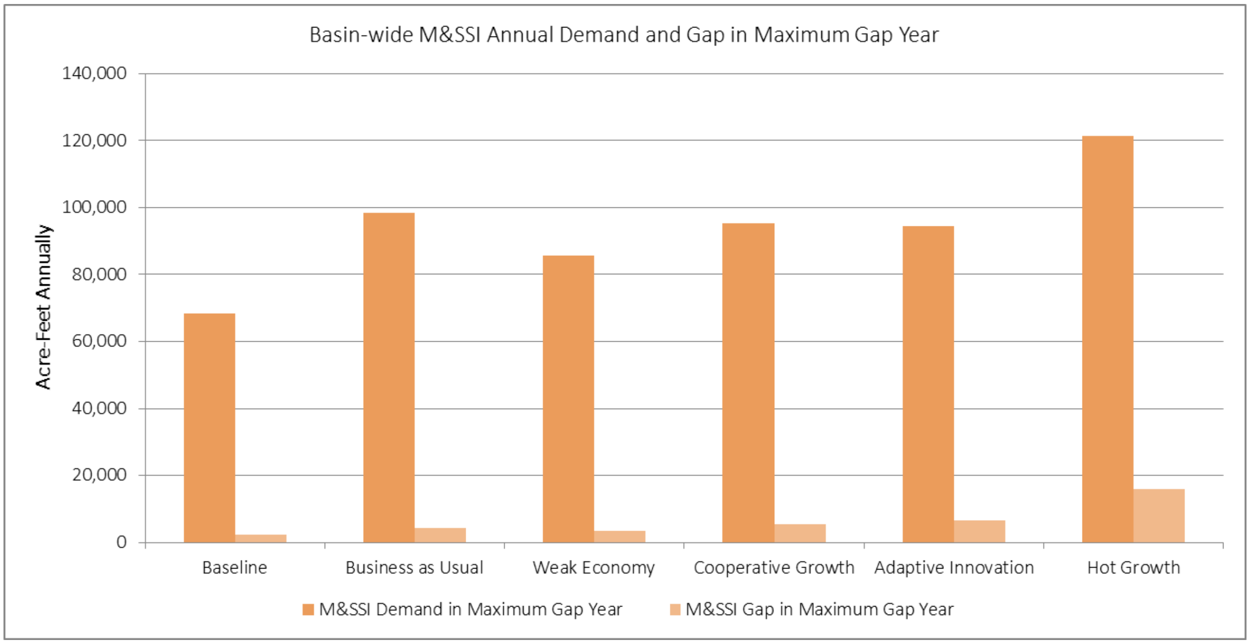


Figure 26: Colorado River Basin M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

Figure 27 reflects the average annual percent gap across a variety of wet, average, and dry year types. The percent gap in the Baseline, Business as Usual, and Weak Economy scenarios generally trend together. For example, these scenarios reach maximum gaps in the dry years of 1977, 2002, and 2013. The Cooperative Growth and Adaptive Innovation scenarios generally have similar gap percentages, but they do not always react to dry years in the same manner. For example, the Adaptive Innovation scenario continues to have relatively large gaps in 2004, 2005, 2006 and 2007 while the Cooperative Growth scenario is projected to recover much more quickly. The Adaptive Innovation scenario uses the Hot and Dry hydrology, which reduces available streamflow and increases the length of time required to refill reservoirs. This further reduces unappropriated flows that some of the M&SSI systems may depend on in the future. The Hot Growth scenario has the largest year to year variability with gaps of near 10 percent for over 3 years.

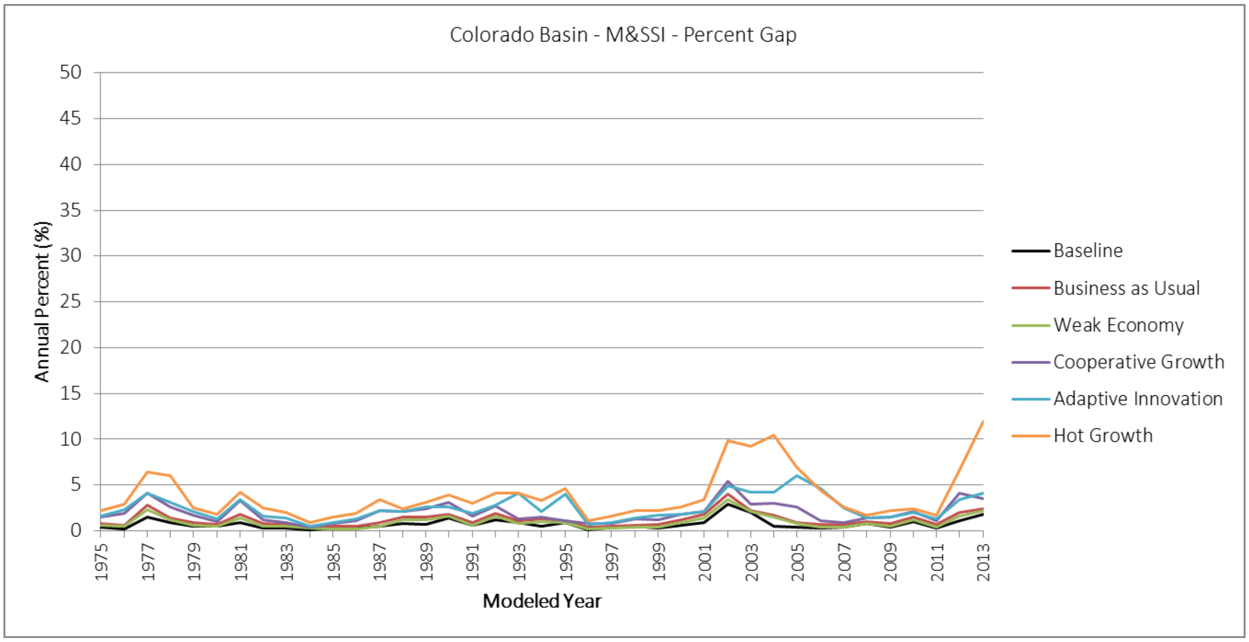


Figure 27: Colorado River Basin M&SSI Average Annual Gap Time Series

5.2.3 COLORADO RIVER BASIN TRANSBASIN EXPORT DEMAND

There are several tunnels and ditches that export water from the Colorado River Basin, delivering water to the South Platte River, Gunnison River, and Arkansas River basins. The model reflects sixteen transbasin diversions; the larger transbasin diversions are:

- Colorado-Big Thompson Project (C-BT) diverts water from the headwaters of the Colorado River through the Alva B. Adams Tunnel for irrigation and municipal use in the South Platte River basin.
- The Moffat Tunnel System diverts water from the headwaters of the Fraser River for Denver Water municipal use.
- Roberts Tunnel System diverts water from the Blue River for Denver Water municipal use.
- Fryingpan-Arkansas Project diverts water from the headwaters of the Roaring Fork through the Charles H. Boustead Tunnel for irrigation and municipal use in the Arkansas River Basin.
- The Twin Lakes Tunnel delivers water from the headwaters of the Roaring Fork River to the Twin Lakes Reservoir and Canal Company in the Arkansas River Basin.

- The Homestake Project diverts water from Homestake Creek and delivers water to both the South Platte River Basin for use by Aurora Water, and to the Arkansas River Basin for use by Colorado Springs Utilities.

On average, the total transbasin export demand from the Colorado River basin is 513,690 ac-ft per year, however this value ranges annually depending availability of water supplies, available storage capacity, and demand in both the Colorado River basin and the destination basins. Note that the transbasin export demand, reflecting approximately 24 percent of the total basin demand, is set to historical levels and the same across all Planning Scenarios. These demands could not be satisfied in all Planning Scenarios; however the shortages are reflected as an import supply gap in the destination basins and not considered a gap in the Colorado River basin.

5.2.4 COLORADO RIVER BASIN SUMMARY

The combined agriculture and M&SSI demands and gaps summary is provided in

Table 11. The summary results are similar to the agricultural results in

Table 9, because M&SSI demands are relatively small compared to the agricultural demands in the Colorado River Basin. As previously discussed, the Colorado River basin is generally able to meet demands in the Baseline, Business as Usual, and Weak Economy scenarios. The gaps increase as the demands increase and/or the hydrology decreases in the Cooperative Growth and the Adaptive Innovation scenarios. The gaps are the largest in the Hot Growth scenario, which combines the largest demands and the smallest streamflow.

Figure 28 shows the relative size of the demands in the Colorado River Basin. Agriculture is the dominant demand, and varies across the Planning Scenarios, whereas the transbasin export demand is constant across all scenarios. While the M&SSI demand does vary, it is difficult to see the changes graphically because it is the smallest demand. Following the graphic are summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage or transbasin import supply gaps.

Table 11: Colorado River Basin Water Supply and Gap Summary

	Agricultural and M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,667,393	1,575,242	1,562,620	1,759,203	1,389,373	1,872,985
	Average Annual Gap (ac-ft)	45,786	45,200	44,798	78,073	63,841	108,459
	Average Annual Percent Gap	3%	3%	3%	4%	5%	6%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	1,667,307	1,575,937	1,563,315	1,682,557	1,352,510	1,789,728
	Gap In Maximum Gap Year (ac-ft)	150,318	145,356	144,397	171,782	138,040	226,271
	Percent Gap In Maximum Gap Year	9%	9%	9%	10%	10%	13%

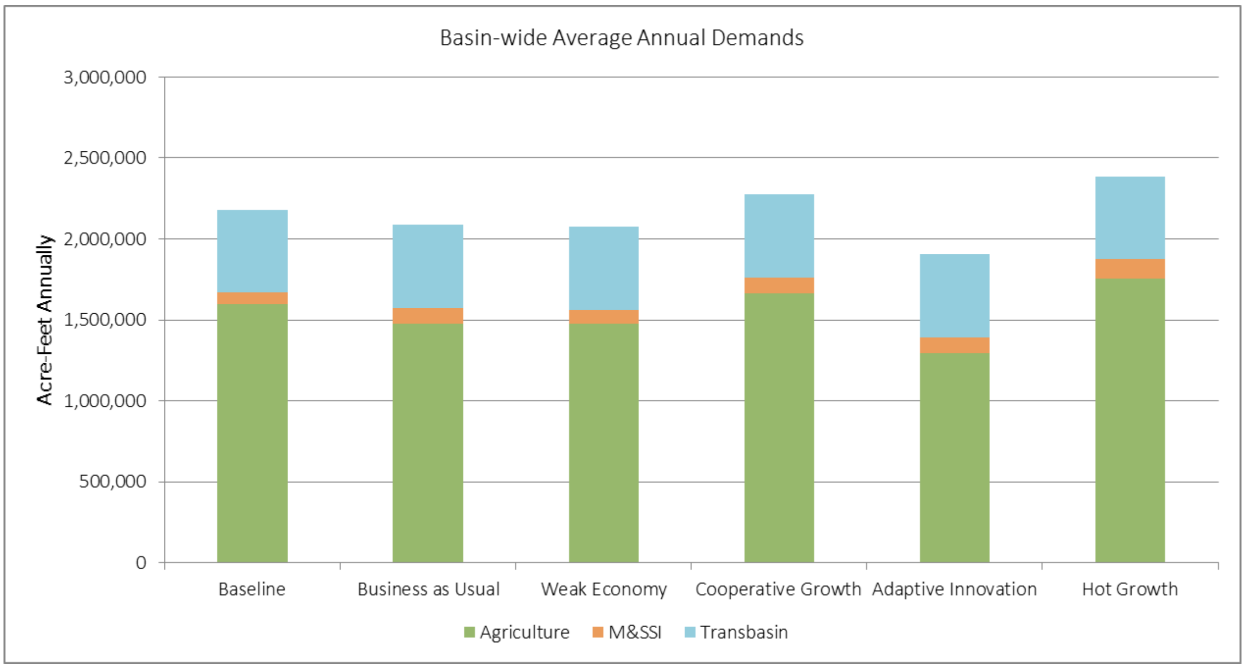


Figure 28: Colorado River Basin Comparison of Average Annual Demands

All of the Planning Scenarios project that 13,590 acres of irrigated land will be taken out of production due to urbanization. Supplies used to irrigate the urbanized acreage could be considered a new municipal supply if the associated water rights were changed to municipal uses. To estimate this new supply, the average consumptive use of the urbanized acreage by Planning Scenario is reflected in Table 12. Note however, it is not known which farms and ranches will be directly impacted; whether the acreage was served by senior/junior direct rights or had supplemental storage supplies; or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use, or whether the supply could directly meet the future municipal demand or would require exchange potential. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 12: Potential Water Supply from Urbanized Acreage in the Colorado River Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage	13,590	13,590	13,590	13,590	13,590
Estimated Consumptive Use (ac-ft/year)	28,264	28,264	30,799	29,744	32,108

The Colorado River Basin benefits from the delivery of a small amount of imported transbasin supplies; these supplies are delivered from the Gunnison River basin for M&SSI purposes in and around the Grand Junction.

Table 13 summarizes the total transbasin import volumes and associated import gap. Note that transbasin imports are the same across the scenarios because they are represented in the model at historical levels, and no Planning Scenario adjustments were applied. A gap indicates that the historical import could not be diverted in the source basin due to a physical or legal limitation of water supply at the diverting location. This is caused by changes in water availability, increases in senior demands in the source basin, or a combination of both.

Ideally the import supply gap in the Baseline scenario would be zero; however the Baseline dataset represents current agricultural and M&SSI demands over the entire model period which can result in minor shortages to junior water rights, including transbasin diversions. With this in mind, the incremental increase in the import gap reflects the increase in gap due to the Planning Scenario adjustments.

Under current hydrology conditions, there was no increase in the gap for the Business as Usual and Weak Economy scenarios. The increased demands and changed hydrology in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios however resulted in more substantial gaps on average and during critically dry years. If exports stay the same in the future, the reported import gaps could increase the total Colorado River basin M&SSI gaps in these scenarios.

Table 13: Summary of Transbasin Imports to the Colorado River Basin

	Transbasin Import Supply Gap Results	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Import Supply (ac-ft)	6,603	6,603	6,603	6,603	6,603	6,603
Average	Average Annual Import Supply Gap (ac-ft)	45	45	45	41	88	79
Average	Average Annual Import Supply Gap Increase from Baseline (ac-ft)	-	0	0	-	43	34
Average	Average Annual Import Supply Percent Gap	1%	1%	1%	1%	1%	1%
Critically Dry Maximum	Import Supply In Maximum Gap Year (ac-ft)	6,601	6,601	6,601	6,601	6,601	6,601
Critically Dry Maximum	Import Supply Gap In Maximum Gap Year (ac-ft)	676	676	676	783	1,123	1,096
Critically Dry Maximum	Increase from Baseline Import Supply Gap (ac-ft)	-	0	0	107	448	420
Critically Dry Maximum	Import Supply Percent Gap In Maximum Gap Year	10%	10%	10%	12%	17%	17%

The Colorado River Basin has a substantial amount of reservoir storage. As shown in Figure 29, the Colorado River Basin has just under 1.4 million ac-ft of storage. The reservoirs serve agriculture, transbasin exports, M&SSI, recreation, and support the recovery of endangered fish species. The storage capacity helps buffer the basin against periods of drought, but then needs average and wet hydrologic conditions to refill. The large reservoirs individually represented model, organized by their primary purpose, are listed below:

Agriculture Reservoirs:
Harvey Gap (a.k.a. Grass Valley Reservoir)
Monument Reservoir System
Rifle Gap Reservoir
Vega Reservoir

Multi-purpose Reservoirs:
Clinton Gulch Reservoir
Eagle Park Reservoir
Green Mountain Reservoir
Ruedi Reservoir
Williams Fork Reservoir
Wolford Mountain Reservoir

Transbasin Reservoirs:
Dillon Reservoir
Granby Reservoir
Grand Lake/Shadow Mountain Reservoir
Homestake Reservoir
Leon Creek Reservoir
Meadow Creek Reservoir
Upper Blue Reservoir
Willow Creek Reservoir

M&SSI Reservoirs:
Bonham Reservoir
Cottonwood Reservoir
Jerry Creek Reservoir

The largest reservoirs in the basin are Granby Reservoir with over half a million ac-ft of storage for the Colorado-Big Thompson Project; and Dillon Reservoir with over a quarter million ac-ft of storage for transbasin diversion for Denver Water. The next largest reservoirs, Green Mountain, Reudi, and Wolford Mountain Reservoirs, provide compensatory storage for West Slope users to mitigate the impacts of transbasin diversions. In general, active reservoir capacity in the basin is drawn down in dry years in all Planning Scenarios; any remaining storage capacity can be attributed to inactive reservoir storage or capacity maintained for environmental or recreational purposes.

Simulated reservoir storage results for the Baseline, Business as Usual, and Weak Economy scenarios are similar and the results are overlapping in the graphic. The Cooperative Growth scenario uses the In-Between hydrology resulting in reservoir storage that is lower than results for scenarios using the current hydrology. The reservoir storage results are very similar for Adaptive Innovation and Hot Growth scenarios, and produce the lowest reservoir storage results of the Planning Scenarios due to the impact of the Hot and Dry hydrology. The Adaptive Innovation usually has slightly more water in storage than the Hot Growth scenario due to lower demands in the Adaptive Innovation scenario.

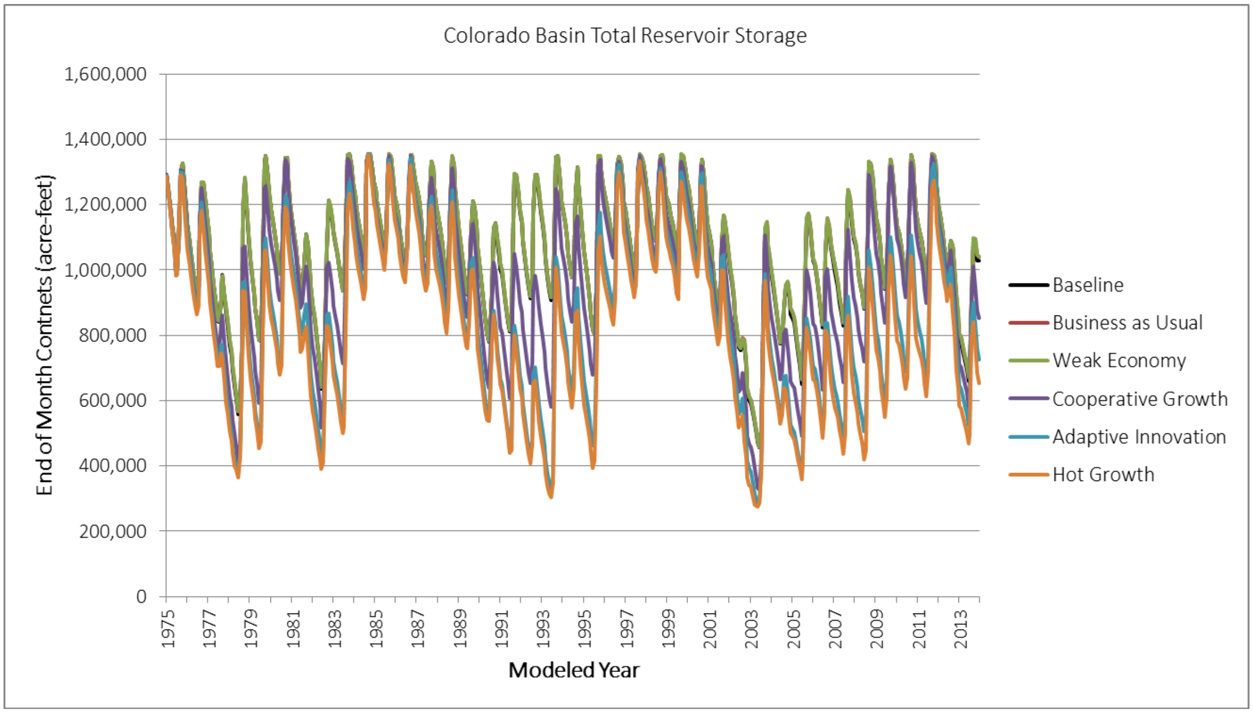


Figure 29: Colorado River Basin Total Reservoir Storage

The following figures reflect average monthly simulated streamflow at key locations across the basin; refer to Figure 21 for the location of the gages. The primary driver of average monthly simulated streamflow across the Planning Scenarios is hydrology. The average monthly streamflow results from Baseline, Business as Usual, and Weak Economy scenarios are often indistinguishable from each other due to their use of current hydrology and only limited differences in demands. In several locations, the results from these scenarios are overlapping. The In-Between hydrology featured in the Cooperative Growth scenario and the Hot and Dry hydrology featured in the Adaptive Innovation and Hot Growth scenarios consistently reduce late season flows across the basin and, in many areas, shift the peak streamflow earlier in the year.

Figure 30 reflects the simulated streamflow results of the Colorado River below Baker Gulch near Grand Lake, which is located high in the headwaters of the Colorado River. The most noticeable impact to streamflow across the scenarios is the shift in peak streamflow from June to May, and the considerable decline in streamflow in July. The average monthly streamflow volume in July under current hydrology is approximately 8,000 ac-ft. For the In-Between hydrology, the streamflow drops to 3,300 ac-ft and for the Hot and Dry hydrology, the streamflow drops to 2,300 ac-ft. This is a significant decline in streamflow during a month which has historically been critical for irrigation water supplies. On an annual basis, the In-Between hydrology has slightly more streamflow volume, but the Hot and Dry hydrology has less streamflow volume than current hydrology. The change in the runoff timing, however, will be challenging in a headwater tributary with limited access to storage.

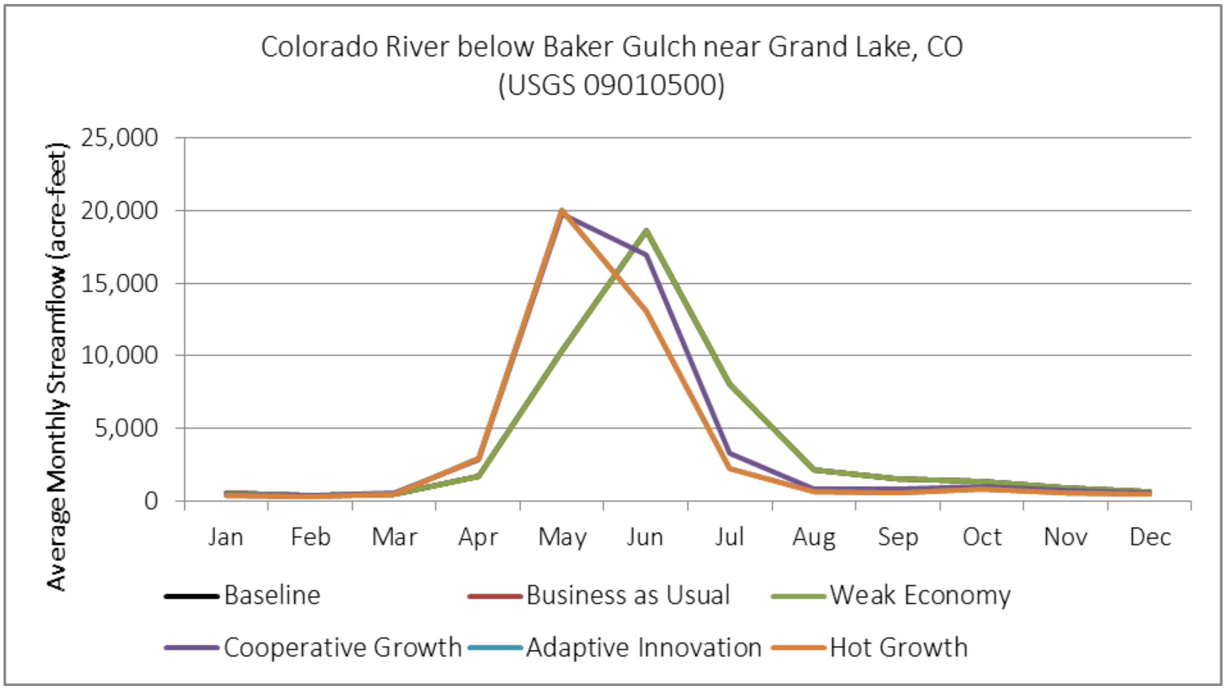


Figure 30: Average Monthly Streamflow for Colorado River below Baker Gulch near Grand Lake

Figure 31 reflects the average monthly simulated streamflow results for the Blue River below Green Mountain Reservoir. The streamflow in this location is projected to have a different response to the In-Between hydrology and the Hot and Dry hydrology compared to streamflow at other locations due to upstream operations. This is because there are two large reservoirs (Green Mountain and Dillon) and several transbasin export diversions upstream of this gage location. Roberts Tunnel is the largest of the transbasin exports above the Blue River below Green Mountain gage location, and its diversions are backed by storage in Dillon Reservoir. The export demand is nearly always satisfied, in some years causing Dillon Reservoir to drop to very low levels. From a streamflow perspective, the reservoirs are storing as much of the peak flow as possible, especially in April and May when the results reflect low levels in all scenarios. During the winter, Green Mountain Reservoir is drawing down for flood control purposes by releasing for hydropower operations. Additionally, Green Mountain releases to contract holders who are called out by senior downstream Shoshone Power Plant. These combined effect of these operations leads to the different streamflow response reflected at this location.

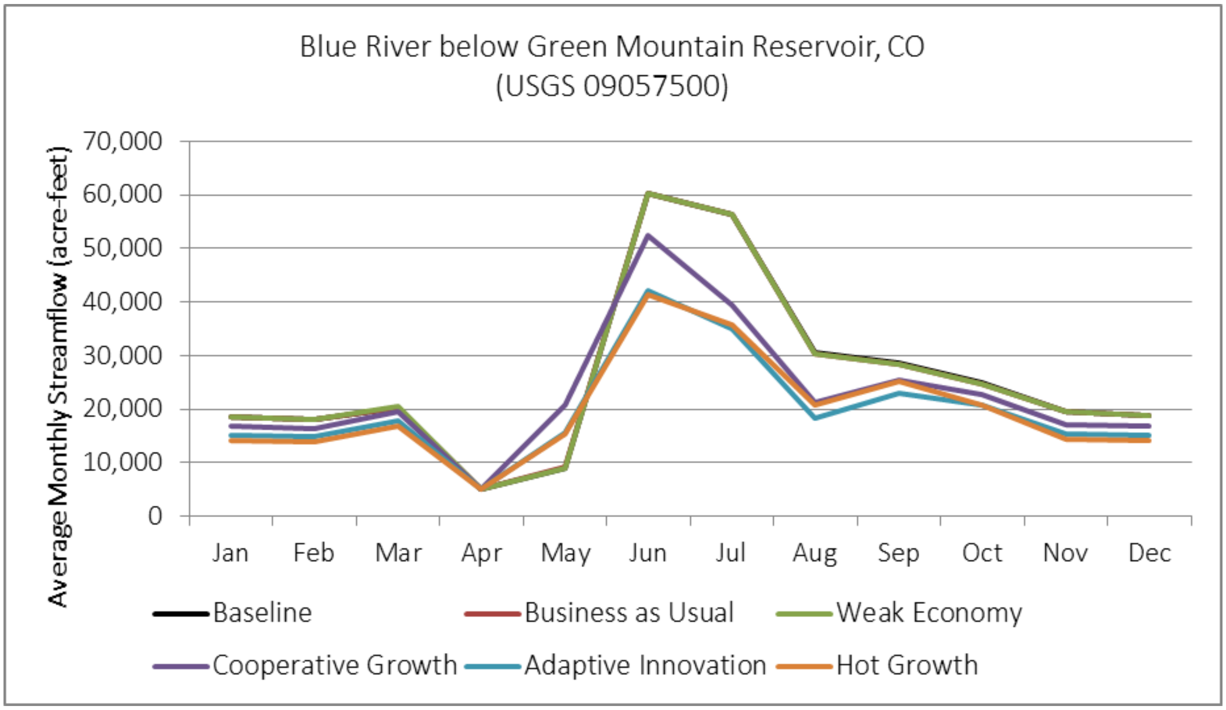


Figure 31: Average Monthly Streamflow for Blue River below Green Mountain Reservoir

The Colorado River near Dotsero average monthly streamflow is shown in Figure 32. This gage is representative of the amount of water available to the Shoshone Power Plant and is located about halfway down the Colorado River Basin. The trends in simulated streamflow across the scenarios are indicative of results at downstream locations. The simulated streamflow is similar between the Baseline, Business as Usual, and the Weak Economy scenarios. Under the In-Between hydrology and the Hot and Dry hydrology, the peak streamflow is shifted from June to May, and there is an overall reduction to streamflow volumes. The annual volume of streamflow is projected to decrease from about 310,000 ac-ft to 274,000 ac-ft for the In-Between hydrology and 238,000 ac-ft for the Hot and Dry hydrology.

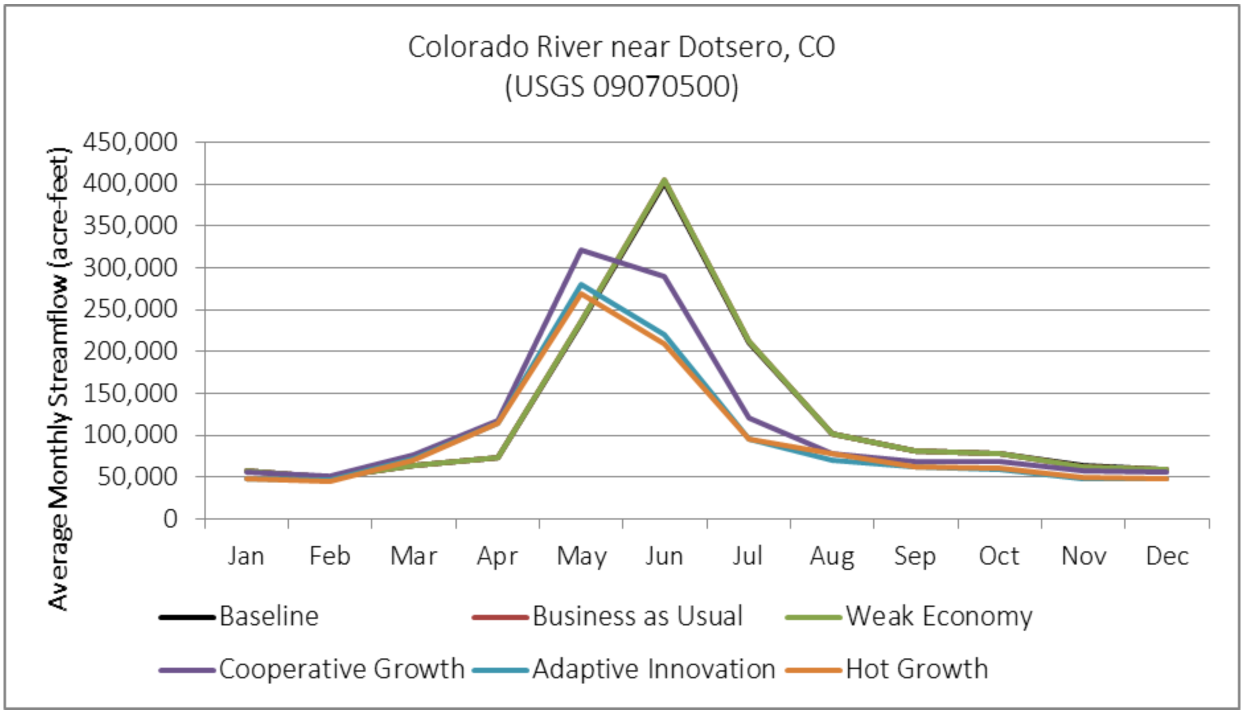


Figure 32: Average Monthly Streamflow for Colorado River near Dotsero

Figure 33 reflects simulated streamflow results for the Roaring Fork River at Glenwood Springs. The streamflow is influenced by upstream transbasin exports, reservoir storage, agricultural use, and M&SSI use. Similar to the Colorado River at Dotsero results, the peak streamflow is shifted from June to May, and the streamflow in July is greatly reduced. The annual streamflow volume is reduced from 870,000 ac-ft under the current hydrology to 822,000 ac-ft in the Cooperative Growth scenario, 730,000 ac-ft in the Adaptive Innovation scenario and 724,000 ac-ft in the Hot Growth scenario.

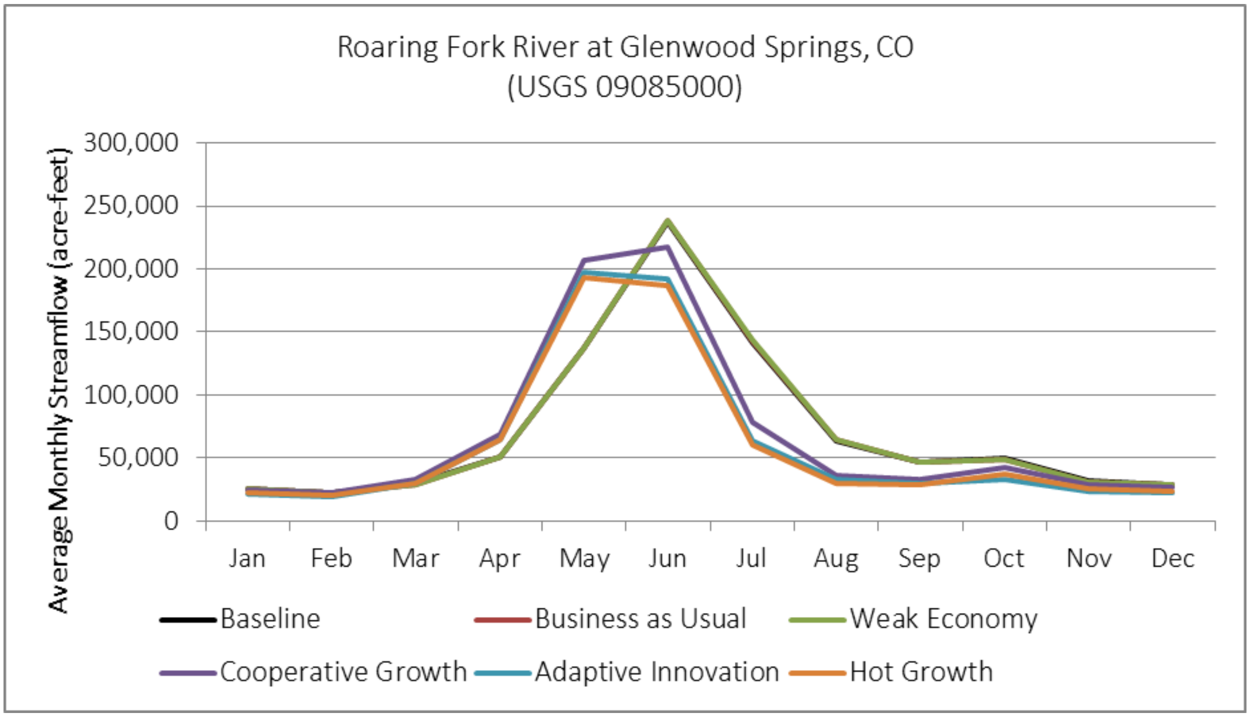


Figure 33: Average Monthly Streamflow for Roaring Fork River at Glenwood Springs

Figure 34 through Figure 37 reflect simulated unappropriated available supply for the Colorado River Basin at locations representative of the Shoshone Power Plant diversion (near Dotsero) and the "Cameo Call", which are generally the controlling rights on the mainstem of the Colorado River. As reflected on the graphics, there is generally unappropriated streamflow available in the Business as Usual and Weak Economy scenarios during runoff, except during critically dry years, when no unappropriated flow is available. Winter-time has severely limited unappropriated streamflow available, as nearly all of the flow is being used to meet existing water rights and demands. Unappropriated available supplies are still available in the climate-adjusted Planning Scenarios during the runoff, but the average volumes are substantially reduced and shifted earlier in the year. Streamflow and unappropriated available flow nearly double between the upstream and downstream locations due to inflows from the Roaring Fork, Parachute Creek, and Rifle Creek. The figures reflect that unappropriated streamflow is available at these locations, but the magnitude and timing vary substantially annually and across the hydrologic year types.

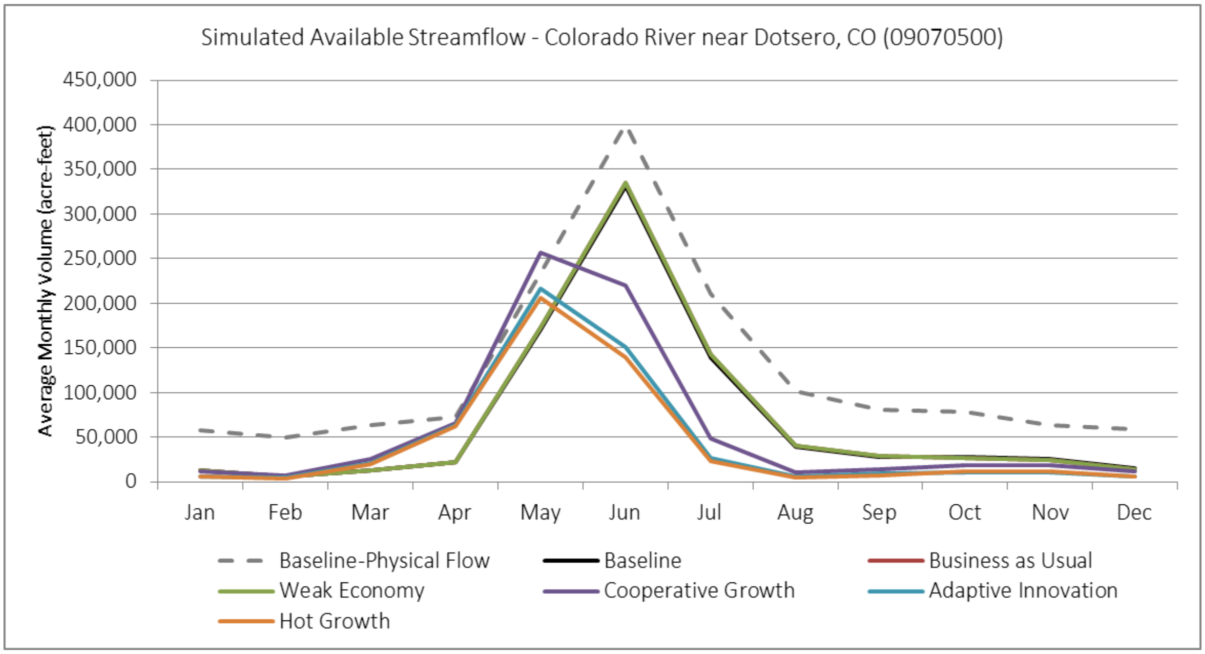


Figure 34: Average Monthly Unappropriated Available Supply at Colorado River near Dotsero

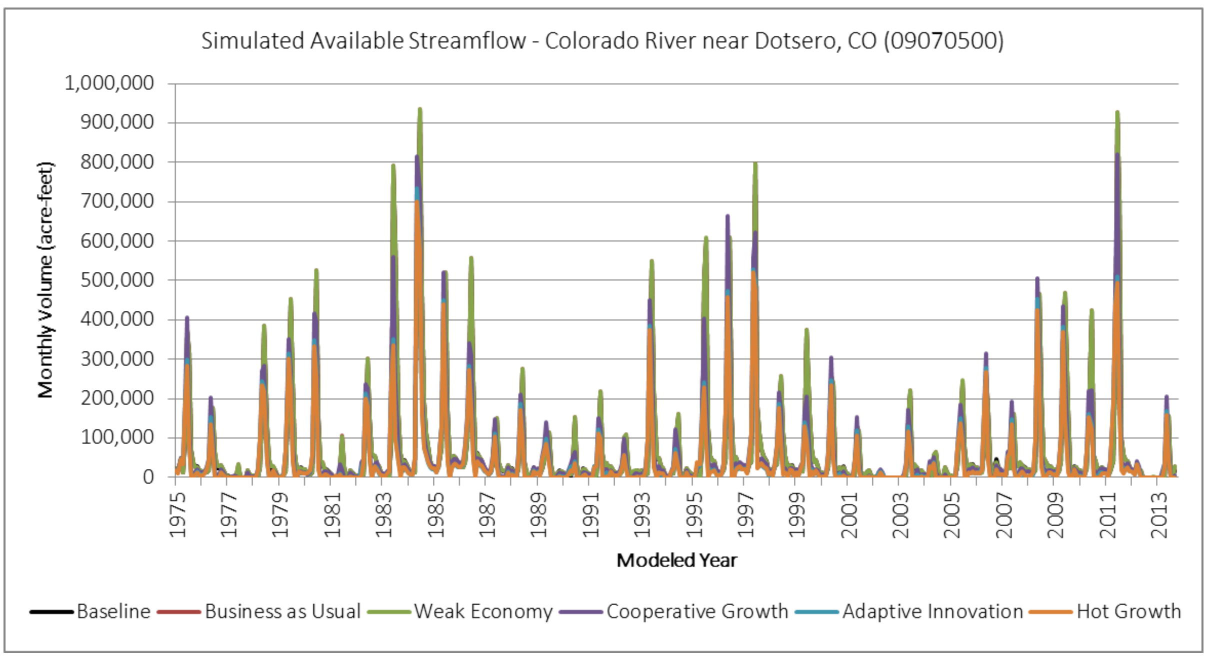


Figure 35: Monthly Unappropriated Available Supply at Colorado River near Dotsero

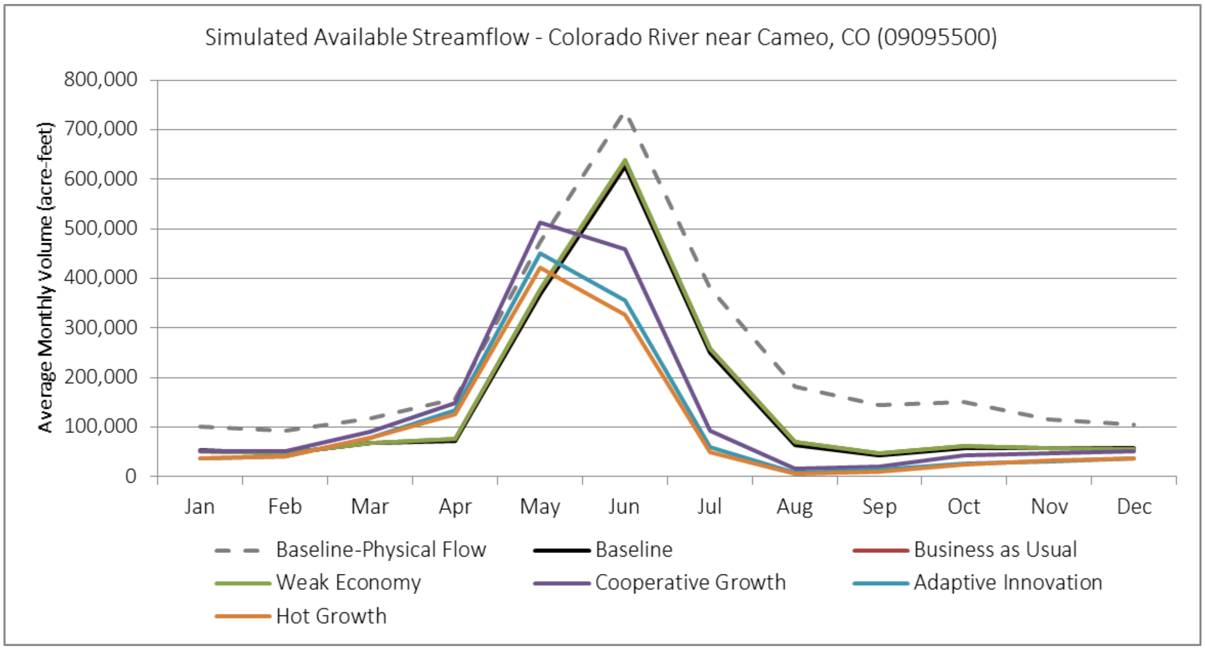


Figure 36: Average Monthly Unappropriated Available Supply at Colorado River near Cameo

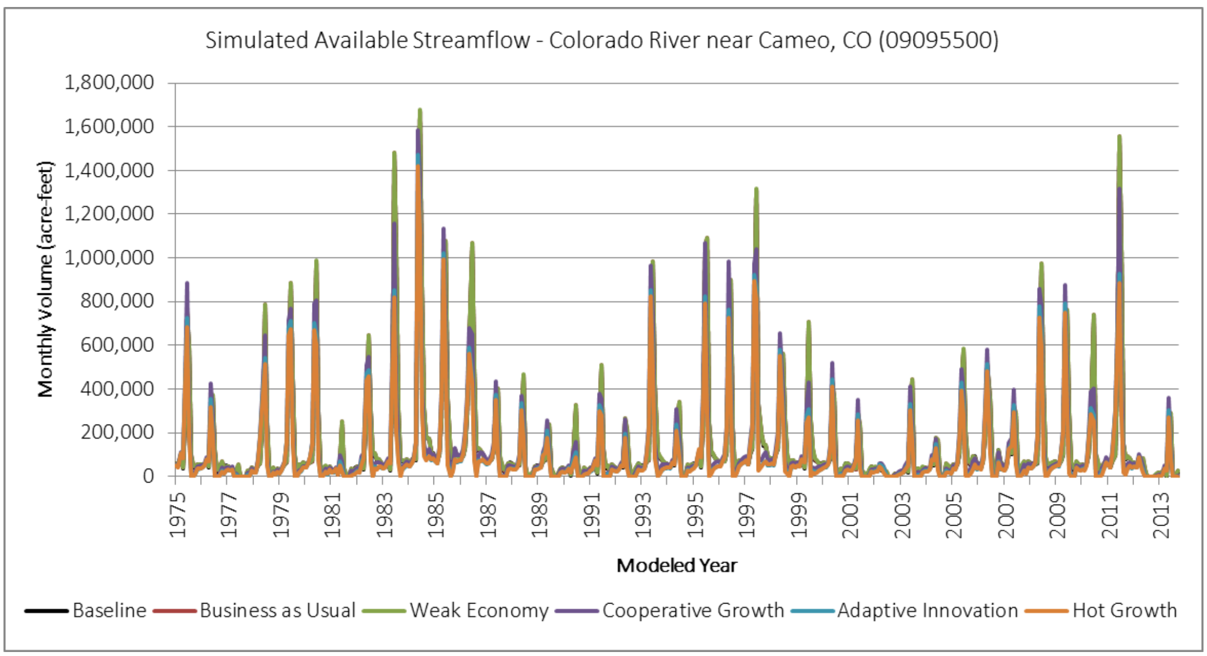


Figure 37: Monthly Unappropriated Available Supply at Colorado River near Cameo

5.3 GUNNISON RIVER BASIN

A vast majority of the water used in the Gunnison River Basin is for agricultural purposes; for mountain ranching at higher elevations and for producing fruits and field crops at lower elevations near the confluence with the Colorado River at Grand Junction. Irrigation in the basin has been supported by several Reclamation projects, including the Uncompahgre Project, which diverts an average of 330,000 ac-ft per year through the Gunnison Tunnel, the Paonia Project, Smith Fork Project, Bostwick Park Project, and the Fruitgrowers Dam Project. In addition to the irrigation projects, the Gunnison River fills the Aspinall Unit, which is comprised of three reservoirs dammed by Blue Mesa Dam, Morrow Point Dam, and Crystal Dam. The three reservoirs are operated in tandem to produce hydropower, provide flood control benefits, support the recovery of endangered fish species, and deliver water to downstream water users.

Several municipal areas are located throughout the Gunnison River Basin, many of which are agricultural communities such as the Delta/Montrose area, Ridgway, and Hotchkiss. Tourism is also an important economic driver in the basin. Recreational opportunities range from the ski resorts in Crested Butte and Telluride to fishing opportunities at the many reservoirs, and the Black Canyon of the Gunnison National Park.

The following sections describe the agricultural, M&SSI, and transbasin export demands in the Gunnison River basin in more detail. Figure 38 shows the basin outline, the administrative boundaries of water districts, and the streamflow gages highlighted in the results section below.

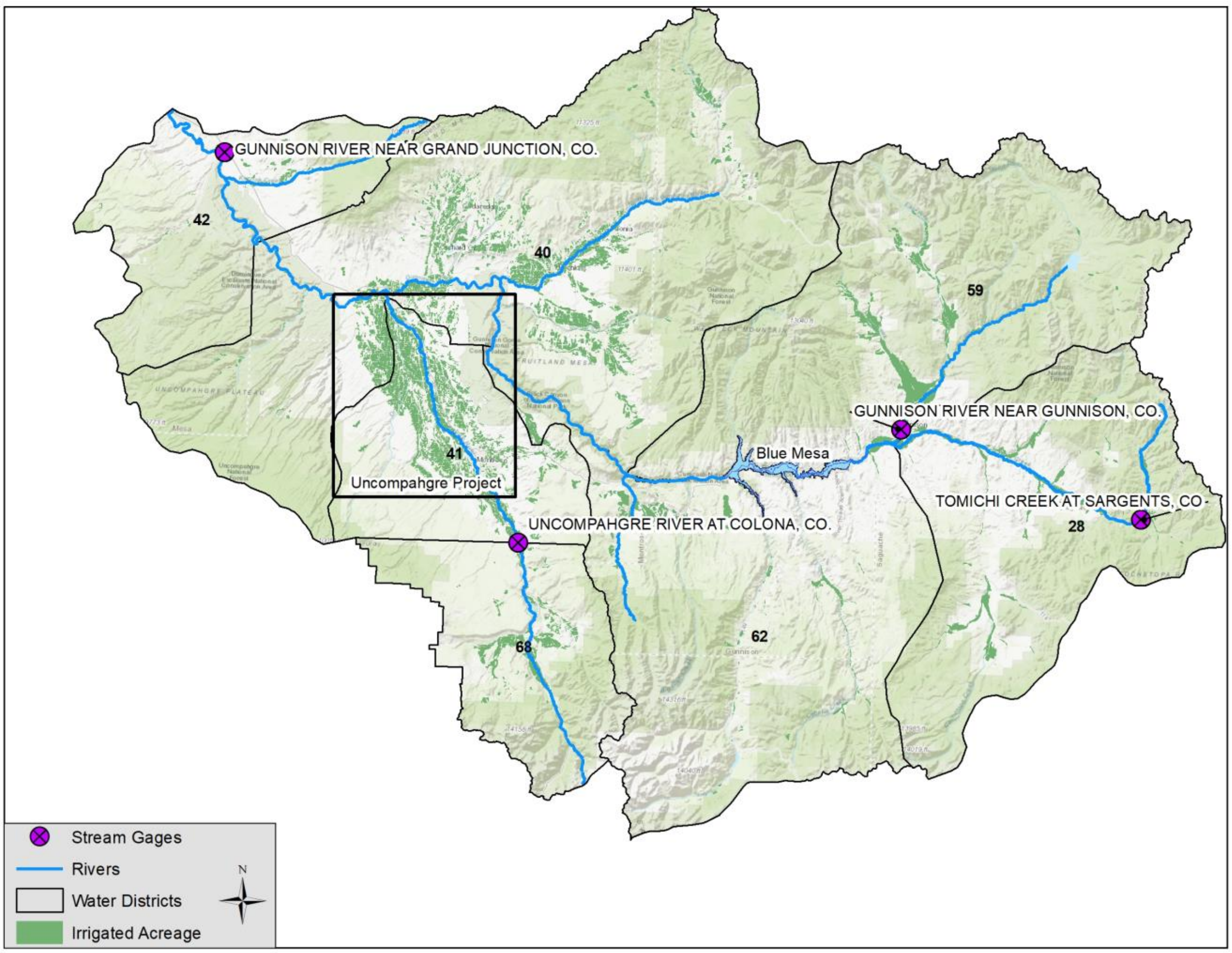


Figure 38: Gunnison River Map with Streamgage Locations

5.3.1 GUNNISON RIVER BASIN AGRICULTURE WATER SUPPLY AND GAP

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. 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.

Another notable feature in the Gunnison River basin are operations that help maximize a tributary's yield by rotating diversions among all irrigators, regardless of the priority of water rights. Sometimes referred to as "gentleman's agreements", these informal operations tend to benefit the more junior water users on a tributary and are motivated by lack of storage. For areas without storage, irrigation supplies are generally available only during the runoff, and water users use these informal agreements to allow more of the runoff to be diverted. One of the more important examples of these types of agreements is the operational practice whereby the Gunnison Tunnel abstains from placing a call during dry years. In some instances, the Gunnison Tunnel water users will coordinate with the Upper Gunnison Water Conservancy District to receive water from Taylor Park Reservoir in lieu of placing a call. At other times, the Gunnison Tunnel water users decide to forego diverting their full entitlement, thus allowing upstream irrigators to divert more water.

These types of agreements are discussed herein because the baseline model allocates water based on strict priority, and does not replicate these informal agreements. This approach allows the model to demonstrate conditions in the basin under current administration, which provides the most certainty to water users for planning purposes. This may also overestimate the amount of agricultural gap compared to historical conditions, and may overestimate the amount of diversions through the Gunnison Tunnel.

The Gunnison River Basin agricultural diversion demands, demand gaps, and consumptive use gaps results for the baseline and Technical Update Planning Scenarios are presented

Table 14. As discussed in the *Current and 2050 Planning Scenario Agricultural Diversion Demand* technical memorandum, 2050 agricultural diversion demands are influenced by a number of drivers, including climate, urbanization, planned agricultural projects, and emerging technologies.

Table 14: Gunnison River Basin Agricultural Water Supply and Gap Summary

	Agricultural Results	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,800,163	1,675,496	1,675,496	1,967,156	1,305,708	2,041,502
	Average Annual Demand Increase from Baseline (ac-ft)	-	-	-	166,994	-	241,339
	Average Annual Gap (ac-ft)	87,314	77,167	77,317	157,596	112,632	221,970
	Average Annual Gap Increase from Baseline (ac-ft)	-	-	-	70,282	25,318	134,656
	Average Annual Percent Gap	5%	5%	5%	8%	9%	11%
	Average Annual CU Gap (ac-ft)	43,202	38,195	38,271	74,838	64,720	104,022
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	1,841,123	1,713,899	1,713,899	1,833,551	1,247,621	1,912,658
	Increase from Baseline Demand (ac-ft)	-	-	-	-	-	71,535
	Gap In Maximum Gap Year (ac-ft)	339,679	313,533	314,821	432,633	319,622	590,803
	Increase from Baseline Gap (ac-ft)	-	-	-	92,954	-	251,124
	Percent Gap In Maximum Gap Year	18%	18%	18%	24%	26%	31%

The average annual agricultural demand decreases from the Baseline to the Business as Usual and Weak Economy Planning Scenarios. Both Planning Scenarios assume 14,600 acres of irrigated acreage is removed from production due to urbanization of irrigated lands. The reduction in acreage does not make additional supplies available for the remaining acreage. As reflected in the table, irrigators in the basin currently experience a relatively small agricultural gap on average with a slightly more substantial gap during critically dry years.

Under the Cooperative Growth scenario, 14,600 acres of irrigated acreage is removed from production due to urbanization and the average annual demand increases due to climate adjustments to IWR. These adjustments combine to increase the agricultural demand by approximately 167,000 ac-ft basin-wide compared to the Baseline scenario, noting however that the impact of the climate change adjustments are larger in the upper basin compared to the lower basin. Irrigators in the upper basin have significantly less or no access to reservoir storage compared to ditches in the lower basin. Increased demands in these areas must be met using available water supply from the river. The Cooperative Growth scenario uses the In-Between hydrology, which shifts the peak runoff and reduces streamflow during the late irrigation season; therefore, shortages increase in this scenario compared to the Baseline scenario.

For the Adaptive Innovation scenario, the average annual demand is less than the Baseline demand, despite reflecting the same reduction to irrigated lands for urbanization and incorporating climate adjustments to IWR under the Hot and Dry conditions. To offset the impact of climate change, the Adaptive Innovation scenario assumes that emerging technologies decrease the IWR and increase irrigation system efficiency for the entire basin. Agricultural demands are highly sensitive to changes in IWR and system efficiency, so the two emerging technology adjustments result in a net decrease of nearly 495,000 ac-ft of agricultural demands on average compared to the Baseline scenario. The average annual gap and the CU gap in the Adaptive Innovation scenario is smaller than the Cooperative Growth scenario, but larger than the Business as Usual scenario, indicating the two adjustments did not fully mitigate the effects of Hot and Dry climate conditions. Finally, the Hot Growth scenario produces the largest agricultural gaps in the Gunnison River Basin. Average annual demands have increased while the runoff is projected to decrease. The annual percent gap is 11 percent on average, but increases to 31 percent in critically dry years.

In general, the Gunnison River Basin is projected to experience relatively low agricultural gaps on average, with more pronounced gaps during critically dry years. This is highlighted in Figure 39 and Figure 40, which show the relative size of the agricultural demands and gaps for the average annual and during a critically dry year. As discussed above, the gap is likely larger for irrigators on smaller tributaries without access to storage due to the reduced annual runoff volumes and more pronounced reductions in late season supplies. For example, Water District 28 (Tomichi Creek) has a maximum gap of 46 percent in the Hot Growth scenario compared to a maximum gap of 19 percent in Water District 41 (Lower Uncompahgre River). Agricultural storage in Water District 28 is limited, so irrigators depend on direct diversions whereas Water District 41 benefits from the Uncompahgre Project, which has storage in Blue Mesa Reservoir and Taylor Park Reservoir, and is supplied by the Gunnison Tunnel. These supplemental supplies and infrastructure buffer against declining streamflow.

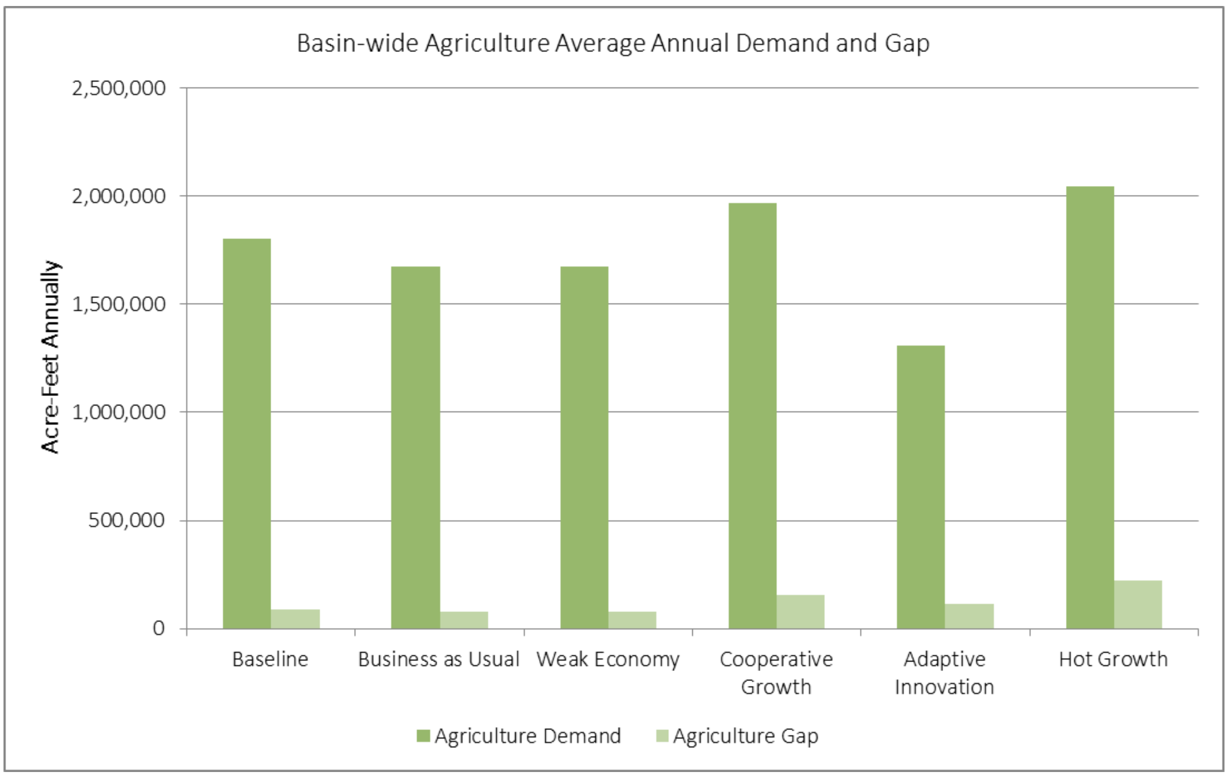


Figure 39: Gunnison River Basin Agriculture Average Annual Demand and Gap

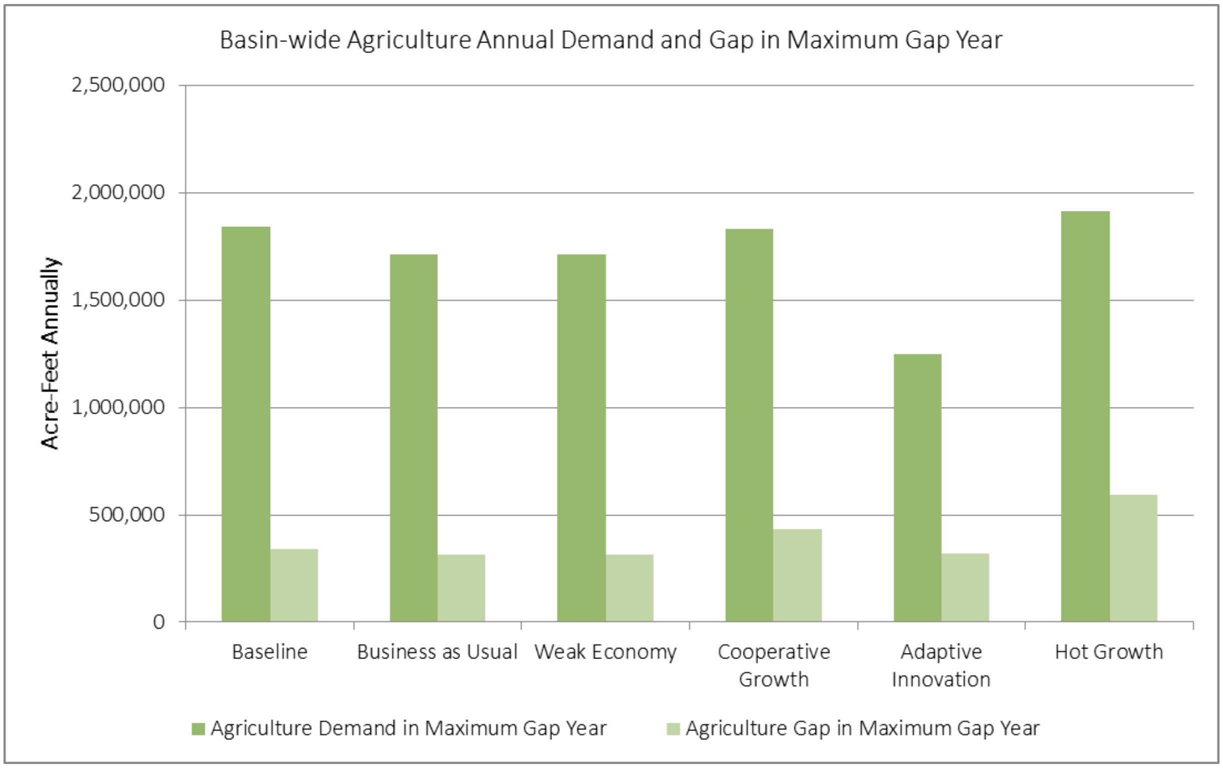


Figure 40: Gunnison River Basin Agriculture Annual Demand and Gap in Maximum Gap Year

In addition to the average annual summary, it is important to consider the variability of gaps across wet, average, and dry year types. Figure 41 reflects the average annual percent gap for modeled years (1975 - 2013). The dry hydrology years of 1977 and 2002 stand out as the largest gaps in the basin, followed by 2012, 1990, and 1981. The Baseline, Business as Usual, and Weak Economy scenarios all produce very similar results and results are often overlapping on the graph. The results for these scenarios indicate that shortages to agriculture, although small, occur in even the wettest years. The Cooperative Growth and the Adaptive Innovation scenarios generally trend together, indicating the emerging technologies adjustments had the effect of partially mitigating the impact of Hot and Dry climate conditions. The Hot Growth scenario produces the largest gaps.

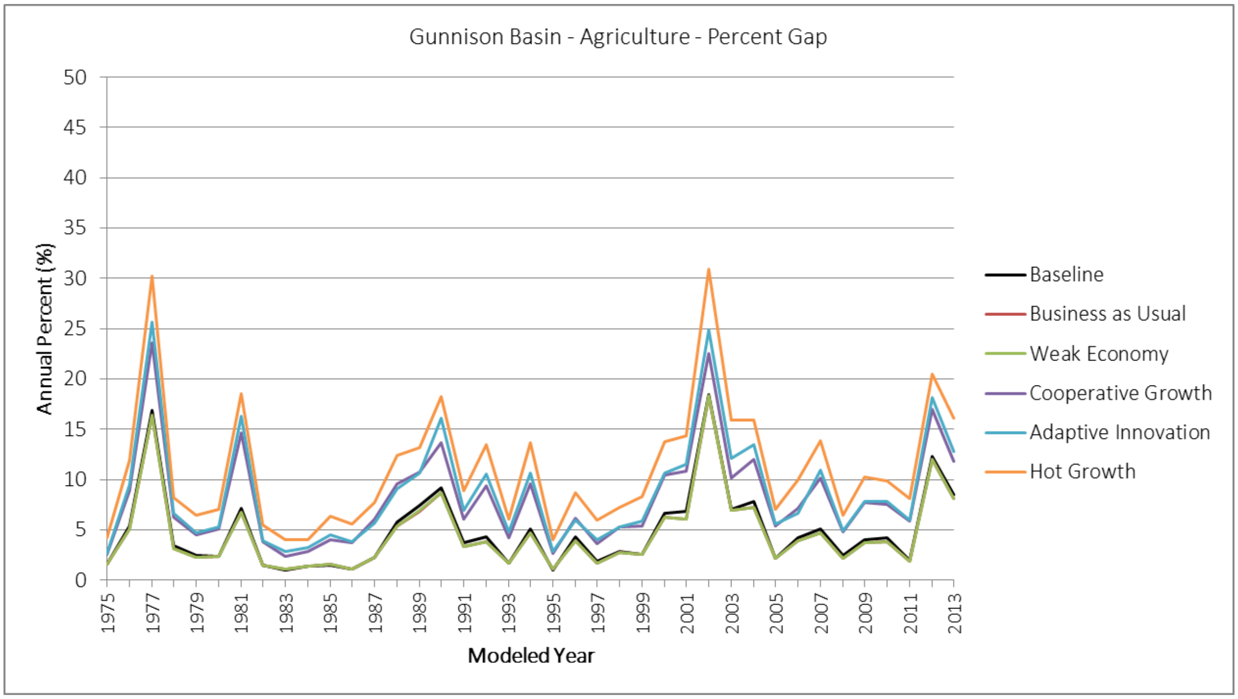


Figure 41: Gunnison River Basin Agriculture Percent Diversion Gap Times Series

5.3.2 GUNNISON RIVER BASIN M&SSI WATER SUPPLY AND GAP

M&SSI demands are small relative to other demands in the basin, consisting of approximately one percent of the total demands. Of the total M&SSI demands, over 99 percent are attributable to municipal demands, with only one percent attributable to SSI demands. Close to half of the municipal demand in the basin occurs in Montrose County, which is projected to increase in all Planning Scenarios. Hinsdale County is projected to have the highest rate of population growth across the Planning Scenarios, whereas Ouray County is projected to have more moderate growth or decrease in population in some Planning Scenarios. Population in the basin overall, however, is projected to increase in all Planning Scenarios, driving increased municipal demands.

In the Gunnison River Basin model, a majority of the municipal demand is represented at grouped locations, with only the Project 7 Water Authority, which provides municipal and domestic water to the Uncompahgre Valley, including the Towns of Montrose and Delta, represented individually as a component of the Dallas Creek Project.

SSI[8] demands in the basin, projected to be less than 700 ac-ft, are attributable to snowmaking operations. These demands are modeled at grouped locations in tributary headwaters. Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin were developed. The water supply and gap results for M&SSI in the Colorado River basin are summarized in Table 15, and graphically reflected in Figure 42 through Figure 44.

[8] Note that water used for hydropower, such as those operations at the Aspinall Unit, are represented in the model but are not included in the SSI demand summaries (i.e. non-consumptive) and are not adjusted between Planning Scenarios.

Table 15: Gunnison River Basin M&SSI Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	17,012	24,763	19,133	22,888	26,393	34,057
	Average Annual Demand Increase from Baseline (ac-ft)	-	7,751	2,121	5,876	9,381	17,045
	Average Annual Gap (ac-ft)	84	980	200	1,372	2,197	5,444
	Average Annual Gap Increase from Baseline (ac-ft)	-	896	116	1,288	2,113	5,360
	Average Annual Percent Gap	0%	4%	1%	6%	8%	16%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	17,012	24,763	19,133	22,888	26,393	34,057
	Increase from Baseline Demand (ac-ft)	-	7,751	2,121	5,876	9,381	17,045
	Gap In Maximum Gap Year (ac-ft)	409	2,290	700	3,486	4,326	11,465
	Increase from Baseline Gap (ac-ft)	-	1,881	291	3,077	3,917	11,056
	Percent Gap In Maximum Gap Year	2%	9%	4%	15%	16%	34%

As reflected in the table, there is an M&SSI gap in the Baseline scenario. Ideally, the Baseline scenario would have no M&SSI gaps because the current conditions in the basin fully satisfy the existing M&SSI demands. This small amount of gap is likely a result of minor calibration issues in the model associated with the representation of the Project 7 Water Authority. Dallas Creek Project operations in dry years differ from those in average and wet years; the model currently represents average year conditions.

The Gunnison River Basin is projected to increase in population in 2050; therefore all of the Planning Scenarios reflect an increase in M&SSI demand compared to the Baseline scenario. The average annual demand increases from the Baseline scenario to the Business as Usual scenario, primarily because of the increase in municipal demands. The average annual gap of 4 percent is relatively small, however the 9 percent gap in critically dry years is more substantial. M&SSI demand in the Weak Economy increases approximately 2,100 ac-ft compared to the Baseline Scenario, and the gap results on average and during critically dry years are similar to those experienced in the Baseline scenario.

The Cooperative Growth scenario has smaller increase in demands than the Business as Usual scenario, but the gaps are larger due to the reduction in streamflow volume reduction in water available in the basin under the In-Between hydrological conditions. The percent gap reaches 6 percent and 15 percent for the average annual and during critically dry years, respectively.

M&SSI demands projected in Adaptive Innovation scenario are considerably larger than the Baseline scenario, driven by projected population growth. In addition to increasing the demands, streamflow is further reduced under the Hot and Dry hydrology. The average annual gap is 8 percent and reaches 16 percent in critically dry years.

Finally, the Hot Growth scenario demand doubles the Baseline M&SSI demand and reduces the available water supply with Hot and Dry hydrological conditions. The average annual gap is nearly 5,500 ac-ft or 16 percent of the demand. The gap in critically dry years reaches 11,000 ac-ft or 34 percent of the total demand.

Overall conclusions on the M&SSI demand and gap in the Gunnison River Basin vary depending on the scenario. Scenarios that incorporate current hydrological conditions have relatively low gaps, indicating that river conditions, even during critically dry years, are sufficient to meet much of the projected demand. Gaps increase, however, once drier hydrological conditions are incorporated alongside the increased gaps, leading to consistent annual gaps on average and larger gaps during critically dry years.

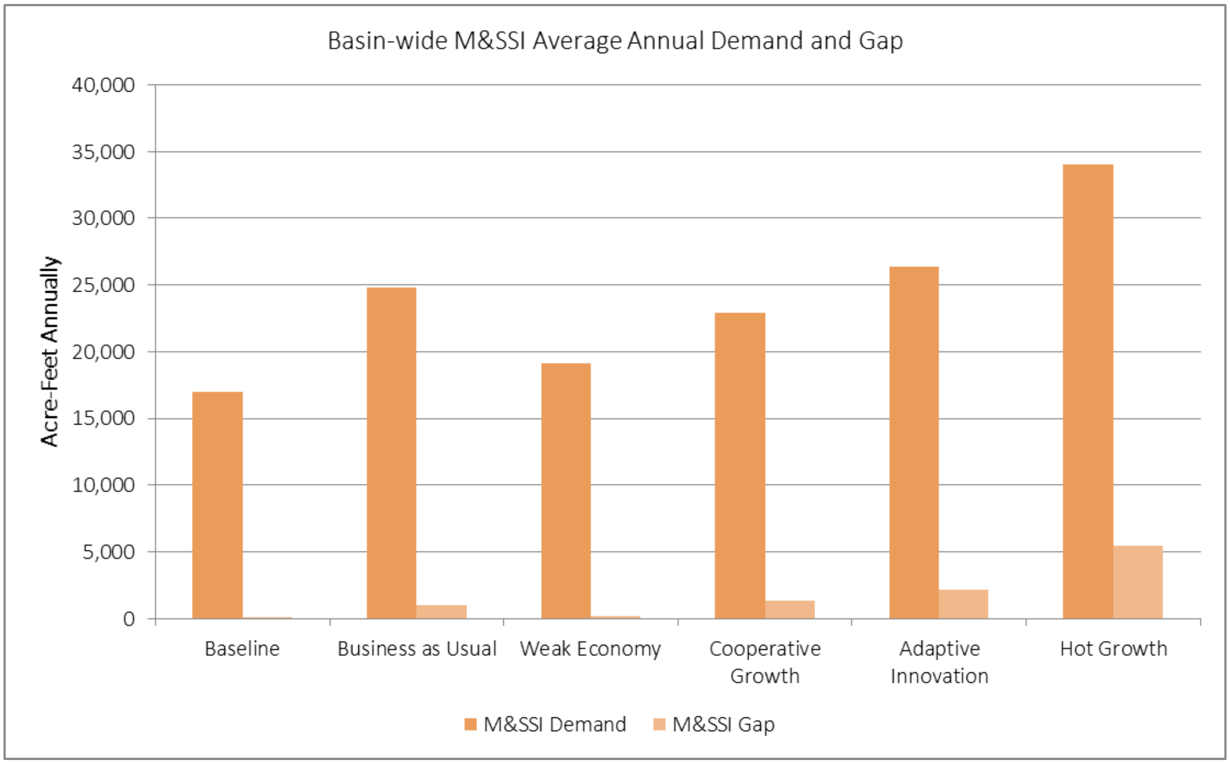


Figure 42: Gunnison River Basin M&SSI Average Annual Demand and Gap

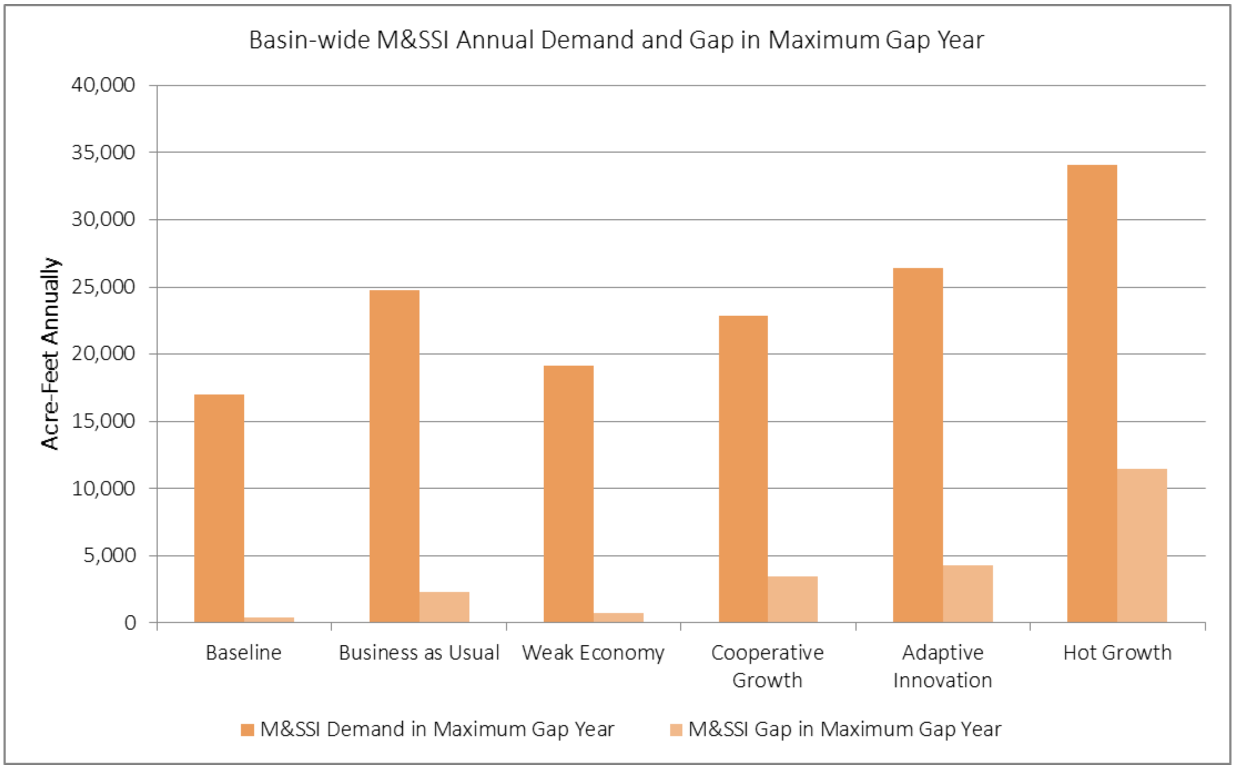


Figure 43: Gunnison River Basin M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

Figure 44 reflects average annual percent gap across a variety of wet, average, and dry year types. The scenarios respond differently to the dry hydrology periods. Due to low water availability, 1977, 1985, 2002, and 2012 stand out as the years with the largest gaps, particularly for the Business as Usual, Cooperative Growth, and Hot Growth scenarios. The Adaptive Innovation scenario gap results appear to have a unique pattern, particularly during drier periods (e.g. 2000 – 2004), despite using the same hydrological conditions as the Hot Growth scenario. This is likely due to the emerging technologies adjustment for the agricultural demands. Improvements to irrigation system efficiency reduce the amount of agricultural demand, and change the amount and timing of irrigation return flows available in the system. In an agriculturally dominated system, these conditions would change water availability for more junior users in the system.

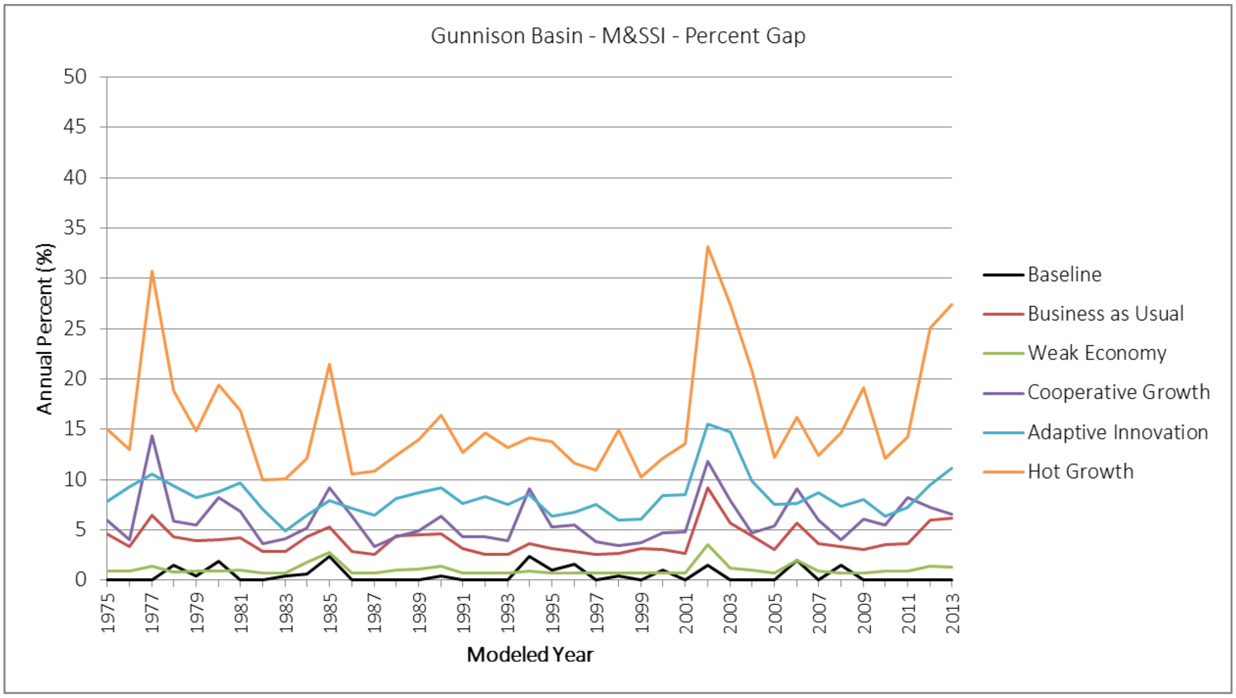


Figure 44: Gunnison River Basin M&SSI Average Annual Gap Time Series

5.3.3 GUNNISON RIVER BASIN TRANSBASIN EXPORT DEMAND

There is one transbasin export reflected in the Gunnison River Basin; a diversion from Kannah Creek for use in Grand Junction's municipal supply. Transbasin exports range depending on the in-basin supplies and the need for supplies at Grand Junction; however, on average the transbasin export demand from the Gunnison River Basin is 6,600 ac-ft. These demands could not be satisfied in all Planning Scenarios; however the shortages are reflected as an import supply gap in the destination basin and not considered a gap in the Gunnison River basin.

5.3.4 GUNNISON RIVER BASIN SUMMARY

The combined agriculture and M&SSI demands and gap summary is provided in Table 16. The results in Table 16 are very similar to the agricultural results in

Table 14, because the Gunnison River Basin is dominated by agriculture uses. The Gunnison River basin is generally able to meet much of the total demand in the Baseline, Business as Usual and Weak Economy scenario, except during critically dry years. The gaps increase as the demands increase and/or the hydrology decreases in the Cooperative Growth and the Adaptive Innovation scenarios. The gaps are largest in the Hot Growth scenario, which has the largest demands and the smallest streamflow.

Figure 45 shows the relative size of the demands in the Gunnison River Basin. Agriculture is the dominate demand; it is difficult to reflect the relative size of the M&SSI and transbasin export demands in the basin. Following the graphic are summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage or transbasin import supply gaps.

Table 16: Gunnison River Basin Water Supply and Gap Summary

	Agricultural and M&SSI Results	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,817,175	1,700,259	1,694,629	1,990,044	1,332,101	2,075,559
Average	Average Annual Gap (ac-ft)	87,398	78,147	77,517	158,967	114,829	227,414
Average	Average Annual Percent Gap	5%	5%	5%	8%	9%	11%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	1,858,135	1,738,662	1,733,032	1,856,439	1,274,014	1,946,715
Critically Dry Max	Gap In Maximum Gap Year (ac-ft)	340,088	315,823	315,521	436,119	323,948	602,268
Critically Dry Max	Percent Gap In Maximum Gap Year	18%	18%	18%	23%	25%	31%

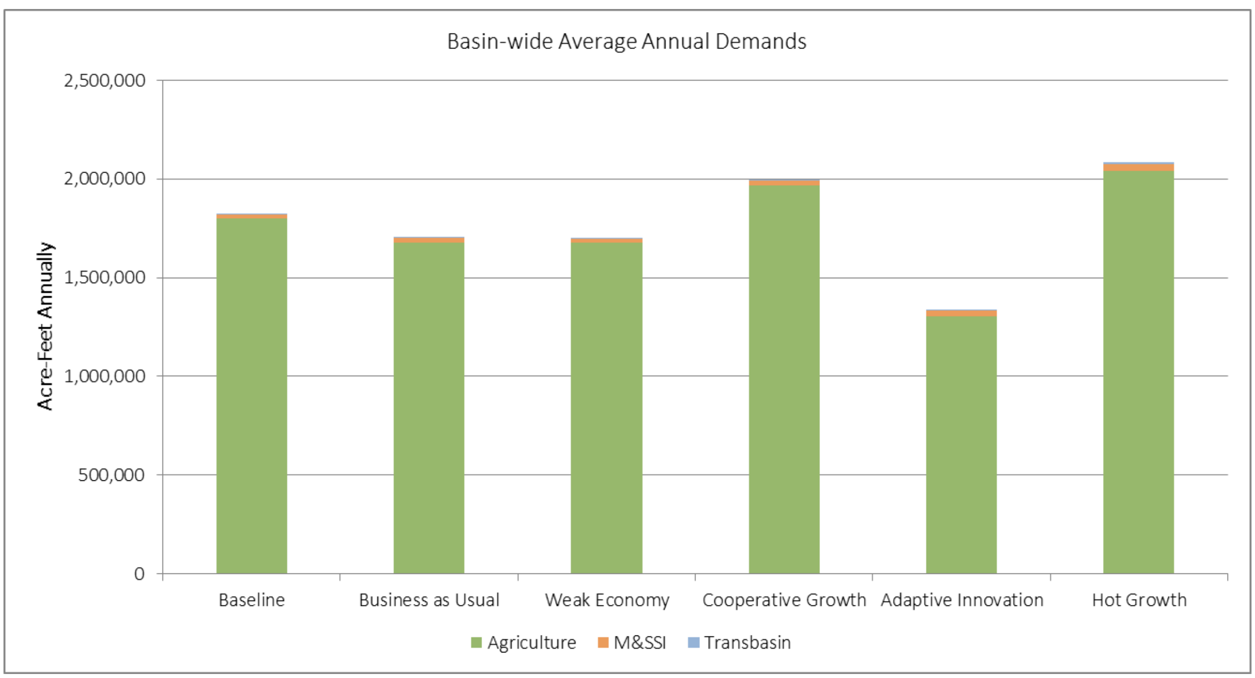


Figure 45: Gunnison River Basin Comparison of Average Annual Demands

All of the Planning Scenarios project 14,600 acres of irrigated agriculture will be taken out of production due to urbanization. Many counties in the basin are projected to have substantial population increases by 2050. Supplies used to irrigate the urbanized acreage could be considered a new municipal supply if the associated water rights were changed to municipal uses. To estimate this new supply, the average consumptive use of the urbanized acreage by Planning Scenario is reflected in Table 17. Note however, it is not known which farms and ranches will be directly impacted; whether the acreage was served by senior/junior direct rights or had supplemental storage supplies; or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use, or whether the supply could directly meet the future municipal demand or would require exchange potential. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 17: Potential Water Supply from Urbanized Acreage in the Gunnison River Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage	14,600	14,600	14,600	14,600	14,600
Estimated Consumptive Use (ac-ft/year)	30,276	30,271	33,090	31,636	33,011

The Gunnison River Basin benefits from the delivery of a small amount of imported transbasin supplies including:

- Leon Tunnel Canal imports water from the Colorado River Basin to Surface Creek for irrigation.
- Mineral Point Ditch and Red Mountain Ditch imports water from the Southwest Basin to high mountain irrigation in the headwaters of the Uncompahgre River.

Ideally the import supply gap in the Baseline scenario would be zero; however the Baseline dataset represents current agricultural and M&SSI demands over the entire model period which can result in minor shortages to junior water rights, including transbasin diversions. With this in mind, the incremental increase in the import gap reflects the increase in gap due to the Planning Scenario adjustments.

Under current hydrology conditions, there was no increase in the gap for the Business as Usual and Weak Economy scenarios. The increased demands and changed hydrology in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios however resulted in more substantial gaps during critically dry years. If exports stay the same in the future, the reported import gaps could increase the total Gunnison River basin M&SSI gaps in these scenarios.

Table 18: Summary of Transbasin Imports to the Gunnison River Basin

	Transbasin Import Supply Gap Results	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Import Supply (ac-ft)	1,711	1,711	1,711	1,711	1,711	1,711
	Average Annual Import Supply Gap (ac-ft)	1	1	1	24	34	40

	Average Annual Import Supply Gap Increase from Baseline (ac-ft)	-	0	0	24	33	40
	Average Annual Import Supply Percent Gap	0%	0%	0%	1%	2%	2%
Critically Dry Maximum	Import Supply In Maximum Gap Year (ac-ft)	2,455	2,455	2,455	2,082	2,082	2,082
	Import Supply Gap In Maximum Gap Year (ac-ft)	15	15	15	216	368	368
	Increase from Baseline Import Supply Gap (ac-ft)	-	0	0	201	353	353
	Import Supply Percent Gap In Maximum Gap Year	1%	1%	1%	10%	18%	18%

As shown in Figure 46, the Gunnison River Basin has just under 1,400,000 ac-ft of storage. The largest reservoirs are:

- Aspinall Unit, including Blue Mesa Reservoir and smaller reservoirs impounded by Morrow Point Dam, and Crystal Dam
- Taylor Park Reservoir
- Ridgway Reservoir

The Aspinall Unit accounts for about a million ac-ft of the total storage in the basin, with the primary purpose of storing water for the Upper Colorado River Basin states. Secondary purposes include hydropower, delivery of irrigation supplies to the Uncompahgre Project via the Gunnison Tunnel, flood control, and maintaining flows for fish habitat. Blue Mesa Reservoir is the primary operational reservoir in the unit; storage in the two downstream reservoirs does not fluctuate much and used more to re-regulate flows. Due to the size of the Blue Mesa Reservoir, the results in the following graphic largely reflect the simulated reservoir operations of this reservoir. Taylor Park Reservoir is operated for supplemental irrigation water to the Uncompahgre Project and replacement water for irrigation in the Upper Gunnison River basin. Reservoir storage in Taylor Park is heavily used, especially in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios. Ridgway Reservoir provides supplemental irrigation water, but only about half of the reservoir is allocated to consumptive uses. The remaining half of the reservoir is either inactive storage or maintained for recreational purposes. Other reservoirs in the basin, including Paonia, Crawford, Silverjack, Gould, Overland and Fruit Growers, are primarily used for irrigation. These irrigation reservoirs generally fill and release their full contents annually with limited carry-over storage, however many of these reservoirs are unable to fill during dry years under the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios

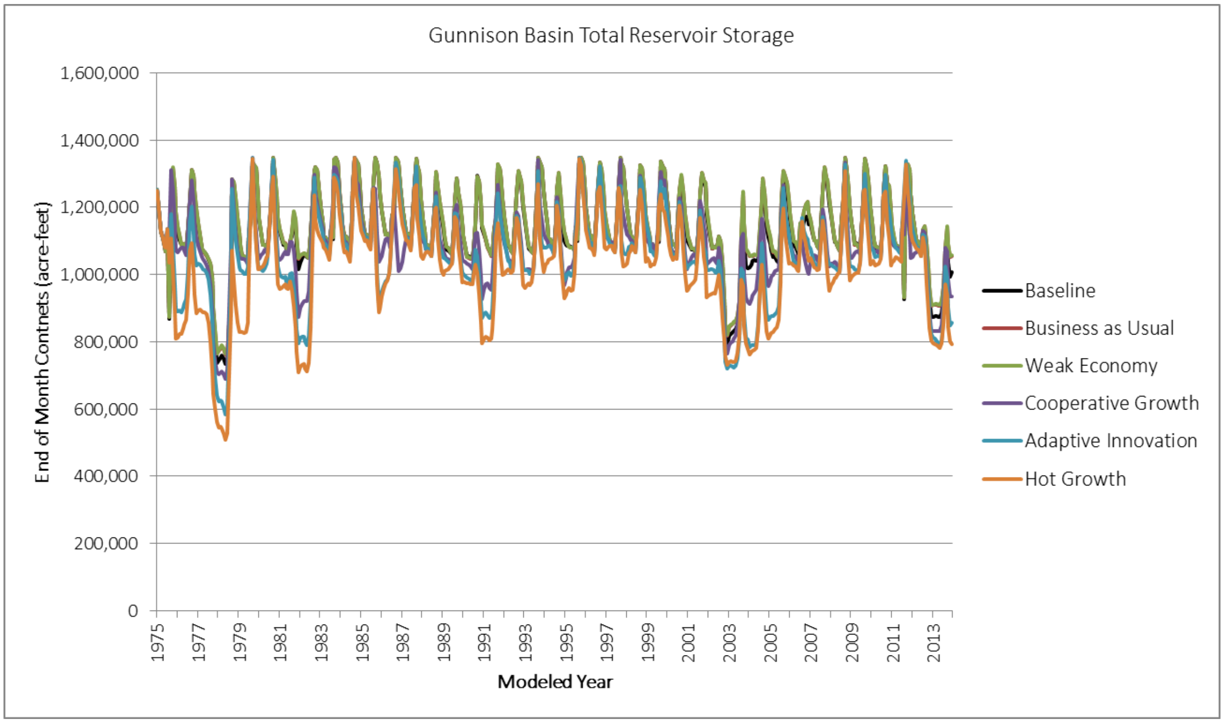


Figure 46: Gunnison River Basin Total Reservoir Storage

The following figures reflect average monthly simulated streamflow at key locations across the basin; refer to Figure 38 for the locations of the gages. The primary driver of average monthly simulated streamflow across the Planning Scenarios is hydrology. The average monthly streamflow results from Baseline, Business as Usual, and Weak Economy scenarios are often indistinguishable from each other because they use current hydrology. In several locations, the results are overlapping. The In-Between hydrology featured in the Cooperative Growth scenario and the Hot and Dry hydrology featured in the Adaptive Innovation and Hot Growth scenarios consistently reduce late season flows across the basin and, in many areas, shift the peak streamflow earlier in the year.

There are limited diversions to agriculture located upstream of the Tomichi Creek at Sargents gage and the average monthly streamflow generally reflects near-natural flow conditions. The In-Between hydrology projects slightly more water than current hydrology in April and May, but significantly less water in June and July. The Hot and Dry hydrology also projects slightly more water in April, but less water in all other months. This projected decline in streamflow causes the agricultural gaps, primarily in late season irrigation demands, in the scenarios that use the climate projections.

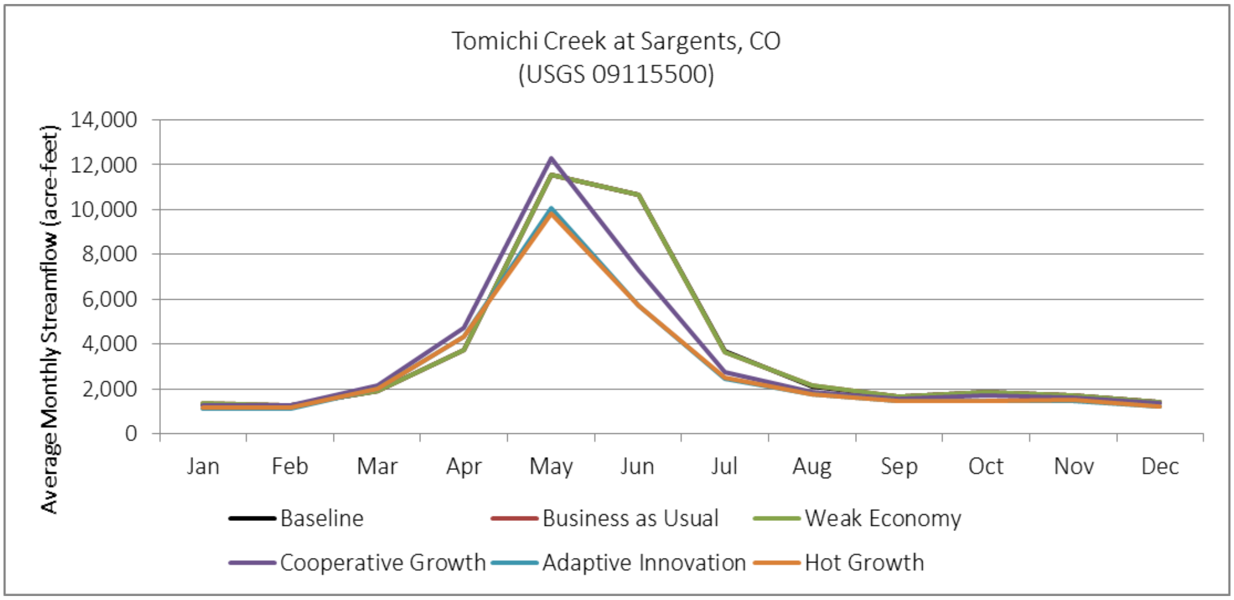


Figure 47: Average Monthly Streamflow for Tomichi Creek at Sargents

The Gunnison River near Gunnison gage is located downstream of Taylor Park Reservoir and a substantial amount of agricultural demand. The Business as Usual and Weak Economy scenarios have slightly more projected streamflow than the Baseline scenario due the reduction in upstream agricultural demand in these scenarios, but in general, mirror the results from the Baseline scenario. A drastic shift in streamflow is projected for the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios. The peak is shifted from June to May and the peak flow volume is slightly higher than the Baseline scenario flows. However, the annual flow volume is less than the Baseline scenario because of the streamflow decline in most other months. The projected decrease in late season streamflow is the primary cause of the increased agricultural gaps in these climate-adjusted scenarios.

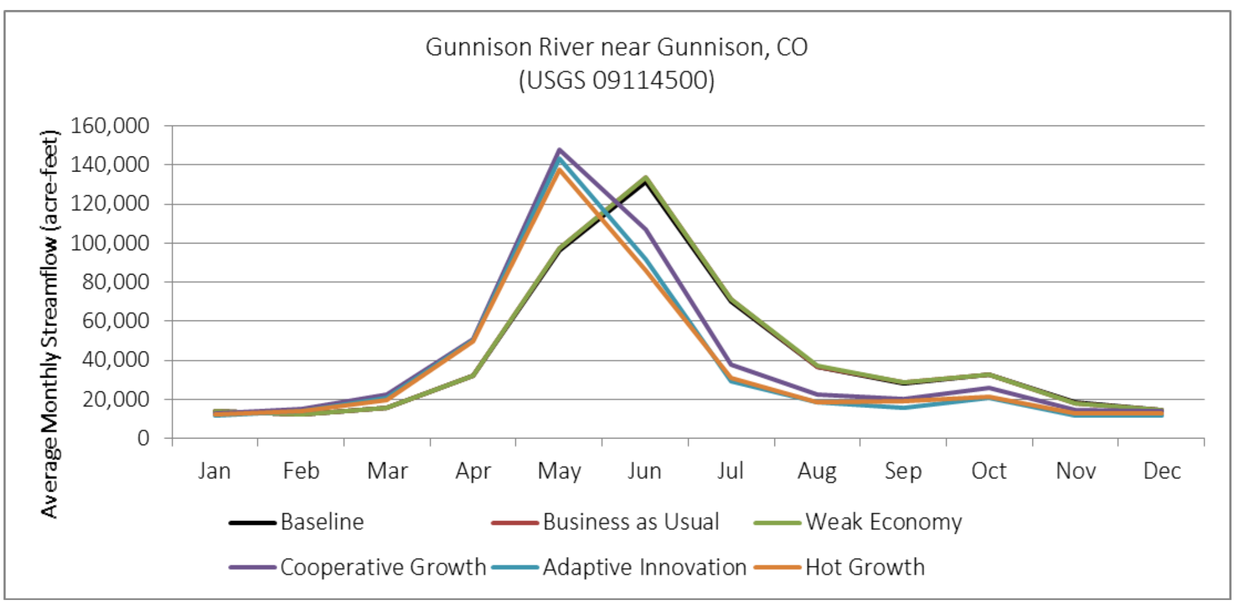


Figure 48: Average Monthly Streamflow for the Gunnison River near Gunnison

The Uncompahgre River at Colona gage is downstream of Ridgway Reservoir and some agricultural demand, but upstream of the majority of the Uncompahgre Project area. The Cooperative Growth, Adaptive Innovation and Hot Growth scenarios are projected to have muted runoff responses in May and June and significantly reduced flows during the late irrigation season. Annual streamflow is projected to experience a 20 percent decline on average in the Cooperative Growth scenario and a 30 to 33 percent decline on average in the Adaptive Innovation and Hot Growth scenarios, respectively.

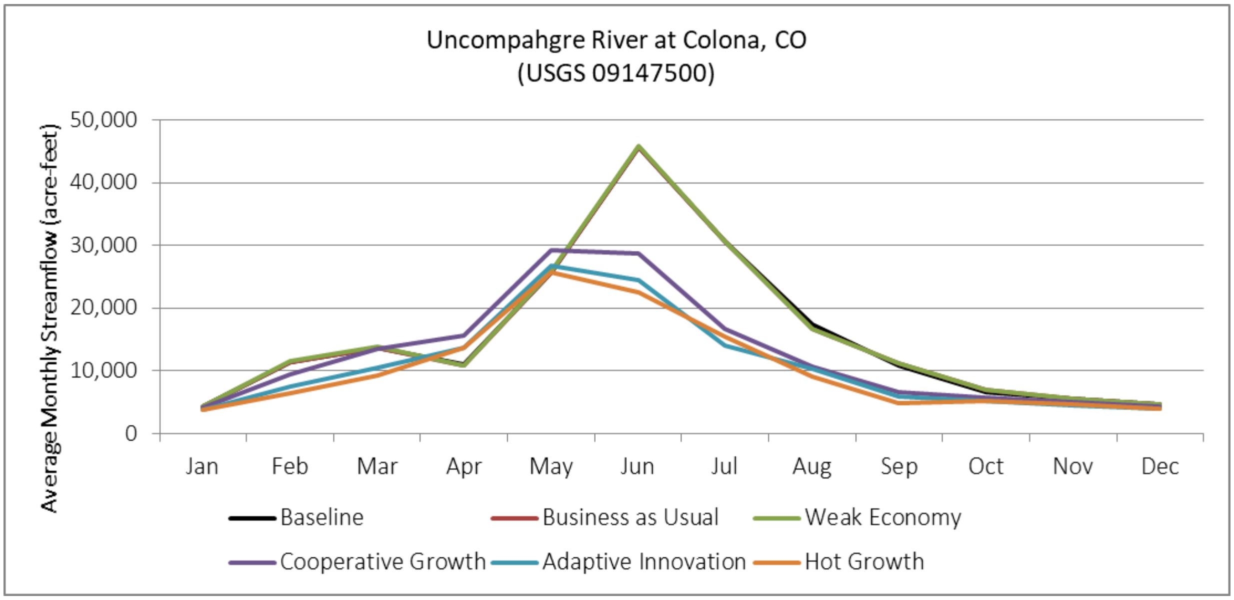


Figure 49: Average Monthly Streamflow for the Uncompahgre River at Colona

The Gunnison River near Grand Junction gage is near the bottom of the river, and provides an estimate of the amount of water that flows into the Colorado River. Streamflow results at the gage reflects the cumulative effect of changed agricultural and M&SSI demands, and climate-adjusted hydrology in the entire Gunnison River basin for each scenario. Overall, the scenarios project similar results for winter and springs months. Larger differences are projected for the late irrigation season, with the climate-adjusted scenarios reflecting a substantial decline in flows. This is consistent with the streamflow results discussed above, and indicates an overall decline on average of late irrigation season flows.

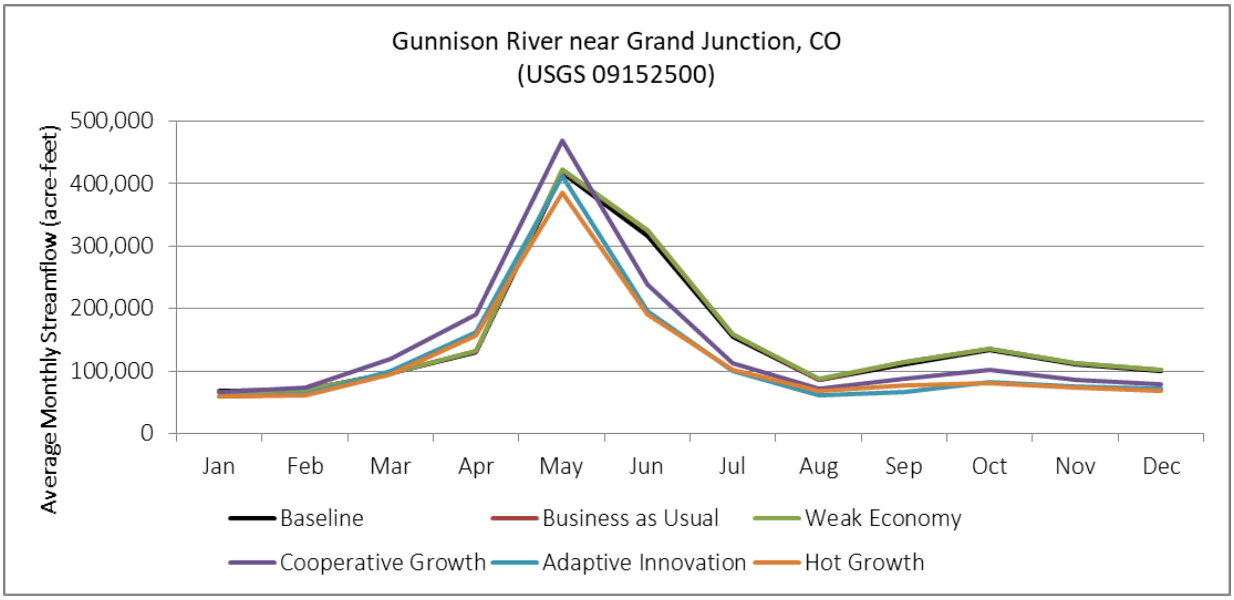


Figure 50: Average Monthly Streamflow for the Gunnison River near Grand Junction

Figure 51 and Figure 52 reflect simulated unappropriated available supply in the Gunnison River at a location downstream of the Aspinall Unit and Gunnison Tunnel diversion but upstream of the Redlands Canal, which is the primary calling right in the lower basin. The canal diverts for power and irrigation, and return flows accrue to the Colorado River Basin, reflecting a total depletion to the Gunnison River. Streamflow, and by extension unappropriated available flow, is heavily influenced by storage and releases from the Aspinall Unit and Gunnison Tunnel diversions located upstream. As reflected on the graphics, there is generally unappropriated streamflow available in the Business as Usual and Weak Economy scenarios except during critically dry years, when no unappropriated flow is available. Unappropriated available supplies are still available in the climate-adjusted Planning Scenarios, but the average volumes are substantially reduced and shifted earlier in the year. The figures reflect that unappropriated streamflow is available at these locations, but the magnitude and timing vary substantially annually and across the hydrologic year types.

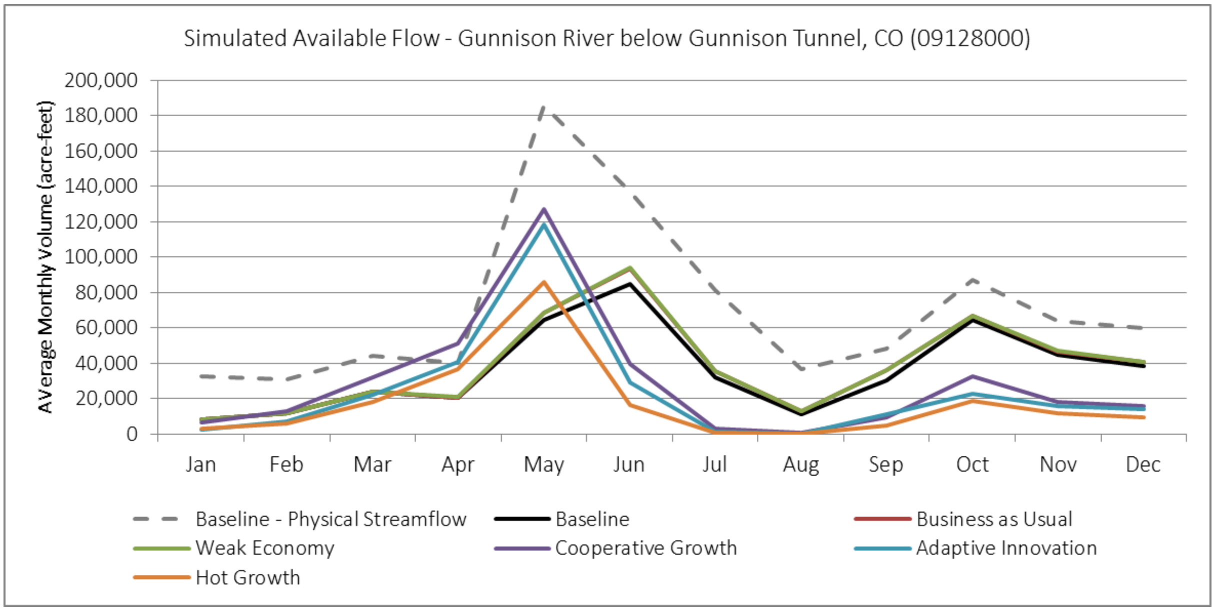


Figure 51: Average Monthly Unappropriated Available Supply at Gunnison River below Gunnison Tunnel

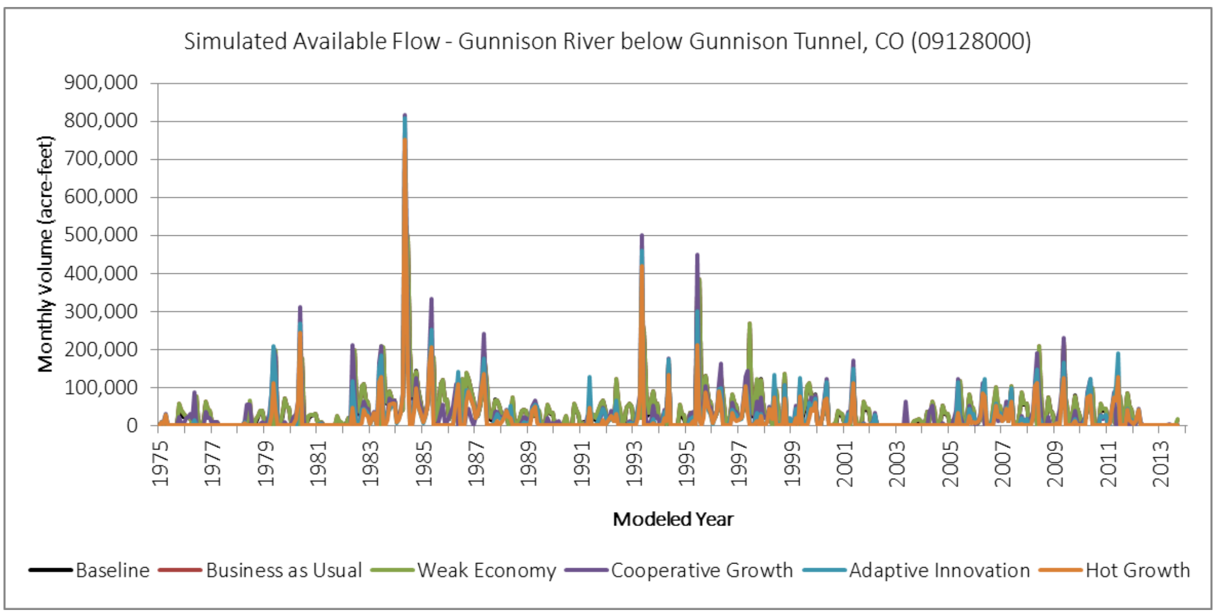


Figure 52: Monthly Unappropriated Available Supply at Gunnison River below Gunnison Tunnel

5.4 NORTH PLATTE RIVER BASIN

Irrigation of high mountain meadows for ranching operations is the largest use of water in the North Platte River basin, accounting for nearly all of total basin demands. 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. Water used for M&SSI and transbasin diversions is limited in the basin relative to agricultural use, constituting less than 1 percent of the total demand in the basin.

The following sections describe the agricultural, M&SSI, and transbasin export demands in the North Platte River basin in more detail. Figure 53 reflects the basin outline, the administrative boundaries of water districts, and the streamflow gages highlighted in the results section below.

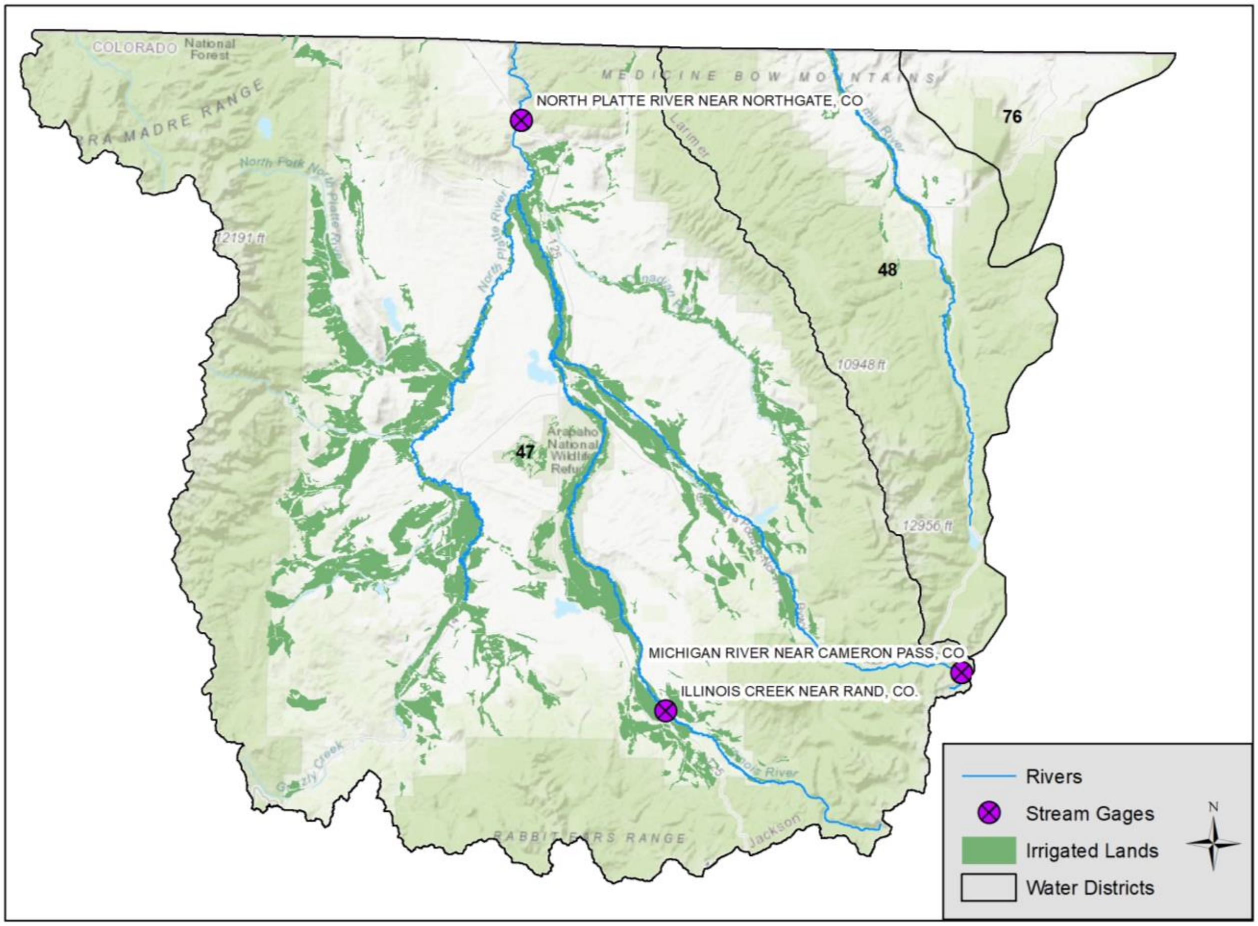


Figure 53: North Platte River Map with Streamgage Locations

5.4.1 NORTH PLATTE RIVER BASIN AGRICULTURE WATER SUPPLY AND GAP

Grass and hay are the primary crops grown in the basin to support numerous calf/cow operations. Irrigators rely on runoff from the snowpack in the late spring and early summer to flood their fields. Relative to the agricultural demand, there is limited storage[9] available to supplement irrigation supplies after the runoff is over. With limited access to supplies later in the irrigation season, irrigators will generally begin to dry out fields for the first hay cutting in late June or early July, and then many choose not to continue irrigating later in the season for a second cutting.

These irrigation practices are not explicitly reflected in the Technical Update models (i.e. the models did not stop allocating water to meet the agricultural demand every year in mid-July). This modeling assumption was made because these current irrigation practices may not be appropriate or continued in the future if climatic, hydrological, or economic conditions in the basin change by 2050. The results

[9] The Equitable Apportionment Decree limits storage for irrigation purposes to 17,000 ac-ft annually in the basin

summarized below reflect the full season agricultural diversion demand; modeled water supplies as if irrigators continued to irrigate as long as water is physically and legally available; and the resulting agricultural gap.

The North Platte River Basin agricultural diversion demands, demand gaps, and consumptive use gap results for the baseline and Technical Update Planning Scenarios are presented in Table 19 and reflected graphically in Figure 54 and Figure 55. As discussed in the *Current and 2050 Planning Scenario Agricultural Diversion Demand* technical memorandum, 2050 agricultural diversion demands are influenced by a number of drivers, including climate, urbanization, planned agricultural projects, and emerging technologies.

Table 19: North Platte River Basin Agricultural Water Supply and Gap Summary

	Agriculture Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	529,204	602,431	602,431	688,308	502,345	733,493
	Average Annual Demand Increase from Baseline (ac-ft)	-	73,227	73,227	159,105	-	204,289
	Average Annual Gap (ac-ft)	85,733	107,962	107,937	177,854	168,136	231,084
	Average Annual Gap Increase from Baseline (ac-ft)	-	22,228	22,204	92,120	82,402	145,351
	Average Annual Percent Gap	16%	18%	18%	26%	33%	32%
	Average Annual CU Gap (ac-ft)	40,308	50,845	50,833	83,584	91,997	108,494
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	521,572	582,442	582,442	659,426	494,854	693,975
	Increase from Baseline Demand (ac-ft)	-	60,870	60,870	137,854	-	172,403
	Gap In Maximum Gap Year (ac-ft)	296,925	336,720	336,654	394,815	320,762	440,981
	Increase from Baseline Gap (ac-ft)	-	39,795	39,729	97,890	23,837	144,055
	Percent Gap In Maximum Gap Year	57%	58%	58%	60%	65%	64%

As reflected in the table, irrigators in the basin currently experience a relatively small agricultural gap on average. Considering the irrigation practice discussion above, water users and stakeholders in the basin may consider the average agricultural gap to be over-estimated (i.e. there is not a late season gap if irrigators choose not to irrigate). The current agricultural gap in a critically dry year with low snowpack levels and extremely limited irrigation supplies, however, is substantially greater.

The average annual agricultural demand increases from the Baseline to the Business as Usual and Weak Economy Planning Scenarios by approximately 73,000 ac-ft due to the addition of approximately 10,600 irrigated acres in these scenarios for planned agricultural projects in the basin. The additional acreage leads to an average increase to the agricultural gap of approximately 22,000 ac-ft, indicating the new planned agricultural projects may expect to see an agricultural gap of nearly 30 percent on average in 2050 if developed under the Business as Usual and Weak Economy Planning Scenario conditions.

Results for the Cooperative Growth Planning Scenario incorporate the additional acreage for planned agricultural projects as well as an increase in agricultural demand due to climate change adjustments to IWR and climate-adjusted hydrology associated with the projected In-Between climate conditions. Climate adjustments to IWR in the Cooperative Growth Planning Scenario lead to an increase of nearly 86,000 ac-ft of agricultural demand compared to the Business as Usual and Weak Economy scenarios. Climate adjustments to hydrology shift in the peak runoff, on average, from June to May and reduce the amount of late season supplies. The combined impact of these adjustments is an increase of 70,000 ac-ft of agricultural gap compared to the Business as Usual and Weak Economy scenarios on average.

For the Adaptive Innovation scenario, which includes the additional acreage for planned agricultural projects and a slight decrease in acreage due to urbanization, the average annual demand is approximately 5 percent less than the Baseline demand. In this scenario, emerging technologies are assumed to mitigate approximately 10 percent of the increase in IWR due to projected Hot and Dry climate conditions as well as increase irrigation system efficiency by 10 percent, which results in an overall net decrease in agricultural demand. Despite the reduced agricultural demand, the agricultural gap actually increases by approximately 82,000 ac-ft compared to the Baseline Scenario primarily due to the shifting of the peak runoff month associated with the projected hydrology under the Hot and Dry climate conditions.

The Hot Growth scenario reflects the largest agricultural demand and the largest agricultural gap, driven by the full impact of the projected Hot and Dry climate conditions. In this scenario, the agricultural demand is approximately 204,000 ac-ft greater than the Baseline agricultural demand on average, however approximately 145,000 ac-ft or 70 percent of the increased demand is shorted in the Hot Growth scenario due the climate-adjusted hydrology. The agricultural gap is over 440,000 ac-ft in critically dry years, or 64 percent of the total agricultural demand in the same year. The following figures reflect the agricultural demand and gap on average and in a critically dry year, relative to the demand and across Planning Scenarios.

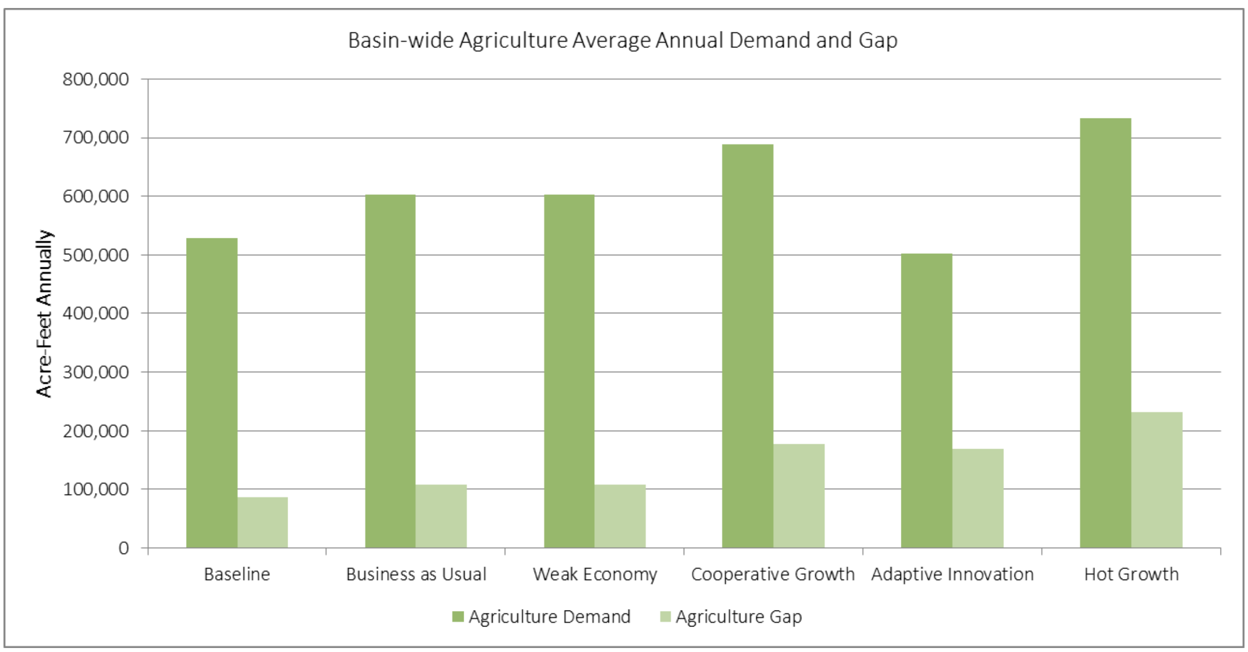


Figure 54: North Platte River Basin Agriculture Average Annual Demand and Gap

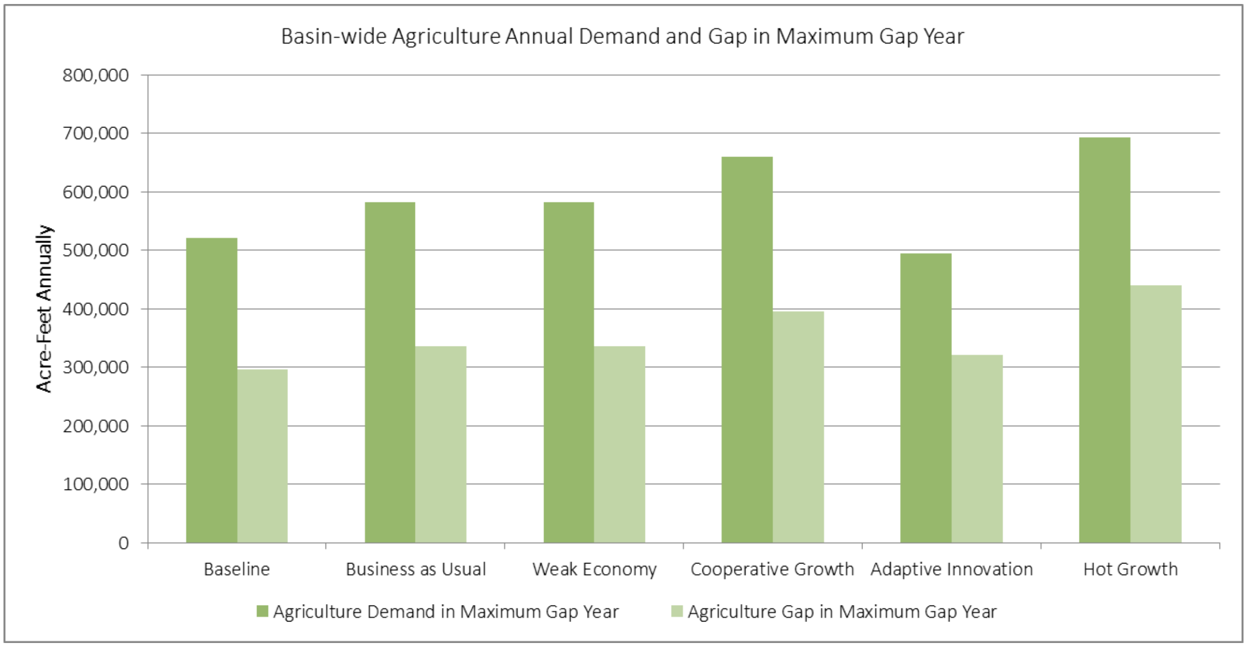


Figure 55: North Platte River Basin Agriculture Annual Demand and Gap in Maximum Gap Year

As reflected in Figure 56, the agricultural gap varies annually based on the demand and the available water supplies in the basin. With only the planned agricultural projects differentiating the Baseline, Business as Usual, and the Weak Economy scenarios, the agricultural gaps are very similar over the study period and the lines on the graph are overlapping. The wet hydrology years of the mid-1980s and the late 1990s reflect minimal shortages across all scenarios, with minimal impacts of the climate adjustments. The average to below average hydrology years from 2004 to 2009 reflect separation between the Baseline agricultural gap and the gaps in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios due to the reduction in already limited water supplies. In the critically dry years of 2002 and 2012, only the irrigators with the most senior water rights are able to divert the limited supplies, regardless of climate-adjusted hydrology and the agricultural gaps are similar across all the Planning Scenarios.

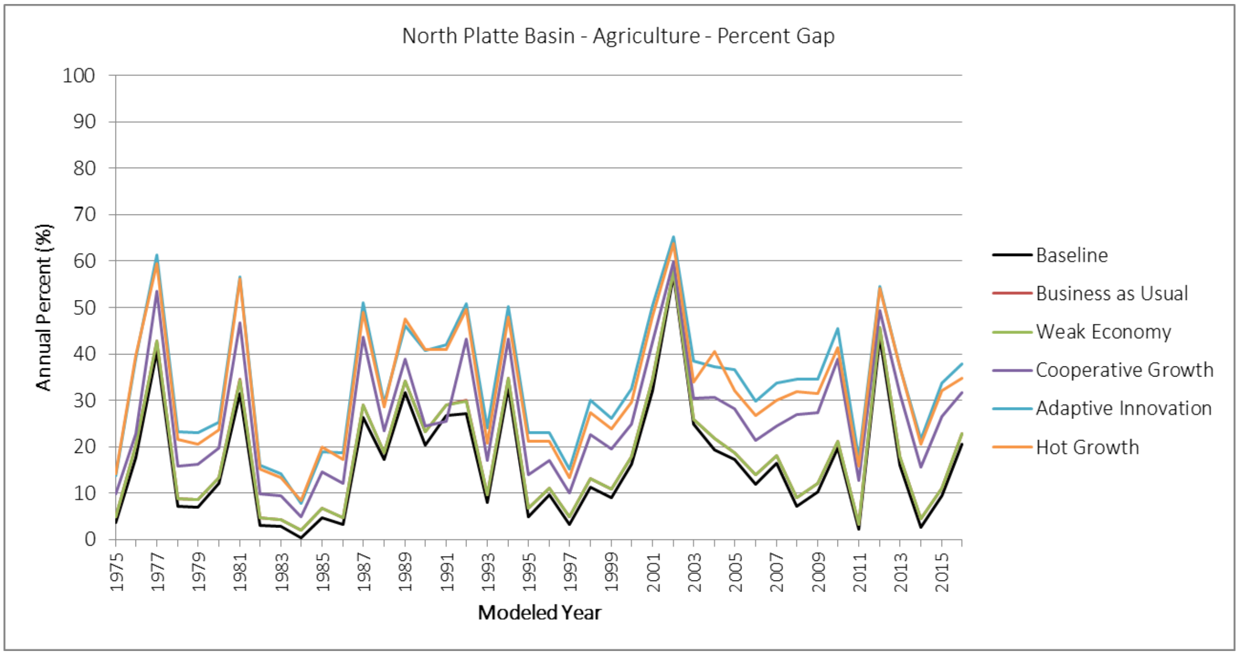


Figure 56: North Platte River Basin Agriculture Percent Diversion Gap Times Series

5.4.2 NORTH PLATTE RIVER BASIN M&SSI WATER SUPPLY AND GAP

A majority of the M&SSI demands in the North Platte River basin are grouped and represented at several general locations throughout the model, with only the Town of Walden's demands and surface water rights modeled individually. The M&SSI demands in the basin are low compared to the agricultural demand, reflecting less than 1 percent of the total demand in the basin. Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin were developed. The water supply and gap results for M&SSI in the North Platte River basin are summarized in

Table 20, and graphically reflected in Figure 57 through Figure 59.

Table 20: North Platte River Basin M&SSI Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	402	369	311	345	382	458
Average	Average Annual Demand Increase from Baseline (ac-ft)	-	-	-	-	-	56
Average	Average Annual Gap (ac-ft)	0	0	0	1	2	21
Average	Average Annual Gap Increase from Baseline (ac-ft)	-	-	-	1	2	20
Average	Average Annual Percent Gap	0%	0%	0%	0%	1%	5%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	402	369	311	345	382	458
Critically Dry Maximum	Increase from Baseline Demand (ac-ft)	-	-	-	-	-	56
Critically Dry Maximum	Gap In Maximum Gap Year (ac-ft)	17	15	13	13	18	45
Critically Dry Maximum	Increase from Baseline Gap (ac-ft)	-	-	-	-	1	28
Critically Dry Maximum	Percent Gap In Maximum Gap Year	4%	4%	4%	4%	5%	10%

The M&SSI demand in the basin is projected to decrease in all but the Hot Growth scenarios compared to the Baseline scenario. This projection correlates to population levels that are expected to remain the same or decline by 2050 in the basin in all but the Hot Growth scenario. Population growth in the Hot Growth scenario is modest, with an increase in demand of just over 10 percent compared to the Baseline demand level.

As reflected in the table, the M&SSI demand is fully or nearly satisfied on average in all but the Hot Growth scenario. The demands, however, experience a 4 to 5 percent shortage during critically dry years. Ideally these scenarios would have no M&SSI gaps because the current conditions in the basin should fully satisfy the Baseline demand levels. These shortages are likely due to minor calibration issues stemming from the representation of individual M&SSI demands at a grouped location drawing only from surface water supplies, and not accounting for ground water supplies (i.e. exempt wells) or dispersion of the demands across several tributaries.

The larger M&SSI gap experienced in the Hot Growth scenario may be more indicative of chronic shortages in 2050, as reflected in Figure 59. Gaps tend to range between 2.5 and 10 percent for the full study period, and are caused by climate-adjusted hydrology on smaller tributaries (e.g. Illinois Creek, Canadian River) as opposed to the increase in demand under the Hot Growth scenario.

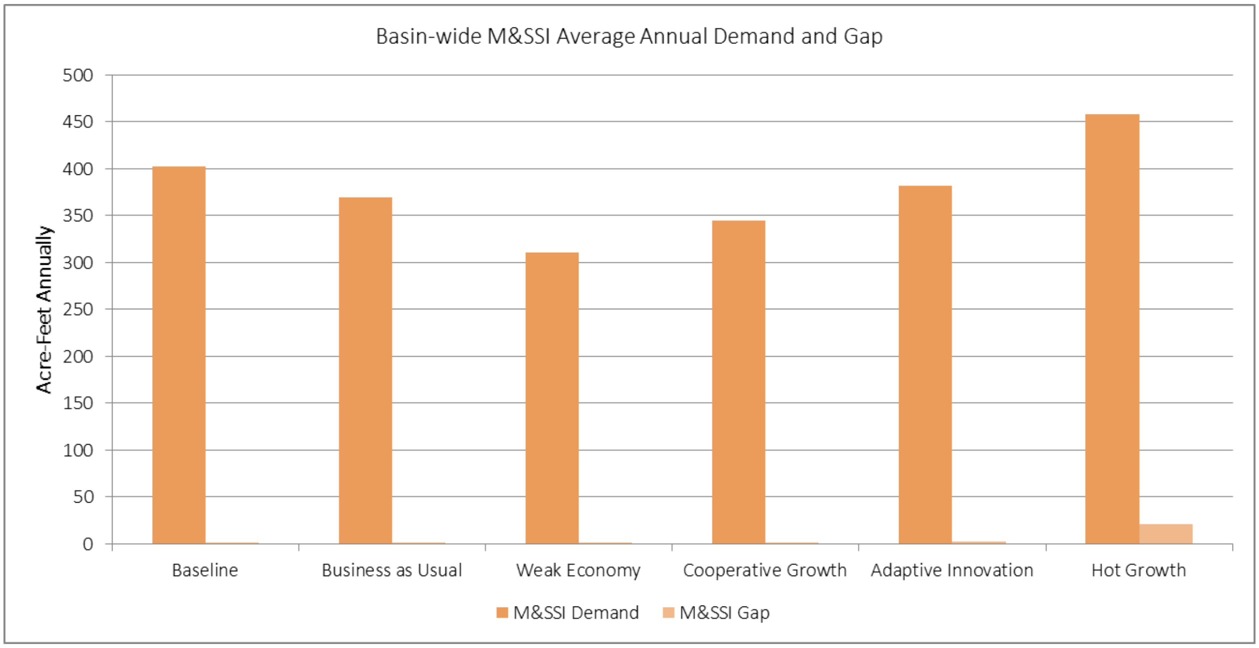


Figure 57: North Platte River Basin M&SSI Average Annual Demand and Gap

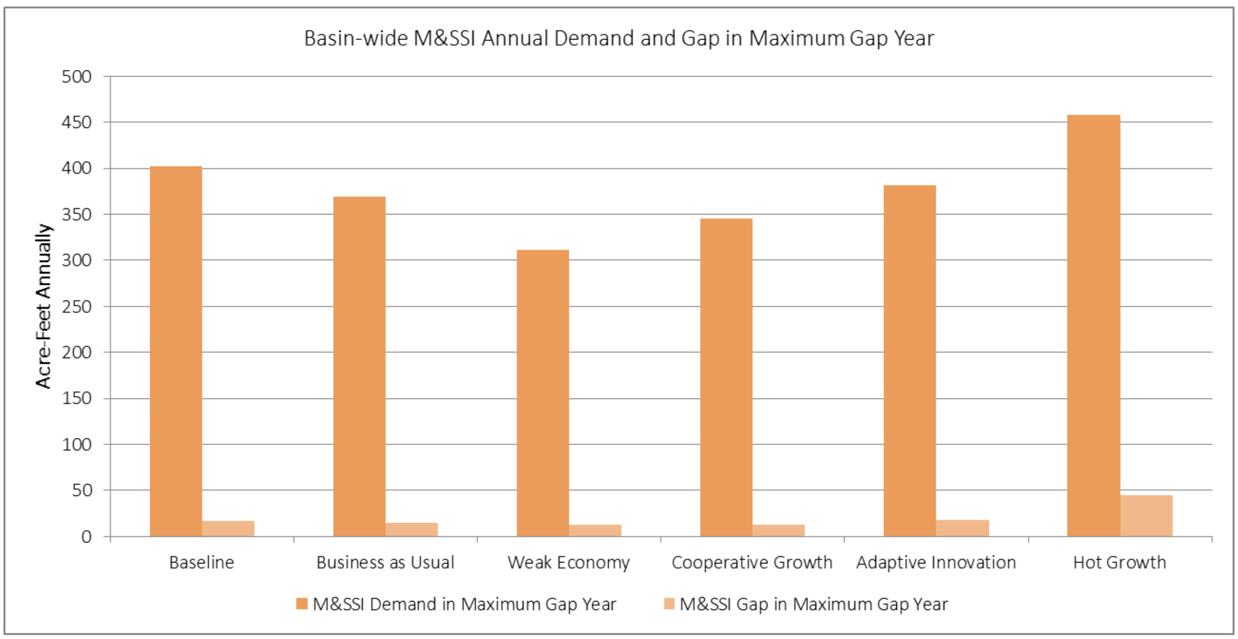


Figure 58: North Platte River Basin M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

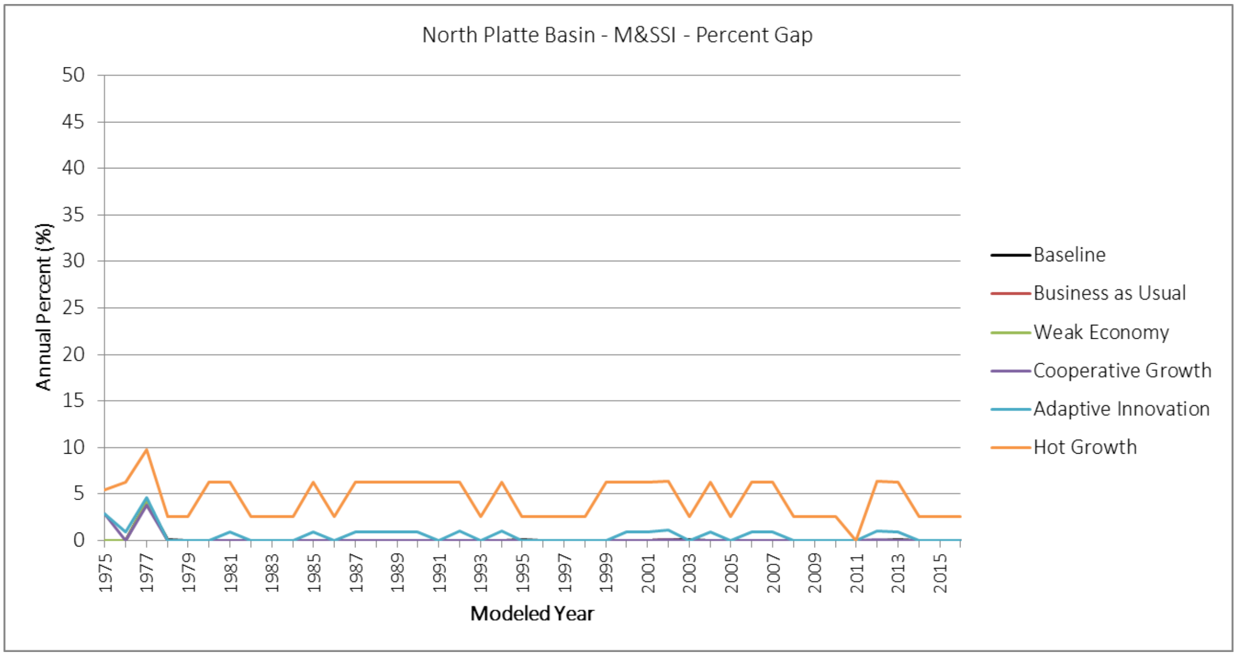


Figure 59: North Platte River Basin M&SSI Average Annual Gap Time Series

5.4.3 NORTH PLATTE RIVER BASIN TRANSBASIN EXPORT DEMAND

There are two transbasin diversions that export water from the Michigan River to the South Platte River basin: Michigan Ditch and Cameron Pass. Transbasin exports range from less than 500 ac-ft to over 6,500 ac-ft annually, depending on availability of in-basin supplies and the need for imported supplies in the South Platte River basin. On average, the transbasin export demand from the North Platte River Basin is 3,265 ac-ft. Note that the transbasin export demand is set to historical levels and the same across all Planning Scenario. These demands could not be satisfied in all Planning Scenarios; however the shortages are reflected as an import supply gap in the destination basin and not considered a gap in the North Platte River basin.

5.4.4 NORTH PLATTE RIVER BASIN SUMMARY

The combined agriculture and M&SSI demands and gap summary is provided in Table 21. The results are very similar to the agricultural results in Table 19, because water supplies in the North Platte River basin are predominantly used for agriculture. As previously discussed, gaps during average years are relatively low in the Baseline, Business as Usual and Weak Economy scenario, particularly considering late season irrigation practices. Gaps during critically dry years, which tend to occur at least once every ten years, are much larger. The gaps increase in the Cooperative Growth and the Adaptive Innovation scenarios as a result of increasing demands and the shift to the peak runoff. The gaps both on average and during critically dry years are largest in the Hot Growth scenario, due to the increased demands and decreased hydrology from the climate projections.

Figure 60 reflects the relative size of the agricultural, M&SSI, and transbasin demands in the North Platte River basin. The M&SSI and transbasin demands are difficult to reflect graphically on the same scale because they are significantly smaller than the agricultural demands. Following the graphic are summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage.

Table 21: North Platte River Basin Water Supply and Gap Summary

	Agriculture and M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	529,606	602,800	602,742	688,653	502,727	733,951
	Average Annual Gap (ac-ft)	85,734	107,962	107,937	177,855	168,138	231,105
	Average Annual Percent Gap	16%	18%	18%	26%	33%	31%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	521,974	582,811	582,753	659,771	495,236	694,433
	Gap In Maximum Gap Year (ac-ft)	296,942	336,735	336,667	394,828	320,780	441,025
	Percent Gap In Maximum Gap Year	57%	58%	58%	60%	65%	64%

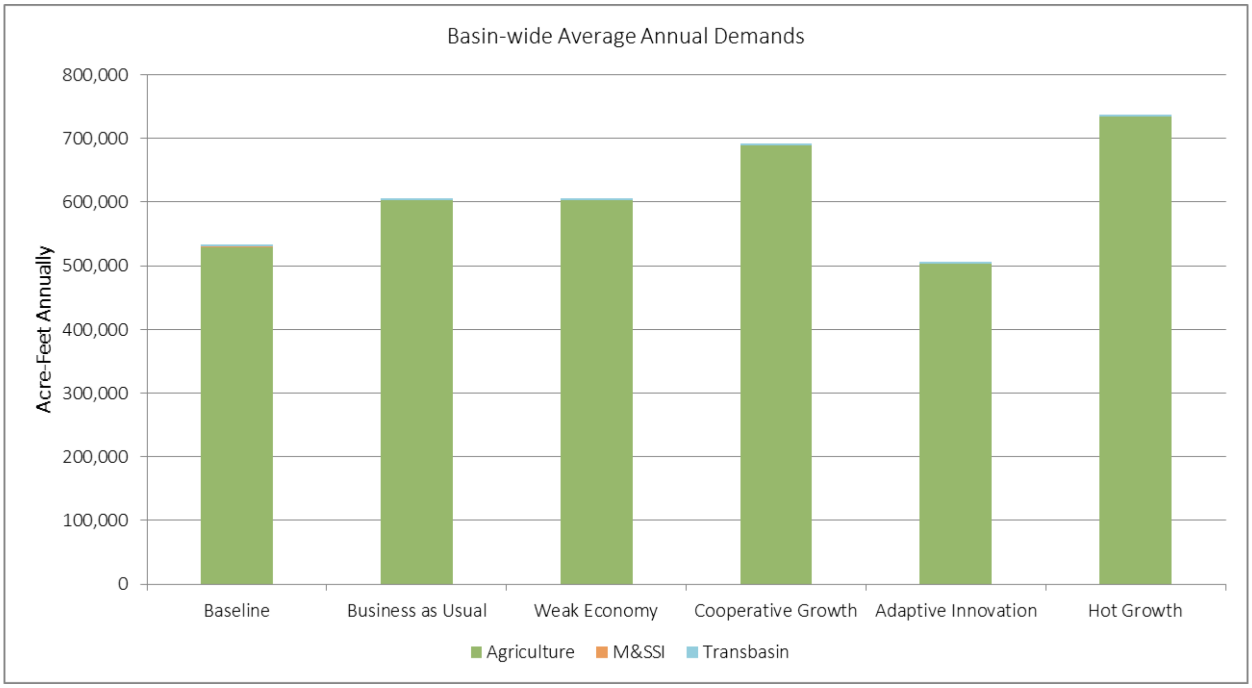


Figure 60: North Platte River Basin Comparison of Average Annual Demands

The Adaptive Innovation and Hot Growth scenarios project 40 acres of irrigated land will be taken out of production due to urbanization as the counties experience municipal growth. Supplies used to irrigate the urbanized acreage could be considered a new municipal supply if the associated water rights were changed to municipal uses. To estimate this new supply, the average consumptive use of the urbanized acreage by Planning Scenario is reflected in Table 22. Note however that it is not known which farms and ranches will be directly impacted; whether the acreage was served by senior/junior direct rights or had supplemental storage supplies; or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use or whether the supply could directly meet the future municipal demand or would require exchange potential. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 22: Potential Water Supply from Urbanized Acreage in the North Platte River Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage	-	-	-	40	40
Estimated Consumptive Use (ac-ft/year)	-	-	-	46	50

The North Platte River basin has approximately 30,000 ac-ft of total storage[10], and approximately half of that storage is used to meet agricultural demands. The remaining half of storage in the basin can be attributed to reservoir supplies owned by Colorado Parks & Wildlife, U.S. Fish and Wildlife, or other governmental entities. These supplies are generally kept in the reservoir in an effort to maintain minimum storage volumes; there are no active releases except to meet environmental demands (e.g. Arapaho National Wildlife Rufuge) in some years. Figure 61 reflects the simulated storage by month for the combined reservoirs in each Planning Scenario. The results reflect very little difference between the Baseline and the Planning Scenario results, primarily because the irrigation reservoirs in the basin generally fill and release supplemental irrigation supplies every year with limited carry-over storage. As the climate-adjusted hydrology shifted runoff volumes in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios, the graph reflects slightly more draw-down as compared to the Baseline scenario, but in general, storage across the entire basin is expected to operate at the same levels in all the Planning Scenarios.

[10] Reflects large operational reservoirs in Water District 47; excludes smaller reservoirs used primarily for recreational/piscatorial uses and reservoirs in Water Districts 48 and 76.

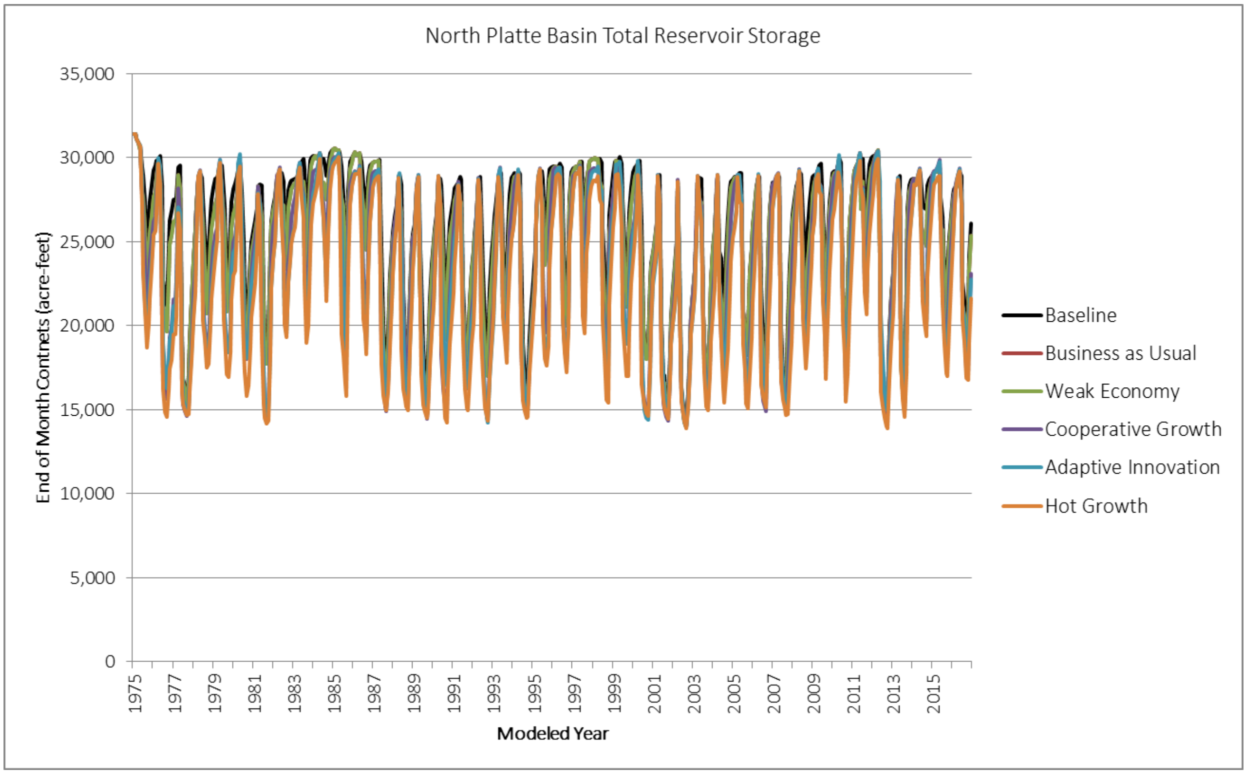


Figure 61: North Platte River Basin Total Reservoir Storage

The following figures show average monthly simulated streamflow at key locations across the basin, as reflected in Figure 53. The primary driver of average monthly simulated streamflow across the Planning Scenarios is hydrology, particularly because the demands were not significantly adjusted across the Planning Scenarios. The average monthly streamflow results from Baseline, Business as Usual, and Weak Economy scenarios are almost indistinguishable from each other because they use the current hydrology. In several locations, the lines graph directly on top of each other. The In-Between hydrology used in the Cooperative Growth scenario reflected a moderate change to total runoff volume, increasing in some areas and decreasing in others. The Hot and Dry hydrology used in the Adaptive Innovation and Hot Growth scenarios further reduces the amount of total runoff volume compared to the In-Between hydrology. This change in runoff is reflected in the Michigan River near Cameron Pass simulated streamflow graph (Figure 62), which is indicative of the supplies available to the transbasin diversions from the basin.

More impactful to the Planning Scenarios with climate-adjusted hydrology was the shift of the peak runoff earlier in the year, leading to the reduction in late irrigation season supplies. Using the Northgate gage (Figure 64) as an indicator of the total cumulative effect, the following can be observed:

- Peak runoff is occurring earlier than the peak irrigation season, therefore less streamflow is diverted for irrigation uses or stored in the soil reservoir during the early irrigation season. As such, the runoff remains in the river and eventually flows out of the basin in April and May at a greater volume than experienced in the Baseline scenario.
- Less streamflow is available during the later irrigation season, leading to increased agricultural gaps and reduced streamflow in June, July, and August compared to the Baseline scenario.

- A reduction in available water supplies and diversions also reduces the amount of lagged irrigation return flows that accrue to the river later in the season, further reducing streamflow during August and September compared to the Baseline scenario

The Illinois Creek near Rand simulated streamflow (Figure 63) reflects a similar impact from the climate-adjusted hydrology, albeit with substantially smaller streamflow volumes. With storage for irrigation purposes limited by the Equitable Apportionment Decree, opportunities to capture the earlier runoff are limited in the basin. Other alternatives to mitigate the impact of this potential future shift in runoff will need to be discussed among water users and stakeholders in the basin.

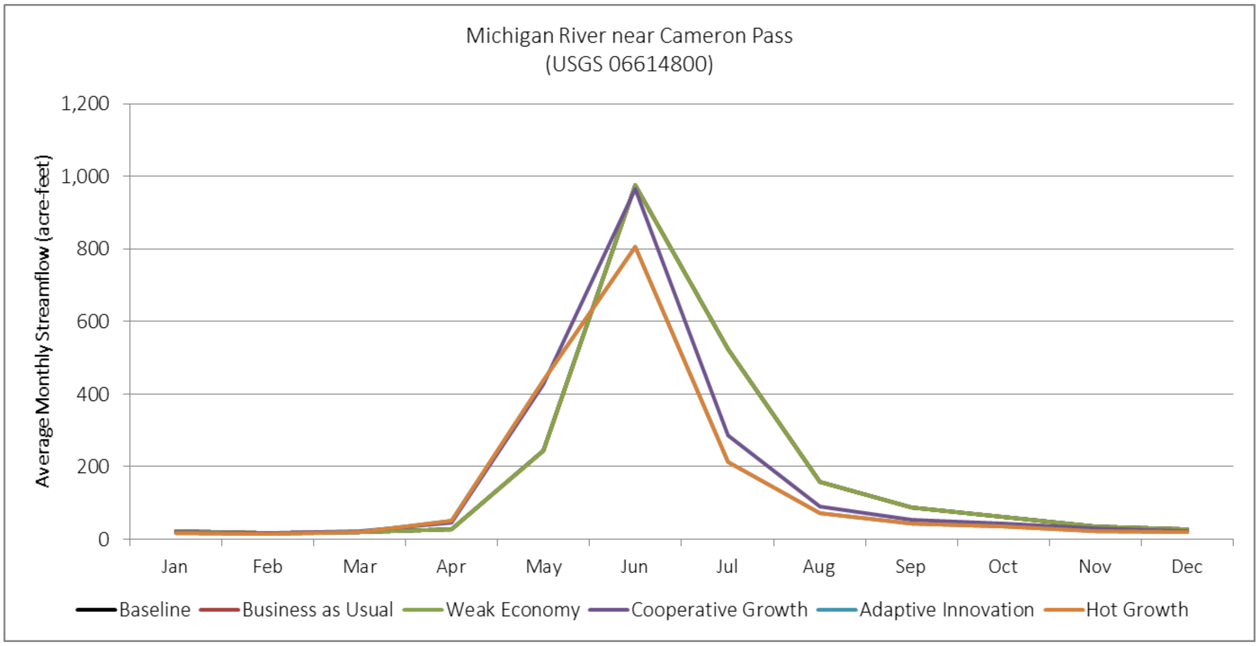


Figure 62: Average Monthly Streamflow for Michigan River near Cameron Pass

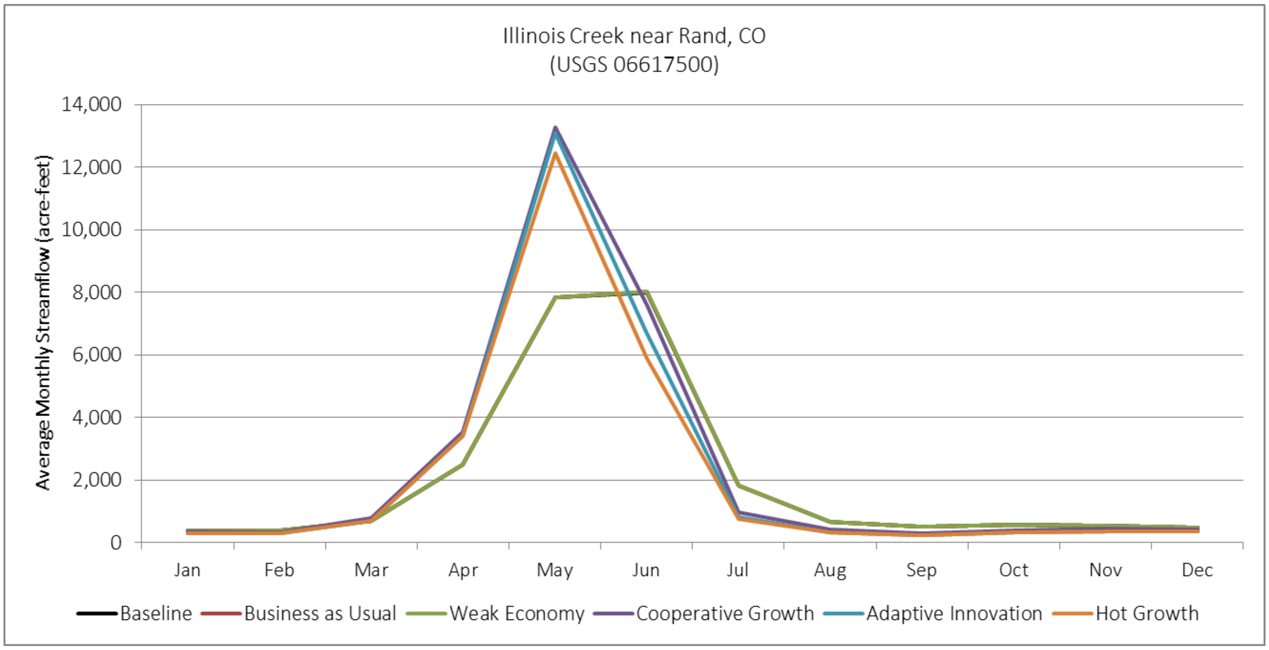


Figure 63: Average Monthly Streamflow for Illinois Creek near Rand

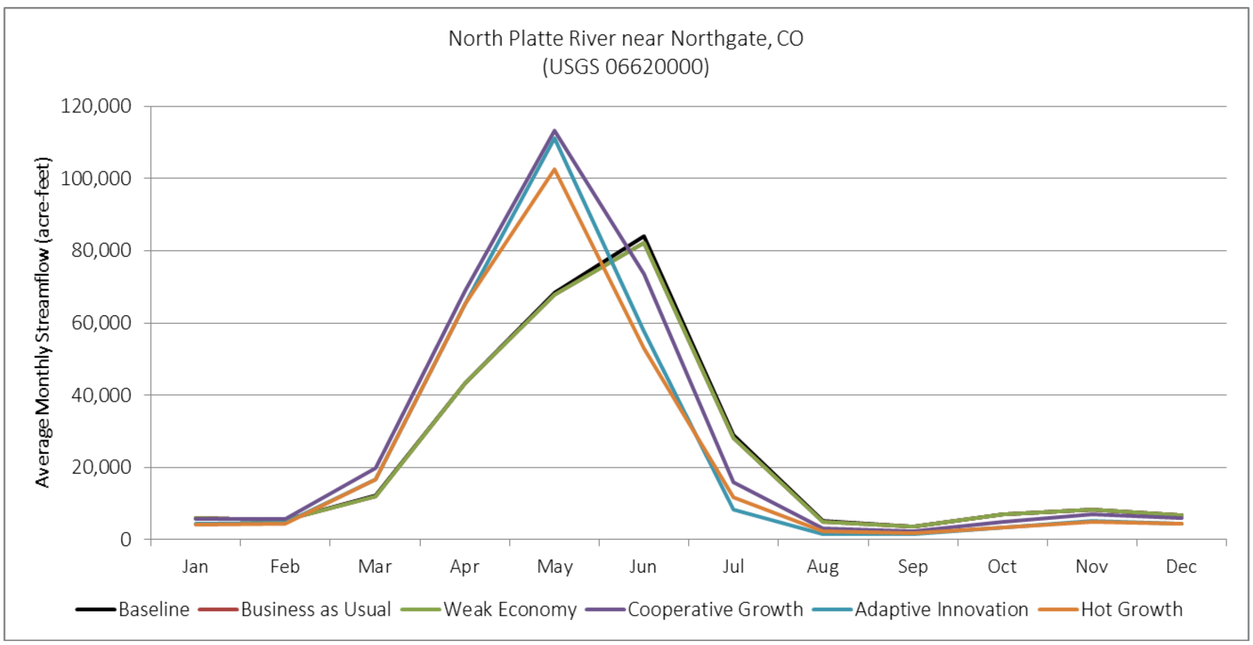


Figure 64: Average Monthly Streamflow for North Platte River near Northgate

Figure 65 and Figure 66 reflect simulated available flow at a location on the Lower Michigan River upstream of the confluence with the North Platte River. The location represents water availability upstream of the primary controlling rights on the tributary, which include the Hiho Ditch, Kiwa Ditch, and diversions to storage in Carlstrom Reservoir. Unappropriated flow availability is only moderately impacted by the calling rights. Flows are projected to be available in most years, except during critically dry years, but vary greatly on an annual basis. Peak flows are projected to increase at this location but could diminish in the late summer in climate-impacted scenarios. As discussed above, by shifting the timing of runoff in the climate-adjusted scenarios, substantially more water is projected to runoff in April and May. This, however, occurs prior to the peak irrigation demands and, without the ability to construct new storage, likely cannot be used to meet projected agricultural gaps in the basin.

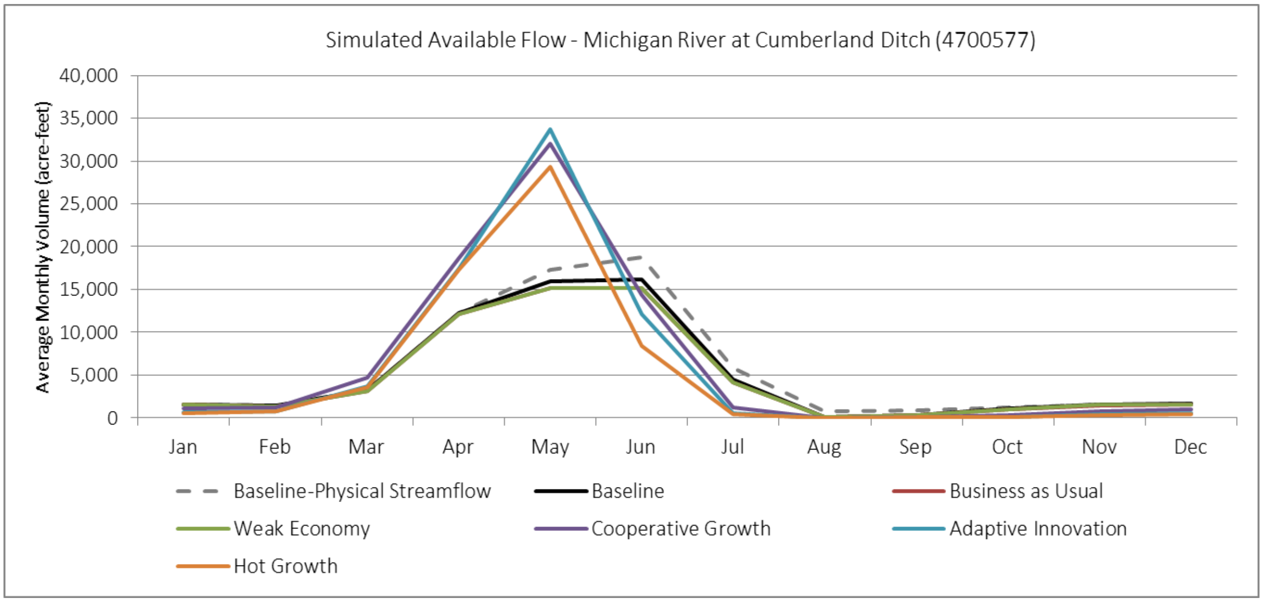


Figure 65: Average Monthly Unappropriated Available Supply at Michigan River at Cumberland Ditch

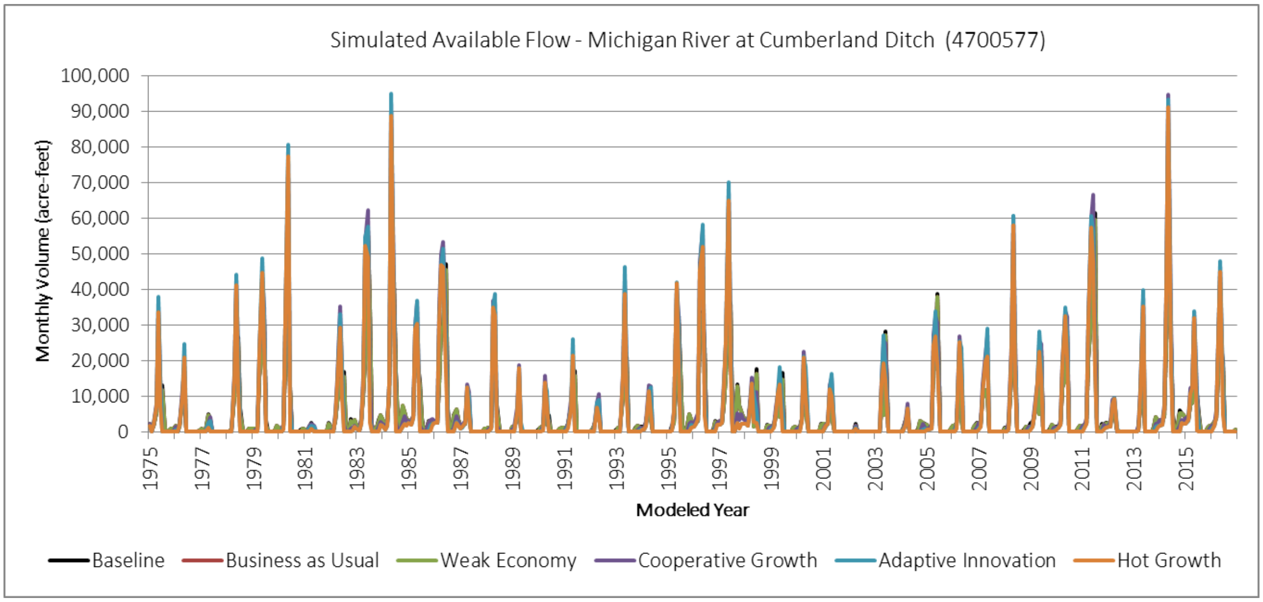


Figure 66: Monthly Unappropriated Available Supply at Michigan River at Cumberland Ditch

5.5 REPUBLICAN RIVER BASIN

Irrigation of nearly 580,000 acres of land is the predominant use of water in the Republican River basin on the eastern Colorado plains. Surface water supplies are scarce in the basin, and irrigators rely on pumping supplies from the High Plains Aquifer (also known as the Ogallala Aquifer). Nearly all of the fields are served by sprinklers, making efficient use of the pumped supplies. The M&SSI use in the basin, accounting for less than 1 percent of the total demand in the basin, can be attributed to the numerous small agricultural towns and communities throughout the basin.

The following sections describe the agricultural and M&SSI demands in the Republican River basin in more detail. Figure 67 reflects the basin outline and administrative boundaries of water districts.

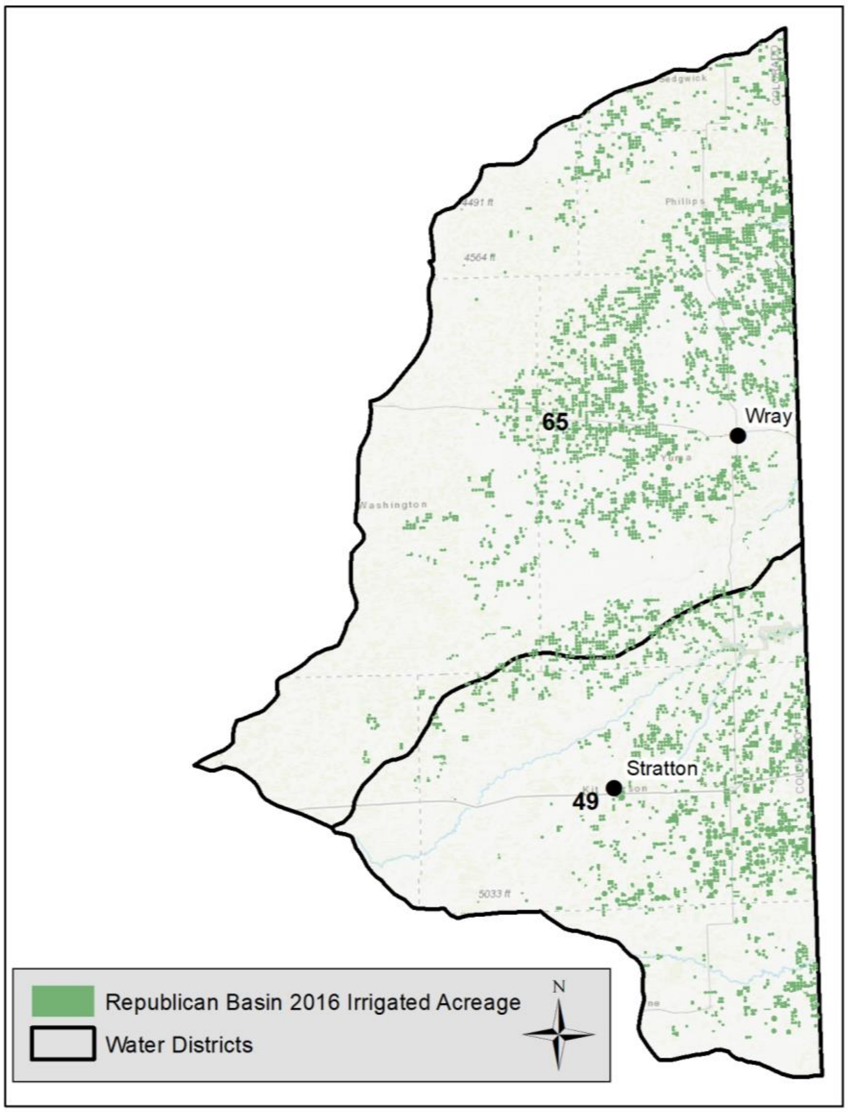


Figure 67: Republican River Map

5.5.1 REPUBLICAN RIVER BASIN AGRICULTURE WATER SUPPLY AND GAP

Corn and wheat are the primary crops grown in the basin, with sorghum, alfalfa, and small grains grown to a lesser degree. With virtually no surface water diversions and no reservoirs, irrigators pump ground water to meet crop demands. Approximately 10 percent of total pumping is subject to the Republican River Compact (RRC) with the remaining 90 percent pumped from "storage" in the High Plains Aquifer. Several efforts have taken place since 2002 to maintain RRC compliance including the establishment of the Republican River Water Conservation District (RRWCD); voluntary retirement of more than 30,000 irrigated acres; draining of Bonny Reservoir; and construction of a Compact Compliance Pipeline to deliver water to downstream states. In addition to RRC 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. These limitations on future pumping were the largest contributing factors on the agricultural pumping demand and gap in the Planning Scenarios. Refer to the *Current and 2050 Planning Scenario Agricultural Diversion Demand* technical memorandum for additional discussion on these and other drivers for the Republican River Basin agricultural demand.

The resulting Republican River Basin agricultural diversion demands, demand gaps, and consumptive use gap results for the baseline and Technical Update Planning Scenarios are presented in Table 23.

Table 23: Republican River Basin Agricultural Water Supply and Gap Summary

	Agriculture Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,067,226	805,492	807,481	835,281	797,185	885,762
	Average Annual Demand Increase from Baseline (ac-ft)	-	-	-	-	-	-
	Average Annual Gap (ac-ft)	266,807	201,373	201,870	208,820	199,296	221,440
	Average Annual Gap Increase from Baseline (ac-ft)	-	-	-	-	-	-
	Average Annual Percent Gap	25%	25%	25%	25%	25%	25%
	Average Annual CU Gap (ac-ft)	211,420	159,804	160,196	165,703	161,605	179,561
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	1,445,179	1,113,049	1,114,721	1,113,164	1,014,395	1,127,106
	Increase from Baseline Demand (ac-ft)	-	-	-	-	-	-
	Gap In Maximum Gap Year (ac-ft)	361,295	278,262	278,680	278,291	253,599	281,777
	Increase from Baseline Gap (ac-ft)	-	-	-	-	-	-
	Percent Gap In Maximum Gap Year	25%	25%	25%	25%	25%	25%

As reflected in the table, the average annual demand decreases in all Planning Scenarios as compared to the Baseline scenario. This is caused by a nearly 25 percent reduction to irrigated acreage in the basin by 2050 driven by the RRC compliance and the declining aquifer levels. Within the Planning Scenarios, the Business as Usual and the Weak Economy are fairly similar, with the slight decrease of demands attributable to the urbanization of approximately 1,400 acres in the Business as Usual scenario. The

Cooperative Growth demands are approximately 5 percent greater than the Business as Usual scenario demands due to the In-Between climate adjustments to IWR. Similarly, the Hot Growth demands are approximately 10 percent greater than the than the Business as Usual scenario demands due to the Hot Growth climate adjustments to IWR. The Adaptive Innovation demands are less than the Business as Usual due to the implementation of the Emerging Technologies adjustments. The 10 percent reduction to IWR in this scenario essentially zeros out the increase to IWR from the Hot and Dry conditions.

The agricultural gap was estimated to be 25 percent across all scenarios based on the current pumping practices; review of RRC Accounting; and through discussions with RRWCD and their ground water modeling consultants. Pumping records for wells serving irrigated land in the basin indicate irrigators pump approximately 25 percent less than the agricultural demand (i.e. deficit irrigate), after accounting for sprinkler efficiencies. Although this amount has varied over time, this gap estimate is appropriate for long-term planning efforts and is in line with the RRC Accounting estimates.

Figure 68 reflects the monthly agricultural gap for each Planning Scenario for the most recent 10 years. As shown, the agricultural gap differs depending on the year, driven by temperature and precipitation. In hot and dry years such as 2012, the agricultural gap is nearly 80,000 ac-ft in the peak of the irrigation season compared to 50,000 ac-ft in cooler and wetter years. The following figures reflect the annual agricultural demand and gap on average and in a critically dry year, relative to the demand and across Planning Scenarios.

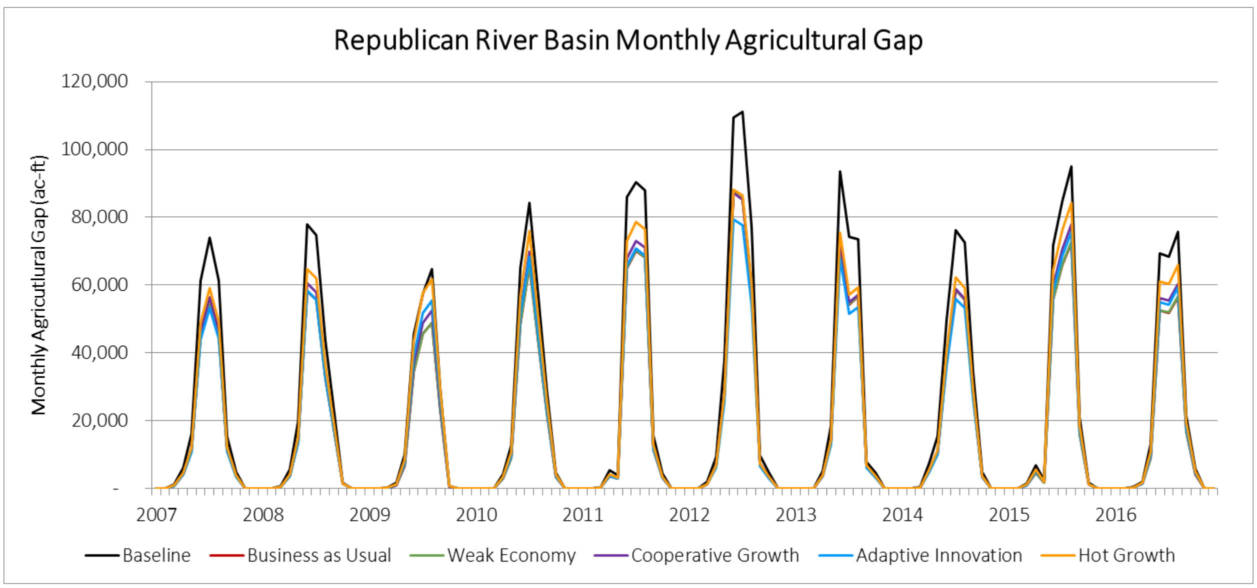


Figure 68: Republican River Basin Monthly Agricultural Gap

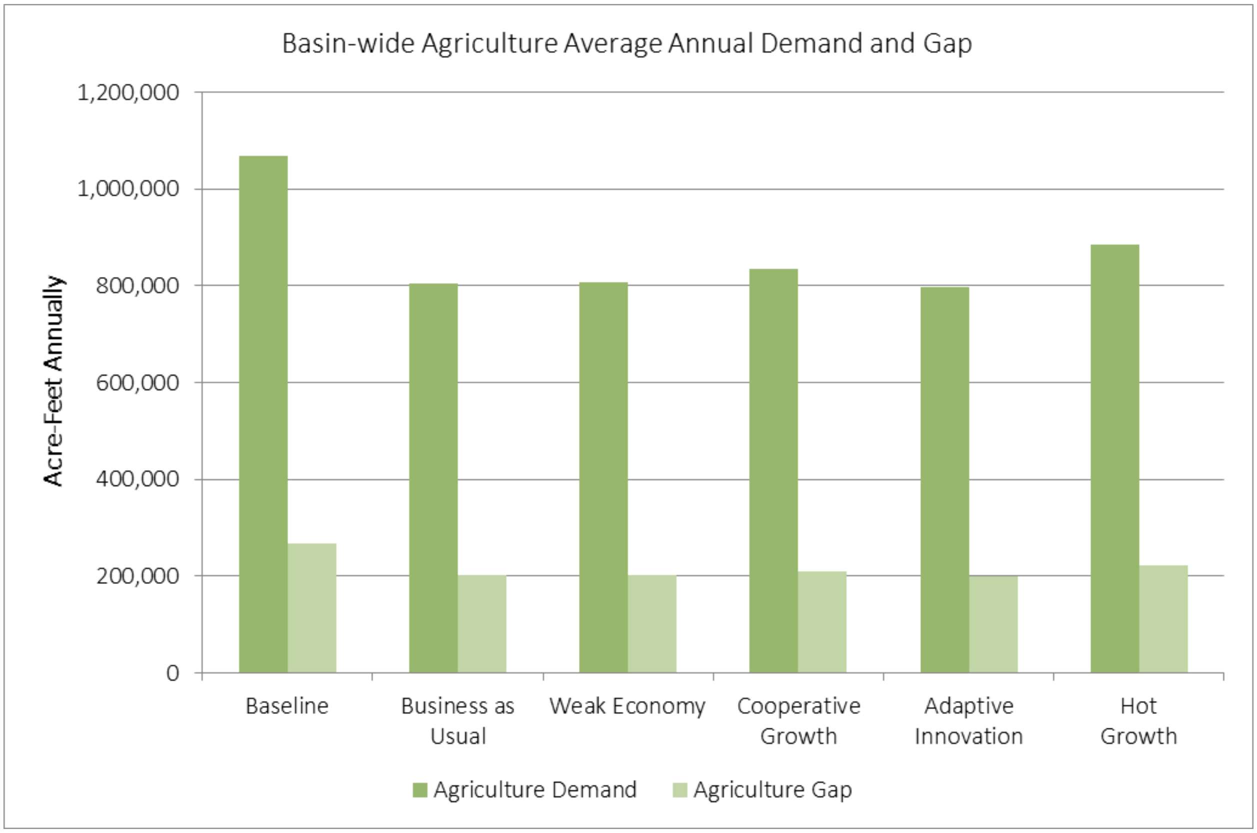


Figure 69: Republican River Basin Agriculture Average Annual Demand and Gap

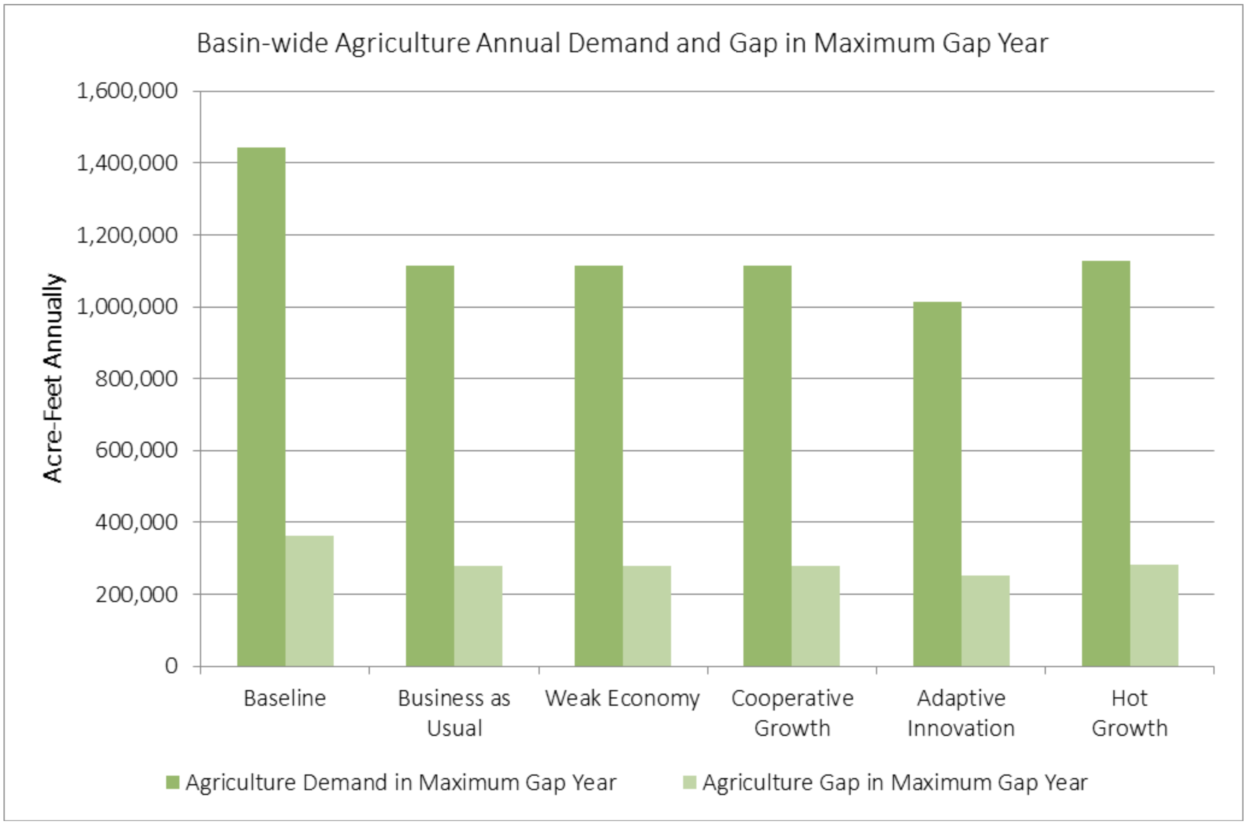


Figure 70: Republican River Basin Agriculture Annual Demand and Gap in Maximum Gap Year

5.5.2 REPUBLICAN RIVER BASIN M&SSI WATER SUPPLY AND GAP

The M&SSI demands in the Republican River Basin consist solely of municipal demands; there are no identified SSI demands in the basin. The municipal demands are dispersed fairly evenly across the counties in the basin, with larger concentrations in and around the agricultural communities in Yuma and Kit Carson counties. The M&SSI demands are low compared to the agricultural demand, reflecting less than 1 percent of the total demand in the basin. Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin was developed. The water supply and gap results for M&SSI in the Republican River basin are summarized in Table 24, and graphically reflected in Figure 71 and Figure 72.

Table 24: Republican River Basin M&SSI Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	8,403	9,151	7,895	8,134	8,947	11,202
Average	Average Annual Demand Increase from Baseline (ac-ft)	-	748	-	-	545	2,799
Average	Average Annual Gap (ac-ft)	-	748	-	-	545	2,799
Average	Average Annual Gap Increase from Baseline (ac-ft)	-	748	-	-	545	2,799
Average	Average Annual Percent Gap	0%	8%	0%	0%	6%	25%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	8,403	9,151	7,895	8,134	8,947	11,202
Critically Dry Maximum	Increase from Baseline Demand (ac-ft)	-	748	-	-	545	2,799
Critically Dry Maximum	Gap In Maximum Gap Year (ac-ft)	-	748	-	-	545	2,799
Critically Dry Maximum	Increase from Baseline Gap (ac-ft)	-	748	-	-	545	2,799
Critically Dry Maximum	Percent Gap In Maximum Gap Year	0%	8%	0%	0%	6%	25%

Population is expected to increase in the basin in all but the Weak Economy Planning Scenario. The two most populous counties, Yuma County followed by Kit Carson County, are projected to account for most of the growth and remain the largest population centers in the basin. Lincoln County is projected to have the highest growth *rate* of any county in the basin, however will still only account for approximately 5 percent of the population in the basin. The reduction in population is largely responsible for the decrease in M&SSI demand in the Weak Economy Planning Scenario compared to the Baseline demand. M&SSI Planning Scenario adjustments captured in each county's projected per capita demand offset the population increase and climate adjustments in the Cooperative Growth scenario leading to a small decrease in M&SSI demand compared to the Baseline demand. Increased population, Planning Scenario adjustments, and climate adjustments lead to a moderate increase in M&SSI demand in the Adaptive Innovation scenario, and more substantial increases in the Hot Growth scenario compared to the Baseline demand.

A simplified approach to estimating the M&SSI gap was taken in the Republican River Basin, because water availability to the M&SSI demand is based largely on ground water conditions and ground water modeling was not included in this Technical Update effort. Unlike agricultural wells, M&SSI wells have historically pumped to meet the full M&SSI demand. Understanding neither surface nor ground water supplies are projected to be available to meet any increases in demand in the future due to the RRC and declining aquifer levels, the Baseline demand served as the maximum amount of demand expected to be met in the future. Any increases to the demand, as reflected in the Business as Usual, Adaptive Innovation, and Hot Growth scenarios, can reasonably be considered an M&SSI gap. This simplified approach does not take into consideration the shift of population and demand within the basin (i.e. decline of population in one county and an increase in population in another county), which may indicate a specific area may experience a larger gap in the future. With this in mind, the basin-wide gap of approximately 750 and 550 ac-ft for the Business as Usual and Adaptive Innovation scenarios, respective, is moderate. The M&SSI gap of approximately 2,800 ac-ft in the Hot Growth is much more substantial.

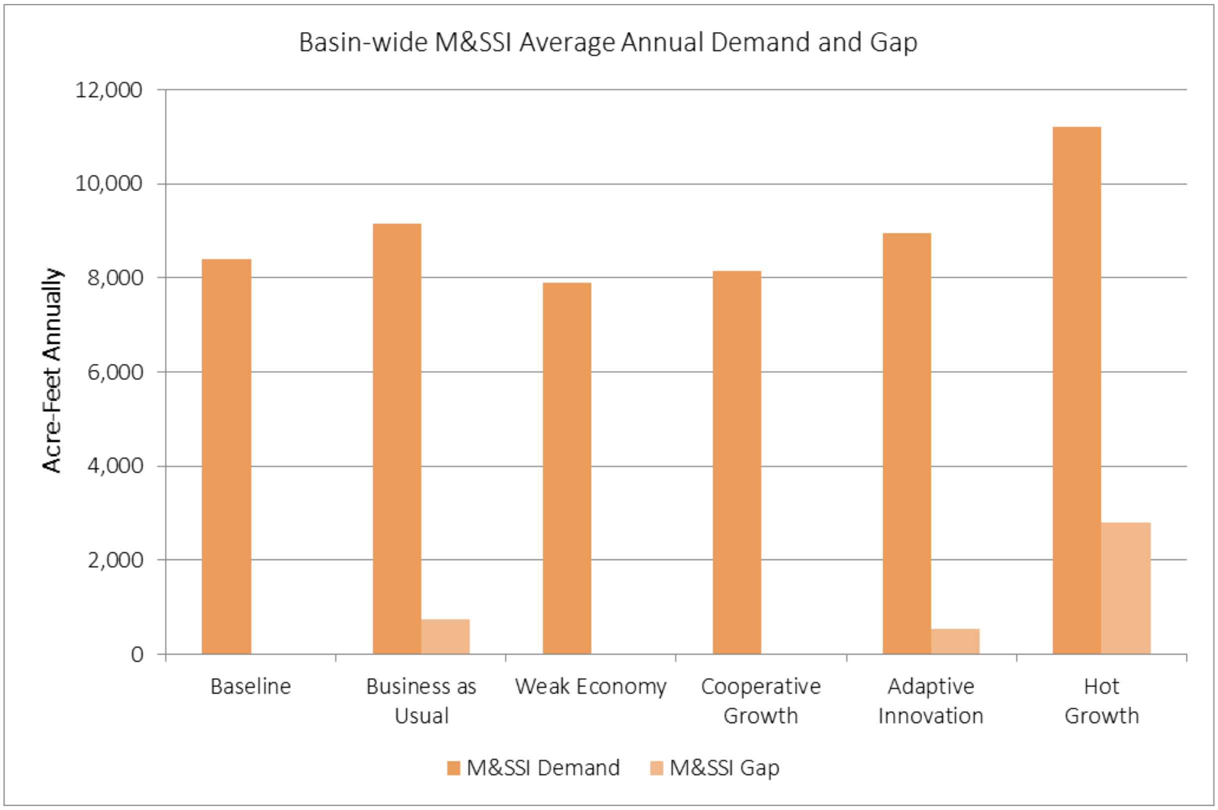


Figure 71: Republican River Basin M&SSI Average Annual Demand and Gap

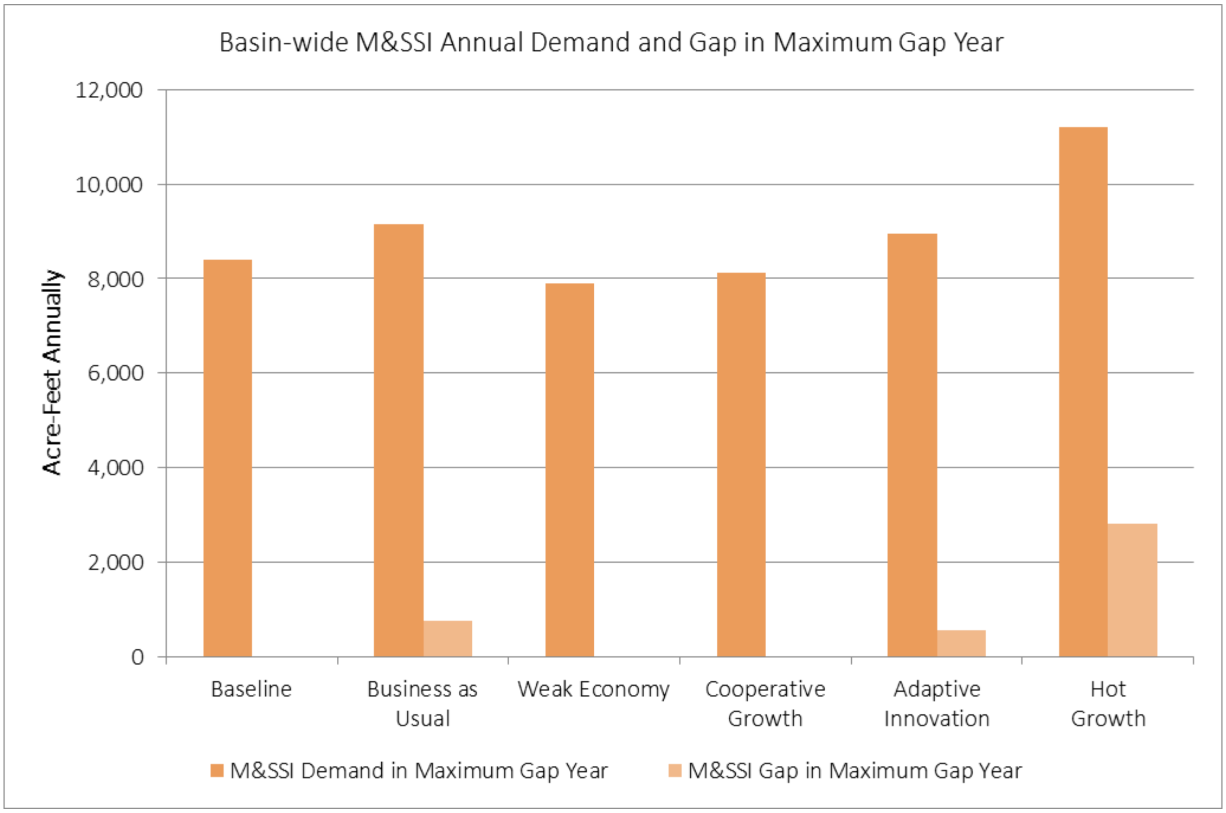


Figure 72: Republican River Basin M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

5.5.3 REPUBLICAN RIVER BASIN SUMMARY

The combined agriculture and M&SSI demands and gap summary is provided in

Table 25. The results are very similar to the agricultural results in Table 23, because water supplies in the Republican River basin are predominantly used for agriculture. Figure 73 reflects the relative size of the agricultural and M&SSI demands in the Republican River basin. The M&SSI demand is difficult to reflect graphically on the same scale because they are significantly smaller than the agricultural demands. Following the graphic are summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage.

Table 25: Republican River Basin Water Supply and Gap Summary

	Agriculture and M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,075,629	814,642	815,376	843,415	806,133	896,963
	Average Annual Gap (ac-ft)	266,807	202,121	201,870	208,820	199,841	224,240
	Average Annual Percent Gap	25%	25%	25%	25%	25%	25%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	1,453,582	1,122,199	1,122,616	1,121,298	1,023,343	1,138,308
	Gap In Maximum Gap Year (ac-ft)	361,295	279,010	278,680	278,291	254,144	284,576
	Percent Gap In Maximum Gap Year	25%	25%	25%	25%	25%	25%

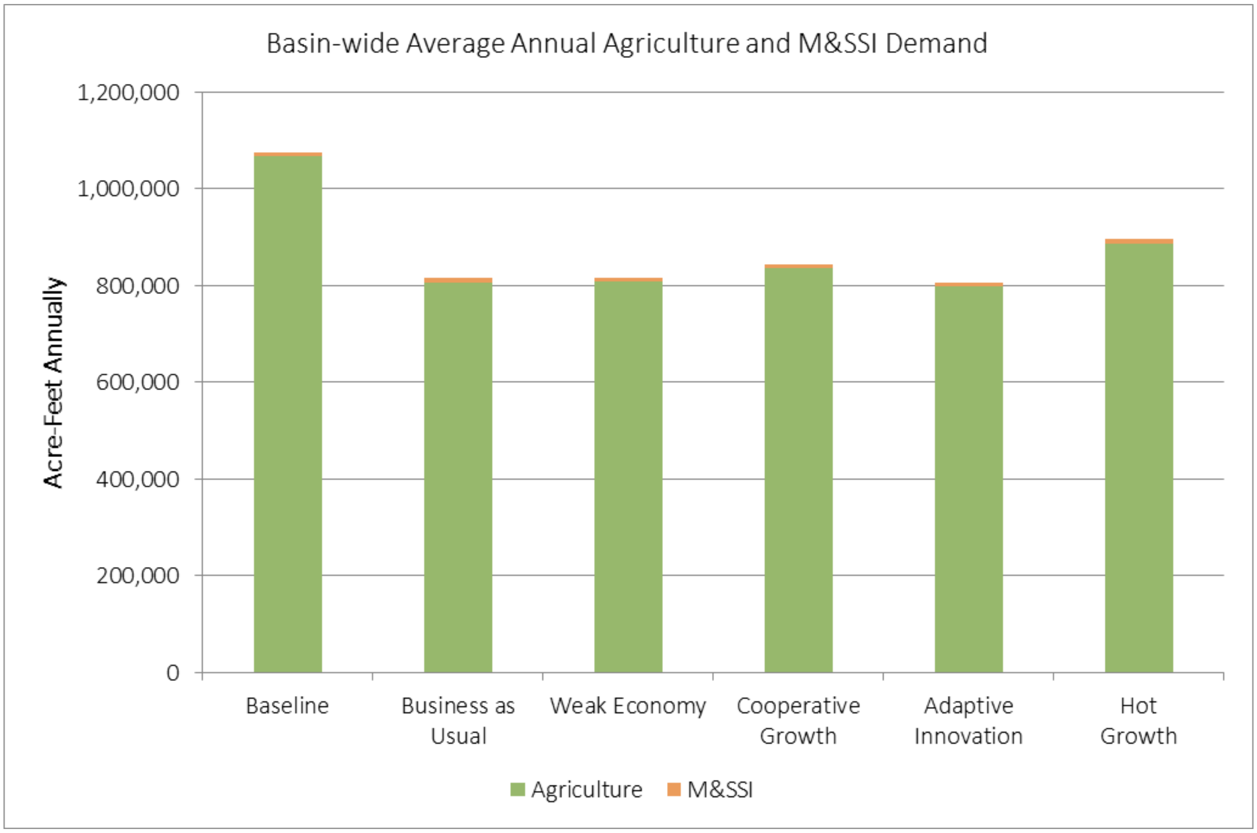


Figure 73: Republican River Basin Comparison of Average Agricultural and M&SSI Annual Demands

All scenarios except the Weak Economy scenario projects 1,410 acres of irrigated land will be taken out of production due to urbanization as the counties experience municipal growth. Supplies used to irrigate the urbanized acreage could be considered a new municipal supply if the associated water rights were changed to municipal uses. It should be noted that the economy in the basin has historically been heavily reliant on agriculture and to the extent ground water levels decline and land comes out of production, populations of local communities may also decline over time.

To estimate this potential new supply, the average consumptive use of the urbanized acreage by Planning Scenario is reflected in Table 22. It is not known which farms and ranches will be directly impacted, or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use or whether the supply could directly meet the future municipal demand. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 26: Potential Water Supply from Urbanized Acreage in the Republican River Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage	1,410	-	1,410	1,410	1,410
Estimated Consumptive Use (ac-ft/year)	1,516	-	1,580	1,555	1,727

5.6 RIO GRANDE BASIN

Water supplies in the Rio Grande Basin are unique, and the development of those supplies to meet M&SSI and agricultural demands has changed significantly over time. Melting snow channeled into streams were first diverted for agricultural and domestic uses by early settlers in the 1850s, leading to the oldest water right in Colorado and the establishment of Colorado's oldest town, San Luis. With the arrival of the railroad in the 1880s, agricultural uses became the dominant economic driver and irrigated acreage increased to 400,000 acres[11]. Surface water supplies in the basin are highly variable from year to year; however newly discovered ground water supplies available through artesian wells provided more reliable and consistent supplies. Agricultural development, construction of ditches and reservoirs, and additional well construction continued through the 1930s. This development led to 700,000 acres[12] of irrigated land, a basin that was over-appropriated, and the Rio Grande Compact.

Fast forward to today, and agriculture is still at the heart of the Rio Grande Basin, and over 99 percent of the total demand for water in the basin can be attributed to agricultural demands. The basin has several small agricultural communities, with M&SSI demands accounting for less than one percent of the total water demand in the basin. Agricultural demands are met from surface water diversions supplemented by reservoir releases, and ground water supplies (i.e. pumping and artesian supplies) withdrawn from stacked aquifers located in the valley floor; the upper unconfined aquifer and the deeper confined aquifer. Although recharge to the unconfined aquifer occurs relatively quickly, decades of withdrawals greater than recharge have left 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 curtailment to meet Compact deliveries, further impacts water availability in the basin.

The following sections describe the agricultural and M&SSI demands in the Rio Grande Basin in more detail. Figure 74 reflects the basin outline, the administrative boundaries of water districts, and the streamflow gages highlighted in the results section below.

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

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

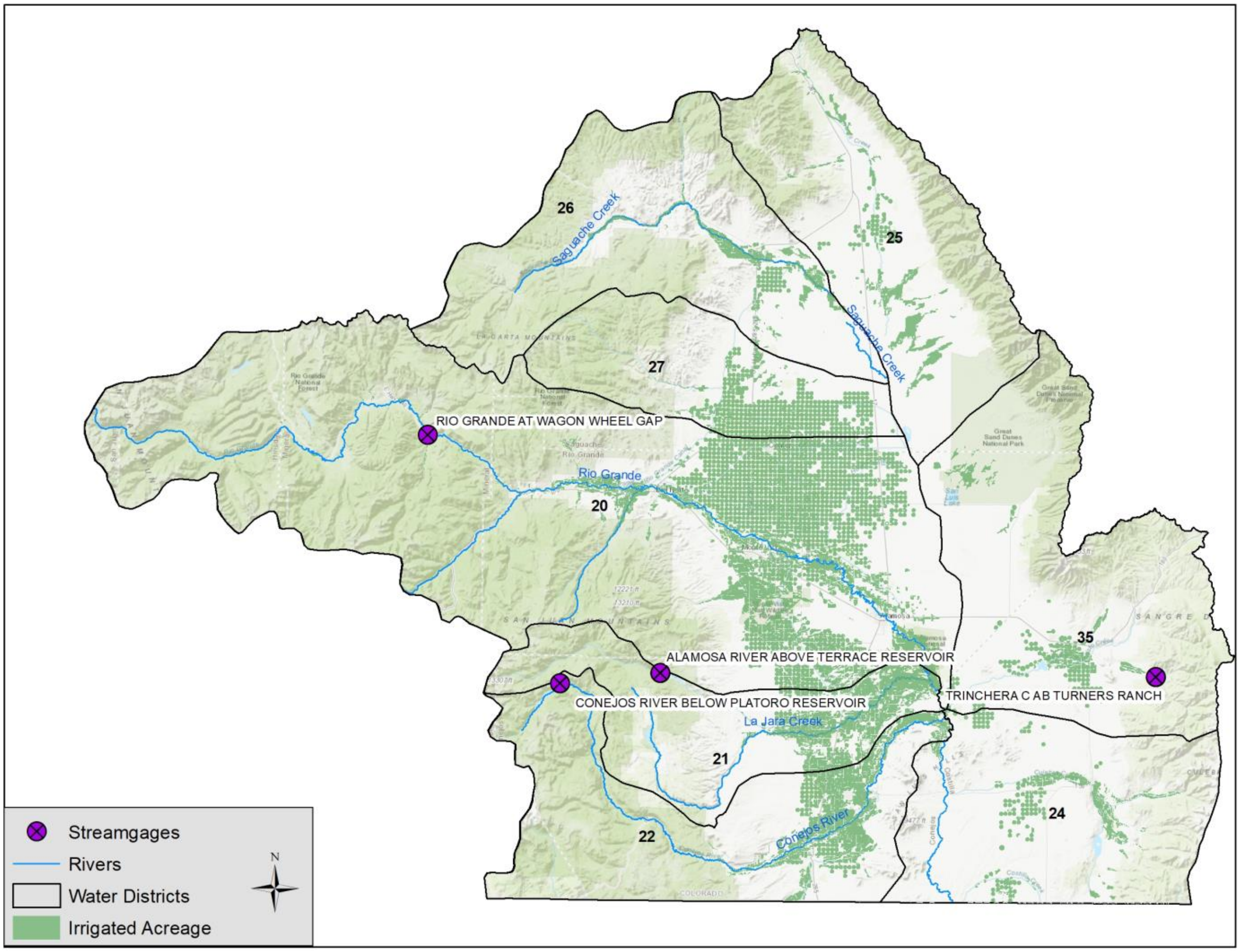


Figure 74: Rio Grande Basin Map with Streamgage Locations

5.6.1 RIO GRANDE BASIN AGRICULTURE WATER SUPPLY AND GAP

There are approximately 515,000 acres of irrigated land in the basin currently, with irrigators predominantly growing grass, alfalfa, small grains, and potatoes. As discussed above, variable surface water supplies, declining aquifer levels, and Compact administration greatly impact water availability in the basin. The basin, through the Rio Grande Water Conservation District (RGWCD), has developed Special Improvement District of the Rio Grande (Subdistrict No. 1) to manage ground water withdrawals and recharge of the aquifers. Subdistrict No. 1 operates on an annual basis to replace injurious stream depletions caused by the wells in the Subdistrict; recover aquifer levels; and maintain a sustainable irrigation supply from the aquifers for the long term. Additional Subdistricts located throughout the basin are currently in various stage of formation. Management of ground water withdrawals and recharge has led to the retirement of irrigated acreage and pumping levels less than the full crop demand in an effort to recover the aquifers in recent years. These management practices, along with the need to mitigate increases in IWR due to climate change in an over-appropriated basin, led to the projected 2050 reductions to irrigated acreage in each Planning Scenario. Refer to the *Current and 2050 Planning*

Scenario Agricultural Diversion Demand technical memorandum for additional discussion on these and other drivers for the Rio Grande Basin agricultural demand.

Table 27: Rio Grande Basin Agricultural Water Supply and Gap Summary

	Agriculture Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,825,178	1,717,781	1,735,702	1,656,255	1,471,434	1,638,935
Average	Average Annual Demand Increase from Baseline (ac-ft)	-	-	-	-	-	-
Average	Average Annual Gap (ac-ft)	683,881	655,775	661,464	737,365	741,866	826,430
Average	Average Annual Gap Increase from Baseline (ac-ft)	-	-	-	53,484	57,986	142,549
Average	Average Annual Percent Gap	37%	38%	38%	45%	50%	50%
Average	Average Annual CU Gap (ac-ft)	348,288	333,392	336,305	374,561	376,927	419,840
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	2,058,802	1,935,437	1,956,199	1,814,118	1,605,689	1,789,675
Critically Dry Maximum	Increase from Baseline Demand (ac-ft)	-	-	-	-	-	-
Critically Dry Maximum	Gap In Maximum Gap Year (ac-ft)	1,059,702	1,017,391	1,026,351	1,112,661	1,110,956	1,238,485
Critically Dry Maximum	Increase from Baseline Gap (ac-ft)	-	-	-	52,959	51,254	178,783
Critically Dry Maximum	Percent Gap In Maximum Gap Year	51%	53%	52%	61%	69%	69%

The average annual agricultural demand decreases from the Baseline to the Weak Economy Planning Scenario by approximately 90,000 ac-ft due to the removal of approximately 45,000 irrigated acres for ground water sustainability efforts in the basin. The Business as Usual agricultural demand is further reduced by 18,000 ac-ft compared to the Weak Economy due to the additional removal of urbanized lands. Larger reductions to acreage were projected for the Planning Scenarios with climate adjustments. To account for this potential future outcome, it was assumed that the percent increase in IWR by Water District would result in the same percent decrease in irrigated acreage. This is potentially an underestimate of the total acreage that may come out of production under potential future climate conditions; however the approach accounts for the potential impact and effectively mitigates the increase in demand due to climate conditions. This approach 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. The Adaptive Innovation demand is further reduced due to Emerging Technology factors.

As discussed in the Water Supply Methodology section above, model development for the Rio Grande Decision Support System has focused on the consumptive use and ground water models and a surface water model was not available for this effort. As such, shortages from the consumptive use model were relied upon to inform the gap in the Baseline, Business as Usual, and the Weak Economy Planning Scenarios. The agricultural demands basin-wide have historically experienced a 37 percent gap on average[13]. If current climate conditions occur again in the future as contemplated in the Baseline, Business as Usual and Weak Economy scenarios, the projected gaps for these scenarios are likely to be similar to the historical gap. Although acreage is removed from the Business as Usual and Weak Economy scenarios, the acreage is served primarily by ground water supplies. The amount of ground water supply not withdrawn due to the removal of acreage is projected to remain in the aquifers and would not available to offset any gaps experienced by the other demands in the basin. The gap results for the critically dry year were developed in a similar fashion, however only using gap information for drought years in each Water District, resulting in a basin-wide average gap of approximately 50 percent for the three scenarios.

For the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios that reflect a change in hydrology, the gap values needed to be further adjusted. In order to capture the combined impact of the climate adjustment in the basin, it would be necessary to simulate the basin operations with the climate-adjusted hydrology in a surface and ground water model; particularly to understand what surface water supplies may be available under Compact administration to meet agricultural demands, augmentation needs, and aquifer recharge. As that level of modeling was beyond the scope of this Technical Update, a simplified approach was developed that captured the change in hydrology and translated the change to a gap value. In short, the average decline in runoff at a representative streamflow gage was used to increase the projected gap for these scenarios. This approach assumes that irrigated acreage served by surface and ground water experience a similar shortage due to a decline in runoff volume because a reduction to surface water supplies would result in a reduction of diversions to irrigated land and diversions for augmentation and recharge to offset ground water pumping. On average, the decline in total runoff volume for the Cooperative Growth scenario increases the gap to 45 percent, and to 50 percent for the Adaptive Innovation and Hot Growth scenarios. The following bar graphs reflect the average and maximum gaps in critically dry years for each Planning Scenario. The gaps increase to 61 and 69 percent for the scenarios, respectively, in critically dry years as reflected in the annual agricultural gap time series below (Figure 77).

It is difficult to determine if this adjustment over or under estimates the future gaps in the basin due to the Rio Grande Compact requirements. The Rio Grande Compact delivery obligation varies based on the flow at index gages on the Rio Grande and Conejos River. In essence, the lower the streamflow at the index gage, the lower the obligation requirement under the Compact. As such, the reduced streamflow may allow a slight increase in the amount of water available to meet agricultural demands in future Planning Scenarios. Despite this uncertainty, the assumption is appropriate for planning purposes and more detailed modeling is recommended in future Technical Updates.

[13] Source: RGDSS Historical Consumptive Use Modeling Results, 1975 – 2010 (rg2012_FactorSoUMeter; June, 2016 Scenario)

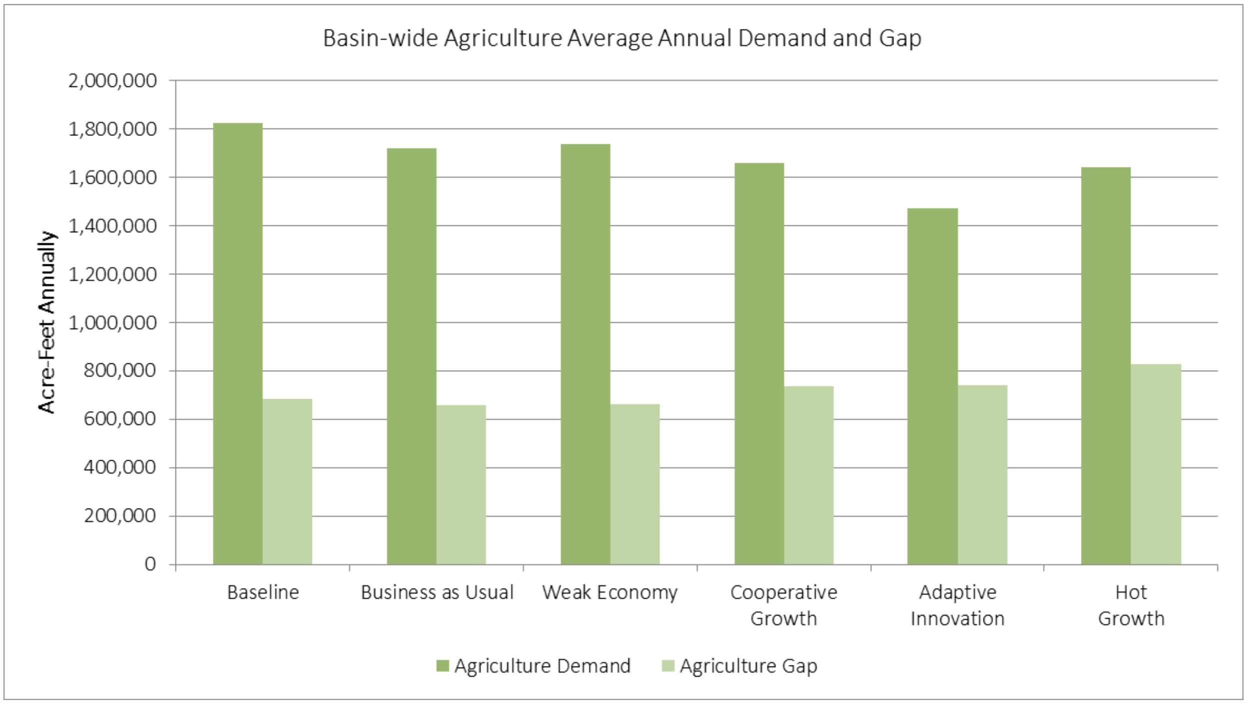


Figure 75: Rio Grande Basin Agriculture Average Annual Demand and Gap

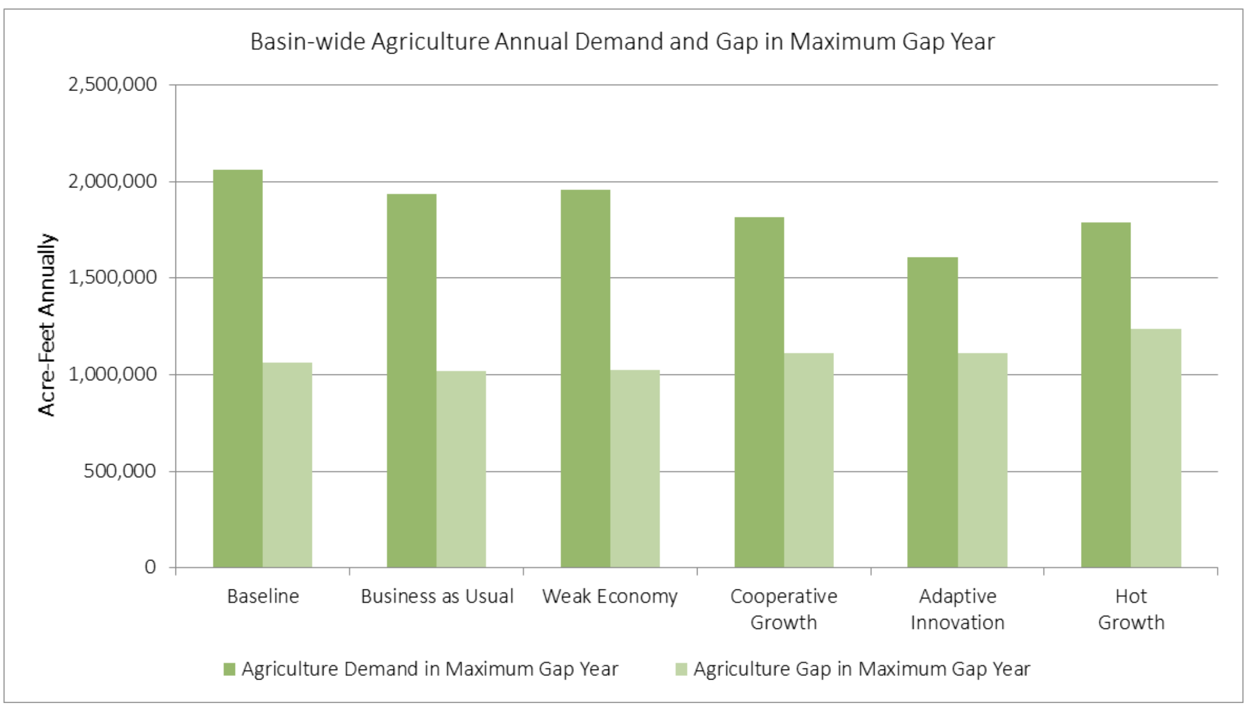


Figure 76: Rio Grande Basin Agriculture Annual Demand and Gap in Maximum Gap Year

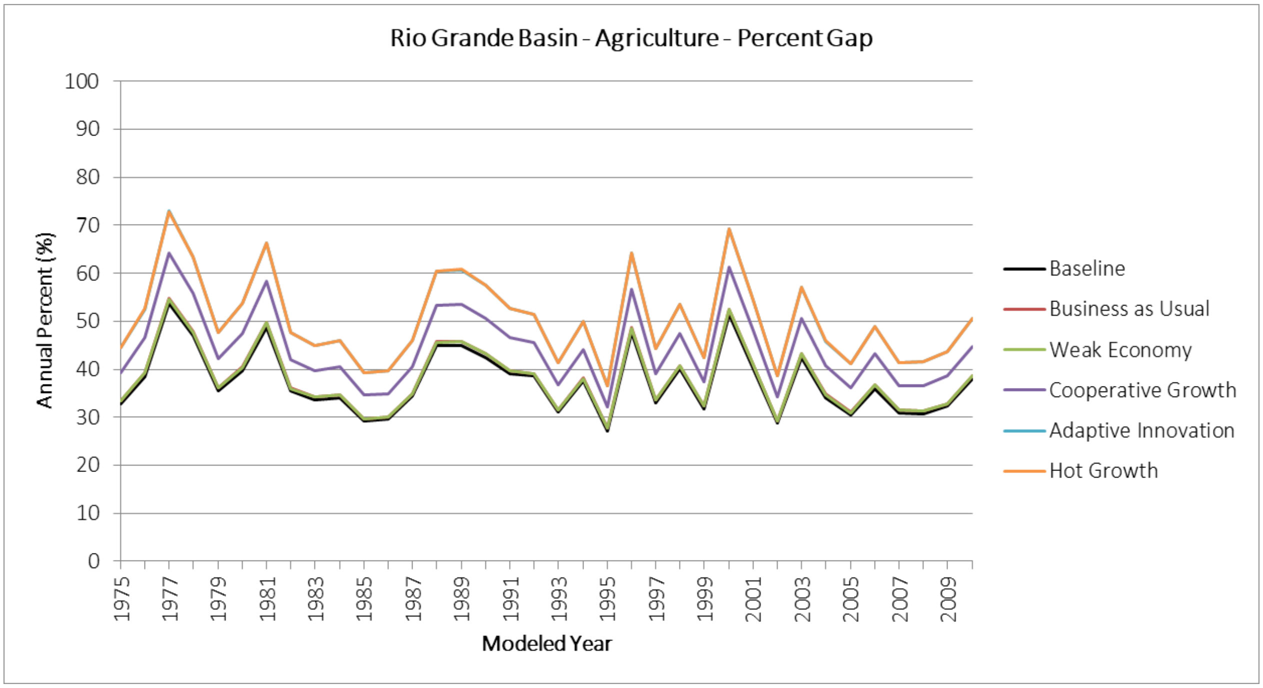


Figure 77: Rio Grande Basin Agriculture Percent Diversion Gap Times Series

5.6.2 RIO GRANDE BASIN M&SSI WATER SUPPLY AND GAP

M&SSI demands in the Rio Grande are low compared to the agricultural demand, accounting for less than one percent of the total demands in the basin. Municipal demands account for approximately 60 percent of the total M&SSI demand, with the remaining portion attributable to Large Industrial and Energy Development SSI demands. Municipal demands are greatest in Alamosa County, which encompasses the Town of Alamosa. Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin were developed. The water supply and gap results for M&SSI in the Rio Grande basin are summarized in

Table 28, and graphically reflected in Figure 78Figure 71 and Figure 79.

Table 28: Rio Grande Basin M&SSI Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	17,722	21,092	17,653	20,140	21,698	25,786
Average	Average Annual Demand Increase from Baseline (ac-ft)	-	3,370	-	2,418	3,976	8,064
Average	Average Annual Gap (ac-ft)	0	3,370	0	2,418	3,976	8,064
Average	Average Annual Gap Increase from Baseline (ac-ft)	-	3,370	-	2,418	3,976	8,064
Average	Average Annual Percent Gap	0%	16%	0%	12%	18%	31%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	17,722	21,092	17,653	20,140	21,698	25,786
Critically Dry Maximum	Increase from Baseline Demand (ac-ft)	-	3,370	-	2,418	3,976	8,064
Critically Dry Maximum	Gap In Maximum Gap Year (ac-ft)	0	3,370	0	2,418	3,976	8,064
Critically Dry Maximum	Increase from Baseline Gap (ac-ft)	-	3,370	-	2,418	3,976	8,064
Critically Dry Maximum	Percent Gap In Maximum Gap Year	0%	16%	0%	12%	18%	31%

Population is expected to increase in the basin in all but the Weak Economy Planning Scenario. The most populous county, Alamosa County, is projected to increase under all scenarios and accounts for a majority of the growth. The reduction in population is largely responsible for the decrease in M&SSI demand in the Weak Economy Planning Scenario compared to the Baseline demand. The population and M&SSI Planning Scenario adjustments, including climate adjustments, captured in each county's projected per capita demand combine to increase the M&SSI demand in the remaining scenarios compared to the Baseline demand.

A simplified approach to estimating the M&SSI gap was taken in the Rio Grande Basin, because water availability to the M&SSI demand is based largely on ground water conditions and ground water modeling was not included in this Technical Update effort. Unlike agricultural wells, M&SSI wells have historically pumped to meet the full M&SSI demand. Understanding neither surface nor ground water supplies are projected to be available to meet any increases in demand in the future due to Compact administration and declining aquifer levels, the Baseline demand served as the maximum amount of demand expected to be met in the future. Any increases to the demand can reasonably be considered an M&SSI gap. This simplified approach does not take into consideration the shift of population and demand within the basin (i.e. decline of population in one county and an increase in population in another county), which may indicate a specific area may experience a larger gap in the future. With this in mind, even the smallest basin-wide gap of approximately 2,420 ac-ft for the Cooperative Growth scenario is substantial. The M&SSI gaps increase moderately in the Business as Usual and Adaptive Innovation scenarios, but the M&SSI demands increase by 3.5 times in the Hot Growth scenario compared to the Cooperative Growth gap.

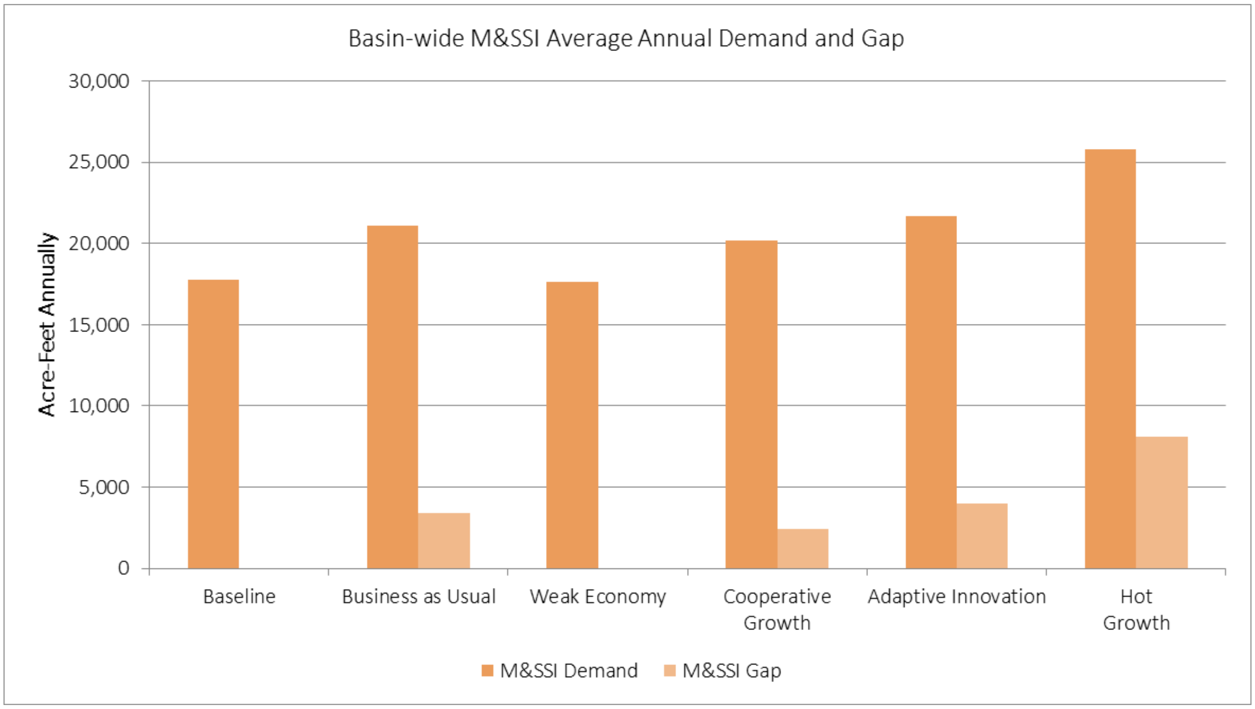


Figure 78: Rio Grande Basin M&SSI Average Annual Demand and Gap

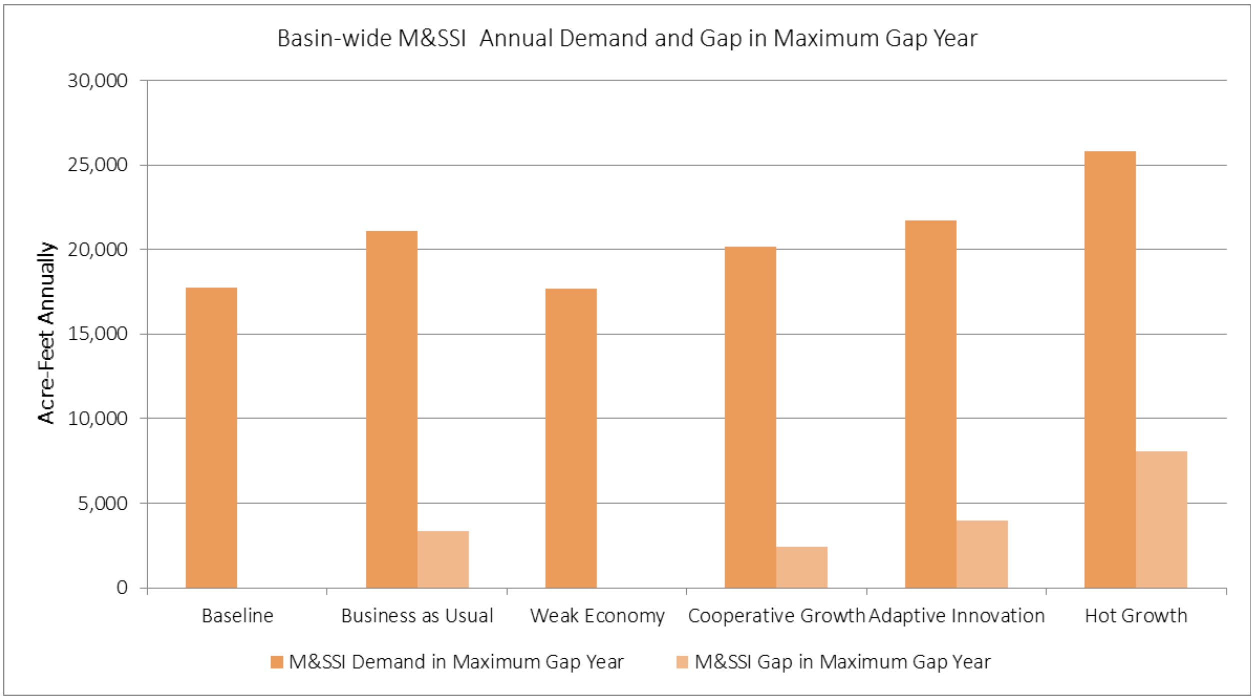


Figure 79: Rio Grande Basin M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

5.6.3 RIO GRANDE BASIN SUMMARY

The combined agriculture and M&SSI demands and gap summary is provided in Table 29. The results are very similar to the agricultural results in Table 27, because water supplies in the Rio Grande basin are predominantly used for agriculture. Figure 80 reflects the relative size of the agricultural and M&SSI demands in the Rio Grande basin. The M&SSI demand is difficult to reflect graphically on the same scale because they are significantly smaller than the agricultural demands. Following the graphic are summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage or transbasin import supply gaps.

Table 29: Rio Grande Basin Water Supply and Gap Summary

	Agriculture & M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,842,900	1,738,873	1,753,355	1,676,395	1,493,132	1,664,722
Average	Average Annual Gap (ac-ft)	683,881	659,145	661,464	739,783	745,842	834,494
Average	Average Annual Percent Gap	37%	38%	38%	44%	50%	50%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	2,076,524	1,956,529	1,973,852	1,834,258	1,627,387	1,815,461
Critically Dry Max	Gap In Maximum Gap Year (ac-ft)	1,059,702	1,020,761	1,026,351	1,115,079	1,114,932	1,246,548
Critically Dry Max	Percent Gap In Maximum Gap Year	51%	52%	52%	61%	69%	69%

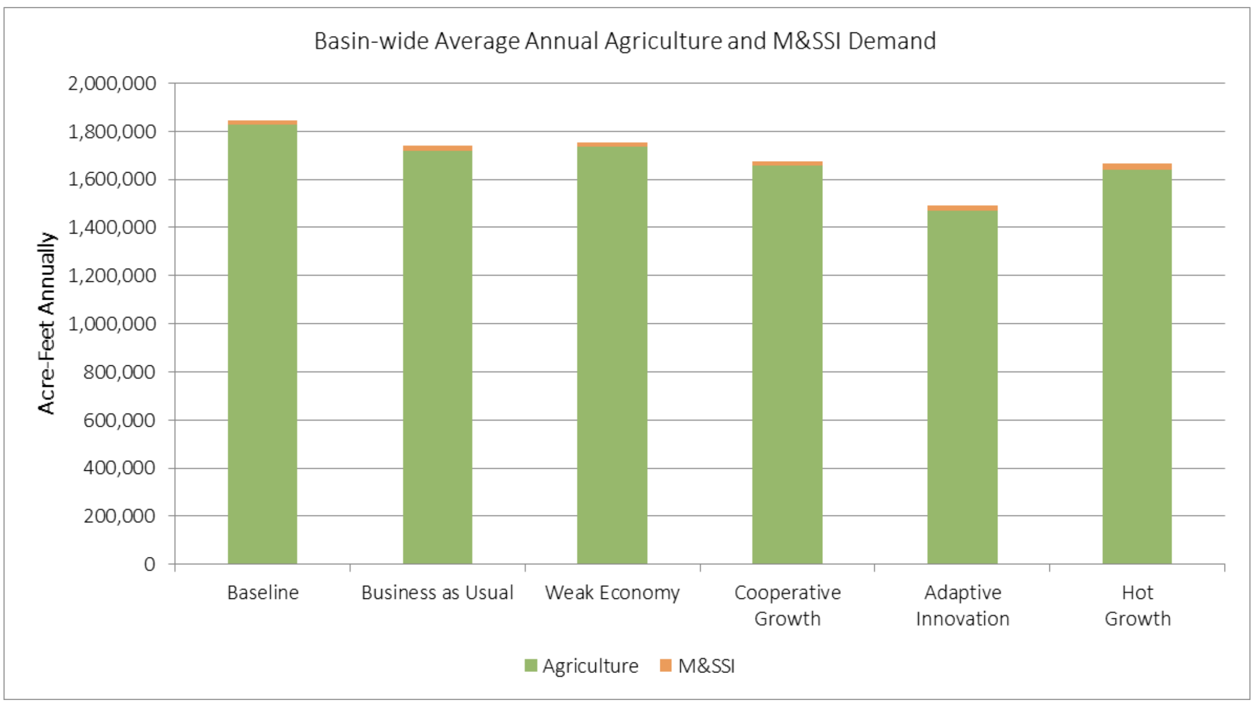


Figure 80: Rio Grande Basin Comparison of Average Agricultural and M&SSI Annual Demands

All scenarios except the Weak Economy scenario projects 4,010 acres of irrigated land will be taken out of production due to urbanization as the counties experience municipal growth. Supplies used to irrigate the urbanized acreage could be considered a new municipal supply if the associated water rights were changed to municipal uses. It should be noted that the economy in the basin has historically been heavily reliant on agriculture and to the extent ground water levels decline and land comes out of production, populations of local communities may also decline over time. Additionally, if the urbanized acreage is supplied by ground water, it is less likely the supply would be used for municipal purposes and instead these supplies may remain in the aquifer for recovery purposes.

To estimate this potential new supply, the average consumptive use of the urbanized acreage by Planning Scenario is reflected in Table 30. It is not known which farms and ranches will be directly impacted, or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use or whether the supply could directly meet the future municipal demand. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 30: Potential Water Supply from Urbanized Acreage in the Rio Grande Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage	4,010	-	4,010	4,010	4,010
Estimated Consumptive Use (ac-ft/year)	5,271	-	5,445	4,592	5,092

The Rio Grande Basin receives imported transbasin supplies primarily from the Southwest Basin. The transbasin imports are diverted at the headwaters of several sub-basins in the Southwest Basin and delivered to the headwaters of the Rio Grande primarily for agricultural purposes. Table 31 summarizes the total transbasin import volumes and associated import gaps. Note that transbasin imports are the same across the scenarios because they are represented in the model at historical levels, and no Planning Scenario adjustments were applied. A gap indicates that the historical import could not be diverted in the source basin due to a physical or legal limitation of water supply at the diverting location. This is caused by changes in water availability, increases in senior demands in the source basin, or a combination of both.

Ideally the import supply gap in the Baseline scenario would be zero; however the Baseline dataset represents current agricultural and M&SSI demands over the entire model period which can result in minor shortages to junior water rights, including transbasin diversions. With this in mind, the incremental increase in the import gap reflects the increase in gap due to the Planning Scenario adjustments. Under current hydrology conditions, there was no increase in the gap for the Business as Usual and Weak Economy scenarios. The increased demands and changed hydrology in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios however resulted in more substantial gaps on average and during critically dry years. If exports stay the same in the future, the reported import gaps could increase the total Rio Grande basin gaps in these scenarios. As transbasin imported supplies are generally able to be reused to extinction within the Rio Grande Basin, the imported supply gap would have the effect of increasing the total Rio Grande basin gap by more than the values shown in the table.

Table 31: Summary of Transbasin Imports to the Rio Grande Basin

	Transbasin Import Supply Gap	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Import Supply (ac-ft)	2,118	2,118	2,118	2,118	2,118	2,118
Average	Average Annual Import Supply Gap (ac-ft)	210	211	211	924	1,061	1,198
Average	Average Annual Import Supply Gap Increase from Baseline (ac-ft)	-	1	1	714	851	989
Average	Average Annual Import Supply Percent Gap	10%	10%	10%	44%	50%	57%
Critically Dry Maximum	Import Supply In Maximum Gap Year (ac-ft)	4,170	4,170	4,170	5,621	5,621	5,621
Critically Dry Maximum	Import Supply Gap In Maximum Gap Year (ac-ft)	1,214	1,214	1,214	2,760	3,384	3,406
Critically Dry Maximum	Increase from Baseline Import Supply Gap (ac-ft)	-	0	0	1,546	2,170	2,192
Critically Dry Maximum	Import Supply Percent Gap In Maximum Gap Year	29%	29%	29%	49%	60%	61%

Although detailed surface water modeling was not completed in the basin, it is important to understand the potential impact the climate conditions may have on the volume and timing of runoff in the basin, particularly with respect to Compact administration. Figure 81 through Figure 88 reflect the average monthly and time series of annual natural flow runoff at following four gaged locations[14]:

- Rio Grande at Wagon Wheel Gap (08217500)
- Alamosa River above Terrace Reservoir (08236000)
- Trinchera Creek above Turners Ranch near Fort Garland (08240500)
- Conejos River below Platoro Reservoir (08245000)

Note that the graphics reflect *natural flow* or the amount of water in the river absent the effects or impact of man, not simulated streamflow. These streamflow gages are generally located in the headwaters with limited impact from upstream irrigation or municipal uses; however any man-induced effects (e.g. Platoro Reservoir) above the gage locations have been removed so that the climate adjustments could be applied. Additionally, the annual natural flow graphics reflect a stacked volume of runoff compared to the volume of runoff for current conditions. The green band in these graphs reflects the incremental increase in runoff under the In-Between conditions compared to the runoff under the Hot and Dry conditions in the blue area.

As reflected, natural flow at the Rio Grande gage is projected to experience a smaller reduction in volume compared to the other gaged locations, with the In-Between conditions projecting a 7 percent decrease on average and the Hot and Dry conditions projecting a 17 percent reduction on average. There is

[14] A majority of the streamflow results presented in this memorandum reflect information from gages selected to support the Environmental Flow Tool. These gages differ from those selected for the Flow Tool; the streamflow results from these gages are provided to better reflect the impact of climate-adjusted hydrology as it may apply to the Compact Delivery Obligations in 2050. Information from the Los Pinos and San Antonio gages near Ortiz were excluded because their contributing drainage areas are primarily in New Mexico and climate adjustments were not considered for areas outside of Colorado.

however a pronounced shift in the peak runoff, projected to occur a month earlier than current conditions, and a reduction to late season flows. Larger reductions are projected for the Conejos and Alamosa gages, projected to be approximately 15 percent with the In-Between conditions and 25 percent with the Hot and Dry conditions. As reflected in the graphs, the reductions to streamflow are projected to occur during years with average and above-average runoff, with smaller reductions projected for years with lower flows. Similar to the Rio Grande gages, the Conejos and Alamosa natural flow is projected to shift earlier by a month and experience lower late season flows. Trinchera Creek is projected to the largest reduction in flows of all the gaged locations; over 45 percent reduction with In-Between conditions and 55 percent reduction with Hot and Dry conditions.

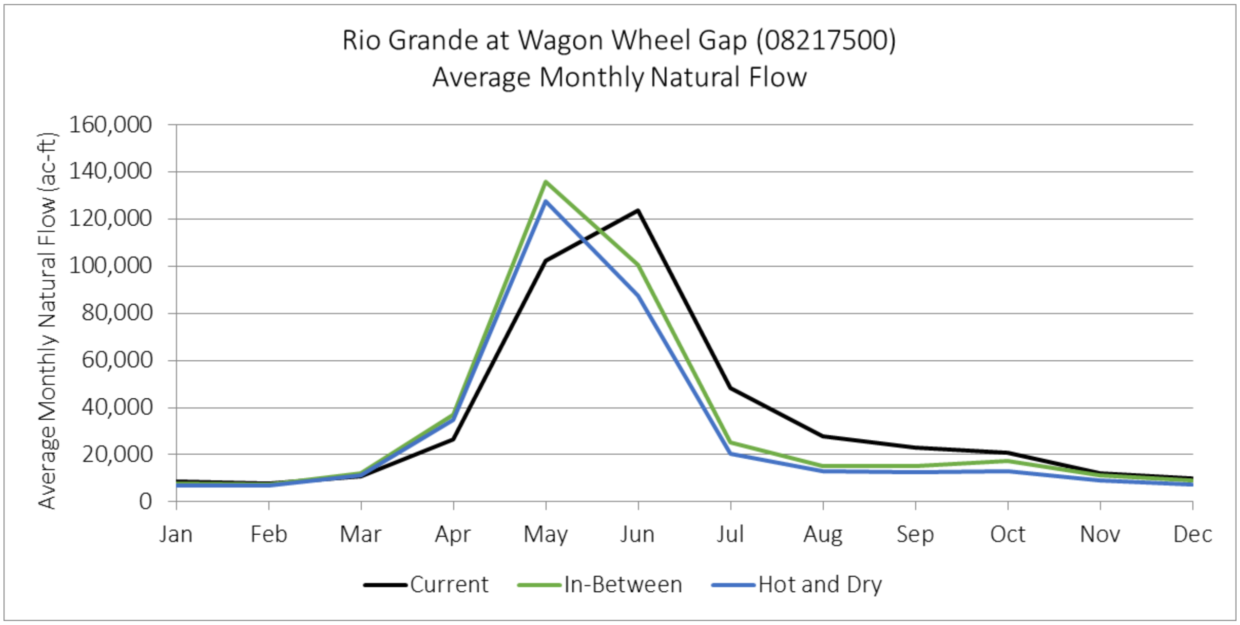


Figure 81: Average Monthly Natural Flow at Rio Grande at Wagon Wheel Gap

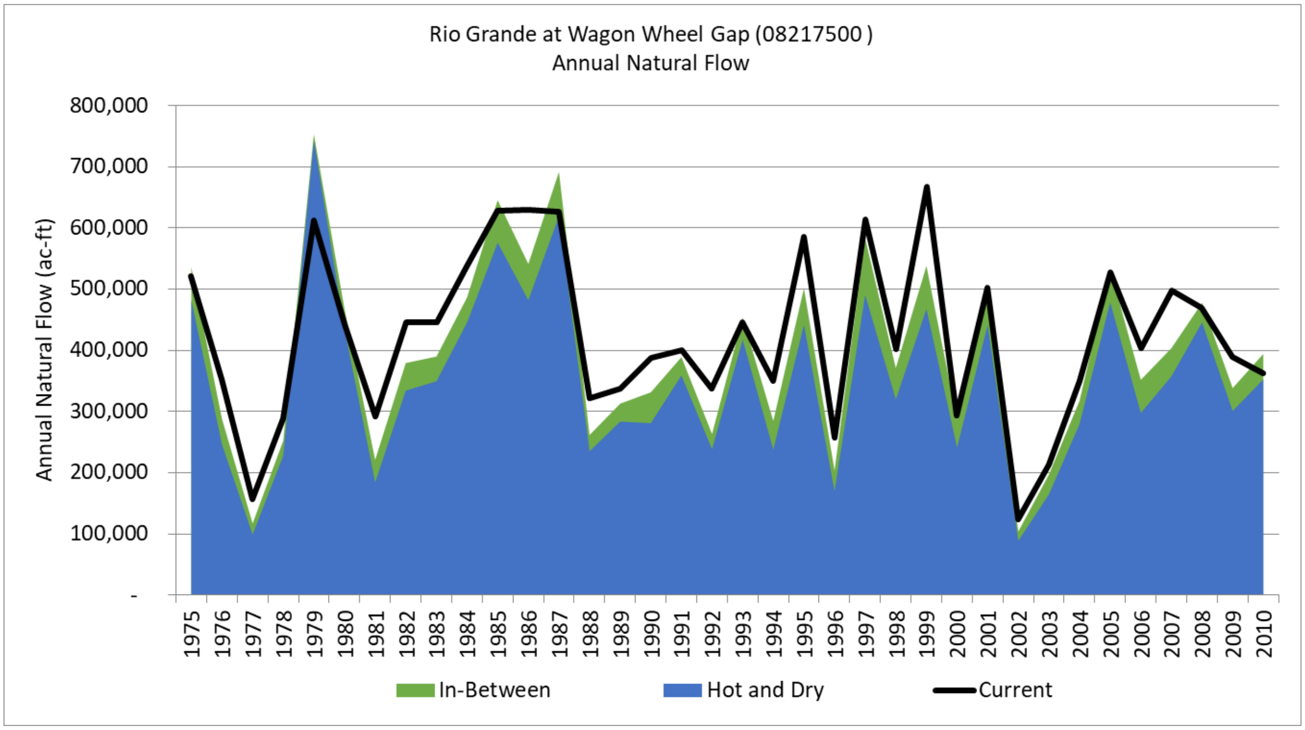


Figure 82: Annual Natural Flow at Rio Grande at Wagon Wheel Gap

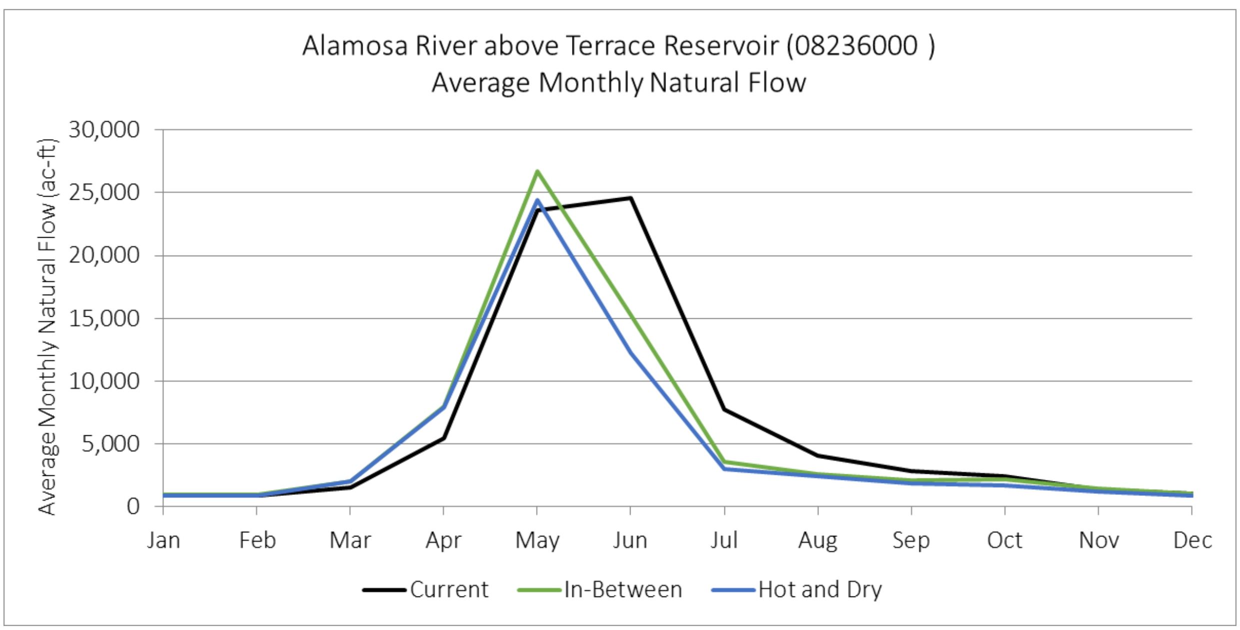


Figure 83: Average Monthly Natural Flow at Alamosa River above Terrace Reservoir

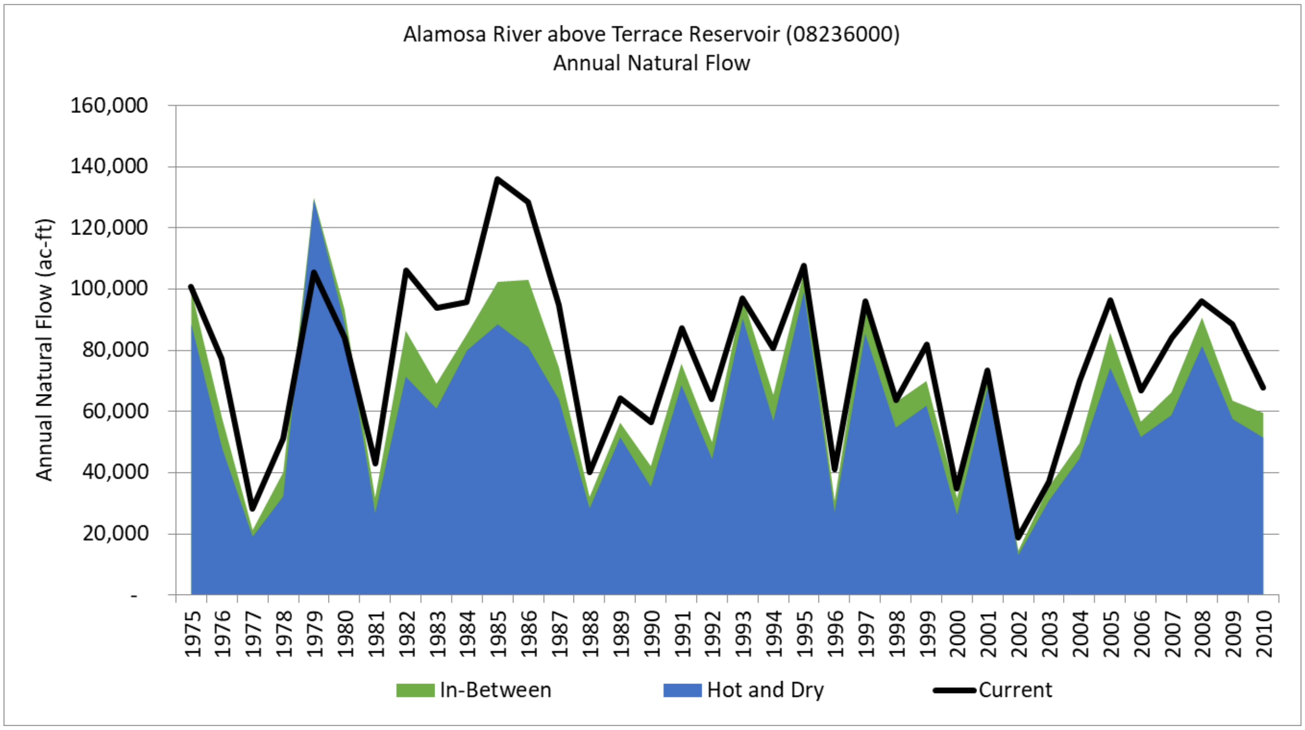


Figure 84: Annual Natural Flow at Alamosa River above Terrace Reservoir

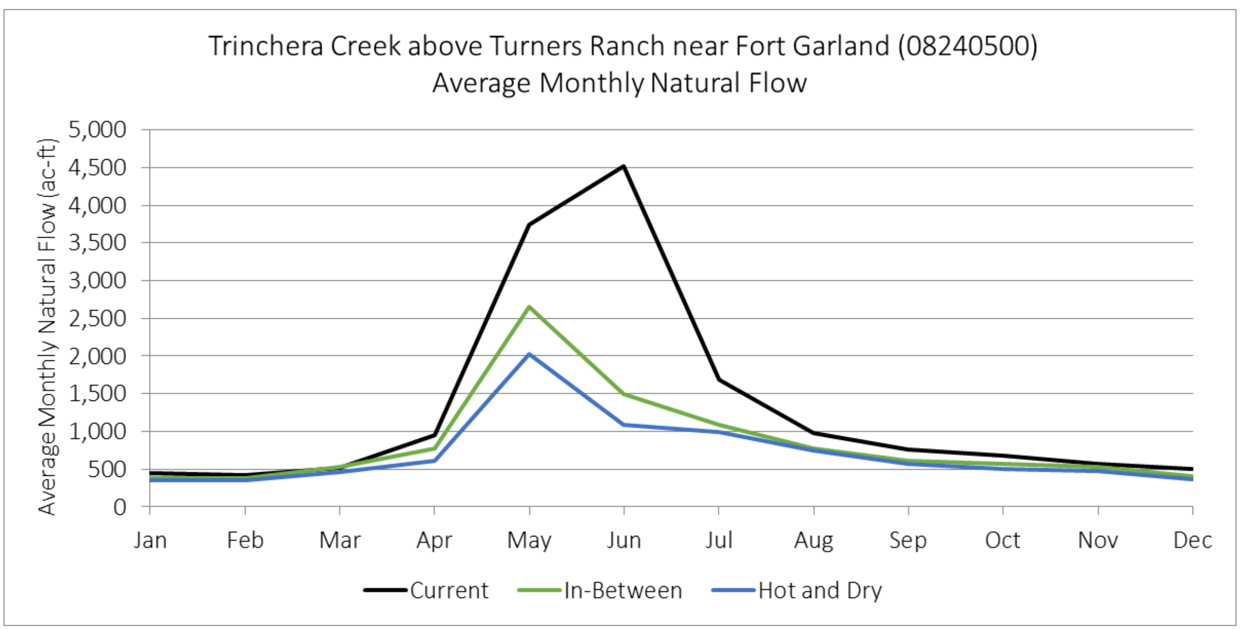


Figure 85: Average Monthly Natural Flow at Trinchera Creek above Turners Ranch near Fort Garland

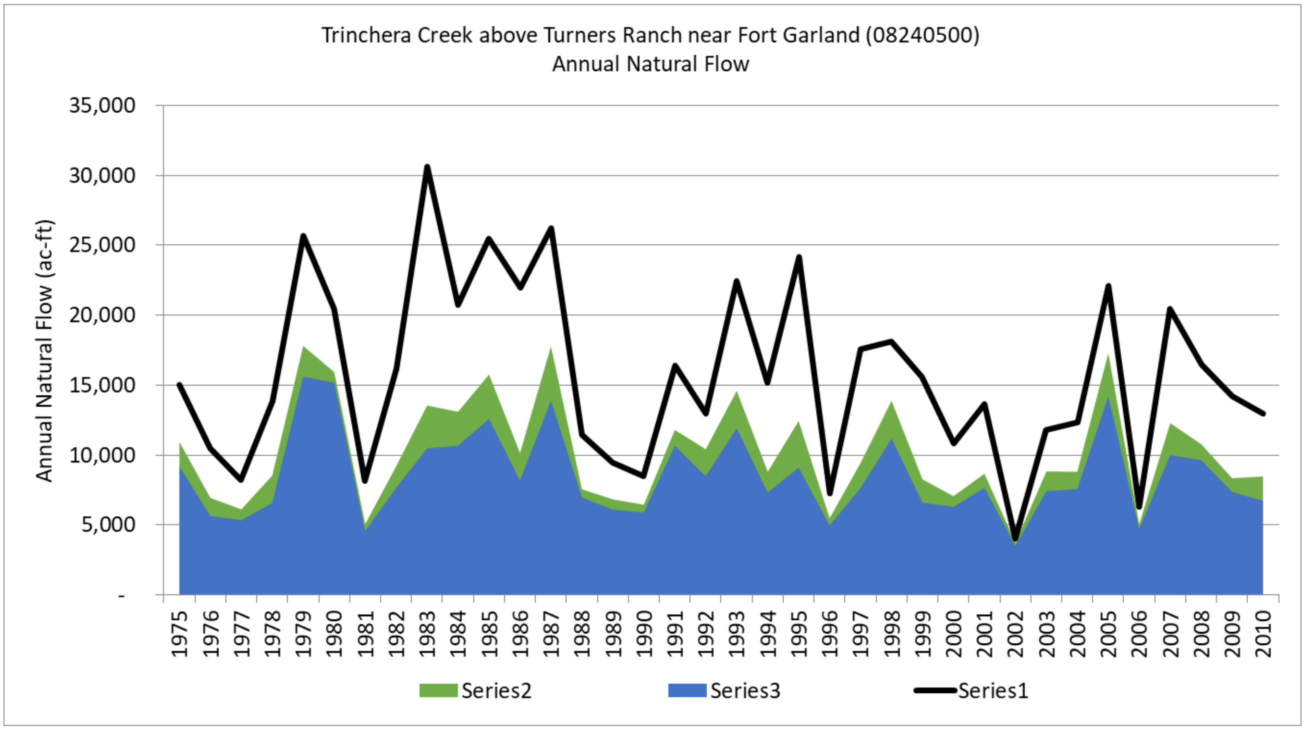


Figure 86: Annual Natural Flow at Trinchera Creek above Turners Ranch near Fort Garland

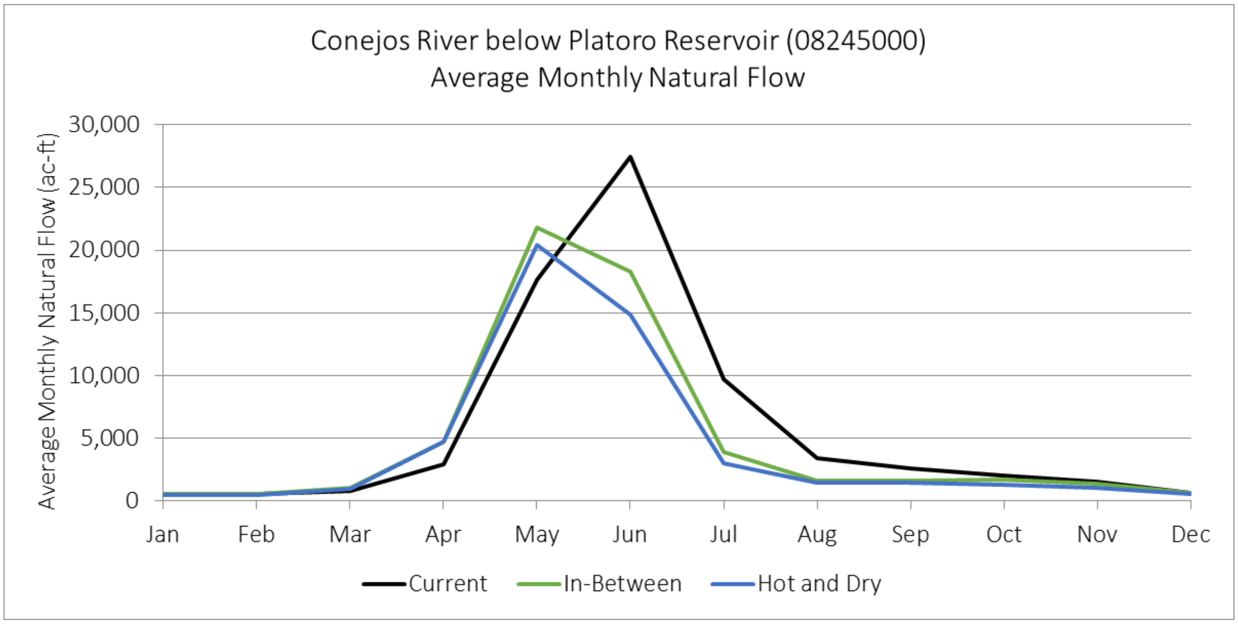


Figure 87: Average Monthly Natural Flow at Conejos River below Platoro Reservoir

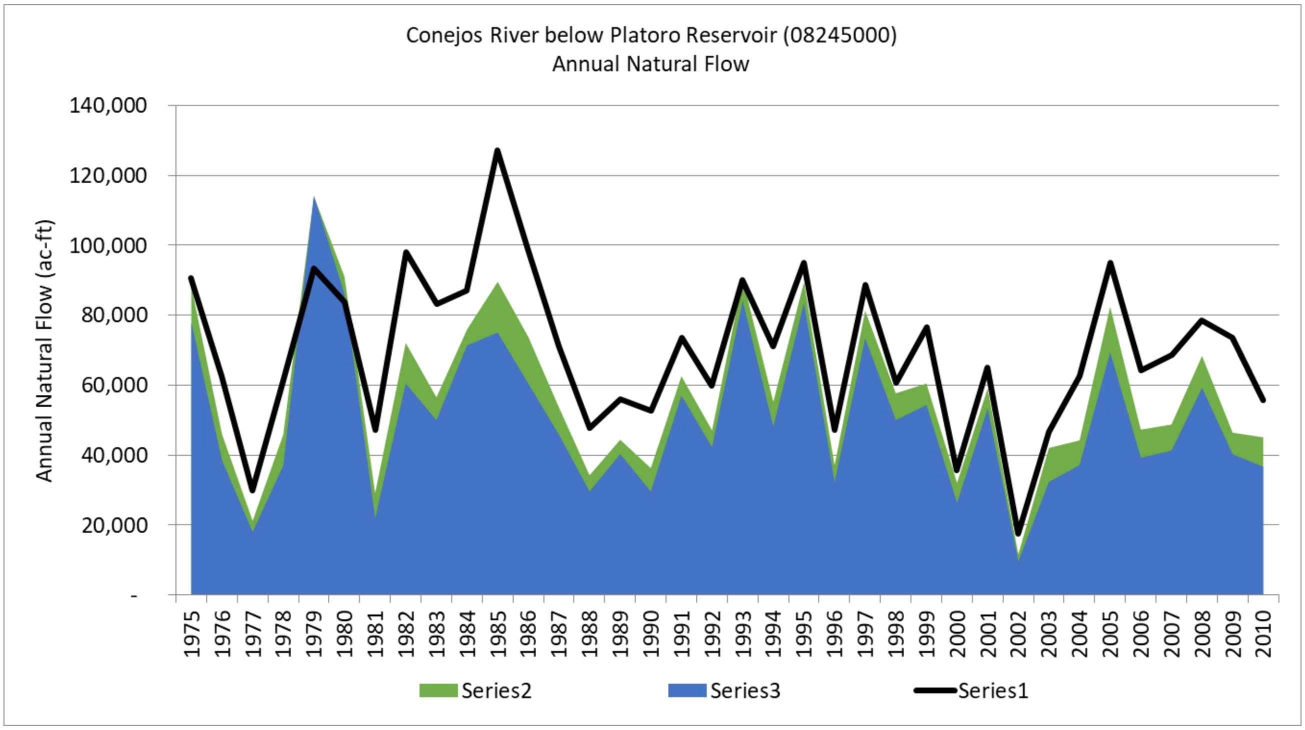
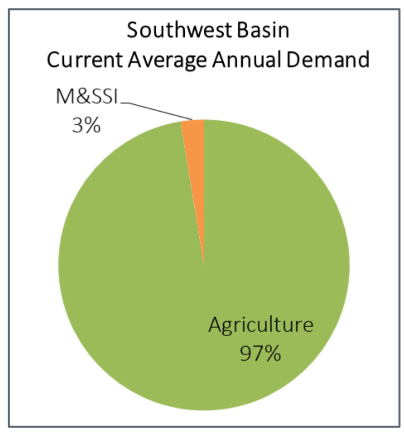


Figure 88: Annual Natural Flow at Conejos River below Platoro Reservoir

5.7 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 is home to a diverse set of demands including 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); the San Juan Chama Project[15] to deliver water to New Mexico; several small transbasin diversions; 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.

Water demands in the basin are predominantly for agricultural uses, with only 3 percent of the total demand in the basin attributable for M&SSI demands and less than one percent attributable to transbasin demands. The following sections describe the agricultural, M&SSI, and transbasin export demands in the Southwest basin in more detail. Figure 89 reflects the basin outline, the administrative boundaries of water districts, and the streamflow gages highlighted in the results section below.

[15] The San Juan Chama Project, developed by Reclamation under the Colorado River Storage Project (CRSP), delivers water from San Juan tributaries to the Rio Grande basin in New Mexico. The Baseline and Planning Scenario models include the current demand and operations, but the project deliveries are not considered a transbasin export under the Technical Update as the project does not operate under a Colorado water right; cannot call out Colorado water users; and the supply is not delivered to a Colorado entity.

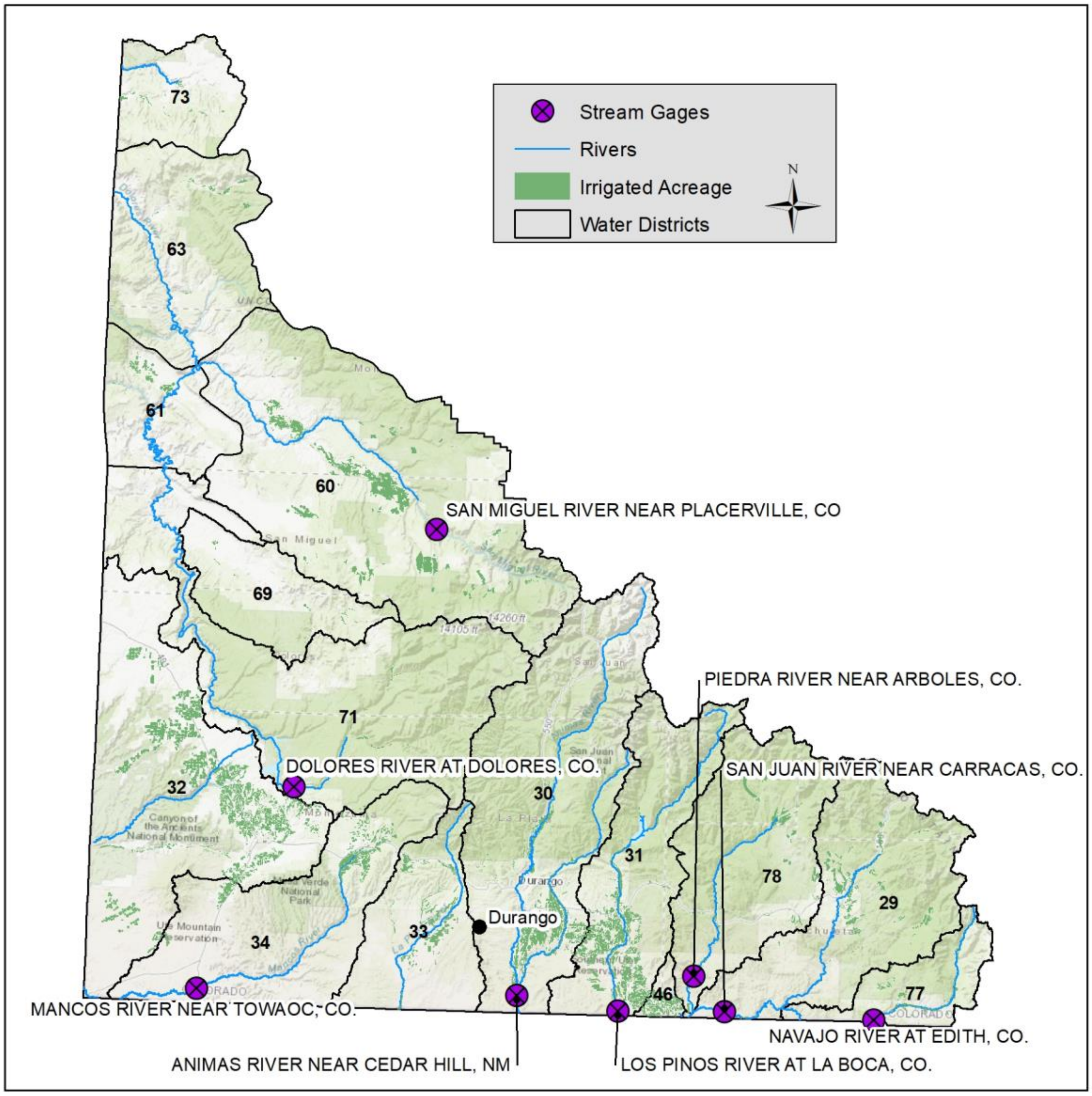


Figure 89: Southwest Basin Map with Streamgage Locations

5.7.1 SOUTHWEST BASIN AGRICULTURE WATER SUPPLY AND GAP

On much of the 222,000 irrigated acres in the basin, producers generally irrigate grass meadows for cattle operations along the rivers and tributaries and rely on supplies available during the runoff season. Reclamation Projects have developed critical supplemental supplies in the basin and producers under these 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.

The Southwest Basin agricultural diversion demands, demand gaps, and consumptive use gaps results for the baseline and Technical Update Planning Scenarios are presented in Table 32. As discussed in Technical Memo *Current and 2050 Planning Scenario Agricultural Diversion Demand*, 2050 agricultural demands are influenced by a number of drivers, including climate, urbanization, and emerging technologies.

Table 32: Southwest Basin Agricultural Water Supply and Gap Summary

	Agricultural Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,024,784	1,005,432	1,005,432	1,220,493	923,100	1,271,671
	Average Annual Demand Increase from Baseline (ac-ft)	-	-	-	195,708	-	246,887
	Average Annual Gap (ac-ft)	126,642	120,297	119,760	276,733	219,000	355,081
	Average Annual Gap Increase from Baseline (ac-ft)	-	-	-	150,091	92,357	228,439
	Average Annual Percent Gap	12%	12%	12%	23%	24%	28%
	Average Annual CU Gap (ac-ft)	72,255	68,721	68,393	158,451	147,241	206,411
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	1,152,958	1,131,100	1,131,100	1,215,185	899,260	1,238,203
	Increase from Baseline Demand (ac-ft)	-	-	-	62,227	-	85,245
	Gap In Maximum Gap Year (ac-ft)	517,556	507,371	504,937	679,498	474,012	738,104
	Increase from Baseline Gap (ac-ft)	-	-	-	161,942	-	220,548
	Percent Gap In Maximum Gap Year	45%	45%	45%	56%	53%	60%

The average annual agricultural demand decreases from the Baseline to the Business as Usual and Weak Economy Planning Scenarios by approximately 20,000 ac-ft due to the reduction of irrigated acreage from urbanization. As reflected in the table, irrigators in the basin currently experience a relatively small agricultural gap on average. Runoff and water availability in each of the sub-basins in the Southwest Basin, however, are widely variable. Agricultural gaps under current conditions are much greater than the 12 percent basin-wide average in sub-basins with more limited supplies, particularly on farms and ranches along smaller tributaries to the Mancos, Dolores, and La Plata Rivers. Current agricultural gaps in these areas range from 25 to 45 percent on average, with even larger gaps during critically dry years, and gaps in these areas trend substantially higher than the basin-wide average in all Planning Scenarios. Consideration of this variability across the sub-basins should be noted during review of the basin-wide results.

Demand for the Cooperative Growth scenario incorporates the urbanized acreage as well as the increase in climate change adjustments to IWR, leading to an increase of 20 percent or approximately 195,000 ac-ft of demand basin-wide. Climate adjustments to hydrology in the Cooperative Growth scenario reduce the magnitude, shift the peak runoff generally from June to May, and reduce the amount of late season supplies. These changes lead to an 11 percent increase in gap (approximately 156,000 ac-ft) compared to the Business as Usual and Weak Scenarios. The gap in a critical dry year surpasses 50 percent on average for the Cooperative Growth scenario, indicating that the more water short sub-basins discussed above are projected to experience even higher gaps during critically dry years.

The Adaptive Innovation scenario reflects the decrease in acreage due to urbanization, improved system efficiencies, and the mitigation of approximately 10 percent of the increase in IWR due to projected Hot and Dry climate conditions. These adjustments lead to an agricultural demand that is approximately 100,000 ac-ft or 10 percent less than the Baseline demand. Despite the reduced agricultural demand, the agricultural gap actually increases by approximately 92,000 ac-ft compared to the Baseline Scenario due to both the reduced return flows from the more efficient irrigation practices and the shift of the peak runoff month associated with the projected hydrology under the Hot and Dry climate conditions.

The Hot Growth scenario reflects the largest agricultural demand and the largest agricultural gap, driven by the full impact of the projected Hot and Dry climate conditions. In this scenario, the agricultural demand and gap are approximately 355,000 ac-ft and 228,000 ac-ft greater than the Baseline agricultural demand on average, respectively. As reflected in Figure 92, the 2002 drought conditions exacerbated by the Hot and Dry climate conditions lead to the projected gap results for the critically dry year. The following figures reflect the agricultural demand and gap on average and in a critically dry year, relative to the demand and across Planning Scenarios.

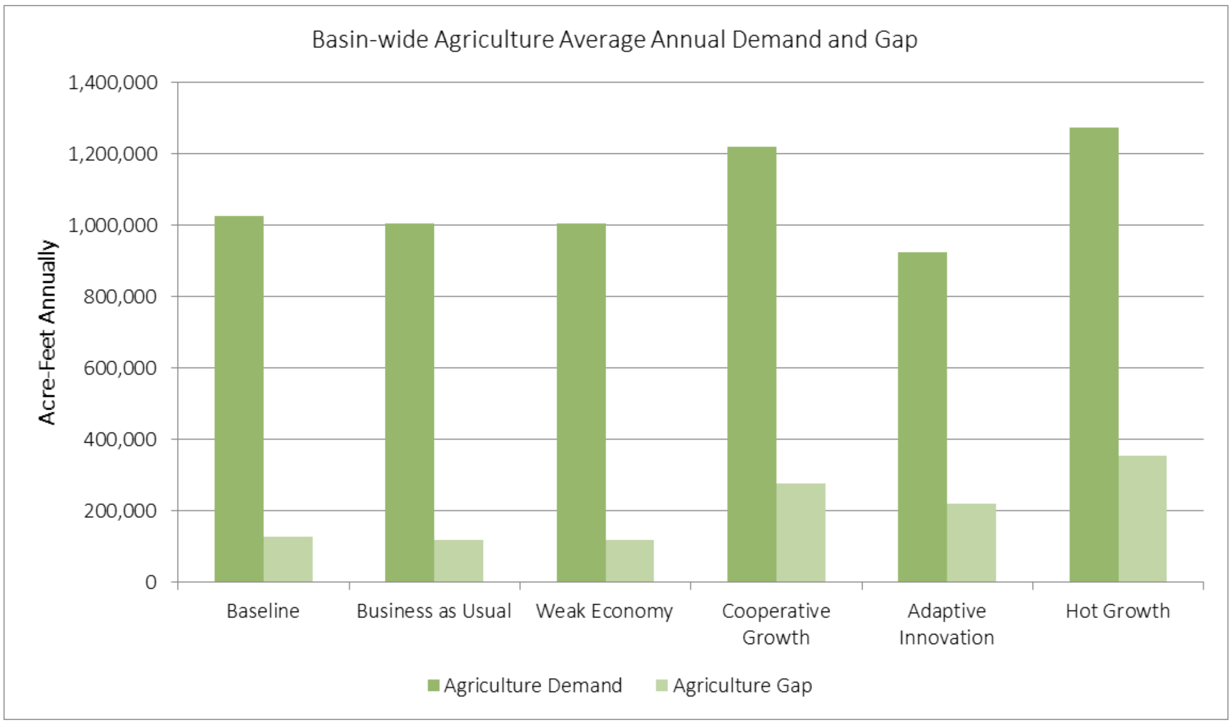


Figure 90: Southwest Basin Agriculture Average Annual Demand and Gap

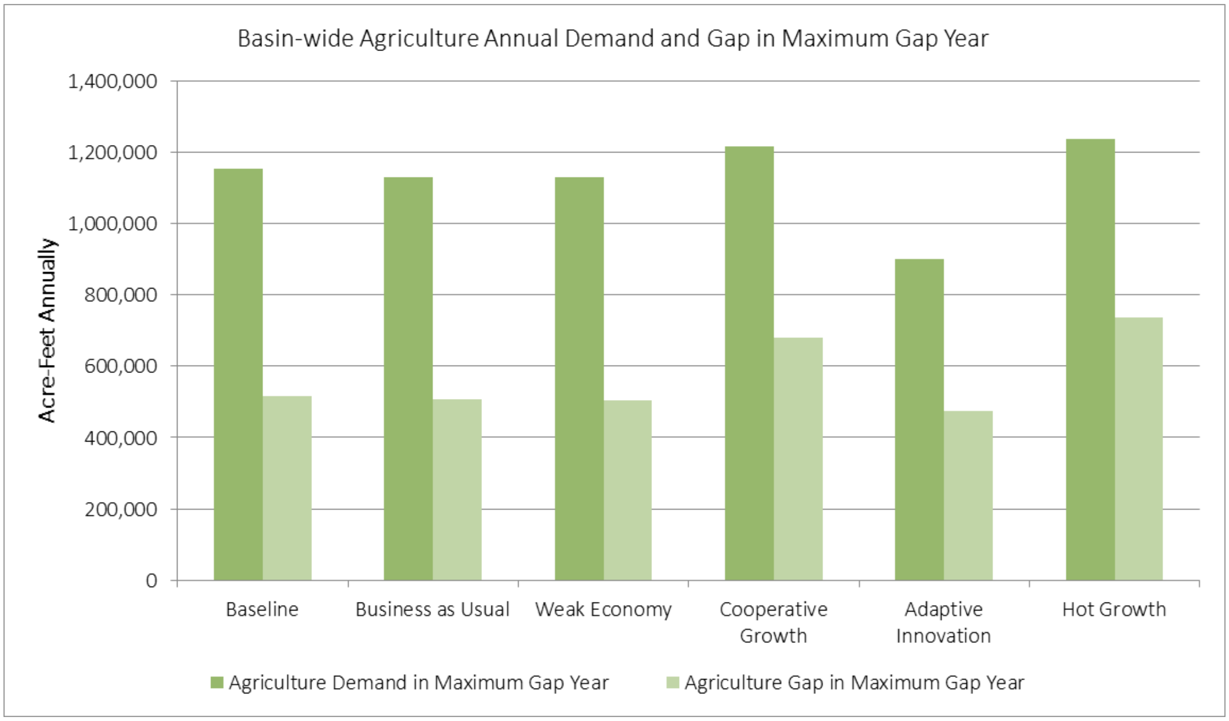


Figure 91: Southwest Basin Agriculture Annual Demand and Gap in Maximum Gap Year

As reflected in Figure 92, the agricultural gap varies annually based on the demand and the available water supplies in the basin. With only the decrease in acreage due to urbanization differentiating the Baseline, Business as Usual, and the Weak Economy scenarios, the agricultural gaps are very similar over the study period and the lines on the graph are overlapping. The impact of climate adjustments is substantial as the agricultural gap from the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios is doubled in average and above average hydrology years compared to the Baseline values. In the critically dry year of 2002, only the irrigators with the most senior water rights are able to divert the limited supplies, regardless of climate-adjusted hydrology, and the agricultural gaps are similar across all the Planning Scenarios.

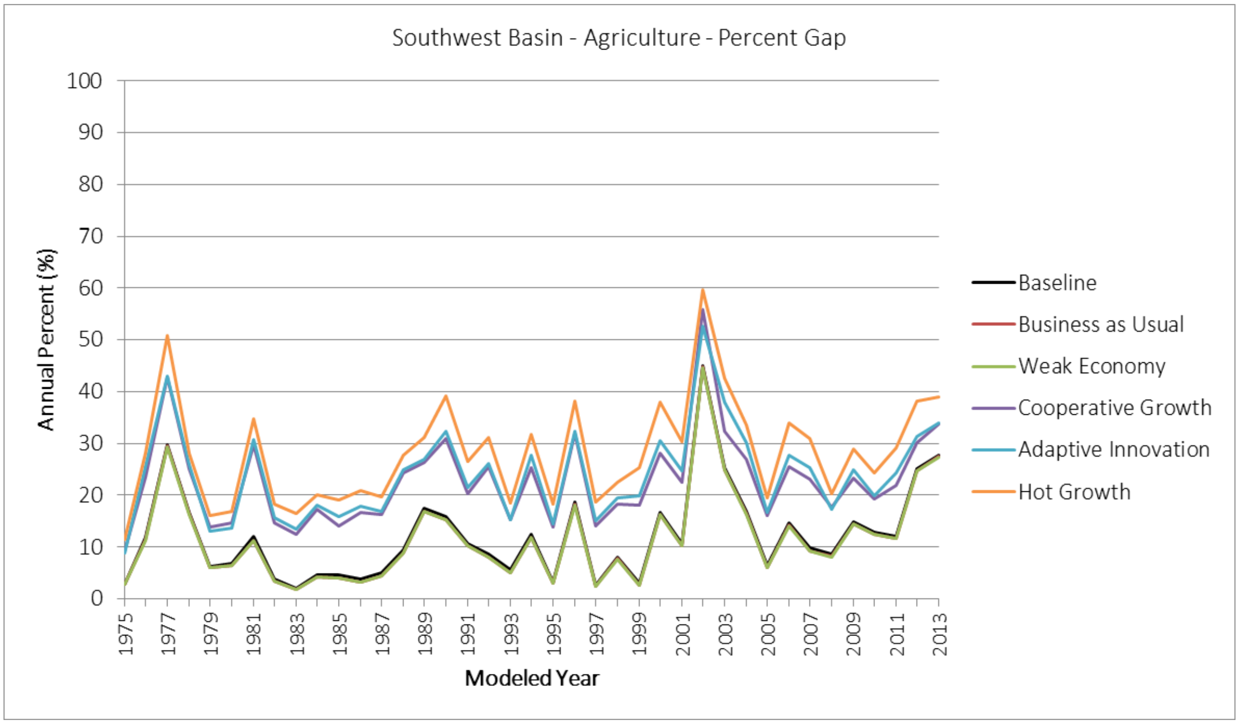


Figure 92: Southwest Basin Agriculture Percent Diversion Gap Times Series

5.7.2 SOUTHWEST BASIN M&SSI WATER SUPPLY AND GAP

Municipal demands in the Southwest Basin account for more than 90 percent of the total M&SSI demand in the basin, with the remaining 10 or less percent attributable to SSI demands in the basin. The SSI[16] in the basin is predominantly thermo-electric demands, with smaller snowmaking demands. From a percentage basis, the Southwest Basin has the largest projected increase in population of all basins throughout the state, ranging from 16 to 161 percent across Planning Scenarios. Much of this growth is projected to occur in La Plata County, which encompasses the larger communities of Durango, Bayfield, and Ignacio.

A majority of the M&SSI demands in the Southwest Basin are grouped and represented in the model at several general locations throughout the model. Municipal demands and surface water supplies, however, are modeled individually for the City of Durango, and the Towns of Rico, Mancos, Cortez, and Dolores. The M&SSI demands in the basin are low compared to the agricultural demand, reflecting 3 percent of the total demand in the basin. Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin was developed. The water supply and gap results for M&SSI in the Southwest basin are summarized in Table 33, and graphically reflected in Figure 93 through Figure 95.

[16] Note that water used for hydropower, such as those operations at Cascade Reservoir, Ames Hydro Project, and Nucla Power Diversion, are represented in the model but are not included in the SSI demand summaries (i.e. non-consumptive) and are not adjusted between Planning Scenarios.

Table 33: Southwest Basin M&SSI Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	27,182	44,760	30,238	43,267	53,968	69,464
Average	Average Annual Demand Increase from Baseline (ac-ft)	-	17,578	3,056	16,085	26,786	42,282
Average	Average Annual Gap (ac-ft)	40	3,325	385	4,100	7,770	13,438
Average	Average Annual Gap Increase from Baseline (ac-ft)	-	3,286	346	4,060	7,730	13,399
Average	Average Annual Percent Gap	0%	7%	1%	9%	14%	19%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	27,182	44,760	30,238	43,267	53,968	69,464
Critically Dry Maximum	Increase from Baseline Demand (ac-ft)	-	17,578	3,056	16,085	26,786	42,282
Critically Dry Maximum	Gap In Maximum Gap Year (ac-ft)	799	7,477	1,820	7,686	13,795	24,811
Critically Dry Maximum	Increase from Baseline Gap (ac-ft)	-	6,679	1,022	6,888	12,997	24,013
Critically Dry Maximum	Percent Gap In Maximum Gap Year	3%	17%	6%	18%	26%	36%

The M&SSI demand in the basin is projected to increase in all scenarios compared to the Baseline scenario due a projected increase in population by 2050 in the basin. Echoing the population projections, M&SSI demand is projected to increase moderately in the Weak Economy scenario compared to the Baseline demand but increase by nearly 60 percent in the Business as Usual and the Cooperative Growth scenarios and double and more in the Adaptive Innovation and Hot Growth scenarios.

As reflected in the table and graphics below, the M&SSI demand under the Baseline scenario experiences a gap in the critically dry years of 2002 and 2012, which is then reflected as a small gap on average. Ideally this scenario would have no M&SSI gaps because the current water supply should fully satisfy the Baseline level demands. These shortages are due to minor calibration issues potentially stemming from the representation of individual M&SSI demands at a grouped location; not accounting for ground water supplies (i.e. exempt wells); or drought restrictions imposed by the towns in the basin.

The M&SSI gap in the Weak Economy scenario is small, but consistent during average and below-average dry year types; the demand is fully satisfied during above-average wet years. The M&SSI gap for the Business as Usual and the Cooperative Growth scenarios vary based on year type as well, reflecting a 5 percent gap during wet years but significantly more gap during average and dry years. The M&SSI gap for the Adaptive Innovation and Hot Growth show chronic shortages for the entire study period indicating the decreased hydrology is not sufficient to meet the increased demands in even the wettest years.

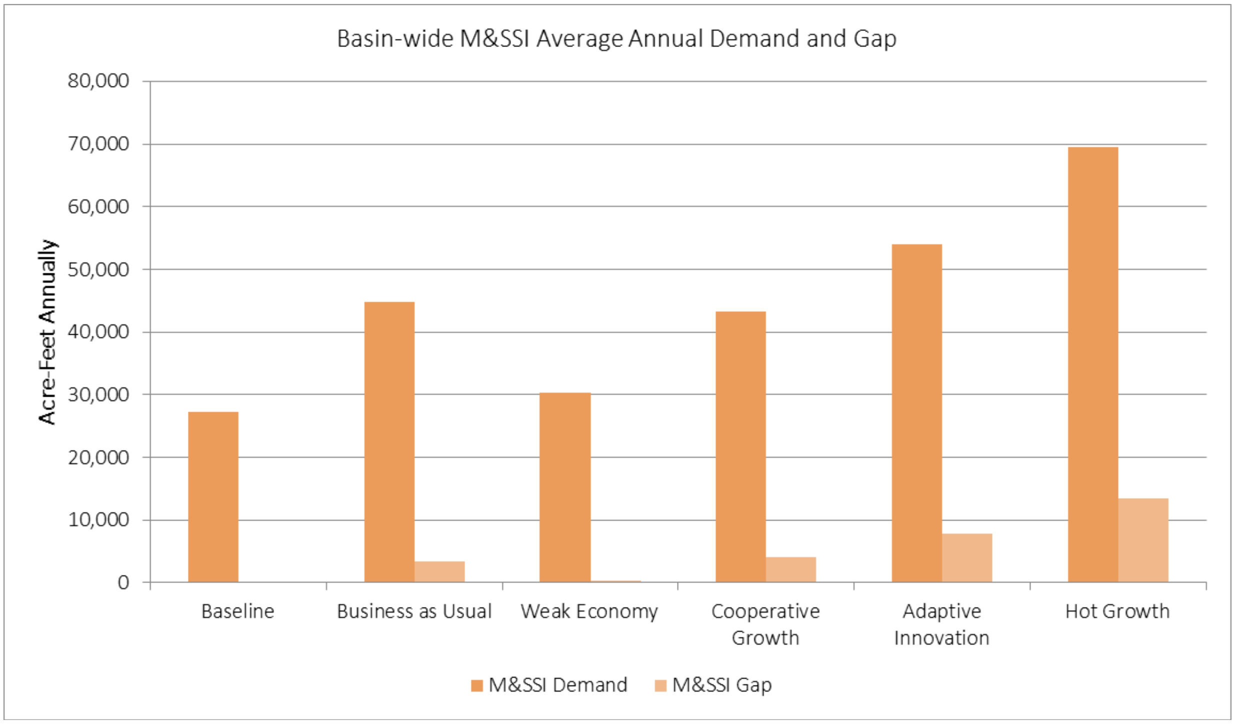


Figure 93: Southwest Basin M&SSI Average Annual Demand and Gap

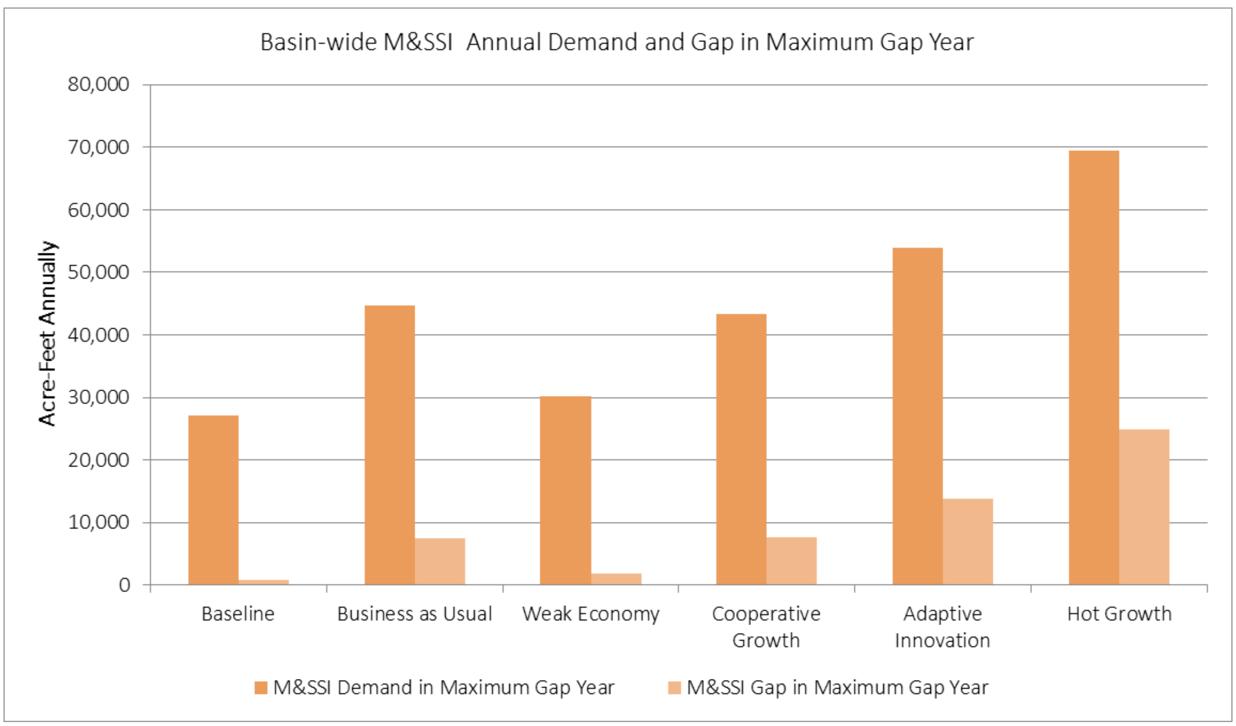


Figure 94: Southwest Basin M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

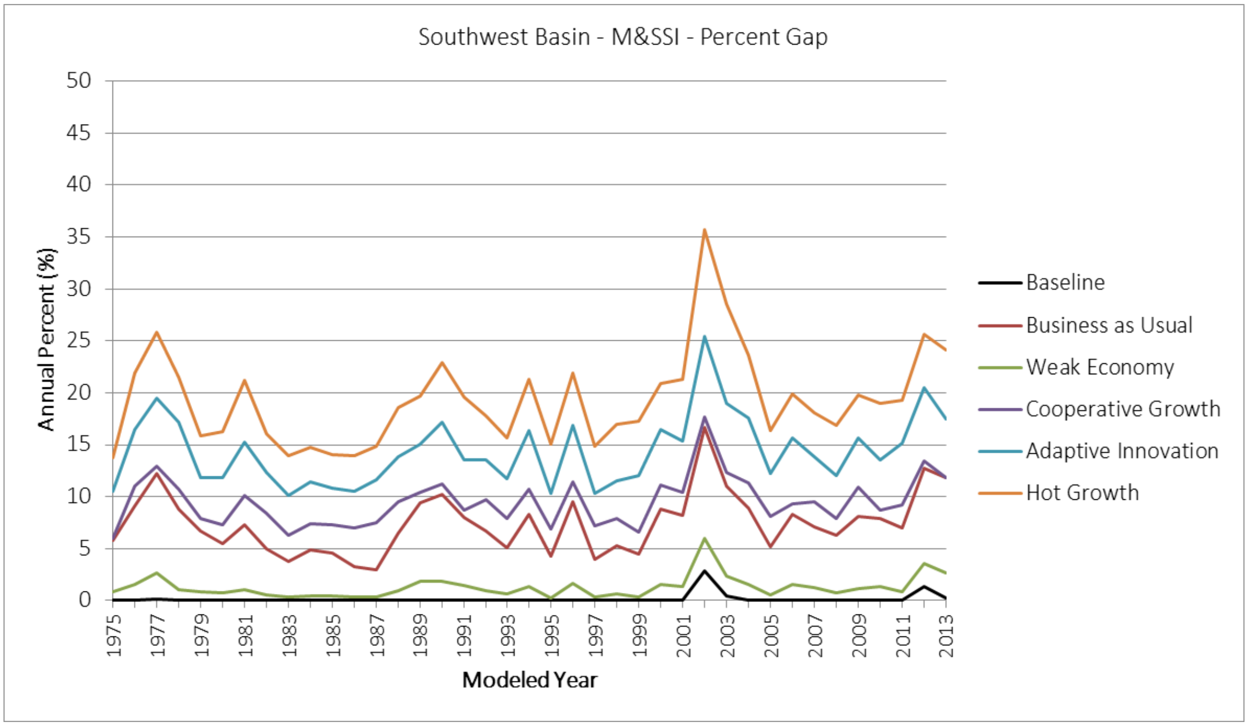


Figure 95: Southwest Basin M&SSI Average Annual Gap Time Series

5.7.3 SOUTHWEST BASIN TRANSBASIN EXPORTS

There are several transbasin diversions that export water from the headwaters of the San Juan, Piedra, Los Pinos, and Animas Rivers to the Gunnison and Rio Grande Basins. Total transbasin exports range from less than 200 ac-ft to nearly 5,800 ac-ft annually, depending on availability of in-basin supplies and the need for imported supplies in the Gunnison River and Rio Grande basins. On average, the transbasin export demand from the Southwest Basin is 2,245 ac-ft. These demands could not be satisfied in all Planning Scenarios; however the shortages are reflected as an import supply gap in the destination basin and not considered a gap in the Southwest Basin.

As noted above, the San Juan Chama Project delivers water from San Juan tributaries to the Rio Grande basin in New Mexico. The Baseline and Planning Scenario models include the current demand and operations, but the project deliveries are not considered a transbasin export under the Technical Update as the project does not operate under a Colorado water right; cannot call out Colorado water users; and the supply is not delivered to a Colorado entity.

5.7.4 SOUTHWEST BASIN SUMMARY

The combined agriculture and M&SSI demands and gap summary is provided in Table 34. The results are very similar to the agricultural results in Table 19, because water supplies in the Southwest Basin are predominantly used for agriculture. As previously discussed, water availability in the basin is widely variable from one sub-basin to the next, and the average basin results may not be indicative of conditions in more water short basins. With that in mind, the M&SSI gaps are relatively low on average in the Baseline, Business as Usual, and Weak Economy scenarios, however, become more substantial in critically dry years. The gaps both on average and during critically dry years become much larger for the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios, due to the climate-adjusted hydrology, particularly as the Adaptive Innovation demand actually decreases compared to the Baseline demand.

Figure 96 reflects the relative size of the agricultural, M&SSI, and transbasin demands in the Southwest Basin. The M&SSI and transbasin demands are difficult to reflect graphically on the same scale because they are significantly smaller than the agricultural demands. Following the graphic are summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage.

The Colorado River Basin Ten Tribes Partnership Tribal Water Study (TWS), completed in December, 2018, summarizes current tribal water use, projects future development of tribal water under a variety of growth scenarios and timeframes, and identifies tribal challenges and opportunities associated with the development of tribal water. The report indicated both municipal and agricultural growth for the Southern Ute Indian Tribe (SUIT) and the Ute Mountain Ute Tribe (UMUT) under the Current Water Development Trends for the 2040 and 2060 scenarios. The municipal growth projected in the TWS is captured in the M&SSI projections for the La Plata and Montezuma County demands. The agricultural growth from the TWS, however, was not represented in the Technical Update agricultural demands. The Technical Update relied on Basin Implementation Plans (BIP) to identify new irrigation projects. The agricultural growth projections in the TWS were developed after the completion of the Southwest BIP and after the agricultural demands were completed for Technical Update. The State recognizes the Tribes intent to fully develop their reserved water rights in the future, part of which may be used for agriculture. Future Tribal use should be incorporated into future Southwest BIP and subsequent Technical Updates.

Table 34: Southwest Basin Water Supply and Gap Summary

	Agricultural and M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,051,966	1,050,192	1,035,670	1,263,760	977,068	1,341,135
	Average Annual Gap (ac-ft)	126,682	123,622	120,145	280,833	226,769	368,520
	Average Annual Percent Gap	12%	12%	12%	22%	23%	27%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	1,180,140	1,175,860	1,161,338	1,258,452	953,228	1,307,667
	Gap In Maximum Gap Year (ac-ft)	518,355	514,849	506,757	687,185	487,808	762,916
	Percent Gap In Maximum Gap Year	44%	44%	44%	55%	51%	58%

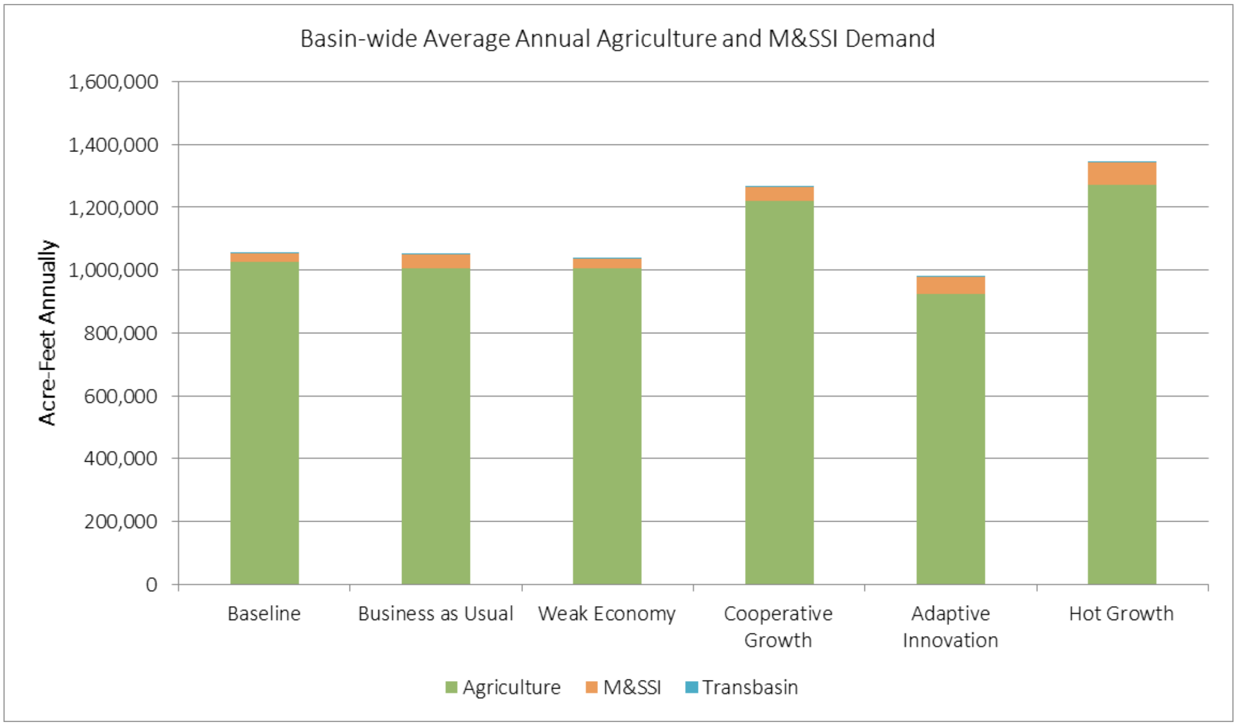


Figure 96: Southwest Basin Comparison of Average Agricultural, M&SSI and Transbasin Annual Demands

All Planning Scenarios project 3,800 acres of irrigated land will be taken out of production due to urbanization, as counties are projected to have municipal growth. Supplies used to irrigate the urbanized acreage could be considered a new municipal supply if the associated water rights were changed to municipal uses. To estimate this new supply, the average consumptive use of the urbanized acreage by Planning Scenario is reflected in Table 35. Note however that it is not known which farms and ranches will be directly impacted; whether the acreage was served by senior/junior/Tribal rights or had supplemental storage supplies; or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use or whether the supply could directly meet the future municipal demand or are located in a different sub-basin compared to the demand. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 35: Potential Water Supply from Urbanized Acreage in the Southwest Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage	3,800	3,800	3,800	3,800	3,800
Estimated Consumptive Use (ac-ft/year)	6,917	6,923	7,130	6,769	6,784

The Southwest Basin has approximately 700,000 ac-ft of total storage[17] used primarily to meet agricultural and M&SSI demands. Reservoirs represented individually in the model are listed below by sub-basin; the simulated contents of these reservoirs are reflected in Figure 97.

- San Miguel River basin: Gurley Reservoir, Miramonte Reservoir, Trout Lake, Lilylands Reservoir, Lone Cone Reservoir, and Lake Hope
- Dolores River basin: Groundhog Reservoir , McPhee Reservoir , Summit Reservoir, and Narraguinnep Reservoir
- San Juan River basin: Jackson Gulch Reservoir, Cascade Reservoir, Vallecito Reservoir, Lemon Reservoir, Ridges Basin Reservoir, Long Hollow Reservoir

As reflected, approximately 300,000 ac-ft of storage in the basin is not drawn down in any of the Planning Scenarios. This storage volume is largely attributable to inactive storage in the basin (e.g. 151,000 ac-ft in McPhee Reservoir) and the newly constructed Lake Nighthorse. Lake Nighthorse Reservoir, completed in 2012, was constructed to meet the requirements of the 1988 Colorado Ute Indian Water Rights Settlement Act and the Colorado Ute Settlement Act Amendment of 2000 by delivering water to both Colorado Ute Tribes as well as several non-tribal participants. The reservoir will be used to meet M&SSI demands for the Tribes, the City of Durango, and other water providers in Colorado and New Mexico in the future and infrastructure is being constructed to improve the delivery of those supplies. However, these operations are not reflected in the baseline model dataset. It is recommended that future analysis of potential solutions to the meet the gap incorporate Lake Nighthorse Reservoir operations.

The results reflect very little difference between the Baseline, Business as Usual, and the Weak Economy Planning Scenarios and the reservoir content results are overlapping in the graphic below. As the climate-adjusted hydrology decreased runoff volumes and increases agricultural demand in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios, the graph reflects more draw-down compared to the Baseline scenario. In addition to more draw-down, the reservoirs in the climate-adjusted scenarios have slightly longer post-drought recovery (e.g. early 1990s) and are not able to fully refill to the same content reached in the non-adjusted scenarios (e.g. late 2000s). As reservoirs are generally able to store water even if the peak runoff is shifted earlier in the year, these decreased reservoir contents are more indicative of the decreased runoff in the climate-adjusted scenarios.

[17] Total storage represents the total reservoir capacity for large operational reservoirs located within Colorado in the Southwest Basin. Therefore, Navajo Reservoir with a 1.7 million ac-ft capacity located primarily in New Mexico is excluded from this summary.

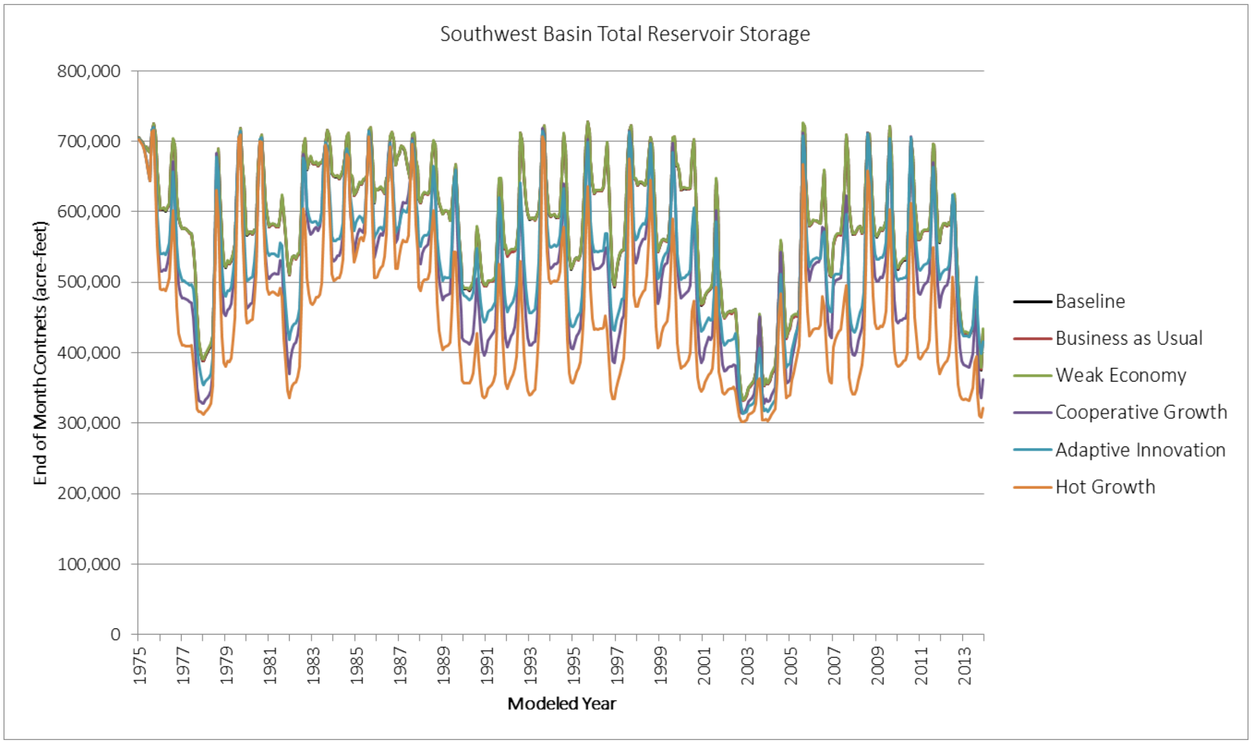


Figure 97: Southwest Basin Total Reservoir Storage

Figure 98 through Figure 105 reflect the simulated streamflow results for each Planning Scenario at key locations reflected on the basin map above. There are no significant differences in streamflow between the Baseline, Business as Usual, and the Weak Economy Planning Scenarios at the key locations, and the results are overlapping on the graphics. This result is expected due to relatively small changes in demands and no change in hydrology for these scenarios.

There are also limited differences between the Adaptive Innovation and Hot Growth scenarios, as the climate-adjusted hydrology is the same in these scenarios and serves as the primary driver on streamflow results in basins with limited changes in demands. The Los Pinos gaged location reflects the largest difference between these two scenarios, likely due to increased agricultural demands in the Pine River Irrigation District and storage operations of Vallecito Reservoir, which is an on-channel reservoir located in the headwaters of the tributary. The Cooperative Growth scenario results tend to track with the other climate-adjusted scenario results with slightly higher streamflow volumes. All the climate-adjusted scenarios reflect a substantial shift in the peak runoff, from June to May, at all locations except the Dolores River and Piedra River gages.

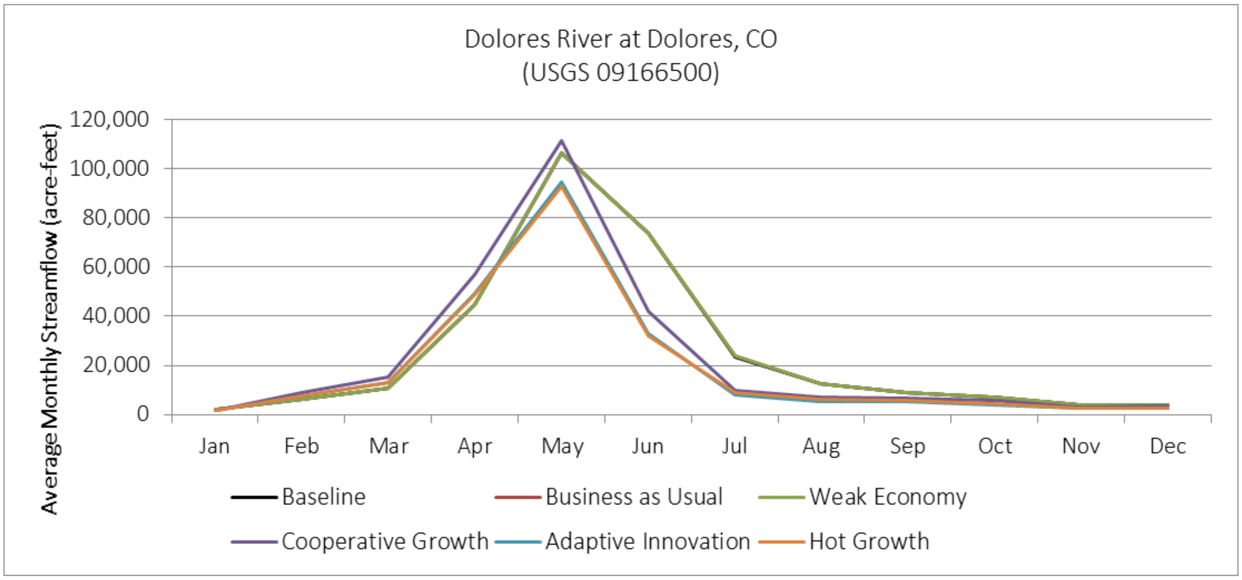


Figure 98: Average Monthly Streamflow at Dolores River at Dolores

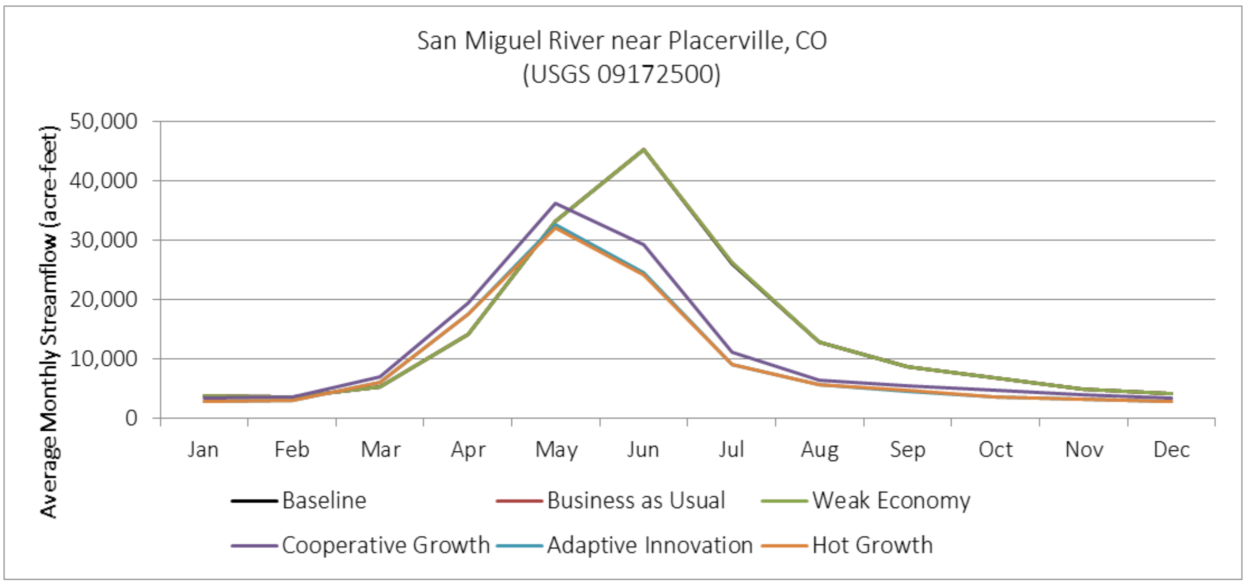


Figure 99: Average Monthly Streamflow at San Miguel River near Placerville

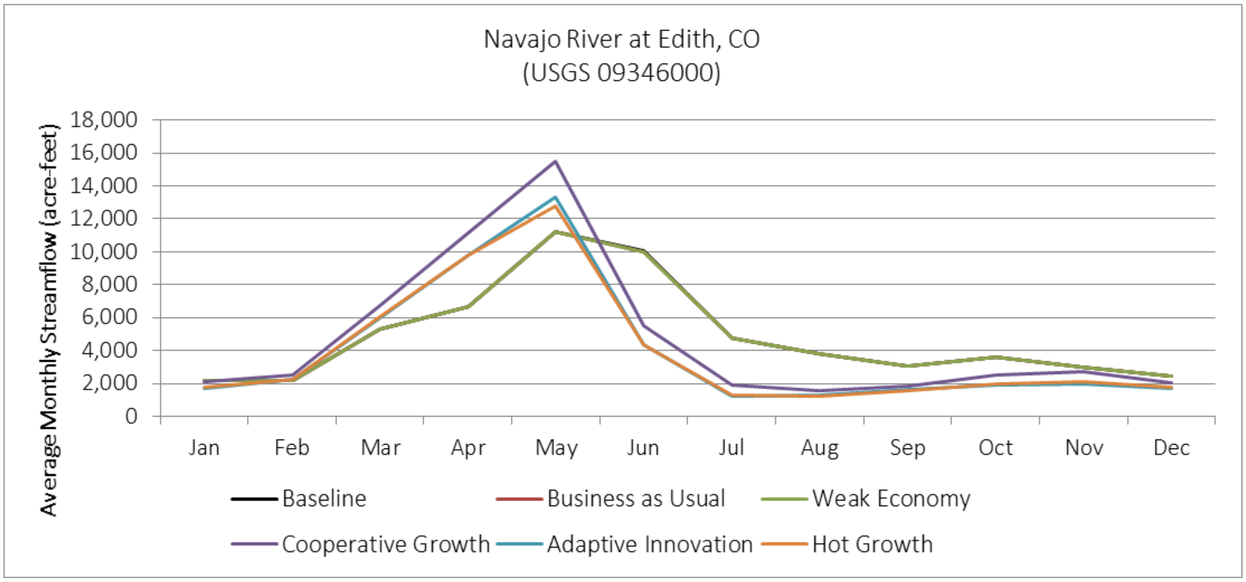


Figure 100: Average Monthly Streamflow at Navajo River at Edith

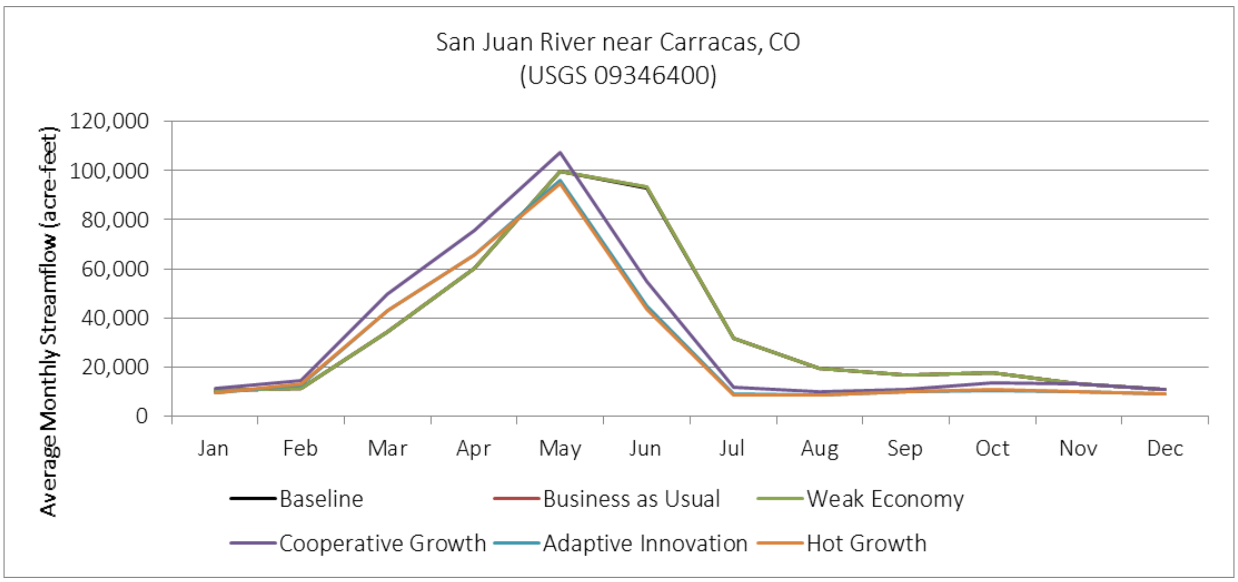


Figure 101: Average Monthly Streamflow at San Juan River near Carracas

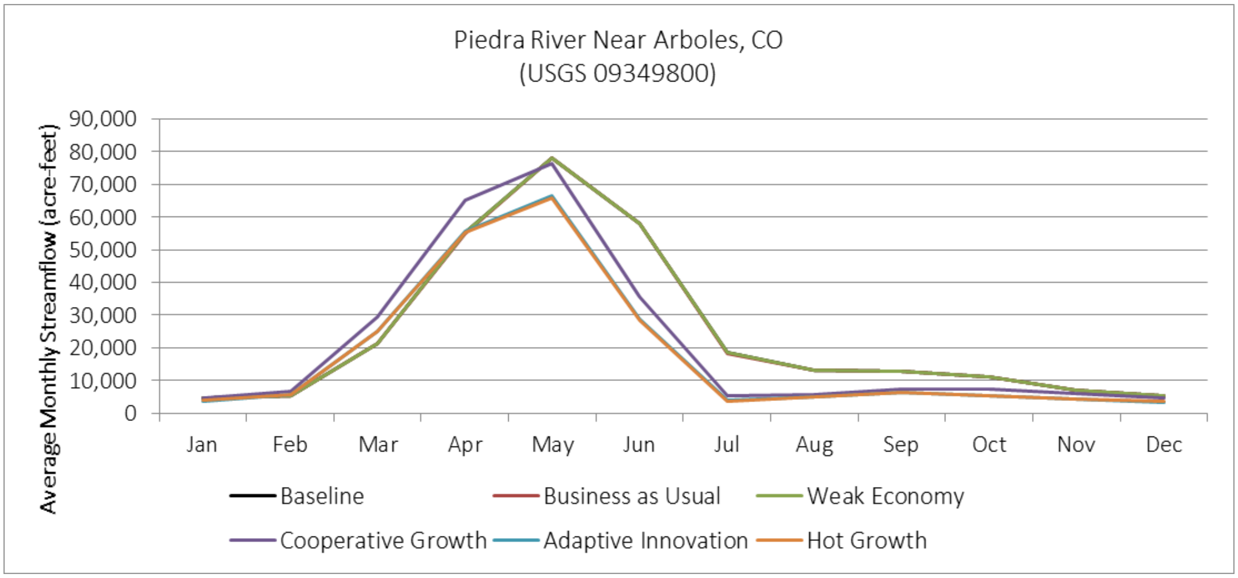


Figure 102: Average Monthly Streamflow at Piedra River Near Arboles

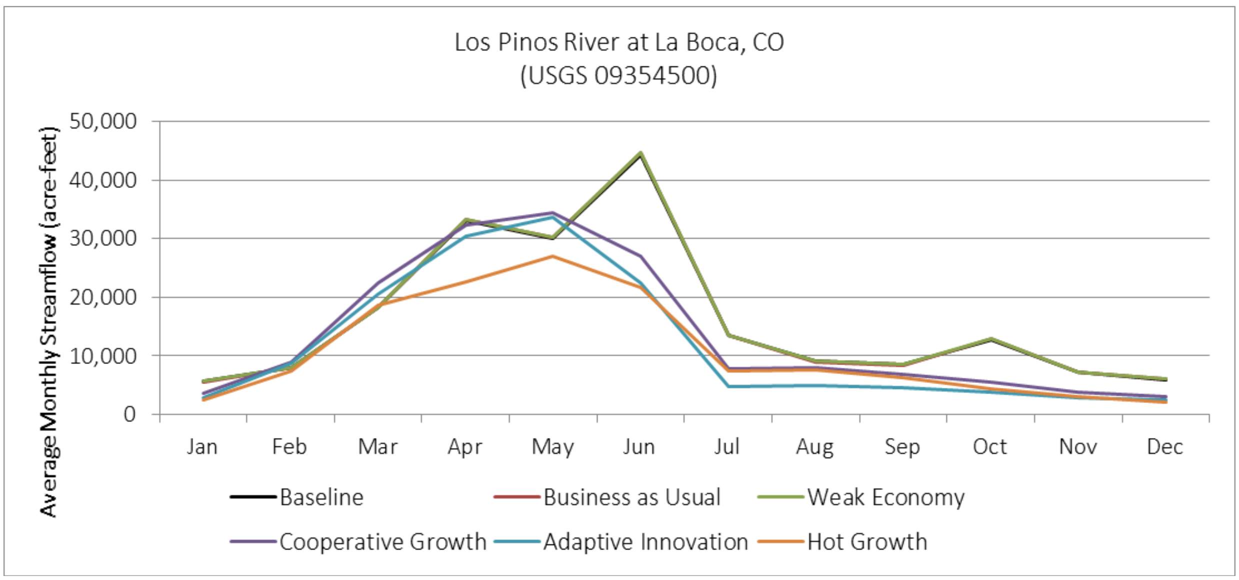


Figure 103: Average Monthly Streamflow at Los Pinos River at La Boca

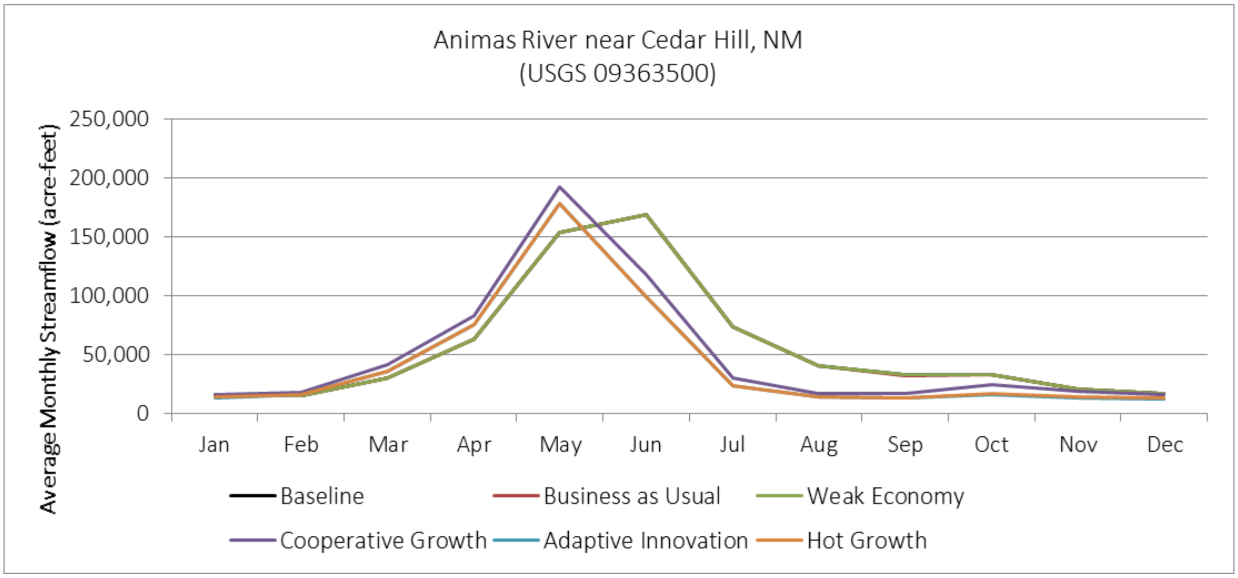


Figure 104: Average Monthly Streamflow at Animas River near Cedar Hill

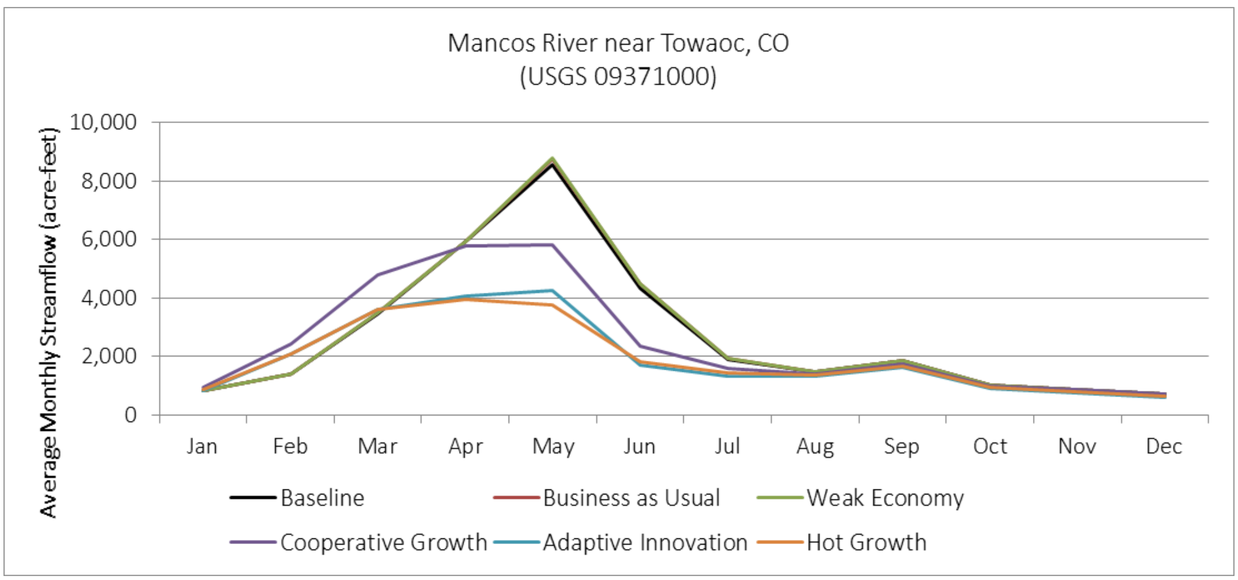


Figure 105: Average Monthly Streamflow at Mancos River near Towaoc

Figure 106 through Figure 109 reflect simulated unappropriated available supply for the Southwest Basin at two locations to illustrate the difference in hydrology and water availability across the multiple sub-basins. The Animas River at Durango gage is located just upstream of the Durango Boating Park, which is a recreational instream flow water right and demand of 1,400 cfs. Available flow greatly increases downstream of the Boating Park reach. Conversely, the La Plata River produces very little runoff and demands on the river chronically experience shortages due to physical flow limitations and curtailment due to the La Plata Compact. At both of the locations, unappropriated available supply are projected to diminish and peak flows are projected to occur earlier in the runoff season under climate-adjusted Planning Scenarios. Unappropriated available supply is limited or essentially zero during the winter months and during critically dry years at both locations.

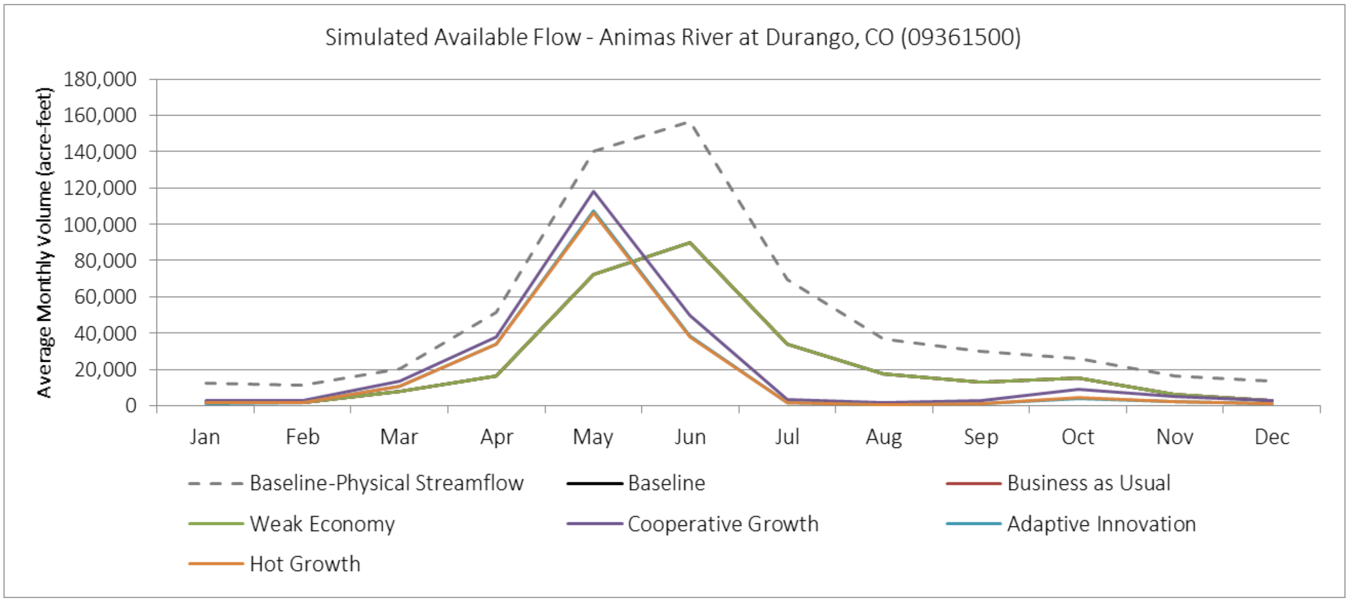


Figure 106: Average Monthly Unappropriated Available Supply at Animas River at Durango

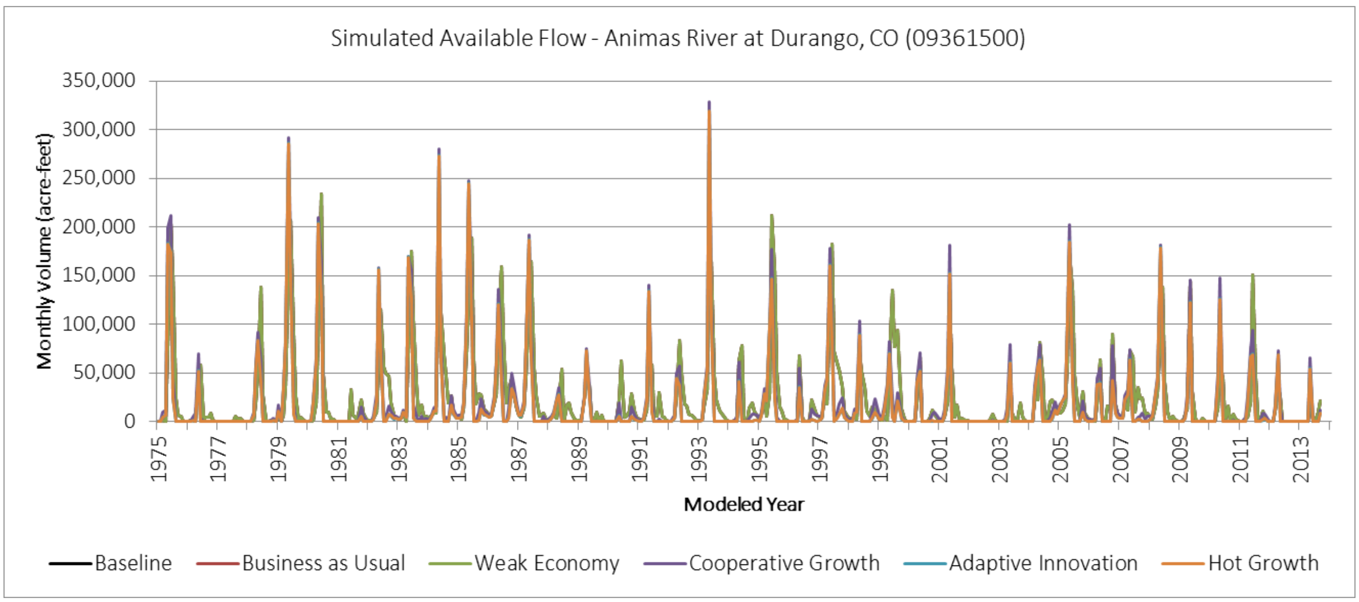


Figure 107: Monthly Unappropriated Available Supply at Animas River at Durango

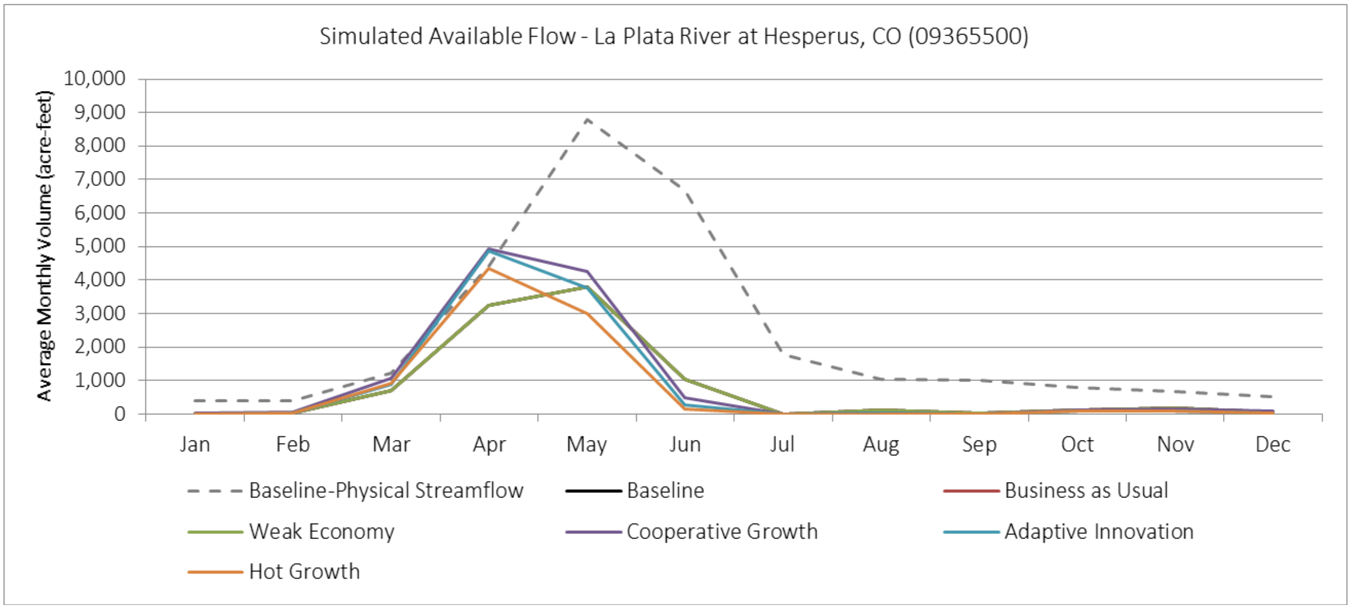


Figure 108: Average Monthly Unappropriated Available Supply at La Plata River at Hesperus

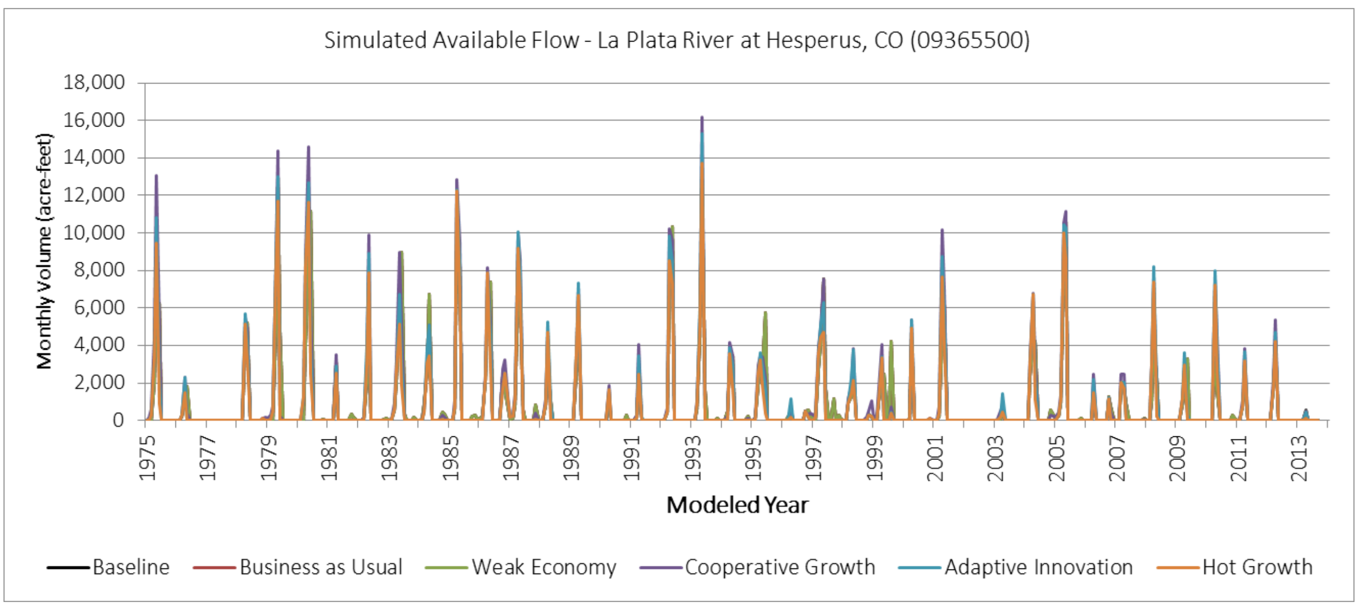
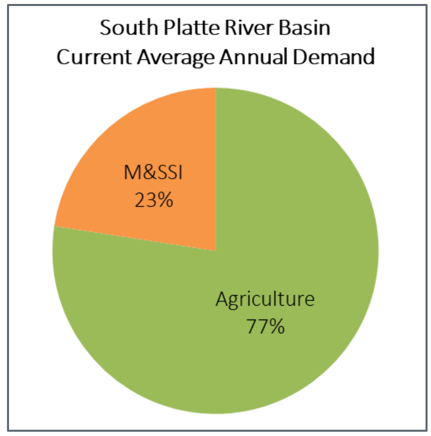


Figure 109: Monthly Unappropriated Available Supply at La Plata River at Hesperus

5.8 SOUTH PLATTE RIVER BASIN

The South Platte River basin is home to the vast majority of Colorado's population and has more irrigated acreage than any other basin. The South Platte River starts in the high mountain meadows of South Park, fueled by snowmelt. The river flows out of the mountains and heads north as it runs through the Front Range metropolitan corridor. Along the way, it is fed by several large tributaries, including Clear Creek, Boulder Creek, St. Vrain Creek, Big Thompson River, and Cache La Poudre River. The South Platte River then turns east and crosses the plains before leaving the northeast corner of Colorado to Nebraska. The natural hydrology of the river is highly variable, and the growing demands in the basin turned to transbasin supplies and ground water resources to supplement supplies from the river.



Over three-quarters of the total demand in the South Platte River is associated with irrigated agriculture, with the remaining quarter of demand tied to M&SSI uses. There are over 850,000 acres of irrigated land in the basin, located both in the tributary sub-basins and along the mainstem, primarily downstream of the Denver metropolitan area. Irrigators along the tributaries rely on surface water supplies and reservoir storage to meet agricultural demand, with limited ground water supplies. Acreage lower in the basin is served by surface water supplies, several large agricultural reservoirs, and supplemental ground water supplies. Agricultural and, recently to a larger extent, M&SSI users along the Big Thompson River, Cache La Poudre River, St. Vrain Creek, Boulder Creek, and South Platte River mainstem also benefit from transbasin supplies from the Colorado-Big Thompson (C-BT) Project.

Several major municipal areas are located in the South Platte River Basin, with the largest being the City of Denver and the surrounding metropolitan area. Other larger municipalities along the Front Range corridor include Boulder, Loveland, Longmont, Fort Collins, and Greeley. The basin is projected to have the largest M&SSI growth in the State, with a majority of this growth projected within this I-25 corridor. M&SSI water providers in the basin rely on surface and ground water supplies, several municipal reservoirs, and are supplemented with transbasin supplies.

Similar to the Arkansas, Republican, and Rio Grande Basins, ground water supplies are an important source of supply in the South Platte River basin. Relatively shallow wells pump ground water supplies from the alluvial aquifer, largely along the mainstem of the lower South Platte River. Alluvial supplies are generally pumped under junior water rights and depletions must be augmented to avoid injuring the senior water right holders. Maintaining sufficient augmentation supplies in the future will be critical for continued use of alluvial ground water. Deeper wells higher up in the basin pump water from the Denver Basin aquifer system, a series of stacked aquifer layers that are largely disconnected from the overlying river system. This disconnection means that the pumped supplies do not have to be augmented to the same degree as alluvial supplies, but also means that recharge of the aquifer is limited and depletions have exceeded recharge rates.

The following sections describe the agricultural and M&SSI demands in the South Platte River basin in more detail. Figure 110 reflects the basin outline, the administrative boundaries of water districts, and the streamflow gages highlighted in the results section below.

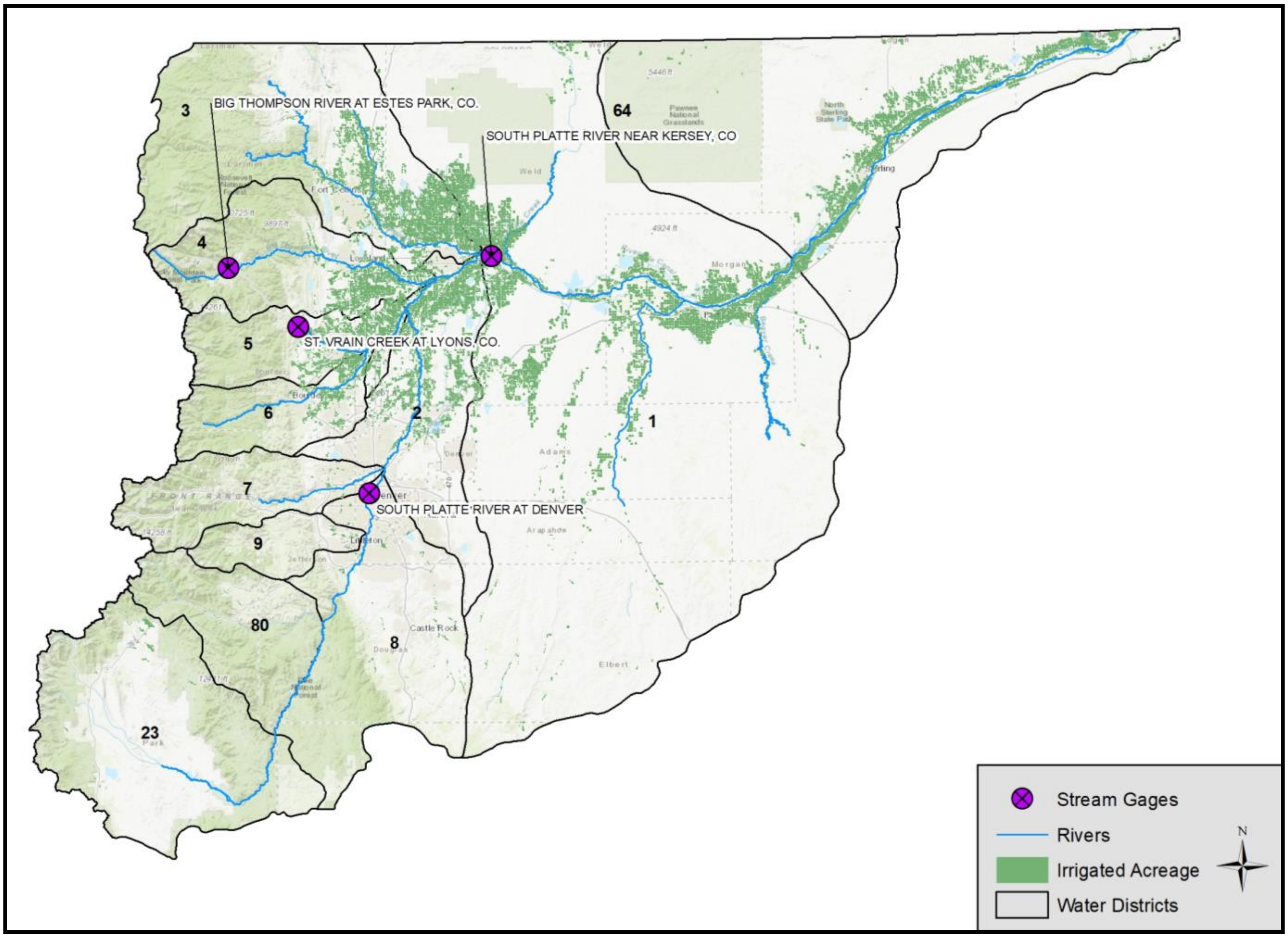


Figure 110: South Platte River Map with Streamgage Locations

5.8.1 SOUTH PLATTE RIVER BASIN AGRICULTURE WATER SUPPLY AND GAP

Irrigated agriculture varies across the basin. High elevation ranches grow hay and alfalfa to support cattle operations. Lower in the basin, agriculture benefits from warmer temperature and a longer growing season and crops include corn, beans, vegetables, potatoes, sugar beet, and various grains. Irrigated agriculture benefits from the most senior water rights in the basin, however native South Platte River supplies are often not sufficient to meet the crop demand for the full irrigation season. As such, surface water supplies are supplemented by releases from reservoirs, ground water supplies, and transbasin supplies.

Irrigated acreage in the basin steadily increased between the 1950s to the 1980s, driven by the development of supplemental transbasin and ground water supplies, reaching over 1 million acres. Irrigated acreage in the basin then began to decline, due in part to the transfer of agricultural water rights over to municipalities (i.e. “buy and dry”). The drought of the mid-2000s resulted in another decline in irrigated acreage as augmentation supplies were not sufficient to cover well depletions and acreage served solely by ground water were taken out of production. Current levels of irrigation are near 850,000 acres, although this projected to substantially decline by 2050.

The South Platte River Basin agricultural diversion demands, demand gaps, and consumptive use gaps results for the baseline and Technical Update Planning Scenarios are presented in Table 36. As discussed in the *Current and 2050 Planning Scenario Agricultural Diversion Demand* technical memorandum, 2050 agricultural diversion demands are influenced by a number of drivers, including climate, urbanization, planned agricultural projects, and emerging technologies.

Table 36: South Platte River Basin Agricultural Water Supply and Gap Summary

	Agricultural Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	2,465,767	1,988,661	1,988,661	2,157,439	1,696,494	2,063,094
Average	Average Annual Demand Increase from Baseline (ac-ft)	-	-	-	-	-	-
Average	Average Annual Gap (ac-ft)	506,724	404,936	402,121	402,055	378,256	444,016
Average	Average Annual Gap Increase from Baseline (ac-ft)	-	-	-	-	-	-
Average	Average Annual Percent Gap	21%	20%	20%	19%	22%	22%
Average	Average Annual CU Gap (ac-ft)	277,969	220,376	218,718	220,309	237,796	247,633
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	2,982,292	2,411,177	2,411,177	2,419,670	2,006,209	2,360,925
Critically Dry Maximum	Increase from Baseline Demand (ac-ft)	-	-	-	-	-	-
Critically Dry Maximum	Gap In Maximum Gap Year (ac-ft)	1,206,124	978,381	960,652	901,935	824,750	1,064,020
Critically Dry Maximum	Increase from Baseline Gap (ac-ft)	-	-	-	-	-	-
Critically Dry Maximum	Percent Gap In Maximum Gap Year	40%	41%	40%	37%	41%	45%

The average annual agricultural demand decreases approximately 477,000 ac-ft from the Baseline to the Business as Usual and Weak Economy Planning Scenarios. Both Planning Scenarios assume 148,400 acres of irrigated land is taken out of production due to urbanization basin-wide and “buy and dry” practices in the Lower South Platte. Additionally, 20 percent or 4,800 acres of ground water irrigated acreage is projected to be taken out of production because of lack of augmentation supplies. This is a total reduction of 153,200 acres. Total agricultural demand also declines due to projected sprinkler development in the basin. The agricultural gaps on average are substantial, estimated to be 400,000 ac-ft, and are projected to more than double during critically dry years. Note however, that despite the decline in agricultural demand, the percent gap in these two scenarios is similar to Baseline conditions, indicating the remaining irrigated acreage projected gap levels are consistent with currently experienced shortages.

The Cooperative Growth scenario is projected to have the largest agricultural demand compared to all Planning Scenarios, however it is still substantially less than the Baseline demand. The Cooperative Growth scenario assumes a total of 127,100 acres of irrigated land is taken out of production due to urbanization and projected “buy and dry” trends, with an additional 4,800 acres removed because of lack of augmentation supplies. This scenario also projects sprinkler development, further reducing the agricultural demand. Adjustments to IWR under the In-Between climate conditions, however, increase the crop demand of the remaining acreage, moderately increasing the agricultural demand in the scenario. The average annual gap volume is about the same as the previous scenarios. Adjustments to hydrology under the In-Between climate conditions do not generally result in lower annual streamflow volumes. Rather, the average annual streamflow at many locations is projected to slightly increase compared to current hydrology. The pattern of streamflow throughout the year shifts at some locations, however agricultural and M&SSI storage in the basin largely mitigates the effect of this shift in timing.

The Adaptive Innovation scenario is projected to have the lowest agricultural demand. The projected reduction to irrigated acreage is the same as that projected in the Cooperative Growth scenario. The emerging technology factors in this scenario substantially reduce the agricultural demand by partially mitigating the effects of the Hot and Dry climate conditions on crop demand and improving irrigation system efficiency. The projected agricultural demand in the scenario is nearly 1,700,000 ac-ft annually, or approximately 770,000 ac-ft less than the Baseline demand. Volumetrically, the agricultural gap in the Adaptive Innovation scenario is less than all other scenarios. The percent gap, however, is similar to the percent gap projected for other basins, indicating that despite the lower demand, irrigated acreage is still projected to experience similar patterns of shortages (e.g. late irrigation season shortages, larger gaps during dry years) largely due to the reduced hydrology under the Hot and Dry climate conditions.

The Hot Growth scenario is projected to have the greatest amount of irrigated acreage removed due to urbanization and “buy and dry” trends, resulting in an agriculture demand of approximately 2.06 million ac-ft annually. Similar to other Planning Scenarios, this scenario projects 105,900 acres will be removed from production due to urbanization and 4,800 acres of ground water irrigated acreage will be taken out of production because of lack of augmentation supplies. This scenario also projects 63,700 acres served by surface water will be removed due to “buy and dry” trends in the Lower South Platte, bringing the total reduction in the basin to 174,400 acres. This reduction, along with sprinkler development in the Lower South Platte River basin, offsets the increase in demand due to the climate adjustment to IWR under the Hot and Dry conditions. Streamflow is projected to decline under the Hot and Dry hydrology, resulting in the largest gaps on average, and gaps in critically dry years that exceed 1 million ac-ft. Despite the significant reduction to demand, the gaps are nearing those currently experienced by producers in the basin.

The average gap and gap during critically dry years relative to the demand is reflected in Figure 111 and Figure 112. The Planning Scenario results, both demand and gap values, do not substantially differ across the Planning Scenarios, largely due to the substantial reductions to irrigated acreage across all scenarios. Figure 113 reflects the percent of basin-wide agricultural gap across a variety of wet, average, and dry year types. As reflected, the drought beginning in the early 2000s produces the largest percent gaps in all scenarios. The separation of results following the peak in 2002 is largely due to hydrological conditions; slightly increased hydrology in the Cooperative Growth scenario leads to a smaller gap, particularly compared to the climate-adjusted Adaptive Innovation and Hot Growth scenarios. Gap results are also impacted by the availability of supplemental storage, ground water, and transbasin supplies, discussed in more detail Section 5.8.3. The largest separation of results across the Planning Scenarios is experienced by the Adaptive Innovation and Hot Growth, which tend to project larger gaps during the average to above-average hydrological year types in the early and late 1990s due to the climate-adjusted hydrology.

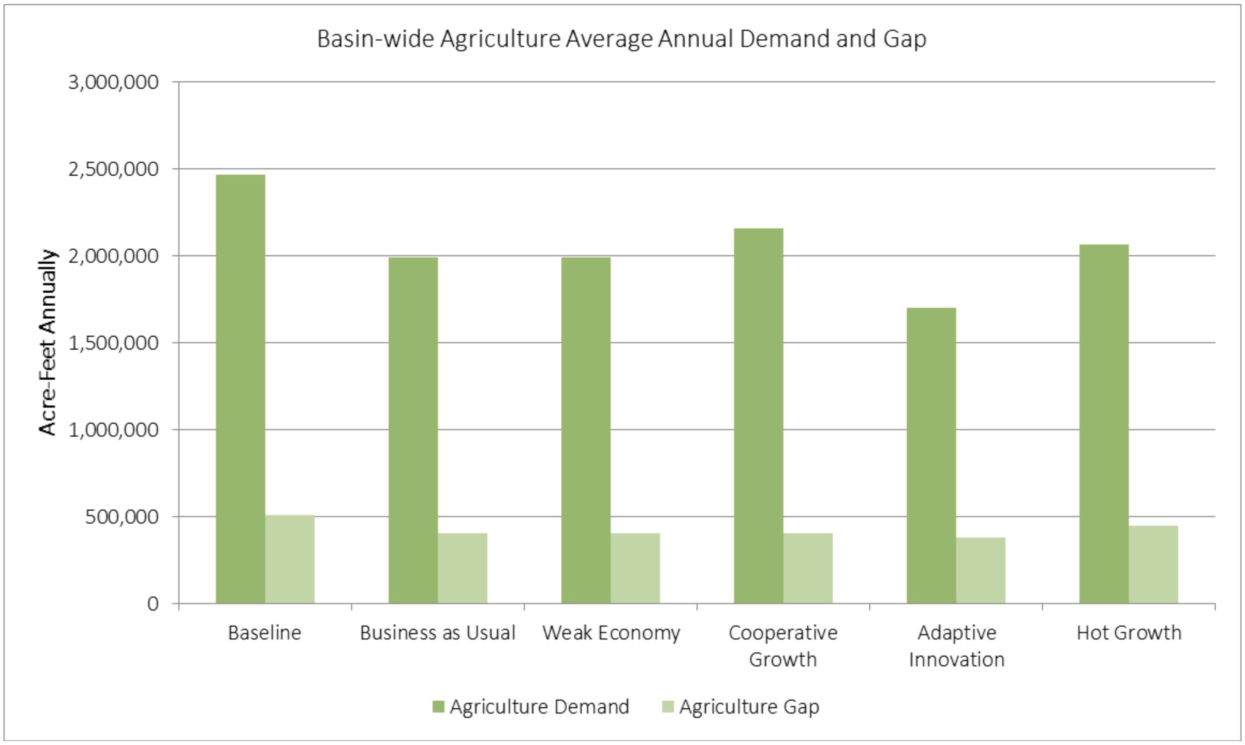


Figure 111: South Platte River Basin Agriculture Average Annual Demand and Gap

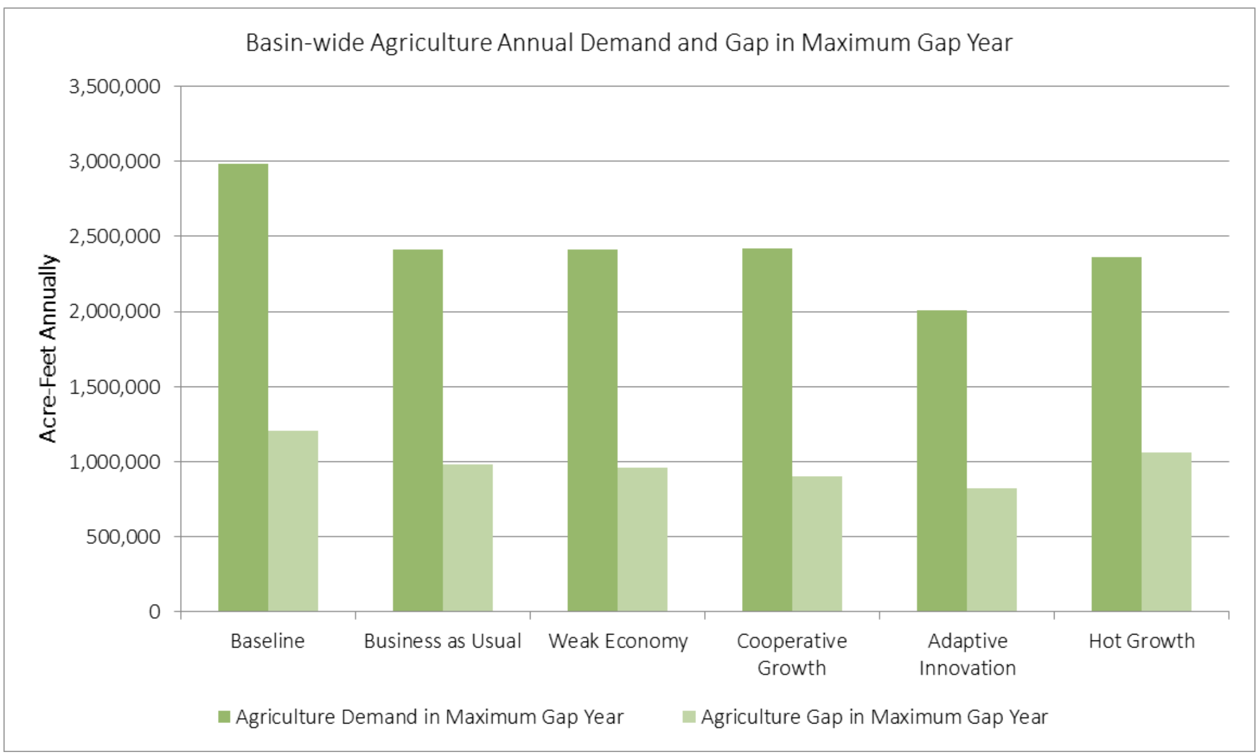


Figure 112: South Platte River Basin Agriculture Annual Demand and Gap in Maximum Gap Year

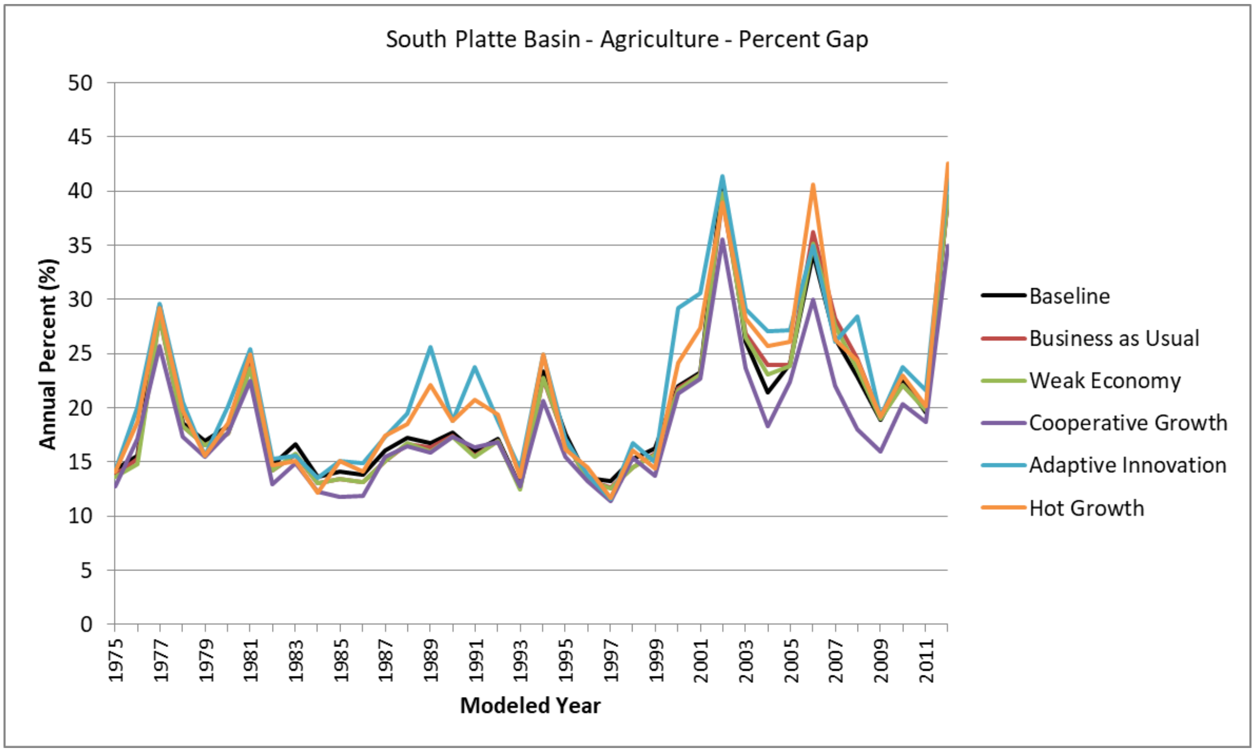


Figure 113: South Platte River Basin Agriculture Percent Diversion Gap Times Series

5.8.2 SOUTH PLATTE RIVER BASIN M&SSI WATER SUPPLY AND GAP

The South Platte River basin currently has the largest M&SSI demand of any basins in the state, representing nearly a quarter of the total demand for water in the basin. Of the total demands, approximately 90 percent can be attributed to municipal demands, with the remaining 10 percent attributable to SSI demands in the basin.

The municipal demands are largest in counties which encompass the larger cities along Front Range corridor, including Adams, Arapahoe, Denver, Jefferson, Larimer, and Weld. Population is projected to substantially increase in all Planning Scenarios, driving an increase in municipal demands by 2050. Of the total municipal demands, approximately 40 percent are represented in the model at grouped locations and the remaining 60 percent is represented in the model using the municipalities' individual demands, water rights, and operations. Entities represented individually in the model include:

- City of Arvada
- Aurora Water
- Denver Water
- City of Englewood
- Town of Estes Park
- Town of Fort Morgan
- City of Golden
- City of Lafayette
- City of Longmont

- City of Loveland
- City of Louisville
- City of Northglenn
- South Adams County Water and Sanitation District Boulder
- Town of Sterling
- City of Thornton
- City of Westminster

The SSI[18] in the basin is predominantly large industry and thermos-electric demands, with smaller demands for snowmaking. Similar to the municipal demands, the SSI demands can be modeled individually or at grouped locations. SSI operations represented individually in the model include:

- Arapahoe Power Plant
- Cherokee Power Plant
- Coors Brewery
- Eldora Ski Resort
- St. Vrain Power Plant
- Loveland Ski Area
- Valmont Power Plant
- Metropolitan Golf Courses

As discussed in the Water Supply Methodology section, the baseline model reflects one representation of the current water rights portfolio, infrastructure, available storage, and operations for the individually represented M&SSI entities. This representation does not capture the full flexibility of the water resources operations available to the entities, and in some cases, may not represent all of the entities' currently owned supplies if they have yet to be developed. The model representation was developed to capture the predominant operations that typically occur during average years. As such, this model may not fully capture operations the M&SSI entities may use during drought years.

Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin were developed. The water supply and gap results for M&SSI in the South Platte River basin are summarized in Table 37, and graphically reflected in Figure 114 through Figure 116.

[18] Note that water used for hydropower, such as those operations for the Colorado-Big Thompson Project, are represented in the model but are not included in the SSI demand summaries (i.e. non-consumptive) and are not adjusted between Planning Scenarios.

Table 37: South Platte M&SSI Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	718,737	1,073,023	968,879	1,002,775	1,070,141	1,257,699
	Average Annual Demand Increase from Baseline (ac-ft)	-	354,286	250,142	284,038	351,405	538,962
	Average Annual Gap (ac-ft)	1,882	192,812	136,573	159,843	221,361	390,565
	Average Annual Gap Increase from Baseline (ac-ft)	-	190,930	134,692	157,961	219,479	388,683
	Average Annual Percent Gap	0%	18%	14%	16%	21%	31%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	720,019	1,074,305	970,162	1,004,057	1,070,160	1,257,717
	Increase from Baseline Demand (ac-ft)	-	354,286	250,142	284,038	350,141	537,698
	Gap In Maximum Gap Year (ac-ft)	17,323	256,318	184,473	213,331	333,157	540,743
	Increase from Baseline Gap (ac-ft)	-	238,995	167,150	196,008	315,834	523,420
	Percent Gap In Maximum Gap Year	2%	24%	19%	21%	31%	43%

As reflected in the table, the Baseline scenario reflects a small M&SSI gap. Ideally, the Baseline scenario would have no M&SSI gaps as the current conditions in the basin satisfy the existing M&SSI demands. As these gaps only occur during dry years, the small amount of shortages is likely due to the representation of average year operations that may not account for watering restrictions or other drought operations implemented by municipal entities.

The average annual demand increases from the Baseline scenario to the Business as Usual scenario by approximately 354,000 ac-ft annually, primarily due to the increase in municipal demands driven by substantial population growth. The annual gap is 18 percent on average and increases to 24 percent, or 256,000 ac-ft annually, during critically dry years. This indicates that approximately 70 percent of the total increased M&SSI demand could not be satisfied under drought conditions. There is limited unappropriated flow in the South Platte River basin on average, and generally no unappropriated flow during dry years. As such, it is expected that any increased demands that could not be met under an entities' existing water rights portfolio and operations, would be significantly shorted.

The Weak Economy scenario reflects the smallest increase in M&SSI demand of any Planning Scenario, however the scenario still reflects a 25 percent increase compared to the Baseline demand. The corresponding gaps are also the smallest of any Planning Scenario, but still substantial. Similar to the Business as Usual scenario, more than 50 percent of the increased M&SSI demand is shorted on average and over 70 percent is shorted during critically dry years.

The Cooperative Growth scenario projects an increase to M&SSI demand of approximately 284,000 ac-ft annually, again driven largely by population growth in the basin. The Planning Scenario also reflects the climate-adjusted hydrology under the In-Between conditions. Recall from the agricultural results discussion that the In-Between hydrology increases the average annual streamflow volume in some locations. Therefore, the gaps are more similar to the scenarios using the current hydrology.

The level of M&SSI demand in the Adaptive Innovation scenario is very similar to the Business as Usual scenario. Recall that the agricultural demands are smaller in the Adaptive Innovation scenario, allowing more water available to the M&SSI demands on average. Even with the climate-adjusted hydrology under Hot and Dry conditions, the average annual gap is only slightly larger than the Business as Usual scenario gap. The Adaptive Innovation scenario reflects more a substantial gap during critically dry years, in which 95 percent of the increased M&SSI demand was shorted. This maximum gap is related to the decline in hydrology under the Hot and Dry hydrology.

The Hot Growth has both the largest M&SSI demand and gap compared to any other scenario. M&SSI demand increases by approximately 539,000 ac-ft. The demand is again driven primarily by population growth, but also reflects moderate increases to SSI demands and to the per-capita municipal demand. The streamflow declines under the Hot and Dry conditions, which coupled with the increased demands, leads to a 31 percent gap on average. The gap during critically dry years exceeds 540,000 ac-ft, larger than the increased M&SSI demand projected for the scenario. This indicates that from a basin-wide perspective, all of the projected increased demand as well as a small amount of existing demand may not be satisfied under this scenario in 2050.

As reflected in the Figure 114 and Figure 115, the M&SSI demand in the South Platte River basin is projected to experience substantial gaps under many of the Planning Scenarios, particularly those with climate-adjusted hydrology. There is essentially no unappropriated flow available in the South Platte River during drought years; however, municipal entities' existing water supply portfolios and storage were able to meet a portion of the increased demand during critically dry years. In many areas, these basin-level results cannot be translated to a sub-basin or entity level, as M&SSI water providers are impacted differently throughout the basin. On a percentage basis, municipal water providers with water supplies in Water Districts 4 and 5 are projected to have the lowest average annual gap, whereas providers with water supplies in Water Districts 2 and 7 have the highest average annual gap in the Hot Growth scenario. Systems that depend on ground water supplies are also particularly vulnerable to gaps in the Planning Scenarios due to limited augmentation supplies.

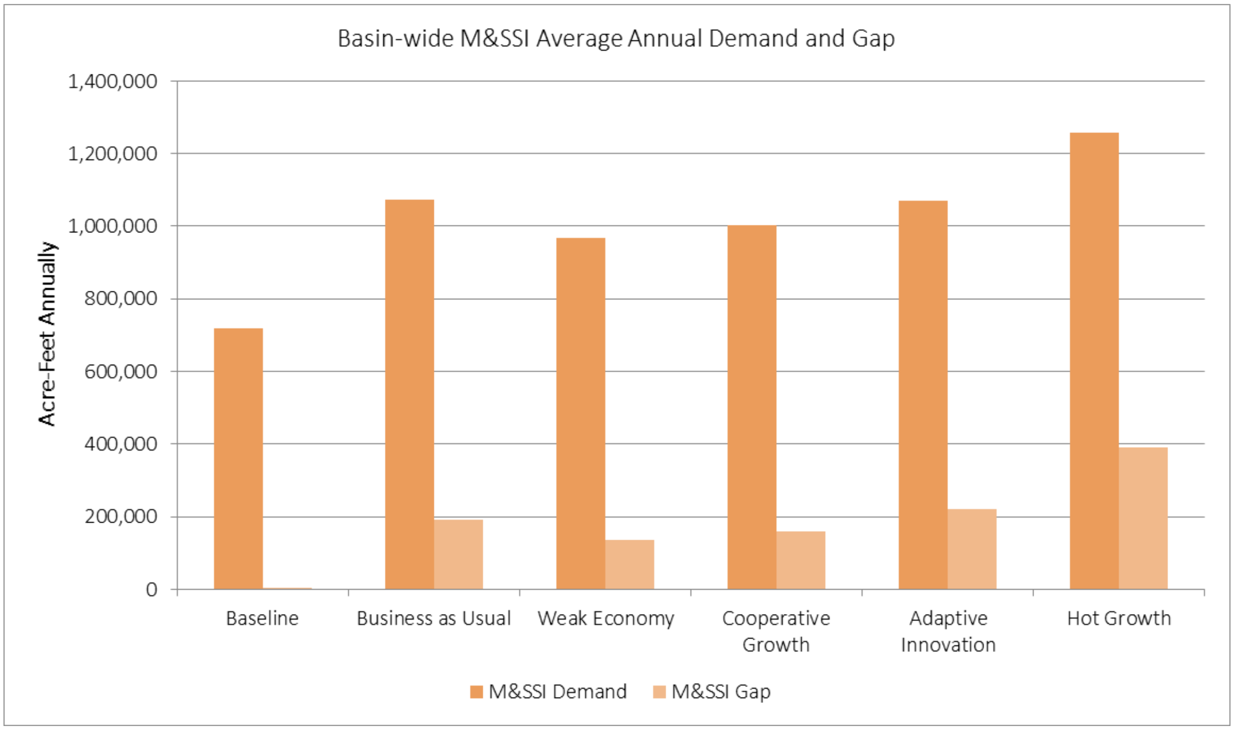


Figure 114: South Platte M&SSI Average Annual Demand and Gap

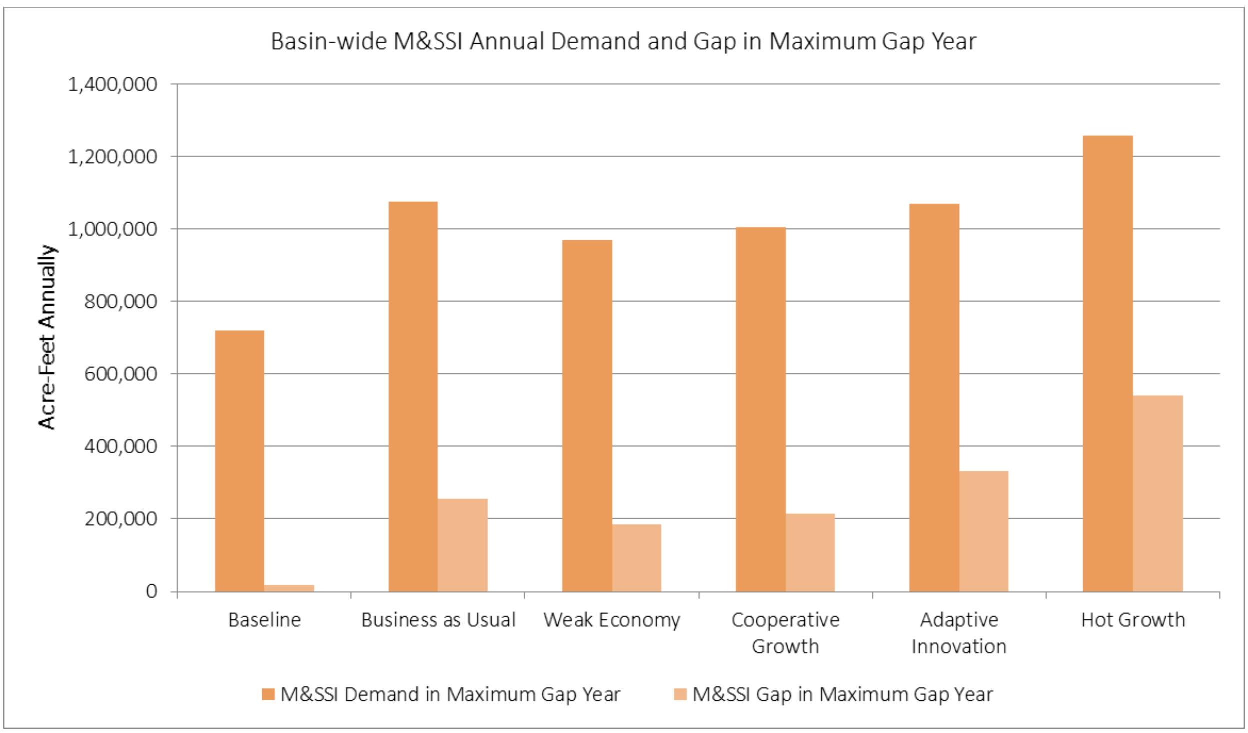


Figure 115: South Platte M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

Figure 116 reflects the average annual percent gap across a variety of wet, average, and dry year types. The percent gap in the Business as Usual, Weak Economy, and Cooperative Growth scenarios generally trend together, reflecting consistent shortages that range between 10 and 20 percent. The graphic reflects a consistent systematic shortage of approximately 20 percent for the Adaptive Innovation scenario, with larger gaps during the dry hydrology years of 1977 and 2002. The Hot Growth scenario, however, reflects more variability than other scenarios depending on year type, with gaps reaching or exceeding 40 percent during dry years. In general, however, the scenarios show less year-to-year variability than other basins. This indicates that a portion of the average annual gap is a systematic shortage to the water supply needs of the M&SSI demands, and not strictly driven by annual variability in hydrology.

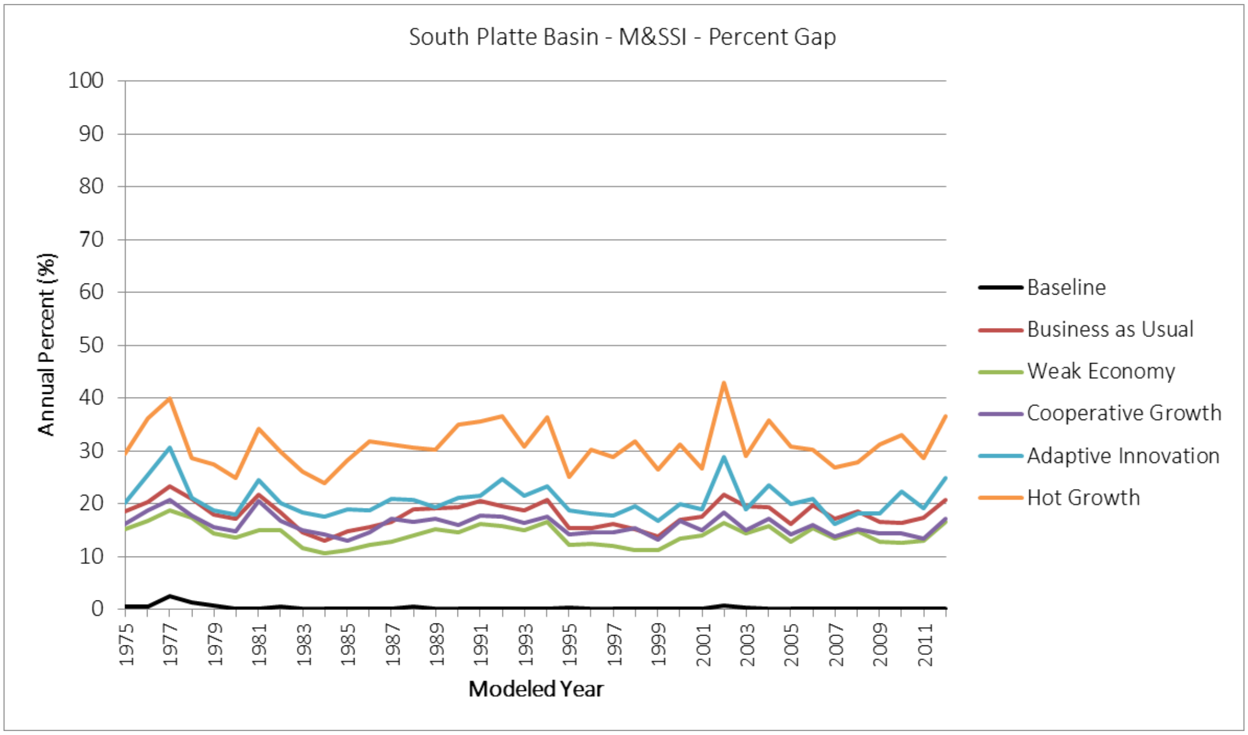


Figure 116: South Platte River Basin M&SSI Average Annual Gap Time Series

5.8.3 SOUTH PLATTE RIVER BASIN SUMMARY

The combined agriculture and M&SSI demands and gaps summary is provided in Table 38. Figure 117 reflects the relative size of the basin-wide average annual demand for the agriculture and M&SSI components, while Figure 118 reflects the relative size of the gaps of each component. The South Platte River Basin differs from the rest of the state in that M&SSI demands are a substantial portion of the total basin demand, and are projected to have gaps on par with agricultural gaps. Following the graphic are summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage or transbasin import supply gaps.

Table 38: South Platte River Basin Water Supply and Gap Summary

	Agricultural and M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	3,184,504	3,061,684	2,957,540	3,160,214	2,766,635	3,320,793
	Average Annual Gap (ac-ft)	508,606	597,748	538,694	561,898	599,617	834,581
	Average Annual Percent Gap	16%	20%	18%	18%	22%	25%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	3,702,311	3,485,482	3,381,339	3,423,728	3,076,369	3,618,642
	Gap In Maximum Gap Year (ac-ft)	1,223,447	1,234,699	1,145,125	1,115,266	1,157,907	1,604,763
	Percent Gap In Maximum Gap Year	33%	35%	34%	33%	38%	44%

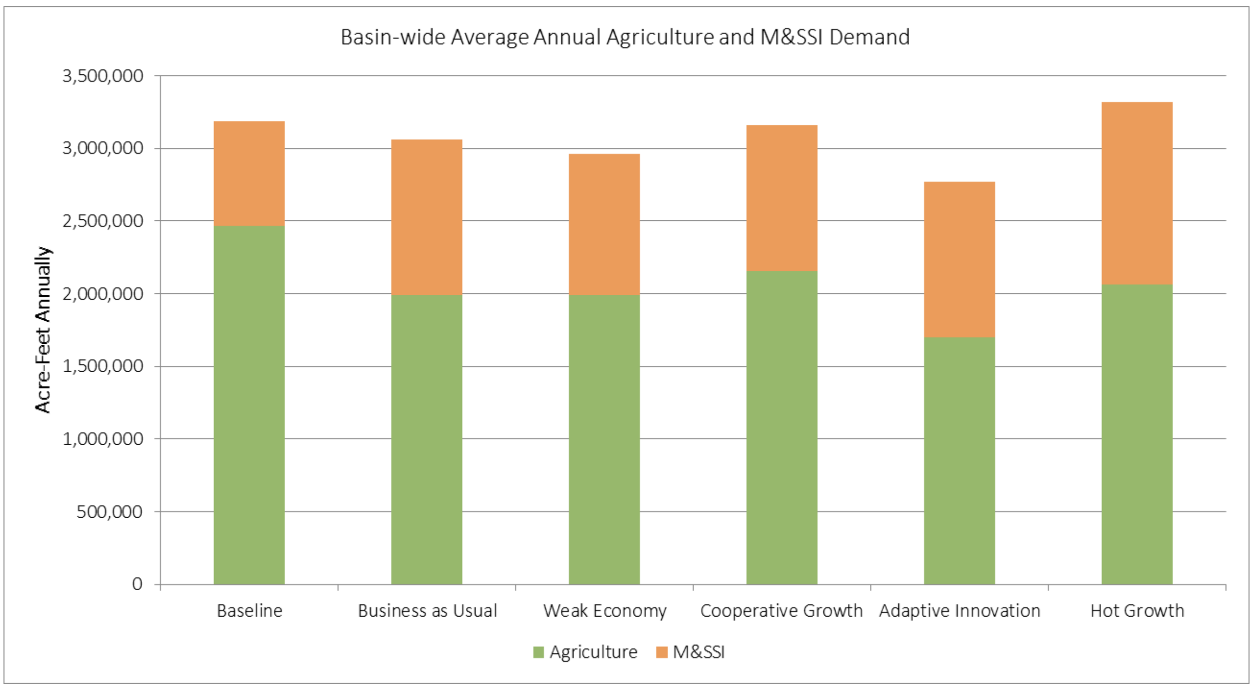


Figure 117: South Platte River Basin Comparison of Average Annual Demands

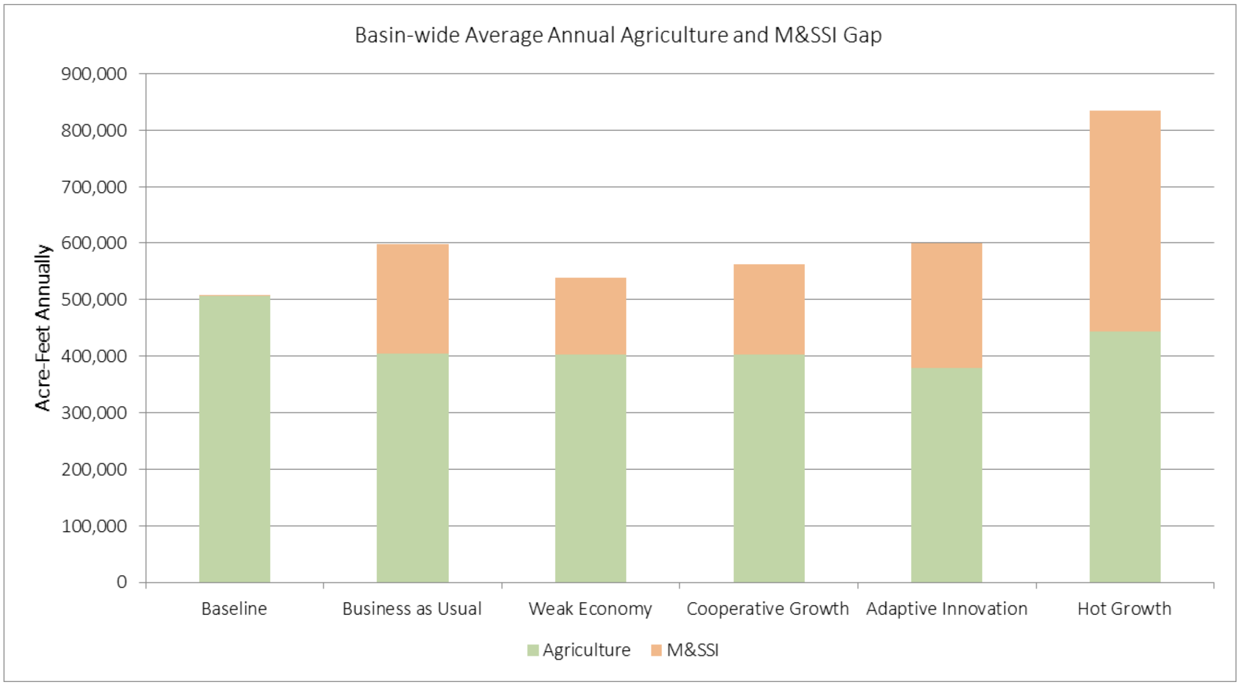


Figure 118: South Platte River Basin Comparison of Average Annual Gaps

The Planning Scenarios project 127,100 to 169,600 acres of irrigated agriculture will be taken out of production due to urbanization or for "buy and dry". Supplies used to irrigate the urbanized acreage could be considered a new municipal or SSI supply if the associated water rights were changed. Note that these acreage values do not include acreage served by ground water removed due to lack of augmentation water, as the junior water supply would likely not provide a reliable new supply.

To estimate this potential new supply, the consumptive use of the urbanized acreage by Planning Scenario is reflected in Table 39. Note however, it is not known which farms and ranches will be directly impacted; whether the acreage was served by senior/junior direct rights or had supplemental ground water or storage supplies; or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use, or whether the supply could directly meet the future M&SSI demand or would require exchange potential. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap[19].

[19] Unlike models in other basins, the projected urbanized and buy and dry irrigated acreage in the South Platte River Basin consumes a substantial amount of water. As it was unknown where and how these supplies would be used in the future (i.e. IPP), and the water supply associated with this acreage could not just be left in the river to be diverted by senior users, the irrigated acreage was kept in the South Platte River basin model dataset. The demand and gap results in the basin summaries removed the impact from this acreage, and were instead used for the potential urbanized supply summary. Future BIP modeling efforts will need to address where and how this potential supply may be used in the future.

Table 39: Potential Water Supply from Urbanized Acreage in the South Platte River Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage	148,400	148,400	127,100	127,100	169,600
Estimated Consumptive Use (ac-ft/year)	209,754	210,229	179,360	172,709	238,572

As noted above, the South Platte River basin benefits from the delivery of several imported transbasin supplies from the Colorado River and North Platte River basins. These transbasin diversions include:

- Vidler Tunnel diverts water for the City of Golden via Guanella Pass.
- Roberts Tunnel, part of the Blue River Diversion Project, delivers water via Dillon Reservoir to Denver Water's system.
- Boreas Pass Ditch diverts water for the City of Englewood.
- Grand River Ditch delivers water to irrigators along the Cache La Poudre River.
- Berthoud Pass Ditch delivers water to the Cities of Golden and Northglenn.
- Adams Tunnel delivers Colorado-Big Thompson Project water from the collection system in the Colorado River Basin to water users inside the Northern Colorado Water Conservancy District boundaries.
- Moffat Tunnel delivers water to Denver Water's Gross Reservoir.
- The Homestake Project delivers water to both the South Platte River Basin for use by Aurora, and to the Arkansas River Basin for use by Colorado Springs. Only the South Platte deliveries are accounted for in this section.
- The Busk-Ivanhoe Tunnel delivers water to Busk Creek upstream of Turquoise Lake for use by Pueblo Board of Water Works and Aurora Water. Only the portion delivered to Aurora is accounted for in the results below.
- Cameron Pass Ditch diverts water from the North Platte River Basin and supplies irrigators along the Cache La Poudre River.
- Michigan Ditch diverts water from the North Platte River Basin and supplies the City of Fort Collins.

Table 40 summarizes the total transbasin import volumes and associated import gaps. Note that transbasin imports are the same across the scenarios because they are represented in the model at historical levels, and no Planning Scenario adjustments were applied. A gap indicates that the historical import could not be diverted in the source basin due to a physical or legal limitation of water supply at the diverting location. This is caused by changes in water availability, increases in senior demands in the source basin, or a combination of both.

Ideally the import supply gap in the Baseline scenario would be zero; however the Baseline dataset represents current agricultural and M&SSI demands over the entire model period which can result in minor shortages to junior water rights, including transbasin diversions. With this in mind, the incremental increase in the import gap reflects the increase in gap due to the Planning Scenario adjustments.

Under current hydrologic conditions, there is essentially no projected increase in the gap for the Business as Usual and Weak Economy scenarios. The climate-adjusted hydrology in the Cooperative Growth scenario led to a relatively small projected increase in gap on average and during critically dry years. The climate-adjusted hydrology in the Hot Growth scenario, however, projected substantial gaps to transbasin import supplies. There were projected shortages each year in these scenarios, generally ranging from 5 to 10 percent annually during average hydrological year types. Peak shortages occur during the 2003 to 2006 drought period, reaching to more than 20 and 30 percent in the two scenarios, respectively.

If exports stay the same in the future, the reported import gaps could increase the total South Platte River basin gaps in these scenarios. As transbasin imported supplies are able to be reused to extinction either by the importing entity or by downstream users within the South Platte River basin, the imported supply gap would have the effect of increasing the total South Platte River basin gap by more than the values shown in the table.

Table 40: Summary of Transbasin Imports to the South Platte River Basin

	Transbasin Import Supply Results	Baseline	Business as Usual	Weak Economy	Cooperative Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Import Supply (ac-ft)	392,126	392,126	392,126	392,126	392,126	392,126
	Average Annual Import Supply Gap (ac-ft)	1,155	1,102	1,101	9,730	22,654	27,252
	Average Annual Import Supply Gap Increase from Baseline (ac-ft)	-	-	-	8,575	21,500	26,098
	Average Annual Import Supply Percent Gap	0%	0%	0%	2%	6%	7%
Critically Dry Maximum	Import Supply Demand In Maximum Gap Year (ac-ft)	339,871	339,871	339,871	405,267	339,871	339,871
	Import Supply Gap In Maximum Gap Year (ac-ft)	5,336	5,560	5,543	21,364	71,879	109,405
	Increase from Baseline Import Supply Gap (ac-ft)	-	224	208	16,028	66,543	104,069
	Import Supply Percent Gap In Maximum Gap Year	2%	2%	2%	5%	21%	32%

The South Platte River Basin has approximately 1.2 million ac-ft of reservoir storage (excluding Water District 3 reservoirs), used for both agricultural and M&SSI purposes. A substantial number of agricultural users own and operate off-channel reservoir storage to provide supplemental irrigation or augmentation supplies. Municipal water providers have networks of reservoirs, both on-channel and off-channel, to store in-basin and transbasin supplies. A smaller number of SSI entities also own and operate smaller reservoirs throughout the basin to re-regulate variable river supplies. Several reservoirs also operate for flood control purposes, such as Cherry Creek and Bear Creek Reservoirs. The storage capacity helps buffer the basin against periods of drought, but then requires wet hydrologic conditions to refill.

Figure 119 reflects the aggregated simulated monthly reservoir contents for 67 individually represented reservoirs in the South Platte River basin model. Note that the model does not include Cache La Poudre operations, therefore the reservoir content summary excludes the reservoirs in this sub-basin.

The graphic indicates that storage is used more frequently in all Planning Scenarios compared to the Baseline scenario results, and that additional use is not isolated to just dry periods. Reservoir contents are consistently lower than the Baseline scenario results for the entire study period.

While the reservoir storage in the Business as Usual, Weak Economy, and Cooperative Growth scenarios is projected to experience significant use, these scenarios have years when the reservoirs across the basin are generally able to refill, although wetter conditions are needed to do so. The Adaptive Innovation and Hot Growth scenarios, however, project reservoir storage across the basin cannot fully recover or refill following drought periods. Increased demands in these scenarios places more demands on reservoir storage continuously and the climate-adjusted hydrology reduces the hydrological conditions such that even the wetter hydrological years are not sufficient to allow all the reservoirs to refill. Although this is the case, it does not indicate that future storage projects are not warranted in the South Platte Basin since the existing storage may not be located in locations where water may still be available, such as the lower reaches of the basin.

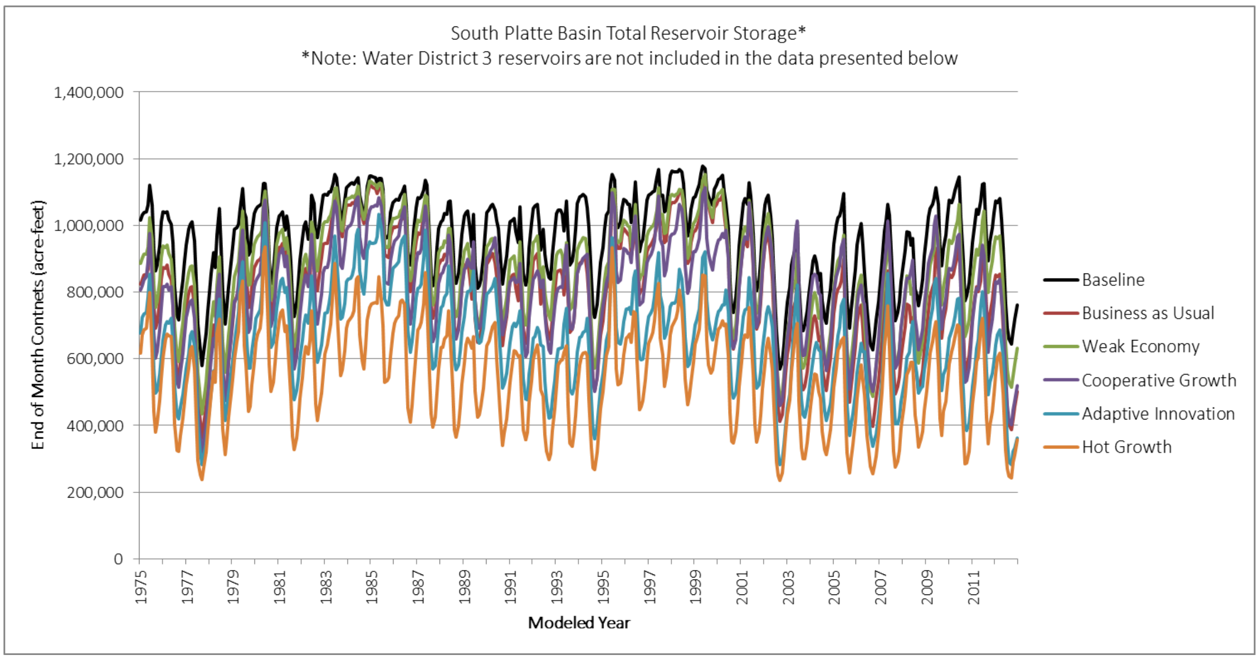


Figure 119: South Platte River Basin Total Reservoir Storage

The following figures reflect average monthly simulated streamflow at key locations across the basin; refer to Figure 110 for the location of the gages. The streamflow conditions vary substantially across the basin due to impacts from natural hydrology and upstream agricultural and M&SSI diversions, storage, and transbasin import supplies.

The average monthly simulated streamflow of the South Platte River at Denver is reflected in Figure 120. This streamgage is located in the City of Denver and represents the combined upstream influence of several on-channel reservoirs owned and operated by Denver Water and Aurora Water along the upper South Platte River before the river benefits from several tributary inflows. The simulated streamflow through the city is projected to be substantially lower in all Planning Scenarios as the municipal demand increases and more water is needed to meet those demands. The Business as Usual and Cooperative Growth scenarios project a 24 percent reduction in total annual flow, whereas the Weak Economy projects an 18 percent reduction. The Adaptive Innovation and Hot Growth scenarios project a larger reduction to annual streamflow of 42 percent. Additionally, note that the peak flows in the Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios have been shifted forward to the month of May. This is a common trend projected for the climate-adjusted hydrology across the state.

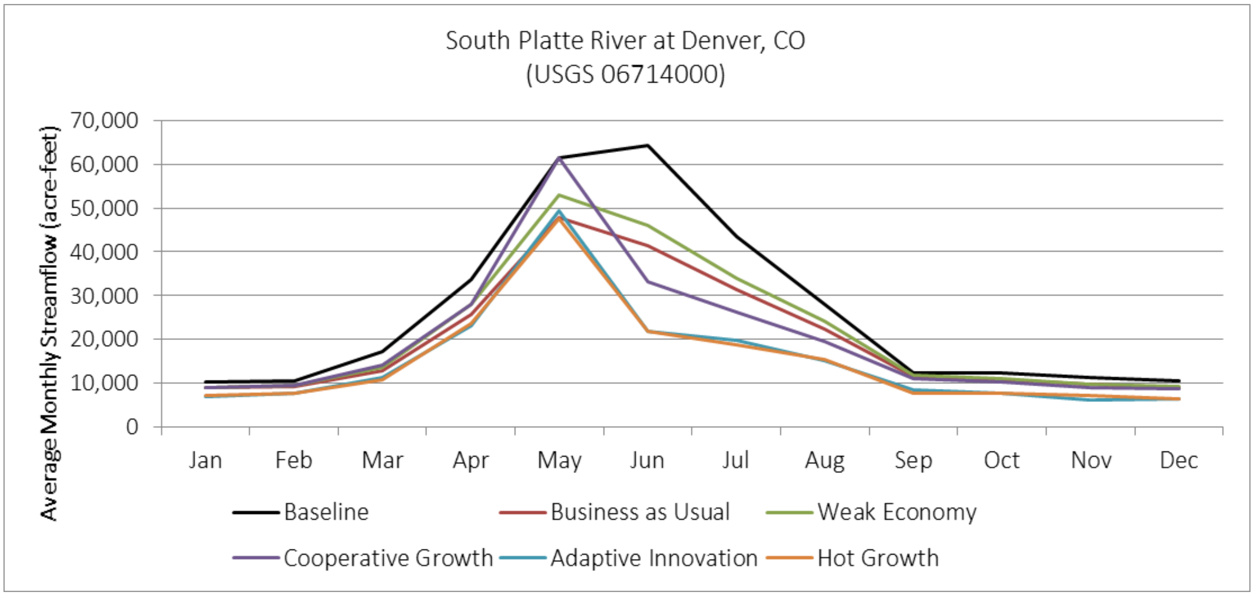


Figure 120: Average Monthly Streamflow for South Platte River at Denver

Figure 121 shows the average monthly simulated streamflow for St. Vrain Creek at Lyons. This location is high in the headwaters of the basin and represents near-natural flow conditions. The largest upstream operations are driven by the City of Longmont, which operates diversion pipelines and Button Rock Reservoir. Additionally, the Left Hand Ditch Company has a diversion point upstream of the gage to serve irrigated acreage lower in the basin. Much of the agricultural diversions in the basin, along with the delivery of transbasin supplies from the C-BT Project occur downstream of the reservoir. The Business as Usual and Weak Economy scenarios are projected to have slightly lower streamflow than the Baseline scenario. On an annual basis, the streamflow volume declines from about 91,600 ac-ft in the Baseline scenario to 86,000 and 89,000 ac-ft in the Business as Usual and the Weak Economy scenarios, respectively. This change is likely caused by the increase in M&SSI demands, including City of Longmont.

The Cooperative Growth streamflow primarily reflects increased M&SSI demands and a change in the runoff due to the climate-adjusted hydrology under the In-Between conditions. The scenario projects less than a 10 percent reduction in streamflow, but shifts that streamflow forward to the month of May. The Adaptive Innovation and the Hot Growth scenarios have overlapping results on the graphic, which are dominated by the Hot and Dry climate-adjusted hydrology. These scenarios also reflect a shift in streamflow forward to the month of May, but project a 30 percent decline overall in streamflow at this location on average.

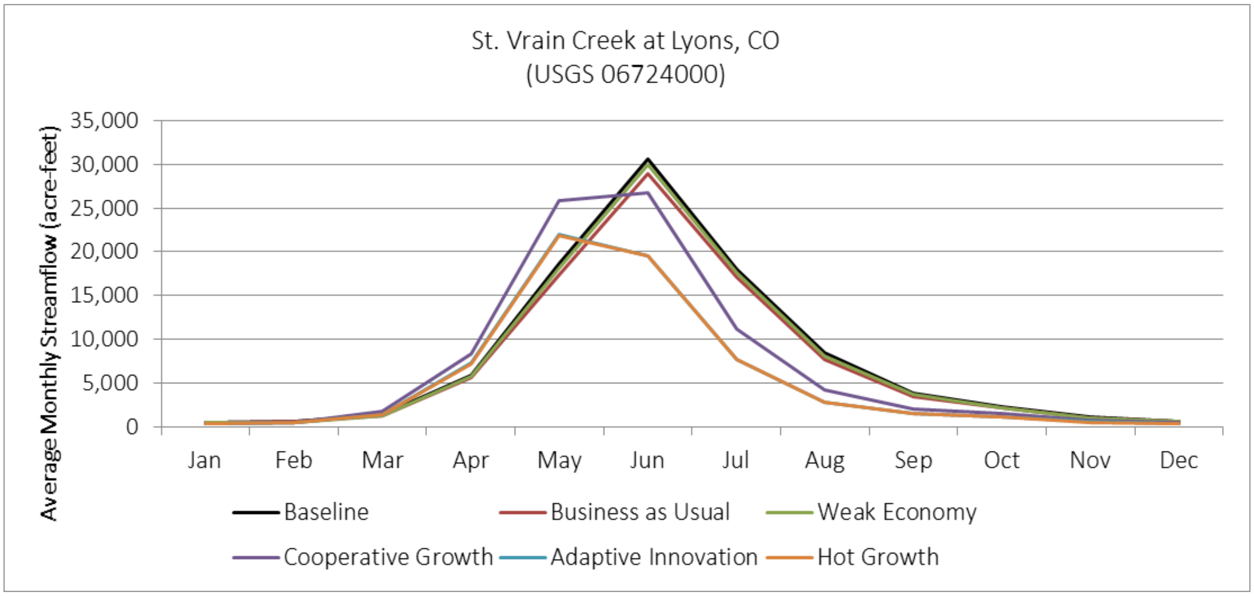


Figure 121: Average Monthly Streamflow for St. Vrain Creek at Lyons

The average monthly simulated streamflow on the Big Thompson River at Estes Park streamflow gage, reflected in Figure 122, represents natural conditions in the basin as there are no upstream diversions or reservoirs in the model. The total volume of natural flow at the gaged location is approximately 88,200 ac-ft, however substantial transbasin supplies are imported via Adams Tunnel directly downstream of the gage, resulting in a much larger water supply for the tributary.

The climate-adjusted hydrology in the Cooperative Growth scenario does not project a decline in overall streamflow volume, but does reflect a shift in runoff and a substantial reduction to late irrigation season streamflow supplies. A similar trend is projected for the Adaptive Innovation and Hot Growth scenarios, which both reflect the Hot and Dry natural flow. These scenarios do, however, project an 11 percent reduction to overall streamflow. For a system like the South Platte River Basin, which has significant reservoir storage, the shift in streamflow timing can be buffered by reservoir storage. However, as projected in the reservoir storage graph in Figure 119, the total reservoir storage in these climate-adjusted scenarios does not refill as frequently as scenarios using the current hydrology.

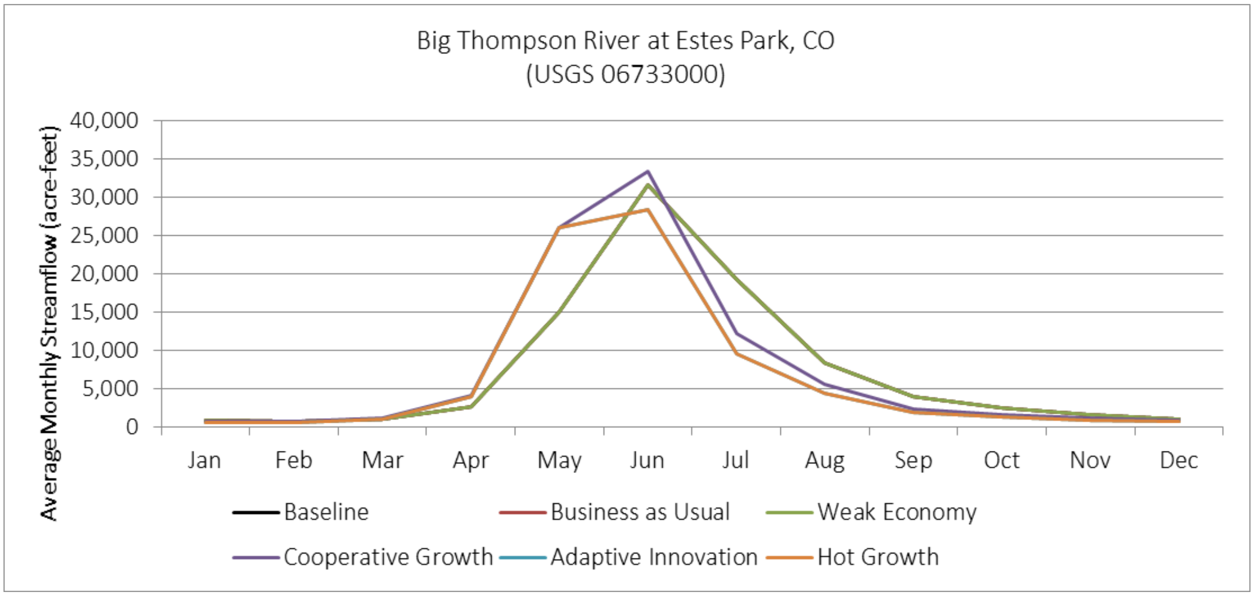


Figure 122: Average Monthly Streamflow for Big Thompson River at Estes Park

Finally, the average monthly simulated streamflow at the South Platte River near Kersey gaged location is shown in Figure 123. This location is downstream of a majority of the Front Range M&SSI demands, includes contributions from all the major tributaries and transbasin import supplies to the South Platte River. This represents the amount and pattern of streamflow projected to be available to large irrigation operations in the lower South Platte River Basin. The Business as Usual and the Weak Economy scenario project lower streamflow than the Baseline scenario. This is due to the increase in municipal demands, most of which are located upstream of Kersey.

The Cooperative Growth, Adaptive Innovation, and Hot Growth scenarios continue the trend of shifting the peak flow into the month of May. At this location, the Cooperative Growth scenario projects the overall streamflow will be very near Baseline scenario conditions, benefitting from an increase in runoff from tributaries feeding into the South Platte River. The Hot and Dry climate-adjusted hydrology used by the Adaptive Innovation and Hot Growth scenarios, along with larger M&SSI demand combine to project an approximately 20 percent reduction in streamflow on average, or a reduction of about 150,000 ac-ft on average annually. The shift in streamflow timing combined with the decline in streamflow during July, August, and September places more demands on reservoir storage during the late season. As shown in Figure 119, reservoir storage in the Adaptive Innovation and Hot Growth scenarios is lower than other Planning Scenarios and the basin-wide storage never refills.

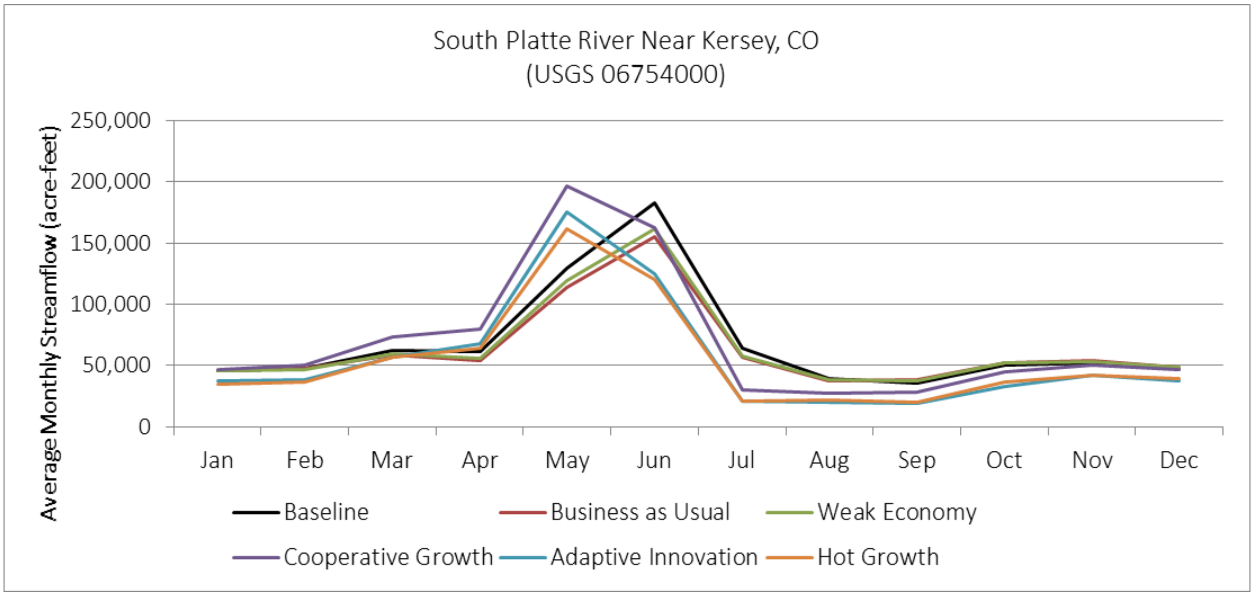


Figure 123: Average Monthly Streamflow for South Platte River near Kersey

The South Platte River basin is over-appropriated, and demands far exceed the native supply in the river. That being said, there are limited times when unappropriated supply are available, however these supplies are generally only available during above-average hydrological conditions and for a couple weeks or even days. Flooding conditions on tributaries and the mainstem do produce large volumes of unappropriated flows, however the high flow rates prohibit substantial diversions during this time for many water users, except those with on-channel reservoirs high up in the basin. The Planning Scenarios project the already limited unappropriated available supplies will be further reduced due to increasing M&SSI demands and climate-adjusted hydrology.

Figure 124 through Figure 127 reflect simulated unappropriated available supply at two locations on the South Platte River, the South Platte River at Denver and South Platte River at Kersey gaged locations. The Denver gage is located upstream of the Burlington Canal, the primary calling right on the mainstem of the Upper South Platte River. The Kersey gage reflects the impact to available flow downstream of the confluence with the Cache La Poudre River and the Lower South Platte River calling rights for storage and irrigation. As reflected in the graphics, available flow at both locations is generally only available during high flow years and for relatively short periods of time. In climate-adjusted scenarios, available flows are projected to diminish, and peak flows are projected to occur earlier in the runoff season.

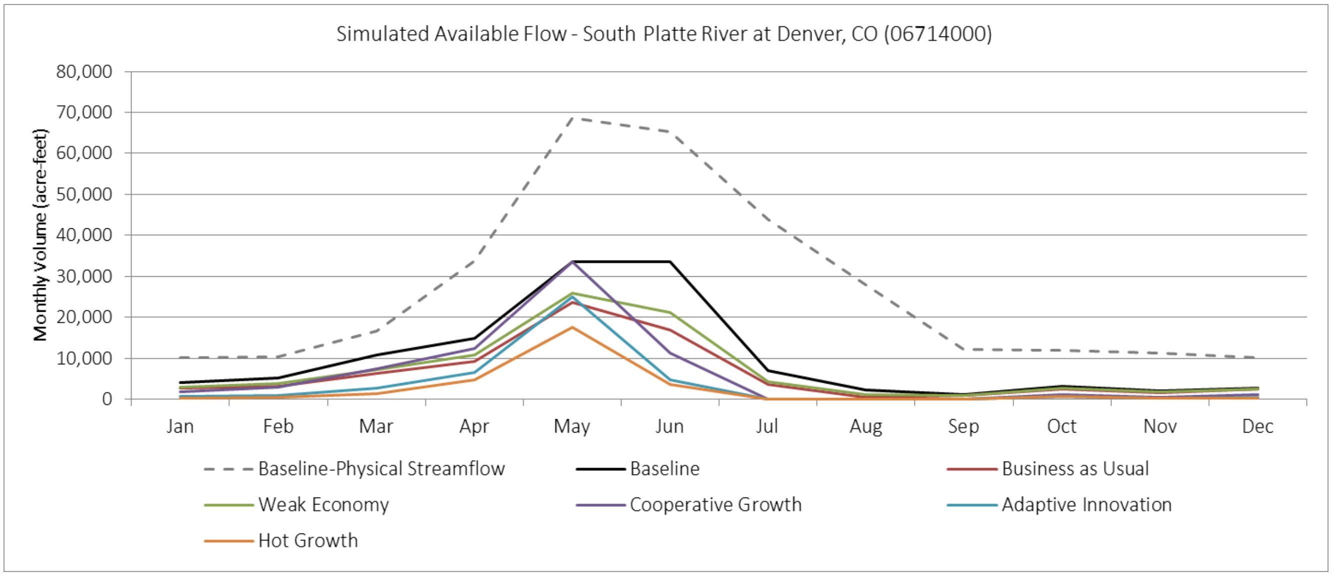


Figure 124: Average Monthly Unappropriated Available Supply at South Platte River at Denver

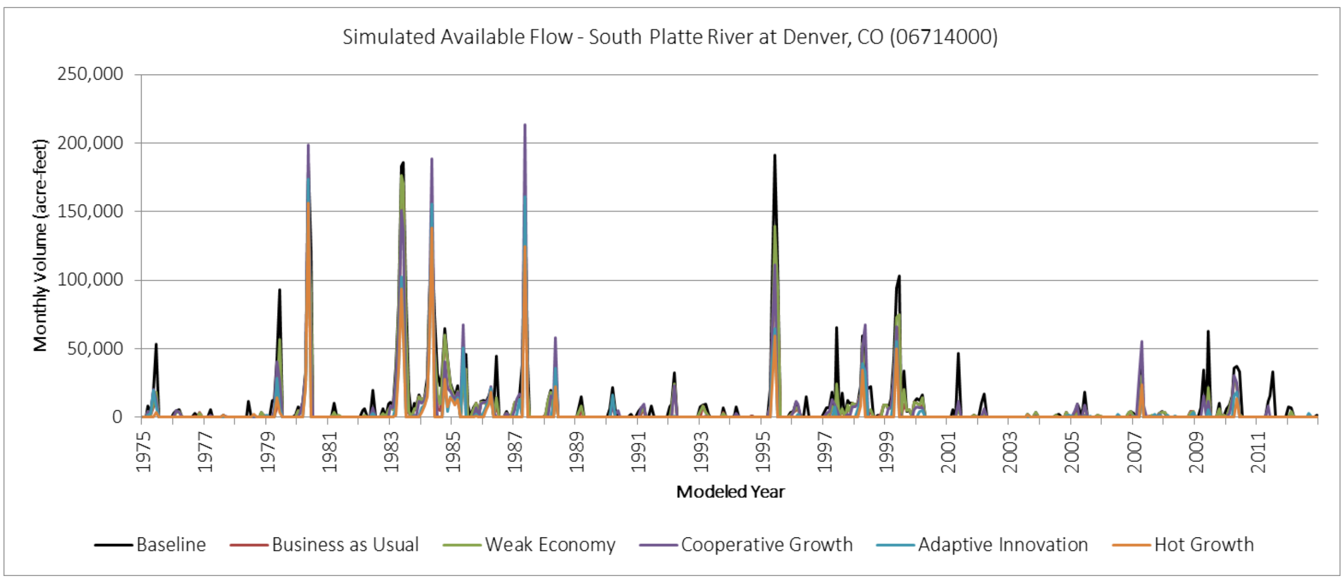


Figure 125: Monthly Unappropriated Available Supply at South Platte River at Denver

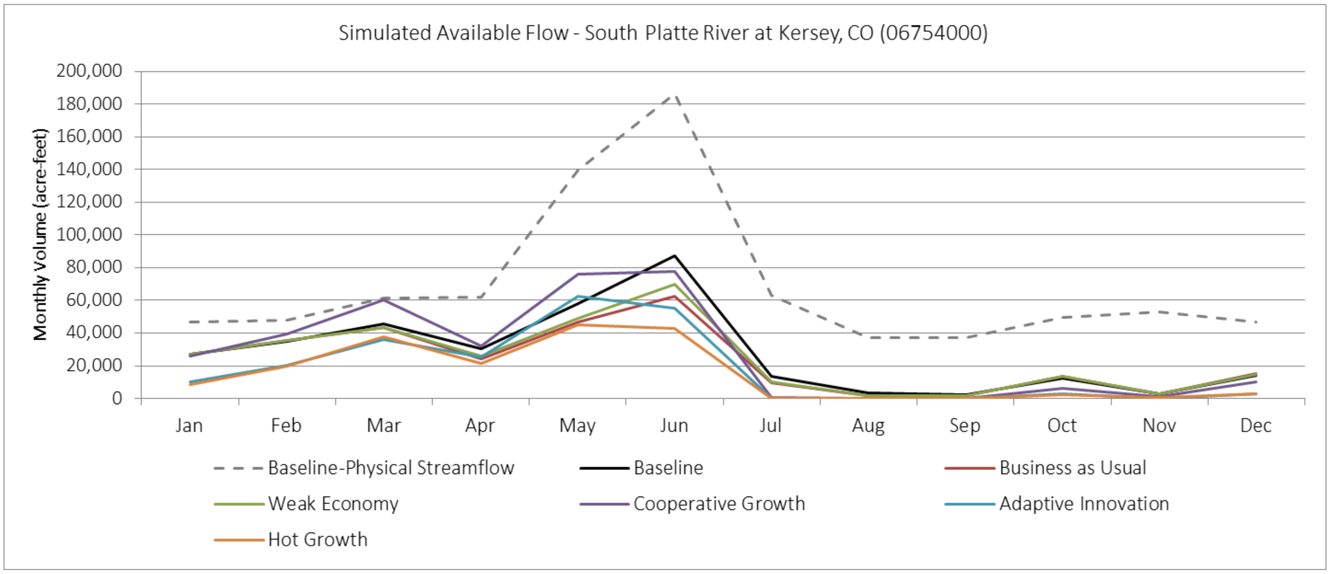


Figure 126: Average Monthly Unappropriated Available Supply at South Platte River at Kersey

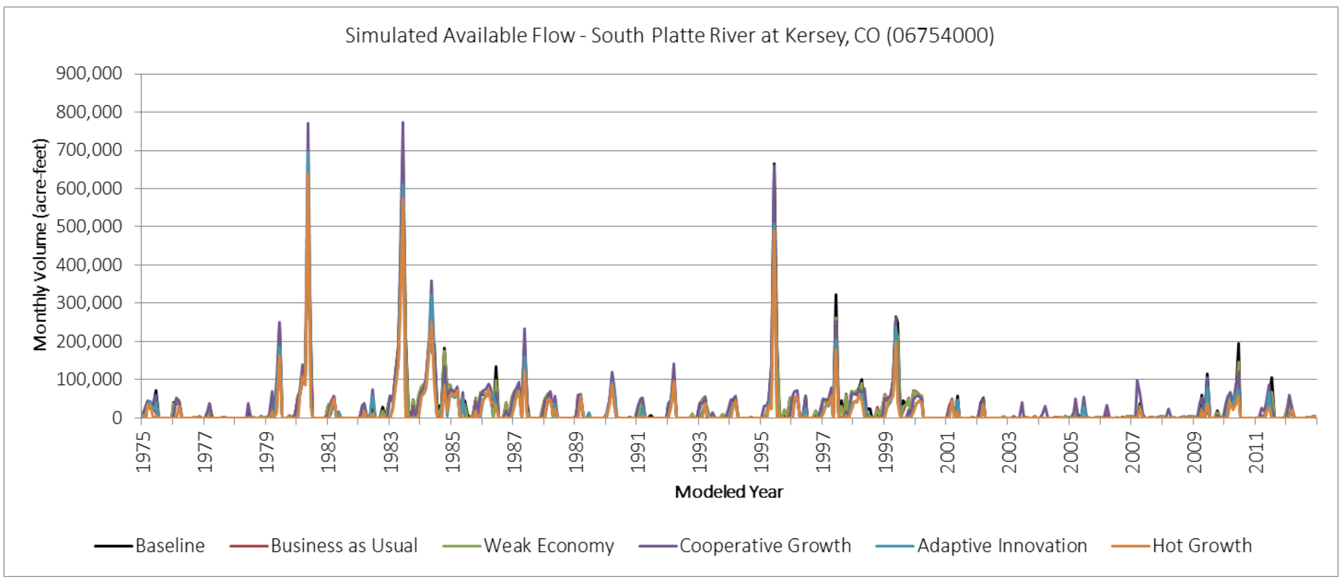


Figure 127: Monthly Unappropriated Available Supply at South Platte River at Kersey

5.9 WHITE RIVER BASIN

Irrigation for ranching operations is the largest demand for water in the White River basin, accounting for approximately 98 percent of total basin demands. These mountain ranches are generally flood irrigated, and with no storage in the basin for agricultural uses, irrigators rely on diversions of runoff for supplies.

Water used to meet M&SSI demands is limited in the basin relative to agricultural use, constituting less than 2 percent of the total demand in the basin. The two municipal areas in the White River Basin are the Town of Rangely and the Town of Meeker. Both towns are popular with outdoor enthusiasts as they offer access to a variety of destinations, from Dinosaur National Monument, Kenney Reservoir, or the Flattops

Wilderness. The region also benefits from large natural gas deposits in the Piceance Basin, which have driven several boom-and-bust cycles of development in the basin over the past several decades.

The following sections describe the agricultural and M&SSI demands in the White River basin in more detail. Figure 128 reflects the basin outline encompassing all of Water District 43 and the streamflow gages highlighted in the results section below.

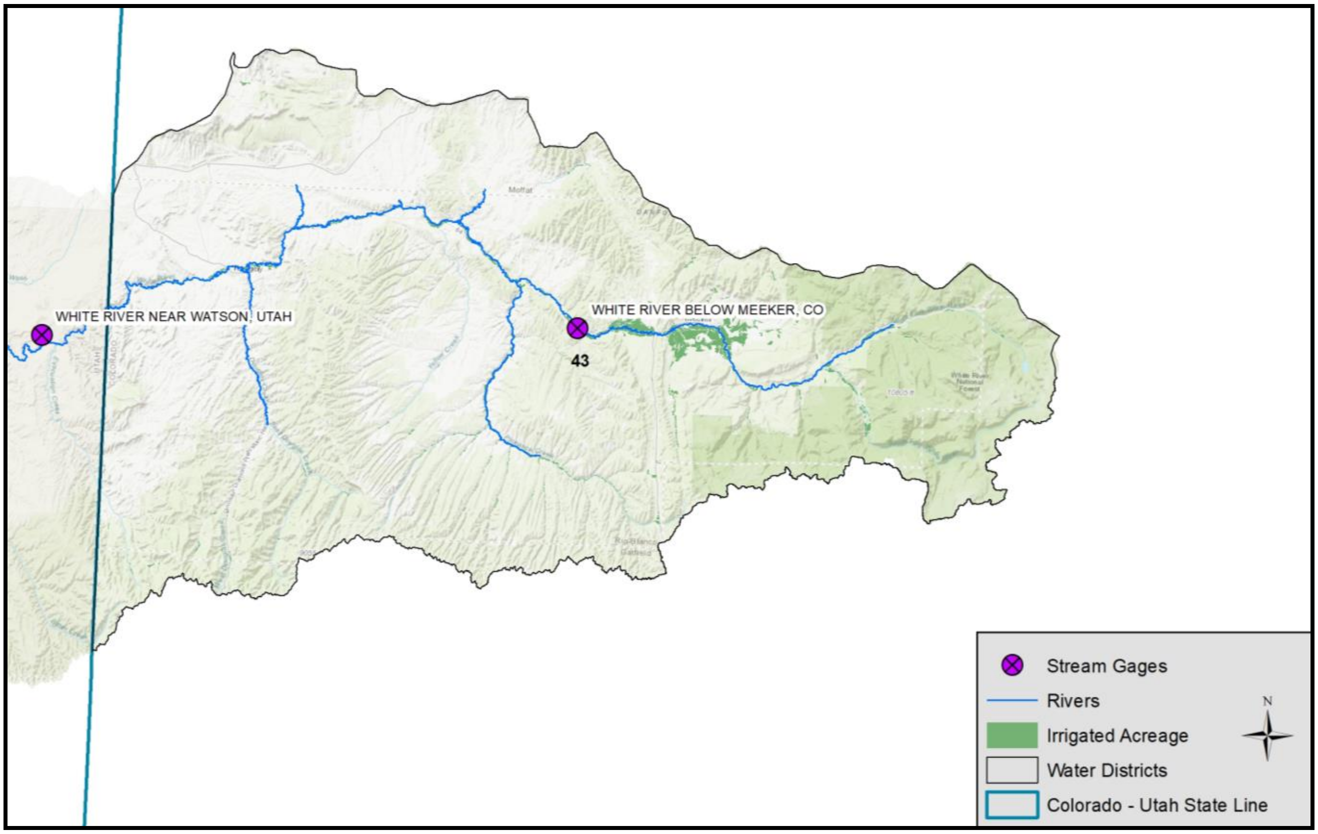


Figure 128: White River Map with Streamgage Locations

5.9.1 WHITE RIVER BASIN AGRICULTURE WATER SUPPLY AND GAP

The majority of irrigation is for grass pasture fields, concentrated in the tributary and river valleys, that are able to produce a single cutting of hay before turning the fields over for grazing cattle. Due to warmer temperatures, the lower portion of the basin is able to produce two cuttings and has more alfalfa fields. Flood irrigation is common and irrigators depend on late-season irrigation return flows because there is no storage for agriculture in the basin. There are no Reclamation or other large-scale irrigation projects in the basin. In areas where it is economically feasible, some ranchers are switching to sprinkler irrigation. Agriculture was identified as a priority for the White River Basin in the Basin Implementation Plan and water users in the basin hope to keep current irrigated acreage in production.

The White River Basin agricultural diversion demands, demand gaps, and consumptive use gaps results for the baseline and Technical Update Planning Scenarios are presented in Table 41. As discussed in Technical Memo *Current and 2050 Planning Scenario Agricultural Diversion Demand*, 2050 agricultural demands are influenced by a number of drivers, including climate, urbanization, and emerging technologies.

Table 41: White River Basin Agricultural Water Supply and Gap Summary

	Agricultural Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	246,744	242,917	246,744	293,889	177,755	319,741
Average	Average Annual Demand Increase from Baseline (ac-ft)	-	-	-	47,146	-	72,998
Average	Average Annual Gap (ac-ft)	1,219	1,221	1,222	3,163	3,367	5,829
Average	Average Annual Gap Increase from Baseline (ac-ft)	-	3	4	1,945	2,149	4,611
Average	Average Annual Percent Gap	0%	1%	0%	1%	2%	2%
Average	Average Annual CU Gap (ac-ft)	658	660	660	1,715	2,162	3,163
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	242,254	238,492	242,254	281,374	174,299	307,552
Critically Dry Maximum	Increase from Baseline Demand (ac-ft)	-	-	-	39,120	-	65,298
Critically Dry Maximum	Gap In Maximum Gap Year (ac-ft)	6,017	6,029	6,029	9,493	8,525	12,199
Critically Dry Maximum	Increase from Baseline Gap (ac-ft)	-	12	12	3,475	2,508	6,182
Critically Dry Maximum	Percent Gap In Maximum Gap Year	2%	3%	2%	3%	5%	4%

As reflected in the table, irrigators in the basin currently experience a gap, however the gap is relatively small and occurs during drier years. The average annual agricultural demand decreases slightly from Baseline to the Business as Usual Planning Scenario due to the projected urbanization of approximately 360 irrigated acres. The Weak Economy Planning Scenario assumes no acreage is removed for urbanization and agricultural demands are the same as Baseline. Despite having slightly lower agricultural demands, the Business as Usual Planning Scenario has a slightly higher percent gap than the Baseline and Weak Economy scenarios. This is due to the higher future M&SSI demands, as a large portion of the projected M&SSI demands are met by existing municipal water rights portfolios that in some cases are senior or the same priority as irrigation rights. More details on M&SSI demands and gaps are discussed in the next section.

Under the Cooperative Growth scenario, the agricultural demands are projected to increase approximately 22 percent compared to Baseline scenario due to the climate-adjustment to IWR under the In-Between conditions. Additionally, the hydrology under the In-Between conditions is predicting snowmelt runoff will occur earlier in the year. There is no agricultural reservoir storage available in the White River Basin, so the general irrigation practice is to fill the soil moisture and narrow alluvial aquifers during the runoff and use the soil moisture and lagged return flows to meet crop demands during the late irrigation season, when streamflow is low. When the runoff occurs earlier in the year as projected, there are fewer lagged return flows later in the summer and soil moisture supplies are used earlier in the year. This, in combination with larger agricultural demands, causes a moderate increase in agricultural gaps. The streamflow supplies, however, still appear to be sufficient to meet a majority of the agricultural demand in the basin.

For the Adaptive Innovation scenario, the average annual demand is approximately 30 percent less than the Baseline demand. In this scenario, emerging technologies are assumed to mitigate approximately 10 percent of the increase in IWR due to projected Hot and Dry climate conditions as well as increase irrigation system efficiency by 10 percent, which results in an overall net decrease in agricultural demand. While the demand has decreased, the average annual gap and the average annual CU gap have increased under this scenario. The increased system efficiency reduces the demands; however, it also causes return flows to decrease. The White River Basin is highly dependent on return flows, and coupled with the decrease in streamflow under Adaptive Innovation scenario, the result is an increase in the agricultural gap.

The Hot Growth scenario projects the largest volume of agricultural gaps in the White River Basin. Average annual diversion demands have increased compared to all previous scenarios due to the Hot and Dry climate conditions. Overall, the Hot Growth scenario projects an increase of approximately 73,000 ac-ft of agricultural demand compared to the Baseline scenario, with only a 4,600 ac-ft increased gap. This indicates that although the Hot and Dry hydrological conditions reduce streamflow and shift the peak runoff in the basin, the decreased streamflow is still sufficient to meet a majority of the increased agricultural demand.

Agricultural demands in the White River Basin are projected to experience small increases in gaps, despite large increases to demands, as reflected in Figure 129 and Figure 130. As with other basins, it should be noted that agricultural water users are not impacted to the same degree throughout the basin. For example, the White River Basin average annual agricultural gap in the Hot Growth scenario is only two percent, but the agricultural gap in the Piceance River basin is closer to 16 percent. While this is a relatively low gap compared to other basins, it is significantly higher than other areas of the White River Basin.

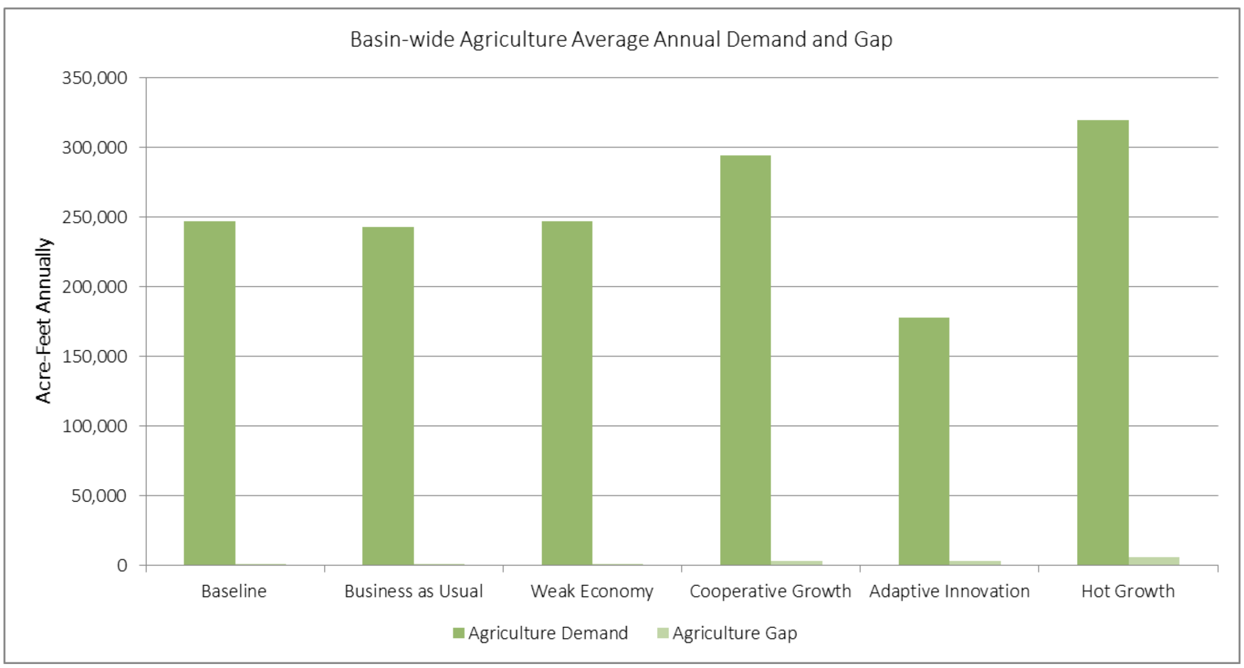


Figure 129: White River Basin Agriculture Average Annual Demand and Gap

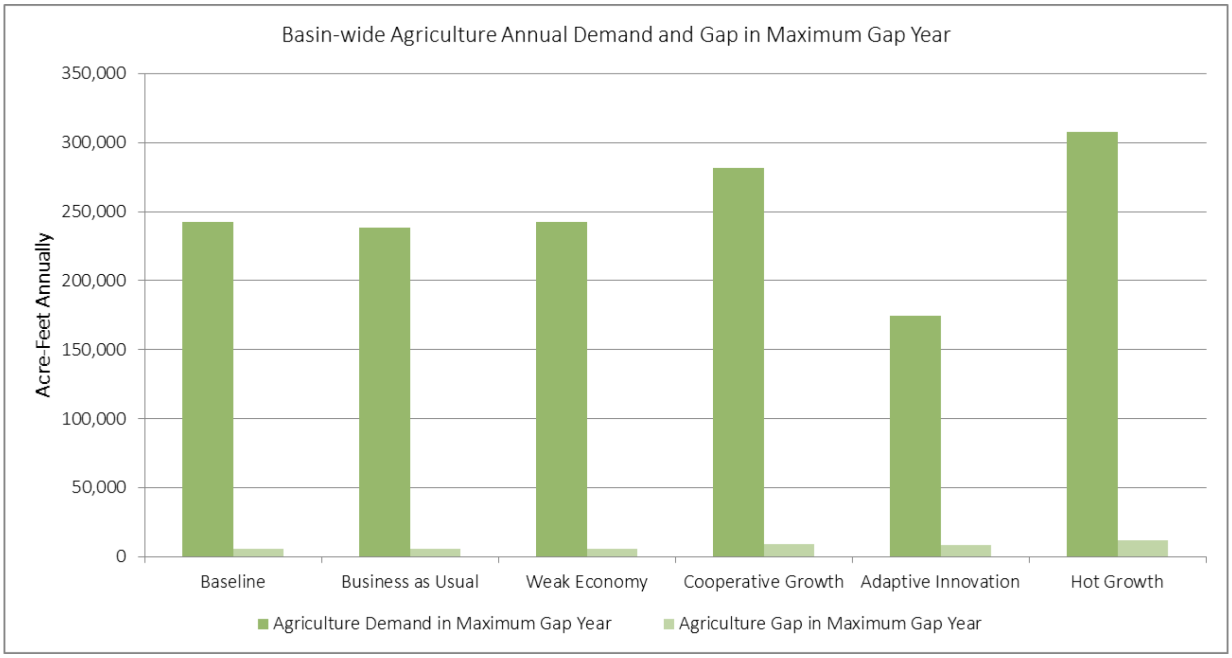


Figure 130: White River Basin Agriculture Annual Demand and Gap in Maximum Gap Year

The annual agricultural gap variability over the model study period is reflected in Figure 131. Note that the years with the largest percent gaps do not necessarily align with the "typical" dry years. For example, the largest percent gap occurs in 2004, after continually growing during the drought of the early 2000s. Given the high dependency on late season return flows and soil moisture in the White River basin, the last year in a series of dry years produces the largest gap, due to the lack of moisture from previous years build up. In generally, the scenarios have very similar results over the study period. As discussed above, the Adaptive Innovation scenario projects the largest gap during the 2002 to 2013 period due to the increased irrigation system efficiency and reduction to late season return flows.

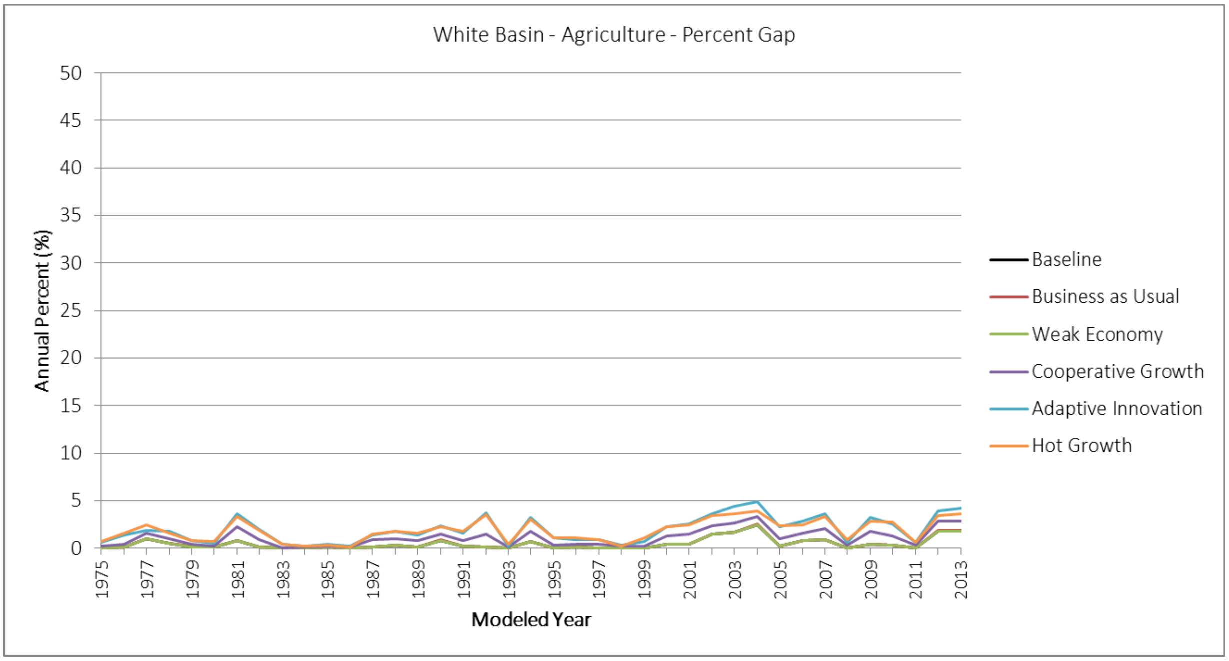


Figure 131: White River Basin Agriculture Percent Diversion Gap Time Series

5.9.2 WHITE RIVER BASIN M&SSI WATER SUPPLY AND GAP

Population in Rio Blanco County is projected to increase in all scenarios except the Weak Economy scenario, leading to moderate increases to the municipal demand in the basin in many scenarios. The SSI demand[20] is projected to have moderate increases in all scenarios except the Hot Growth scenario, in which the SSI demand is projected to increase nearly twenty-five times the Baseline demand. This large increase in the Hot Growth demand is attributable to the projected increase of energy development in the Piceance River basin.

A majority of the municipal demand is grouped and represented in the model at a general location, with only the Town of Rangley and Town of Meeker's demands and surface water rights modeled individually. For the SSI demands, the individual operations and demands associated with the California Co Water Pipeline are included in the model and the remaining SSI demand is represented at two grouped locations. A quarter of the future SSI demands are represented on the Piceance River and the remaining three quarters of the SSI demand is represented on the mainstem of the White River. Although there are several large conditional water rights for energy development in the White River Basin, these were not included in the water right assignment for this effort. Refer to Appendix A for more information on how water rights were assigned to grouped SSI demands in the model; future analyses may consider incorporating these water rights with the projected demand.

Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin were developed. The water supply and gap results for M&SSI in the White River basin are summarized in Table 42, and graphically reflected in Figure 132 and Figure 133.

[20] Note that water used for hydropower, such as those operations at Kenney Reservoir, are represented in the model but are not included in the SSI demand summaries (i.e. non-consumptive) and are not adjusted between Planning Scenarios.

Table 42: White River Basin M&SSI Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	5,265	10,015	6,086	6,936	7,658	40,960
Average	Average Annual Demand Increase from Baseline (ac-ft)	-	4,750	821	1,671	2,393	35,695
Average	Average Annual Gap (ac-ft)	0	3,048	704	708	788	27,498
Average	Average Annual Gap Increase from Baseline (ac-ft)	-	3,047	704	708	788	27,498
Average	Average Annual Percent Gap	0%	30%	12%	10%	10%	67%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	5,265	10,015	6,086	6,936	7,658	40,960
Critically Dry Maximum	Increase from Baseline Demand (ac-ft)	-	4,750	821	1,671	2,393	35,695
Critically Dry Maximum	Gap In Maximum Gap Year (ac-ft)	0	3,934	910	934	1,282	33,465
Critically Dry Maximum	Increase from Baseline Gap (ac-ft)	-	3,934	910	934	1,282	33,465
Critically Dry Maximum	Percent Gap In Maximum Gap Year	0%	39%	15%	13%	17%	82%

The average annual demand increases from the Baseline scenario to the Business as Usual scenario, primarily due to the increase in SSI demands. The average annual gap is 30 percent, with gaps increasing 39 percent in critically dry years. The gap is driven by primarily by legal water availability. Projected increases in energy development are represented in the model with a priority that is junior to the hydropower production at Taylor Draw Dam (Kenney Reservoir). As such, the large hydropower demand calls down much of the streamflow outside of the peak runoff, thus shorting nearly all of the increased M&SSI demand in the Business as Usual scenario. This is one representation of water rights priorities and operations, and can be changed in the future based on stake holder input.

The Weak Economy, Cooperative Growth, and Adaptive Innovation scenarios have modest increases in the average annual demands and experience similar levels of gaps on average and during critically dry years. Although each scenario reflects different demands and climate-adjusted hydrological conditions, the average annual gap is approximately the same amount. Similar to the Business as Usual scenario, this is caused by a lack of legally available flow during months outside of the peak runoff, as the water is called down by the hydropower production at Taylor Draw Dam (Kenney Reservoir). There is slightly more water available in the Adaptive Innovation scenario primarily due to the reduction in agricultural demands.

The Hot Growth scenario has a large increase in average annual M&SSI demand caused by the projected energy development average annual demand reaching 35,340 ac-ft. This represents a large-scale build out of oil and gas extraction and energy development in the basin. As with previous scenarios however, much of the increased demand is shorted. This is again caused by the hydropower production at Taylor Draw Dam (Kenney Reservoir), but can also be attributed to substantially larger agricultural demands in the scenario. These combine with the overall reduction to and shift of streamflow under the Hot and Dry conditions to produce substantial projected gaps.

The overall picture for M&SSI in the White River Basin varies greatly depending on energy development assumptions, both magnitude and priority of water supplies. Figure 132 and Figure 133 reflect the relative size of the M&SSI demands and gaps on average and during critically dry years. The Business as Usual and Hot Growth scenarios experience the largest increases in demands, driven by energy development. The gaps increase as the energy demand increases indicating the water supplies are not sufficient to reliably meet the projected M&SSI demands while still meeting the hydropower demands.

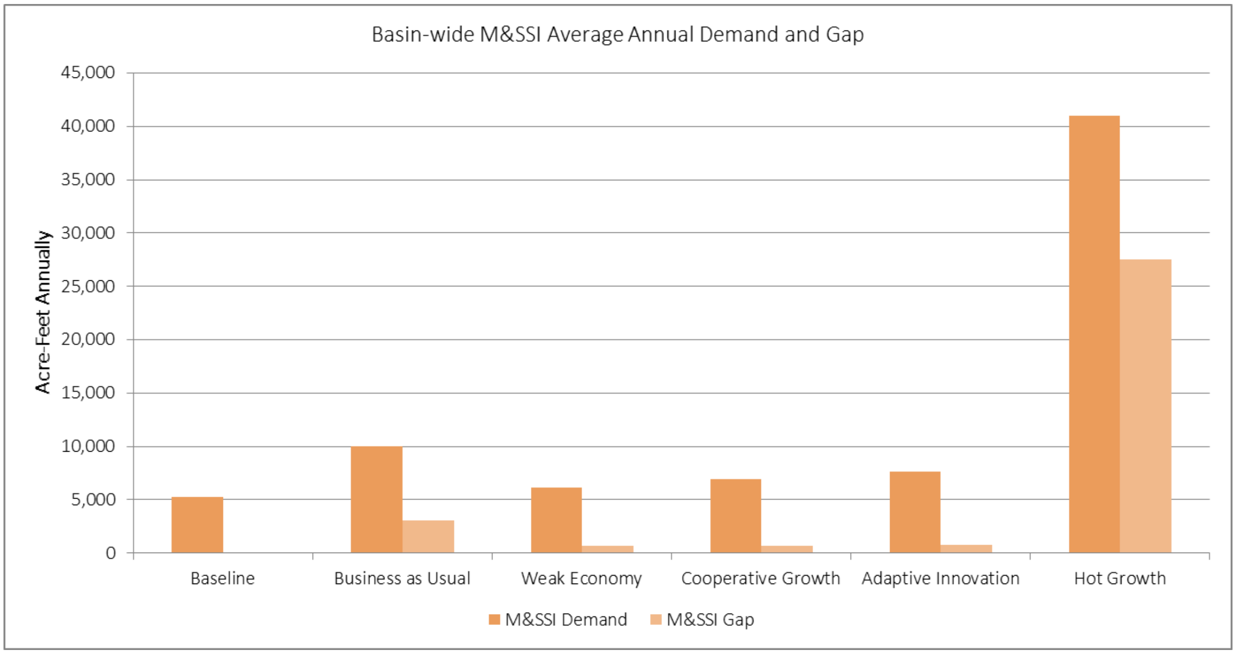


Figure 132: White River Basin M&SSI Average Annual Demand and Gap

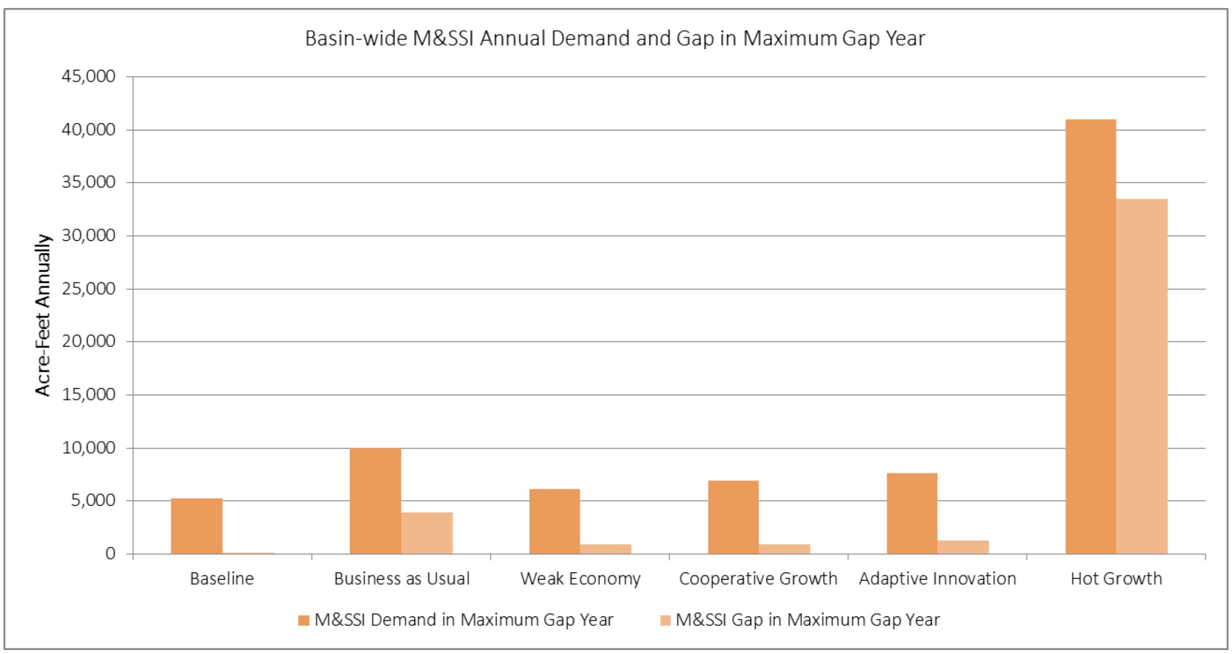


Figure 133: White River Basin M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

Figure 134 reflects average annual percent gap across a variety of wet, average, and dry year types. The graphic reflects relatively consistent shortages of 10 percent for the Weak Economy, Cooperative Growth, and Adaptive Innovation scenarios, regardless of year type. The Business as Usual and Hot Growth scenario results have similar trends and responses to different year types, separated by the magnitude of their demands.

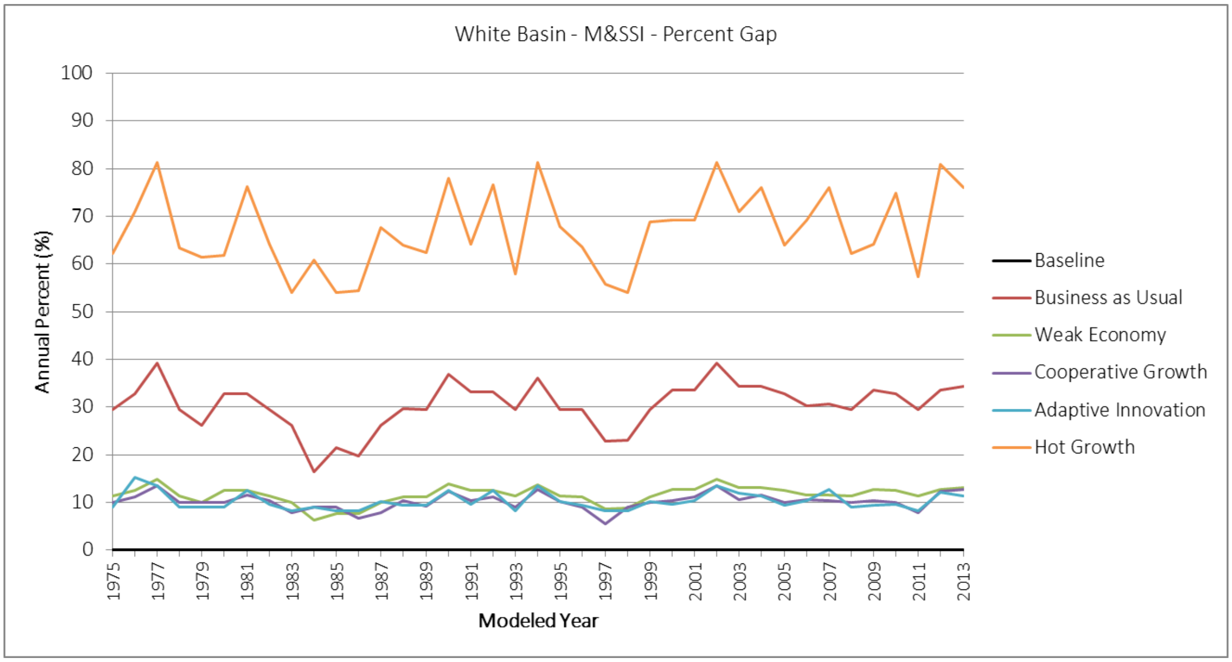


Figure 134: White River Basin M&SSI Average Annual Gap Time Series

5.9.3 WHITE RIVER BASIN SUMMARY

The combined agriculture and M&SSI demand and gap summary is provided in Table 43. While the White River Basin is dominated by agricultural demands (Figure 135), the following Figure 136 reflects that the gaps are a mix of agriculture and M&SSI growth. As previously discussed, agricultural demands in the basin are generally satisfied across all Planning Scenarios. The largest gaps are projected for increased M&SSI demands due to limited legal water availability, with the largest gaps occurring in the Business as Usual and Hot Growth scenarios. Summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage, are provided below the table and graphics.

Table 43: White River Basin Water Supply and Gap Summary

	Agricultural and M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	252,009	252,932	252,830	300,825	185,413	360,701
	Average Annual Gap (ac-ft)	1,219	4,269	1,927	3,871	4,155	33,327
	Average Annual Percent Gap	0%	2%	1%	1%	2%	9%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	247,519	248,507	248,340	288,310	181,957	348,512
	Gap In Maximum Gap Year (ac-ft)	6,018	9,963	6,939	10,426	9,807	45,664
	Percent Gap In Maximum Gap Year	2%	4%	3%	4%	5%	13%

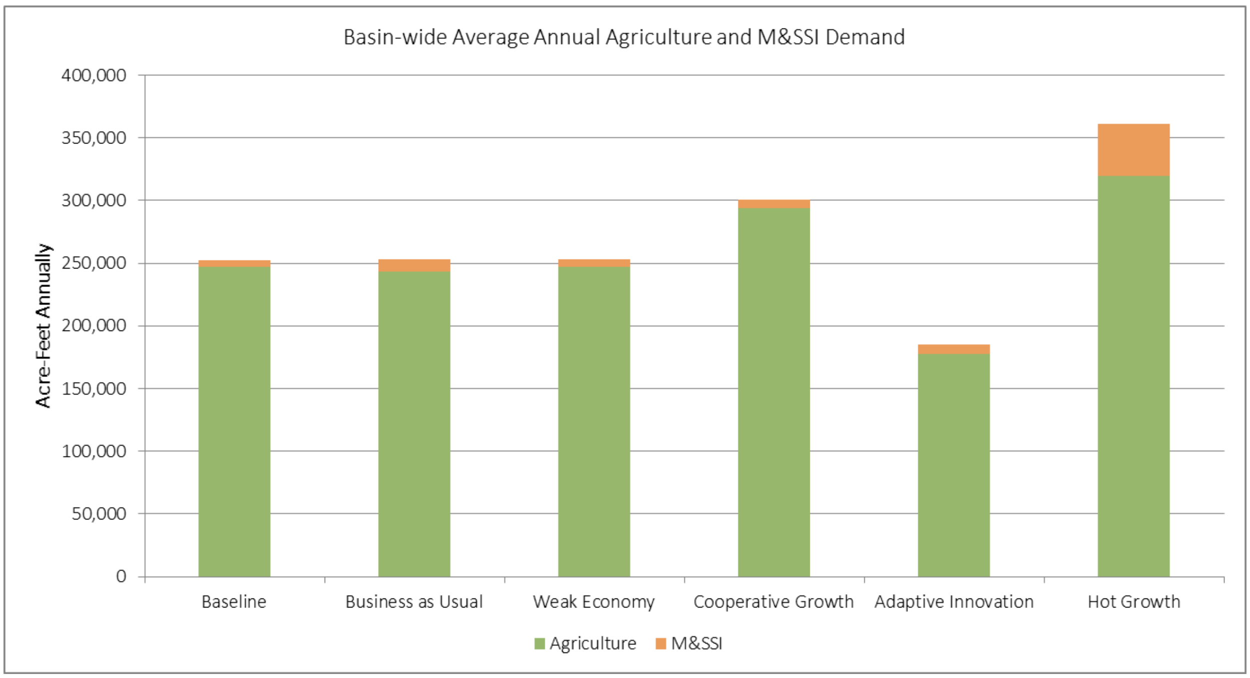


Figure 135: White River Basin Comparison of Average Annual Demands

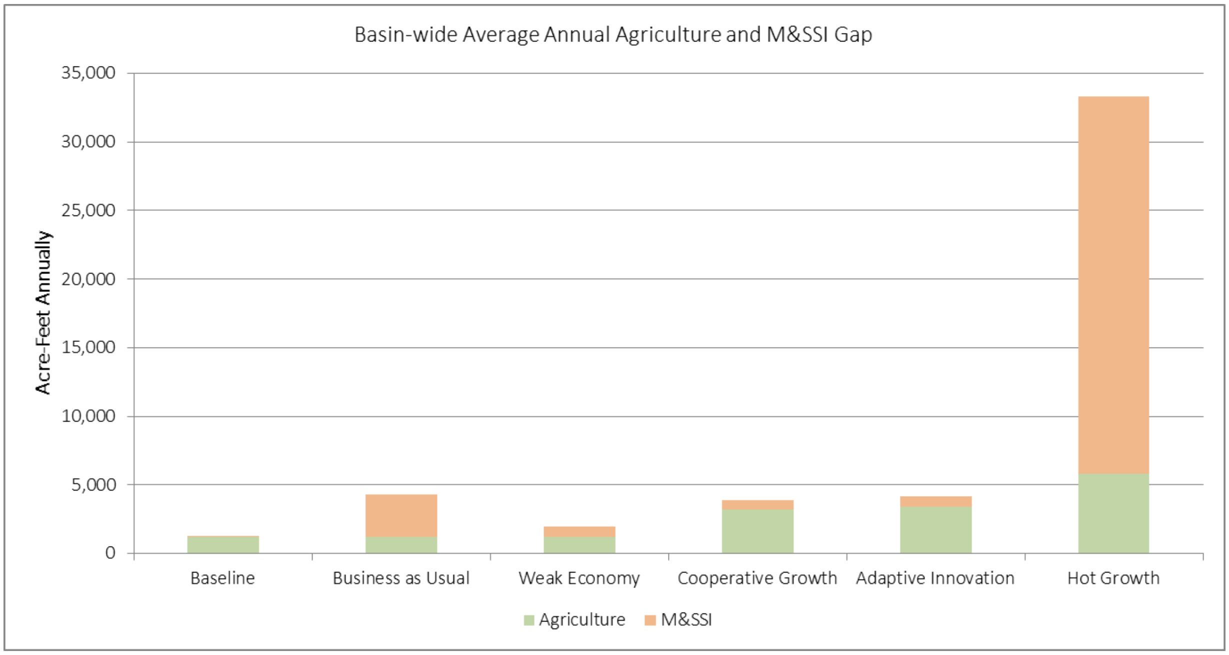


Figure 136: White River Basin Comparison of Average Annual Gaps

All Planning Scenarios, except the Weak Economy, project up to 360 acres of irrigated acreage will be taken out of production due to urbanization. Supplies used to irrigate the urbanized acreage could be considered a new municipal or SSI supply if the associated water rights were changed. To estimate this new supply, the average consumptive use of the urbanized acreage by Planning Scenario is reflected in Table 44. Note however, it is not known which farms and ranches will be directly impacted; whether the acreage was served by senior/junior direct rights or had supplemental storage supplies; or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use, or whether the supply could directly meet the future M&SSI demand or would require exchange potential. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 44: Potential Water Supply from Urbanized Acreage in the White River Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Urbanized Acreage	360	-	360	360	360
Estimated Consumptive Use (ac-ft/year)	587	-	702	698	766

Reservoir storage is very limited in the White River Basin, and available reservoir storage is not operated for agricultural uses. As shown in Figure 137, the entire basin only has about 22,000 ac-ft of storage and it generally remains full. Lake Avery is operated for wildlife habitat. Colorado Parks and Wildlife has recently explored releasing water from Lake Avery to support streamflow for the mountain white fish, but this is a pilot experiment that has not be incorporated into the modeling. Kenney Reservoir is operated as a runof-the-river hydropower facility and provides flat-water recreation. It can supply emergency supply to the Town of Rangely, but this is rarely used in any of the scenarios.

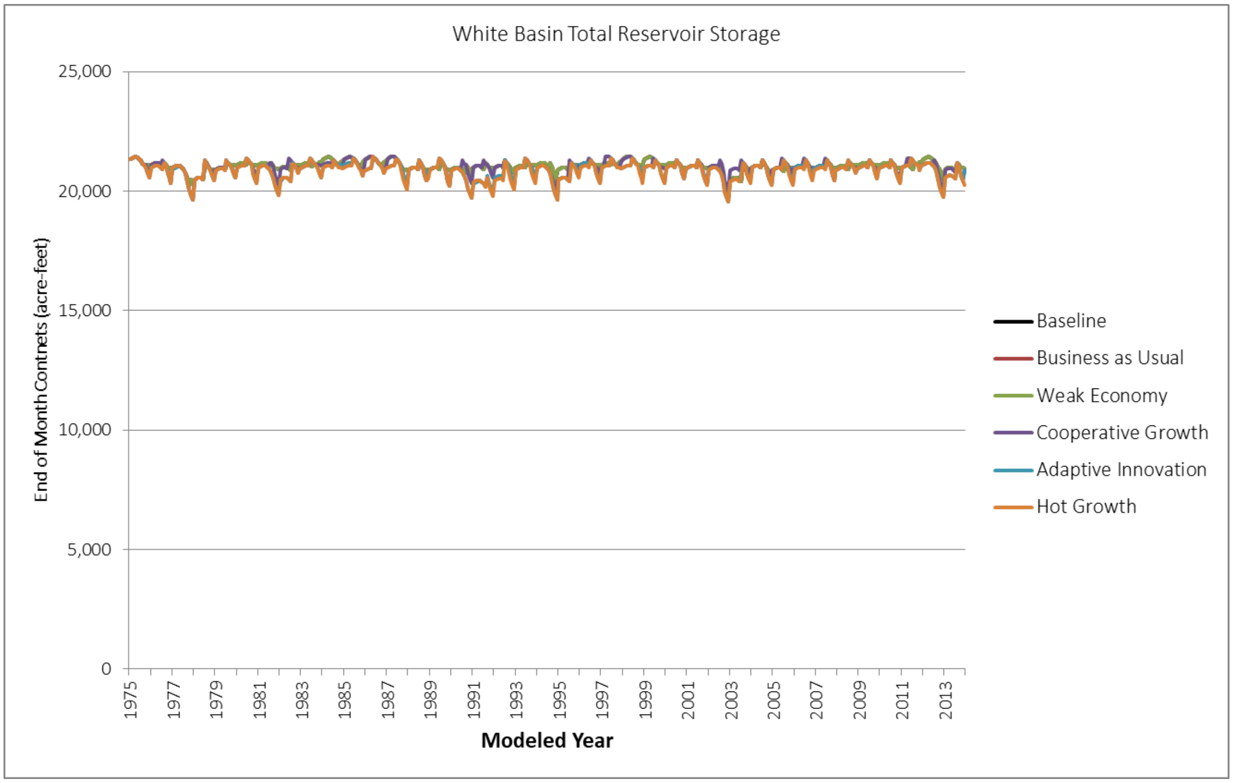


Figure 137: White River Basin Total Reservoir Storage

The following figures show average monthly simulated streamflow at key locations across the basin, as reflected in Figure 128. The primary driver of average monthly simulated streamflow across the Planning Scenarios is hydrology. The average monthly streamflow results from Baseline, Business as Usual and Weak Economy scenarios are almost indistinguishable from each other because they use current hydrology. At both gaged locations, the lines graph directly on top of each other. The modest changes in demands for agriculture and M&SSI result in very similar streamflows.

The In-Between hydrology incorporated in the Cooperative Growth scenario and the Hot and Dry hydrology incorporated in Adaptive Innovation and Hot Growth scenarios consistently reduce late season flows across the basin. The change in streamflow during the month of July is particularly dramatic. For example, Figure 138 reflects the streamflow volume decrease from about 45,000 ac-ft in July under current hydrology to 18,000 ac-ft under the In-Between hydrology and 11,500 ac-ft under the Hot and Dry hydrology. Simulated streamflow results in August through December also reflect consistently lower streamflow under the two climate projections.

Note that although the climate-adjusted scenarios experience a similar or larger peak runoff volume than current conditions, the annual streamflow volume is less than the current annual volume. This indicates that the climate-adjusted hydrological conditions are significantly shifting the streamflow pattern, which may present as many challenges as the decline in streamflow.

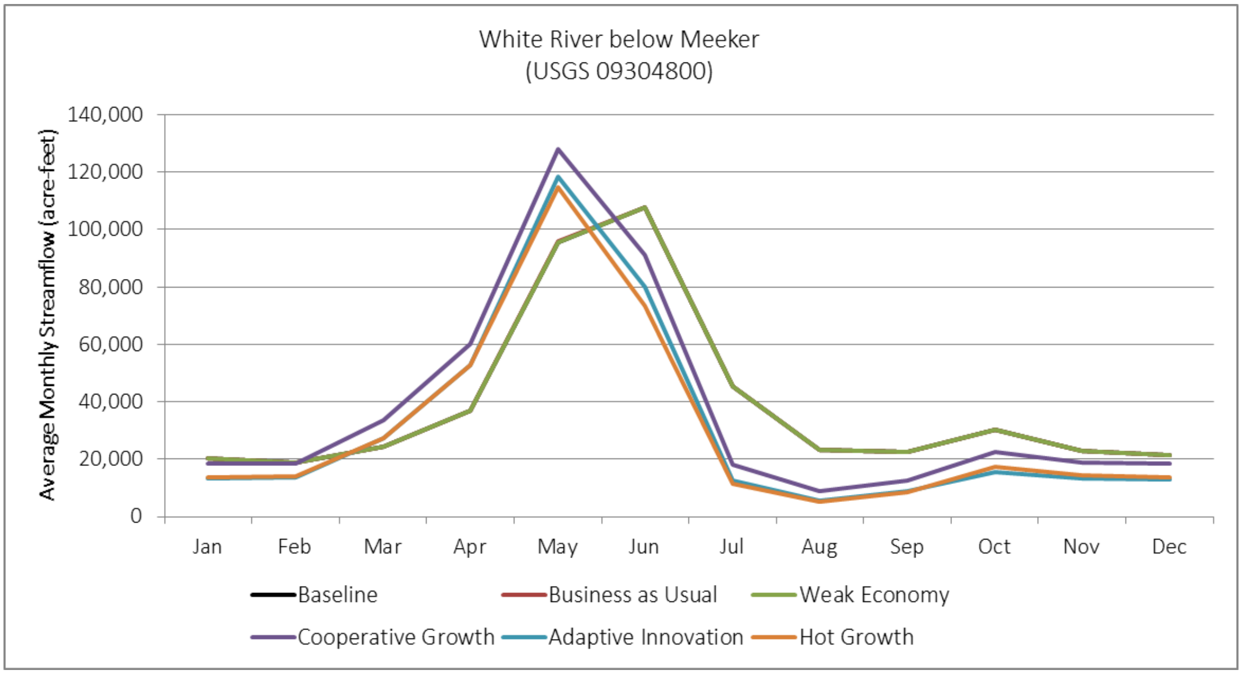


Figure 138: Average Monthly Streamflow for the White River below Meeker

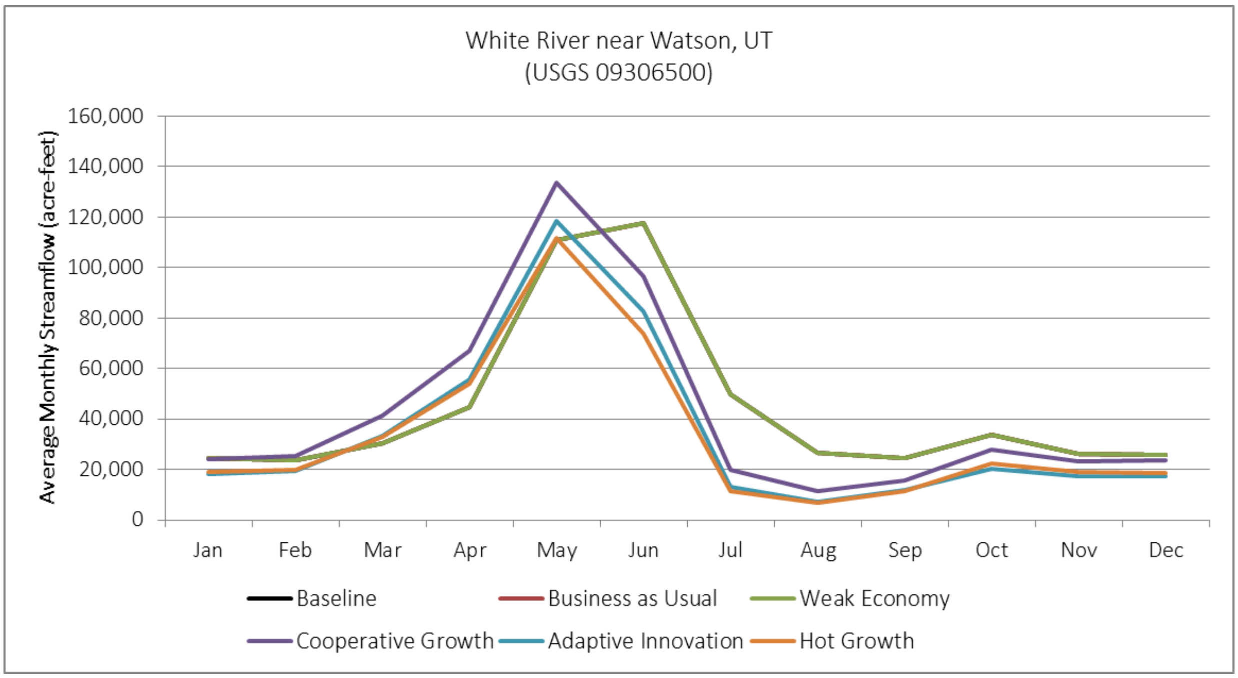


Figure 139: Average Monthly Streamflow for the White River near Watson, UT

Figure 140 and Figure 141 reflect the simulated monthly available flow on the White River below Boise Creek, which is located above Kenney Reservoir. The reservoir has a hydropower water right that is not fully satisfied and serves as the controlling right in the model. The figures reflect that unappropriated flows are projected to be available in most years, though the amounts will vary annually and across scenarios. In some years, very little to no flow is available under current and future conditions at this location, particularly during the winter and during critically dry years. Unappropriated available supply under climate-adjusted Planning Scenarios is projected to decline and to occur earlier in the year.

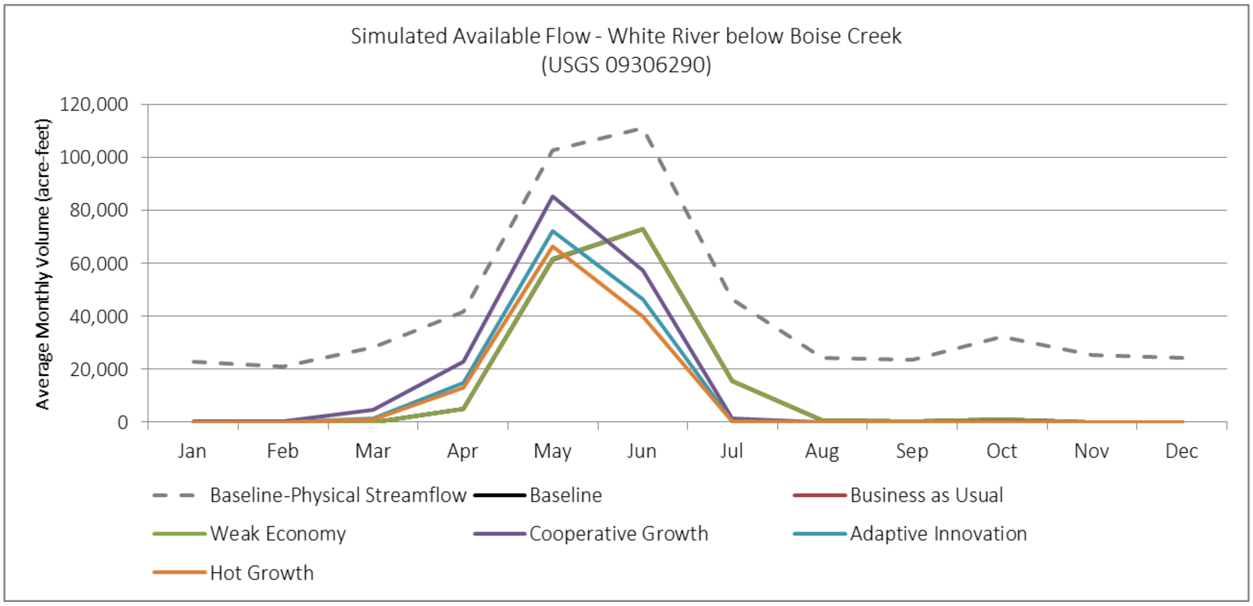


Figure 140: Average Monthly Unappropriated Available Supply at White River below Boise Creek

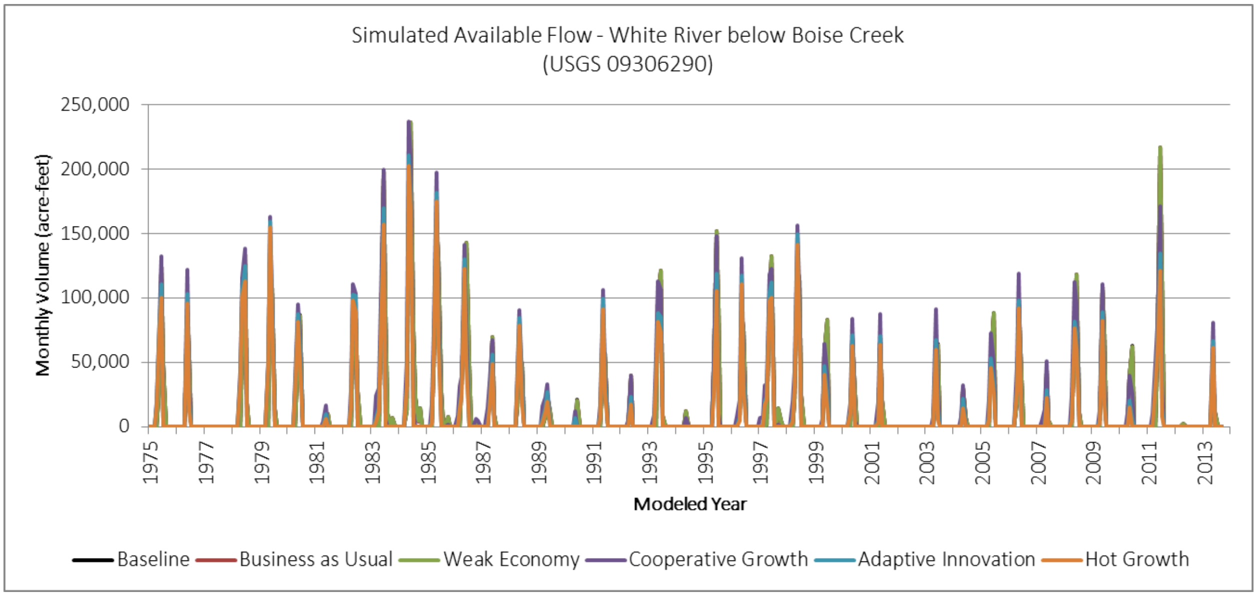
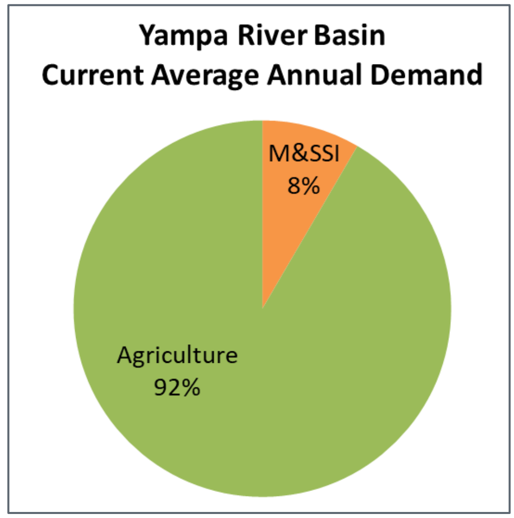


Figure 141: Monthly Unappropriated Available Supply at White River below Boise Creek

5.10 YAMPA RIVER BASIN



Irrigation for ranching operations is the largest demand for water in the Yampa River basin, accounting for over 92 percent of total demand basins. Mountain ranches produce hay and alfalfa to support cow/calf operations, with irrigators generally flood irrigating their fields.

Water used to meet M&SSI demands in the basin is relatively small compared to agricultural uses, accounting for approximately 8 percent of the total current demand in the basin. The two major municipal areas in the Yampa River Basin are the City of Steamboat Springs and the City of Craig. These population centers have a strong tourist economy, driven by Steamboat Springs resort, Dinosaur National Monument, boating, fishing and hunting.

One unique feature of the Yampa River is the amount of unappropriated streamflow compared to other basins in the state. The Yampa River mainstem only recently experienced a call in 2018, a critically dry year, however tributaries throughout the Yampa River Basin experience local calls more frequently.

The following sections describe the agricultural and M&SSI demands in the Yampa River basin in more detail. Figure 142 shows the basin outline, the administrative boundaries of the water districts, and the streamflow gages highlighted in the results section below.

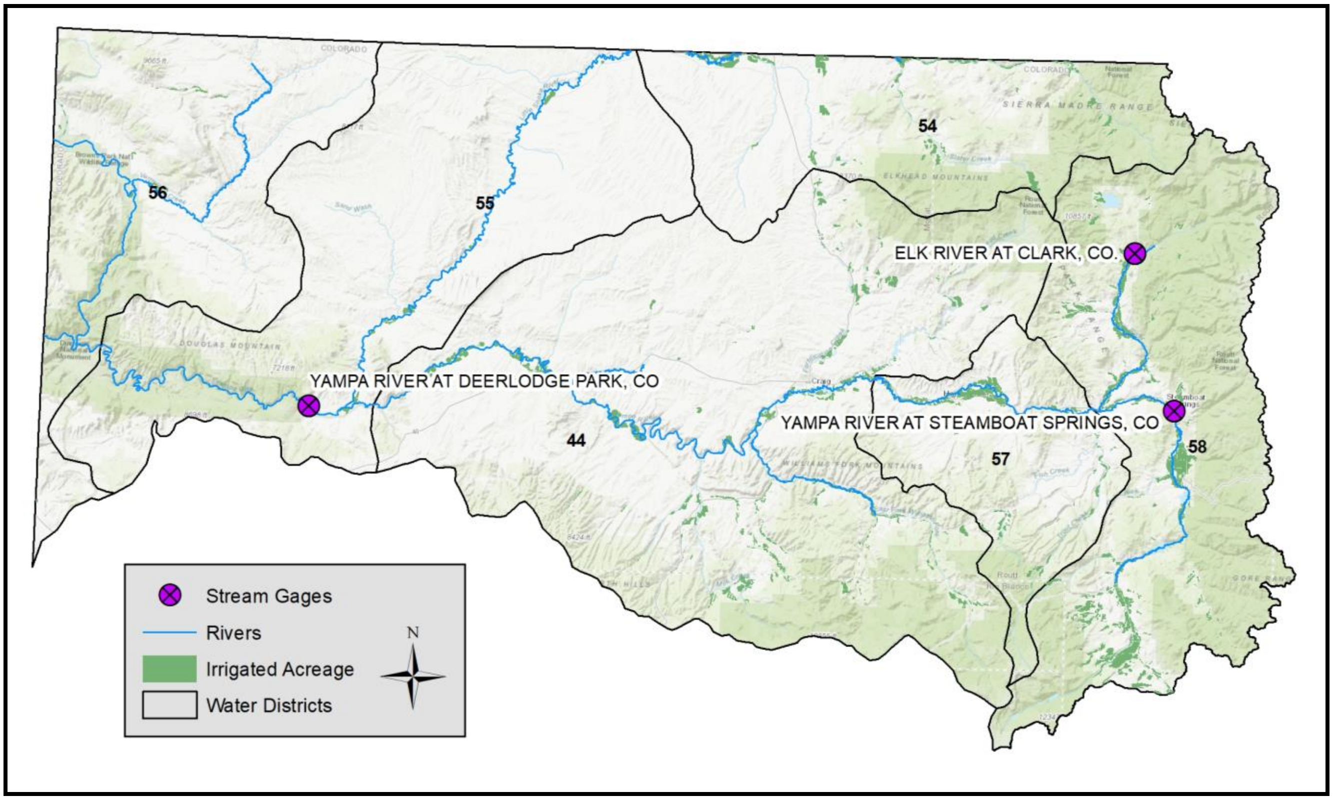


Figure 142: Yampa River Map with Streamgage Locations

5.10.1YAMPA RIVER BASIN AGRICULTURE WATER SUPPLY AND GAP

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. Irrigated fields are concentrated in the tributary and river valleys, and are able to produce a single cutting of hay before turning the fields over for grazing cattle. Due to warmer temperatures, the lower portion of the basin is able to produce two cuttings and can support more fields of alfalfa. Flood irrigation is common, especially in the upper portions of the basin. In areas where it is economically feasible, some ranchers are switching to sprinkler irrigation. 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 Yampa River Basin agricultural diversion demands[21], demand gaps, and consumptive use gaps results for the baseline and Technical Update Planning Scenarios are presented in Table 45. As discussed in Technical Memo *Current and 2050 Planning Scenario Agricultural Diversion Demand*, 2050 agricultural diversion demands are influenced by a number of drivers, including climate, urbanization, planned agricultural projects, and emerging technologies.

[21] There are a few small transbasin diversions from the Yampa River basin that are used on irrigated fields just outside of the basin boundaries. These diversions are reported under the agricultural sector, and not reflected as transbasin exports herein.

Table 45: Yampa River Basin Agricultural Water Supply and Gap Summary

	Agricultural Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	402,488	403,627	403,627	522,453	460,985	684,260
	Average Annual Demand Increase from Baseline (ac-ft)	-	1,139	1,139	119,965	58,497	281,772
	Average Annual Gap (ac-ft)	13,254	13,609	13,588	63,053	58,948	150,012
	Average Annual Gap Increase from Baseline (ac-ft)	-	354	333	49,799	45,694	136,757
	Average Annual Percent Gap	3%	3%	3%	12%	13%	22%
	Average Annual CU Gap (ac-ft)	7,394	7,585	7,574	34,422	37,840	81,475
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	448,870	450,513	450,513	532,972	463,792	667,456
	Increase from Baseline Demand (ac-ft)	-	1,643	1,643	84,102	14,922	218,586
	Gap In Maximum Gap Year (ac-ft)	55,578	55,354	55,219	123,445	97,729	246,537
	Increase from Baseline Gap (ac-ft)	-	-	-	67,867	42,151	190,958
	Percent Gap In Maximum Gap Year	12%	12%	12%	23%	21%	37%

As reflected in the table, irrigators in the basin currently experience a relatively small gap on average, but a more substantial gap during critically dry years. There are several small tributaries in the Yampa River basin that currently experience physical water shortages, such that streamflow is not sufficient to meet the crop demand for the full growing season. Gaps are typically experienced during the late irrigation season, after runoff has occurred.

The average annual agricultural demand increases slightly from Baseline to the Business as Usual and Weak Economy Planning Scenarios. Both the Business as Usual and Weak Economy scenarios assume 1,500 acres of agriculture is removed from production due to urbanization. At the same time, the scenarios project 1,000 acres of new alfalfa fields are put into production. The reduction in demand due to urbanization of primarily grass pasture fields is offset by the increase in alfalfa acreage, which has a higher crop demand compared to grass pasture. Despite having the same agricultural demands and hydrology, the Business as Usual scenario has slightly more shortages than the Weak Economy scenario. This is due to the slightly higher projected M&SSI demands in the Business as Usual scenario; more details on M&SSI demands and gaps are discussed in the next section.

The Cooperative Growth Planning Scenario projects additional irrigated acreage will be put into production, as well as incorporates an increase in agricultural demand due to climate change adjustments to IWR and climate-adjusted hydrology associated with the projected In-Between climate conditions. The hydrological conditions at many locations predict limited reductions to total runoff in the basin, but do reflect a substantial shift in the peak streamflow. There is very limited agricultural reservoir storage available in the Yampa River Basin, so the general irrigation practice is to fill the soil moisture during the runoff and use the soil moisture to meet crop demand during the late irrigation season, when the streamflow is low. When the runoff occurs earlier in the year as projected, there are fewer lagged return flows later in the summer and soil moisture supplies are used earlier in the year. This, in combination with larger agricultural demands, causes an increase in agricultural gaps.

For the Adaptive Innovation scenario, the average annual demand is greater than the Baseline scenario demand, but less than the Cooperative Growth scenario demand. This is due to a combination of adjustments, including the removal of urbanized acreage; the addition of 14,805 irrigated acres; climate-adjustments to IWR under the Hot and Dry conditions; and adjustments for emerging technologies. The overall effect of these adjustments is an agricultural demand approximately 60,000 ac-ft greater than the Baseline demand. Agricultural gaps in the scenario, which are moderate on average but more substantial in critically dry years, can be attributed to the shift in peak runoff due to climate-adjusted and improved system efficiencies that reduce late irrigation season return flows.

The Hot Growth scenario projects the largest volume of agricultural gaps in the Yampa River Basin. Average annual diversion demands have increased compared to all previous scenarios due to the Hot and Dry climate conditions. Overall, the Hot Growth scenario projects an increase of approximately 282,000 ac-ft of agricultural demand on average compared to the Baseline scenario, with a 137,000 ac-ft increased gap on average. This indicates that approximately half of the increased demand could be met under the Hot and Dry hydrological conditions.

The overall picture for agriculture in the Yampa River Basin shows relatively low average annual percent gaps, with gaps in critically dry years projected to be more severe. This is highlighted in Figure 143 and Figure 144, which show the relative size of the agricultural demands and gaps on average and for critically dry years. As with other basins, agricultural water users are not impacted evenly throughout the basin, depending on the available water supply and relative seniority of the agricultural water rights. For example, the Yampa River Basin average annual agricultural gap in the Hot Growth scenario is 22 percent, the agricultural gap in Water District 44 (Lower Yampa River) is 35 percent on average. The largest gaps are found on smaller tributaries to the Yampa River because of physical shortages, but irrigators with more junior water rights on the mainstem are also projected to have gaps. The 14,805 acres of new irrigated land put under production is projected to experience an average annual gap of 56 percent in the Hot and Dry scenario.

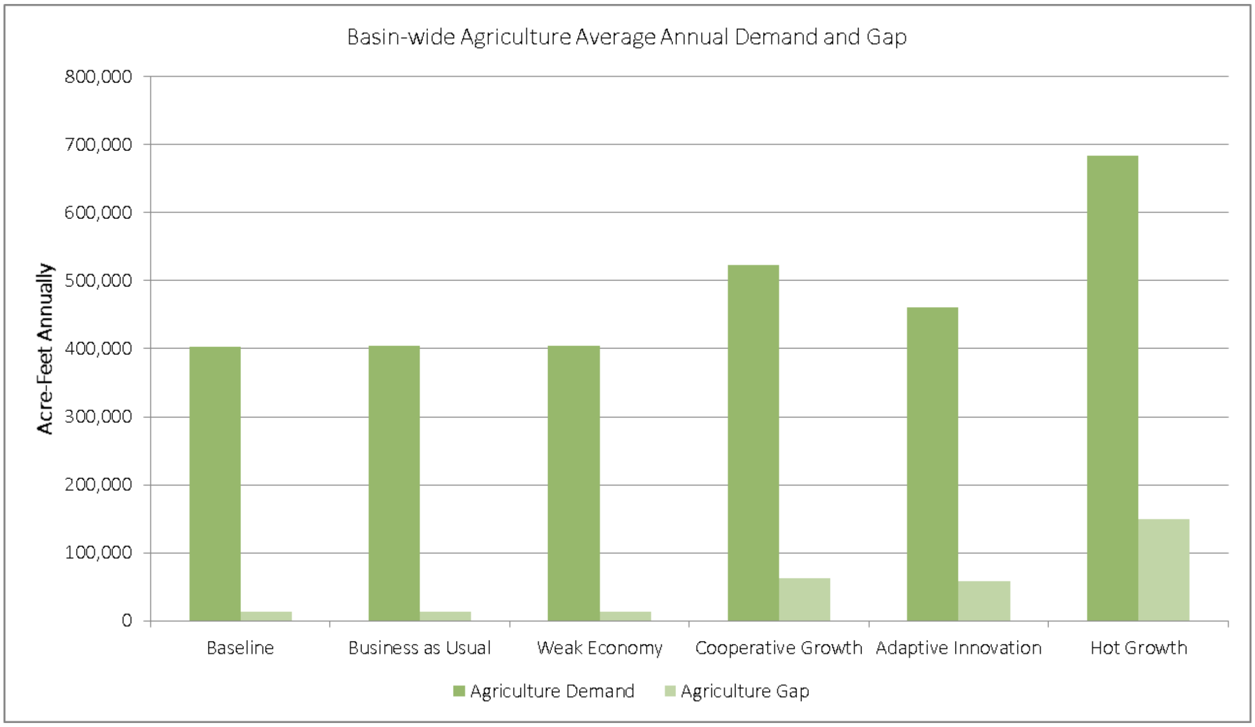


Figure 143: Yampa River Basin Agriculture Average Annual Demand and Gap

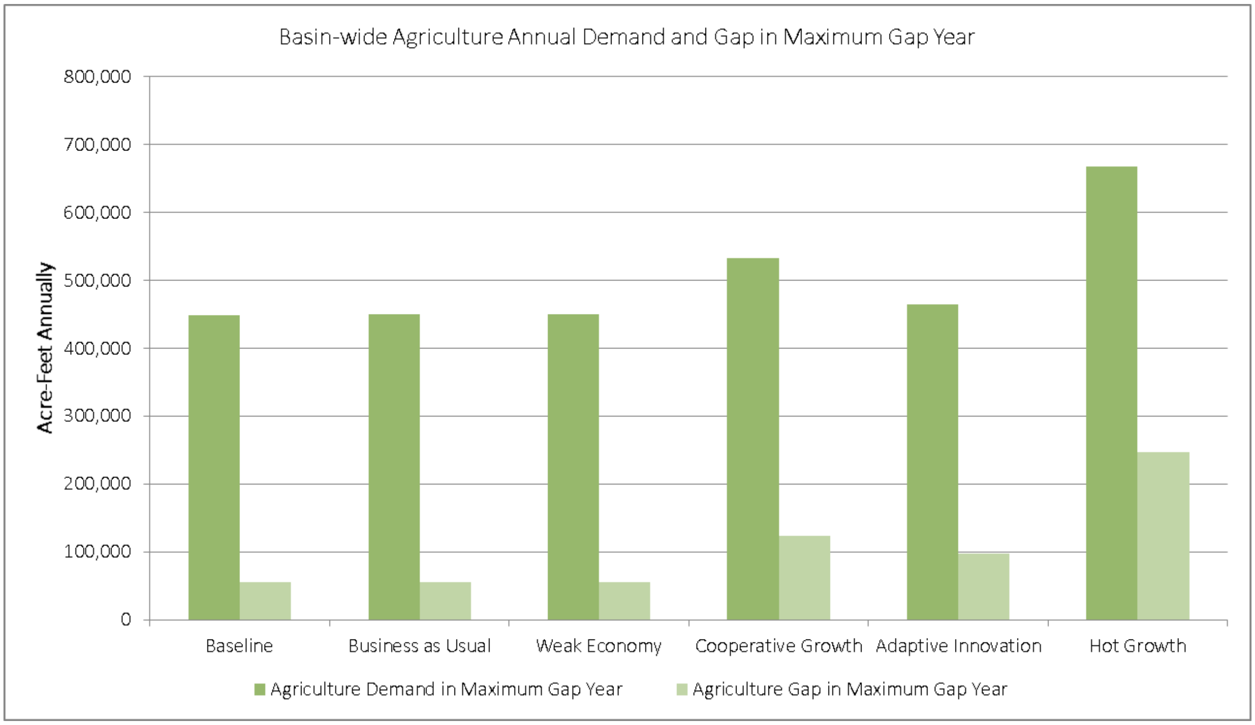


Figure 144: Yampa River Basin Agriculture Annual Demand and Gap in Maximum Gap Year

The annual agricultural gap variability over the model study period is reflected in Figure 145. As expected, the dry hydrology years of 1977, 2002, and 2012 produce the largest gaps regardless of scenario. The Baseline, Business as Usual, and Weak Economy scenarios use current hydrology and the results are very similar on the graph, with results often overlapping. Gaps in these three scenarios are minimal in years with wetter hydrology; however a gap is projected in all years in the study period. Gaps increase as the agricultural demand increases and hydrology is adjusted. Despite differences between projected hydrology, the changes to IWR and irrigation system efficiency in the Adaptive Innovation scenario compensate for the decline in streamflow and the gap results are very similar to the Cooperative Growth scenario gap results. With increased demands and climate-adjusted hydrology, the Hot Growth scenario is projected to have the largest agricultural gaps.

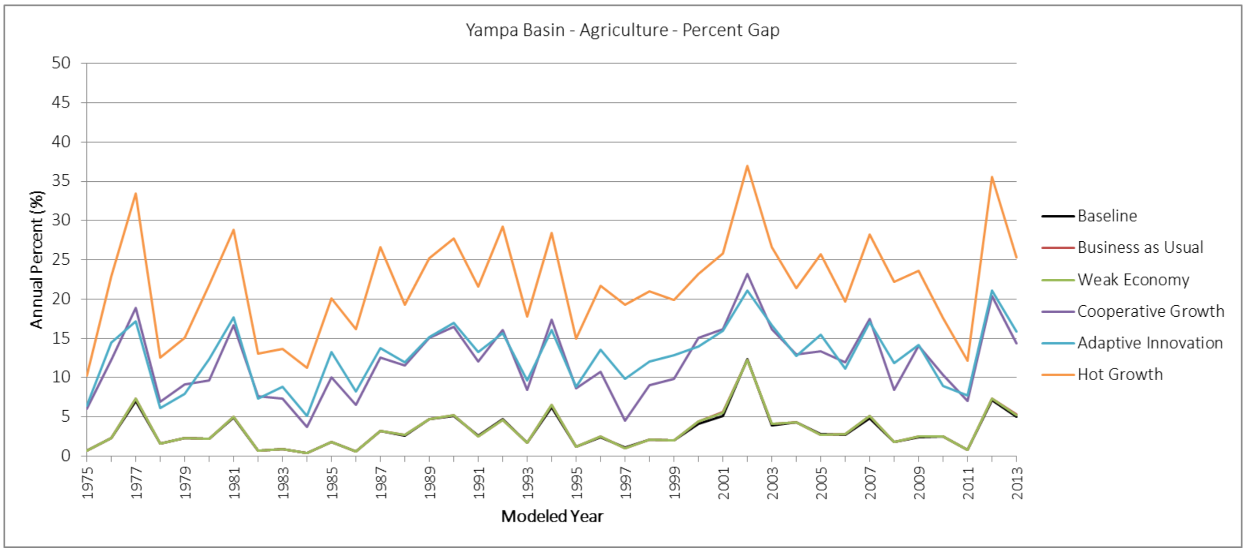


Figure 145: Yampa River Basin Agriculture Percent Diversion Gap Times Series

5.10.2 YAMPA RIVER BASIN M&SSI WATER SUPPLY AND GAP

There is currently approximately 36,000 ac-ft of M&SSI demand in the Yampa River basin; approximately a quarter of the demand is attributable to municipal demands and the remaining three quarters is attributable to SSI demands. Population in the Yampa River basin is projected to increase in all scenarios except the Weak Economy scenario, leading to moderate increases to the municipal demand in the basin in many scenarios. The SSI demand is projected to increase in all scenarios, nearly doubling by the Hot Growth scenario.

Approximately 60 percent of the municipal demand is grouped and represented in the model at several locations throughout the model. The remaining 40 percent is associated with two municipal entities, City of Steamboat Springs (Mt. Werner Water District) and the City of Craig. The demands and surface water rights for these municipalities are represented individually in the model. Approximately 25 percent of the total SSI demand is grouped and represented at several locations in the model. The remaining 75 percent of the SSI demand is attributable to the following entities, which are represented individually in the model:

- Craig Station
- Maybell Mills Pipeline
- Colowyo Mine

- Hayden Station
- Steamboat Resort Snowmaking

Refer to the *Baseline and Projected 2050 Planning Scenario Municipal and Self Supplied Industrial Water Demands* technical memorandum for additional discussion on how the M&SSI demands in the basin were developed. The water supply and gap results for M&SSI in the Yampa River Basin are summarized in Table 46, and graphically reflected in Figure 146 and Figure 147.

Table 46: Yampa River Basin M&SSI Water Supply and Gap Summary

	M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	36,894	53,346	46,664	48,914	52,970	68,306
Average	Average Annual Demand Increase from Baseline (ac-ft)	-	16,452	9,770	12,020	16,076	31,412
Average	Average Annual Gap (ac-ft)	105	573	217	849	1,407	4,813
Average	Average Annual Gap Increase from Baseline (ac-ft)	-	468	112	744	1,302	4,708
Average	Average Annual Percent Gap	0%	1%	0%	2%	3%	7%
Critically Dry Maximum	Demand In Maximum Gap Year (ac-ft)	36,894	53,346	46,664	48,914	52,970	68,306
Critically Dry Maximum	Increase from Baseline Demand (ac-ft)	-	16,452	9,770	12,020	16,076	31,412
Critically Dry Maximum	Gap In Maximum Gap Year (ac-ft)	397	1,634	684	1,642	2,548	8,190
Critically Dry Maximum	Increase from Baseline Gap (ac-ft)	-	1,237	287	1,245	2,151	7,793
Critically Dry Maximum	Percent Gap In Maximum Gap Year	1%	3%	1%	3%	5%	12%

Ideally, the Baseline scenario would have no gaps however a small baseline gap is reported. This is due to the model representation of the tributary that supplies water to Colowyo Mine diversion. The mine sources water from pumps on several tributaries, some of which are small and difficult to represent in the model due a runoff signature that differs from other streams in the area. It is difficult to estimate the runoff on this small tributary without measured streamflow information.

The average annual demand increases from the Baseline scenario to the Business as Usual scenario, primarily due to an increase in SSI demand. The annual gap on average and during critically dry years is small, only 1 percent and 3 percent respectively. This indicates that the projected M&SSI demands can largely be satisfied from the entities' existing water rights portfolio and unappropriated flows in the Yampa River basin in the Business as Usual scenario.

The Weak Economy, Cooperative Growth, and Adaptive Innovation scenarios have smaller increases in average annual demand than the Business as Usual scenario and the gaps are also small. Note that even with the climate-adjusted agricultural demands and hydrology in the Cooperative Growth and Adaptive Innovation scenario, the average gap is 2 to 3 percent and the gap in critically dry years is 3 to 5 percent. As with the Business as Usual scenario, the projected M&SSI demands can largely be satisfied from the entities' existing water rights portfolio and unappropriated flows in the Yampa River basin in these scenarios.

The M&SSI demand in the Hot Growth scenario is nearly double the Baseline demands, driven by substantial increases in both municipal and SSI demands. This increase, in combination with increased agricultural demands and reduced hydrology under the Hot and Dry climate conditions, results in larger gaps, with the average annual gap reaching 7 percent and the gap in critically dry years reaching 12 percent. The impact of the Hot and Dry conditions in this scenario is a decline in unappropriated flows available to meet projected M&SSI demands throughout the basin, as a result of both the climate-adjusted hydrology and increased agricultural demand in the basin

In general, M&SSI in the Yampa River Basin is projected to experience relatively low gaps both on average and during critically dry years, as highlighted in Figure 146 and Figure 147. As with other basins, M&SSI water users are not impacted equally throughout the basin, with entities represented individually having far less shortages than those demands represented at grouped locations. For example, the Yampa River Basin average annual M&SSI gap in the Hot Growth scenario is 7 percent. The municipal entities represented with their existing water rights and operations are projected to have no gaps and the individually modeled SSI entities are projected to have a 2 percent gap. Conversely, the demand represented at grouped municipal locations is projected to have an 18 percent gap on average and grouped SSI demand is projected to have a 14 percent gap. The individually modeled entities have robust water rights portfolios capable of meeting a large part of their projected growth and generally have access to reservoir storage. It is likely the demands at grouped locations would have smaller gaps if their water rights portfolios and operations (e.g. reservoir releases) were reflected in the model; it is recommended the representation of these grouped demands is refined in future modeling efforts.

Figure 146: Yampa River Basin M&SSI Average Annual Demand and Gap

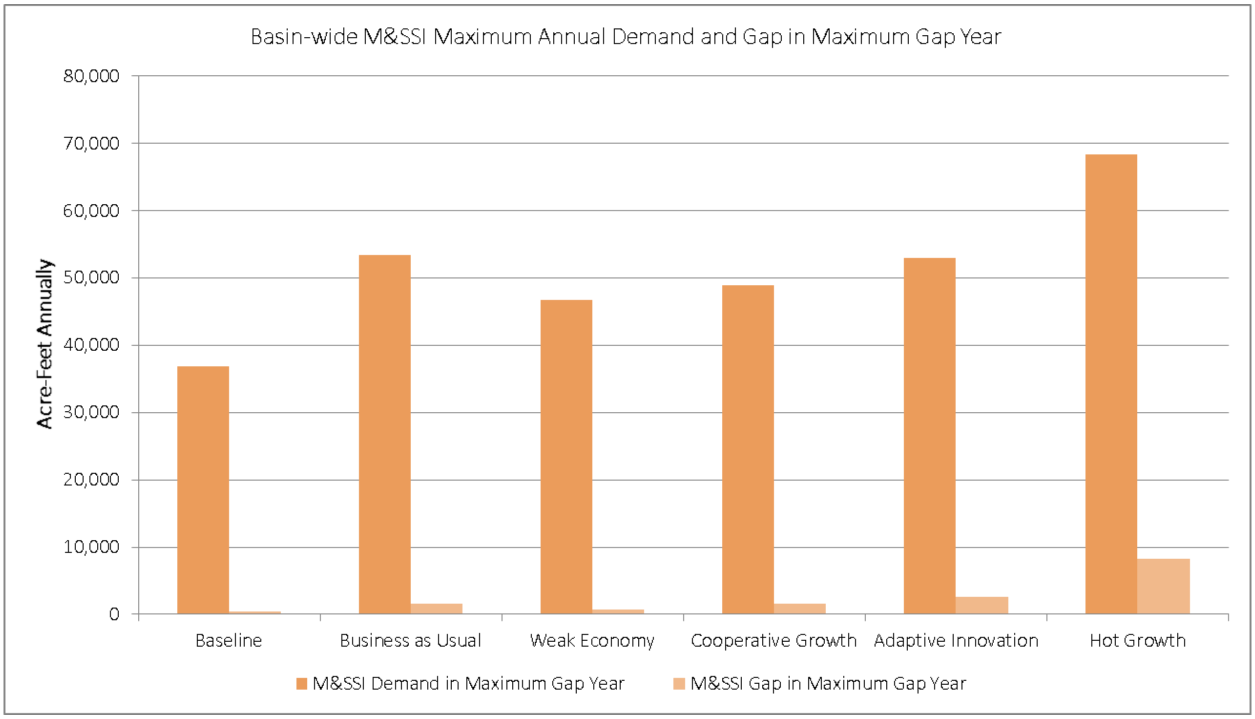


Figure 147: Yampa River Basin M&SSI Maximum Annual Demand and Gap in Maximum Gap Year

Figure 148 reflects the average annual percent gap across a variety of wet, average, and dry year types. The dry hydrology years of 1977 and 2002 produce the largest gaps, regardless of scenario. Note that 2012, despite being an extremely dry year, does not produce as large a gap as other similar dry years. This is because the majority of the M&SSI structures have access to storage, which was filled during the preceding wet year of 2011. The primary drivers of gap appear to be a combination of demand and hydrology.

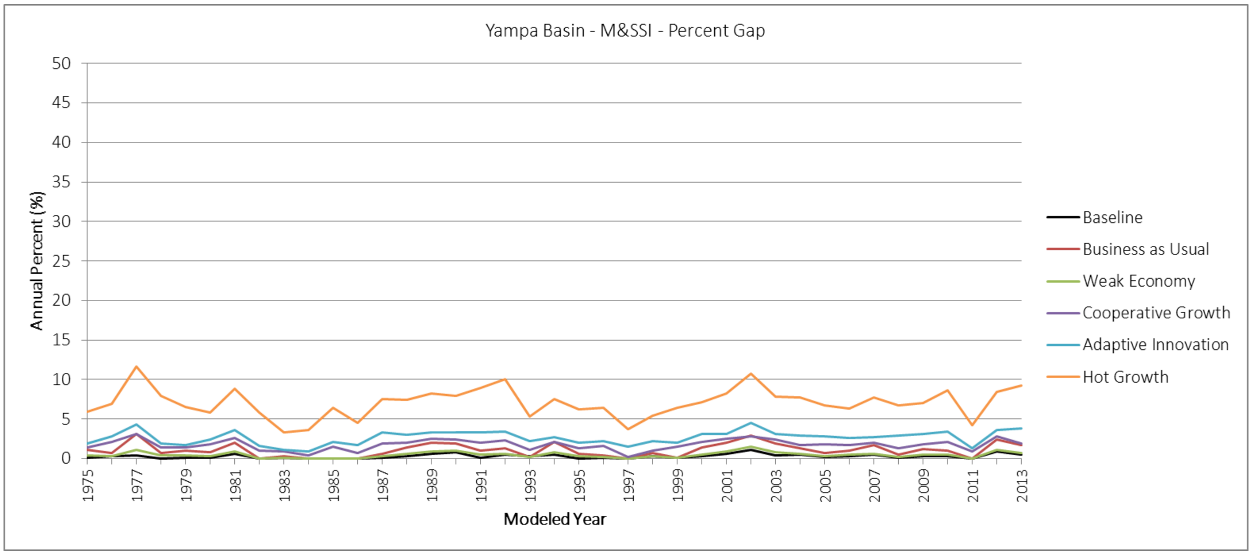


Figure 148: Yampa River Basin M&SSI Average Annual Gap Time Series

5.10.3 YAMPA RIVER BASIN SUMMARY

The combined agriculture and M&SSI demands and gap summary is provided in Table 47. The results are very similar to the agricultural results in Table 45 because water supplies in the basin are predominantly used for agriculture. As previously discussed, gaps are relatively low in the Baseline, Business as Usual and Weak Economy scenarios. Gaps during critically dry years, which occur during drier years, are projected to be more substantial. The gaps increase in the Cooperative Growth and the Adaptive Innovation scenarios as a result of increasing demands and a shift in hydrology. The gaps, both on average and during critically dry years, are largest in the Hot Growth scenario, due to the increased demands and decreased hydrology from the climate projections.

Figure 149 reflects the relative size of the agricultural and M&SSI demands in the Yampa River basin. Following the graphic are summaries regarding other considerations that may impact the basin-wide gap, including potential M&SSI supplies from urbanized acreage.

Table 47: Yampa River Basin Water Supply and Gap Summary

	Agricultural and M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	439,382	456,973	450,291	571,367	513,955	752,566
	Average Annual Gap (ac-ft)	13,359	14,182	13,805	63,902	60,354	154,825
	Average Annual Percent Gap	3%	3%	3%	11%	12%	21%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	485,764	503,859	497,177	581,886	516,762	735,762
	Gap In Maximum Gap Year (ac-ft)	55,975	56,988	55,903	125,087	100,277	254,727
	Percent Gap In Maximum Gap Year	12%	11%	11%	21%	19%	35%

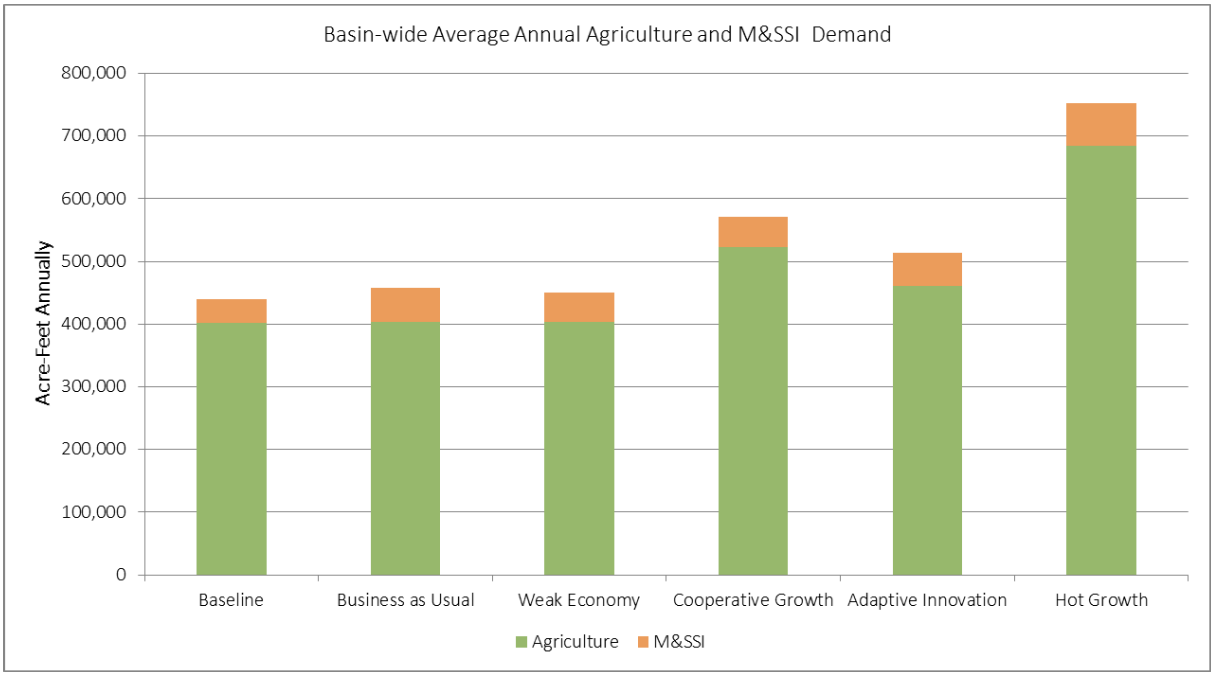


Figure 149: Yampa River Basin Comparison of Average Annual Demands

The Planning Scenarios project 1,500 acres of irrigated agriculture will be taken out of production due to urbanization. Supplies used to irrigate the urbanized acreage could be considered a new municipal supply if the associated water rights were changed to municipal uses. To estimate this new supply, the average consumptive use of the urbanized acreage by Planning Scenario is reflected in Note however that it is not known which farms and ranches will be directly impacted; whether the acreage was served by senior/junior direct rights or had supplemental storage supplies; or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use or whether the supply could directly meet the future municipal demand or would require exchange potential. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 48. This water could be used to help close the M&SSI gap. Note however that it is not known which farms and ranches will be directly impacted; whether the acreage was served by senior/junior direct rights or had supplemental storage supplies; or the crop type or specific irrigation practices on this acreage. Additionally, it is unknown if the water rights would be changed to municipal use or whether the supply could directly meet the future municipal demand or would require exchange potential. In light of these uncertainties, the table reflects a planning-level estimate of this potential new supply. Although it has not been applied to the M&SSI gap presented above, it would likely have the effect of decreasing the gap.

Table 48: Potential Water Supply from Urbanized Acreage in the Yampa River Basin

Urbanized Acreage Results	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth

Urbanized Acreage	1,500	1,500	1,500	1,500	1,500
Estimated Consumptive Use (ac-ft/year)	2,725	2,725	2,796	2,782	2,446

The Yampa River basin has approximately 120,000 ac-ft of storage, as reflected in the simulated reservoir storage results in Figure 150. Many of the larger reservoirs are for multiple purposes, including flatwater recreation, emergency drought supplies, municipal and industrial storage, and Endangered Fish Recovery Program water (e.g. Elkhead Reservoir). Only the smaller reservoirs, which are concentrated in the upper Yampa, provide water to agriculture, including Stillwater, Yamcolo, Allen Basin, and a portion of Stagecoach Reservoir. The reservoir storage results reflect the portion of storage used annually for agricultural demands; with the majority of the reservoir storage across the basin remains relatively full in all scenarios. Even in scenarios with the Hot and Dry hydrology, the agricultural supplies in the reservoirs are able to recover and refill the majority of study period.

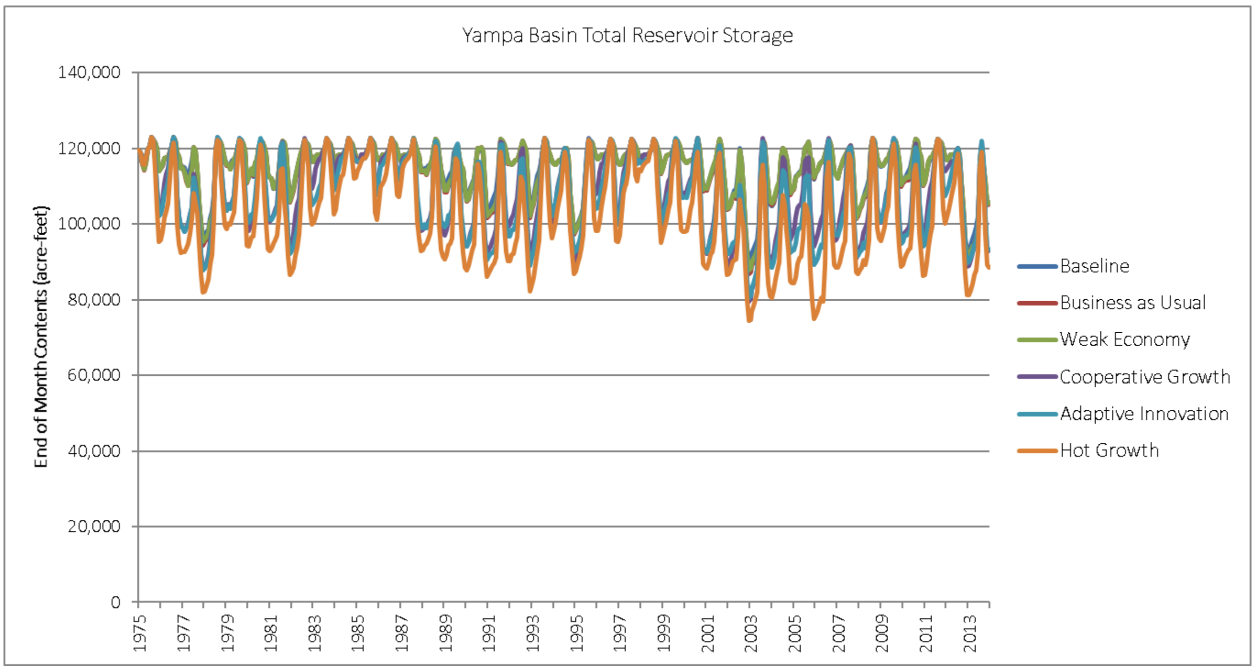


Figure 150: Yampa River Basin Total Reservoir Storage

The following figures show average monthly simulated streamflow at key locations across the basin, as reflected in Figure 142. The primary driver of average monthly simulated streamflow across the Planning Scenarios is hydrology. The average monthly streamflow results from Baseline, Business as Usual, and Weak Economy scenarios are almost indistinguishable from each other because they use the current hydrology. In several locations, the lines graph directly on top of each other. The In-Between hydrology used in the Cooperative Growth scenario reflected a moderate change to total runoff volume, increasing in some areas and decreasing in others. The Hot and Dry hydrology used in the Adaptive Innovation and Hot Growth scenarios further reduces the amount of total runoff volume compared to the In-Between hydrology.

The average streamflow results for gaged locations higher up in the basin best reflect the impact of the climate-adjusted hydrology, particularly the more pronounced peak runoff projected to occur in May and the sharp reduction to streamflow June, July, and August. The total annual volume of flow is actually projected to slightly increase under the In-Between conditions at both the Elk Creek and upper Yampa River locations; however the shift in streamflow availability leads to larger gaps later in the irrigation season. The climate-adjusted hydrology under the Hot and Dry conditions project a one percent decline to total annual streamflow volume for the Elk Creek location and a 9 percent decline for the Steamboat location.

The Yampa River at Deerlodge gage (Figure 153) is the most downstream gage in the basin, and is a good indicator of the total impact of the increased demands and the climate-adjusted hydrology. The simulated streamflow results indicate larger streamflow in March and April for scenarios with climate-adjusted hydrology, primarily because the upper basins projected an earlier runoff. Diversions to the increased demands and reservoir storage deplete the large peak runoff in May under the climate-adjusted hydrology, resulting in similar results between all scenarios for May. The scenario results separate again in the late irrigation season due to the climate-adjusted hydrology, leading to a 13 to 17 percent reduction in total annual streamflow at this location in the Adaptive Innovation and Hot Growth scenarios, respectively.

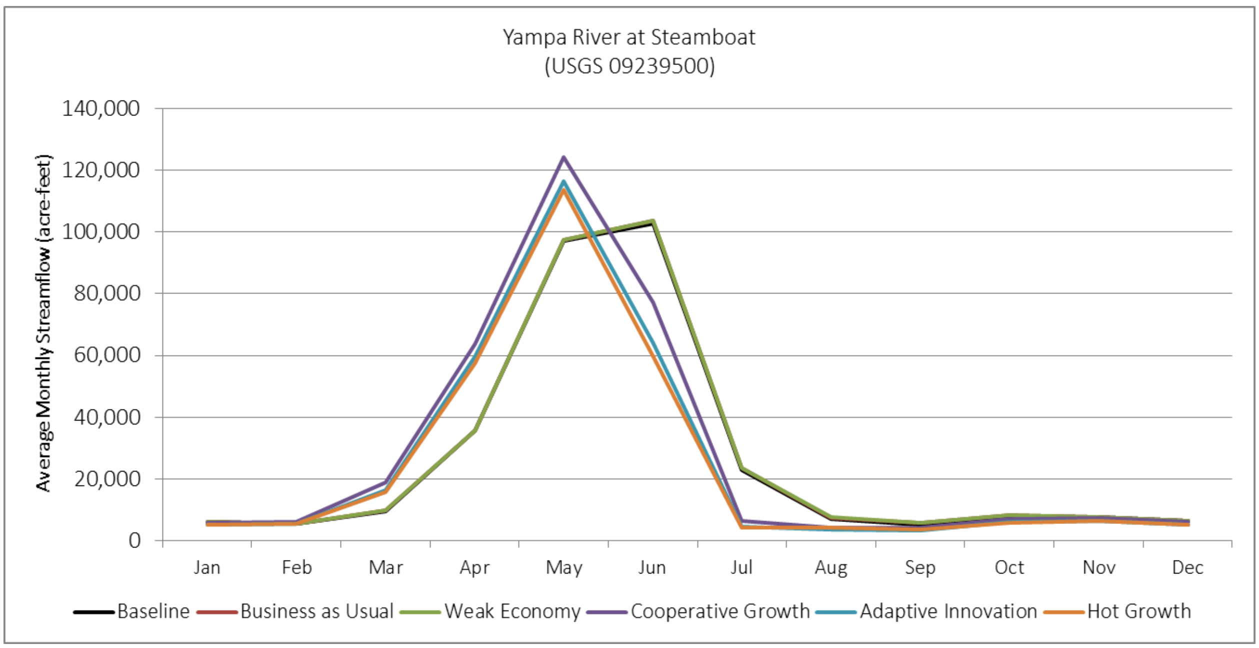


Figure 151: Average Monthly Streamflow for the Yampa River at Steamboat

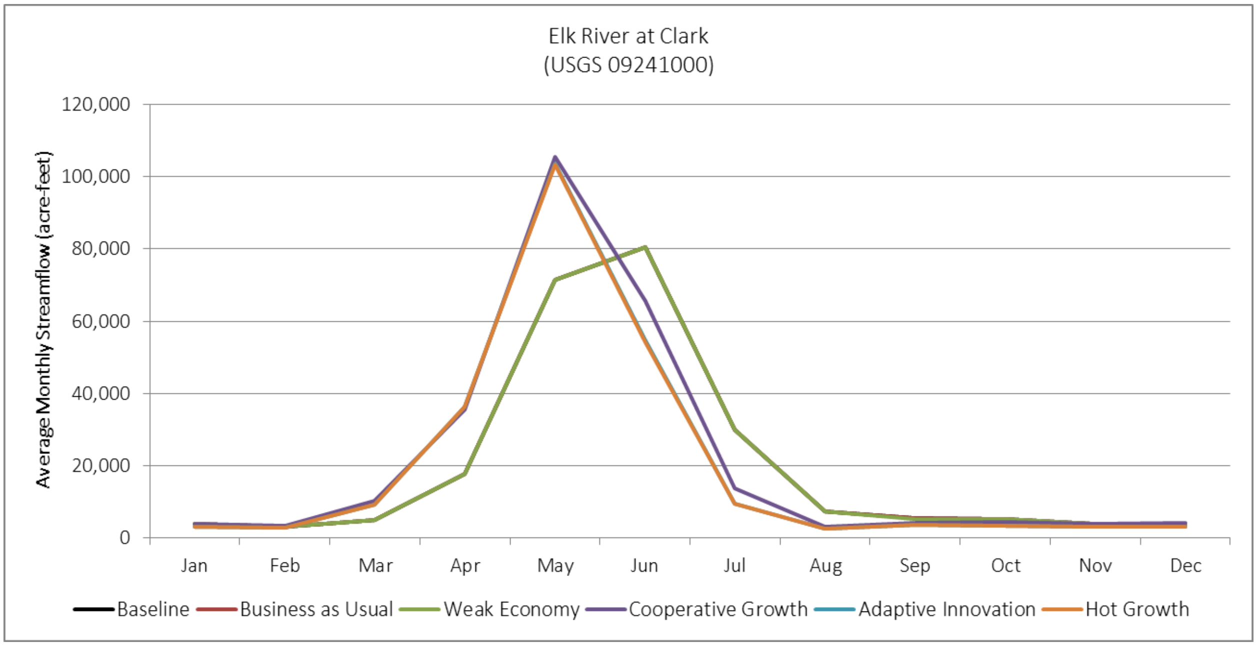


Figure 152: Average Monthly Streamflow for the Elk River at Clark

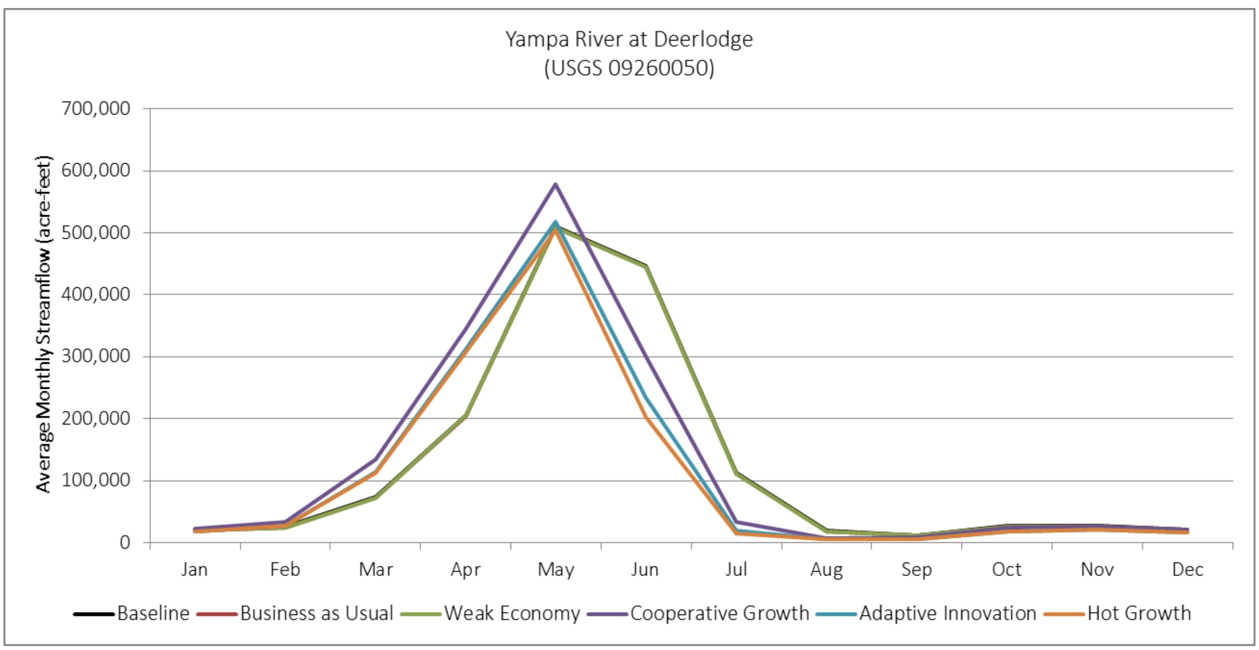


Figure 153: Average Monthly Streamflow for the Yampa River at Deerlodge

Figure 154 and Figure 155 reflect simulated unappropriated available flow for the Yampa River Basin near the Maybell Canal, which is typically the senior calling right in the basin. Available supplies at this location are very near to the physical flow in the stream, indicating that the Maybell Canal does not have a large impact on the available flow upstream. In general, there are substantial unappropriated available supplies throughout the Yampa River basin under current hydrological conditions, particularly on the mainstem which first went under administration during the late irrigation season in 2018. Climate-adjusted hydrology shifts both the streamflow (refer to graphics above) and the unappropriated available supply earlier in the year, leading to lower available supplies during June and July. The figures reflect that available supplies will continue to be available each year, though the amounts will vary annually and across scenarios.

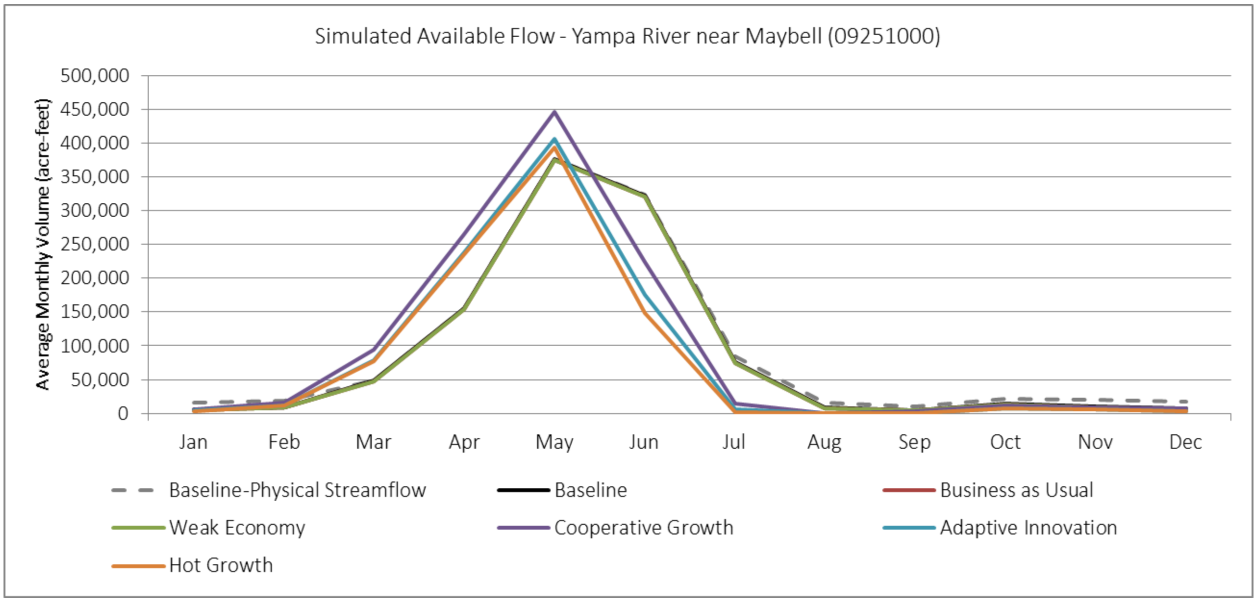


Figure 154: Average Monthly Unappropriated Available Supply at Yampa River near Maybell

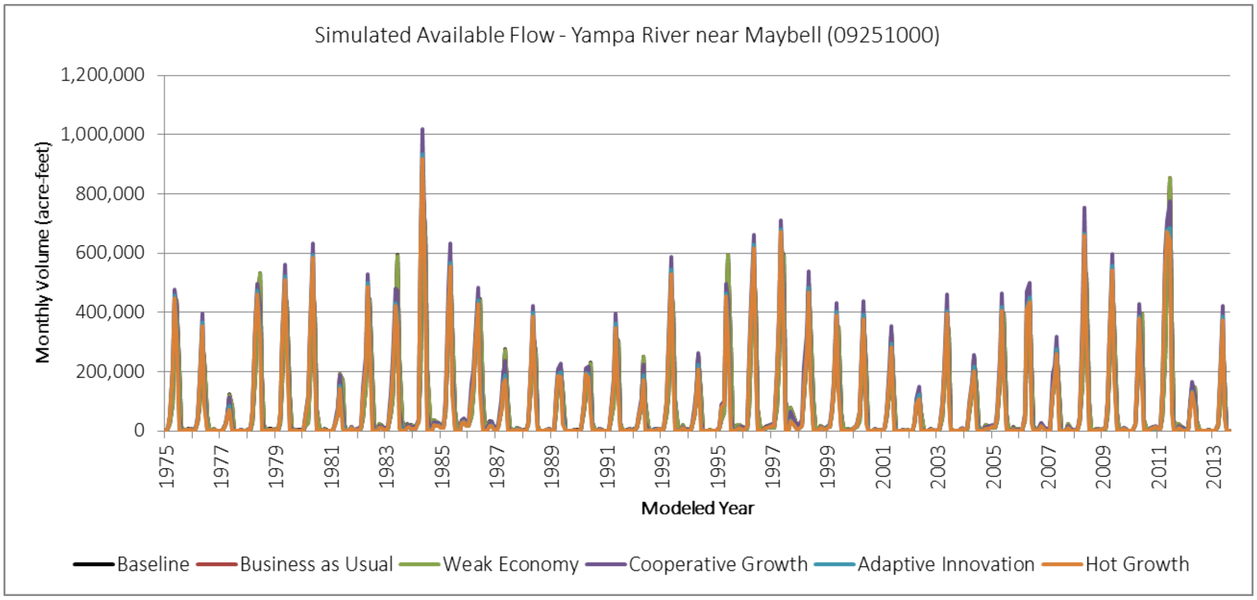


Figure 155: Monthly Unappropriated Available Supply at Yampa River near Maybell

Section 6: Statewide Water Supply and Gap Results

The following graphics and tables reflect the total demand and gap results at a statewide level projected for the 2050 Planning Scenarios. Total demand for water in the state ranged from 12.6 million ac-ft in the Adaptive Innovation scenario to 15.9 million ac-ft in the Hot Growth scenario, compared to the Baseline demand of 14.6 million ac-ft. Agricultural demands are the largest component of the total demand, currently accounting for approximately 88 percent of the statewide demand for water supplies. M&SSI demands are the next largest component of total demand, currently accounting for approximately 8 percent of the total demand. The remaining 4 percent of demand is attributable to transbasin diversions.

Agricultural users also experience the largest gap, both currently and in the 2050 Planning Scenarios. Average annual statewide gaps range from 2.4 million ac-ft in the Weak Economy scenario to 3.9 million ac-ft in the Hot Growth scenario. During critically dry years, however, the statewide gap essentially doubles in magnitude when compared to the average gap for each scenario. Although a smaller component of the overall Planning Scenario demand, M&SSI demands are projected to experience substantial gaps, particularly in dry years.

Similar to the basin summaries, the individual agricultural and M&SSI demand and gap results are presented, followed by the combined total statewide demand and gap results.

6.1 STATEWIDE AGRICULTURAL DEMAND AND GAP RESULTS

Table 49 reflects the total statewide agricultural demand and gap results; the following figures graphically illustrate the information in the table. As shown, the agricultural demand ranges from 10.3 million ac-ft in the Adaptive Innovation scenario to 13.3 million ac-ft in the Hot Growth scenario, an increase of nearly a half million ac-ft of demand over current levels. This increase in demand is largely due to projected climate adjustments to IWR because the total irrigated acreage in the State is projected to decline by approximately 400,000 to 500,000 acres depending on the scenario. As reflected, basins with the most irrigated acreage have the largest agricultural demands. The South Platte River, Arkansas River, and Rio Grande basins currently experience, and are projected to continue experiencing, the largest agricultural gaps. Conversely, the Colorado and Gunnison River basins have the smallest agricultural gap relative their agricultural demand.

Table 49: Statewide Agricultural Water Supply and Gap Summary

	Statewide Agricultural Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	12,860,355	11,696,986	11,712,629	12,883,977	10,351,049	13,308,032
	Average Annual Gap (ac-ft)	2,434,152	2,212,779	2,214,511	2,804,507	2,677,782	3,379,106
	Average Annual Percent Gap	19%	19%	19%	22%	26%	25%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	14,595,766	13,205,689	13,221,367	13,605,979	11,096,804	13,923,741
	Gap In Maximum Gap Year (ac-ft)	5,437,291	5,003,738	4,990,958	5,631,276	5,107,488	6,573,161
	Percent Gap In Maximum Gap Year	37%	38%	38%	41%	46%	47%

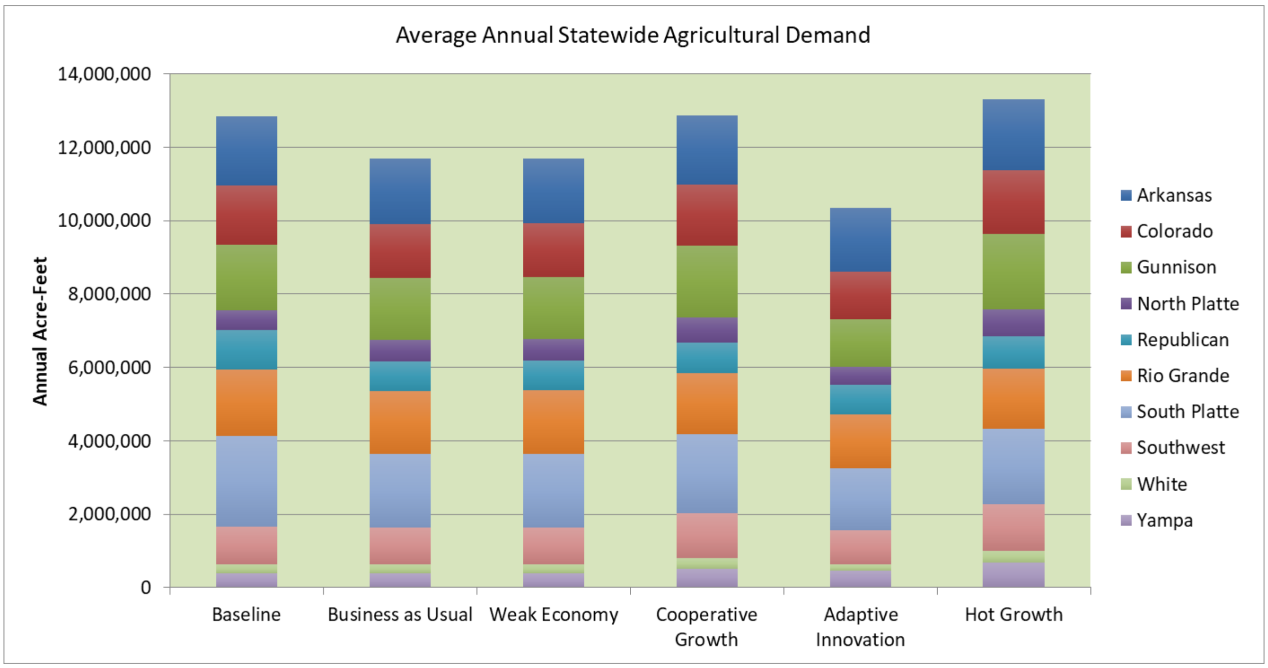


Figure 156: Average Annual Statewide Agricultural Demand

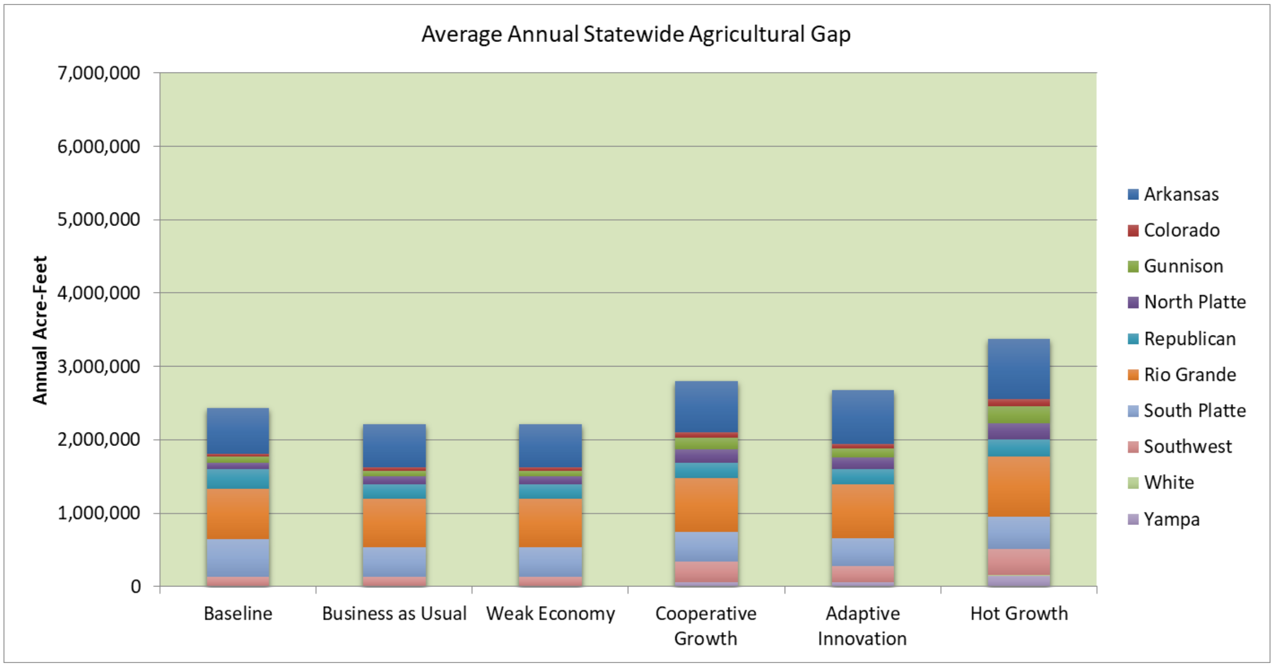


Figure 157: Average Annual Statewide Agricultural Gap

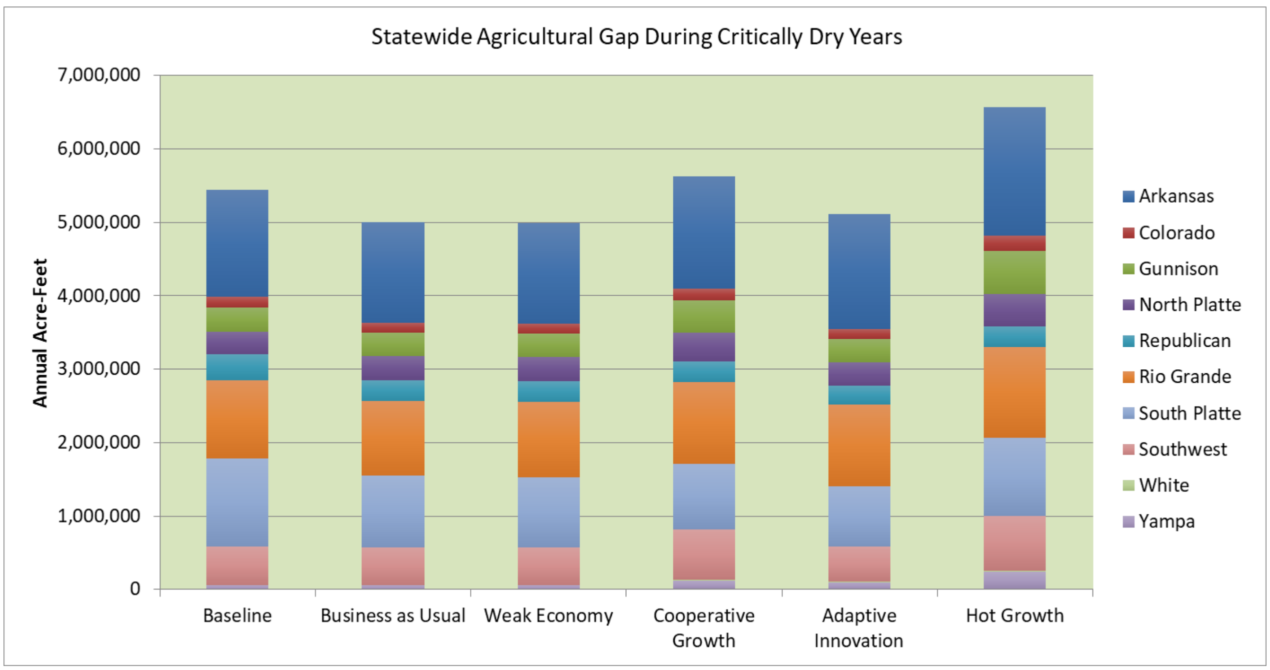


Figure 158: Statewide Agricultural Gap During Critically Dry Years

6.2 STATEWIDE M&SSI DEMAND AND GAP RESULTS

Table 50 reflects the total statewide M&SSI demand and gap results; the following figures graphically illustrate the information in the table. As shown, the M&SSI demand ranges from 1.5 million ac-ft annually in the Weak Economy scenario to over 2 million ac-ft annually in the Hot Growth scenario, an increase of 350,000 to 850,000 ac-ft annually, respectively, over Baseline demands. This projected increase is driven by population growth, primarily in the South Platte and Arkansas River basins. As the demand in these basins already exceeds available supplies, it is expected that these basins are also projected to experience the largest M&SSI gaps. The average annual M&SSI gap ranges from 192,000 to 566,000 ac-ft across the Planning Scenarios, however maximum gap information is used more frequently in planning efforts by M&SSI water providers. Gaps in critically dry years range between 245,000 to 754,000 ac-ft annually depending on the Planning Scenario, with over 85 percent of that gap projected to occur in the South Platte and Arkansas River basins.

Table 50: Statewide M&SSI Water Supply and Gap Summary

	Statewide M&SSI Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	1,176,840	1,698,192	1,530,538	1,601,985	1,694,295	2,032,851
	Average Annual Gap (ac-ft)	2,608	274,583	192,041	229,620	303,297	566,066
	Average Annual Percent Gap	0%	16%	13%	14%	18%	28%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	1,178,122	1,699,475	1,531,820	1,603,268	1,694,313	2,032,869
	Gap In Maximum Gap Year (ac-ft)	21,284	348,546	245,095	293,282	429,150	754,178
	Percent Gap In Maximum Gap Year	2%	21%	16%	18%	25%	37%

As noted throughout this report, the gaps presented above do not take into account potential future water supplies from urbanized irrigated acreage nor the potential impact from a reduction to transbasin supplies in climate-adjusted scenarios. Refer to the basin sections above for more information on the modeling assumptions regarding these drivers.

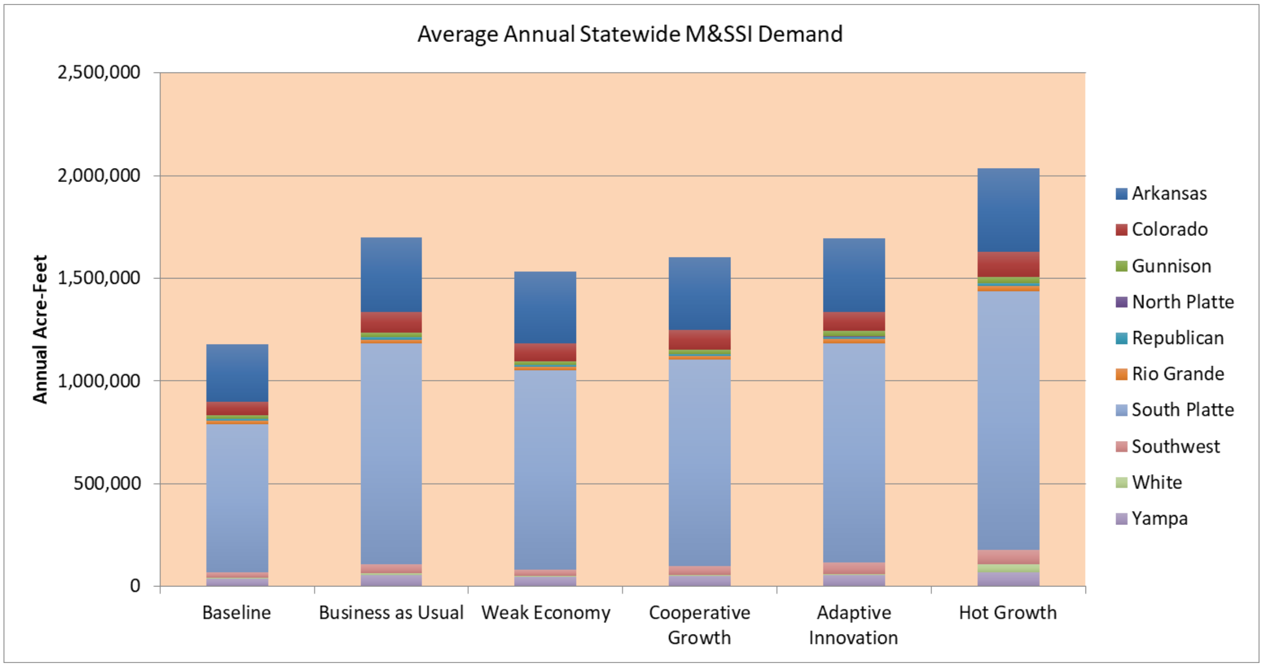


Figure 159: Average Annual Statewide M&SSI Demand

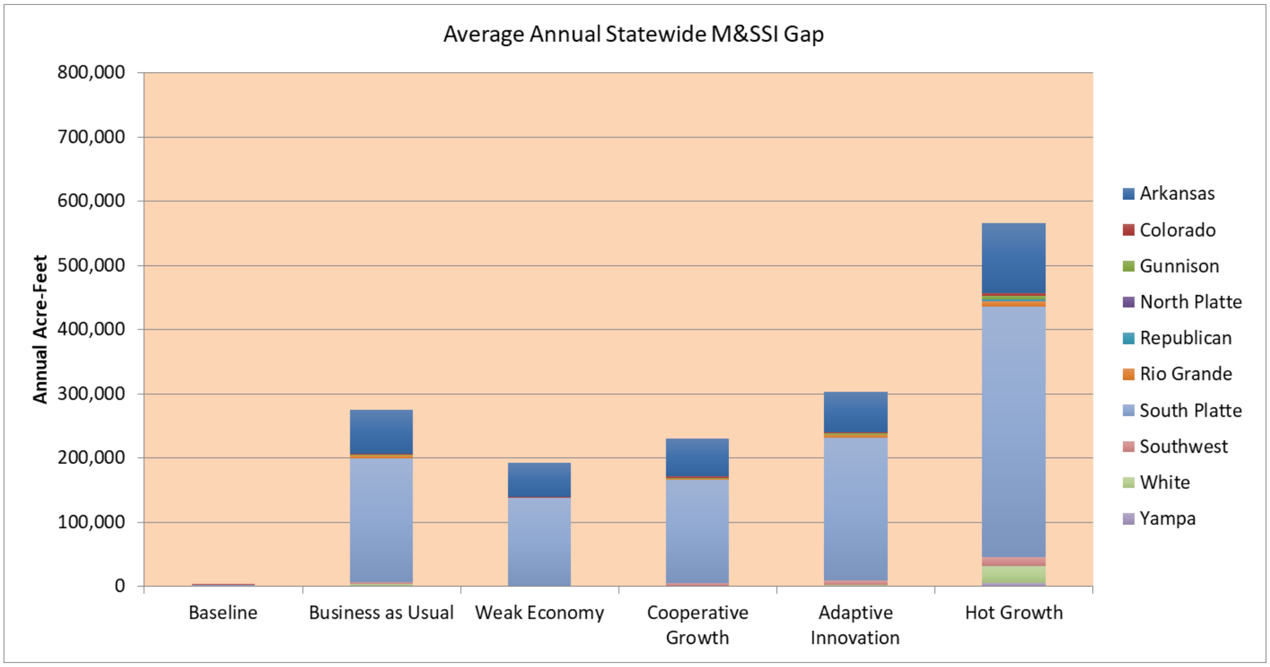


Figure 160: Average Annual Statewide M&SSI Gap

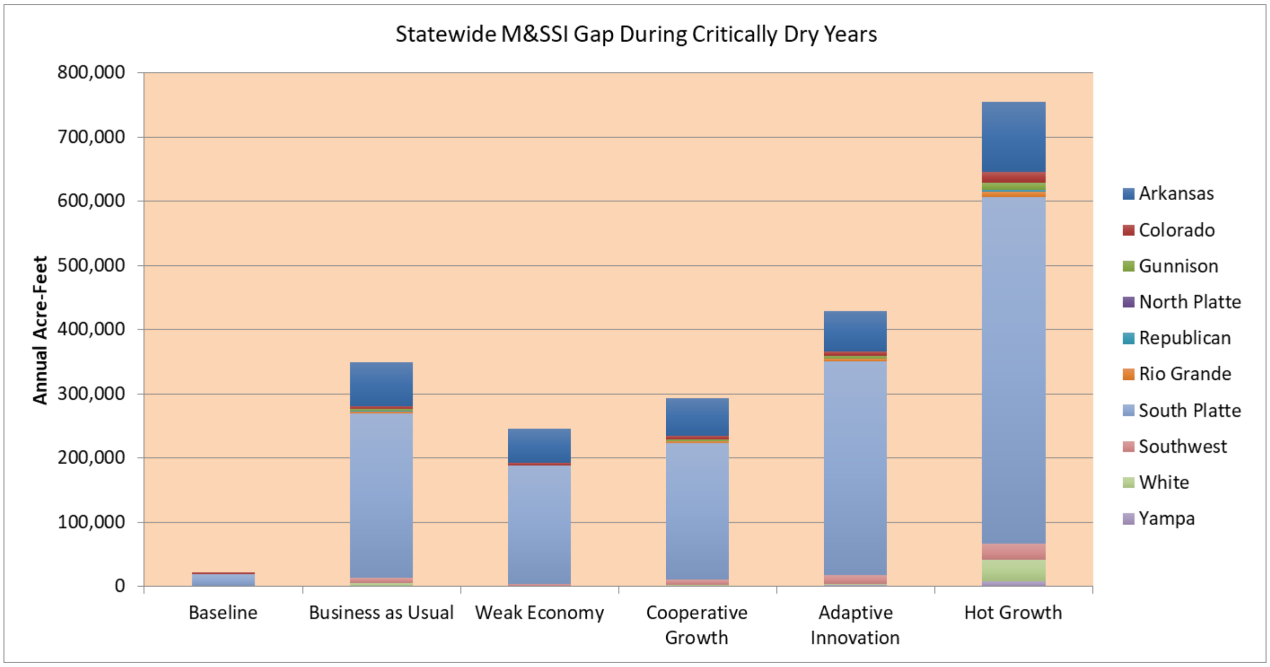


Figure 161: Statewide M&SSI Gap During Critically Dry Years

6.3 STATEWIDE TOTAL DEMAND AND GAP RESULTS

Table 51 reflects the total statewide demand and gap results; the following figures graphically illustrate the information in the table. The total statewide demand values include the agricultural and M&SSI demand summarized above plus approximately 530,000 ac-ft of transbasin demand. The agricultural component of the demand and gap dominate the statewide results, therefore the results look very similar to those presented in Table 49.

As shown, the statewide demand for water ranges from 12.6 million ac-ft annually in the Adaptive Innovation scenario to 15.9 million ac-ft annually in the Hot Growth scenario. Three out of the five Planning Scenarios reflect a decrease in statewide demand, largely due to the projected reduction in irrigated acreage and associated reduction in agricultural demand. The Cooperative Growth and Hot Growth scenarios reflect a moderate increase in demand compared to Baseline levels. Over 20 percent of the statewide demand is projected to occur in the South Platte River basin, the largest of any basin.

The average statewide gap increases in all Planning Scenarios, except the Weak Economy scenario, which shows a modest decline of approximately 30,000 ac-ft annually. Gaps during critically dry years essentially double in magnitude compared to the average values. During these dry years, one-third of total statewide demand is shorted in the Business as Usual and Weak Economy scenarios, with this increasing in the remaining climate-adjusted scenarios to reach 45 percent of shorted demand in the Hot Growth scenario.

Statewide gaps provide a broad overview of how the demands and water supply may react under the Planning Scenarios drivers. It is important to remember that local water supply conditions are impacted by hydrology, demands, and operations within a stream reach and that more detailed analysis on a sub-basin level is necessary to further understand and begin planning for the mitigation of future shortages.

Table 51: Statewide Water Supply and Gap Summary

	Statewide Results	Baseline	Business as Usual	Weak Economy	Coop. Growth	Adaptive Innovation	Hot Growth
Average	Average Annual Demand (ac-ft)	14,562,997	13,920,980	13,768,969	15,011,764	12,571,146	15,866,684
	Average Annual Gap (ac-ft)	2,436,760	2,487,362	2,406,551	3,034,127	2,981,079	3,945,173
	Average Annual Percent Gap	17%	18%	17%	20%	24%	25%
Critically Dry Max	Demand In Maximum Gap Year (ac-ft)	16,304,295	15,435,571	15,283,594	15,892,849	13,268,079	16,433,571
	Gap In Maximum Gap Year (ac-ft)	5,458,575	5,352,284	5,236,053	5,924,558	5,536,638	7,327,339
	Percent Gap In Maximum Gap Year	33%	35%	34%	37%	42%	45%

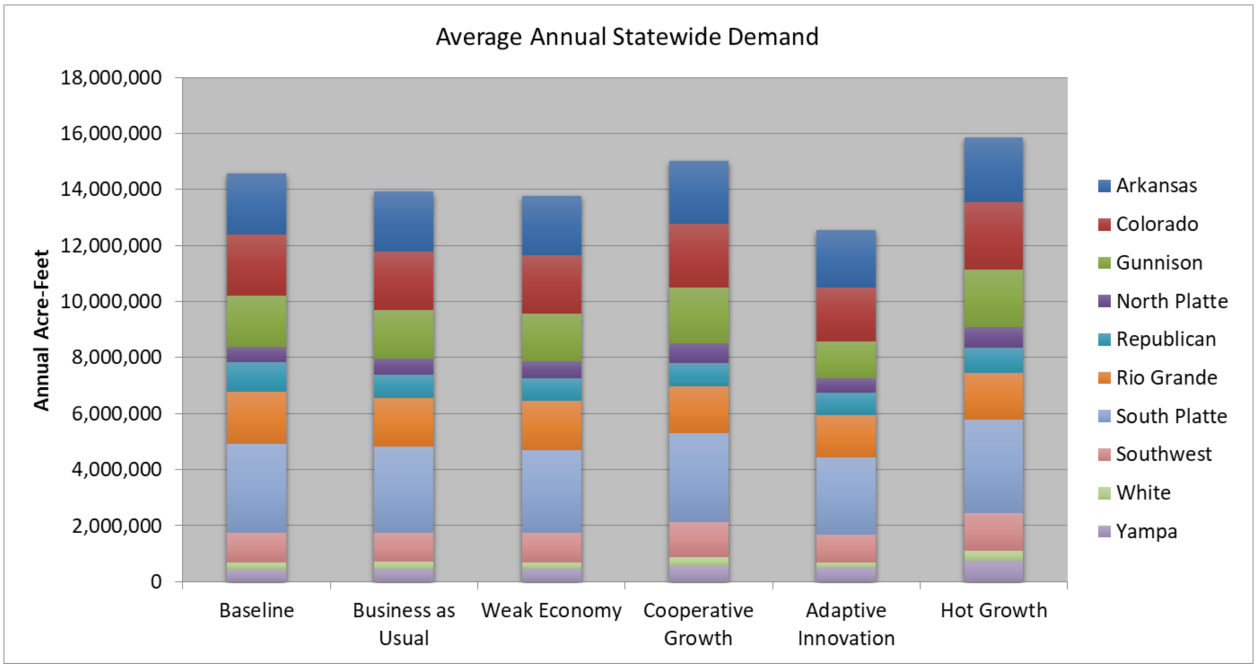


Figure 162: Average Annual Statewide Demand

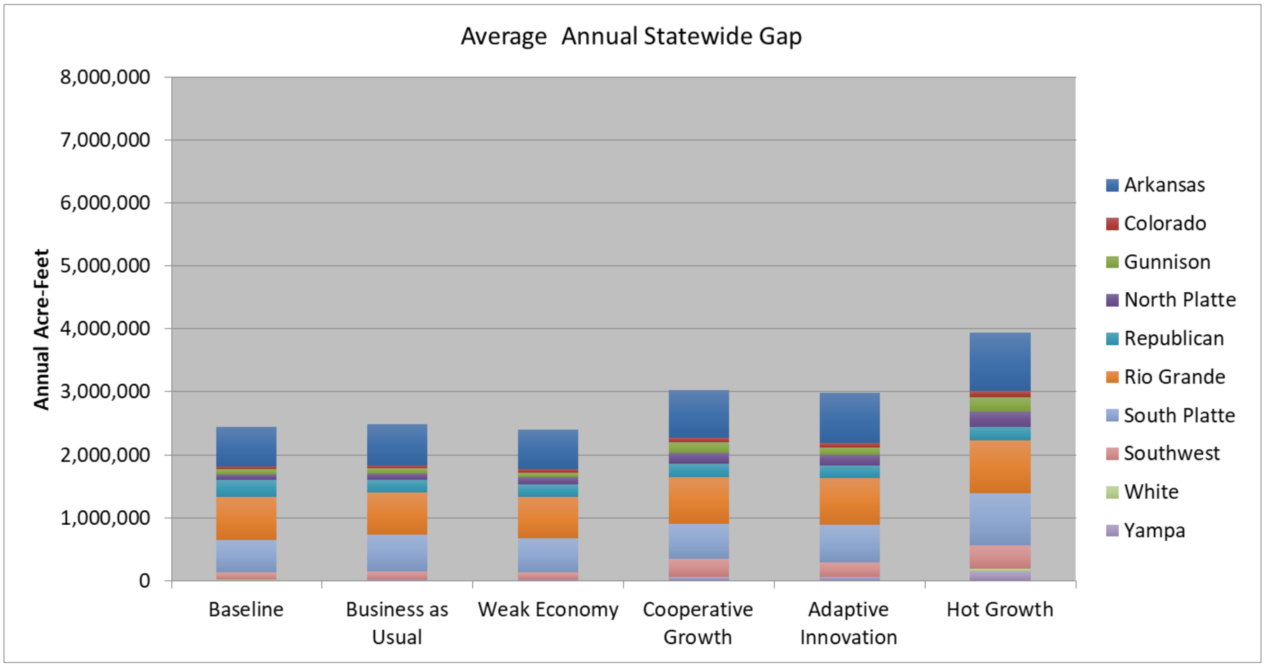


Figure 163: Average Annual Statewide Gap

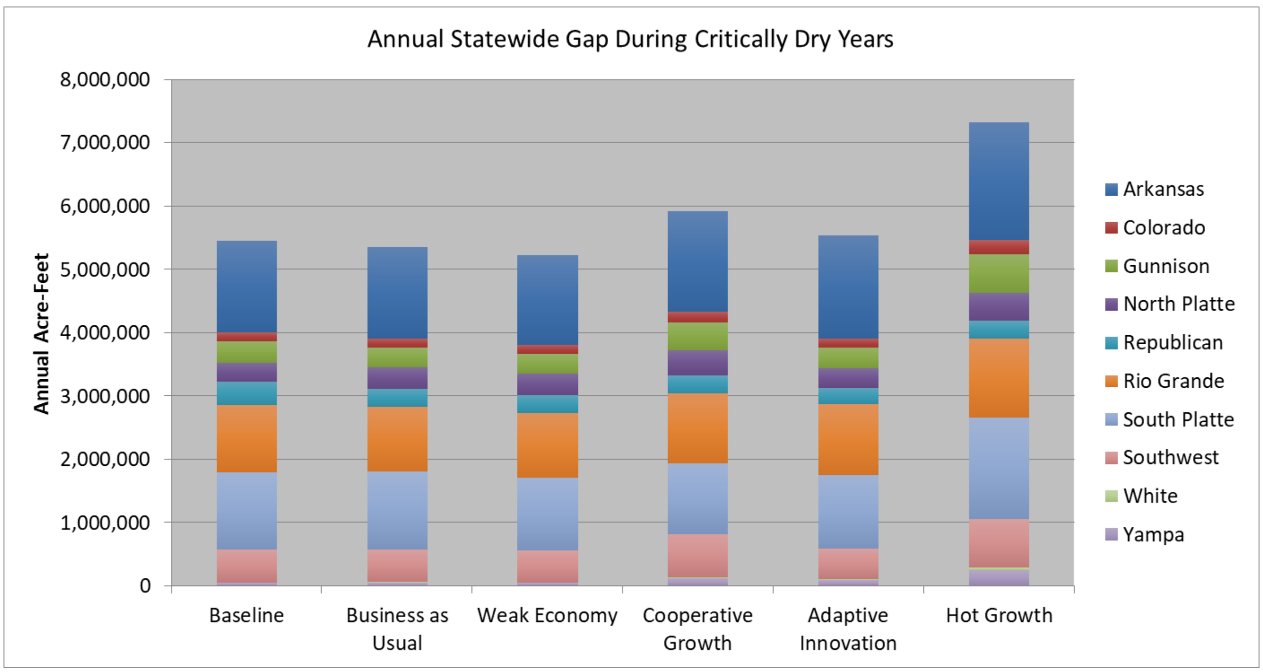


Figure 164: Annual Statewide Gap During Critically Dry Years

Section 7: Comments and Concerns

The following reflects observations and comments that should be considered when reviewing the current and 2050 Planning Scenario water supply and gap results.

- 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 but does 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. Additionally, the current agricultural diversion demands are not directly comparable to historical diversions, because historical diversions reflect changing irrigation practices, crop types, and acreage, as well as physical and legal water availability shortages.
- Planning Scenario Adjustments. The five planning scenarios describe plausible futures with characteristics that require several adjustments to demands. It is difficult to isolate the impact of a specific adjustment because the adjustments tend to compound and overlap within a planning scenario. If water resources planners are interested in the impact of an individual adjustment, they are encouraged to obtain the model datasets and implement the adjustments in a stepwise fashion, analyzing the results after each adjustment is implemented.
- Basin-wide Planning Models. A primary objective of CDSS is to develop water allocation models that can be used to evaluate potential future planning issues or management alternatives based on Colorado Water Law at a regional level. The level of detail regarding representation of hydrology, operations, and demands in the model is appropriate for the Technical Update efforts. The models operate on a monthly time-step, therefore do not capture daily changes in streamflow, routing of reservoir releases, or daily accretions or depletions to the river system. One hundred percent of the consumptive use demands are represented in the model, and many are represented with their individual water rights and operations. Smaller streams are not individually represented in the model; rather the demands and contributing inflow from those tributaries are grouped and represented on larger tributaries in the model. Information used in the modeling datasets is based on available data collected and developed through CDSS, including information recorded by the State Engineer's Office. The model datasets and results are intended for basin-wide planning purposes. Individuals seeking to use the model dataset or results in any legal proceeding are responsible for verifying the accuracy of information included in the model.
- Representation of Water Supplies and Operations. The Baseline models reflect one representation of water user's operations associated with their current infrastructure. The representation in the model is intended to capture their typical operations; however they are simplified and do not reflect the full suite of operations generally available to larger water providers. This representation may not capture operational adjustments or agreements implemented during drought conditions, or the maximum operational flexibility of using water supplies from multiple sources. In addition, the model allocates water according to prior appropriation and non-decreed "gentlemen's agreements" are generally not represented in the models.
- Compacts in Model. The Technical Update analysis did not contemplate the potential impacts of a Colorado River Compact call. To do so in a defendable way would have required the use of a linked model that accounts for actions and conditions in other states; this level of analysis was beyond the scope of the Technical Update study. Interstate compact requirements in other

basins (e.g. South Platte River, La Plata) are reflected in the modeling or other analyses that were used to evaluate gaps and available water supplies.

- **Solutions/Projects.** The Technical Update is intended to develop water supply and gap information that can be used by basin roundtables for future planning efforts, including the development of potential solutions to mitigate gaps. The models can be used to evaluate the effectiveness of a future solution, though future projects and/or solutions are not currently included in the models.
- **Model Calibration**. Each water allocation model undergoes calibration, in which the model developer adjusts model inputs to achieve better agreement between the simulated and measured streamflow, diversions, and reservoir contents. The model builds on historical water supply information, and if information is missing, errant, or there are data inconsistencies, the model cannot be well calibrated and cannot accurately predict future conditions. The models are only as good as the input. The following graphic reflects an area in the South Platte Model that will require additional winter-time calibration in the future. The South Platte River at Julesburg gage is located just upstream of the Colorado-Nebraska stateline on the mainstem of the South Platte River. Simulated streamflow at this location is an accumulation of all of the operations in the South Platte River, but is heavily influenced by well pumping, storage, and augmentation operations in the Lower South Platte. As discussed above, ground water pumping levels are estimated as long term pumping records were not available. Additionally, at the time of the South Platte River model development, only a couple years of records were available for the relatively new practice of making diversions to recharge pits where the lagged return flow from those pits meet future augmentation requirements. These records were used to inform the model calibration, however the records were not available for a long enough period for the model to be fully calibrate over a variety of hydrological conditions. The models are continually improved and calibrated as they are used, and it is recommended the South Platte River basin roundtable improve the model calibration and operations in this area prior to using it in future BIP efforts.

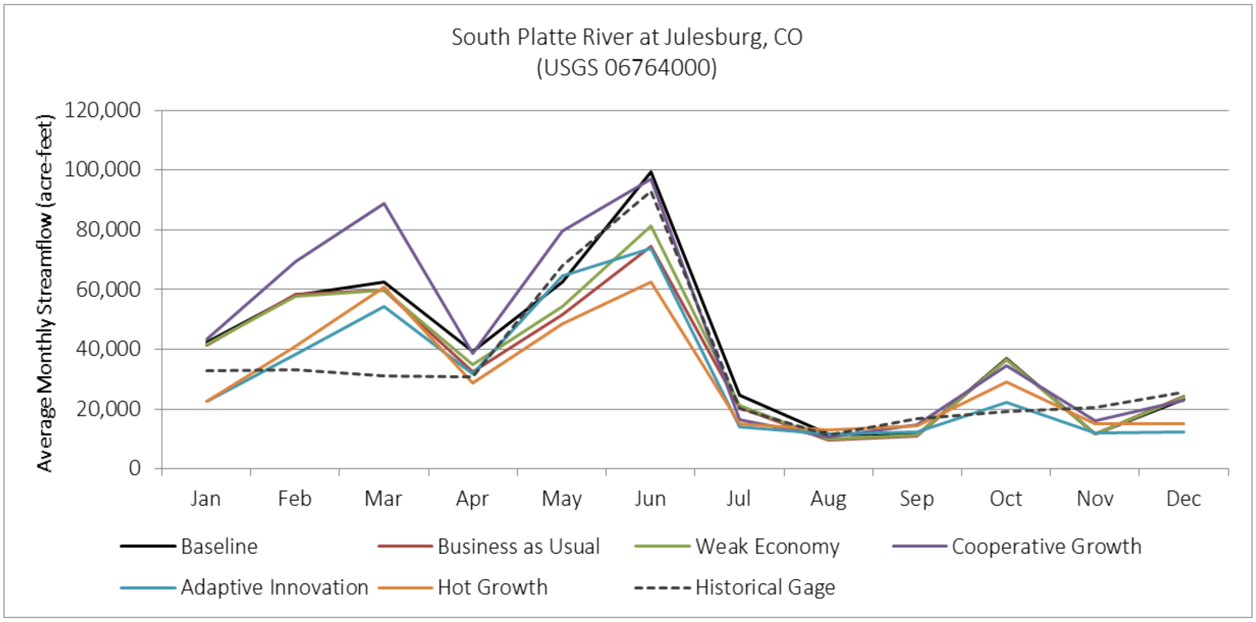


Figure 165: South Platte River at Julesburg Calibration Example

- **Groundwater Pumping Levels/ Transbasin Diversions**. The models reflect current levels of groundwater pumping and transbasin diversions. Noting that administration of groundwater pumping shifted due to the mid-2000s drought, post-drought groundwater pumping levels were used in the baseline and planning scenario models. Similarly, the historical transbasin diversions were used in the baseline and planning scenario models. Transbasin diversions are based on many factors; including water availability and storage in the source and destination basins, demands, other water supplies available to the water provider, and other operational considerations like water quality. Projecting how these factors may change under the 2050 planning scenarios was beyond the Technical Update scope, therefore transbasin diversions were set to historical levels.

Section 8: References

Colorado Water Plan
Colorado Water Conservation Board, 2015, Colorado Water Plan Website (www.colorado.gov/cowaterplan)

Basin Implementation Plans
Colorado Water Conservation Board and Basin Roundtables, 2015,
Colorado Water Plan Website (www.colorado.gov/cowaterplan)

The Administration of the Rio Grande Compact in Colorado
Steve Vandiver, Division of Water Resources, WRRI Conference Proceedings, 1999
New Mexico Water Resources Research Institute Website (https://nmwrri.nmsu.edu/wp-content/uploads/2015/watcon/proc44/vandiver.pdf)

Current and 2050 Planning Scenario Agricultural Diversion Demand
Colorado Water Conservation Board Technical Update, Prepared by Wilson Water Group and Jacobs Engineering Group, 2019, Colorado Water Plan Website (www.colorado.gov/cowaterplan)

Baseline and Projected 2050 Planning Scenario Municipal and Self-Supplied Industrial Water Demands
Colorado Water Conservation Board Technical Update, Prepared by Element Water Consulting and Jacobs Engineering Group, 2019, Colorado Water Plan Website (www.colorado.gov/cowaterplan)

Temperature Offsets and Precipitation Change Factors Implicit in the CRWAS-II Planning Scenarios
Colorado Water Conservation Board Technical Update, Prepared by Lynker Technologies, 2019, Colorado Water Plan Website (www.colorado.gov/cowaterplan)

Temperature Offsets and Precipitation Change Factors Implicit in the CRWAS-II Planning Scenarios
Colorado Water Conservation Board Technical Update, Prepared by Lynker Technologies and Wilson Water Group, 2019, Colorado Water Conservation Board website (http://cwcb.state.co.us/technical-resources/colorado-river-water-availability-study/Pages/CRWASSupportingDocuments.aspx)

The Gunnison River Basin, A Handbook for Inhabitants
Gunnison River Basin Roundtable, Prepared by Public Education and Outreach Committee of the Roundtable and Colorado Mesa University, 2013-2014, Upper Gunnison River Water Conservancy District Website (www.ugrwcd.org)

Appendix A: Incorporation of Agricultural and M&SSI Diversion Demands

Current and 2050 Planning Scenario M&SSI demands were developed by the Technical Update municipal demand technical consultant (Element Water Inc.) based on current and projected population and daily per capita demands. The methodology for developing these demands, including discussion on drivers used to adjust demands across Planning Scenarios, is documented in the *Baseline and Projected 2050 Planning Scenario Municipal and Self-Supplied Industrial Water Demands* memorandum. Annual municipal and SSI demands were developed and provided at a county level. This appendix summarizes how the M&SSI demands were disaggregated to a monthly time-step, converted from a county to Water District level, and incorporated into the water supply modeling efforts.

Municipal Demands

Annual indoor and outdoor municipal demands were primarily grouped at the county level, with demands for larger cities provided separately in order to represent them individually in the model. The following approach was used to process the individual and grouped municipal demands for use in the baseline and 2050 Planning Scenario models:

- Annual indoor demands for residential and non-residential were summed to develop a single annual indoor demand for an individual city or county.
- Outdoor and non-revenue demands were summed to produce a single annual outdoor demand for an individual city or county.
- Annual indoor and outdoor demands were disaggregated to a monthly time-step.
    - Indoor demands were assumed to be constant throughout the year.
    - Outdoor demands were distributed to a monthly time-step based on a representative IWR demand curve (i.e. percent of total IWR demand each month) for bluegrass. A bluegrass demand curve was developed using the Modified Blaney-Criddle equation with climate information from a representative weather station in each basin. Table 52 reflects the monthly factors used in each basin, note that winter months have no outdoor demands.

Table 52: Outdoor Demand Disaggregation Curves

Basin	Apr	May	Jun	Jul	Aug	Sep	Oct
Arkansas River Basin	10%	14%	20%	20%	17%	14%	5%
Colorado River Basin	10%	14%	20%	21%	16%	12%	7%
Gunnison River Basin	10%	14%	20%	21%	17%	13%	5%
North Platte River Basin	2%	19%	29%	28%	18%	4%	0%
Republican	10%	13%	19%	21%	18%	14%	5%
Rio Grande Basin	8%	17%	22%	23%	19%	11%	-
South Platte River	9%	15%	19%	20%	17%	13%	7%
Southwest Basin	10%	14%	21%	21%	17%	13%	4%
White River Basin	8%	15%	22%	24%	19%	11%	1%
Yampa River Basin	5%	17%	25%	27%	20%	6%	-

- County monthly indoor and outdoor demands were distributed to Water Districts so they could be included on a representative tributary in the model. A spatial process was used to calculate the percent area of each county in a Water District. The demands were grouped by Water District by first multiplying the percent of county area in a Water District by the county demand and then summing the portions of the demand in each Water District to create one grouped municipal indoor and outdoor demand by basin. This process assumes that grouped municipal demands occur uniformly across each county and/or Water District.
    - An exception to the process above was made for Water Districts 76 and 48. These Water Districts are located in Larimer County and are included within the North Platte River basin results. Larimer County is expected to experience large population growth, which is likely to occur in and around Fort Collins. Water Districts 76 and 48 are unlikely to see large population growth and are more likely to grow at rates similar to neighboring Water District 47 (Jackson County). Therefore, grouped municipal demands for the two Water Districts were added to the Water District 3 grouped demands.
- Grouped monthly indoor and outdoor demands were assigned to either a diversion structure or well structure in the model, depending on the source of supply generally used to meet municipal demands in the basin[22]. Grouped municipal structures were placed near cities and towns not represented individually in the model to mimic the current municipal use. Particularly large Water District demands, such as Water District 1 in the South Platte River basin, were divided and modeled at two different locations, so as not to overestimate demands at a particular location on the river.
- Grouped monthly indoor demands were reflected as 10 percent consumptive and outdoor demands were reflected as 80 percent consumptive in the model.
- Monthly indoor and outdoor demands for cities and towns modeled individually were assigned to their existing structures in the basin models; no adjustments to currently-modeled efficiencies were made.
- Grouped monthly indoor and outdoor demands were assigned a senior water right sufficient to meet their baseline demand, acknowledging that the full baseline demand is assumed to be currently satisfied. For projected increases in demand from the baseline scenario, junior water rights were assigned to the structures. Note that agricultural diversions were given first chance to divert unappropriated streamflow, with any additional streamflow beyond the agricultural needs available to meet the projected increase in grouped municipal demands under the junior water rights.
    - In addition to assigning the water rights described above, operations were included in the Colorado River Basin that would release contract supplies from Green Mountain Reservoir, Ruedi Reservoir, and Wolford Mountain Reservoir to meet the current and Planning Scenario grouped municipal structures in the basin. These reservoirs currently

[22] Grouped municipal demands in the West Slope and North Platte River Basin were assumed to be met by surface water supplies, while the demands in the Rio Grande and Arkansas were assumed to be met by ground water supplies. Grouped municipal demands for higher elevation Water Districts in the South Platte River basin were assumed to met by surface water supplies, whereas the Water District demands in the plains were assumed to be met by ground water supplies.

release contract supplies (i.e. supplies available for lease on a contract basis) to meet smaller municipal and/or augmentation demands in the basin, and these operations were assumed to continue into the future.

- Indoor and outdoor demands for an individually represented city in the model are met by water supplies available under the city's current water rights portfolio, operations, and infrastructure. No additional water rights, capacity, or operations were added to meet projected increases in demand.
- Refer to the basin summaries above for more information on how municipal demands and gaps were accounted for in basins without the full suite of CDSS models.

SSI Demands

Annual SSI demands were provided by county and for facilities (i.e., powerplants, ski resorts, etc.) currently represented individually in the models. The SSI demands were divided into five categories

1. Energy Development
2. Large Industry
3. Snowmaking
4. Thermoelectric
5. Hydropower

The following approach was used to process the individual and grouped SSI demands for use in the baseline and 2050 Planning Scenario models:

- Annual SSI demands for each scenario were first disaggregated to a monthly time-step using distribution factors provided by the municipal demand technical consultant. Energy Development and Large Industry were assumed to have constant demands every month, while Snowmaking, Thermoelectric, and Hydropower demands were assumed to vary monthly within the year. Since Energy Development and Large Industry had the same monthly disaggregation factors, the demands were combined and represented in the model together. Table 53 reflects the monthly disaggregation curves for each SSI category.

Table 53: SSI Demand Disaggregation Curves

Month	Energy Development	Large Industry	Snowmaking	Thermoelectric	Hydropower
Jan	8.3%	8.3%	14.8%	7.9%	7.2%
Feb	8.3%	8.3%	11.8%	6.7%	7.0%
Mar	8.3%	8.3%	0.1%	6.3%	7.7%
Apr	8.3%	8.3%	0.2%	7.8%	7.6%
May	8.3%	8.3%	0.0%	9.2%	9.7%
Jun	8.3%	8.3%	0.0%	10.5%	11.3%
Jul	8.3%	8.3%	0.0%	10.4%	10.5%
Aug	8.3%	8.3%	0.3%	9.7%	9.2%
Sep	8.3%	8.3%	0.1%	7.7%	8.5%
Oct	8.3%	8.3%	5.5%	8.3%	7.8%

Month	Energy Development	Large Industry	Snowmaking	Thermoelectric	Hydropower
Nov	8.3%	8.3%	35.4%	7.8%	6.4%
Dec	8.3%	8.3%	31.8%	7.7%	7.2%

- County SSI demands for each category were distributed to the Water District level using the same spatial method described above for the municipal county demands. The same consideration for Water Districts 48 and 76 discussed above was made for the SSI demands in those areas as well.
- Grouped monthly SSI demands for each category were assigned to either a diversion structure or well structure in the model, depending on the source of supply generally used to meet SSI demands in the basin. Grouped SSI demands were placed at locations in the model representative of where the demand may currently exist; for example, snowmaking structures were placed in the headwaters of tributaries. Similar to the municipal demands, if the demand was large it was split into two nodes and modeled in different locations.
    - Note that Hydropower was only considered a demand for facilities currently represented individually in the model; there are no grouped Hydropower demands.
- Grouped SSI demands were assigned efficiencies based on Table 54. Efficiencies were based on efficiencies of currently modeled facilities or feedback from the M&SSI Technical Advisory Group.

Table 54: SSI Demand Modeled Efficiencies

SSI Category	Efficiencies
Energy Development	100%
Large Industry	100%
Snowmaking	47%
Thermoelectric	91%
Hydropower	0%

- Grouped SSI demands were assigned a senior water right sufficient to meet their baseline demand, acknowledging that the full baseline demand is assumed to be currently satisfied. For projected increases in demand from the baseline scenario, junior water rights were assigned to the structures. Note that agricultural diversions were given first chance to divert unappropriated streamflow, with any additional streamflow beyond the agricultural needs available to meet the projected increase in group SSI demands under the junior water rights. Assumptions regarding contract deliveries in the Colorado River basin discussed above also apply to the grouped SSI structures.
- SSI demands for facilities represented individually in the model are met by water supplies available under the facility's current water rights portfolio, operations, and infrastructure. No additional water rights, capacity, or operations were added to meet projected increases in demand.

- Refer to the basin summaries above for more information on how SSI demands and gaps were accounted for in basins without the full suite of CDSS models.

The total M&SSI demand summarized by basin herein differs from the basin-wide totals presented in the *Baseline and Projected 2050 Planning Scenario Municipal and Self-Supplied Industrial Water Demands* memorandum. This is due to differing approaches used to estimate the portion of each county in each basin. The approach discussed above relied on a spatial process to distribute county demands first to a Water District level, then summed to a basin-wide level. The M&SSI Demand memorandum relied on an estimate of each county in a basin. For example, Rio Blanco County is almost completely encompassed by the White River basin (Water District 43). The M&SSI Demand memorandum included only the demands from Rio Blanco County in the total White River basin demand. The spatial process outlined above, however, accounts for the demand associated with the small portion of Rio Blanco County that falls outside of the White River Basin, and the demand associated with the small portion of Moffat County that falls inside the White River Basin. The total M&SSI demand is represented in the models, however the reporting of where that demand is located differs between this memorandum and the M&SSI Demand memorandum due to this differing approach.