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Colorado Water Conservation Board
Colorado River Water Availability Study
Phase I Report
DRAFT

March 22, 2010

Colorado River Water Availability Study

CONTENTS

TABLES

FIGURES

ACRONYMS

AF – Acre Feet
AG – Attorney General
ASCE – American Society of Civil Engineers
BRT – Basin Roundtables
CCTAG – Climate Change Technical Advisory Group
CDSS – Colorado Decision Support System
CIR – Crop Irrigation Requirement
CMIP3 – Coupled Model Inter-comparison Project Phase 3
CRDSS – Colorado River Decision Support System
CRSP – Colorado River Storage Project
CRSS – Colorado River Simulation System
CRWAS – Colorado River Water Availability Study
CWCB – Colorado Water Conservation Board
CWRRI – Colorado Water Resources Research Institute
DMI – Data Management Interface
DNR – Department of Natural Resources
DWR – Division of Water Resources
ET – Evapotranspiration
FRCCVS – Front Range Climate Change Vulnerability Study
FRVS – Front Range Vulnerability Study
GAO – Government Accountability Office
GCM – Global Climate Model (also General Circulation Model)
GHG – Greenhouse Gas
HydroBase – State of Colorado's Relational Database
IBCC – Interbasin Compact Committee
IPCC – Intergovernmental Panel on Climate Change
IPPs – Indentified Projects and Programs
JFRCCVS – Joint Front Range Climate Change Vulnerability Study (same as FRCCVS above)
LLNL – Lawrence Livermore National Laboratory
M&I – Municipal and Industrial
MAF – Million Acre Feet
MLR – Multiple Linear Regression
NHMC – Non-Homogeneous Markov Chain
NOAA – National Oceanic and Atmospheric Administration
PC – Principal Component
RISA – Regional Integrated Sciences and Assessments
RMRS – Rocky Mountain Research Station
SCS – Soil Conservation Service
SCU – Santa Clara University
SRES – Special Report on Emissions Scenarios
StateCU – State of Colorado's Consumptive Use Model

StateMod – State of Colorado's Stream Simulation Model
TR-21 – Technical Release 21
TSTool – Time Series Tool
UCRC – Upper Colorado River Commission
USBR – United States Bureau of Reclamation
USDA – United States Department of Agriculture
USFWS – United States Fish and Wildlife Service
USGS – United States Geological Survey
VIC – Variable Infiltration Capacity (Model)
WCRP – World Climate Research Program
WWA – Western Water Assessment

Where to find more detailed information:

A glossary of standard water resources and water rights terms and terms related to paleohydrology and climate change topics is provided in CRWAS Task 3.1 – *Glossary of Terms*, available at: http://cwcb.state.co.us/.

ACKNOWLEDGEMENTS

Phase I of the CRWAS involved extensive collaboration to share the Study's technical approaches, to participate in related programs, and to receive feedback on draft Study results. These activities enhance statewide dialogue and foster understanding of the Study. CRWAS outreach activities were closely coordinated with the public communication programs of the CWCB Water Supply Planning Section and on-going State-sponsored IBCC processes. Interested stakeholders helped refine the State's water resources modeling tools. The additional hydrologic data and operational expertise they provided help assure that the State's systems have credibility with all types of water users and stakeholders. The Study outreach process facilitated by the State demonstrated its collaborative and transparent approach to water management.

The rapidly evolving science and practice of climate change assessments warrants collaboration and participation with other organizations focusing on potential climate change impacts to water resources. Many of these organizations made staff available through the State's Climate Change Technical Advisory Group and these individuals provided considerable effort into providing input on the Study's technical approaches.

The CRWAS study team is comprised of the following lead team members: Blaine Dwyer and Matt Brown (AECOM – project management and technical review), Ben Harding (AMEC Earth & Environmental – paleohydrology, climate change, and compact implications), Erin Wilson and Meg Frantz (Leonard Rice Engineers and AECOM, respectively, water allocation modeling), Jim Pearce (Canyon Water Resources – forest change assessment), and Joel Smith (Stratus Consulting – climate change). The study team thanks the following individuals and groups for their support of the Study and collaboration with the CRWAS study team:

- Senator Isgar and Representative Curry – sponsors of the legislation authorizing the Study
- Colorado Governor – Bill Ritter
- Colorado Water Conservation Board (CWCB)
    - Appointed Board Members
        - Geoff Blakeslee, Chair (Yampa/White Rivers)
        - Eric Wilkinson, Vice Chair (South Platte River)
        - Reed Dils (Arkansas River)
        - John D. Redifer (Colorado River)
        - Barbara Biggs (City & County of Denver)
        - John H. McClow (Gunnison-Uncompahgre River)
        - Carl Trick II (North Platte River)
        - Travis Smith (Rio Grande River)
        - April Montgomery (San Miguel, Dolores, Animas & San Juan Rivers)
    - Ex-Officio Members
        - James Martin, Executive Director Department of Natural Resources
        - John Stulp, Commissioner Department of Agriculture
        - Jennifer Gimbel, Director Colorado Water Conservation Board
        - Tom Remington, Director Division of Wildlife
        - Dick Wolfe, State Engineer Division of Water Resources
        - John Suthers, Attorney General

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- Staff of the CWCB – Nearly all sections of the CWCB contributed to the CRWAS; in particular, the following individuals provided direction throughout the Study at progress meetings; facilitated IBCC, BRT, and public input; and reviewed draft work products:
    - Eric Hecox
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- CWCB Climate Change Technical Advisory Group (CCTAG)
- Interbasin Compact Committee (IBCC) and IBCC Basin Roundtables (BRTs)
- Joint Front Range Climate Change Vulnerability Study (JFRCCVS) Program
- NOAA Regional Integrated Sciences and Assessments (RISA) Program
- University of Colorado's Western Water Assessment (WWA) NOAA Program
- Northern Colorado Water Conservancy District (Water User Meeting)
- Colorado River Water Conservation District (Annual Water Meeting)
- Colorado House-Senate Joint Agriculture Committee
- Front Range Water Council
- Colorado Water Congress

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Executive Summary

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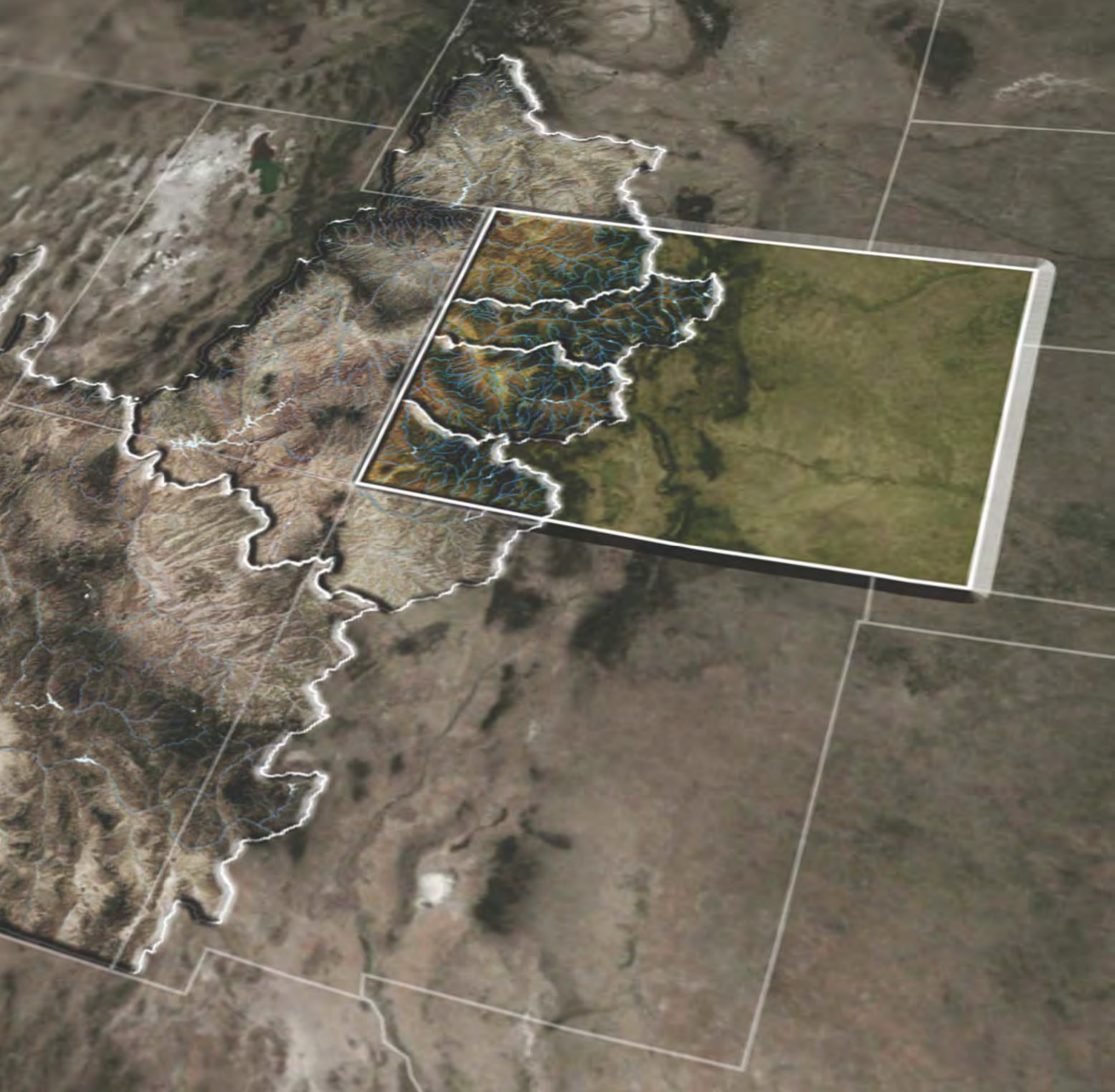

EXECUTIVE SUMMARY

Background and Objectives

Colorado faces increasing demands on its water supply for both traditional consumptive (agriculture, municipal, industrial, commercial and other) uses and for non-consumptive (recreational and environmental) uses. Population growth, recent drought, energy development, and potential climate change generate concern about the adequacy of Colorado's water supplies. The Colorado River Water Availability Study (the Study or CRWAS) was authorized by SB 07-122 and HB 08-1346 of the Colorado General Assembly. These bills direct the Colorado Water Conservation Board (CWCB) to conduct the Study 1) in collaboration with the Interbasin Compact Committee (IBCC) and the State's river "basin roundtables" (BRTs) and 2) with consideration for current and potential future in-basin consumptive and non-consumptive needs.

The CWCB, working closely with the IBCC, concluded that the Study be conducted in two phases, with Phase I (the subject of this report) presenting a water availability assessment based only on existing levels of water use. For Phase I, water uses (also referred to as water demands) were limited to current levels of water demands served by water rights that are currently being used ("perfected" or "absolute" water rights). Phase I is also restricted to interpretations of current operating and management practices for water diversion, storage and conveyance facilities. Assessments of water availability to meet future water needs are reserved for Phase II of the CRWAS.

The draft Scope of Work for Phase I posed the following types of questions to help guide the Study:

- *How much water from the Colorado River Basin System is available to meet Colorado's water needs?* Phase I of the CRWAS provides important information to help Colorado prepare for a range of future hydrologic conditions and to deal with uncertainty in making water management decisions.

- *What is a reasonable base of existing uses for Phase I of the CRWAS?* Each year the State of Colorado, like other Colorado River basin states, prepares assessments of the State's water consumption and losses. These reports support on-going inter-state water management activities and help assure agreement that Colorado's water management is in general compliance with inter-state agreements (river compacts and the "Law of the River" documents). The estimate of Colorado's current consumptive use (developed in Phase I) helps provide a basis for comparing future water availability with current conditions. It does not, however, supersede the official estimates of consumptive uses and losses submitted by the State in accordance with defined inter-state water management protocols.

- *How does historical hydrology compare to a longer hydrologic trace based on tree ring analysis?* Careful analysis of the width of annual growth rings in tree trunks and statistically correlating them with wet and dry weather patterns is one method to assess long-term or "paleo" hydrology prior to streamflows being recorded by man. For Phase I of the CRWAS, historical hydrology is extended back more than 1200 years using paleohydrology developed by others.

- *What is a reasonable projection for hydrology affected by climate change?* A CWCB-sponsored report, *"Climate Change in Colorado – A Synthesis to Support Water Resources Management and Adaptation"* (CWCB and CU-NOAA Western Water Assessment, 2008) provides a comprehensive review of greenhouse gas emission scenarios, global climate models, and resulting climate projections. Readers interested in the "storylines" supporting the development of these projections should review this report and reference the definitions in the glossary of the report. For the CRWAS, climate projections previously developed by others were used to estimate potential changes in temperature and precipitation, which were then used to develop changes in streamflows.

- *How much water is available to Colorado for future consumptive use given certain compact assumptions?* The results and conclusions of this Study are based on assumptions made for study purposes only. Phase I of the CRWAS presents the amount of water that may be available for future consumptive use in Colorado solely for the purposes of this Study and is neither the State of Colorado's nor any party's compact interpretation.

A study team led by AECOM and including AMEC Earth and Environmental, Canyon Water Resources, Leonard Rice Engineers and Stratus Consulting began work in late 2008. To date, more than 30 public presentations of the CRWAS have been made to various groups including the CWCB, IBCC, BRTs, Colorado Water Congress and others. The Phase I results presented below provide important information to Colorado water users, managers, policy makers and stakeholders on future water availability in the Colorado River basin.

The process of defining the potential future water demands that will be used in Phase II is currently underway through the State's IBCC processes in coordination with CWCB. Phase II will update and further refine the hydrologic computer models and the data supporting them. Categories of water use in Phase II will include beneficial uses recognized under Colorado water law and other potential "non-water right" future consumptive and non-consumptive uses. Future water demands and potential project portfolios to meet those demands are being developed through several processes facilitated by the CWCB's Water Supply Planning Section. Phase II will also provide information essential for wide ranging programs of the CWCB. The study will provide estimates of streamflows and reservoir levels to support water supply, flood management, instream flow protection, water conservation, endangered species recovery, and other intra-state, interstate and federal programs.

Technical Approach and Findings

The CRWAS Phase I Study is comprised of five inter-related components or steps as follows.

1. Update and expand the State's water availability computer simulation tools based on input solicited from water users (consumptive and non-consumptive) through the BRTs.

2. Assess potential future water availability using records of historical water supplies.

3. Use scientific analyses previously developed by others to estimate streamflows over the past several hundred years using annual growth of trees (especially as an indicator of transitions between wet and dry years and as an indicator of the potential lengths of dry and wet periods) and use this extended hydrology to assess remaining water availability as if today's water uses existed throughout the extended period.

4. Superimpose the effects of potential changes in precipitation and temperature from previously developed global climate models (GCMs, also known as General Circulation Models) to reflect hydrologic conditions that may exist in 2040 and 2070 if the greenhouse gas emissions occur as postulated in the various scenarios ("storylines") simulated by the GCMs.

5. Consider the effects of potential compact constraints, using certain assumptions, on water use in the State of Colorado.

In addition to the five step process described above, the Study also reviewed the practicality of modeling the hydrologic effects of forest change. Forest disturbance, such as forest fire, disease or logging may cause an increase in runoff volume[1] because less precipitation is lost through the processes of evaporation and plant transpiration. The U.S. Forest Service, in conjunction with the CWCB and the North Platte River Basin Roundtable, is completing a multi-year study to collect information regarding forest change processes that most influence the hydrology of disturbed forests within Colorado. Information from the study is expected to better describe corresponding hydrologic processes and to constrain assumptions to be used in future hydrological models. It is therefore appropriate to re-assess the potential for quantifying the impact of forest change on water availability when results of that ongoing work become available and the science of forest change assessment advances.

Water availability studies like the CRWAS compare supply and demand to determine whether there is enough water to meet either current demands or future demands based on the "supply-and-demand equation": **Supply – Demand = Water Available for Future Consumptive Use**

CRWAS Phase I holds the demand side of the water availability equation constant at current levels and considers three different conditions for the water supply side of the equation as follows:

1. Historical Hydrology–Traditionally, water supply agencies have used recorded historical information on water supply as an indication of likely future conditions; the premise being that history tends to repeat itself. Many agencies in Colorado used streamflow records dating back to at least 1950 so they could consider the impacts of the 50's multi-year drought on the reliability of their systems. The State has developed hydrology back to 1909 in the Colorado River basin in Colorado, but this required filling missing records or records for discontinued stream and weather gages with scientifically estimated values. For the purposes of this Study, a 56-year study period is used to represent historical hydrology (1950 through 2005). This period includes both very wet and very dry years, contains the most reliable historical data upon which to base comparisons of the effects of climate change, and uses information that Colorado River stakeholders can relate to through their own experiences. Historical hydrologic conditions are characterized by the record of natural flows at hundreds of points throughout the basin, basin-scale record of precipitation, temperature, and wind disaggregated to thousands of cells in a rectangular grid covering the entire Colorado River Basin, and a record of local weather recorded at 54 weather stations within Colorado.

2. Paleohydrology–This approach extends historical records using information from more than 1200 years of previously published tree-ring records. The CRWAS reviews alternative methods for correlating annual tree growth with streamflow and concludes that a "re-sequencing" approach best serves the needs of the Study. This approach focuses on the probabilities of transitioning back and forth between wet and dry years. The lengths of the wet periods and dry periods have significant effects on water availability for future use, especially when combined with the effects of climate change. This Study concludes that development of 100 equally probable 56-year-long flow traces is appropriate to test the effects of more severe droughts on water supply and management in Colorado and on the state's amount of water available for future consumptive use as potentially constrained by the compacts.

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[1] In addition, forest disturbance can impact the timing and rate of snow pack and snow melt (earlier peak flows) and water quality.

3. Climate-Adjusted Hydrology–This approach assesses the magnitude of future water supply availability considering the effects of climate change scenarios. This Study reviews many methods to use information from the climate projections that are available for the Colorado River basin. After coordinating with the State's Climate Change Technical Advisory Group (CCTAG) that is comprised of many federal, state and private scientists, water resource engineers and managers and also coordinating with the Front Range Climate Change Vulnerability Study (FRCCVS), this Study uses five projections for each of the 2040 and 2070 planning horizons (ten total). The Variable Infiltration Capacity (VIC) model is used to translate changes in temperature and precipitation from the Global Climate Models (GCMs, also known as General Circulation Models) to changes in natural flows throughout the river basin. In Colorado, the potential climate-induced changes have been introduced into two models comprising the State's Colorado Decision Support System (CDSS). First, "State-CU" is used to estimate altered consumptive use of water by crops resulting from higher temperatures and longer growing seasons. Second, "StateMod" is used to simulate the altered water management (for example, diversions, return flows, reservoir operations and instream flows) that would result from changes in natural flows. Input of the BRTs during Phase I significantly enhanced the performance of the models in the CDSS.

Some climatologists question the science supporting climate change projections, the work of the Intergovernmental Panel on Climate Change (IPCC), and the effects of greenhouse gas emissions, in particular, the contributions of anthropogenic (human-caused) factors like carbon dioxide emissions to climate change. Phase I of the CRWAS compares the effects of three alternative water supply scenarios (historic hydrology, paleohydrology and climate change hydrology) as described above. While the projections of future climate represented by the GCMs are possible representations of future conditions, the Study provides other hydrologic scenarios to allow water managers, policy makers and stakeholders to base their decisions and actions on a broad range of future possibilities.

Assessments of all the potential hydrologic scenarios presented in this report are supported by the updated CDSS computer tools made possible through interaction with the BRTs. These tools allow the most detailed analysis performed to-date of water supply and use in the Colorado River basin. All three hydrologic scenarios are useful to Colorado River stakeholders in assessing their potential policies and programs. Consideration of all three approaches will help each organization further define its roles and positions in water management, the resources available to it to adapt to alternative potential futures and select its tolerance or appetite for risk of water shortage.

The Study's consulting team recognizes the challenges of using GCMs to create scenarios on which to base assessments of future water availability, and on interpreting the results of those assessments. Until more detailed GCMs are created, including "regional" climate models that can more directly simulate the weather processes that affect temperature and precipitation of the Colorado River basin, (including summer monsoons and the orographic effects of the basin's rugged topography), the scientific information used in this Study is currently the best available for a study of this nature. This Study is likely the most rigorous and detailed study performed to date that utilizes GCM output and extends the analysis of potential effects to potential impacts on all the water uses (consumptive and non-consumptive) in an entire river basin.

Table 1 summarizes the ***technical approach*** for CRWAS Phase I. Table 2 summarizes the ***primary findings*** of CRWAS Phase I.

Table 1 – Phase I Technical Approach Summary

- Historical Hydrology includes hydrology observed for period 1950-2005.
- Paleohydrology is based on an extended record dating to AD 762 (more than 1200 years ago)
  - Provides estimated streamflow duration / frequency / intensity for years prior to gage data.
  - Estimated using statistical models applied to tree ring data.
  - Paleohydrology flow magnitudes are derived from the historical flow record (1950-2005).
  - Flow sequences are derived from paleohydrology flow record to provide more robust variety of year to year flow sequences than historical record.
  - Re-sequencing – Future sequences of wet and dry years cannot be predicted; therefore, 100 different 56-year hydrologic traces were developed.
    - Represents 100 alternative possible future sequences of wet and dry years.
    - Each of the 100 alternative possible futures is equally probable and differs from the other 99.
    - Although more sequences would have been statistically more valid, 100 traces are sufficient for the purposes of the Phase I Study and are considered the maximum practical number of traces given the Study's funding and schedule.
- Climate-Adjusted Hydrology is based on five climate projections selected in consultation with the State's Climate Change Technical Advisory Group.
  - Five climate projections were chosen for each of the 2040 and 2070 planning horizons (these are the same ten projections selected by the participants in the FRCCVS).
  - Subsequent analysis of the selected projections showed that the 2040 projections were representative of streamflow conditions at both time frames, while the 2070 projections were biased toward dry conditions. For this reason, the 2040 projections are used as the basis for values in this report.
  - Each of the selected climate projections is equally probable; but differs from the others.
  - Projections are "downscaled" to the Colorado River basin and temperature and precipitation changes were translated into effects on hydrology using the VIC hydrologic model. Flow sequences (dry/wet spells) were derived from those used in the paleohydrology flow record because it has been shown in the literature that GCMs alone do not simulate flow sequences reliably.
- Water Available for Future Consumptive Use under Compact Assumptions: Two methods are used to assess the amount of water that may be available for future consumptive use: 1) CRSS – Bureau of Reclamation model used for Federal planning and recent negotiations and 2) Hydrologic Determination – Mass balance analysis used in the 2007 Hydrologic Determination. Analysis also incorporates two separate assumptions, for purposes of this study only, for the Upper Division's potential compact obligation at Lee Ferry (75 MAF and 82.5 MAF) and the assumptions listed below:
  - Reservoirs
    - Simulated major federal reservoirs
    - Capacity adjusted for estimated sedimentation through 2060 per the Hydrologic Determination
    - Allowed use of CRSP minimum power pools
  - Evaporation
    - Consistent with Hydrologic Determination
    - Includes Lake Powell, Flaming Gorge and Aspinall reservoirs
    - Other evaporation chargeable to states
  - Inflows
    - Mass balance conducted at Lee Ferry
    - Hydrologic Determination used total inflow above Lees Ferry (not including Paria River)
    - CRWAS Phase I used total inflow above Lee Ferry (including Paria River inflow)
  - Depletions
    - Applied Upper Basin water use from the 2007 Hydrologic Determination.
    - Assumed that all Upper Basin states are physically using their full apportionments.
  - Estimated by StateMod
    - 1950-2005 natural flows and weather
    - Current irrigated acreage and M&I demands
    - Simulates diversions, crop CU, and evaporation
    - Excludes evaporation from Aspinall Unit and Navajo evaporation chargeable to NM
    - Excludes exports to New Mexico
  - Colorado Current Consumptive Use (~2.6 MAF)

Table 2 – Primary Phase I Findings Based on 2040 Climate Projections

Compared to current conditions, CRWAS Phase I findings show that projected future climate conditions may lead to the following changes to hydrologic conditions in the Colorado River Basin:

Temperature
- Increases basin-wide by 3.3 to 3.7 degrees Fahrenheit (deg F)
- Lower elevations show largest increase
- Increase occurs each month of the year

Winter Precipitation (Nov-Mar)
- Increases basin-wide by 6 to 13 percent
- Increases more in the northern part of the river basin
- Increases more at higher elevations
- Shifts from snow to rain in the shoulder months

Summer Precipitation (Apr-Oct)
- Decreases basin-wide by 4 to 10 percent
- Decreases more in the southern part of the basin
- Decreases less at higher elevations

Crop Irrigation Requirement (based on acreage and crop types identified in a 1993 acreage inventory)
- Increases basin-wide (2.6 to 6.7 inches per year for pasture grass)
- Increases basin-wide by 20 percent (based on current estimated acreage and crop types)
- Growing season for perennial crops increases basin-wide by about 15 to 22 days
- Increases more at lower elevations

Natural Flow
- Annual flow increases in some possible futures and decreases in others
- Annual flow generally increases in parts of the Yampa River basin and at higher elevation watersheds
- Annual flow generally decreases in south-western watersheds and at lower elevations
- Shifts toward earlier peak runoff
- Flow decreases in late summer and early fall

Modeled Streamflow
- Annual modeled streamflow decreases basin-wide, except in the Yampa River basin, and higher elevation locations in the Upper Colorado River basin
- Modeled Flow increases in April and May and decreases in later summer and fall months

Water Available to Meet Future Demands
- Higher elevations generally have less annual flow available to meet future demands, as a percent of modeled streamflow
- Available flow generally increases in April and May, corresponding to the shift in natural flow hydrographs

Use of Reservoirs
- Reservoirs show increased use (pool levels fluctuate more than historical)

Modeled Consumptive Use
- Increases in Yampa, White, Upper Colorado, and Gunnison basins by 4 to 18 percent
- Decreases in the San Juan and Dolores basins by 8 percent

Water Available for Future Consumptive Use based on Specific Compact Assumptions
- Estimates overlap with range of previous studies
- Water available under Colorado's compact apportionment may be limited under drier climate projections
- Same or higher unused water under its compact apportionment for the wetter climate projections (compared to historical period estimates)

Results presented in Table 2 are based on comparing conditions for the 2040 climate projections compared with historical conditions. The five 2040 projections selected for CRWAS proved to be representative of the distribution of the 112 available global climate projections, while the five 2070 projections selected for CRWAS proved to be not as representative of the distribution of the 112 available global climate projections as they are clustered on the low end of the distribution of 112 climate projections. Comparison of the distribution of 2040 and 2070 projections show that climate-induced effects on streamflow are very similar for the two time frames. Therefore, results presented in Table 2 and in the body of the report focus on the 2040 time frame. Results associated with the 2070 time frame are included in the report's appendices. Limitations to the modeling approaches used in the analyses and exceptions to the general findings in Table 2 are discussed in detail in the main report.

Conclusions and Recommendations

The CRWAS responds to the General Assembly's direction to the CWCB to provide information on how much water is available from the Colorado River basin to meet the State's water needs. As a starting point, the Phase I work presented in this report provides a water availability assessment based on existing levels of water use (also referred to as water demands) served by water rights that are currently being used ("perfected" or "absolute" water rights) and by interpretations of current operating and management practices for water diversion, storage and conveyance facilities. Assessments of water availability to meet future water needs are reserved for Phase II of the CRWAS.

Conclusions of the Phase I Study are summarized below:

- Interaction with the BRTs provided essential information to update and refine the State's hydrologic planning tools (including CDSS); improving model calibration and enhancing the representation of current water management.

- Computer models used in Phase I (including CDSS) proved appropriate to simulate current water uses (demands) and alternate hydrologic scenarios (historical, paleohydrology, and a broad range of equally-probable climate projections). The models were effective in simulating a broad range of possible future conditions associated with crop irrigation requirement, streamflow, consumptive use, and water availability that vary (in magnitude and time) with elevation and geographic region of the state.

- Phase I demonstrates a broad range of water availability for future Colorado consumptive use under various compact assumptions used for purposes of this Study. The upper end of this range lies within the range of previous studies, while the corresponding lower range suggests that Colorado may have no or limited additional water available for development.

- The primary underlying drivers for the broad range of Phase I results are 1) the inherent uncertainties in the available global climate models in projecting the magnitude and nature of future greenhouse gas emissions; 2) the complexity of modeling atmospheric circulation; and 3) down-scaling the resulting effects of changed temperature and precipitation on natural flows in an area the size of the Colorado River basin.

- Phase I results are based only on current water uses (consumptive and non-consumptive water demands). Stakeholders demonstrated strong interest in more than 30 Study presentations to expand analysis to include future demands and operating conditions.

The following recommendations are offered for consideration:

- *Continue refinements to the CDSS* – This Study, with its large geographic scale and detailed analysis, would not have been possible without the availability of the CDSS system. The process of presenting the Study's approach and tools in Phase I through the use of BRT meetings should continue in Phase II in close collaboration with the processes and programs of the CWCB Water Supply Protection Section and the Bureau of Reclamation's Colorado River Basin Study. A key element in developing additional CRWAS refinements is demonstrating openness and transparency in displaying hydrologic data, modeling procedures and calibration results. Specific CDSS refinements that should be considered include the following:
    - Revise baseflows in Plateau Creek based on information currently being developed by Collbran Water Conservancy District and the Division of Water Resources. Delivery of water from Vega Reservoir through the Southside Canal has a significant effect on both baseflows and the ability to meet future demands in Plateau Creek basin. Historical delivery records and locations of direct delivery to irrigated lands are being compiled and provided to the CRWAS study team. Incorporating this information into the Upper Colorado River StateMod model will greatly improve calibration and, therefore, confidence in simulated results.
    - Consider alternatives to representing the USFWS fish flow recommendations for the 15-mile reach in the Upper Colorado River model. As discussed in this report, the USFWS recommendations are modeled as an instream flow agreement. Although the flows are modeled as junior to other basin demands (therefore they cannot "place a call" on the river), the approach used in the current modeling effort allocates water to the demands, thereby decreasing the reported water available for future uses upstream.
    - Revise current release rules for reservoirs that operate for flood control to account for changes in timing of peak runoff. Four reservoirs in the Study basin (Green Mountain, Ruedi, Lemon, and Vallecito reservoir) release water for flood control based on target rules that reflect current inflow hydrographs. The climate projections indicate a shift in the peak runoff that would likely result in a change to flood control operations.
    - Consider revisions to Aspinall Unit reservoir operations. The Aspinall Unit reservoirs (Blue Mesa, Morrow Point, and Crystal) operate primarily for non-consumptive uses within and outside of Colorado. An EIS is currently in draft form that will revise reservoir operations.
    - Incorporate alternative transbasin demands affected by climate change. In Phase I, transbasin demands were not revised to reflect the effects climate change may have on current levels of demands in the South Platte River and Arkansas River basins. In addition, transbasin demands are dependent on eastern slope supplies. The State should continue their efforts to develop a South Platte StateMod model that can be used, along with the current western slope models, to better represent the basin inter-dependence. Combined with an Arkansas River StateMod model, the entire State could be modeled together to better understand how future statewide demands will be met under climate change.
    - Remove New Mexico structures from the San Juan/Dolores StateMod model. The current StateMod model for the San Juan and Dolores basins includes structures that divert and consume water in New Mexico. These structures, along with Navajo Reservoir, were included in the model to assist the State in identifying options to meet recommended fish flows for the San Juan Recovery Program. New Mexico structures are modeled as junior to Colorado demands, therefore, they cannot "place a call" on the river. However, the current modeling effort allocates water to these demands, thereby decreasing the reported water available for future uses upstream.

- *Incorporate new water management strategies and interpretations of existing operating rules and agreements* – Stakeholder input (in Phase I) shows that there are many potential interpretations of the methods in which water can be managed in accordance with state water law. Phase II should identify additional interpretations to compare the effects of additional future consumptive and non-consumptive water demands.

- *Use the CRWAS to support the CWCB / IBCC programs and continue use of the CCTAG* – The data and models used in Phase I should be used to support the many on-going programs of the CWCB and the IBCC. Phase I demonstrated the benefits of independent input from these groups. Colorado is in an enviable position in terms of its resident professional expertise in water resources planning and management, including climate change expertise in the state. Future studies should take advantage of the multiple CWCB / IBCC programs and the CCTAG as a cost-effective source of key technical review and enhanced credibility.

- *Recommendation to Stakeholders* – Phase I results help Colorado River stakeholders better understand potential effects of climate change on water available for future uses in Colorado. These results can be used by stakeholders to prepare for a range of future hydrologic conditions, to better deal with uncertainty in their water management decisions and to support development of their individual policies and programs. It is recommended that each stakeholder interpret the broad range of future water availability from its own perspective, considering its own assessment of the possible future conditions, its role in water management, the resources it has to adapt to alternative potential futures, and its tolerance for risk.

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Introduction

1 INTRODUCTION

1.1 Background and Objectives

Colorado faces increasing demands on its water supply for both traditional consumptive (agriculture, municipal, industrial, commercial and other) uses and for non-consumptive (recreational and environmental) uses. Population growth, recent drought, energy development, and potential climate change generate concern about the adequacy of Colorado's water supplies. The Colorado River Water Availability Study (the Study or CRWAS) was authorized by SB 07-122 and HB 08-1346 of the Colorado General Assembly. These bills direct the Colorado Water Conservation Board (CWCB) to conduct the Study 1) in collaboration with the Interbasin Compact Committee (IBCC) and the State's river "basin roundtables" (BRTs) and 2) with consideration for current and potential future in-basin consumptive and non-consumptive needs.

The CWCB, working closely with the IBCC, concluded that the Study be conducted in two phases, with Phase I (the subject of this report) presenting a water availability assessment based only on existing levels of water use. For Phase I, water uses (also referred to as water demands) were limited to current levels of water demands served by water rights that are currently being used ("perfected" or "absolute" water rights). Phase I is also restricted to interpretations of current operating and management practices for water diversion, storage and conveyance facilities. Assessments of water availability to meet future water needs are reserved for Phase II of the CRWAS.

The draft Scope of Work for Phase I posed the following types of questions to help guide the Study:

- *How much water from the Colorado River Basin System is available to meet Colorado's water needs?* Phase I of the CRWAS provides important information to help Colorado prepare for a range of future hydrologic conditions and to deal with uncertainty in making water management decisions.

- *What is a reasonable base of existing uses for Phase I of the CRWAS?* Each year the State of Colorado, like other Colorado River basin states, prepares assessments of the State's water consumption and losses. These reports support on-going inter-state water management activities and help assure agreement that Colorado's water management is in general compliance with inter-state agreements (river compacts and the "Law of the River" documents). The estimate of Colorado's current consumptive use (developed in Phase I) helps provide a basis for comparing future water availability with current conditions. It does not, however, supersede the official estimates of consumptive uses and losses submitted by the State in accordance with defined inter-state water management protocols.

- *How does historical hydrology compare to a longer hydrologic trace based on tree ring analysis?* Careful analysis of the width of annual growth rings in tree trunks and statistically correlating them with wet and dry weather patterns is one method to assess long-term or "paleo" hydrology prior to streamflows being recorded by man. For Phase I of the CRWAS, historical hydrology is extended back more than 1200 years using paleohydrology developed by others.

- *What is a reasonable projection for hydrology affected by climate change?* A CWCB-sponsored report, *"Climate Change in Colorado – A Synthesis to Support Water Resources Management and Adaptation"* (CWCB and CU-NOAA Western Water Assessment, 2008) provides a comprehensive review of greenhouse gas emission scenarios, global climate models, and resulting climate projections. Readers interested in the "storylines" supporting the development of these projections should review this report and reference the definitions in the glossary of the report. For the CRWAS, climate projections previously developed by others were used to estimate potential changes in temperature and precipitation, which were then used to develop changes in streamflows.

- *How much water is available to Colorado for future consumptive use given certain compact assumptions?* The results and conclusions of this Study are based on assumptions made for study purposes only. Phase I of the CRWAS presents the amount of water that may be available for future consumptive use in Colorado solely for the purposes of this Study and is neither the State of Colorado's nor any party's compact interpretation.

A study team led by AECOM and including AMEC Earth and Environmental, Canyon Water Resources, Leonard Rice Engineers and Stratus Consulting began work in late 2008. To date, more than 30 public presentations of the CRWAS have been made to various groups including the CWCB, IBCC, BRTs, Colorado Water Congress and others. The Phase I results presented below provide important information to Colorado water users, managers, policy makers and stakeholders on future water availability in the Colorado River basin.

The process of defining the potential future water demands that will be used in Phase II is currently underway through the State's IBCC processes in coordination with CWCB. Phase II will update and further refine the hydrologic computer models and the data supporting them. Categories of water use in Phase II will include beneficial uses recognized under Colorado water law and other potential "non-water right" future consumptive and non-consumptive uses. Future water demands and potential project portfolios to meet those demands are being developed through several processes facilitated by the CWCB's Water Supply Planning Section. Phase II will also provide information essential for wide ranging programs of the CWCB. The study will provide estimates of streamflows and reservoir levels to support water supply, flood management, instream flow protection, water conservation, endangered species recovery, and other intra-state, interstate and federal programs.

1.2 Relationship with other Programs and Processes

In addition to the CRWAS, the CWCB is currently conducting several other programs and processes that are highly interrelated and where results of one effort provide input to others. Extensive collaboration is underway to share Study objectives, approaches, data, and findings, thereby enhancing statewide dialogue and fostering a collaborative State water management approach. These activities are closely coordinated with the CWCB Water Supply Protection Section, the CWCB Water Supply Planning Section, and on-going State-sponsored IBCC processes. In addition, the State is collaborating with the Colorado River basin states and federal agencies to enhance interstate dialogue and foster a collaborative basin-wide water management approach through a Colorado River Basin Study to be administered by the U.S. Bureau of Reclamation (Reclamation).

CRWAS Phase I has been conducted simultaneously with the water needs assessments being prepared by the following BRT subgroups: 1) Consumptive Water Needs Group and 2) Non-Consumptive Water Needs Group. The results of the Phase 1 Study will be supplemented by these needs assessments to formulate water demand alternatives for CRWAS Phase II.

In addition to the State's ongoing processes and studies, the rapidly evolving science and practice of climate change assessment warrants the State's collaboration with other organizations focused on potential climate change impacts to water resources management.

Listed below are many of the programs and studies currently involving State agencies such as the CWCB, IBCC, DWR, and the Attorney General's Office in relation to the types of water supply questions being addressed (agencies are shown parenthetically).

Key Colorado Water Supply Questions and the Studies and Processes to Provide Answers

- **What are Colorado's water needs?**
    - *Consumptive and Non-consumptive Water Needs Assessments* (IBCC and BRTs with CWCB facilitation)
- **What water is available under current and future conditions?**
    - *Colorado River Water Availability Study Phase I* (CWCB with IBCC and BRTs)
    - *Colorado River Water Availability Study Phase II* (CWCB with IBCC and BRTs)
    - *Colorado River Basin Study* (Reclamation with multiple state agency sponsors including Colorado)
- **What could we do to meet these needs?**
    - *Strategies for Colorado's Water Supply Future* (CWCB with IBCC and BRTs)
    - *Basin Needs Decision Support System and IPPs* (CWCB with IBCC and BRTs)
    - Filter Through Vision Goals (CWCB with IBCC and BRTs)
- **How do we ensure that Colorado's future is the one we want?**
    - Use Portfolio Tool (CWCB with IBCC and BRTs)
    - Build Portfolios and Scenarios (CWCB with IBCC and BRTs)
    - Develop Framework (CWCB with IBCC and BRTs)
- **How are we going to mitigate the risks?**
    - *Colorado River Compact Compliance Study* (CWCB with DWR and Attorney General's Office)
    - *State Drought Plan* (CWCB)

1.3 General Approach

Water availability studies like the CRWAS compare supply and demand to determine whether there is enough water to meet either current demands or future demands based on the "supply-and-demand equation": **Supply – Demand = Water Available for Future Consumptive Use**

CRWAS Phase I holds the demand side of the water availability equation constant at current levels and considers three different conditions for the water supply side of the equation as follows:

1. Historical Hydrology – Traditionally, water supply agencies have used recorded historical information on water supply as an indication of likely future conditions; the premise being that history tends to repeat itself. Many agencies in Colorado used streamflow records dating back to at least 1950 so they could consider the impacts of the 50's multi-year drought on the reliability of their systems. The State has developed hydrology back to 1909 in the Colorado River basin in Colorado, but this required filling missing records or records for discontinued stream and weather gages with scientifically estimated values.

   For the purposes of this Study, a 56-year study period is used to represent historical hydrology (1950 through 2005). This period includes both very wet and very dry years, contains the most reliable historical data upon which to base comparisons of the effects of climate change, and uses information that Colorado River stakeholders can relate to through their own experiences.

   Historical hydrologic conditions are characterized by the record of natural flows at hundreds of points throughout the basin, basin-scale record of precipitation, temperature, and wind disaggregated to thousands of cells in a rectangular grid covering the entire Colorado River Basin, and a record of local weather recorded at 54 weather stations within the State of Colorado.

2. Paleohydrology – This approach extends historical records using information from more than 1200 years of previously published tree-ring records. The CRWAS reviews alternative methods for correlating annual tree growth with streamflow and concludes that a "re-sequencing" approach best serves the needs of the Study. This approach focuses on the probabilities of transitioning back and forth between wet and dry years. The lengths of the wet periods and dry periods have significant effects on water availability for future use, especially when combined with the effects of climate change. This Study concludes that development of 100 equally probable 56-year-long flow traces is appropriate to test the effects of more severe droughts on water supply and management in Colorado and on the state's amount of water available for future consumptive use as potentially constrained by the compacts.

3. Climate-Adjusted Hydrology – This approach assesses the magnitude of future water supply availability considering the effects of climate change scenarios. This Study reviews many methods to use information from the climate projections that are available for the Colorado River basin. After coordinating with the State's Climate Change Technical Advisory Group (CCTAG) that is comprised of many federal, state and private scientists, water resource engineers and managers and also coordinating with the Front Range Climate Change Vulnerability Study (FRCCVS), this Study uses five projections for each of the 2040 and 2070 planning horizons (ten total). The Variable Infiltration Capacity (VIC) model is used to translate changes in temperature and precipitation from the Global Climate Models (GCMs, also known as General Circulation Models) to changes in natural flows throughout the river basin. In Colorado, the potential climate-induced changes have been introduced into two models comprising the State's Colorado Decision Support System (CDSS). First, "State-CU" is used to estimate altered consumptive use of water by crops resulting from

higher temperatures and longer growing seasons. Second, “StateMod” is used to simulate the altered water management (for example, diversions, return flows, reservoir operations and instream flows) that would result from changes in natural flows. Input of the BRTs during Phase I significantly enhanced the performance of the models in the CDSS.

The process of estimating the impact of future climate begins with the development of scenarios of future emissions of greenhouse gases. These emission scenarios, developed by the Intergovernmental Panel on Climate Change (IPCC), are used to drive a global climate model (GCM) that simulates future conditions in the Earth’s atmosphere and on its surface. GCMs estimate atmospheric and surface conditions in a three-dimensional grid with a resolution of hundreds of kilometers per side. GCMs are developed and run at dozens of research institutions worldwide. The outputs from GCMs are too coarse for use directly for a study with the spatial detail of CRWAS, so a downscaling step is required to bring the data from a scale of a grid with about 200 miles on a side down to a grid with eight miles on a side.

The output of a GCM is called a projection, and contains an overlap period that runs from 1950 through 1999 and a projection period, that runs from 2000 through 2099. In CRWAS the projection is used to determine the difference between the weather conditions today and the weather conditions projected for 30 or 60 years in the future.

To know how the different weather conditions will affect the availability of water, estimates of their effect on streamflow and water use are needed. To estimate the effect on streamflow, a specialized hydrology model is used that is designed expressly for translating weather conditions into streamflow. The hydrology model is run twice, once with the historical weather conditions and once with the historical weather conditions adjusted according for the GCM’s simulation of changed weather conditions. The difference between those two hydrology model runs gives the impact of climate on streamflow. That difference is used to adjust the historical streamflow to get a new set of streamflow to reflect the impact of projected future climate conditions.

The effect of climate on the consumptive use of water is estimated using a specialized hydrology model (StateCU) that operates in the Colorado River Decision Support System (CDSS) based on the adjusted temperature and precipitation estimates.

The impact of extended droughts and wet spells is accounted for by incorporating the climate adjustments into the extended historical hydrology.

The last step in the process is to estimate the availability for future uses of water using a water resources model, the climate-adjusted streamflow and the climate-adjusted water use. The water resources models allocate streamflow to water uses according to water rights priorities, contractual agreements and operating rules.

This process is repeated for a number of possible future conditions—in CRWAS ten projections of future climate conditions were analyzed; five each for two future time frames, 2040 and 2070. Each of these analyses provides a picture of possible future conditions, which can be compared to current conditions.

Some climatologists question the science supporting climate change projections, the work of the Intergovernmental Panel on Climate Change (IPCC), and the effects of greenhouse gas emissions, in particular, the contributions of anthropogenic (human-caused) factors like carbon dioxide emissions to climate change. Phase I of the CRWAS compares the effects of three alternative water supply scenarios (historic hydrology, paleohydrology and climate change hydrology) as described above. While the projections of future climate represented by the GCMs are possible representations of future conditions, the Study provides other hydrologic scenarios to allow water managers, policy makers and stakeholders to base their decisions and actions on a broad range of future possibilities.

Assessments of all the potential hydrologic scenarios presented in this report are supported by the updated CDSS computer tools made possible through interaction with the BRTs. These tools allow the most detailed analysis performed to-date of water supply and use in the Colorado River basin. All three hydrologic scenarios are useful to Colorado River stakeholders in assessing their potential policies and programs. Consideration of all three approaches will help each organization further define its roles and positions in water management, the resources available to it to adapt to alternative potential futures and select its tolerance or appetite for risk of water shortage.

The Study's consulting team recognizes the challenges of using GCMs to create scenarios on which to base assessments of future water availability, and on interpreting the results of those assessments. Until more detailed GCMs are created, including "regional" climate models that can more directly simulate the weather processes that affect temperature and precipitation of the Colorado River basin, (including summer monsoons and the orographic effects of the basin's rugged topography), the scientific information used in this Study is currently the best available for a study of this nature. This Study is likely the most rigorous and detailed study performed to date that utilizes GCM output and extends the analysis of potential effects to potential impacts on all the water uses (consumptive and non-consumptive) in an entire river basin.

Figure 1-1 on the following page presents the Study's execution in accordance with five major steps:

1. Update and expand the State's water availability computer simulation tools based on input solicited from water users (consumptive and non-consumptive) through the BRTs.

2. Assess potential future water availability using records of historical water supplies.

3. Use scientific analyses previously developed by others to estimate streamflows over the past several hundred years using annual growth of trees (especially as an indicator of transitions between wet and dry years and as an indicator of the potential lengths of dry and wet periods) and use this extended hydrology to assess remaining water availability as if today's water uses existed throughout the extended period.

4. Superimpose the effects of potential changes in precipitation and temperature from previously developed global climate models (GCMs, also known as General Circulation Models) to reflect hydrologic conditions that may exist in 2040 and 2070 if the greenhouse gas emissions occur as postulated in the various scenarios ("storylines") simulated by the GCMs.

5. Consider the effects of potential compact constraints, using certain assumptions, on water use in the State of Colorado.

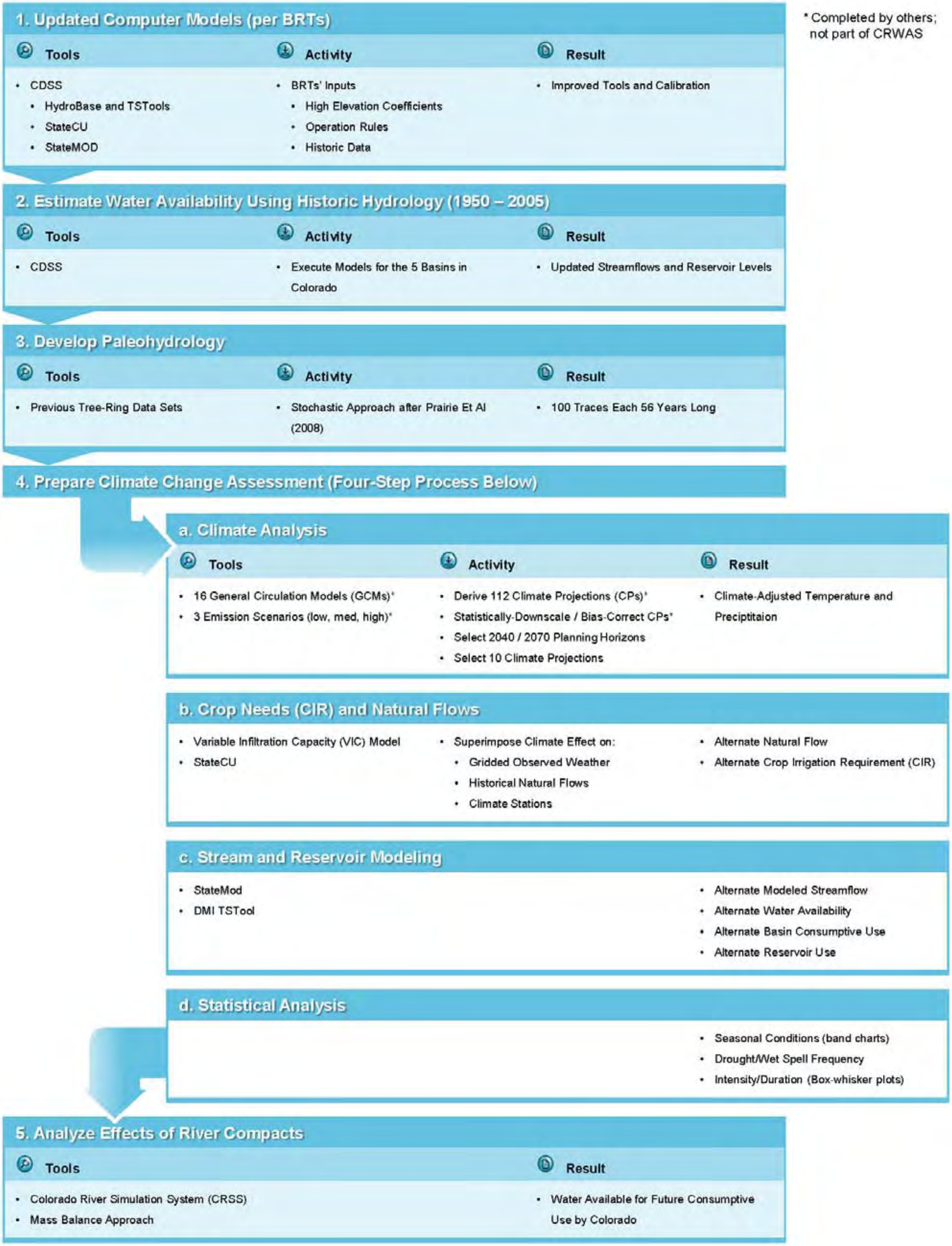

Figure 1-1 – CRWAS General Analysis Approach

In Association with
AMEC Earth & Environmental
Canyon Water Resources
Leonard Rice Engineers
Stratus Consulting

Approach

2 APPROACH

2.1 Outreach, Literature Review, and Analysis Tools

2.1.1 Outreach

CRWAS activities included a significant level of outreach activities to communicate and share Study objectives, approaches, progress, and findings; to collaborate and participate with other organizations, programs, and processes focused on similar study objectives; and to solicit feedback on Study methods and techniques for presenting results. Outreach activities included newsletters; regular meetings with DNR, CWCB, DWR, and AG staff; and approximately 30 public meetings, presentations, and workshops with water users and managers, stakeholders, and other interested parties, enhancing statewide dialogue and fostering understanding of the CRWAS process through knowledge transfer to interested parties and solicitation of feedback.

Outreach activities were able to take advantage of, and integrate productively with, the public communication efforts of the CWCB Water Supply Planning Section and on-going State-sponsored IBCC processes. Outreach activities also provided opportunities for interested parties to actively participate in development of State water resources modeling tools (e.g., CDSS), providing the State with an opportunity to more fully engage water users, managers, and stakeholders in its collaborative State water management approach.

The rapidly evolving science and practice of climate change assessments warranted collaboration and participation with other organizations focused on potential climate change impacts to water resources management and direct involvement in other related intrastate programs and projects.

CRWAS outreach activities included meetings, presentations, and workshops with:

- CWCB Board
- CWCB, DNR, DWR, and AG Staff
- CWCB Climate Change Technical Advisory Group (CCTAG)
- Interbasin Compact Committee (IBCC) and IBCC Basin Roundtables (BRTs)
- Joint Front Range Climate Change Vulnerability Study (JFRCCVS) Program
- NOAA Regional Integrated Sciences and Assessments (RISA) Program
- University of Colorado's Western Water Assessment (WWA) Program
- Northern Colorado Water Conservancy District (Water User Meeting)
- Colorado River Water Conservation District (Annual Water Meeting)
- Colorado House-Senate Joint Agriculture Committee
- Front Range Water Council
- Colorado Water Congress

Where to find more detailed information:

Outreach presentations and newsletters associated with CRWAS Task 1.1 – *Start-up, Coordination, and Reporting*, CRWAS Task 1.2 – *IBCC / BRT Meetings*, CRWAS Task 1.3 – *Public Information*, CRWAS Task 4.2 / 5.2 – *BRT Workshop Presentations*, CRWAS Task 7.1 – *Coordination with Front Range Vulnerability Study*, and CRWAS Task 7.13 – *Coordination with CWCB Climate Change Technical Advisory Group* are available at http://cwcb.state.co.us/.

2.1.2 Literature Review

CRWAS activities included a significant level of literature review associated with alternate historical hydrology, climate change and forest change hydrology, and Colorado River Compact analyses. This included tasks to identify, review, and summarize relevant and readily available previous studies and investigations pertinent to the execution of primary Study tasks. High priority, readily available, previous studies and investigations pertinent to the execution of the Study are provided in CRWAS technical memoranda (TM) direct reference sections and TM appendix reference sections.

Where to find more detailed information:

A concise list of documents most pertinent to CRWAS and summaries of those documents are provided in CRWAS Task 2.1 – *Pertinent Document List* and CRWAS Task 2.2 – *Summary Briefs*; comprehensive reference lists and literature reviews are provided in technical memoranda and modeling briefs associated with CRWAS Tasks 3.1, 4.1, 6.1, 6.2, 6.3, 6.4, 6.7, 7.2, 7.3, 7.4, 7.5, 7.12, 8.1, 8.2, and 8.6; available at http://cwcb.state.co.us/.

2.1.3 Analysis Tools

Variable Infiltration Capacity (VIC) Hydrology Model

The Variable Infiltration Capacity (VIC) hydrology model was used to quantify the effect of projected changes in climate on naturalized streamflow. The VIC model is a distributed gridded physical hydrology model with several applications to climate change studies and successful application to numerous basins around the world. The VIC model has a number of favorable attributes for the Study, but VIC's three most significant advantages are that it has a reliable, physically-based model of evapotranspiration, it has a physically-based model of snow dynamics, and it has been used for two studies of climate change in the Colorado River Basin for which calibrated parameters are available.

Evapotranspiration (ET) is the most significant water loss process in the hydrologic water balance. As such, the reliability of a hydrology model is directly related to the accuracy and reliability of the representation of ET. In mountainous terrain such as constitutes much of the significant water-producing areas of the Colorado River basin, temperature-based ET models do not perform well without local calibration and physically-based ET models such as is used in VIC, are preferred.

Snow accumulation and snow melt are also important processes in simulating the seasonal pattern of streamflow. Because all of the available projections of future climate show that temperature will increase, changes in the seasonal pattern of snow accumulation and melt will result. A more physically-based snow model, of the sort used in VIC, provides more confidence that simulations involving changes in temperature will result in realistic changes in snow accumulation and snow melt.

Colorado Decision Support System (CDSS)

Water availability under historical and projected climate conditions was estimated using tools developed for the Colorado Decision Support System (CDSS). CDSS was developed by the Colorado Water Conservation Board (CWCB), with support from the Colorado Division of Water Resources and consists of a database of hydrologic and administrative information related to water use in Colorado, and a variety of tools and models for reviewing, reporting, and analyzing the data. Historical water-related data, including stream flows, diversions, water rights, climate records, and reservoir contents are stored in a central database called HydroBase. Spatial data, such as irrigated acreage and point locations of ditch headgates, stream flow gages, and climate stations, are also stored in HydroBase.

These underlying data were fundamental to the development of the CDSS modeling tools available for use in the CRWAS. Data sets for the consumptive use model, StateCU, have been developed for each of the five major basins (study basins) that collectively make up the Colorado River Basin in Colorado; Yampa River basin, White River basin, Upper Colorado River basin, Gunnison River Basin, and the combined San Juan River and Dolores River basins. These data sets include current levels of irrigated acreage, crop types, and irrigation practices superimposed on climate data for the 1950 through 2005 study period.

The CDSS water resources planning models are water allocation models, which determine availability of water to individual users and projects, based on hydrology, water rights, and operating rules and practices. They are implementations of “StateMod,” a code developed by the State of Colorado for application in the CDSS project. CDSS planning models have been developed for each of the five study basins. These model data sets used in CRWAS extend from 1950 through 2005 and simulate current demands, current infrastructure and projects, and the current administrative environment as though they were in place throughout the modeled period.

StateCU and StateMod are used to represent each basin’s hydrology, demand, water rights, and operations. StateCU generates crop irrigation demand estimates that are used directly in the StateMod model. StateMod starts with hydrology then operates based on Colorado water right priorities to meet the irrigation, municipal, industrial, transbasin, storage, and instream flow demands.

Figure 2-1 shows the general data-centered philosophy that governed the development of CDSS. As shown, information is stored in HydroBase and extracted for viewing, analysis, and use in subsequent modeling efforts using Data Management Interfaces. The procedure allows input files developed for consumptive use and water resources planning models to be created and formatted in a consistent fashion, and updated easily when new data becomes available.

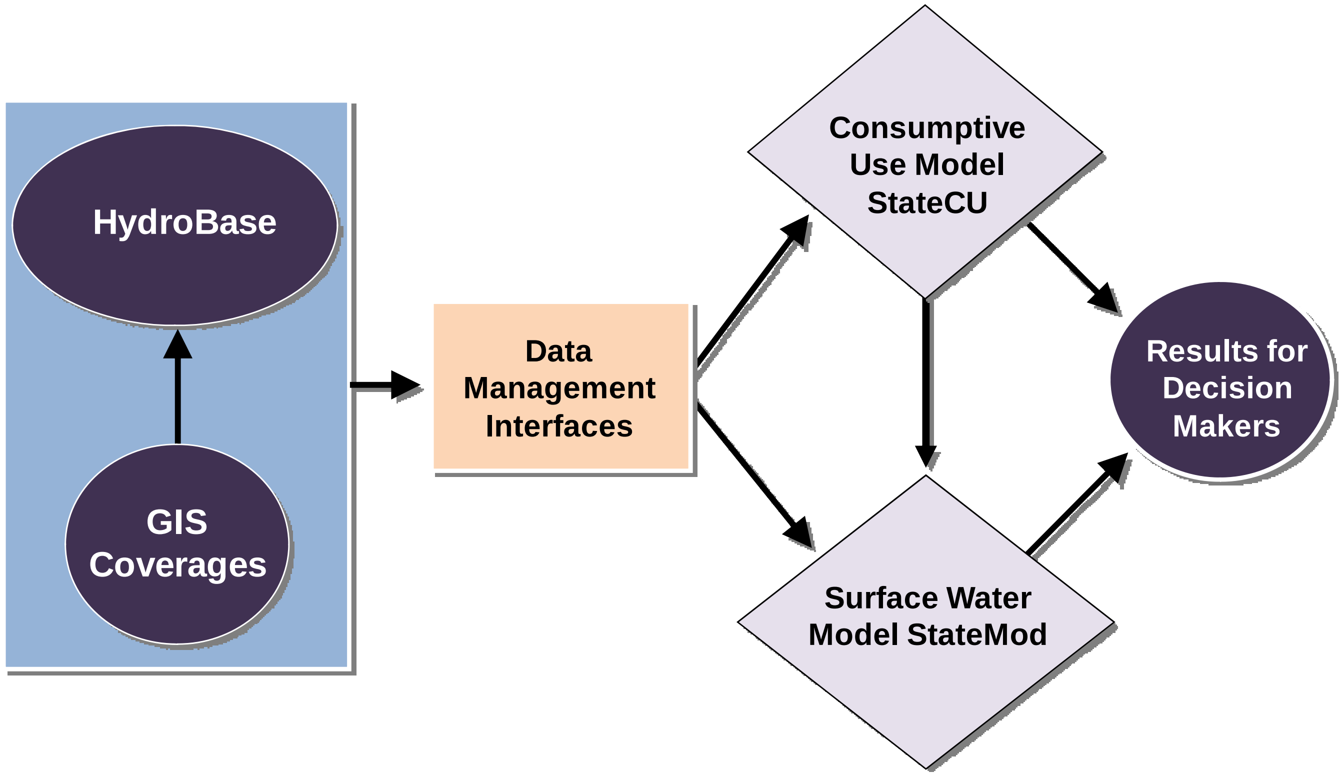

Figure 2-1 – CDSS Data-Centered Approach

The CDSS analysis models were developed as tools to test the impacts of changes to the current water resource systems, including potentially higher agricultural demands and varying natural hydrology due to projected climate changes. The models can simulate these potential changes constrained by current reservoir and diversion infrastructure, operations, and water rights administration. The models are publically available and have been reviewed, enhanced, and used to help in water resources planning decisions since development began in the 1990s. The reliability and acceptance of the models, plus the ease in which model inputs can be revised due to the data-centered approach, make them the perfect tools to investigate the impact projected climate change may have on water available for future development in the Study basins.

Colorado River Simulation System (CRSS)

The Colorado River Simulation System (CRSS) model was used to make quantitative estimates of the amount of consumptive use available to Colorado while simultaneously meeting the cumulative flow provision in the Colorado River Compact for future uses.

The CRSS model was developed by and is maintained by the Bureau of Reclamation (Reclamation). Within the CRSS, Reclamation maintains the current naturalized historical hydrologic inflows, future demand schedules, and one interpretation of legal and operational policies. Although not all of the Colorado River stakeholders agree with certain elements of that interpretation, CRSS is the modeling tool that is most widely used and accepted, for study purposes, among stakeholders. This model provides the most comprehensive and current collection of physical, legal, and operational aspects that affect the management of the River.

The results of model analyses indicate that the CRSS model may underestimate the ability of Upper Basin states to put their full demand for water physically to use, particularly under drier conditions. For this reason the CRSS model was not used to quantify the amount of water available for future consumptive use in Colorado for purposes of this Study.

Hydrologic Determination Mass Balance Analysis

In addition to the CRSS model, a simulation based on the Bureau of Reclamation 2007 Hydrologic Determination (hereinafter “Hydrologic Determination”; U.S. Department of the Interior, 2007) was also used to estimate the amount of consumptive use legally available to Colorado after meeting the provisions of the Colorado River Compact. The Hydrologic Determination employed a mass balance analysis that encompassed the entire Upper Basin above the Lees Ferry gauge. Section 2.6.2 of this report provides a detailed description of the approach associated with the mass balance analysis.

The structure of the CRWAS mass balance analysis puts no limitation on physical use of water. While this may overestimate physical use, it insures that the assumed constraints arising from the Colorado River Compact are the sole limitation to water use in the Upper Basin. Because this result is more appropriate for this Study, the results from the CRWAS mass balance analysis were used as the basis for quantifying the amount of water available for consumptive use in Colorado.

Where to find more detailed information:

For more information on the CDSS development, see the Task 4.1 – *Overview of the CDSS* memorandum available on the Colorado River Water Availability link via the CWCB website (http://cwcb.state.co.us/). For summaries of the Study basin StateMod models, the Task 4.1 – *Modeling Briefs* are also available at that link. StateMod and StateCU data sets and full User Manual documentation can be downloaded, along with StateMod and StateCU executables, from the CDSS website (http://cdss.state.co.us/).

2.1.4 CDSS Model Refinement, Automation, and Testing

CDSS Model Refinement

As discussed above, the CRWAS project was able to take full advantage of the previous development of the CDSS modeling tools. The extensive CRWAS public outreach through Basin Roundtable (BRT) meetings, IBCC meetings, and modeling workshops also provided an opportunity to enhance the existing model data sets for the CDSS.

Workshops were held in conjunction with BRT meetings in the Yampa/White basin, the Colorado basin, the Gunnison basin, and the San Juan basin. The BRT workshops provided a forum to educate water users and interested parties on the CDSS models’ operations and to solicit input based on their local experience. Information was presented on StateCU and StateMod model development, model calibration, and project representation. Specific areas where a better understanding of operations or user-supplied data could improve the model were highlighted and discussed.

Prior to each BRT Workshop, basin-specific model briefs and a general “Overview of the Colorado Decision Support System” document were developed and provided for background information. The Study team presented specific information about model operations. The primary focus of these meetings was to obtain specific comments and suggestions for potential refinements to the CDSS data and models based on the participants’ knowledge of current water supply and management.

Feedback collected from each of the four BRT Workshops provided valuable insight to basin hydrology, operations, and administration. Many of the comments and suggestions received simply required clarification to help the BRT attendees better understand the model representation and operations. Several suggested refinements were common between the BRTs, resulting in twenty-nine unique refinements from the process. Several refinements to the consumptive use modeling applied to all five study basins, including revisions to maximum ditch system efficiencies and the use of a standard elevation adjustment to consumptive use results. Other suggestions were basin specific, including refinement of operations of several reservoir projects.

The recommended model refinements were categorized based on their potential effect on estimates of water available to meet future demands for the CRWAS project. Funding was available to investigate and, potentially include, twenty-two specific refinements. Based on the recommendations, StateCU historical consumptive use analyses were revised, and documented, for each study basin.

Refinements were made to each of the StateMod water resources planning models, including the inclusion of new crop irrigation requirements from the consumptive use analyses. Calibration targets for each model were reviewed and the planning models' User Manuals were updated to reflect the refinements.

Where to find more detailed information:

CRWAS outreach presentations of CDSS model review and refinement activities are provided in CRWAS Task 4.2 – *BRT Workshop Presentations* and CRWAS Task 5.2 – *BRT Workshop Presentations*, available at http://cwcb.state.co.us/.

Documentation of general background information on CDSS models and model refinement activities are provided in CRWAS Task 4.1 – *CDSS Modeling Briefs*, CRWAS Task 4.4 – *Recommended Model Refinements*, and CRWAS Task 5.3 – *Document Model Refinements* (updates to Basin Information Reports and Model User's Manuals), available at http://cwcb.state.co.us/.

StateMod and StateCU revised data sets and full User Manual documentation can be downloaded, along with StateMod and StateCU executables, from the CDSS website (http://cdss.state.co.us/).

CDSS Model Automation and Testing

Thousands of CDSS model runs were used to develop results associated with alternate historical hydrology and projected climate hydrology. The Data Management Interface tools needed to be run prior to each StateCU and StateMod model execution to generate the revised model input files, using the established CDSS standards. StateMod climate-based input files of crop irrigation requirements, headgate demands, and natural flows were re-sequenced to represent climate variability seen in the paleohydrologic record for the historical and projected climate analyses. In addition, StateMod results needed to be quickly reviewed for potential issues. Therefore, an automated procedure was developed to create new input files, to run StateCU and StateMod, and to graphically review the results.

StateCU generates crop irrigation requirement estimates for over 1,250 ditch structures and aggregated irrigation structures represented in the Colorado River Decision Support System (CRDSS) models for each month in the 1950 through 2005 study period. StateMod results for the Study basins are extensive and include simulated estimates of physically and legally available flow at more than 2,200 locations. It was necessary to identify a manageable subset of locations to view, analyze, and compare results. The following general criteria were used to select analysis locations:

- Select locations that correspond to USGS stream gages
- Include locations in each of the five study basins
- Select locations that represent total tributary runoff (locations above river confluences)
- Include locations that represent critical areas (calling rights, for example near Shoshone Power Plant or near the Grand Valley Diversions in the upper Colorado River Basin)
- Consider locations below significant transbasin diversions or reservoirs
- Include locations that overlap with locations selected for presentation in the Front Range Vulnerability Study

Using the criteria, forty-three (43) locations were selected as shown in Table 2-1and Figure 2-2. In addition, four reservoirs that provide supplemental supplies to meet irrigation demands with the Study basins were selected: Vega Reservoir, Yamcolo Reservoir, Ridgway Reservoir, and McPhee Reservoir. Water availability information at these locations is provided within this report.

Table 2-1 – Locations for Results Analysis

Study Basin	Location Description	USGS Gage ID
UPPER COLORADO	COLORADO RIVER NEAR GRAND LAKE	09011000
UPPER COLORADO	MUDDY CREEK AT KREMMLING	09041500
UPPER COLORADO	BLUE RIVER BELOW DILLON	09050700
UPPER COLORADO	BLUE RIVER BELOW GREEN MOUNTAIN RES	09057500
UPPER COLORADO	EAGLE RIVER BELOW GYPSUM	09070000
UPPER COLORADO	COLORADO RIVER AT DOTSERO	09070500
UPPER COLORADO	ROARING FORK RIVER NEAR ASPEN	09073400
UPPER COLORADO	ROARING FORK RIVER AT GLENWOOD	09085000
UPPER COLORADO	COLORADO RIVER NEAR CAMEO	09095500
UPPER COLORADO	PLATEAU CREEK NEAR CAMEO	09105000
UPPER COLORADO	COLORADO RIVER NEAR CO-UT STATE LINE	09163500
GUNNISON	EAST RIVER AT ALMONT	09112500
GUNNISON	TAYLOR RIVER AT ALMONT	09110000
GUNNISON	TOMICHI CREEK AT GUNNISON	09119000
GUNNISON	GUNNISON RIVER NEAR GUNNISON	09114500
GUNNISON	CIMARRON RIVER AT CIMARRON	09126500
GUNNISON	GUNNISON RIVER BELOW GUNNISON TUNNEL	09128000
GUNNISON	GUNNISON RIVER NEAR LAZEAR	09136200
GUNNISON	UNCOMPAHGRE RIVER AT DELTA	09149500
GUNNISON	GUNNISON RIVER NEAR GRAND JUNCTION	09152500
SAN JUAN/DOLORES	SAN JUAN RIVER NEAR CARRACAS	09346400
SAN JUAN/DOLORES	PIEDRA RIVER NEAR ARBOLES	09349800

SAN JUAN/DOLORES	LOS PINOS RIVER AT LA BOCA	09354500
SAN JUAN/DOLORES	FLORIDA RIVER AT BONDAD	09363200
SAN JUAN/DOLORES	ANIMAS RIVER NEAR CEDAR HILL, NM	09363500
SAN JUAN/DOLORES	LA PLATA RIVER AT HESPERUS	09365500
SAN JUAN/DOLORES	LA PLATA RIVER AT CO-NM STATE LINE	09366500
SAN JUAN/DOLORES	MANCOS RIVER NEAR TOWAOC	09371000
SAN JUAN/DOLORES	MCELMO CREEK NEAR CO-UT STATE LINE	09372000
SAN JUAN/DOLORES	DOLORES RIVER NEAR BEDROCK	09171100
SAN JUAN/DOLORES	SAN MIGUEL RIVER AT NATURITA	09175500
YAMPA	YAMPA RIVER BELOW STAGECOACH RES	09237500
YAMPA	ELK RIVER AT CLARK	09241000
YAMPA	ELKHEAD CREEK NEAR ELKHEAD	09245000
YAMPA	WILLIAMS FORK AT MOUTH, NEAR HAMILTON	09249750
YAMPA	YAMPA RIVER NEAR MAYBELL	09251000
YAMPA	LITTLE SNAKE RIVER NEAR LILY	09260000
YAMPA	YAMPA RIVER AT DEERLODGE PARK	09260050
WHITE	NORTH FORK WHITE RIVER AT BUFORD, CO	09303000
WHITE	SOUTH FORK WHITE RIVER AT BUFORD	09304000
WHITE	WHITE RIVER BELOW MEEKER	09304800
WHITE	PICEANCE CREEK AT WHITE RIVER	09306222
WHITE	WHITE RIVER NEAR CO-UT STATE LINE	09306395

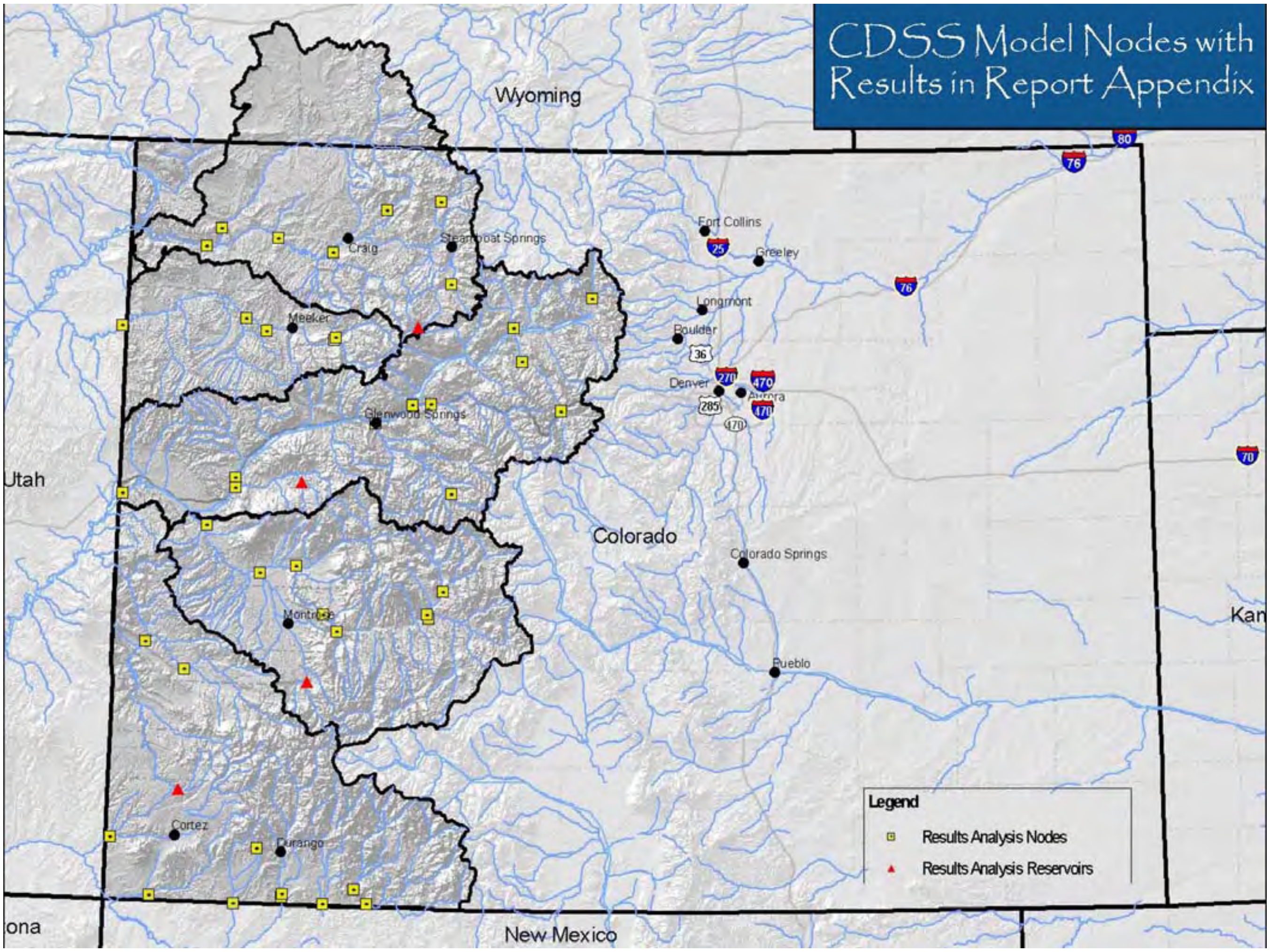

Figure 2-2 – Locations for Results Analysis

An automated data-centered approach was developed that incorporated projected temperature, precipitation, and natural flow data associated with the climate projections into the StateCU and StateMod input. To incorporate the information from the paleohydrologic record, the automated approach included re-sequencing of climate-based input files. Figure 2-3 graphically shows the five steps associated with incorporating climate projection into the CDSS models.

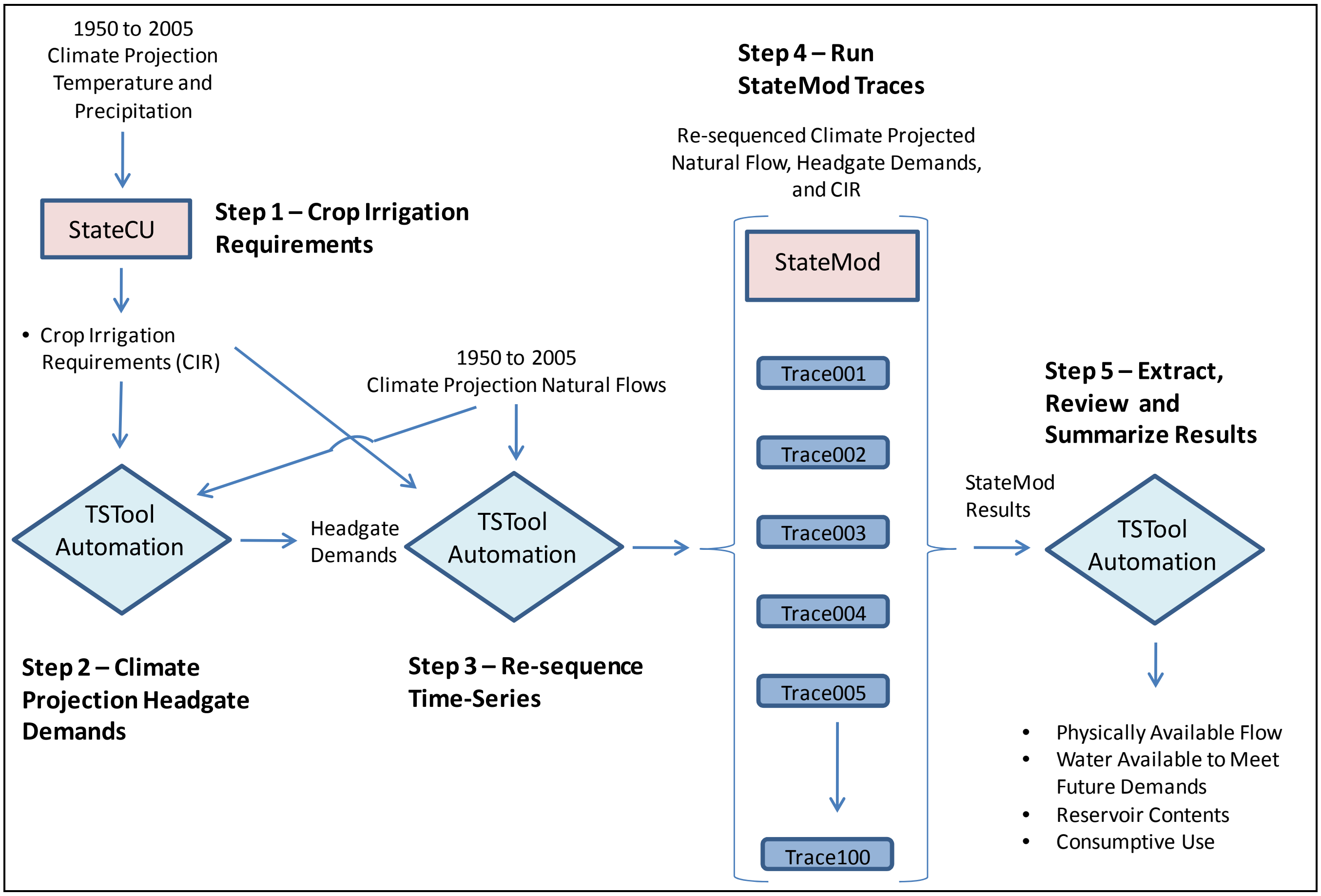

Figure 2-3 – Steps to Develop and Analyze Climate Projection Traces

Step 1 incorporated the ten climate projection alternate temperature and precipitation data sets into the StateCU consumptive use analysis to determine crop irrigation requirements “as-if” the projected climate conditions had been fully realized in 1950 and Colorado again experienced the 1950 through 2005 climate variability. The CDSS Data Management Interface, TSTool, was used in Step 2 to estimate headgate demand for the StateMod analyses. Step 3 automated the re-sequencing of the climate-related input files (CIR, headgate demands, and natural flows) to generate 100 traces for each study basin model that incorporated additional climate variability seen in the paleohydrologic record. Step 4 automated the StateMod execution of each study basin model for each trace. Finally, Step 5 extracted the results and the selected locations so they could be reviewed and summarized.

The steps incorporated the data-centered command approach, that included instructions for TSTool and execution of StateMod, automated using a simple DOS “batch file” approach. This alleviated the need for extensive staff time to “start” the process for each climate projection and each StateMod trace execution.

Review of the model simulation output files showed that the StateMod code simulated correctly. The 1,100 model simulations for each of the five study basins ran successfully through the full 56 year period (1,100 = 100 traces for historical climate conditions and 100 for each of ten climate projections). Review of the model results proved that each model maintained mass balance. In addition, review of reservoir operations indicated that current operations represented in each of the models are appropriate for Phase I. The automation approach, and the use of multiple computers, allowed for the scenarios to be completed in about 170 hours (24 hours a day for 7 days) without the need for more sophisticated hardware.

Where to find more detailed information:

For more information on the CDSS Automation, see the Task 6.6 / 7.11 – *CDSS Automation, Testing, and Application* memorandum available on the Colorado River Water Availability link via the CWCB website (http://cwcb.state.co.us/).

2.2 Historical Hydrology

Together, the historical natural flows and the observed weather are the data that are used to represent the historical hydrologic conditions and are referred to as the "historical hydrology". The historical hydrology serves as the basis for the development of extended hydrologic data that reflect the more extreme droughts and wet spells contained in the prehistoric record of tree rings, and adjusted hydrologic data that reflect the impact of projected future climate. All of the CRWAS water availability analyses have been anchored to historical natural flows: For the five study basins these are the CDSS naturalized flow (baseflow) data; for the Colorado River Basin as a whole, these are the CRSS natural flow data. The historical period was defined to be the period from 1950 through 2005. This period was determined by the availability of the gridded observed weather data that are required for hydrology modeling.

The CDSS naturalized flow data are available for 227 locations in the Study basins; the CRSS natural flow data are available for 29 inflow points throughout the Colorado River Basin. CDSS weather data are available at 54 weather stations within the Study basins. Gridded weather data are available at 4,518 grid points throughout the Colorado River Basin.

2.3 Alternate Historical Hydrology

The State's Request for Proposals for the Study called for the development of a method to use information from prehistoric tree-ring records to extend observed records of flows (i.e., to develop an "alternative historical hydrology") consisting of at least 100 traces, each 50 to 100 years in length. Collectively, such a set of traces is referred to as an "ensemble" of traces.

The water resources models used in the Study are the Bureau of Reclamation's CRSS model and the State of Colorado's StateMod model, part of the CRDSS. The CRDSS and CRSS models (as used in the Study) require monthly inflows. The CRSS model requires monthly inflows at 29 inflow points throughout the basin while the CRDSS StateMod models to be used in the Study require monthly flows at 227 natural flow (baseflow) gage points throughout the Study basins. Thus, the method that is adopted to extend flow records had to be capable of generating traces of monthly flows at two different levels of spatial detail throughout the Colorado River Basin.

Information from the tree-ring records was also used to extend the data set that represents conditions during the observation period that reflect the development of climate change (the climate-adjusted observed flows). This was done because there is evidence in the literature describing climate modeling to indicate that in some locations global climate models (GCMs) do not reliably replicate the year-to-year variability of climate and therefore hydrology.

The approach used to extend historical hydrology is described in this section. The same method is used to extend climate-adjusted streamflows, the development of which is described in Section 2.4.5.

2.3.1 Resequencing Historical Hydrology

The overall context for extension of flows using paleohydrology is illustrated using Figure 2-4, a chart showing paleohydrologic reconstructed annual streamflow for the period 1490-1997 on the Colorado River at Lees Ferry, AZ, (Woodhouse et al., 2006), along with the naturalized observed flows at that site. The observation period in Figure 2-4 extends from 1906 through 2005, while the pre-observation period extends from 1490 until 1905. The period over which tree-ring chronologies overlap observed flows extends from 1906 through 1997 and is referred to as the overlap period. The reconstructions are based on a functional relationship, typically a linear regression, between tree-ring chronologies and the streamflows (e.g., Stockton, 1975; Stockton and Jacoby, 1976, Meko et al., 2007), developed over the overlap period, which is then used to estimate flows during the pre-observation period.

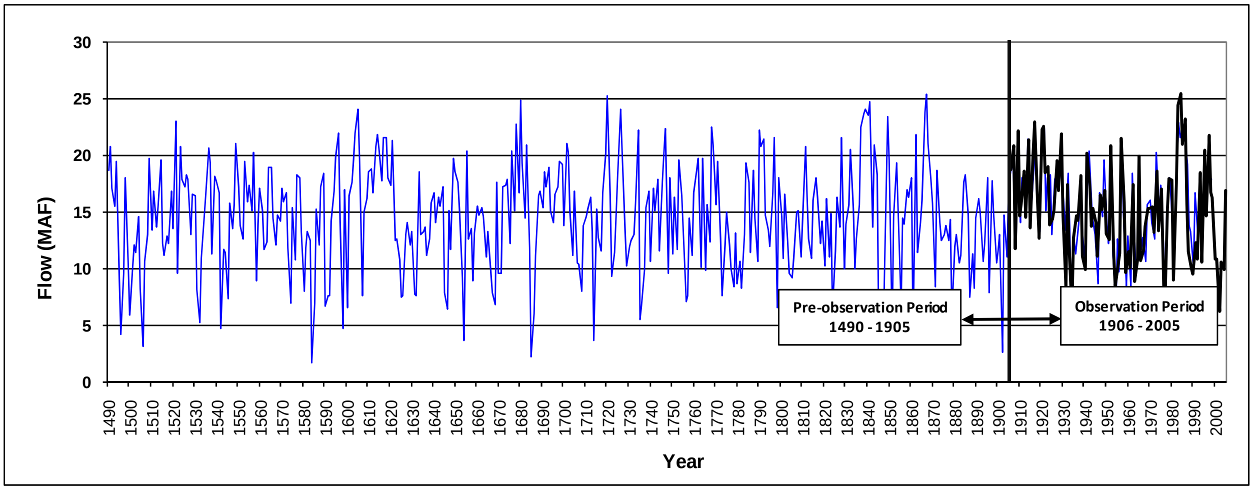

Figure 2-4 – Reconstruction of Colorado River Annual Flow at Lees Ferry

In the linear regression approach, a suite of trees are cored to obtain a record of tree-ring widths, which are corrected for physiological and other biases to obtain tree-ring growth indices[2]. Tree-ring growth indices for many trees at one site are typically aggregated (usually by averaging) into a chronology, which contains a single index value for each year in the chronology. A stepwise regression approach is used to select the best subset of tree-ring chronologies, based on the ability of that subset to predict streamflows at a specified location, and a multiple linear regression (MLR) model is fitted to the observed streamflow. This MLR model is then used to estimate streamflows during the pre-observation period using tree-ring chronologies. Variations of this basic approach have been proposed[3].

[2] Trees actually add a *volume* of new growth each year and that volume varies depending on environmental conditions and other factors such as disease. As the tree diameter increases, a given volume of growth will be contained in a thinner ring. Thus, this geometric effect must be accounted for in the creation of tree-ring indices. Other effects also require compensation, such as autocorrelation caused by physiological factors such as energy storage.

[3] For instance, Hidalgo et al., (2000) used the MLR approach on the Principal Components (PC) of the tree-ring indices. The reconstructions in this approach are sensitive to the number of PCs retained, as shown by Hidalgo et al. (2000) in their comparison with traditional MLR-based reconstructions.

These reconstruction techniques, applied to the suite of available tree-ring information, capture very well the variability of the observed flow (i.e. what years are wet or dry), but the flow magnitudes generated by these techniques differ from one reconstruction to another in the pre-observation period. This can be seen in seven reconstructions of Lees Ferry flows (Stockton and Jacoby, 1976; Hidalgo et al., 2000, Woodhouse et al., 2006) shown in Figure 2-5.

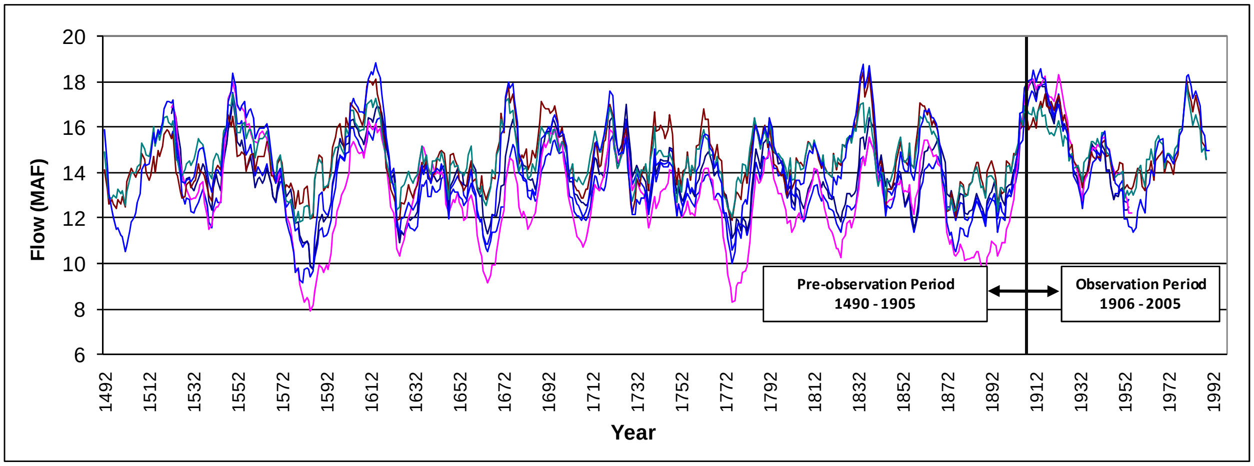

Figure 2-5 – Seven Reconstructions of Colorado River Annual Flow at Lees Ferry

The divergence of streamflows among the various reconstructions during the pre-observation period is due to the use of different reconstruction calibration techniques, different tree-ring data treatment, different tree-ring data, and different gage data (both the years used and the hydrologic time series itself) for the calibration. All of these are potential sources of the differences, and these differences should be expected. The fact that these different reconstructions show coherent wet and dry periods is a testament to the robustness of the hydroclimatic signal in the trees.

In recent years several statistical methods have become available that obtain information regarding the sequence of wet and dry states from the tree-ring record and sample flow magnitudes from the observed records.[4] For a more complete description of these methods the reader is referred to Gangopadhyay et al. (2008) and references contained therein.

Where to find more detailed information:

A literature review and evaluation of approaches for extending historical and climate adjusted hydrology are described in detail in CRWAS Technical Memorandum Task 6.1 / 6.2 / 6.3 – *Literature Review and Method Evaluation, Analyses of Tree-Ring Data, Recommendation for Extending Historical Hydrology*., available at http://cwcb.state.co.us/.

A method developed by Prairie et al. (2008) was determined to be well-suited for creating input data sets for complex water resources models and was adopted for use in the Study. This approach was adopted for several reasons. Most importantly, it was the most effective and cost effective method for

[4] A year is said to be in a "wet" state if its annual flow is equal to or greater than a threshold flow, often the mean or median flow. A year is said to be in a "dry" state if its annual flow is less than the threshold flow.

blending drought intensity-duration-frequency information from the paleo record with the impact of projected climate, and it is the only available method that can maintain the correlation between water use estimates and flows. In addition, the method has considerable credibility from its use in the recent model studies used in developing guidelines for Lower Basin shortages and coordinated operations for Lake Powell and Lake Mead on the Colorado River (Lower Colorado River Guidelines, Reclamation, 2007).

Prairie et al. (2008) used the information in the tree-ring chronologies to construct a stochastic model of annual sequences that was in turn used to construct traces of streamflows to be used as model input. A stochastic model is one that is driven by probabilities, and in this case, the probability of a particular year being used in a particular position in a sequence is based on information contained in the prehistoric tree ring record.

This type of re-sequencing approach does not model the individual flow magnitudes, but instead arranges years from the observation period in sequences that are statistically consistent with the information about hydrologic conditions (i.e. wet or dry year) contained in the tree-ring chronologies. In the first application of this method, for the Lower Colorado River Guidelines, sequences of annual flows at Lees Ferry were developed and subsequently disaggregated for use in the CRSS model. However, traces of any type of input data that is associated with an historical year, including complex, structured data, can be constructed using this approach. This allows a trace of monthly model input data to be constructed by re-sequencing the historical monthly input data one year at a time (including all monthly inflow data for all inflow points in a model) according to the order of years in a sequence.

A year is selected and all monthly data for all inflow points are used. For example, when building a trace of inflow data for the CRDSS models, if a sequence contains the year 1964, the monthly model input data for all 227 base flow points for 1964 would be appended to the input data set. This flexibility also allows the method to be used to extend climate-adjusted streamflows, historical and climate-adjusted weather, and historical and climate adjusted water use, so long as those data can be associated with an historical year.

Where to find more detailed information:

The details of the re-sequencing method, a technical description of the process and references to the relevant literature is provided in CRWAS Technical Memorandum Task 6.4 – *Methods for Alternate Hydrology and Water Use* available at http://cwcb.state.co.us/.

Table 2-2 and Figure 2-6 illustrate the results of re-sequencing. Table 2-2 shows 15-year portions of the historical sequence (1950-1964) and five sequences of years generated by the stochastic model used to extend historical hydrology. (For readability, only 15-years of each 56-year sequence are shown.) Note in Table 1 that years are sometimes used more than once in a single sequence, and can sometimes follow in sequence, e.g. 2004 is used in positions 12 and 13 in Sequence 2.

Table 2-2 – Year Sequences

Sequence Position	Historical Record	Sequence 1	Sequence 2	Sequence 3	Sequence 4	Sequence 5
1	1950	1955	1992	1971	1976	1993
2	1951	1965	1955	1979	1954	1963
3	1952	1980	1956	1963	1957	1977
4	1953	1994	2003	1977	1998	2001
5	1954	1965	1995	1973	1983	1977
6	1955	1983	1994	1983	1994	1955
7	1956	1984	2004	1985	1961	1956
8	1957	1971	1960	2000	1991	1968
9	1958	1994	1995	1969	1992	1995
10	1959	1954	1994	1997	1962	1996
11	1960	1956	2001	1976	1972	1972
12	1961	1977	2004	1977	1993	1952
13	1962	2003	2004	1964	1996	1953
14	1963	2004	1991	2002	1997	2001
15	1964	1961	1992	1978	1953	1991

Figure 2-6 shows the year sequences in Table 2-2 converted into flow traces by replacing the historical year designation with the magnitude of flow from that historical year. The Historical Trace is the historical record of natural flows (in this case, at Lees Ferry Arizona on the Colorado River). The five traces from the extended historical hydrology all contain only annual flows from the Historical Trace. Figure 2-6 shows the entire 56-year period for each trace.

Trace	Historical Trace	Trace 1	Trace 2	Trace 3	Trace 4	Trace 5
Mean Flow	14.26	15.62	14.56	13.01	16.02	13.16

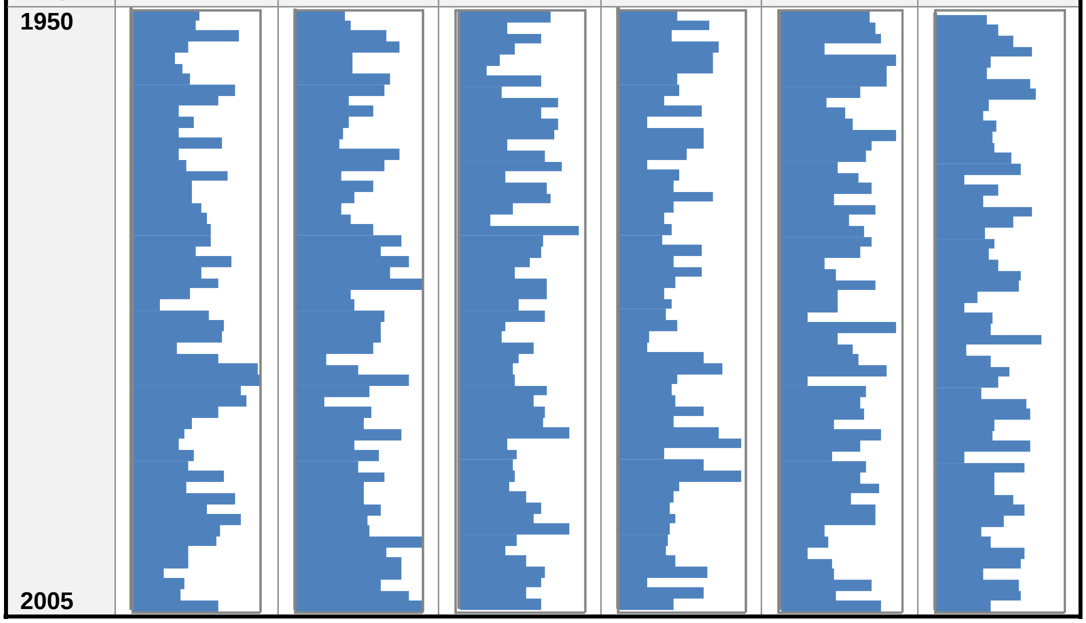

Figure 2-6 – Flow Traces

Figure 2-6 shows the mean flow over each 56-year trace just above the graphic representation of the trace. Mean flows vary significantly depending on the relative number of wet and dry years in the year sequence. If all of the years in the historical record were to be used in a trace the mean of the trace will always equal the mean of the historical record, regardless of the order in which the years/flows occur. Why the means differ from trace to trace is explained by examining the extent to which years recur or are omitted in the sequences shown in Table 2-2.

The value of using information from the paleo-record is that it describes droughts and wet spells more intense and of longer duration than those in the historical record. Trace 3 has a mean flow over the entire 56-year period that is more than one million acre-feet lower than experienced from 1950 through 2005. Trace three also has more severe dry periods than does the historical period: The driest ten-year period in the historical record is about 12.4 MAF while the driest ten-year period in Trace three is 10.8 MAF. Trace 3 contains three independent ten-year periods that are nearly one million acre-feet drier than the driest ten-year period in the historical trace.

Figure 2-6- shows only annual flow magnitudes, but the re-sequencing method as applied in the Study is used to assemble time-series of complex model input. For example, a trace of model input data for CRSS would be constructed from Sequence 1 by starting the trace with the entire CRSS data set (for 29 inflow points) for the year 1955. The trace would be extended to the second year by adding the entire data set for 1965, followed by the data for 1980, and so on until a full 56-year trace had been constructed. A similar approach is used for assembling input data for the CRDSS models, including water use data developed by the StateCU model.

2.3.2 Statistical Analysis of Alternate Historical Hydrology

Statistical diagnostic analyses were conducted to characterize the nature of the alternate historical hydrology by comparing the statistical characteristics of the alternate historical hydrology with the statistical characteristics of the historical hydrology[5].

The measures selected for comparing statistical characteristics of alternate historical hydrology and historical hydrology fall into two major categories, the statistics of the distribution of annual flow volumes and the statistics of wet and dry spells. The former helps to understand the frequency with which a single dry (or wet) year may occur, while the latter help to understand the frequency with which a drought (or wet spell) may occur. As described above, information about the magnitudes of annual flows comes from the historical flow record, while information about the sequence of annual flows comes from the paleohydrologic flow record. Accordingly, we expect that the mean of the alternate historical hydrology will be similar to the mean of the historical hydrology. The means of the two records (historical and paleo) will differ if the paleo record indicates that the relative frequency of dry versus wet years is different than that experienced in the historical period.

Where to find more detailed information:

A detailed description of methods and results of testing StateCU and StateMod, and describing any changes made to StateCU and StateMod to accommodate alternate flows is provided in CRWAS Task 6.6 / 7.11 – *CDSS Automation, Testing, and Application*, available at http://cwcb.state.co.us/.

CRWAS Task 6.7 – *Summarize Alternate Historical Hydrology* technical memo is available at http://cwcb.state.co.us/.

2.4 Climate Change Hydrology

Global Climate Model (GCM) projections of future climate over a multi-decadal time frame indicate that the Colorado River basin will become warmer. Temperatures in Colorado are projected to increase by 2.5º F by 2025 and 4º F by 2050 (Ray et al., 2008). Projections of future precipitation are more complex, with the multi-model average of projections showing little change in annual precipitation, but generally showing a seasonal shift in the temporal pattern of precipitation. Changes in temperature and precipitation will influence hydrologic processes on the land surface, which in turn will cause changes in streamflows (Hayhoe et al., 2004; Barnett et al., 2005; Maurer, 2007). The objective of CRWAS is to provide quantitative estimates of the impact of projected change in climate on streamflows, water use and water availability to Colorado water rights.

Figure 2-7 depicts the analysis process required to make quantitative estimates of impacts to water resources from projected changes in climate.

[5] Statistical diagnostic analyses are also used to validate the reliability of a model or method; such validation analyses were completed by the developers of the Non-Homogeneous Markov Chain model (NHMC model) that was used to develop the alternate historical hydrology, and are reported in Prairie, et al. (2008).

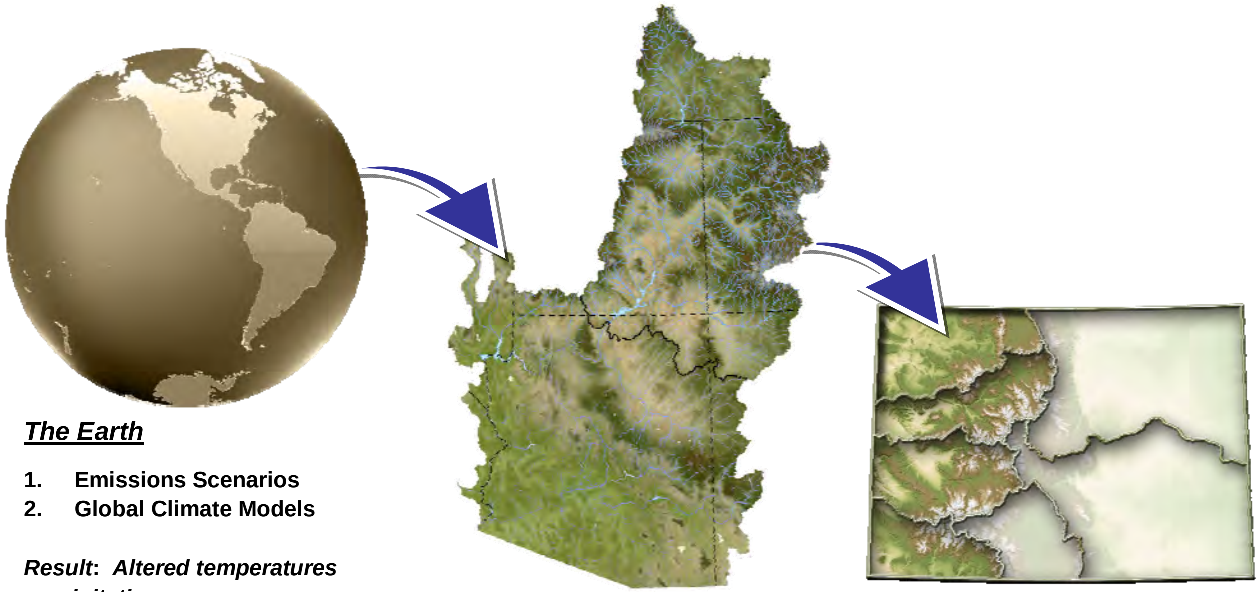

Figure 2-7 – Climate Change Modeling Approach

The process begins with the development of scenarios of future emissions of greenhouse gases (Step 1 in Figure 2-7)[6]. These emission scenarios are used to drive a global climate model (GCM)[7] that simulates future conditions in the Earth's atmosphere and on its surface (Step 2). GCMs estimate atmospheric and surface conditions in a three-dimensional grid with a resolution of approximately two hundred miles per side; each grid cell covers an area of approximately 40,000 square miles. The problems with this coarse resolution are that it does not represent very well the mountainous terrain in Colorado, and the scale of the grid cells is very large compared to the scale of the watersheds that supply water within Colorado. Therefore, a downscaling step is required to translate the outputs from GCMs to a scale that is useful for hydrologic modeling in Colorado (Step 3). The downscaled GCM output (usually projections of temperature and precipitation) are then used to drive a hydrologic model to estimate the impact of climate change on streamflows (Step 4). Information about long-term drought that is determined from paleohydrology is blended with the information about climate change impacts to streamflows to generate sequences of flows at many points in the Study area (Step 5) and these in turn are used to drive water resources planning models to determine water availability (Step 6).

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[6] Carbon dioxide is the best-known greenhouse gas, but methane and nitrous oxide also contribute to the greenhouse effect.

[7] Global climate models were originally called *generalized circulation models*, but this terminology, though still in use, has recently become less common.

The Study developed an alternate hydrology of climate change that includes estimates of streamflow and estimates of water use that would result from projected future climate conditions. Information from tree-ring records was combined with information from climate projections so that the resulting alternate hydrology of climate change also reflected the less frequent but more intense droughts and wet spells captured in the prehistoric record of tree rings. The elements of the approach used to develop the alternate hydrology of climate change correspond to Steps 4 and 5 in Figure 2-7 and are illustrated in Figure 2-8.

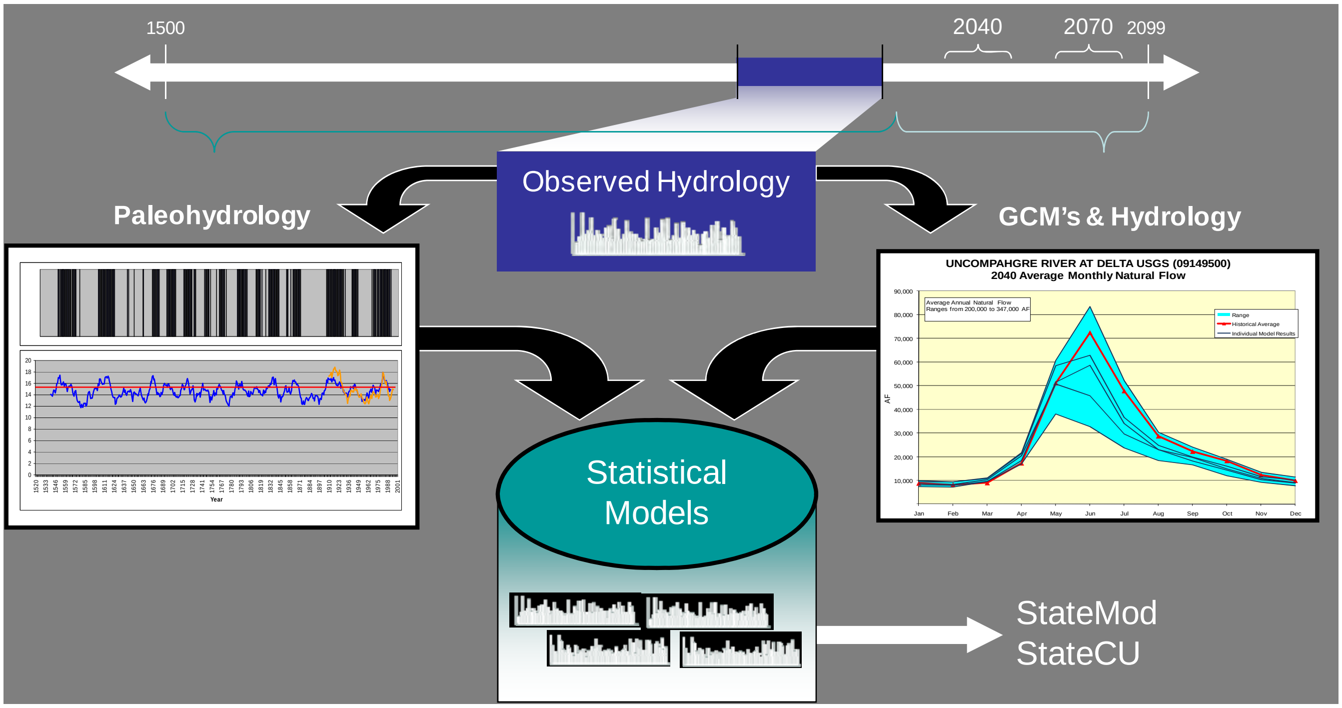

Figure 2-8 – Approach to Developing Alternate Hydrology of Climate Change

All of the hydrology utilized in the Study is anchored to an observed period that runs from 1950 through 2005. (The selection of this period is explained in Section 2.4.3.) The observed hydrology includes natural flows and observed weather (temperature, precipitation and wind). Statistical models were used to adjust the observed hydrology based on information about the occurrence of droughts and wet spells obtained from tree ring records (paleohydrology) and information from global climate models (GCMs) about the impact of projected climate on average streamflows and the shape of the annual hydrograph. The resulting set of climate-adjusted hydrology—weather (see Section 2.4.3), water use (see Section 2.4.4) and streamflows (see Section 2.4.5)—was used in analyses of water availability that employed the StateMod and StateCU models in the Colorado River Decision Support System (CRDSS), Step 6 in Figure 2-7.

Where to find more detailed information:

CRWAS Task 7.5 – *Climate Change Approach* technical memo is available at http://cwcb.state.co.us/.

2.4.1 Coordination with FRCCVS and CCTAG

A second study of climate change impacts, the Front Range Climate Change Vulnerability Study (FRCCVS) proceeded contemporarily with the CRWAS. The FRCCVS is a cooperative effort among six front-range water providers and the CWCB. The CWCB directed that the CRWAS coordinate its efforts with the FRCCVS to help assure that the two studies are as cost effective as possible, to maximize consistency and comparability of results (while remaining consistent with the different objectives of each study) and to maximize the technical value of the two studies to their respective stakeholders. In addition, the CWCB directed that the CRWAS would review the Study approach and results with the Colorado Climate Change Technical Advisory Group (CCTAG). The most important elements of these coordination activities involved a review of the proposed CRWAS technical approach that occurred before the Study Scope of Work was finalized, selection of the time frames at which future climate would be characterized, and selection of the climate projections to be used to characterize the future time frames.

For the first step in coordination between the CRWAS and the FRCCVS, prior to the development of the detailed technical scope of work for the CRWAS, an outline of the technical approach suggested by CRWAS for use in characterizing climate-adjusted hydrology was provided to the FRCCVS and the CCTAG. A joint meeting of members of the CRWAS technical team, the FRCCVS technical team and stakeholders, and the CCTAG was held to address the technical validity of the approach being considered by CRWAS and its consistency with the approach being considered by the FRCCVS. The joint review identified areas in both the CRWAS and FRCCVS study approaches where refinements would provide benefits in terms of technical reliability and consistency between the two studies.

The most significant coordination between the FRCCVS and the CRWAS involved selection of time frames at which future climate would be characterized and selection of the climate projections to be used to characterize the future time frames. At the time that the CRWAS began its efforts to develop its approach the FRCCVS had already identified two time frames for characterization of future climate, 2040 and 2070, to be characterized by average conditions over the periods 2025-2054 and 2055-2084, respectively. These two time frames were acceptable to the CCTAG, and were therefore adopted by the CRWAS. Selection of the climate projections used to characterize the future time frames is described in Section 2.4.2.

Where to find more detailed information:

Coordination between the FRCCVS and CRWAS continued during the course of the two studies; details of those coordination activities are described in CRWAS Technical Memorandum Task 7.1 – *Coordination with Front Range Vulnerability Study*, available at http://cwcb.state.co.us/.

2.4.2 Selection of Downscaled Climate Projections

A climate *projection* is the output of one run of a GCM using a specific set of initial and boundary conditions and a specific set of input data. For practical purposes, the climate projections available to FRCCVS and CRWAS were those in an archive created and maintained by a joint effort of the Lawrence Livermore National Laboratory (LLNL), the Bureau of Reclamation and Santa Clara University (SCU) (LLNL-Reclamation-SCU, 2008). The LLNL-Reclamation-SCU archive contains 112 projections created using 16 different climate models and three different emission scenarios.

Where to find more detailed information:

The Colorado Water Conservation Board asked the Western Water Assessment to develop a report that synthesized information about climate change that was relevant to Colorado. That report, *Climate Change in Colorado, A Synthesis to Support Water Resources Management and Adaptation* (Ray et al., 2008), provides a great deal of valuable information about Colorado's climate, climate science, and projected climate conditions in Colorado. It provides particularly valuable descriptions of greenhouse gas emission scenarios and global climate models (http://cwcb.state.co.us/).

Climate Models (GCMs)

A GCM is a mathematical model of the Earth's atmosphere and its interaction with the ocean and land surface. Global climate models are used for weather forecasting and projecting climate change. In the latter application, they provide estimates of future conditions that reflect the levels of greenhouse gas emissions.

Emission Scenarios

Projections of future changes in climate attributed to human activity rely on projections of future concentrations of greenhouse gases (GHG), which in turn depend on current concentrations and future rates of GHG emissions. GHG emissions depend, in complex ways, on socio-economic development, technology, demographics and politics. The Intergovernmental Panel on Climate Change (IPCC) has developed a number of "storylines" of future global conditions, which are used as the basis for estimates of future GHG emissions. These storylines are documented in the Special Report on Emissions Scenarios (SRES) and are often referred to as SRES scenarios. IPCC did not assign a likelihood to the SRES scenarios—all are considered equally probable "alternative images of how the future might unfold" (Nakicenovic et al., 2000, Technical Summary). From the four SRES scenario "families" (A1, A2, B1, B2), only the B1, A1B (a member of the A1 family) and A2 scenarios have been used as the basis for projections on many GCMs. These have come to be known, respectively, as the "low", "medium" and "high" emissions scenarios, based on their impact on climate conditions in the year 2100[8].

Downscaling

GCM output is available in grid scales that range from about 100 to about 200 miles square (10,000 to 40,000 square miles) a substantial fraction of the area of western Colorado. While one GCM grid cell covers from 10,000 to 40,000 square miles, a substantial mountain watershed might cover several hundred to a thousand square miles, and many tributaries drain considerably smaller areas. Before GCM output can be used for analysis of local conditions, or for local hydrologic modeling, it must go through a process called downscaling, which relates the large scale GCM data to detailed terrain and observed climate conditions. GCM projections contain bias, which is exhibited as systematic error in replicating observed conditions, and these biases are usually removed during downscaling in a process called bias correction.

FRCCVS and CRWAS used statistically downscaled and bias-corrected data developed jointly by the Bureau of Reclamation, Santa Clara College and the Lawrence Livermore National Laboratory (LLNL-

[8] The impacts of different GHG emissions scenarios do not begin to diverge substantially until roughly 2050.

Reclamation-SCU archive) (WCRP CMIP3, 2008). These data have been placed in a readily available archive that contains downscaled output for 112 projections of future climate based on 16 GCMs and the B1, A1B and A2 emission scenarios. The LLNL-Reclamation-SCU archive has been developed using peer reviewed methods (Maurer et al., 2002) and is currently being used by the Bureau of Reclamation for climate change impact analyses.

Selection of Projections

GCMs differ in their simulation approach and their degree of sophistication, and different runs of a particular GCM using the same SRES scenario may differ in how they are initialized. A particular run of a GCM using a particular SRES scenario and a particular set of initial and boundary conditions is referred to as a projection. No two projections will be the same, and there can be substantial differences among multiple projections from the same GCM and based on the same SRES scenario. For consistency between FRCCVS and the CRWAS both studies used the same projections. After consultation between the FRCCVS and CRWAS technical teams, FRCCVS adopted an approach for selection of projections that is described here. Five qualitative future climate scenarios were defined as follows:

- Hot and Dry
- Hot and Wet
- Warm and Dry
- Warm and Wet
- Median

For each future time frame, a projection was selected for each of the five qualitative scenarios. The selected projections were intended to cover 80% of the overall range of climate change represented by the entire set of 112 projections. For each of the five qualitative scenarios, a characteristic value of change in temperature and precipitation was determined as shown in Table 2-3.

Table 2-3 – Characteristic Temperature for Qualitative Future Climate Scenarios

Qualitative Scenario	Characteristic Temperature	Characteristic Precipitation
Hot and Dry	90th Percentile[9]	10th Percentile
Hot and Wet	70th Percentile	70th Percentile
Warm and Dry	30th Percentile	30th Percentile
Warm and Wet	10th Percentile	90th Percentile
Median	50th Percentile	50th Percentile

[9] *Percentile* is the same as *relative position*, and both terms refer to the position of a particular measurement, such as a temperature or an amount of precipitation, in a sorted list that contains all values of that measurement. Typically, percentiles and relative position are expressed relative to the smallest value, so the 90th percentile is the value that is 90% of the way from the smallest value to the largest value, in terms of the number of values. For example, if there are about 100 values, the 90th percentile would be at about the 90th value counting from smallest to largest.

Figure 2-9 illustrates the characteristic conditions for the qualitative scenarios in the context of all 112 projections of future temperature and precipitation. Each projection is designated as a triangle, and the characteristic conditions for the five scenarios are designated by the.

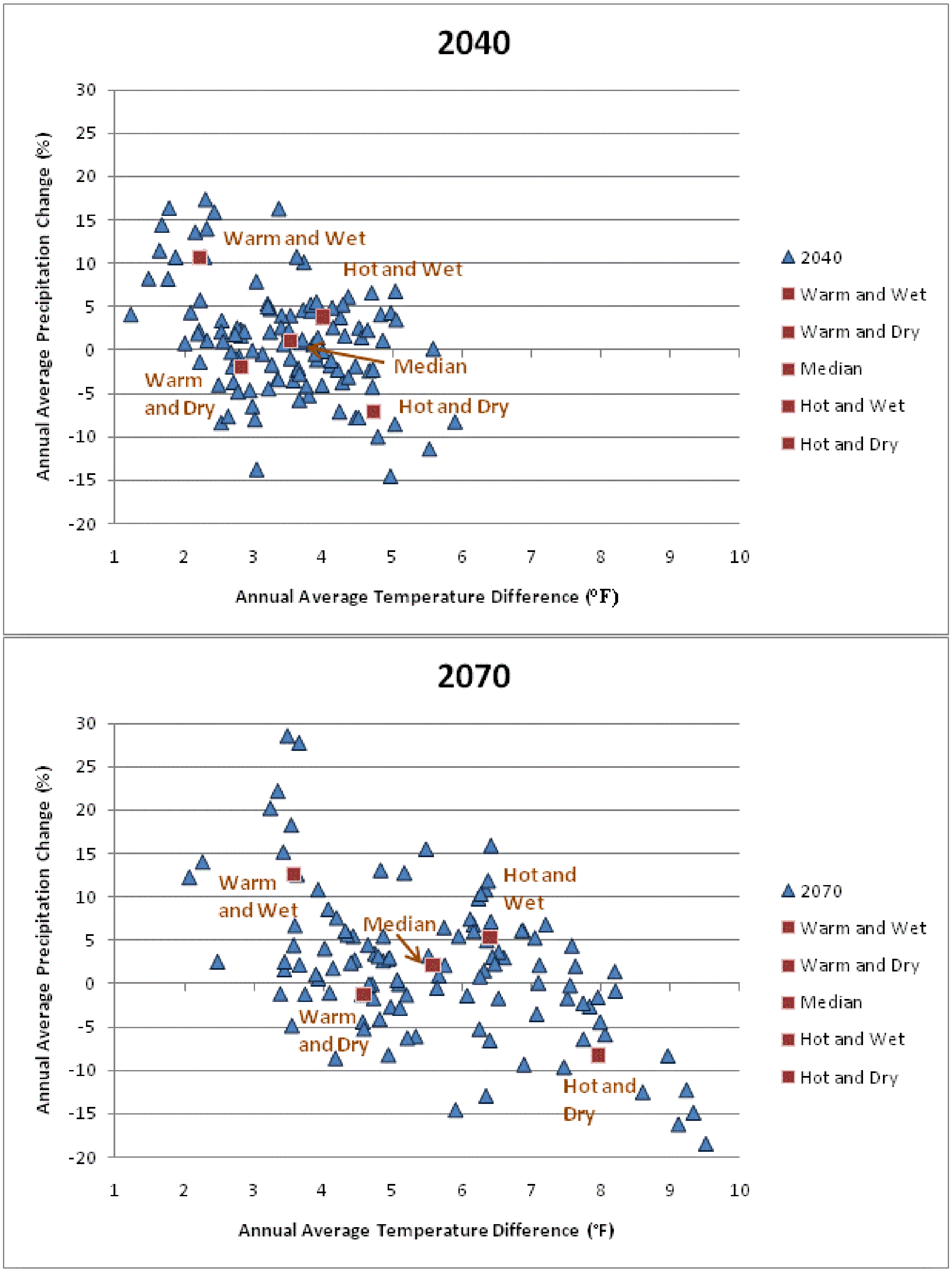

Figure 2-9 – Annual Temperature and Precipitation Changes for 112 individual GCMs with Idealized Qualitative Scenarios as compared to 1950-1999 annual averages (Woodbury, et al., 2010)

For each of the two time frames, five projections were selected based on their proximity to the characteristic values for the five scenario points and based on how similar their monthly pattern precipitation change is to other projections near the characteristic values. The projections used are shown in Table 2-4.

Table 2-4 – Selected Projections

Qualitative Scenario	Time Frame	SRES Scenario	Model	Version	Run
Warm & Wet	2040	A2	ncar_pcm	1	3
Warm & Dry	2040	A2	mri_cgcm	2.3.2a	1
Median	2040	B1	cccma_cgcm	3.1	2
Hot & Wet	2040	A1B	ncar_ccsm	3.0	2
Hot & Dry	2040	A2	miroc	3.2.medres	1
Warm & Wet	2070	A2	ncar_pcm	1	3
Warm & Dry	2070	A1B	mri_cgcm	2.3.2a	4
Median	2070	B1	mpi_echam	5	1
Hot & Wet	2070	A1B	ncar_ccsm	3.0	2
Hot & Dry	2070	A1B	gfdl_cm	2.0	1

Analysis of Selected Projections

As described above, climate projections used by CRWAS and FRCCVS were selected to represent conditions at each of two future time frames based on each projection’s change in temperature and precipitation. At the time projections were selected, the CRWAS and FRCCVS technical teams did not have information about the relative change in overall hydrologic conditions that would result from these projected changes in climate and how those projected changes would fit into the context of all of the 112 available projections. Subsequently, that information became available and that allowed an analysis of how well the selected projections represent each of the time frames.

That analysis was conducted by comparing for each time frame the selected projections against the entire set of available projections using as a measure of climate impact the estimated change in streamflow for the Colorado River below Glenwood Springs. Figure 2-10 shows a comparison of the entire set of 112 projections for both the 2040 and 2070 time frame.

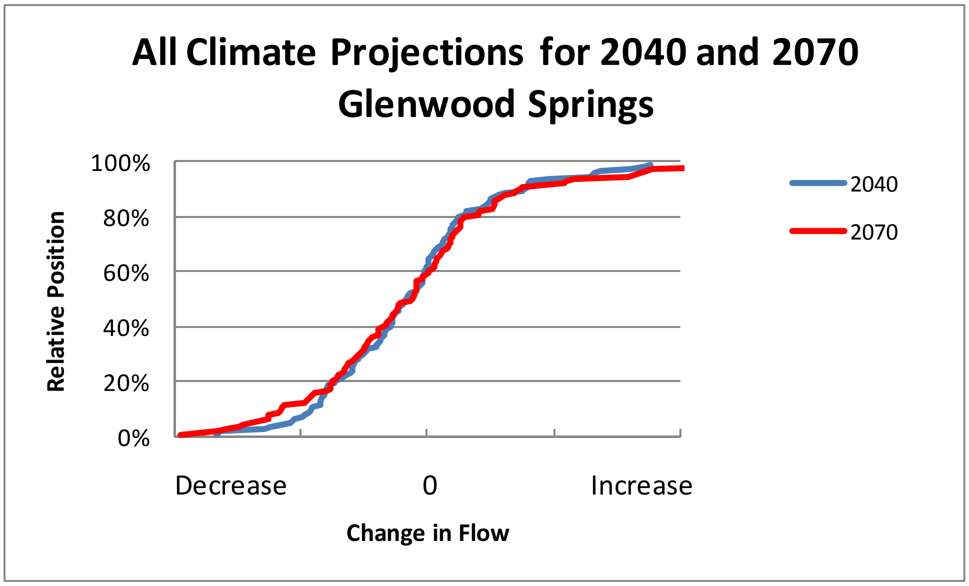

Figure 2-10 – Comparison of Relative Impact on Flow at Glenwood Springs All 2040 and 2070 Projections

Figure 2-10 is a *cumulative distribution function*, which is simply a plot of all the projections sorted from smallest to largest, in terms of projected change in natural flow. The projection with the largest decrease is first in the list (the largest decrease is the most negative number and thus the smallest number). The projection with the largest increase in flow will be last on the list. Magnitudes of change in flow are plotted along the horizontal axis. The relative position of each projection, expressed as a percent of the distance from the lowest flow to the highest flow, is plotted along the vertical axis.[10] Figure 2-10 shows that the projected impacts on natural flow in 2040 and 2070 are similar except in approximately the driest 20% of the projections.

The modeled streamflows that form the basis for Figure 2-10 and the following figures were developed as part of a separate analysis of climate change impact that has different objectives than CRWAS and that uses different methods. Nevertheless, those modeled streamflows are internally consistent and therefore provide a basis from which to illustrate the relationship, in terms of hydrologic impact, of the projections used for CRWAS to the entire set of 112 projections.

[10] Standard practice is to calculate the relative position in such a way that no value will be at exactly zero or exactly100%.

Figure 2-11 illustrates the distribution of the projections selected to represent the 2040 time frame compared to the cumulative distribution function for all the projections in the 2040 time frame.

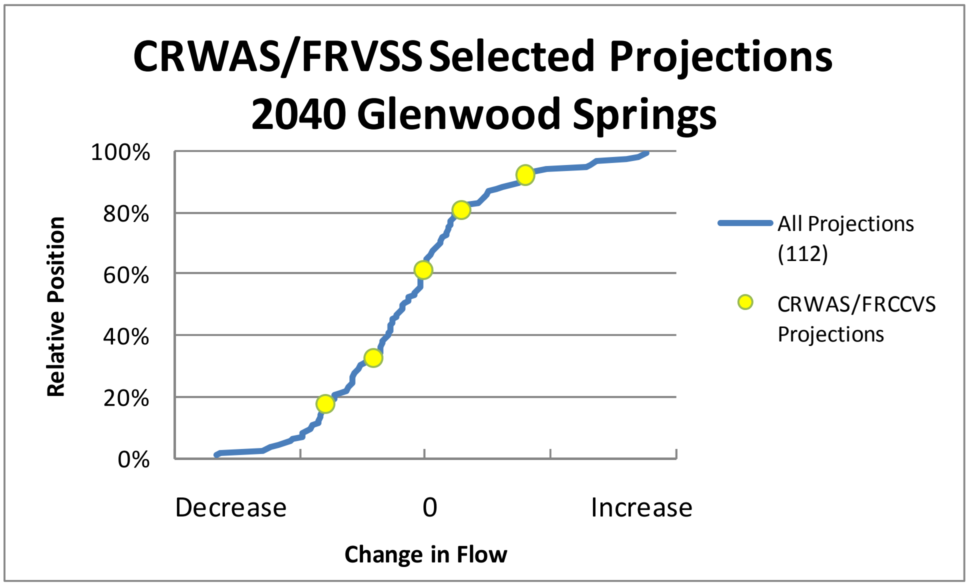

Figure 2-11 – Comparison of five 2040 Selected Projections to all 2040 Projections (flow-Glenwood Springs)

Figure 2-11 indicates that the selected projections for 2040 are reasonably representative of the overall distribution of projections for that time frame. Table 2-4, above, shows that the objective of the selection of projections was to cover the range from the 10th percentile (synonymous with a relative position of 10%) to the 90th percentile, while Figure 2-11 shows that the selected projections cover the range from about the 18th percentile to about the 92nd percentile.

Figure 2-12 illustrates the distribution of the projections selected to represent the 2070 time frame compared to the cumulative distribution function for all the projections in the 2070 time frame.

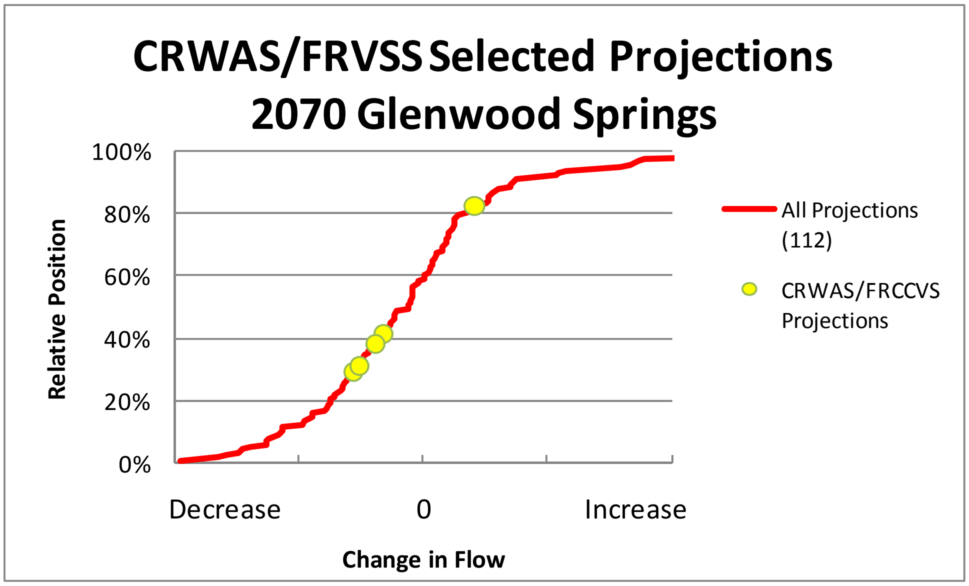

Figure 2-12 – Comparison of five 2070 Selected Projections to all 2070 Projections (flow-Glenwood Springs)

Figure 2-12 shows that the selected projections for 2070 cover the range from about the 29th percentile to the 82nd percentile, and do not meet the objective to cover the range from the 10th percentile to the 90th percentile.

Figure 2-13 illustrates the distribution of the projections selected to represent the 2040 time frame compared to the cumulative distribution functions for all the projections in both the 2040 and the 2070 time frames.

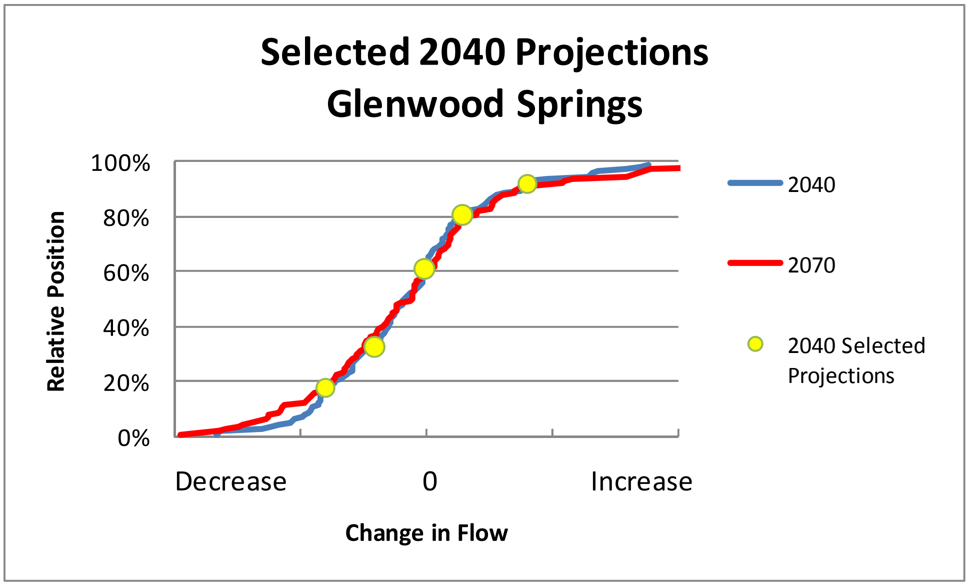

Figure 2-13 – Comparison of five 2040 Selected Projections to all 2040 and 2070 Projections (flow-Glenwood Springs)

Figure 2-13 shows that the selected 2040 projections are representative of 2070 conditions except for the driest projections. Thus, for the purpose of comparing the impacts of climate on streamflow, the projections selected for 2040 provide a reasonable representation of conditions in the time frame from 2040 to 2070, particularly considering the uncertainty in future projections indicated by the broad range of projected impacts on natural flow.

Throughout the remainder of the body of this report climate impacts are characterized by the projected conditions for 2040. Tabular data and charts describing the impact of projected climate in 2070 are provided in the appendices and in the electronic data.

2.4.3 Climate-Adjusted Weather

Climate change affects weather, which in turn affects streamflow and water use. *Climate-adjusted weather* is used in hydrology modeling (see Section 2.4.5) to develop estimates of *climate-adjusted natural flows.* Climate-adjusted weather is also used in consumptive use models (see Section 2.4.4) to develop estimates of *climate-adjusted crop irrigation requirements* (CIR). Hydrology and water use modeling use weather data in different forms, but the approach to applying adjustments to reflect climate change is the same.

Observed Weather

CRWAS hydrology modeling uses weather data that have been disaggregated to a regular grid. The data set used in CRWAS, originally developed by Maurer, et al. (2002) and later extended by Andrew Wood, is a model-derived dataset of daily maximum and minimum temperature, precipitation depth and wind for the conterminous United States and portions of Canada and Mexico spanning from 1950-2005. The grid geometry of this data set is identical to the climate projections from the LLNL-Reclamation-SCU archive described in Section 2.4.2.

The availability of the Maurer, et al. gridded weather to serve as the basis for the CRWAS hydrology modeling was the limiting factor in determining that the CRWAS observed hydrology period would run from 1950 through 2005.

CRWAS water use modeling uses temperature and precipitation data from 54 weather stations in the Study basins.

Applying Climate Adjustments

The first step, common to developing both climate-adjusted CIR and climate-adjusted natural flows, is generating a time series of weather that represents the climate-adjusted condition—the observed weather adjusted to represent the projected change in temperature and precipitation[11]. The development of the climate-adjusted weather is illustrated in Figure 2-14.

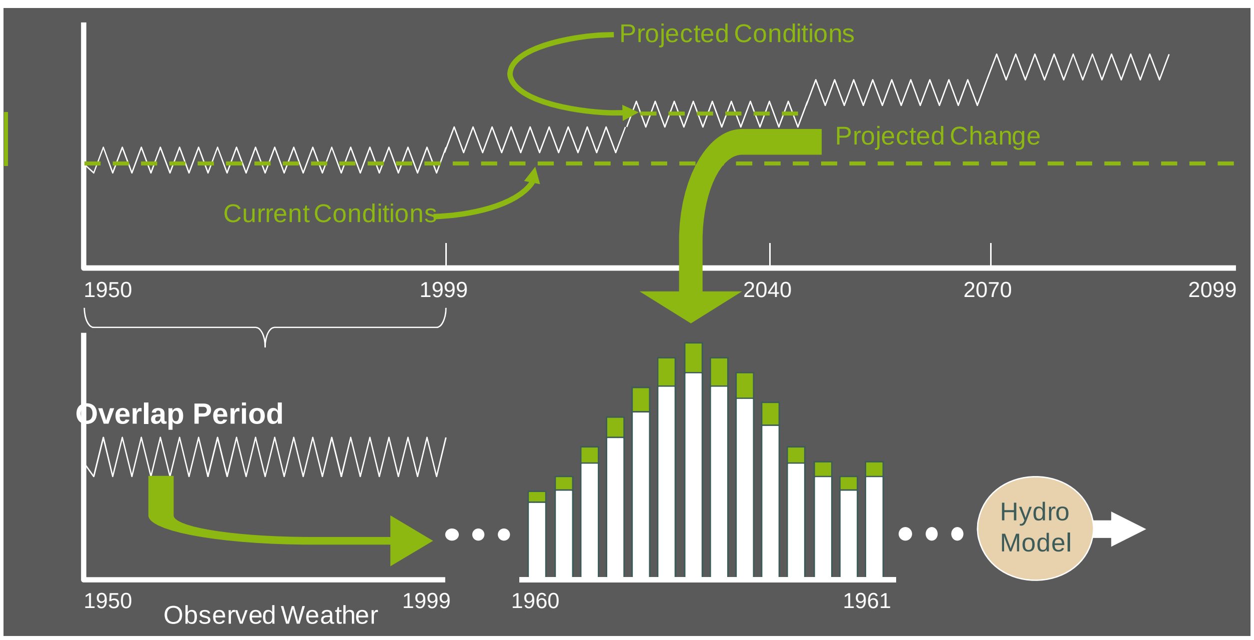

Figure 2-14 – Illustration of Development of Climate-Adjusted Weather

A climate projection is the output of one run of a global climate model (GCM) with a given set of initial and boundary conditions. In Figure 2-14 the climate projection is illustrated in the upper half of the figure. Each projection consists of an overlap period and a projection period. In Figure 2-14 the

[11] No down-scaled data for winds are available, so wind was not adjusted in the CRWAS climate-adjusted weather data set.

overlap period runs from 1950 through 1999 and the projection period runs from 2000 through 2099. Projected climate change at a particular point in the future is determined by comparing the average condition during all or part of the overlap period with the average future condition. In CRWAS, the change in temperature for the period 2040 was characterized by calculating the monthly average temperature for the period 2025 – 2054 (projected conditions in Figure 2-14) and for each month of the year subtracting the corresponding average value for the period 1970-1999 (current conditions in Figure 2-14). The same approach is used with precipitation except a ratio rather than a difference is used. This yields the projected change shown in Figure 2-14, which is expressed as a monthly pattern of change.

The projected change is then applied to each month in the historical weather. For temperature the change is additive, for precipitation it is a scaling factor.

For the gridded data used in the CRWAS hydrology modeling this process is repeated for each grid cell, and for each month of the year. Because the hydrology modeling (VIC) uses daily data, each day of the month is adjusted by the same offset (for temperature) and the same ratio (for precipitation). This process is straightforward because the grid geometry for the observed weather and the climate projections are identical.

The consumptive use analyses for the Study basins superimposes historical or projected mean monthly temperature and total monthly precipitation for each of the 54 climate stations in the Study area on current irrigated acreage and crop types to estimate crop irrigation requirements (CIR). The weather stations are distributed throughout the Study basins, as shown on the maps presented in Section 3.1. Climate adjustments for each of the ten climate projections were developed by adjusting the data at each weather station location by the projected change for the 1/8th degree grid cell in which the weather station is located. Projected change in temperature was provided as net monthly increases to historical temperature, in degrees Celsius, for the Study period 1950 through 2005. Projected change in precipitation was provided as a scale factor of historical precipitation for the Study period 1950 through 2005.

Historical temperature and precipitation StateCU input files were developed as part of the CDSS. The CDSS Data Management Interface, TSTool, includes the capabilities to perform addition and scaling operations, and was used to create new mean monthly temperature and total monthly precipitation input files for each of the ten climate projections. The data-centered “command” approach allowed instructions to be created that directed TSTool to perform the analysis for one climate projection; then the commands were duplicated for the other nine projections.

Trend analyses were performed to better understand the spatial aspect of temperature and precipitation changes associated with the climate projections. Maps and tables describing changes in temperature and precipitation compared to historical are presented in Sections 3.1 and 3.2.

2.4.4 Climate-Adjusted Crop Irrigation Requirement

StateCU Consumptive Use Methodology

The consumptive use analyses for the Study basins superimpose historical or projected mean monthly temperature and total monthly precipitation on current irrigated acreage and crop types to estimate crop irrigation requirements (CIR). Climate data required for a detailed daily method, such as Penman-Monteith, is not available in the Study basins. Therefore, CDSS has adopted a monthly Blaney-Criddle approach using StateCU, incorporating locally calibrated crop coefficients where available.

Crop irrigation requirement is estimated in CDSS first by using the Blaney-Criddle approach to determine potential crop evapotranspiration (ET). Potential crop ET, also called potential crop consumptive use, is an estimate of the maximum amount of water a crop could consume if given a full water supply. Crop irrigation requirement is the potential crop ET less the amount of precipitation effective in meeting a portion of the potential crop ET. CDSS has selected the SCS Effective Rainfall method outlined in SCS Technical Release 21 (TR-21). Crop irrigation requirement is an estimate of the maximum amount of water a crop could consume if given a full irrigation supply.

For irrigated pasture grass above 6,500 feet elevation, the originally Blaney-Criddle method is used with calibrated crop coefficients recommended in a comprehensive study of high-elevation lysimeter data sponsored by Denver Water, "Evapotranspiration and Agronomic Responses in Formerly Irrigated Meadows, South Park, Colorado." The basin-specific Historic Crop Consumptive Use Analysis reports detail the CDSS investigation that resulted in selection of the coefficients. Nearly 50 percent of the irrigated acreage in the Study basins is pasture grass grown above 6,500 feet elevation.

After the CDSS investigation, a study sponsored by the Upper Gunnison Water Conservancy District was published by Dr. Dan Smith that presented calibrated coefficients based on a more recent lysimeter study near Gunnison, Colorado. As part of CRWAS, the results were reviewed, and the Smith calibrated crop coefficients were compared to the coefficients used in the CDSS modeling effort. Figure 2-15 shows the comparison of crop irrigation water requirement using the CDSS-adopted high-altitude coefficients compared to the coefficients recently developed by Smith. As shown, the differences are minor, resulting in an average annual difference in crop irrigation requirement of less than 1 percent using historical temperature and precipitation at the Gunnison climate station, which allowed the continued use of CDSS-adopted high-altitude crop coefficients.

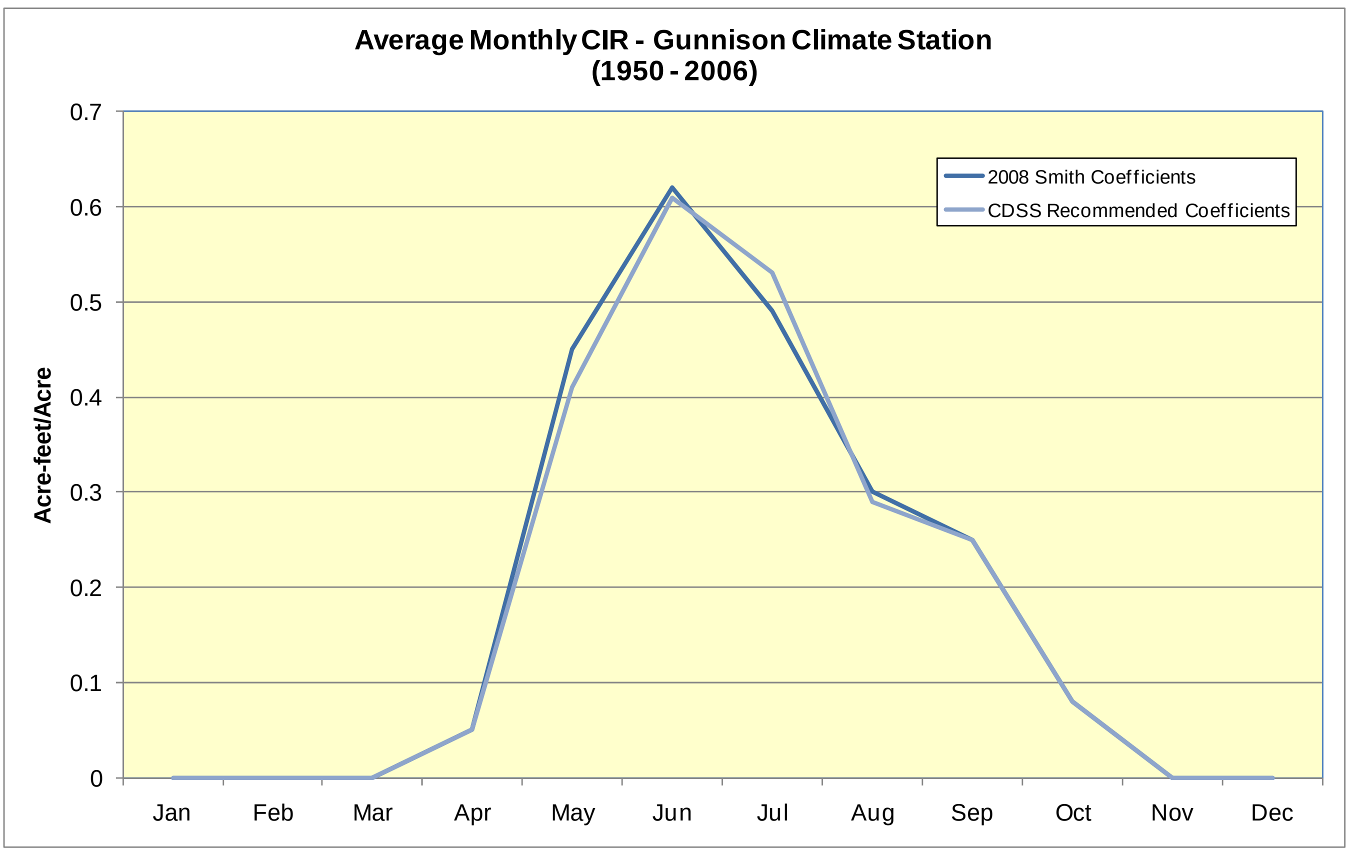

Figure 2-15 – CIR Using CDSS Coefficients and 2008 Smith Coefficients

For irrigated pasture grass grown below 6,500 feet elevation, and for other crops grown in the Study basins, the modified Blaney-Criddle method is used with crop coefficients recommended by TR-21. Because locally calibrated crop coefficients are not available, an elevation adjustment of 10 percent upward for each 1,000 meters above sea level is applied to potential consumptive, as recommended in the ASCE Manuals and Reports on Engineering Practice No. 70, Evapotranspiration and Irrigation Water Requirements (1990) and used by the State Engineer's Office.

In addition to crop coefficients, growing season "triggers" are defined in TR-21. For most perennial crops, including grass pasture, the growing season start and end dates are based on mean monthly temperature. This is ideal for the CRWAS analysis, as it allows growing seasons to vary with alternate projected monthly temperature.

For the perennial crop alfalfa, the beginning of growing season is defined by mean monthly temperature; however the end of growing season trigger is when the minimum daily temperature reaches 28 degrees Fahrenheit. The down-scale process to minimum daily temperature, and therefore killing frost dates, is much more involved than the downscaling to average monthly temperature described in Section 2.4.3. Therefore, an analysis was performed to determine an appropriate mean monthly temperature for alfalfa that can be used to represent, on average, the killing frost date.

The procedure resulted in the recommendation to end alfalfa growing season when the mean daily temperature (based on interpolation of mean monthly temperatures) drops below 54 degrees Fahrenheit. This provides the ability for the alfalfa growing season to vary with alternate projected monthly temperature, and is important since alfalfa makes up approximately 13 percent of the irrigated acreage in the Study basins.

StateCU Inputs

Current estimates of irrigated acreage in the Study basins, by crop type, are used in the CRWAS estimates of crop irrigation requirements under alternate projected climate conditions, as shown in Table 2-5. For CDSS, irrigated acreage is assigned to a water supply ditch, and the analysis is performed on a ditch-wide basis. Ditch structures are paired with the 54 climate stations used in CDSS based on proximity. As discussed previously, there are over 1,200 ditch structures represented in the CDSS analyses of crop irrigation requirements.

Table 2-5 – Current Irrigated Acreage by Crop Type (acres)

Crop Type	Yampa	White	Upper Colorado	Gunnison	San Juan / Dolores	Total
Alfalfa	3,547	3,134	37,965	30,232	26,646	101,524
Grass Pasture<6,500 ft	27,136	16,350	99,097	70,662	55,707	268,952
Orchard and Grapes[1)]	3	0	3,435	6,045	894	10,377
Grains/Vegetables[2)]	400	68	11,831	19,045	4,603	35,947
Corn	0	327	14,847	23,291	1,477	39,942
Grass Pasture>6,500 ft	74,539	6,993	103,672	122,677	134,735	442,616
Basin Totals	105,625	26,872	270,847	271,952	224,062	899,358

1) Orchard and grapes combined for this summary only, CIR is calculated separately for each crop.
2) Spring grains, dry beans, and vegetables are combined for this summary only; CIR is calculated separately for each crop.

Crop irrigation requirements estimated at representative climate stations and for irrigated acreage in the Study basins using temperature and precipitation associated with climate projections are summarized and discussed in Section 3.3.

Where to find more detailed information:

For more information, StateCU data sets and associated Historical Crop Consumptive Use Reports for each of the Study basins can be downloaded, along with the StateCU executable, from the CDSS website (http://cdss.state.co.us/).

2.4.5 Climate-Adjusted Natural Flow

Development of climate-adjusted natural flows uses three primary data sets: historical weather, historical natural flows and projected climate conditions. Development of climate-adjusted natural flows proceeds in two principal steps. First, climate-adjusted weather is developed as described above. The observed weather and the climate-adjusted weather are then used to force a hydrology model in "with" and "without" cases and the changes between the modeled flows from those two cases represent the change in streamflow attributable to the projected change in climate conditions. These changes are applied to the historical water supply condition to produce a *climate-adjusted* water supply condition. This is the water supply condition as if the projected climate conditions had been fully developed at the start of the specified study period. The development of the climate-adjusted hydrology is illustrated in Figure 2-16.

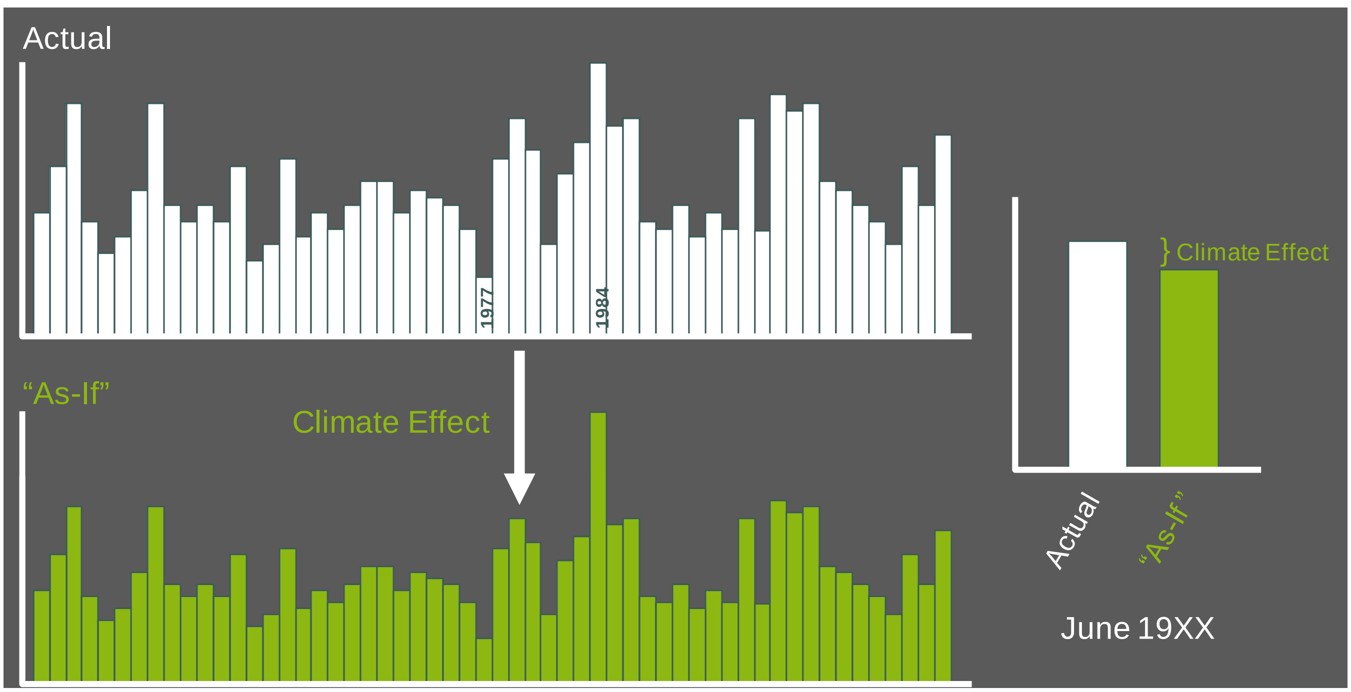

Figure 2-16 – Illustration of development of climate-adjusted water supply

The method illustrated in Figure 2-16 shows the adjustment of a time-series record. For each month of the record the ratio is calculated between the two modeled values of streamflow, one based on observed weather and one based on climate-adjusted weather, and then the historical streamflow for that month is adjusted by that ratio.

The results of this process are traces of climate-adjusted streamflow for 227 locations required by StateMod to model water availability within Colorado, and for 29 points required by CRSS to model water availability in the Colorado River Basin. Each climate-adjusted data set consists of a 56-year trace of monthly flows. For each location there will be eleven flow traces of climate-adjusted flows: one historical trace, five climate-adjusted traces for the 2040 time frame and five climate-adjusted traces for the 2070 time frame.

Hydrology Modeling

The climate effect on streamflows is estimated using hydrology modeling. A hydrology model (VIC) takes as input weather conditions and returns as output estimates of streamflow. It simulates the significant hydrologic processes that affect the water balance and the physical processes that affect the transport of water and thus affect the timing of flows. Two principal categories of hydrology modeling (statistical models and process models) have been applied to climate change research, and within these two primary modeling categories there are a large number of individual models. The suitability of hydrology models for application to climate change impact studies varies based on both practical and scientific considerations. In addition, there are different choices of how hydrology modeling is used to represent the impacts of climate change.

Statistical hydrology models are based on deriving a functional relationship between streamflow and the climate variables – precipitation, temperature, etc—several of which are typically developed for selected seasons (i.e., monthly or for a set of months, e.g., Dec-Jan-Feb, etc.) In climate change studies, like CRWAS, use of statistical models requires the assumption that the relationships on which the model is based will hold under the climate change scenarios. However, under climate change a seasonal shift is expected in the annual streamflow hydrographs with, for example, warmer temperatures bringing earlier spring runoff (Hayhoe et al., 2004; Barnett et al., 2005; Maurer, 2007). Thus, statistical models are expected to have only a limited application in analyzing streamflows under climate change. CRWAS employed a physical process-based hydrology model, the Variable Infiltration Capacity (VIC) macro-scale hydrology model.

The VIC model is a physically distributed (gridded) macro-scale (regional-scale) hydrology model that consists of a variable-layer soil-vegetation-atmosphere transfer (SVAT) scheme used in general and regional circulation and weather prediction models. The VIC model has two main components – (i) a component to model land-surface (e.g., snow dynamics) and, (ii) a sub-surface modeling component (e.g., infiltration). These two components work in a manner with feedbacks controlling coupled land-surface and sub-surface processes such as infiltration and evapotranspiration.

Evapotranspiration (ET) is the most significant water loss process in the hydrologic water balance. As such, the reliability of a hydrology model is directly related to the accuracy and reliability of the representation of ET. In the mountainous terrain of the significant water-producing areas of the Colorado River basin, temperature-based ET models require local calibration and physically-based ET models, as used in VIC, are preferred for hydrology modeling.

Snow accumulation and snow melt are also important processes in simulating the seasonal pattern of streamflow. Because all of the available projections of future climate show that temperature will increase, changes in the pattern of snow accumulation and melt will result. A more physically-based snow model, of the sort used in VIC, provides more confidence that simulations involving changes in temperature will result in realistic changes in snow accumulation and snow melt.

The land-surface component in the VIC model has detailed underlying physical process models, but the sub-surface component is more conceptual. So in terms of calibration, the focus was to calibrate the VIC sub-surface model. A third component is the routing model that transports simulated flows in VIC grid cells to the outlets of the individual sub-basins of the Colorado River. Parameters from the routing model were also not changed from the initial calibrated model as these parameters were determined using a physical basis.

The sub-surface model consists of five parameters that control – (i) shape of the variable infiltration curve (b_infilt), i.e. the partition of surface runoff versus soil infiltration; (ii) maximum velocity of baseflow in the lowest soil layer in a model grid cell (Dsmax); (iii) soil depth for each of the three model soil layers; and two parameters that define the onset of nonlinear baseflow dynamics in the lowest soil layer – (iv) Ws, fraction of maximum soil moisture where nonlinear baseflow occurs and (v) Ds, fraction of the Dsmax parameter at which nonlinear baseflow occurs.

A preliminary calibrated model for the Colorado River Basin was obtained from Niklas Christensen. This calibrated model provided excellent fit of simulated and observed streamflows for gage locations covering large basin areas, for example the Colorado River at the Lees Ferry gage. This is expected because of the focus of the studies for which the calibrated model had been developed. Further calibration was performed to estimate effective sub-surface model parameters to improve fit at some smaller basins using the automated optimal parameter estimation algorithm MOCOM (Yapao, et al., 1998). The five sub-surface parameters described above were optimized using the MOCOM code for a subset of sub-basins and were used to derive a composite soil file consisting of a combination of cells from the initial calibrated model and the cells with optimized soil parameters. This resultant soil file was used in carrying out the VIC model runs. No change was made to the land-surface parameters from the initial calibrated model though sensitivity analysis was carried out to test the performance with respect to simulating snow dynamics (snow water equivalent).

Re-sequencing Climate-adjusted Natural Flows

The climate-adjusted natural flows were re-sequenced into ensembles of 100 56-year traces. Because the climate-adjusted natural flows are associated with an historical year, a 56-year trace of climate-adjusted natural flows can be re-sequenced into a 100-trace ensemble using the same re-sequencing approach and the same year sequences described in Section 2.3.1. One set of climate-adjusted flows resulted for each of the five climate projections associated with each of the two time frames, 2040 and 2070, so a total of ten ensembles of climate-adjusted natural flows were developed.

2.4.6 Climate-Adjusted Water Availability

StateMod Water Resources Planning Model Methodology

The StateMod water resources planning models were used to investigate how a basin's physical streamflow, water availability, consumptive use, and reservoir use react under various hydrologic conditions. The StateMod Baseline data sets were first used to investigate these water use parameters as if current water resource demands, water rights, and projects were in place over the 1950 through 2005 historical hydrologic period.

The climate-based input files were then revised, as discussed in Section 2.1.4, to reflect alternate crop demands, irrigation headgate demands, and natural flows associated with each of the ten climate projections.

The StateMod water allocation models are driven by natural flow hydrology. Natural flows represent natural streamflow, absent human effects including agricultural, municipal, domestic, and industrial water uses. StateMod uses nodes and links to simulate the physical systems developed to support these human uses. StateMod simulates water use restricted by physical properties such as headgate and ditch capacities and by reservoir storage and outlet capacities. Finally, legal and administrative conditions are represented in the models, including water rights and operational policies. StateMod is an ideal tool for CDSS and CRWAS, as its operations follow the Prior Appropriation Doctrine and Colorado water rights administration.

StateMod includes a "Base Flow Module" that is used to create a set of natural flows at locations with measured historical stream flows by removing the upstream impact of diversions, return flows, and reservoir storage, releases, evaporation, and seepage. Based on user input regarding drainage area and average annual precipitation, StateMod then automates the distribution of the natural flow gains seen at gaged locations to ungaged tributaries and headwater nodes. The full set of natural flows at both gaged and ungaged locations provides natural inflows to the model at each time step.

StateMod "Simulation Module" operates each time step based on the Modified Direct Solution Algorithm. At each modeled time step, StateMod allocates available streamflow based on the following general steps.

1. Physical water availability is determined at each river node to include both natural inflows and return flows accruing from a prior time step.
2. The most senior direct, instream, storage, or operational water right is identified.
3. Diversions are estimated to be the minimum of the decreed water right, structure capacity, demand, and available flow in the river. For a direct flow or reservoir right, the available flow in the river is the minimum of available flow at the diverting node and at all downstream nodes. By considering flow at downstream nodes, the model preserves the correct supply for downstream senior water rights when calculating the diversion for an upstream junior right. For an instream right, the available flow at each river node within the instream reach is considered.
4. Downstream flows are adjusted to reflect the senior diversion and its return flows.
5. Return flows for future time periods are determined and stored.
6. The process is repeated in order of priority for each successive direct, instream, storage, and operational water right.
7. If new water is introduced to the system from a reservoir's operation or return flows accrue to a non-downstream node, the process is repeated beginning with the most senior direct, instream, storage or operational right whose demand is not fully satisfied.

For irrigation structures, StateMod allows the system efficiency (conveyance efficiency * application efficiency) to vary, up to a specified maximum efficiency. The crop irrigation requirement, supplied by StateCU for every month in the model period, is met out of the simulated headgate diversion, and efficiency (the ratio of consumed water to diverted water) falls where it may – up to the specified maximum efficiency. If the diversion is too small to meet the irrigation requirement at the maximum efficiency, maximum efficiency becomes the controlling parameter. This derivation is termed the Variable Efficiency Algorithm.

StateMod also simulates an on-farm soil moisture balance, representing the ability for excess diverted water to be "stored" in the soil root zone, and consumed in that time step or a subsequent time step.

This "simplified" description of the model methodology can be supplemented with the detailed description of model operations in each of the five basin's Water Resources Planning Model User's Manuals.

Where to find more detailed information:

For more information, the Water Resources Planning Model User Manual for each basin can be downloaded, CDSS website (http://cdss.state.co.us/). Section 7 of the StateMod Documentation (Technical Notes) describes the model methodology in detail.

StateMod Current Condition Inputs

Baseline data sets that include parameters not directly affected by changes in temperature or natural flows were not revised. The following current conditions were not revised from the Baseline data sets for alternate climate projections:

- Absolute direct flow rights, storage rights, instream flow rights, and minimum flow agreements (except minimum fish flows that vary based on hydrology as discussed below)
- Headgate, conveyance, and reservoir capacities
- Reservoir operations including releases for direct uses, hydropower, and flood control

Only currently perfected Colorado water rights with existing infrastructure and demands are represented in the analyses. Conditional water rights associated with identified demand projections may be considered during Phase II. Water rights, operations and agreements within Colorado are incorporated into the StateMod Baseline data sets, therefore water availability results from the StateMod simulations account for water available to meet future demands within the State, without consideration for Colorado River Compact provisions. As discussed in Section 1.2, other CWCB sponsored programs and processes are in place to investigate both future use of conditional rights and compact considerations.

As presented in Section 3.3, climate projected crop irrigation requirements, and associated irrigation headgate demands, are generally higher than historical demands. No adjustments were made to either current capacities or current water rights, therefore in some cases demands are not met due to water rights and/or capacity limitations even when water is available. Identification of future demands and the projects and processes to meet those demands are being investigated for inclusion in Phase II modeling efforts. Perfecting conditional water rights, additional water rights, structural changes to increase capacity of diversions and reservoirs, new reservoirs, and reservoir operational changes are all potential considerations to meet future demands.

StateMod Alternate Climate Related Inputs

StateMod time series input files directly affected by climate are revised for each of the climate projections. As discussed below in detail, these input files continue to reflect current practices including irrigated acreage and crop type and reservoir operations, but are adjusted for projected climate conditions. Climate-related StateMod inputs include:

- Natural flows
- Crop irrigation requirements
- Irrigation structure headgate demands
- Reservoir forecasting targets (if based on hydrologic year type)
- Fish flow targets (if based on hydrologic year type)

Natural Flows

As discussed in Section 2.4.5, natural flows were adjusted for the 227 locations corresponding to stream gages in the Study basin models for each of the climate projections. Each of the projected climate natural flow data sets was then distributed by StateMod to ungaged and headwater locations. These full data sets of baseflows at both gaged and ungaged locations are the primary climate-related inputs to the Study basins models.

Crop Irrigation Requirements

Section 2.4.4 discusses how StateCU was used to revise estimates of CIR for irrigation structures. The CIR file is read directly by StateMod for use in the Variable Efficiency Approach discussed above. In addition, CIR is used to estimate headgate demands for irrigation structures under varying climate projections.

Irrigation Structure Headgate Demands

Hydrology is the best indicator of system efficiency because water supply generally dictates irrigation practices. During wet months and years, there may be excess water when crop irrigation requirement is low. Therefore irrigation practices during wet years can result in low system efficiencies when excess diverted water is not necessary to meet crop irrigation requirements. During dry years when water supply is limited, the opposite is true, resulting in high system efficiencies due to the shortage of water. The variation in hydrologic conditions as a result of projected climate will influence the irrigation practices and system efficiencies. However, system efficiencies for defined hydrologic year types, for use in modeling climate projections, can be estimated as described below based on the historical hydrologic record.

The following general approach was used to estimate irrigation structure headgate demands for climate projections:

- *Determine Representative Wet, Dry, and Average Year Efficiencies.* Average monthly system efficiencies were calculated, for each irrigation structure, based on its historical irrigation demands and water supply for wet, dry, and average hydrologic years. The determination of year type and associated flows were based on natural streamflow at nearby representative gages (termed “indicator gages”). The procedure for selecting indicator gages is described in detail in the Water Resources Planning Model User Manual documentation for each study basin.

- *Assign Efficiencies to Years based on Projected Climate.* The historical average, wet, and dry year flows from step 1 and associated monthly efficiencies were then assigned to alternate climate hydrology years. As expected, for most climate projections, the number of wet years declined and the number of dry years increased. Average dry-year monthly system efficiencies estimated from step 1 were assigned to structures when the alternate climate hydrology indicated a dry year. The same procedure was used for wet and average alternate climate hydrologic years.

Note that in some basins where water supply has been historically available throughout the irrigation season, calculated monthly wet year efficiencies are very low - lower than would be expected during widespread climate change. Based on engineering judgment, the minimum monthly system efficiency for estimating headgate irrigation demands was set to 30 percent.

- *Determine Headgate Irrigation Demands for Climate Projections.* CIR estimates are divided by average monthly efficiencies considering hydrologic year type determined in step 2, providing estimates of headgate demands for irrigation structures.

Reservoir Forecasting Targets

Four of the USBR reservoirs in the Study basin operate for flood control with operational rules defined by wet, dry, and average forecasted inflow; Green Mountain Reservoir, Ruedi Reservoir, Lemon Reservoir, and Vallecito Reservoir. StateMod mimics the flood forecasting operations by setting monthly storage and release targets, provided by the reservoir operators, for each year in the Study period. For the Baseline dataset, these targets are based on the historical hydrologic year type as determined using nearby indicator gages. For the climate projections, these targets were revised based on the year type from the climate projection natural flows. As expected, for most climate projections, the number of years using a wet-year forecasting declined, and the number of years using a dry-year forecasting increased.

Minimum Flow Targets

In general, CWCB instream flow rights and reservoir minimum bypass agreements do not vary based on hydrologic year type. There are three exceptions in the Study basins: the U.S. Fish and Wildlife Service (USFWS) recommended fish flow through the 15-mile reach of the Colorado River, the U.S. National Park Service (NPS) flow request for its water right through the Black Canyon of the Gunnison National Park, and minimum bypass flows downstream of Taylor Park Reservoir:

- The USFWS 15-mile reach recommended flows can be met from natural flow, if available, and are supplemented with releases from several cooperating reservoirs in the Upper Colorado River basin from July through October. During dry years, the recommended flows are reduced.
- The NPS Black Canyon requested flows vary based on inflows to Blue Mesa Reservoir and water stored in Taylor Park Reservoir, therefore vary with hydrology.
- The minimum bypass requirement from Taylor Park Reservoir has been historically reduced during extremely dry years.

Similar to flood control forecasting for reservoirs for the Baseline dataset, these targets are based on the historical hydrologic year type as determined using nearby indicator gages. For the climate projections, these minimum flow targets were revised based on the year type from the climate projection natural flows. As expected, for most climate projections, the number of years using a dry-year minimum flow target increased.

Note that the USFWS recommend fish flows in the lower Gunnison River are not included as a current demand, as the recommendation is pending the outcome of the EIS process for Aspinall Unit reservoir re-operation.

Climate Related Inputs Not Revised

During CRWAS Phase I, only demands that were irrigation based were revised to reflect climate projections. It is important to note that transbasin diversion demands, which would likely be affected by alternate climate conditions both in the Colorado River basin and the river basins in eastern Colorado, were not revised. In addition, in part because the consumptive use associated with municipal demands in study basins is minimal compared to agricultural consumptive use, the potential increase in municipal demands due to outdoor uses was not considered. Transbasin and municipal demands are expected to be revisited during Phase II of the CRWAS project.

Reservoir evaporation is estimated by StateMod based on net average monthly evaporation rates assigned to each modeled reservoir, and reservoir area/capacity relationships. Net monthly evaporation is gross free-water evaporation less precipitation. The net evaporation rates are affected by both temperature and precipitation. Although there are methods for estimating free-water evaporation based on temperature; evaporation rates were not revised during Phase I. This simplification, which for some climate projections results in underestimating reservoir evaporation, may be revisited during Phase II.

StateMod Simulation Output

StateMod provides results at every location (node) represented in the model. Available results are the mass-balance components at each node. At all nodes except reservoir locations, inflow components must equal outflow components. Inflows can include water from upstream sources; reservoir releases, return flows, water bypassed for downstream senior uses, etc. plus natural flows not allocated to senior downstream uses. Outflows include inflow components plus diversions to meet demands or carried to off-channel use. The mass-balance equation at reservoir nodes includes change in storage: inflows less outflows must equal change in storage.

In addition to the mass-balance accounting at each node, StateMod reports results that separate diversion components into consumptive use and return flows. Similarly, reservoir accounting shows the amount stored, evaporated, and released and end-of-month content by reservoir account and for the entire reservoir.

There are several custom reports generated by StateMod that are useful depending on the focus of the analyses. In addition, all the information generated by StateMod is stored in "binary code" output files that save hard-drive space, but cannot be read directly with a text viewer. Instead, any information can be extracted from these files using the DMI TSTool. TSTool allows information to be viewed in tabular and graphical form or exported to Excel or text editors.

Presenting all the information generated by each climate projection StateMod simulation is not practical nor is it necessary. The following parameters were selected based on their importance to planning for a future with changing water availability:

- Modeled Streamflow
- Water Available to Meet Future Demands
- Basin Consumptive Use
- Reservoir Use

Modeled streamflow represents water in the river at the location of interest. Physical streamflow is important, because it provides opportunities for exchanges and non-consumptive uses regardless of the legal availability. Modeled streamflow is, essentially, natural flow less upstream depletions.

Water available to meet future demands at a given node is modeled streamflow less water "designated" for current downstream demands with existing water rights. Downstream demands include direct diversions, diversions to storage, and non-consumptive demands such as instream flow rights. As discussed above, conditional rights and the potential operation of compact provisions are not included in the Phase I modeling efforts, therefore water available to meet future demands is only a measure of available flow based on current model represented demands.

Basin consumptive use includes water that is removed from the system and fully consumed. Basin consumptive use includes agricultural, municipal, and industrial uses within the Study basins. In addition, basin consumptive use includes transbasin water exported from the Study basins to be consumed elsewhere and includes reservoir evaporation. To be consistent with the USBR Consumptive Uses and Losses reporting requirements, evaporation associated with the Colorado River Storage Project (CRSP) reservoirs are excluded in the reported consumptive use values. The CRSP reservoirs in the Study basin models include Blue Mesa Reservoir, Morrow Point Reservoir, and Navajo Reservoir. In addition, diversions represented in the San Juan/Dolores StateMod model that consume water in New Mexico are also excluded.

Reservoir storage is important to meeting demands in the Study basin under current climate conditions. Reservoir end-of-month contents show how existing reservoirs store and release under climate projections.

As discussed in Section 2.1.4, the method for extracting this information was included in the automation process for select locations, and graphical and tabular results are presented in this report. In addition, the binary output files for each climate projection can be requested on DVD. In conjunction with the DMI TSTool, available on the CDSS website, interested planners can extract the above information, and any other StateMod output parameters of interest, for every location represented in the Study basin models.

Where to find more detailed information:

For more information, Section 5 of the StateMod Documentation (Technical Notes) describes the output reports and parameters available from a StateMod simulation (http://cdss.state.co.us/). TSTool, and associated user documentation, is available for download on the CDSS website (http://cdss.state.co.us/).

2.4.7 Statistical Analysis of Climate Change Hydrology

Three separate statistical analyses were conducted on climate-adjusted environmental variables.

- Low-flow Intensity-duration. Intensity-duration analysis provides a comparison of low-flow intensity for different durations. Mean flow values are calculated for the full 56-year period and for low flows at durations of two years, five years, and ten years. The four values are calculated for a given location for all five climate projections. Separate analyses are done for both time frames.

- Seasonal conditions. The seasonal distribution of climate-adjusted conditions is calculated for natural flow data (a monthly hydrograph) and for temperature, precipitation and CIR.

- Frequency analyses. Frequency analyses were applied only to natural flow data. The frequency analyses were the same as were applied to the extended historical hydrology and described in CRWAS Technical Memorandum Task 6.7 – *Summarize Alternate Historical Hydrology*. These analyses were applied to each of the five ensembles of alternate climate change hydrology for each time frame and a set of box-whisker charts were developed for each site, showing the five statistics (annual mean flows, longest surplus spell length, longest drought spell length, maximum surplus volume, and maximum drought volume) for each of the five alternate streamflow data sets, for the composite population consisting of the combined data from all five alternate streamflow data sets, and, for reference, for the extended historical hydrology.

Where to find more detailed information:

More detail on the statistical analyses described in this section can be found in CRWAS Technical Memorandum Task 6.7 – *Summarize Alternate Historical Hydrology* and CRWAS Technical Memorandum Task 7.12 – *Statistical Analysis of Climate Impacts*, available at http://cwcb.state.co.us/.

Nature of Data

Climate-adjusted data were developed as described above for the following hydrologic and water supply variables:

- Temperature
- Precipitation
- Crop Irrigation Requirement (CIR)
- Naturalized flow

Each climate-adjusted dataset consisted of a 56-year time series of monthly values for each of the ten climate projections. In addition, an ensemble of 100 re-sequenced traces of the climate-adjusted historical data for natural flows was analyzed to evaluate the frequency of annual flows, droughts and wet spells.

Statistical Analyses

Low-flow Intensity-duration analysis was applied to streamflow data to illustrate the impact of projected climate on mean flows and on the intensity of low flows at specified durations. Comparison of these values across the projections illustrates the uncertainty inherent in the climate projections (projection-to-projection variability).

Mean flow values are calculated for the full 56 years and for low flows at durations of two years, five years and ten years. The intensity values for the four durations are calculated for a given location for all five climate projections and plotted in drought comparison charts, which are provided in Section 3 and Appendices D and E.

The low-flow charts illustrate the effect of projected future climate conditions on statistics of low flows but not on wet spells. The modeling methods used to quantify water availability will quantify the impact of both drought and wet spells on the physical and legal availability of water. Phase 2 of CRWAS will address potential projects that can put water from wet spells to use to support new beneficial consumptive or non-consumptive use.

Average monthly values (e.g. an average monthly hydrograph or hyetograph) are calculated for all four hydrologic variables and are used to illustrate the impact of projected climate on the seasonal pattern of those variables. Comparison of these values across the projections illustrates the uncertainty inherent in the climate projections (projection-to-projection variability).

For each month of the year, the mean value of a hydrologic variable is calculated over the 56 values for that month contained in the trace. The twelve average monthly values are calculated for a given location/variable for all five climate projections.

Where to find more detailed information:

Boxplots for statistics of annual flows, surplus spells and drought spells for climate-adjusted flows were developed as described in CRWAS Technical Memorandum Task 6.7 – *Summarize Alternate Historical Hydrology*. The boxplots for climate-adjusted flows can be found in CRWAS Technical Memorandum Task 7.12 – *Statistical Analysis of Climate Impacts*, available at http://cwcb.state.co.us/.

Maps were developed to illustrate the spatial pattern of change in temperature, precipitation and CIR. Changes in precipitation were mapped separately for summer (April through October) and winter (November through March) precipitation.

Results of statistical analyses are provided in Section 3 and in the Appendices.

2.5 Forest Change Hydrology

Forest disturbance, such as forest fire, disease or logging may cause an increase in runoff volume[12] because less precipitation is lost through the processes of evaporation and plant transpiration. Sub-alpine zone (elevation greater than approximately 8,500 feet) forests are known to contribute most of the run-off (MacDonald, 2003). At lower elevations, annual precipitation decreases, and there is sufficient evaporation, soil water storage, and plant transpiration processes such that there is practically no change in the volume of run-off. Forest disturbance below the sub-alpine zone has almost no effect on the quantity of run-off (MacDonald, 2003).

Empirical information regarding forest disturbance indicate at least a 20 to 30 percent reduction in forest basal area is necessary before any increase in annual water yield can be detected (Douglass and Swank 1972, Bosch and Hewlett 1982, Hornbeck et al 1997). At the scale of a small or moderately sized basin, a fire devastating 30% or more of the trees is conceivable. However, disturbance from fires large enough to affect the larger basin are not expected. Consequently, the analysis of fire disturbance is not recommended as a component of the hydrologic runoff modeling regarding forest disturbance mechanisms.

Beetle kill of Colorado's mature lodgepole pine forests exemplify forest change on a large scale (basin wide). Forest officials report that the cumulative impacted area covers 1.9 million acres (US Forest Service and Colorado State Forest Service, 2009). Infestation primarily kills mature (>80 years old and >8 inches in diameter) lodgepole pine trees (Aguayo, 2006), with smaller trees also being infested and killed on a smaller scale. Researchers predict that the epidemic may infect nearly every mature lodgepole pine forest in the State.

Temporary increases in water yield are expected from watersheds with beetle kill in even-aged stands of lodgepole pine trees (Stednick, PowerPoint). No increase in water yield is expected from uneven aged stands of trees because of regeneration or release of the understory. The hydrologic effects decrease over time as the understory and trees grow back. Because of the relatively low sensitivity of flow to clearing, and the notion that substantial vegetative recovery will occur over a period of a few decades, results of the deforestation analysis will have limited value for the two planning horizons (2040 and 2070) adopted for CRWAS.

The preferred technical approach to represent the impact of forest disturbance is use of hydrology modeling, and to be consistent with the other CWRAS efforts, the use of the Variable Infiltration Capacity (VIC) model. The model area would include the Colorado River Basin within Colorado. The scale of forest disturbance would be the area occupied by lodgepole pine. The change in run-off

[12] In addition, forest disturbance can impact the timing and rate of snow pack and snow melt (earlier peak flows) and water quality.

predicted by the VIC model can be compared to empirical ranges described by MacDonald (2003) and others.

The technical approach would include adjusting vegetation parameters within VIC cells to reflect forest change due to insect infestation. The total area of potentially impacted tree types in each VIC grid cell as a fraction of the total coniferous forest would be determined. The vegetation parameters in VIC would then be adjusted to reflect tree mortality on an area basis by reducing the coniferous forest fraction in the VIC vegetation parameter input to reflect elimination of potentially impacted tree types. The percentage of grass or understory vegetation types would be increased to reflect replacement of potentially impacted tree types by other vegetation.

Nonetheless, because an analysis of deforestation is expected to have limited value for the CRWAS planning horizons, the recommended approach is not to conduct a detailed hydrologic analysis and modeling associated with forest change as part of CRWAS. At this time, the U.S. Forest Service, in conjunction with the CWCB and the North Platte River Basin Roundtable, is completing a multi-year study to collect information regarding forest change processes that most influence the hydrology of disturbed forests within Colorado. Information from the study is expected to better describe corresponding hydrologic processes, and to constrain assumptions, to be used in future hydrological models. It may be appropriate to monitor this and other ongoing research in order to re-assess the potential for quantifying the impact of forest change when the results of that ongoing work become available.

Where to find more detailed information:

CRWAS Task 7.3 / 7.4 – *Forest Change Literature Review and Suggested Methods* technical memo is available at http://cwcb.state.co.us/.

2.6 Colorado River Compact Considerations

This Study provides quantitative estimates of the amount of consumptive use, above existing levels, that can occur within Colorado under certain compact assumptions ("water available for future consumptive use"). The assumptions used in this Study were for modeling purposes only and their use does not represent any policy or legal position of the State of Colorado.

2.6.1 Compact Assumptions

In addition to hydrologic variables, the technical evaluation of the water available for future consumptive use in Colorado is influenced by consideration of the documents that govern allocation and management of the Colorado River among the Colorado River Basin States (referred to as the "Law of the River"). The Law of the River includes the 1922 Colorado River Compact, the 1944 Water Treaty between the United States and Mexico, the 1948 Upper Colorado River Basin Compact, and many other documents. The Law of the River is interpreted differently by the stakeholders who are potentially affected by application of the Law of the River. Therefore, this Study sets forth certain assumptions regarding the Law of the River to develop a quantitative estimate of the amount of consumptive use, above existing levels, that can occur within Colorado under specific compact considerations. Such assumptions are for Phase I technical purposes only and do not represent any policy or legal position of the State of Colorado. For modeling purposes, the Study assumes a minimum and maximum ten year flow obligation at Lee Ferry of 75 MAF and 82.5 MAF. In addition, for purposes of this Study only, the models also incorporate assumptions concerning the distribution and allocation of Colorado River water among the Upper Division States. Specifically, the model adopts the calculations of Upper Basin water use from the 2007 Hydrologic Determination, and assumes that all Upper Basin states will be physically using their full apportionments.

Where to find more detailed information:

More detail on the provisions of relevant documents in the Law of the River can be found in CRWAS Technical Memorandum Task 8.1 – *Summarize Key Issues*, available at http://cwcb.state.co.us/ .

2.6.2 Alternative Methods of Analysis

CRWAS Technical Memorandum Task 8.2 – *Colorado River Compact Overview and Analysis, Approach* describes an approach for estimating the quantity of supplementation flows using the Colorado River Simulation System (CRSS) model. Subsequently, Phase I analyses include estimation of the quantity of supplemental flows needed for compliance with the Colorado River Compact, by the States of the Upper Division, and estimation of water available for future consumptive use by Colorado. Two methods of analysis were used to assure there is no underestimation of the physical ability of Colorado to consumptively use water. The two methods of analysis are 1) use of the existing Colorado River Simulation System (CRSS) and 2) a simulation based on the mass balance analysis used in the 2007 Hydrologic Determination (U.S. Department of the Interior, 2007). These methods of analysis were used in order to utilize recognized methodologies for the State's planning purposes. In so doing, this Study and the state of Colorado have adopted neither the methodology nor the assumptions of the CRSS or the Hydrologic Determination.

Initial analyses gave indications that the CRSS model may underestimate the ability of Upper Basin states to put their full demand for water physically to use under conditions that are drier than conditions experienced over the historical period. The structure of the CRWAS mass balance analysis puts no limitation on physical use of water. While this may overestimate physical use, it ensures that the assumptions concerning the Colorado River Compact are the sole limitation to water use in the Upper Basin, which results in the best estimate of the water available for future consumptive use in Colorado. There may be other physical or legal limitations that may limit consumptive use within Colorado, but Phase 1 of this study did not analyze those limitations. Accordingly, the results from the CRWAS mass balance analysis were used as the basis for quantifying the amount of water available for future consumptive use in Colorado under specific compact assumptions.

Figure 2-17 provides a reference to the physical arrangement of the important locations on the Colorado River relevant to the accounting of the cumulative flow requirement of the Colorado River Compact.

Figure 2-17 – Colorado River Basin and Important Locations near Lee Ferry

Hydrologic Determination Mass Balance Analysis

Section 11(a) of the Navajo Indian Irrigation and San Juan-Chama Projects Authorizing Act (P.L. 87-483) (1962) requires the Secretary of the Interior to determine "by hydrologic investigations" that there is enough water available to New Mexico under its Upper Colorado River Basin Compact allocation prior to executing any long-term contract for water stored in Navajo Reservoir.[13] In order to utilize an

[13] *See* P.L. 87-483, § 13(c) (1962) ("No right or claim to the use of the waters of the Colorado River system shall be aided or prejudiced by this Act, and Congress does not, by its enactment, construe or interpret any provision of

existing methodology for planning purposes, this Study utilized portions of the 2007 Hydrologic Determination (hereinafter "Hydrologic Determination"; U.S. Department of the Interior, 2007). In so doing, this Study and the state of Colorado have adopted neither the methodology nor the assumptions of the Hydrologic Determination.

The Hydrologic Determination employed a mass balance analysis, the results of which are provided in Appendix A of that document. The mass balance analysis encompassed the Upper Basin above the Lees Ferry gauge. The mass balance was conducted on an annual basis; for each year it accounted for all inflows above Lees Ferry, any carryover storage in Upper Basin reservoirs, shared evaporation (from Lake Powell, Flaming Gorge and the Aspinall Unit), water use in the Upper Basin and flows below Lees Ferry, including spills and reservoir releases.

For this Study, the Hydrologic Determination mass balance analysis was implemented in computer codes that would automatically apply the analysis to the twenty-two separate datasets that are used to characterize current and projected hydrologic conditions. Other modifications to the Hydrologic Determination are described in CRWAS Technical Memorandum 8.6 – *Summarize Compact Effects*. The most significant of these include:

- Representing the 10-year cumulative volume passing Lee Ferry and reducing the amount of consumptive use in the mass balance analysis when necessary to prevent that volume from falling below the 10-year cumulative flow obligation set out in the Colorado River Compact.
- Establishing a method to choose the most appropriate initial conditions for each 56-year trace.

This implementation of the Hydrologic Determination mass balance is referred to as the CRWAS mass balance analysis.

In 1999 the Upper Colorado River Commission (UCRC) adopted depletion estimates for the states of the Upper Division. In those estimates, total consumptive use in the Upper Basin exclusive of CRSP evaporation projected for 2060 was 5.415 MAF and shared evaporation from CRSP storage units was 0.546 MAF. The UCRC revised the estimates for the year 2060 on December 12, 2007 to 5.573 MAF; exclusive of CRSP evaporation (no value for shared evaporation was included in those estimates). All of the analyses used in the CRWAS mass balance analysis represented Upper Basin water use in excess of the depletion estimates adopted by the UCRC and assumed all Upper Basin states would use their entire apportioned amount.

Where to find more detailed information:

CRWAS Technical Memorandum Task 8.2 – *Colorado River Compact Overview and Analysis Approach* described an approach for estimating the quantity of supplementation flows using the Colorado River Simulation System (CRSS) model; CRWAS Technical Memorandum 8.6 – *Summarize Compact Effects* describes approach related to the Hydrologic Determination, both available at http://cwcb.state.co.us/.

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the Colorado River compact, the Upper Colorado River Basin compact, the Boulder Canyon Project Act, the Boulder Canyon Project Adjustment Act, the Colorado River Storage Project Act, or the Mexican Water Treaty…").

2.6.3 Water Available for Future Consumptive Use by Colorado

Model results from the CRWAS mass balance analysis included the annual volume of consumptive use available to the Upper Basin under compact assumptions. Colorado's share of the amount of water available for future consumptive use in the Upper Basin was calculated by subtracting Arizona's share (50 KAF) from the basin-wide amount and multiplying the remainder by Colorado's percentage share, set out in the Upper Colorado River Basin Compact, which is 51.75%.

Estimation of Current Colorado Consumptive Use

Estimates of current levels of consumptive use in Colorado were obtained by applying the StateMod models to simulate current conditions. StateMod was used to estimate current levels of consumptive use in Colorado based on the 56-year hydrologic period 1950 through 2005. Estimates of agricultural demand based on current levels of irrigated acreage and historical climate conditions, and current levels of municipal and industrial demands were superimposed on historical hydrology. StateMod then estimated diversions and associated consumptive use, and reservoir contents and evaporation, based on water available to currently perfected water rights. Basin-wide consumptive use estimates have been adjusted to exclude shared evaporation from the Aspinall Unit Reservoirs, which are considered "system" losses, and exports to New Mexico through the San Juan-Chama Project, which are chargeable to that state.

The result is an estimated average consumptive use of 2.7 MAF. This estimate represents the current capacity of the water supply systems within Colorado, when used to their full capability, both legally and physically. For this reason this estimate is higher than the estimates of actual consumptive use used by the CWCB of about 2.3 MAF as of 2010 (projected from 2004) but it is consistent with values of current consumptive use that have been used as the basis for other estimates of water available for future consumptive use in Colorado.

Results associated with Colorado River Compact analysis are provided in Section 3.9.

In Association with
AMEC Earth & Environmental
Canyon Water Resources
Leonard Rice Engineers
Stratus Consulting

Findings

3 FINDINGS

This section provides descriptions of primary CRWAS findings associated with the following list of quantitative parameters. In addition to the list below, the last part of this section provides a description of general qualitative Study findings.

- Temperature
- Precipitation
- Crop Irrigation Requirement
- Natural Streamflow
- Modeled Streamflow
- Water Available to Meet Future Demands
- Modeled Reservoir Storage
- Modeled Consumptive Use
- Colorado Water Availability for Future Consumptive Use

Presentation of Findings

The primary chart types used to present quantitative Study findings are referred to herein as “Band Charts” (monthly hydrograph charts) and “Low-Flow Comparison Charts”, for which sample figures and descriptions are included below.

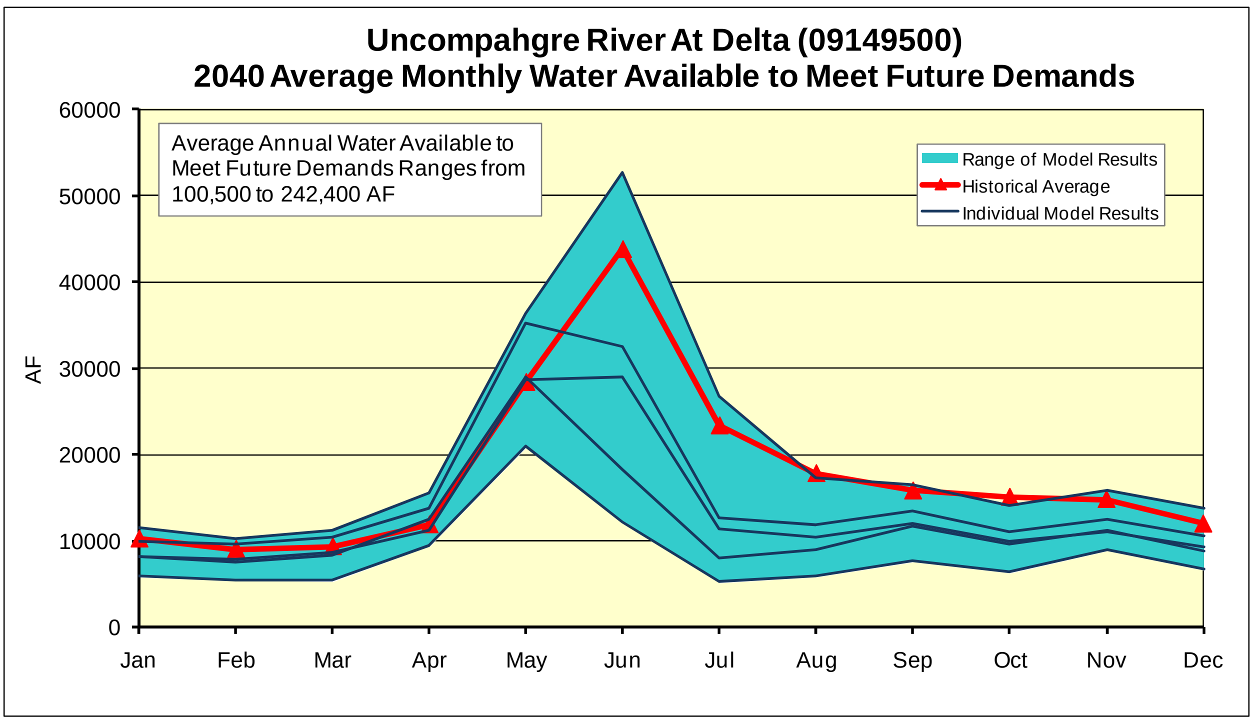
Each of the five projections of future climate for a particular time period (2040 or 2070) represents alternative possible futures with respect to mean climate conditions. The band charts and the low-flow comparison charts in the following sections show the range of those possible futures with respect to historical conditions that were experienced in the 56 years from 1950 through 2005.

Comparisons are sometimes made in the text between historical average values and values estimated by averaging the five climate projections. When the five climate projections are averaged together for comparison, they are referred to as the five climate projections’ “combined average”. For instance, if historical climate-based average annual values are compared to the average of the five climate projections average annual values, the reference will read “historical average annual values are greater than the five climate projections’ combined average.”

Band Charts

The following figure illustrates graphically the effect of projected future climate on the average monthly distribution of flows. This monthly hydrograph chart (band chart) shows several pieces of information. The red line connecting filled triangles represents the average monthly hydrograph from the historical record during the Study period. The estimated average monthly hydrographs for the five different projections of future climate are represented by the thin dark blue lines. The filled band shows at a glance the overall range of the projected future average monthly hydrographs. This chart can help understand how runoff and low flows may shift during the year, and illustrates the uncertainty inherent in the climate projections (projection-to-projection variability).

Each of the five projections of future climate for a particular time period (2040 or 2070) represents alternative possible futures with respect to mean climate conditions. The band charts show historical average monthly values (in CRWAS, the Study period lasted 56 years, so the historical monthly averages for that duration are shown), and the average monthly value for each of the five climate projections. The wide cyan band encompasses the range of the alternative possible future values, calculated from the five climate projections.

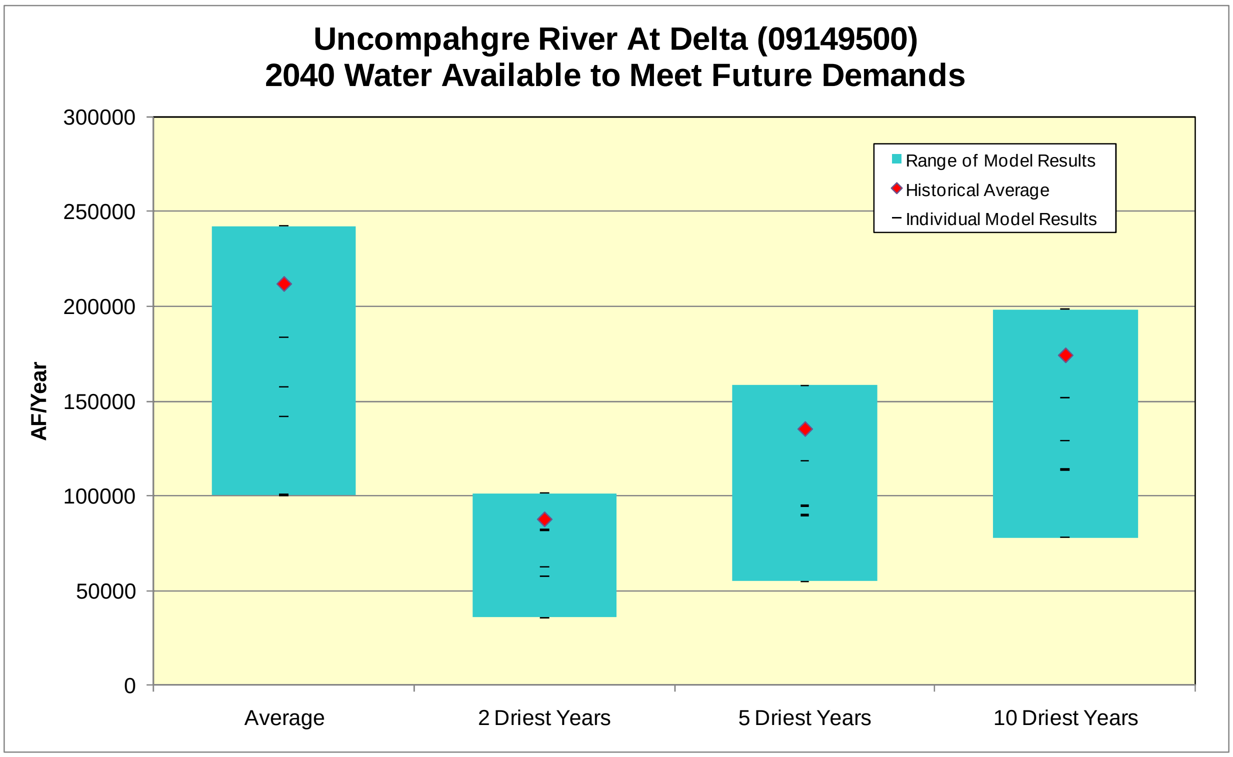


Example Presentation of Findings (Band Chart)

Low-Flow Comparison Charts

The following figure illustrates the effect of projected future climate conditions on mean flows and on low-flow events. From left to right, the chart represents four statistics of annual flow: average annual flow over the 56-year study period, the lowest consecutive 2-year average flow in the 56-year study period, the lowest consecutive 5-year average flow in the 56-year study period, and the lowest consecutive 10-year average flow in the 56-year study period.

For each statistic several pieces of information are shown. The red filled diamond represents the value of the statistic from the historical record during the Study period. The estimated values of the statistics for the five different projections of future climate are represented by dashes. The wide cyan-colored bars show the overall range of the projected future values of the statistic.



Example Presentation of Findings (Low-Flow Comparison Chart)

3.1 Temperature

Temperatures based on projected climate changes were compared to historical temperatures at the 54 climate stations used in the consumptive use analyses. These 54 climate stations are located throughout the Study basins, as shown in Figure 3-1, and represent areas of agricultural production. Figure 3-1 shows the increase in average annual temperature for the 2040 climate projections compared to historical average annual temperature, based on the 54 climate stations shown in the figure over the 1950 through 2005 study period.

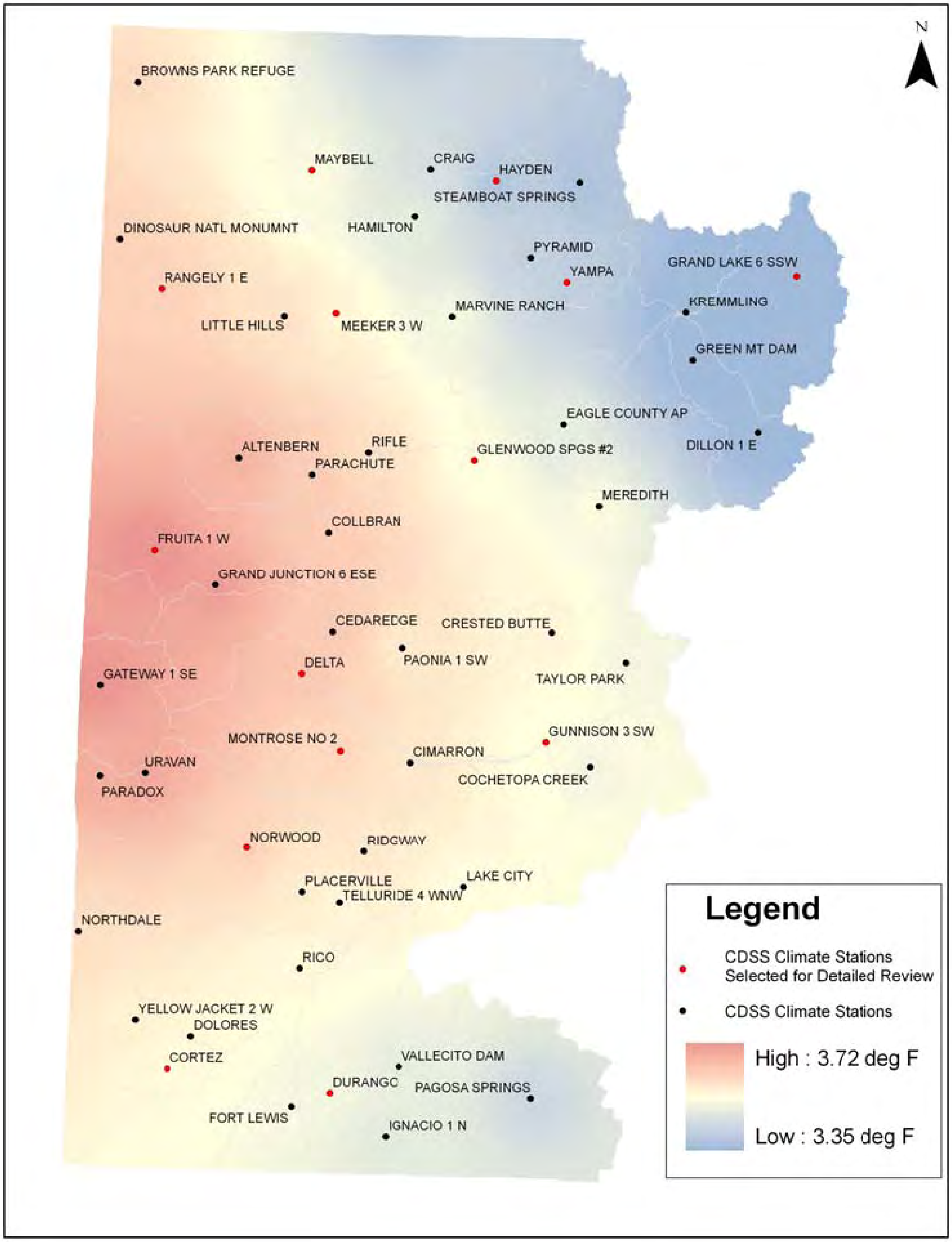


Figure 3-1 – 2040 Projected Average Annual Temperature Increase from Historical (deg F)

Table 3-1 presents the range of average annual temperature increases from historical values for the 2040 climate projections at selected climate stations. Temperature increases are based on the 1950 through 2005 study period. Also presented is the average of the five 2040 climate projections compared to historical values. The climate stations presented in the table were selected to represent lower, middle, and higher elevations in each of the Study basins. The table includes the elevation and elevation designation, plus the location as generally in the northern or southern part of the State. The spatial distribution of these selected climate stations are shown as red dots in Figure 3-2

Table 3-1 – 2040 Average Annual Projected Temperature Compared to Historical Temperature

Climate Station	Elevation	Elevation Designation	Location	Increased Temperatures Degrees Fahrenheit		
				Lowest Projection	Highest Projection	Average of Projections
Fruita 1W	4480	Lower	North	2.0	5.4	3.7
Glenwood Springs 2	5880	Mid	North	1.8	4.6	3.5
Grand Lake 6SSW	8288	Higher	North	1.6	5.0	3.3
Rangely 1E	5290	Lower	North	1.9	5.3	3.6
Meeker 3W	6180	Mid	North	1.9	5.3	3.6
Maybell	5908	Lower	North	1.8	5.2	3.5
Hayden	6440	Mid	North	1.7	5.1	3.4
Yampa	7890	Higher	North	1.8	5.2	3.5
Delta 3E	5010	Lower	South	1.9	5.3	3.7
Montrose No 2	5785	Mid	South	1.8	5.3	3.6
Gunnison 3SW	7640	Higher	South	1.7	5.2	3.5
Cortez	6153	Lower	South	1.9	5.4	3.6
Durango	6592	Mid	South	1.8	5.3	3.5
Norwood	7020	Higher	South	1.9	5.3	3.6

The basin-wide increase for the five climate change projections' combined average is 3.6 degrees Fahrenheit. As shown, the 14 stations show combined average increases ranging from 3.3 to 3.7 degrees Fahrenheit. The lowest increase in average annual projected temperature is 1.6 degrees Fahrenheit in Grand Lake and the greatest increase in average annual projected temperature is 5.4 degrees Fahrenheit in both Fruita and Cortez. The following general trends can be observed from Table 3-1 and Figure 3-1:

- Each of the five climate projections shows average annual temperature increasing over historical values.
- The increase in temperature is greater at lower elevations.
- The increase in temperature is less than the basin-wide average at the higher elevation stations of Grand Lake, Yampa, and Hayden.

Figure 3-2 shows the average monthly temperature for each 2040 climate projection compared to the historical average monthly temperature at the Delta climate station over the 1950 through 2005 study period. Similar graphs are included in Appendix A for each selected climate station for both 2040 and

2070 projections. As with Figure 3-1, similar figures in Appendix A generally shows that temperature increases are similar for each month.

Taken as a whole, the temperature graphs for the 2040 time frame show that the temperature increases each month and that there is not a wide range of average temperatures between the five climate projections.

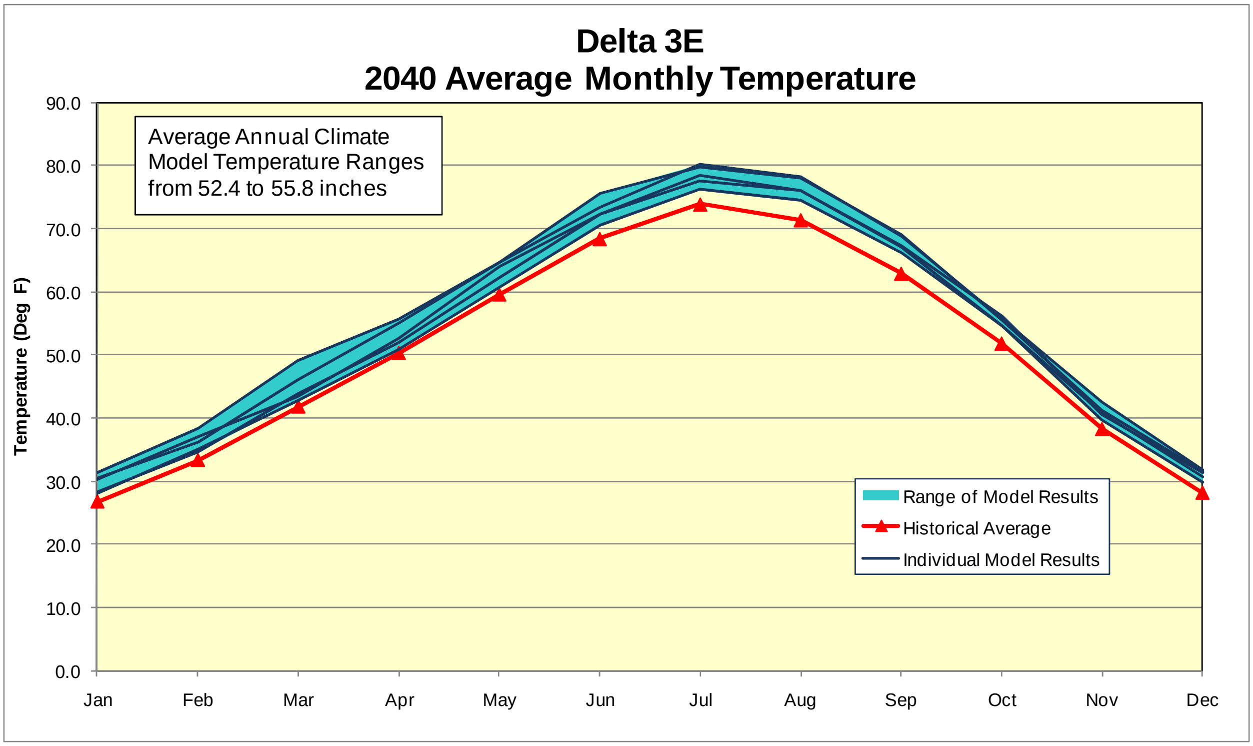


Figure 3-2 – Delta 2040 Average Monthly Temperature Comparison

3.2 Precipitation

Climate projected precipitation was compared to historical precipitation at the 54 climate stations used in the consumptive use analyses. Winter months (November through March) and the months of April through October show different trends, therefore are discussed separately. Table 3-2 presents the range of average winter (November through March) precipitation variation from historical values for the combined 2040 climate projections at selected climate stations over the 1950 through 2005 study period. Also presented is the combined average of the five 2040 climate projections compared to historical values. The climate stations represent lower, mid, and higher elevations in each of the Study basins. The table includes the elevation and elevation designation, plus the location as generally in the northern or southern part of the State.

Table 3-2 – 2040 Average Winter (Nov through Mar) Projected Precipitation Compared to Historical Precipitation

Climate Station	Elevation	Elevation Designation	Location	Percent of Historical *		
				Lowest Projection	Highest Projection	Average of Projections
Fruita 1W	4480	Lower	North	96%	112%	106%
Glenwood Springs 2	5880	Mid	North	104%	115%	109%
Grand Lake 6SSW	8288	Higher	North	109%	122%	113%
Rangely 1E	5290	Lower	North	103%	115%	109%
Meeker 3W	6180	Mid	North	103%	116%	109%
Maybell	5908	Lower	North	104%	118%	110%
Hayden	6440	Mid	North	107%	121%	112%
Yampa	7890	Higher	North	107%	121%	111%
Delta 3E	5010	Lower	South	99%	112%	107%
Montrose No 2	5785	Mid	South	98%	114%	108%
Gunnison 3SW	7640	Higher	South	101%	116%	109%
Cortez	6153	Lower	South	87%	115%	107%
Durango	6592	Mid	South	92%	116%	108%
Norwood	7020	Higher	South	95%	113%	107%

*Less than 100% difference indicates less annual projected rainfall than historical.

Figure 3-3 shows the combined average increase in precipitation during the winter months of November through March for the 2040 climate projections as a percentage of historical average winter precipitation over the 1950 through 2005 study period, based on the 54 climate stations used in the CDSS modeling. The basin-wide combined average precipitation for the five projections in winter months is 109 percent of historical average. Winter precipitation change from historical varies by location. The following general trends can be observed:

- Combined average winter precipitation for the five 2040 climate projections increases from historical values basin-wide, ranging from 106 to 113 percent of historical winter precipitation.
- The projections show winter precipitation both increasing and decreasing throughout the State for individual climate projections.
- Each of the five projections show increases in winter precipitation at the northern most climate stations in the Yampa and White basins.
- Each of the five projections shows an annual increase at the highest elevation climate stations, including Yampa, Grand Lake and Gunnison.
- The stations with the least combined average increase in precipitation are at the lower elevations and in the southwest portion of the State.
- Coupled with the increase in temperature during the winter months, the projections indicate a shift from snow to rain in the early and late winter months.

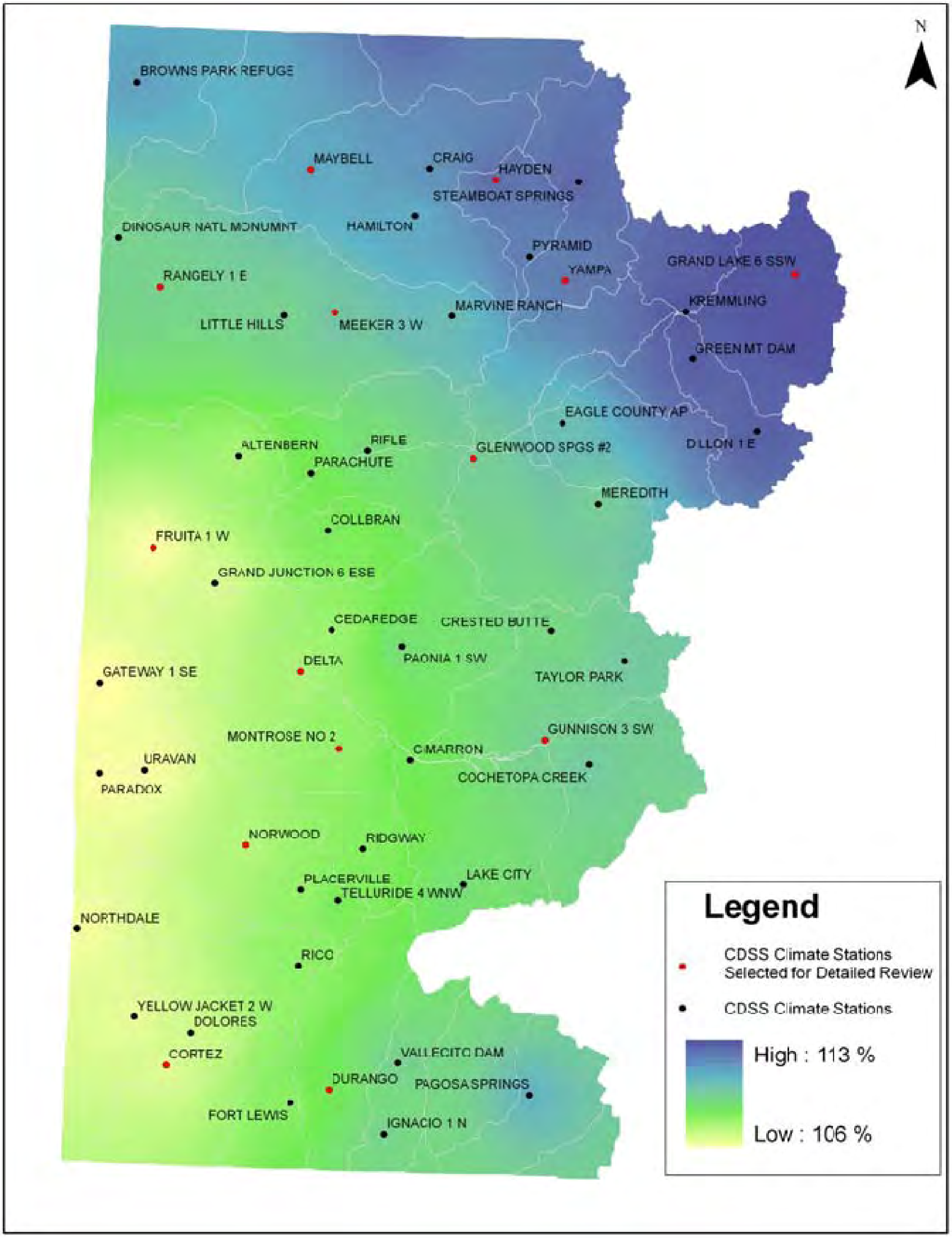


Figure 3-3 – 2040 Percent of Historical Winter (November - March) Precipitation

Table 3-3 presents the range of average April through October precipitation variation from historical values for the combined 2040 climate projections at selected climate stations over the 1950 through 2005 study period. Also presented is the combined average of the five 2040 climate projections compared to historical values. The climate stations represent lower, mid, and higher elevations in each of the Study basins. The table includes the elevation and elevation designation, plus the location as generally in the northern or southern part of the State.

Table 3-3 – 2040 Average Apr through Oct Projected Precipitation Compared to Historical Precipitation

Climate Station	Elevation	Elevation Designation	Location	Percent of Historical *		
				Lowest Projection	Highest Projection	Average of Projections
Fruita 1W	4480	Lower	North	81%	102%	91%
Glenwood Springs 2	5880	Mid	North	82%	107%	93%
Grand Lake 6SSW	8288	Higher	North	82%	104%	92%
Rangely 1E	5290	Lower	North	82%	104%	94%
Meeker 3W	6180	Mid	North	82%	105%	94%
Maybell	5908	Lower	North	83%	106%	95%
Hayden	6440	Mid	North	81%	107%	95%
Yampa	7890	Higher	North	81%	107%	95%
Delta 3E	5010	Lower	South	82%	104%	92%
Montrose No 2	5785	Mid	South	82%	104%	91%
Gunnison 3SW	7640	Higher	South	82%	106%	90%
Cortez	6153	Lower	South	79%	102%	90%
Durango	6592	Mid	South	80%	103%	91%
Norwood	7020	Higher	South	82%	104%	92%

Figure 3-4 shows the combined average decrease in precipitation during the months of April through October for the 2040 climate projections as a percentage of historical average precipitation over the 1950 through 2005 study period, based on the 54 climate stations used in the CDSS modeling. The basin-wide combined average precipitation for the five projections during the months of April through October is 93 percent of historical average. The following April through October precipitation trends can be observed:

- Combined average April through October precipitation for the five 2040 climate projections decreases from historical basin-wide, ranging from 90 to 96 percent of historical April through October precipitation.
- The projections show April through October precipitation both increasing and decreasing throughout the State for individual climate projections.
- April through October precipitation decreases more in the southwestern corner of the State, and decreases less at higher elevations.

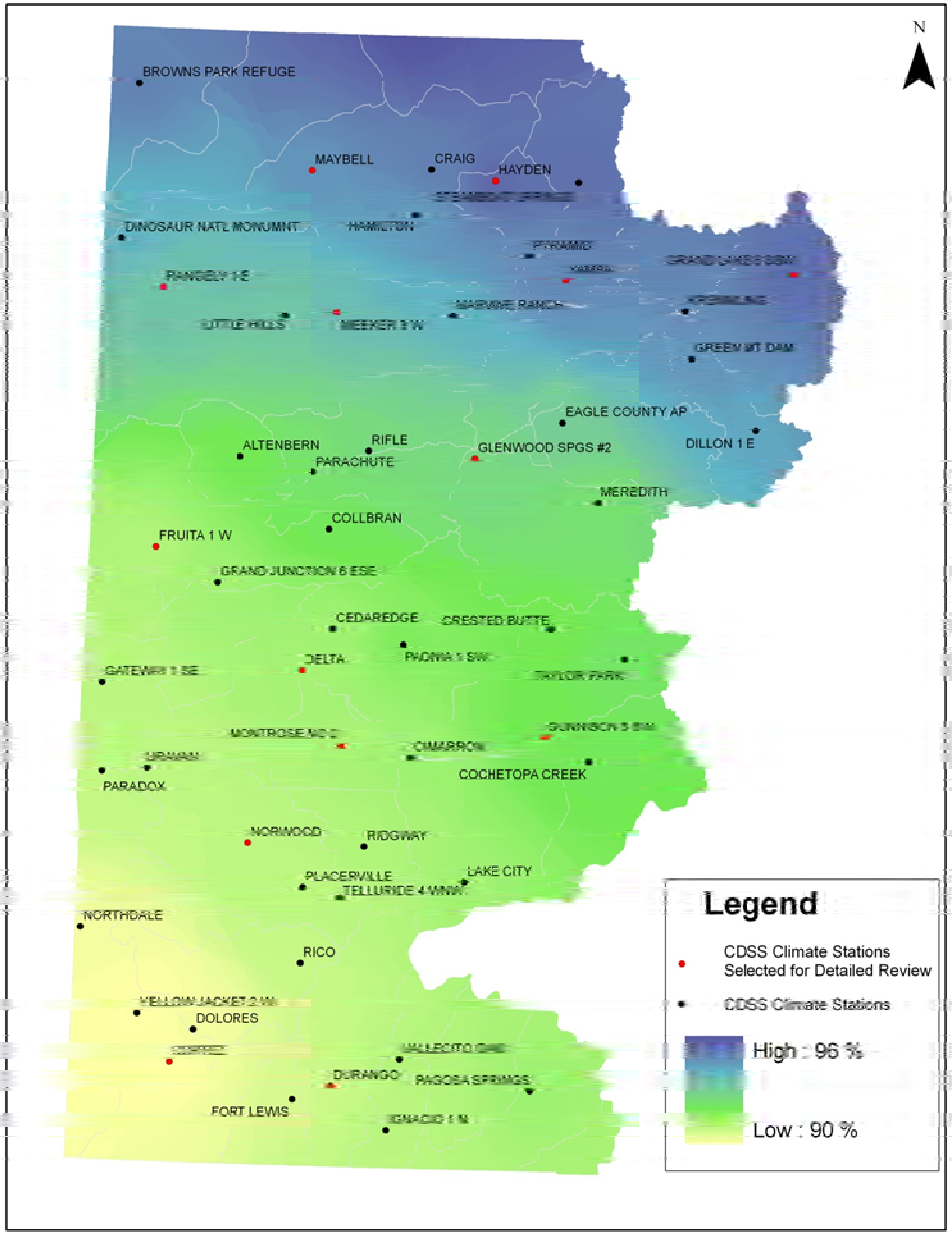


Figure 3-4 – 2040 Percent of Historical Winter (November - March) Precipitation

Figure 3-5 shows the average monthly precipitation for each 2040 climate projection compared to the historical average monthly precipitation for the 1950 through 2005 study period at the Delta climate station. Similar graphs are included in Appendix B for each selected climate station for both 2040 and 2070 projections. As with Figure 3-5, figures in Appendix B generally show the following:

- Each of the climate projections show precipitation generally greater than historical averages during the winter months from November through March throughout the Study basins. However, it is only slightly higher in the winter months for the lowest elevation station at Fruita, and for the southern-most stations including the Cortez, Norwood, and Durango.

- Most of the climate projections show precipitation less than historical averages during the irrigation season, from May through October, with the exception of July. Average projected precipitation in July is about the same as historical average July precipitation throughout the Colorado basins.

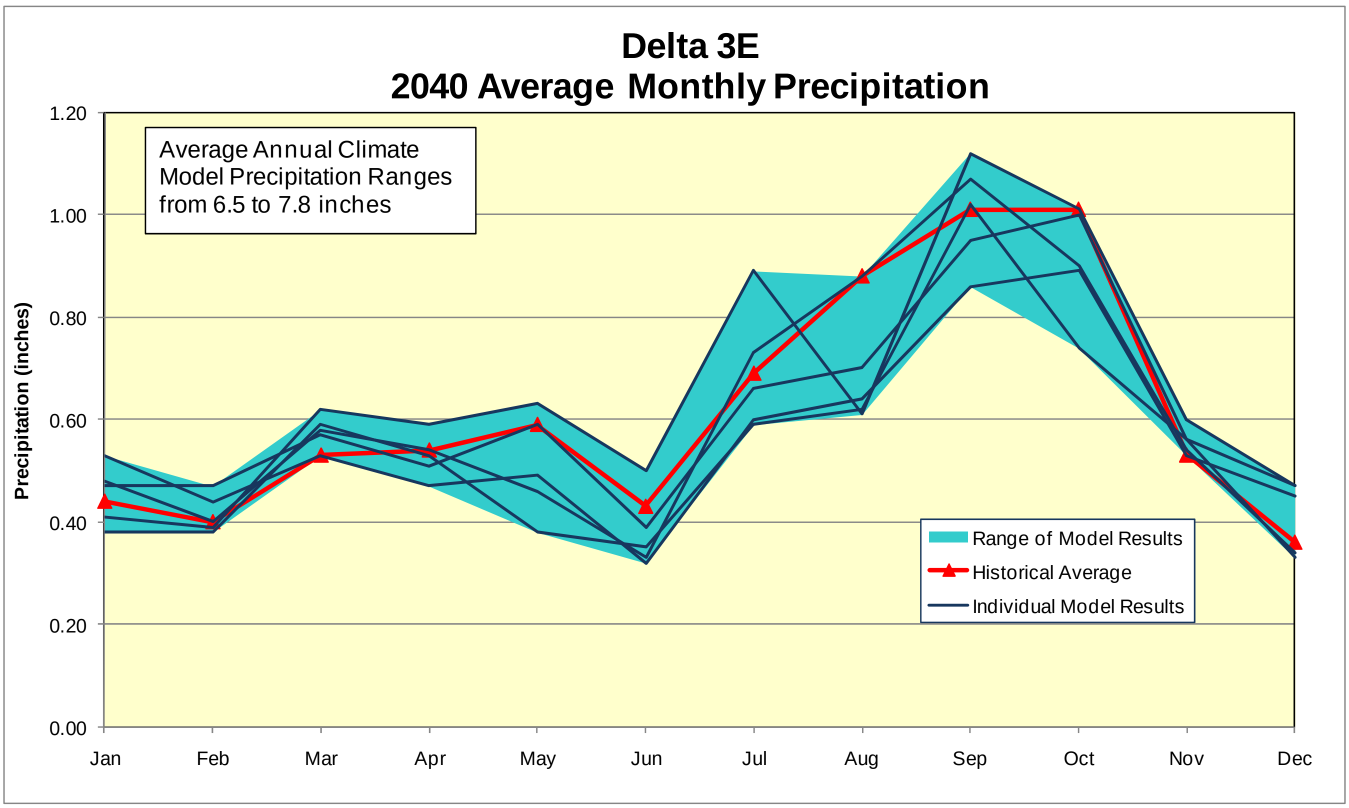


Figure 3-5 – Delta 2040 Average Monthly Precipitation Comparison

Climate model experts recognize that there is more uncertainty in the global climate models' ability to predict summer precipitation than winter precipitation. According to the CWCB-sponsored report "Climate Change in Colorado, a Synthesis to Support Water Resources Management and Adaptation, "the scale of global climate models limits their ability to accurately predict the local thunderstorms that dominate rainfall during the summer months in the Study basins." In addition, the report indicates that larger scale systems such as the monsoon-based conditions that strongly influence the southern areas of the State are not well simulated by climate models. Until more detailed global climate models are created that better represent "regional" weather processes that affect temperature and precipitation of the Colorado River basin, the scientific information used in this Study is currently the best available for a study of this nature.

Where to find more detailed information:

Climate Change in Colorado, a Synthesis to Support Water Resources Management and Adaptation available at http://wwa.colorado.edu/.

3.3 Crop Irrigation Requirement

Crop Irrigation Requirements at Climate Stations

Crop irrigation requirements were estimated using the monthly Blaney-Criddle methods in StateCU, as discussed in Section 2.4.4. The Blaney-Criddle method relies on mean monthly temperature to both define the growing season, and in the monthly equation, to determine potential crop consumptive use. Therefore, as temperature increases, potential crop consumptive use increases.

Crop irrigation water requirement is determined by subtracting the amount of monthly precipitation estimated to be effective in directly meeting crop demands from potential crop consumptive use. Therefore, as irrigation season precipitation decreases, crop irrigation requirement increases.

Table 3-4 presents the combined average annual grass pasture crop irrigation requirement variations from historical for the 2040 climate projection scenarios at the selected climate stations based on the 1950 through 2005 study period. Also shown is the average change in the start and end of the growing season for grass pasture compared to historical seasons.

Table 3-4 – 2040 Average Annual Grass Pasture CIR and Growing Season Length Compared to Historical

Climate Station	% Difference CIR	Increase In CIR (inches)	Earlier Start of Growing Season (days)	Later End to Growing Season (days)	Increase to Growing Season (days)
Fruita 1W	21%	6.4	11	7	18
Glenwood Springs	25%	5.8	11	8	19
Grand Lake 6SSW	16%	3.7	9	9	18
Rangely 1E	22%	6.0	9	7	16
Meeker 3W	28%	5.5	10	8	18
Maybell	26%	5.2	9	7	16
Hayden	25%	4.8	8	7	15
Yampa	13%	3.3	9	8	17
Delta 3E	21%	6.4	11	7	18
Montrose No 2	23%	6.4	12	8	20
Gunnison 3SW	13%	3.5	9	7	16
Cortez	24%	6.2	14	8	22
Durango	10%	2.8	13	8	21
Norwood	10%	2.7	9	8	16
Average	**20%**	**4.9**	**10.5**	**7.6**	**18.1**

As shown in Table 3-4, crop irrigation requirement based on the 2040 climate projection scenarios increased by 20 percent throughout the Colorado River basins, resulting in an average annual increase in crop irrigation requirement ranging from 2.7 to 6.4 inches per year. The following general trends can be observed:

- Increases in crop irrigation requirement throughout the Colorado River basins are primarily due to higher temperature, which increases: 1) the number of days in the growing season for perennial crops such as grass pasture, alfalfa, and orchards and 2) the crop demand for irrigation water. In addition, precipitation is less during the growing season, decreasing the amount of crop demand satisfied from effective precipitation; thereby increasing the crop demand for irrigation water.

- The increase in crop irrigation requirement is greater at lower elevation stations including Fruita, Delta, Montrose, and Cortez.

Figure 3-6 shows the average monthly grass pasture CIR at the Delta climate station for each of the 2040 climate projections compared to the historical average monthly CIR for the 1950 through 2005 study period. Similar graphs are included in Appendix C for each selected climate station for both 2040 and 2070 projections. As with Figure 3-6, the figures shown in Appendix C generally show that peak CIR continues to be in the same month as occurred historically (July in most locations throughout the Study basins) except as noted below.

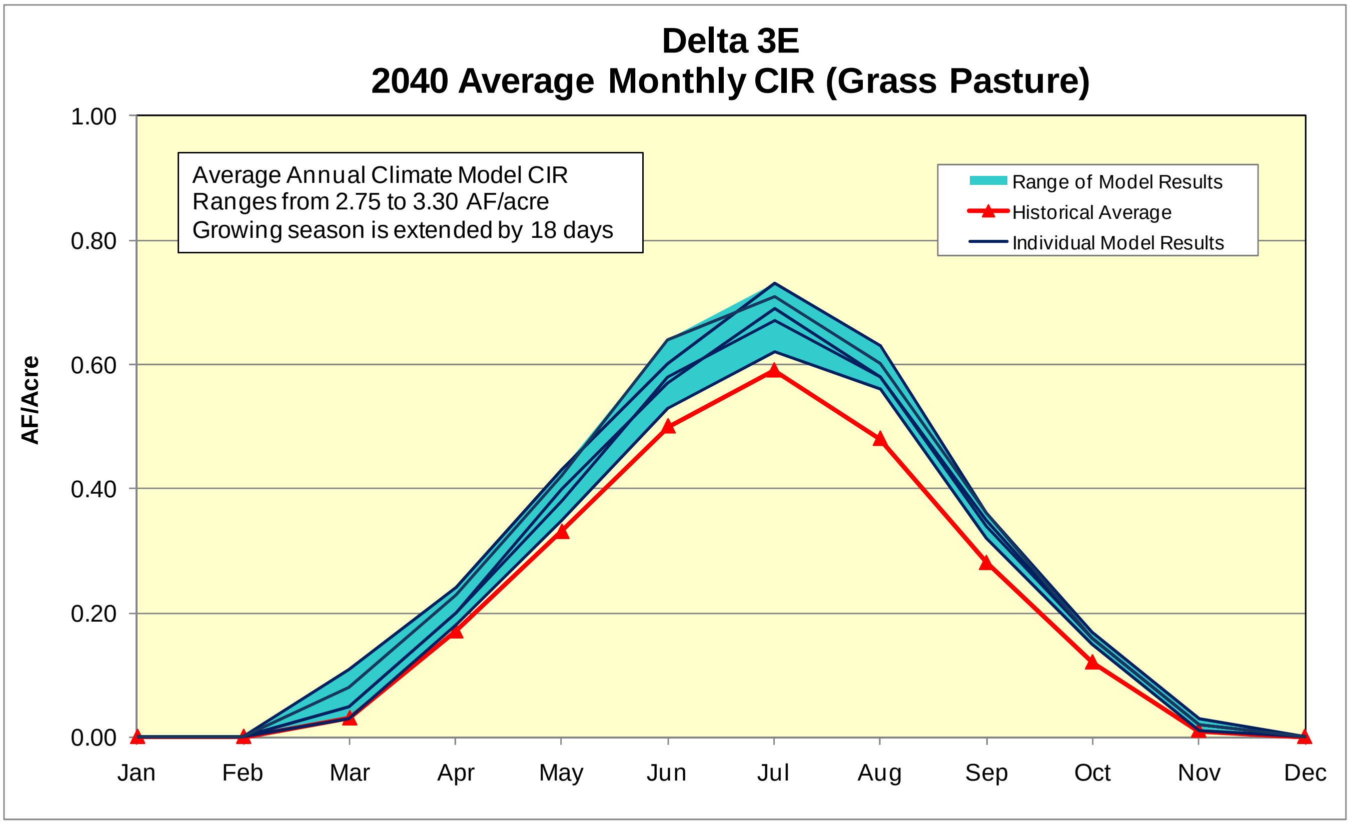


Figure 3-6 – Delta 2040 Average Monthly CIR Comparison

Figure 3-7 shows the average monthly grass pasture CIR at the Gunnison climate station for each of the 2040 climate projects compared to the historical average monthly CIR for the 1950 through 2005 study period. Similar to the Gunnison climate stations, the figures for the higher elevation stations including Grand Lake, Yampa, Durango, and Norwood, included in Appendix C, show both the peak historical and climate projected CIR in June.

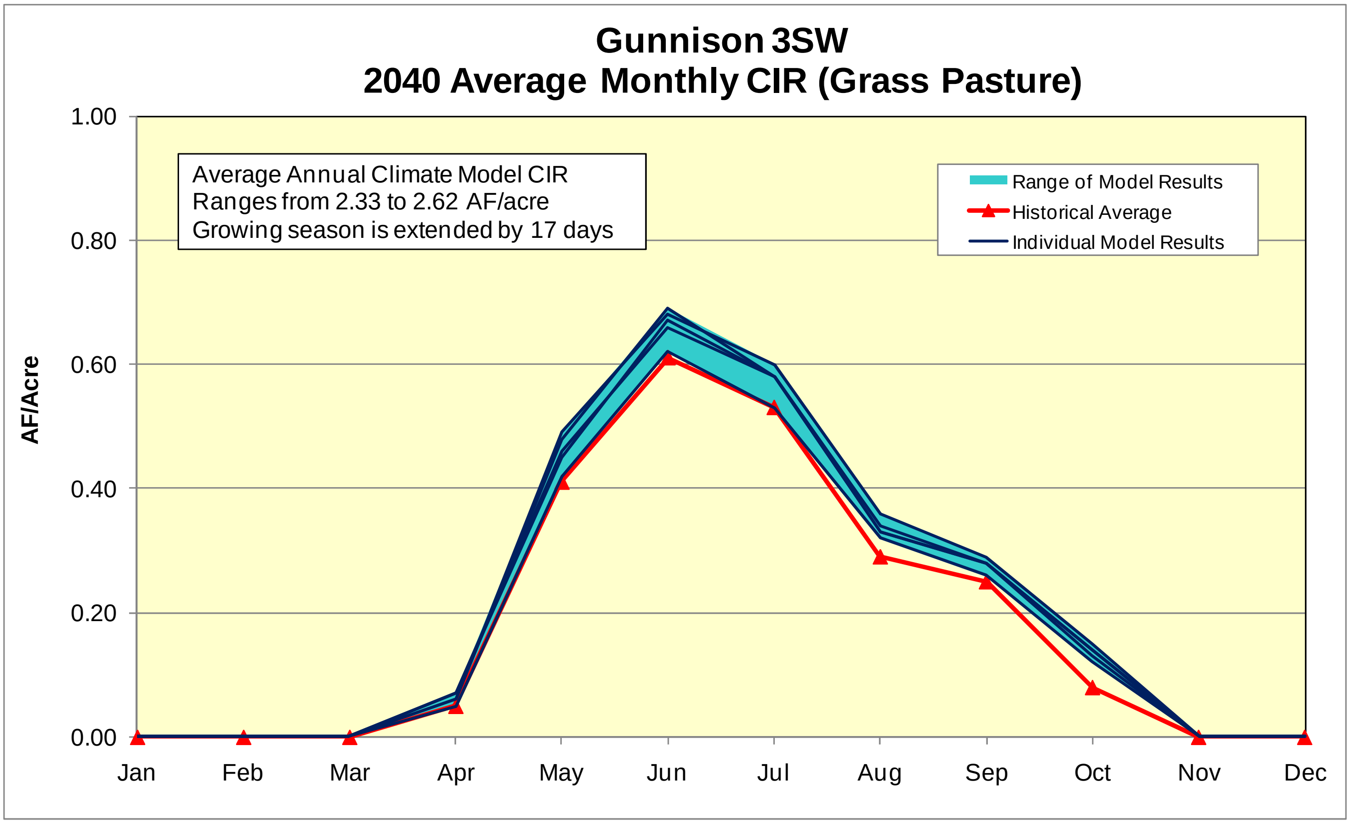


Figure 3-7 – Gunnison 2040 Average Monthly CIR Comparison

Figure 3-8 spatially shows the increase in combined average annual CIR for the 2040 climate projections compared to historical average CIR, based on the 54 climate stations used in the CDSS modeling over the 1950 through 2005 study period. This spatial representation further highlights the greater increase in annual CIR at lower compared to higher elevations.

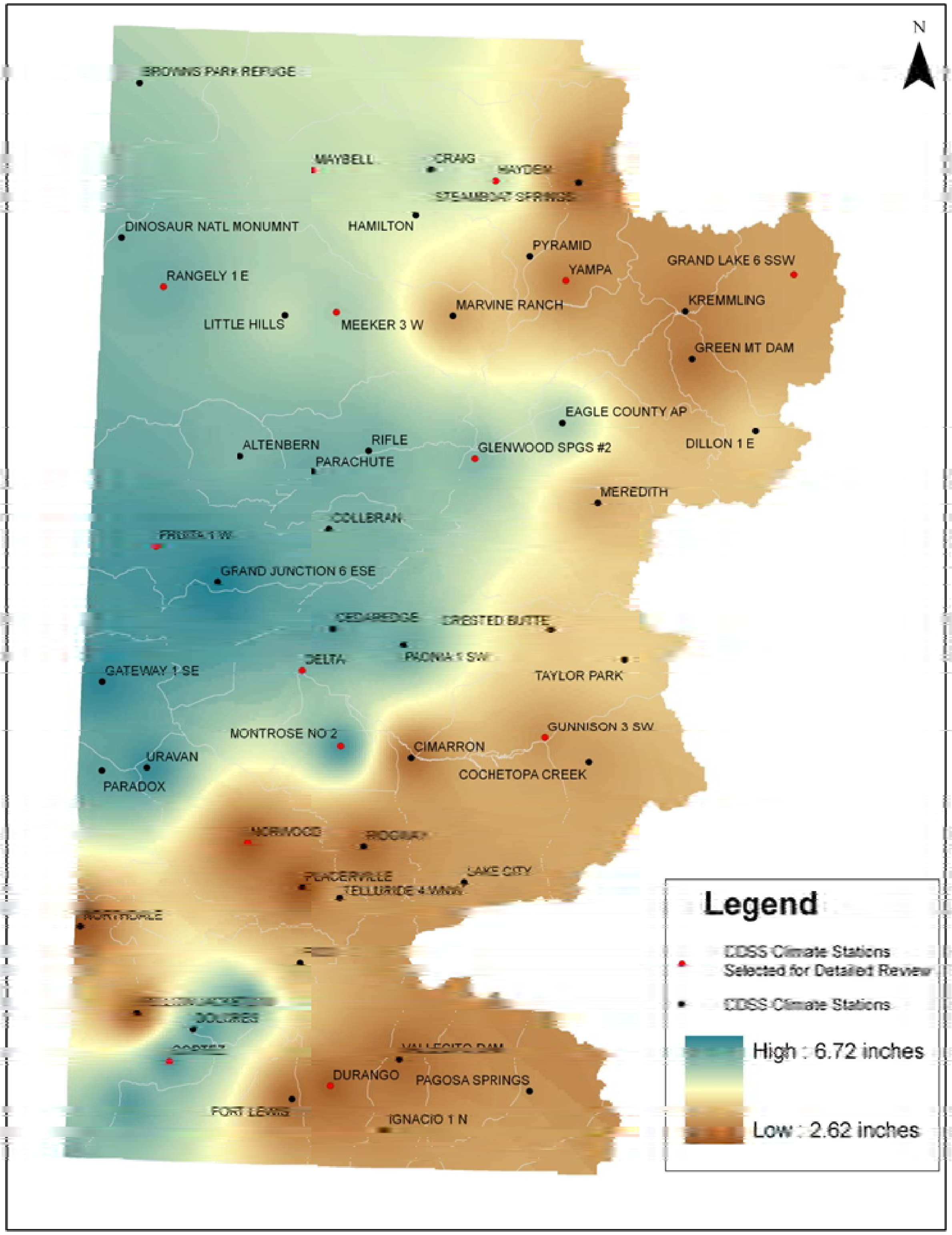


Figure 3-8 – 2040 Increase in Grass Pasture CIR from Historical CIR (inches)

As discussed in Section 2.4.6, the increase in CIR directly impacts irrigation diversion demands represented in the water resources planning models. The results here have been summarized based on grass pasture, which represents about 80 percent of the irrigated acreage in the basin. Other perennial crops grown in the Study basins, including alfalfa and orchard, account for an additional 12 percent of the total irrigated acreage and show similar increases in growing season and CIR. The annual crops grown in the basin, mostly corn, small grains, and dry beans, show an increase in CIR; however growing season, based on maximum days to harvest, does not increase.

Crop Irrigation Requirements for Study Basins

Table 3-5 shows average annual CIR for current irrigated acreage and crop types over the 1950 through 2005 study period, by study basin, based on historical climate conditions and 2040 projected climate. As shown, there is a 17 percent increase in CIR basin-wide. The White River basin experiences the largest increase in CIR from historical, since most of the basin irrigated acreage is at lower elevations and lower elevations experience a greater increase in temperature. Conversely, the Yampa Basin experiences the smallest increase in CIR from historical conditions due to a combination of acreage at higher elevations where there is less temperature increase, plus a smaller decrease in irrigation season precipitation compared to other study basins.

Table 3-5 – 2040 Average Annual Study Basin CIR Compared to Historical Conditions (AF)

Study Basin	Historical Period	Minimum Projection	Maximum Projection	Average of Projections	% Increase From Historical
Yampa River	214,271	225,440	263,438	245,964	15%
White River	45,937	50,123	62,182	56,713	23%
Upper Colorado River	577,043	618,704	736,863	686,314	19%
Gunnison River	618,070	660,364	768,486	724,335	17%
San Juan/Dolores Rivers	554,821	591,795	685,620	647,506	17%
Total	**2,010,142**	**2,146,426**	**2,516,589**	**2,360,832**	**17%**

3.4 Natural Streamflow

Alternate Historical Hydrology

The ensemble of 100 56-year-long flow traces that constitutes the extended historical hydrology was subjected to statistical analysis for the purpose of comparing the extended historical hydrology to those of the historical record. Those statistical analyses are summarized in Section 2.3.2.

Where to find more detailed information:

Statistical analyses are described in detail in CRWAS Technical Memorandum Task 6.7 – *Summarize Alternate Historical Hydrology*, available at http://cwcb.state.co.us/.

The sequence of wet and dry years that will occur over the next 56 years (or for any other period of 56 years in the future) cannot be predicted. Each of the traces in the alternate historical hydrology, though, represents one alternative possible future with respect to the distribution and sequencing of wet and dry years, assuming that the conditions reflected in the paleo record are representative of those conditions that will occur in the future. Each of these alternative possible futures (represented by a flow trace) is equally probable, but differs from all other traces (i.e. other possible futures) in the ensemble in its precise sequence of flows. Taken together, the traces reflect the statistics gleaned from the paleo record so that, collectively, the alternative historical hydrology ensemble can be used to quantify the likelihood of future hydrologic conditions, again assuming that the conditions represented in the paleo record are similar to those in the future. The results of the statistical analysis suggest the following findings:

- Generally, the median mean annual flow from the alternate historical hydrology was slightly higher than the historical mean natural flow. This means that the statistics of the paleo record indicate that in the long-term record wet years were slightly more frequent relative to dry years than was the case in the historical period (1950-2005).

- The median longest surplus and drought spell lengths are generally reasonably similar to the longest spell lengths in the historical record.

- At virtually all sites the paleo record indicates that there was a tendency toward smaller surplus volumes. This characteristic will manifest in more challenging conditions for operation of water storage projects as in many traces the opportunities for storage will be reduced.

- At many, but not all, sites, the paleo record indicates a tendency toward slightly higher deficit (drought) volumes. This characteristic will manifest in more challenging conditions for operation of water storage projects as in many traces the need for reservoir releases will increase.

- A broad range of hydrologic conditions is found in the ensembles of streamflows, so the use of the alternate historical hydrology in water availability analyses using CDSS models and the CRSS models will provide information about the impacts of droughts and wet spells of longer duration and greater intensity than those that have occurred during the historical period.

Climate-Adjusted Natural Flow

Low-flow comparison charts and monthly hydrograph charts (band charts) for natural flow for the Uncompahgre River at Delta are provided below in Figures 3-9 and 3-10. General descriptions for the components of the low-flow comparison charts and monthly hydrograph charts (band charts) are provided on pages 3-1 through 3-3. Corresponding charts for all natural flow sites are provided in the electronic data. Similar graphs are included in Appendix D for each selected flow station for both 2040 and 2070 projections.

The following general observations can be drawn from those results:

- At virtually all flow stations the range of projected average annual flow includes the historical average flow.
- At virtually all flow stations the ranges of projected average annual low flows at all durations include the historical average annual low flows for the same durations.
- The projected average flows and low flows at all durations tend toward higher values in the Yampa basin and at some high-elevation locations, and tend toward lower values in the southwestern basins and some lower-elevation basins.
- The range of projected flows tends to be wider in the more southwestern basins.
- At virtually all sites there is a tendency toward earlier streamflow.
- At virtually all sites the range of flow magnitudes tends to be greater in the summer months.

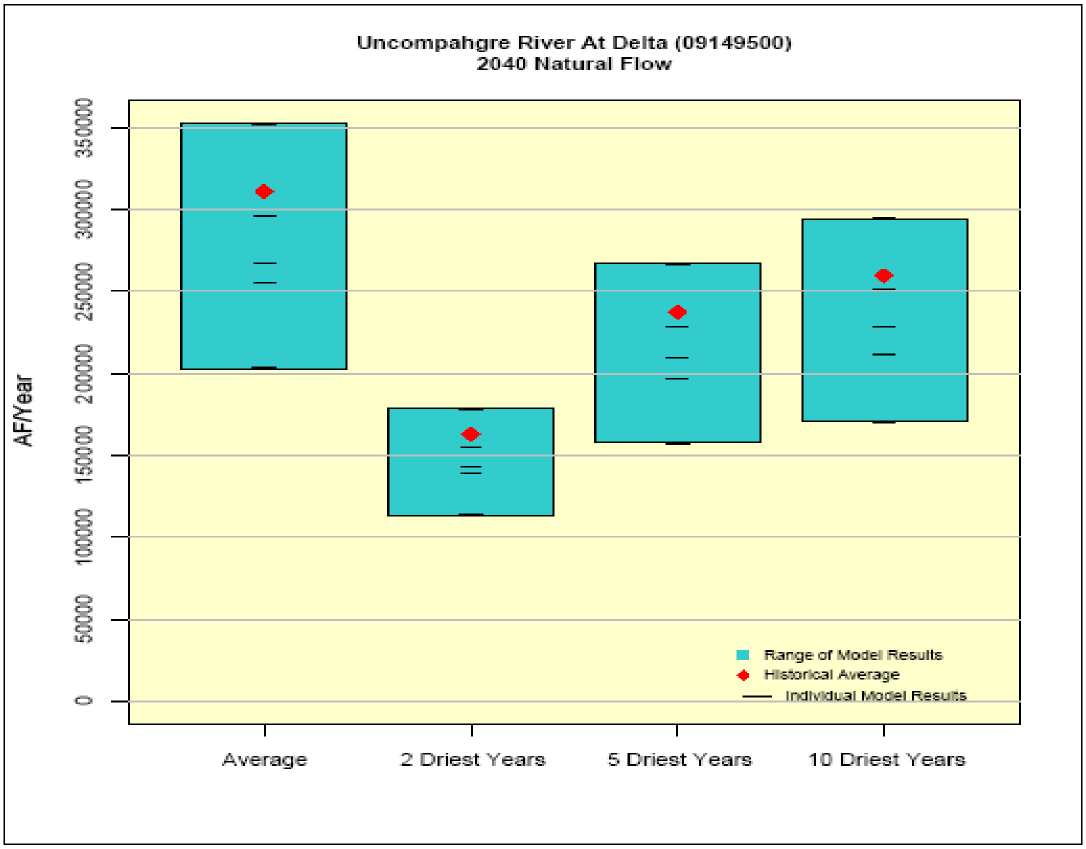


Figure 3-9 – 2040 Climate Impacts on Flows

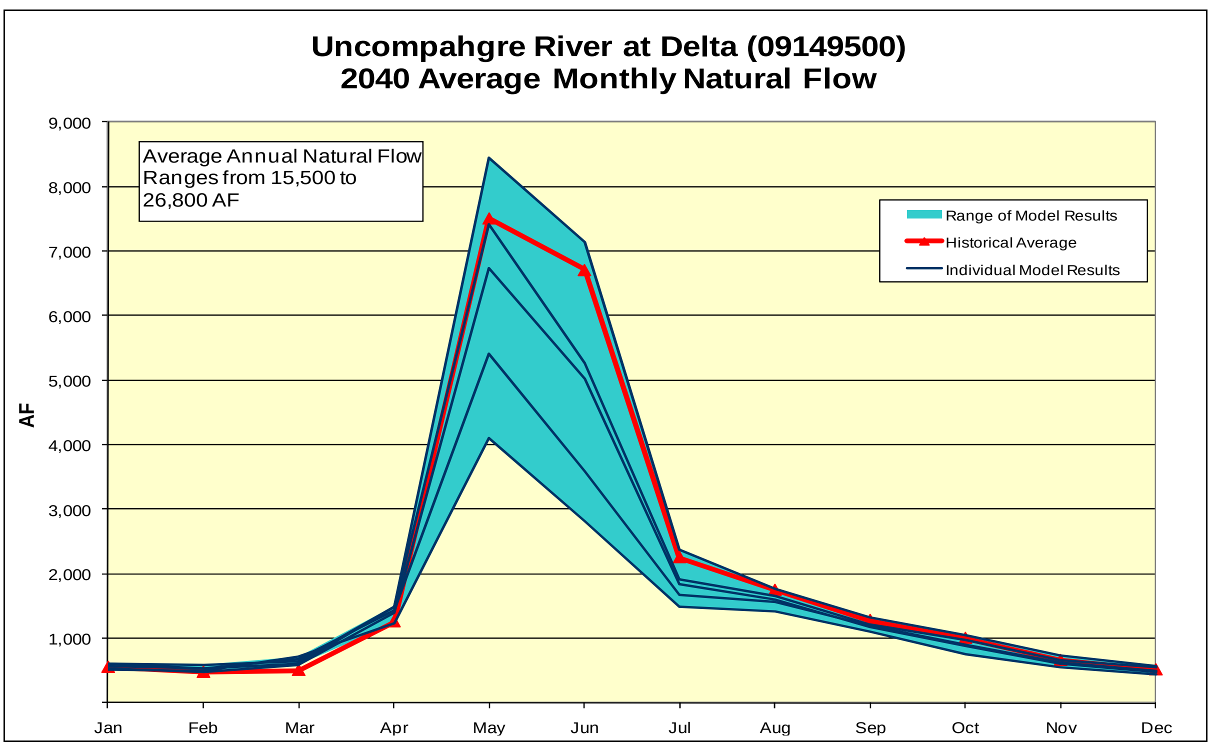


Figure 3-10 – 2040 Climate Impact on Flows

3.5 Modeled Streamflow

StateMod distributes flows to meet demands based on the priorities of water rights and basin operations. During a particular time-step, modeled streamflow at any location represents natural flows less upstream depletions. The modeled streamflow includes flows available to meet future demands plus flow allocated by the model to downstream users. As discussed in Section 2.4.6, the allocation to downstream users can be limited by physical flow in the river, demands, water rights, and diversion capacities.

Modeled streamflow is estimated by StateMod for every location represented in the model. The full amount of modeled streamflow can be used at that location for non-consumptive uses (uses that will not divert or diminish flow required to meet downstream existing demands). A portion of the modeled streamflow may be available to meet future demands, as discussed in Section 3.6.

In addition, modeled streamflow is an indicator of the potential for exchange. An exchange requires water to be added to the river downstream in order for an equal amount of water to be taken at an upstream location, so as not to injure senior water right uses.

Figures 3-11 through 3-13 show the seasonal variation in modeled streamflow at three Colorado River stream gage locations from upper basin to lower basin (Colorado River Near Grand Lake, Colorado River at Dotsero, and Colorado River near Cameo) over the 1950 through 2005 study period for the historical model, and for the models representing demands and natural flows adjusted for the 2040 climate projections.

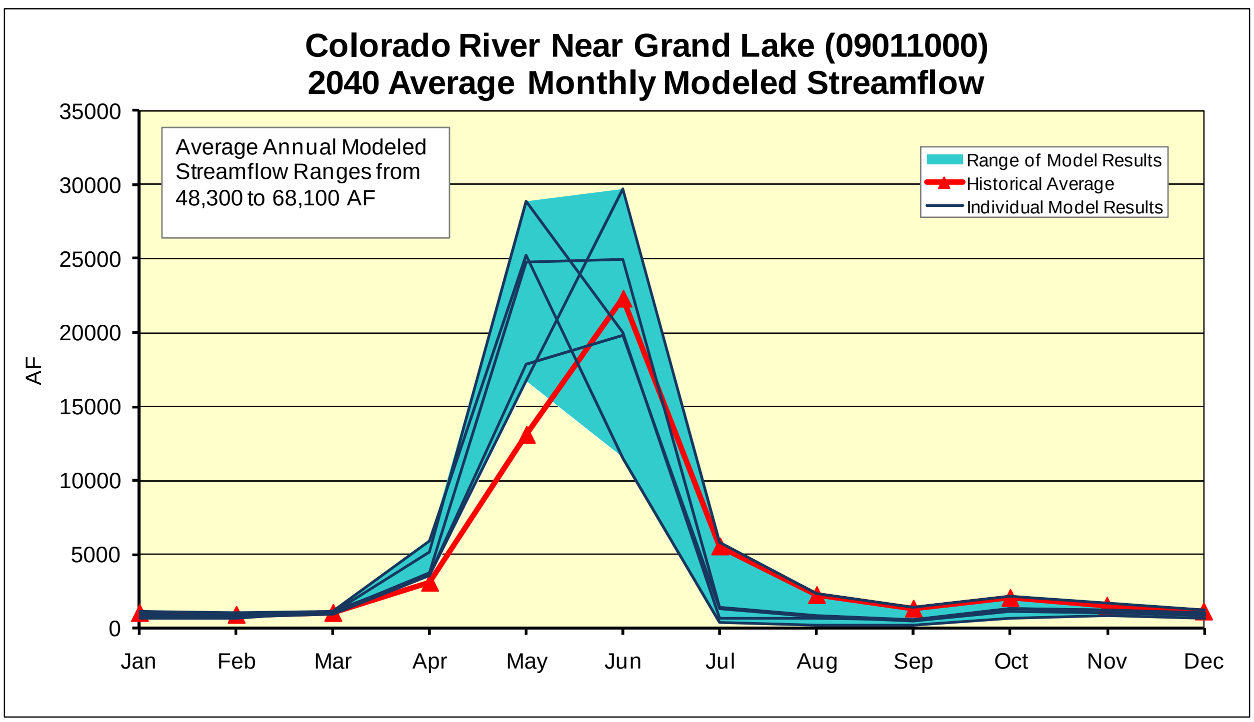


Figure 3-11 – Colorado River near Granby - 2040 Average Monthly Modeled Streamflow

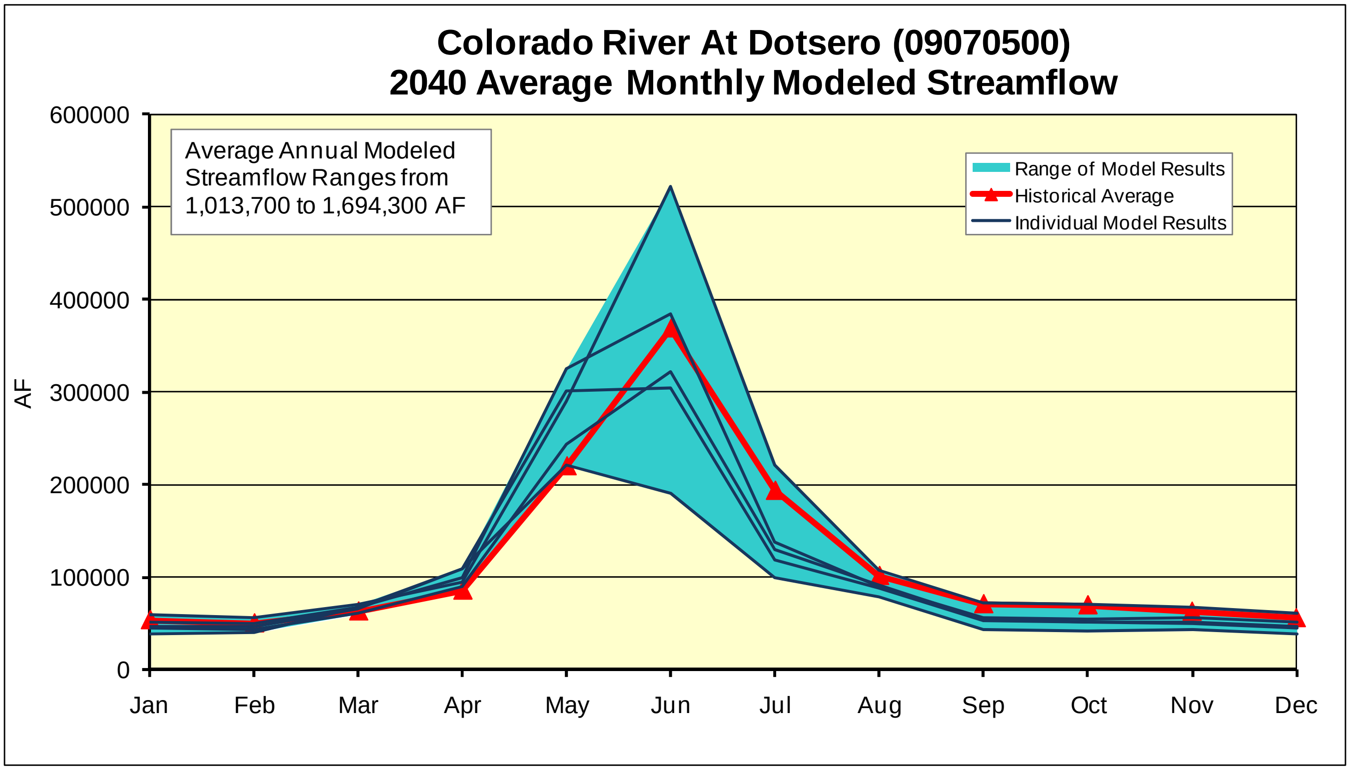


Figure 3-12 – Colorado River at Dotsero 2040 Average Monthly Modeled Streamflow

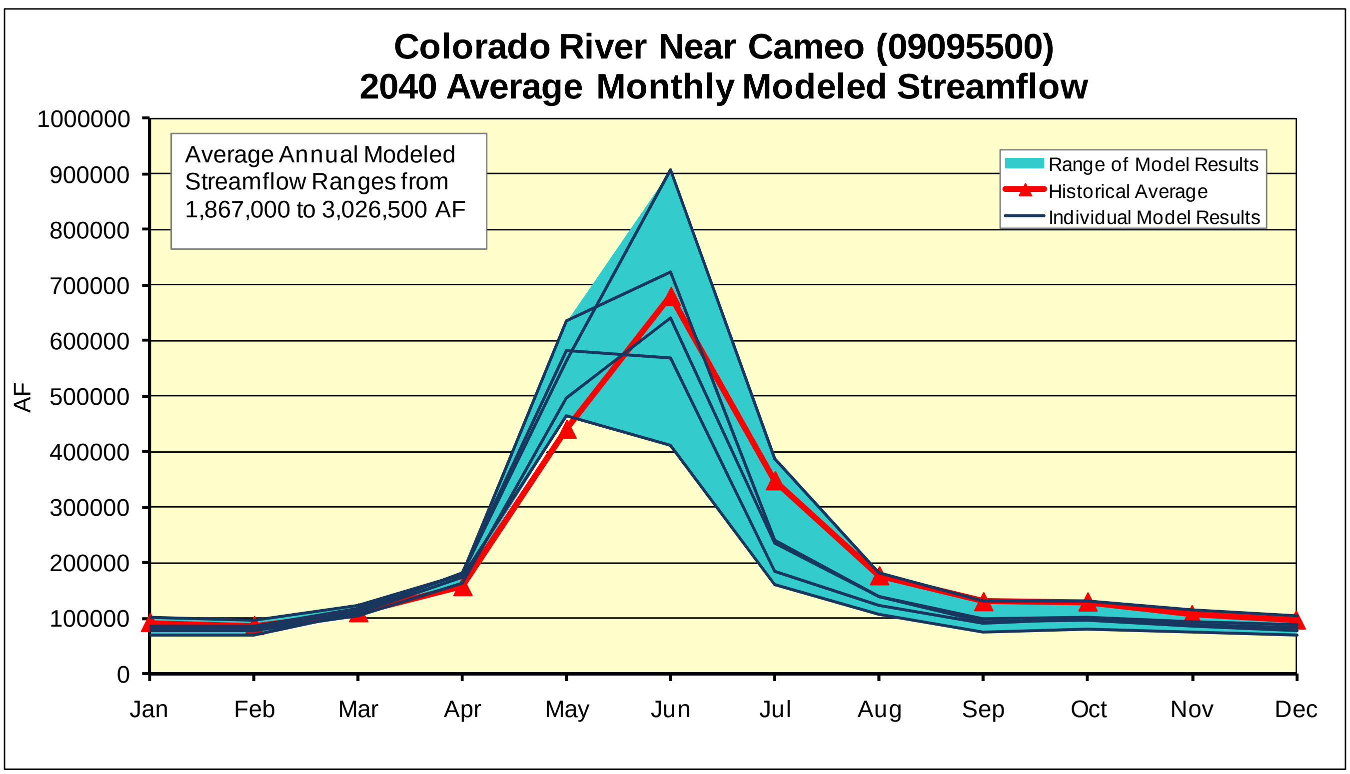


Figure 3-13 – Colorado River near Cameo 2040 Average Monthly Modeled Streamflow

Similar to the climate projected natural flows discussed in Section 3.4, modeled streamflow at the three locations presented indicate a shift towards more river flow in April and May and less river flow in summer months, compared to historical streamflows. This trend of increased modeled streamflow in earlier months, and less flow in later months, is seen in most locations throughout the Study basins, as shown in the figures presented in Appendix E for both the 2040 and 2070 climate projections. Three notable exceptions include McElmo Creek, Muddy Creek, and Los Pinos River discussed below.

As expected, gages located on tributaries where transbasin diversions account for a significant portion of the streamflow do not exhibit a pronounced shift in modeled flow, since water is often imported to the basin to specifically meet irrigation season demands. Irrigation structures diverting in the McElmo Creek basin depend on imports from the Dolores Basin to meet irrigation demands. As shown in Figure 3-14, the climate projections indicate that the early runoff from the relatively small watershed will continue to occur, on average, in March. Starting in May, irrigation use of imports from the Dolores Basin result in irrigation return flows to McElmo Creek, accounting for most of the modeled streamflow.

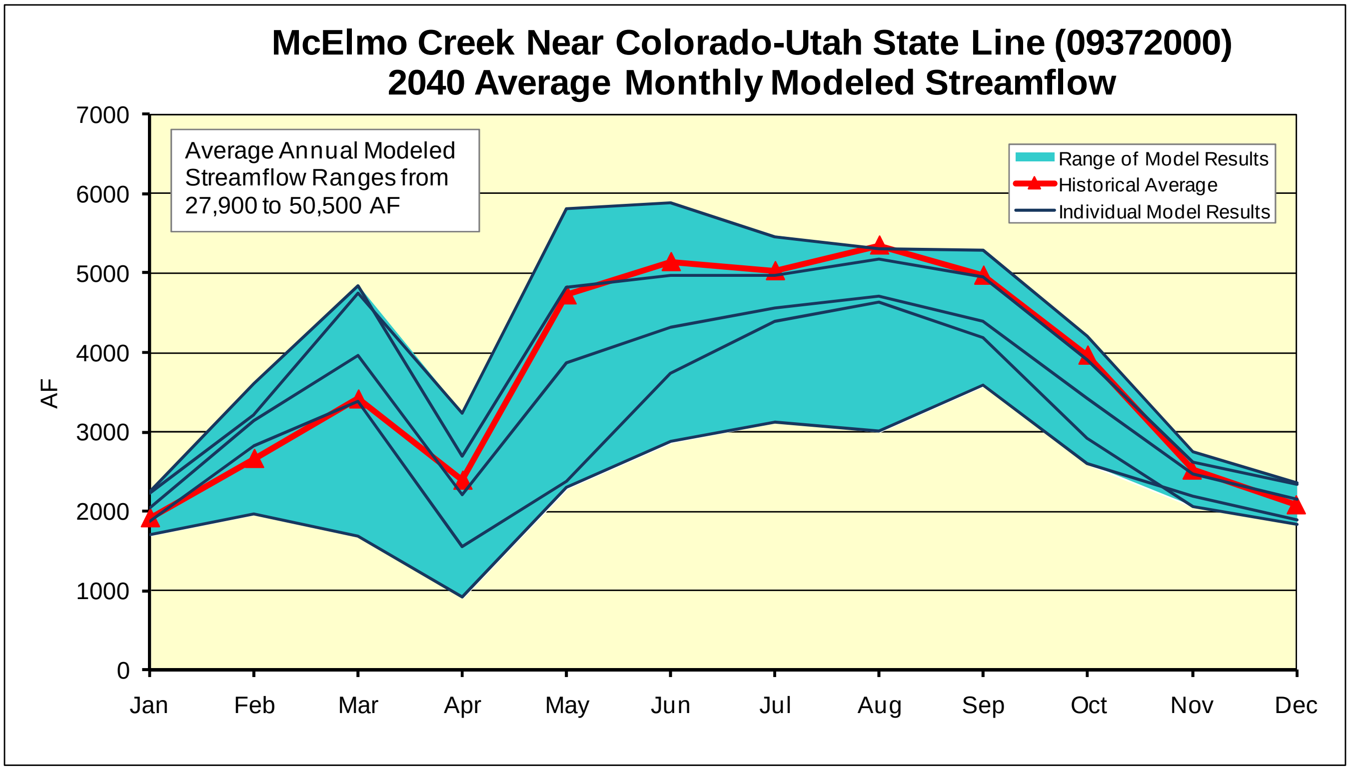


Figure 3-14 – McElmo Creek near CO-UT State Line - 2040 Average Monthly Modeled Streamflow

Gages located below reservoirs that release for uses in the late summer can show modeled streamflow in some months greater than historical, especially if reservoir releases are large compared to the natural streamflow during months of release. For example, Muddy Creek at Kremmling, shown in Figure 3-15, includes releases from Wolford Mountain Reservoir to help meet downstream fish flow requirements during the late irrigation season. As less water is available basin-wide to meet demands under the climate projections, the model simulates Wolford Mountain Reservoir releasing more for downstream fish flows than historically required. As a result, even though inflows to Wolford Mountain Reservoir generally decrease with the climate projections, greater reservoir releases in July and August are reflected in increased streamflows at the downstream gage.

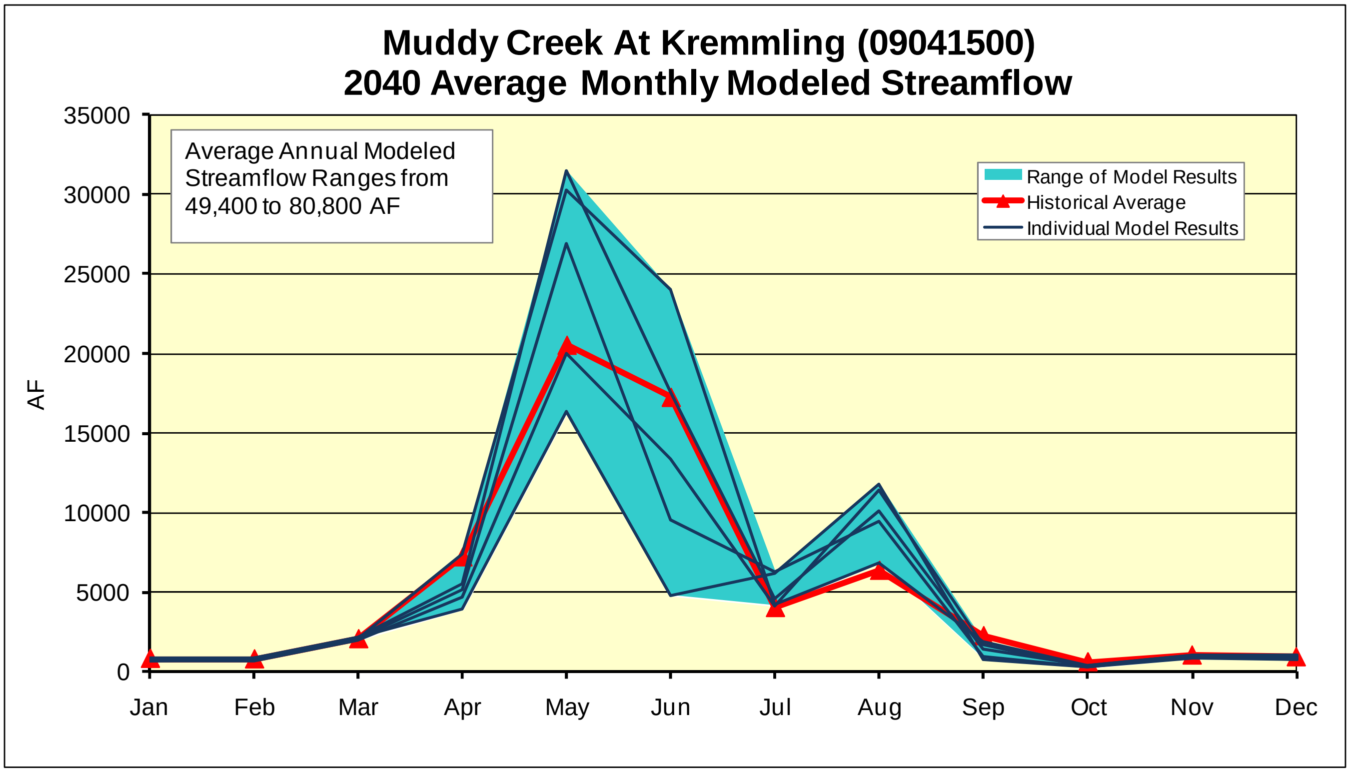


Figure 3-15 – Muddy Creek at Kremmling 2040 Average Monthly Modeled Streamflow

On some tributaries, such as Los Pinos River, flow is highly regulated by reservoirs for flood control and irrigation supplies. Flood release rules used in the basin model were provided for Vallecito Reservoir, in the upper Los Pinos River basin, by the reservoir operator. These operating rules, represented in the StateMod model using wet, dry, and average hydrologic year storage targets, were developed based on current runoff patterns. As shown in Figure 3-16, releases are made beginning in April to allow Vallecito Reservoir the capacity to store the runoff peak and avoid downstream flooding. The model operating rules do not consider the likelihood that the timing of releases would be revised as climate projections result in earlier runoff. Vallecito Reservoir operating rules also include drawing the reservoir down in October to a level below the spillway gates, to avoid damage due to icing. This operation is clearly reflected in the downstream gage flow, as shown in Figure 3-16.

The Vallecito model operating rules reflect operations that may not make sense for the runoff timing associated with projected climate. As a result, the downstream Los Pinos River at La Boca gage shows a different pattern than other gages in the basin.

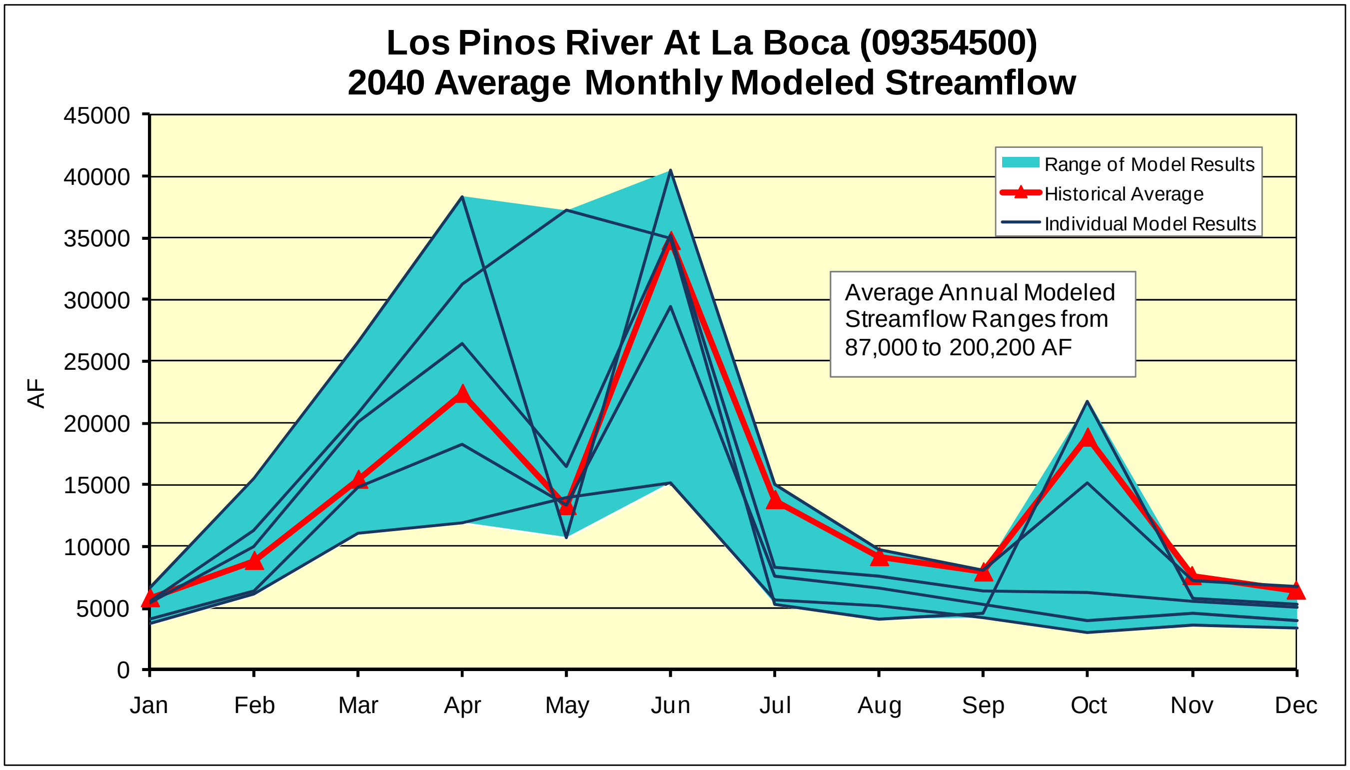


Figure 3-16 – Los Pinos at La Boca 2040 Average Monthly Modeled Streamflow

In addition to the figures showing seasonal differences between historical modeled streamflow and climate projected streamflow, Appendix E also includes tables summarizing the monthly and annual differences for the 2040 and 2070 projections. Information in the tables includes combined average monthly modeled streamflow for the five projections, the range in average annual modeled streamflow for the five projections, and the annual volume reduction and percent reduction from historical. The 2040 tables summarizing monthly and annual differences show the following:

- Most locations in the Study basins show less combined average annual modeled streamflow for the five 2040 climate projections than modeled streamflow based on historical climate conditions (Tables E1 through E5)
- Locations in the Yampa generally show greater combined annual modeled streamflow for the five climate projections than modeled streamflow based on historical conditions (Table E4)
- Locations in higher elevations in the Upper Colorado River study basin, including Colorado River near Granby and Roaring Fork River near Aspen, show greater combined annual modeled streamflow for the five climate projections than modeled streamflow based on historical conditions (Table E1)
- As noted above, Muddy Creek at Kremmling shows higher annual flow due to increased use of Wolford Mountain Reservoir (Table E1)

Figure 3-17 shows low-flow information at the Gunnison River near Gunnison gage location. Three low-flow statistics are provided in Figure 3-17. General descriptions for the components of the low-flow comparison charts are provided on pages 3-1 through 3-3.

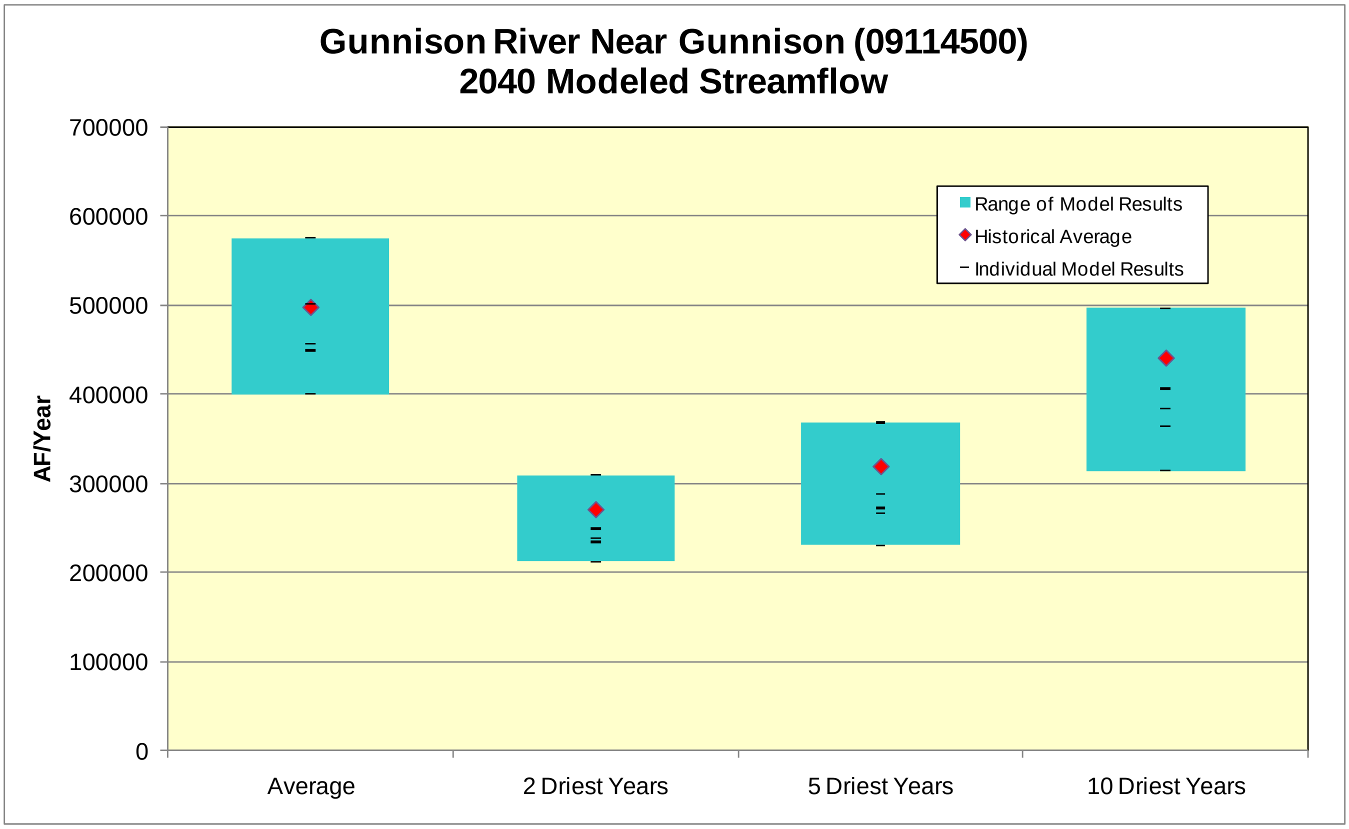


Figure 3-17 – Gunnison River near Gunnison - 2040 Modeled Streamflow Low-Flow Comparison

Low-flow comparison graphs for the selected locations are included in Appendix E for the 2040 and 2070 climate projections. Similar to the comparison shown in Figure 3-17, the following general observations can be draw from the 2040 low-flow comparison graphs:

- The historical annual low-flow values fall within the 2040 low-flow statistic ranges at every location in the Study basins
- There is a wider range of annual low-flow statistic values for the 2040 climate projections in the more southwestern locations

3.6 Water Available to Meet Future Demands

StateMod distributes natural flow to meet demands based on the priorities of water rights and basin operations. During a particular time-step, water available to meet future demands at any location represents the portion of modeled streamflow that is not allocated to current downstream demands with existing water rights. As discussed in Section 2.4.6, the allocation to downstream users can be limited by physical flow in the river, demands, water rights, and diversion capacities. Water rights not serving current demands, including conditional rights, are not included in the Phase I model, nor does the StateMod model currently consider potential obligations under the compacts. Therefore, water available to meet future demands includes water that may be used to satisfy future demands associated with existing absolute and conditional rights and future compact obligations.

Figure 3-18 and 3-19 show the seasonal variation in water available to meet future demands at two Gunnison River stream gage locations (Gunnison River near Gunnison, and Gunnison River near

Lazear) over the 1950 through 2005 study period for the historical model, and for the models representing demands and natural flows associated with the 2040 climate projections.

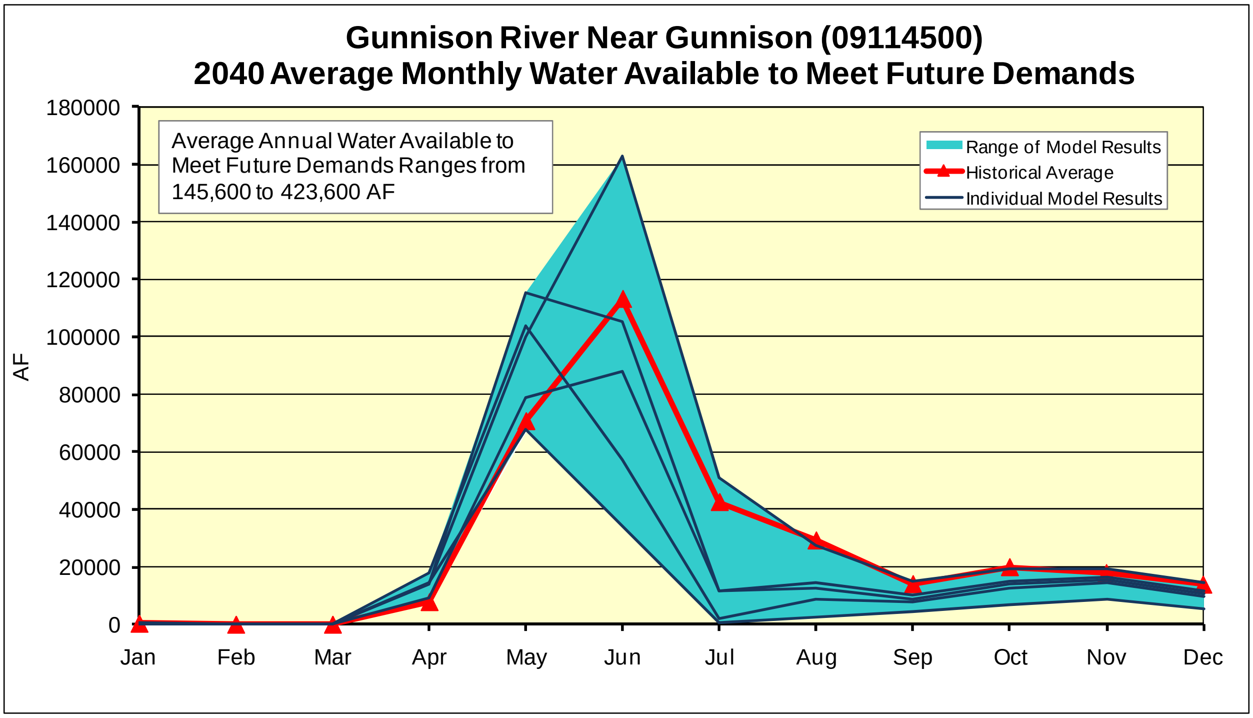


Figure 3-18 – Gunnison River near Gunnison - 2040 Average Monthly Water Available to Meet Future Demands

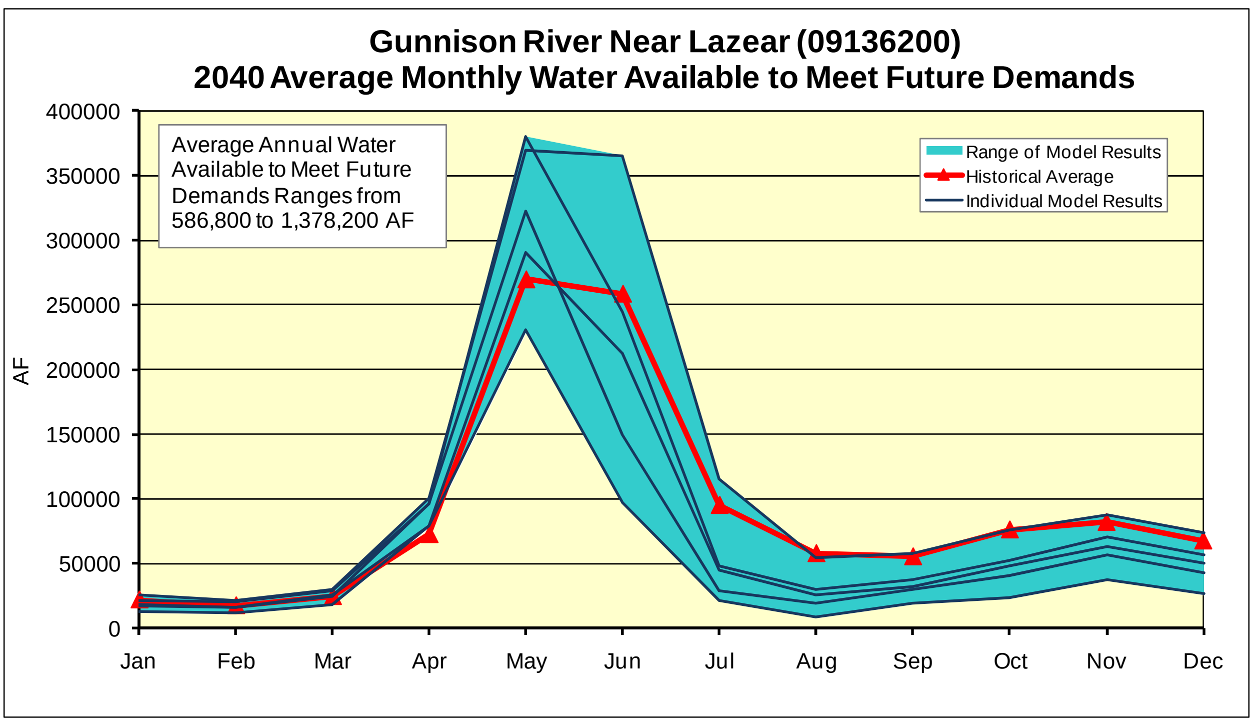


Figure 3-19 – Gunnison River near Lazear - 2040 Average Monthly Water Available to Meet Future Demands

As shown, water available at the upstream Gunnison River near Gunnison gage is much less than the amount of water available at the Gunnison River near Lazear gage. Water available to meet future demand at both locations is reduced because it includes flow allocated to uses downstream of the Gunnison River near Lazear gage, including Redlands irrigation and power demands. However, there are several tributaries in between the two gages that contribute flow to help meet downstream demands. In addition, there are significant current demands in between the two gages that must be met by a portion of the modeled streamflow at the Gunnison River at Gunnison gage, further reducing available flow. Table 3-6 compares average annual modeled streamflow based on historic climate conditions with water available to meet future demands at the two locations:

Table 3-6 – 2040 Average Modeled Streamflow and Available Flow at Gunnison Gages - Historical Climate

	Gunnison River near Gunnison	Gunnison River near Lazear
Modeled Streamflow (AF/Year)	498,047	1,214,257
Water Available to Meet Future Demands (AF/Year)	329,142	1,100,578
Difference (Flow Allocated to Downstream Current Demands, AF/Year)	168,905	113,679
% Modeled Streamflow Allocated to Current Demands	34%	9%

The above table illustrates the pattern of water available to meet future demands that is consistent throughout the Study basins as follows:

- Upstream locations on main rivers generally have less flow available to meet future demands as a percent of modeled streamflow than gages farther downstream that include more tributary inflow
- Tributaries with less modeled streamflow generally have less flow available to meet future demands as a percent of modeled streamflow
- Because compact considerations are not included in the Study basin StateMod models, flow available to meet future demands are similar or equal modeled streamflow for gages on or near the State line

Figure 3-20 shows the average monthly modeled streamflow compared to water available to meet future demands for historical climate conditions over on the 1950 through 2005 study period at the Gunnison River near Lazear gage. This graph is presented to better understand modeled streamflow compared to water available to meet future demands. The following summary is based Figure 3-20 and Table 3-6:

- As shown in Table 3-6, on average, 9 percent of the annual modeled streamflow is allocated to current downstream demands in this example
- In the high-flow months of May and June, less than 3 percent of the monthly flow is required to satisfy current downstream demands
- In the low flow winter months (January through March), more than 30 percent of modeled streamflow is required to satisfy current downstream demands.

Note again that the USFWS fish flow recommendation for the lower Gunnison River is not included as a current demand, as the Final EIS for reoperation of the Aspinall Unit reservoirs has yet to be published.

Figure 3-20 also illustrates the effect that large regulated reservoirs can have on a system, and the difficulty in representing reservoir operations that are not driven by water-user demands. Unlike irrigation and municipal release operations, hydropower needs are not defined by water demands in the basin. Blue Mesa Reservoir operational targets for storing and releasing were provided by the USBR to allow the Gunnison StateMod model to represent releases for hydropower generation. The operational rules define an upper limit for storage fill through the month of December, thus allowing water to be bypassed for hydropower generation. According to the USBR-provided rules, beginning in January there are no operational restrictions on filling, and no requirements for releasing for hydropower. Therefore, Blue Mesa Reservoir begins to fill with flow not required to meet other existing downstream demands. As shown in Figure 3-20 using the results based on historical climate conditions, as Blue Mesa Reservoir begins filling in January, modeled streamflow is reduced significantly from the streamflow modeled in December. These operational targets appear to be used by the USBR as guideline only, as historical measured streamflows downstream of Blue Mesa Reservoir do not always follow a similar pattern.

Because of the large capacity of Blue Mesa Reservoir, the impacts of the modeled hydropower operations for Blue Mesa Reservoir affect both modeled streamflow and water available to meet future demands throughout the basin during the winter months. The model results accurately represent the current operations provided by the USBR, and are believed to provide a good estimate for total reservoir storage under varying conditions. Therefore, the model results are an appropriate basis for comparing the effects of climate projection on water available to meet future demands assuming current operations continue.

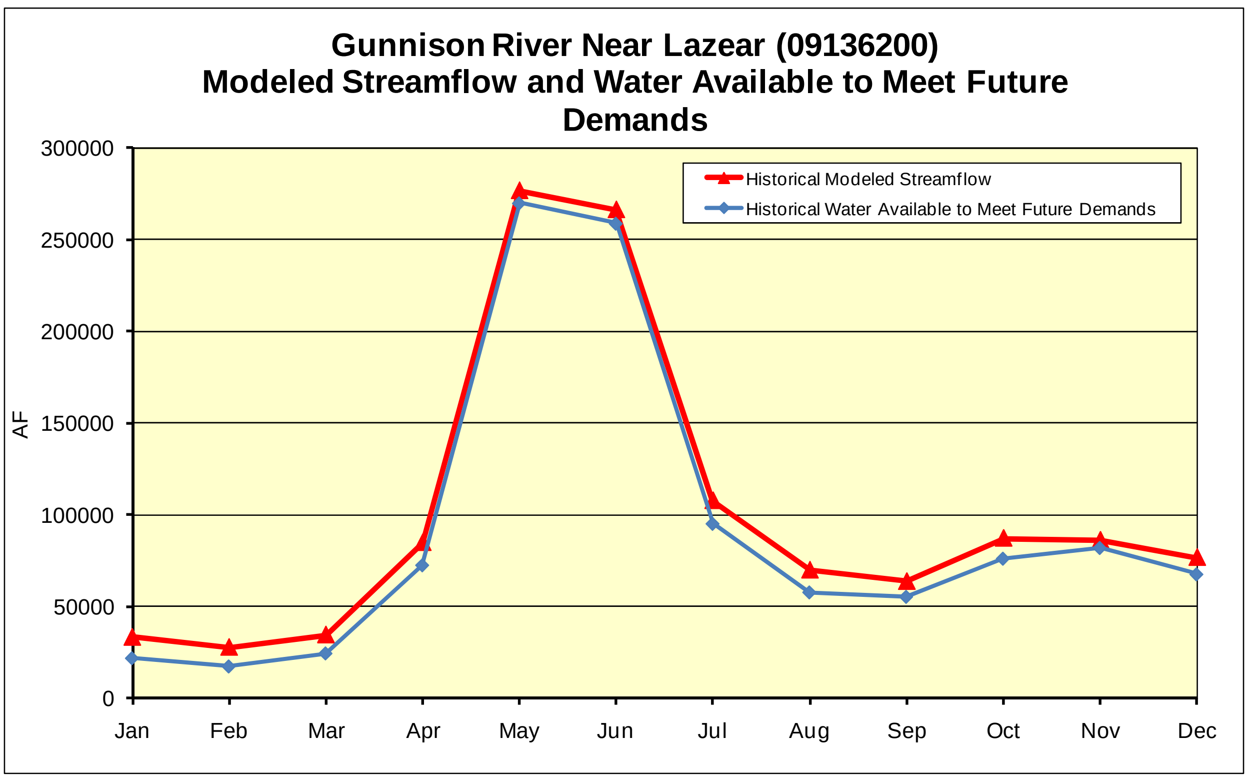


Figure 3-20 – Gunnison River near Lazear - Average Monthly Modeled Streamflow and Water Available to Meet Future Demands for Historical Climate Conditions

Figures showing seasonal differences between historical modeled water available to meet future demands and climate projected water available to meet future demands for selected locations in each study basin are included in Appendix F for both the 2040 and 2070 projections. The 2040 figures are similar to the Figures 3-18 and 3-19 and show the following:

- The climate projections generally indicate more available flow in April and May, corresponding to the shift in the natural flow hydrographs discussed in Section 3.4
- The locations in the southwestern corner of the State show more variation in water available to meet future demands than other locations in the State. This is may be because, as noted in Section 3.2, larger scale systems such as the monsoon-based conditions prevalent in the southern areas of the State, are not well simulated by climate models

In addition to the figures showing seasonal differences between historical modeled water available to meet future demands and climate projected available flow, Appendix F also includes tables summarizing the monthly and annual differences. Information in the tables includes combined average monthly water available to meet future demands for the five 2040 projections, the range in average annual modeled streamflow for the five projections, and the annual volume reduction and percent reduction from historical. Tables with the same information for the 2070 projections are also included in Appendix F. The 2040 tables summarizing monthly and annual differences show the following annual results:

- Most locations in the Study basins show less combined average annual flow available to meet future demands for the five climate projections than available flow based on historical climate conditions (Tables F1 through F5)
- Similar to modeled streamflow results, locations in the Yampa generally show greater combined average annual flow available to meet future demands for the five climate projections than available flow based on historical conditions (Table F4)
- Similar to modeled streamflow results, locations in higher elevations in the Upper Colorado River study basin, including Colorado River near Grand Lake and Roaring Fork River near Aspen, show greater combined average annual flow available to meet future demands for the five climate projections than modeled stream based on historical conditions (Table F1)

Figure 3-21 shows the 2040 water available to meet future demands band chart for the Colorado River near Cameo gage. The available flow in this graph is the amount of water not currently allocated based on either a Colorado water right or by operating agreements. The Phase I CRWAS estimates of available flow in the Colorado River basin are based on the current configuration of the CDSS model that includes the USFWS flow recommendation agreement for the 15-mile reach. The fish flow “demand” is simulated as junior in priority to other uses modeled; therefore does not restrict other users in the basin from meeting their current demands. However, because it is represented as a demand on the system, in those months when modeled streamflow through the 15-mile reach is less than the USFWS flow recommendation, the model results shows that there is no water available to meet future demands upstream.

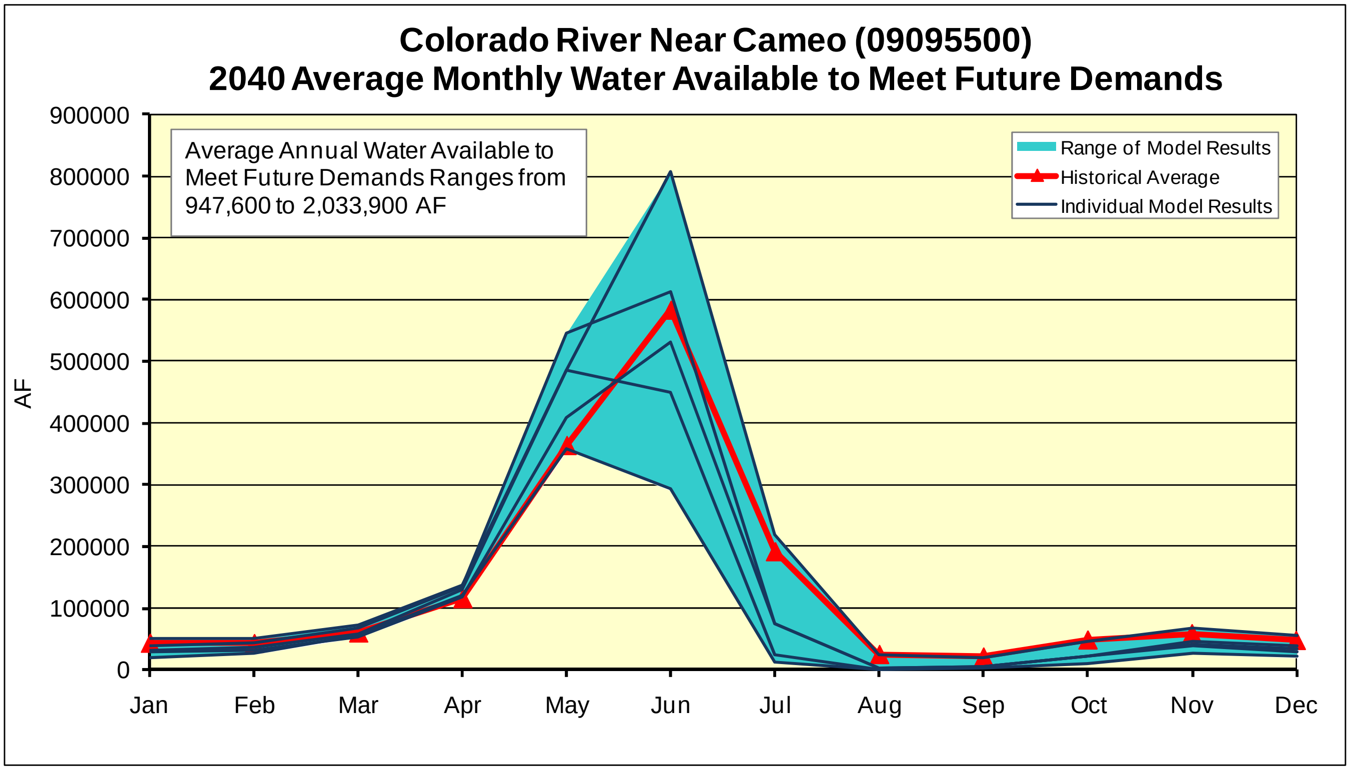


Figure 3-21 – Colorado River near Cameo 2040 - Average Monthly Water Available to Meet Future Demands

As shown in Figure 3-21, the water available to meet future demands is considerably reduced in August and September for historical and projected climate conditions. This is a direct result of the approach used to model the USFWS fish recommendations. This modeling of the flow recommendations and associated reduction in water available for future demands is consistent with CRWAS Phase I objective to include simulation of current operating agreements and administrative practices. However, USFWS recommendations are not absolutes, but recommendations that are subject to change. Furthermore, there are actions in the various PBO's that can be taken to offset the need to meet the flow recommendations. Therefore, it is important that when identifying water available to meet future demands, the 15-mile reach fish flow recommendations not be viewed as a major factor limiting potential future development. Phase II efforts may consider an alternative method for estimating the effects the USFWS flow recommendation has on available flow.

Figure 3-22 shows the difference between the water available to meet future demands upstream and downstream of the 15-mile reach based on historical climate conditions – note that there are no consumptive diversions within this reach. The difference between the two lines is the average flow "allocated" to meet the USFWS flow recommendations. Water available to meet future demands at all upstream gages, not just at the Colorado River at Cameo gage, reflects water "allocated" to meet the USFWS flow recommendations.

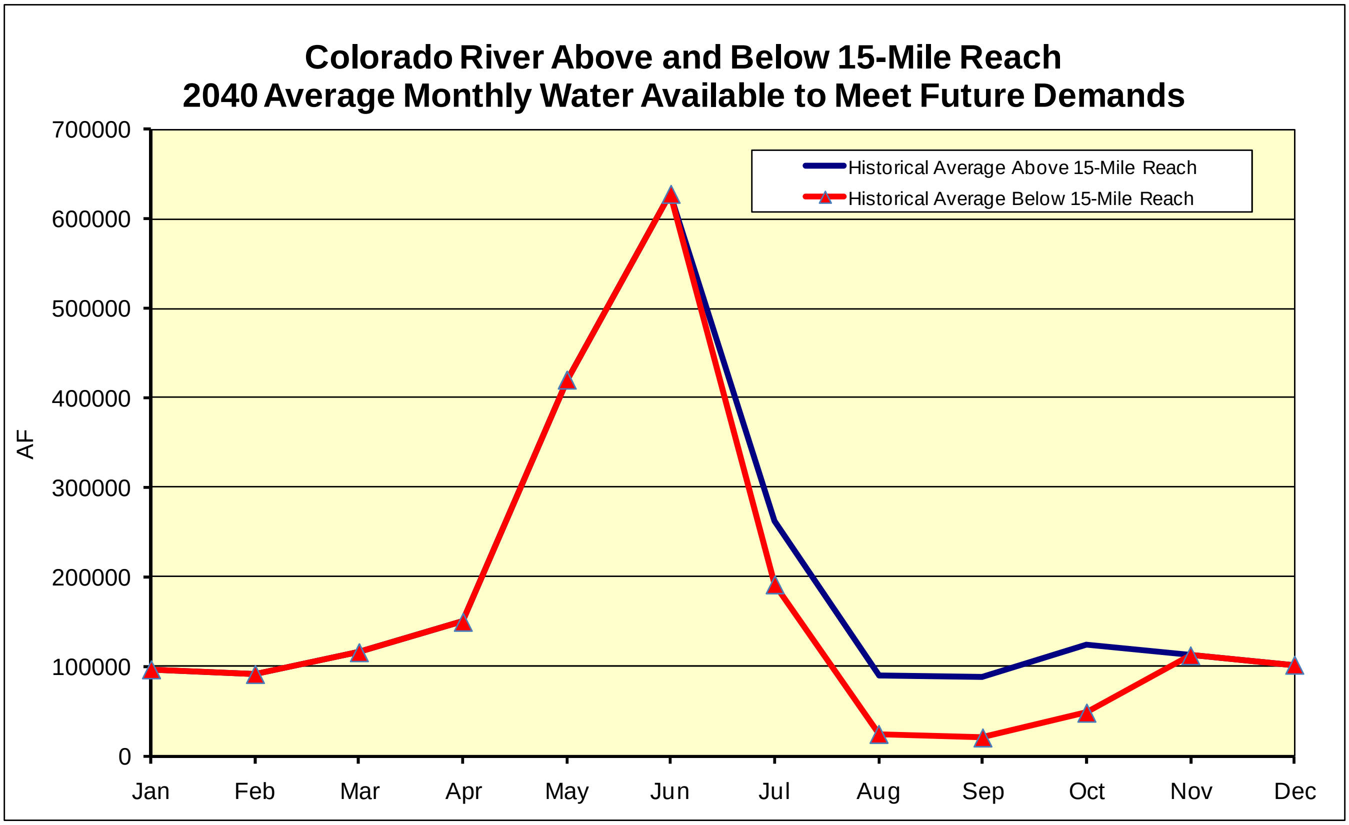


Figure 3-22 – Colorado River Above and Below 15-Mile Reach - Average Monthly Water Available to Meet Future Demands for Historical Climate Conditions

The monthly graphs discussed highlight the seasonal differences between historical and climate projected flow available to meet future demands. They are useful to help planners and operators understand general characteristics and trends associated with climate projections. Low-flow statistics regarding flow available to meet future demands are even more important for water providers and administrators than modeled streamflow. Figure 3-23 shows low-flow information at the Yampa River near Maybell gage location. The "Average" box indicates the range of average annual modeled streamflow for 56-year study period for the five climate projections, the red diamonds indicate the average annual historical value for the 1950 to 2005 period, and the black dashes show the average annual value for each of the five individual climate projections.

Three low-flow statistics are provided in Figure 3-23. The "2 Driest Years" box represents the average annual value for the driest consecutive two-year period historically and for each climate projection. The "5 Driest Years" box represents the average annual value for the driest consecutive five-year period historically and for each climate projection. The "10 Driest Years" box represents the average annual value for the driest consecutive ten-year period.

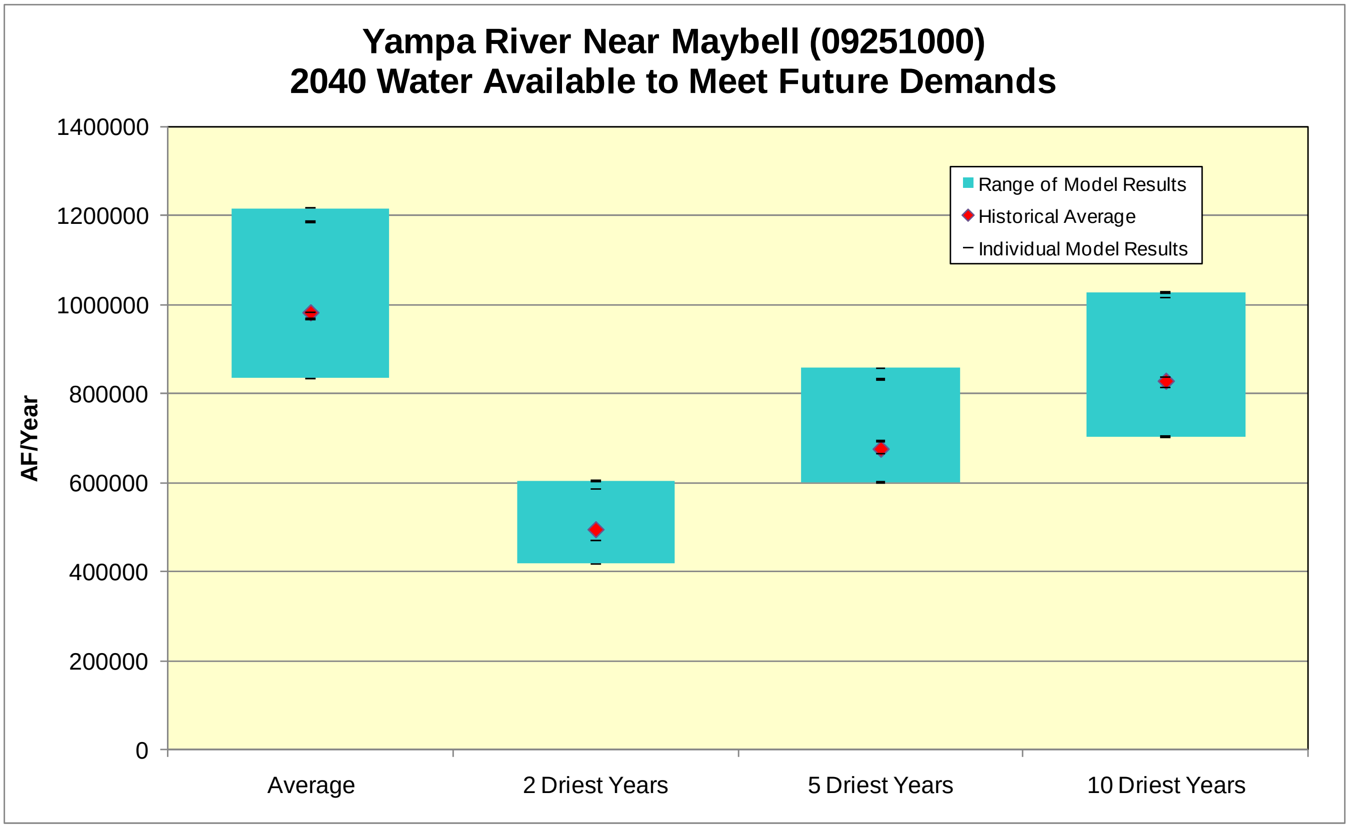


Figure 3-23 – Yampa River near Maybell - 2040 Modeled Streamflow Low-flow Comparison

Low-flow comparison graphs for the selected locations are included in Appendix F for the 2040 and 2070 climate projections. Similar to the comparison shown in Figure 3-23, the following general observations can be drawn from the 2040 low-flow comparison graphs:

- The historical annual low-flow values fall within the 2040 low-flow statistic ranges at every location in the Study basins
- There is a wider range of annual low-flow statistic values for the 2040 climate projections in the more southwestern locations

3.7 Modeled Reservoir Storage

The StateMod models include 60 operating reservoirs in the Colorado River basin in Colorado. Several of the larger reservoirs are operated primarily for direct transbasin diversions or for exchange to allow transbasin diversions (Granby, Shadow Mountain, Williams Fork, Dillon, and Green Mountain). Storage and releases from these reservoirs are do not directly satisfy demands in the Study basins and, as noted in Section 2.4.6, potential increased demand in the South Platte River and Arkansas River basins due to climate change have not been addressed in the CRWAS modeling efforts. In addition, the

Aspinall Unit reservoirs (Blue Mesa, Morrow Point, and Crystal) are primarily operated by the USBR for non-consumptive uses not directly affected by increased irrigation demand due to climate projections.

To understand the effects of climate projections on storage, four reservoirs were selected that are used to supplement irrigation demands within the Study basins. These reservoirs, discussed below, are impacted by changes in timing and volume of natural flow, and by changes to crop irrigation requirements due to projected temperature changes. Operations of the reservoirs were not revised for the modeling efforts; only current operational strategies are represented.

Figure 3-24 shows the time series of modeled reservoir end-of-month contents based on historical climate (red line) and 2040 climate projections (blue lines) for Yamcolo Reservoir, located in the upper reaches of the Yampa River basin. Yamcolo Reservoir is primarily used to meet late season irrigation demands, and also has an account for municipal and industrial use. Although the model study period is 1950 through 2005, the graph only shows 1980 through 2005 to enhance readability.

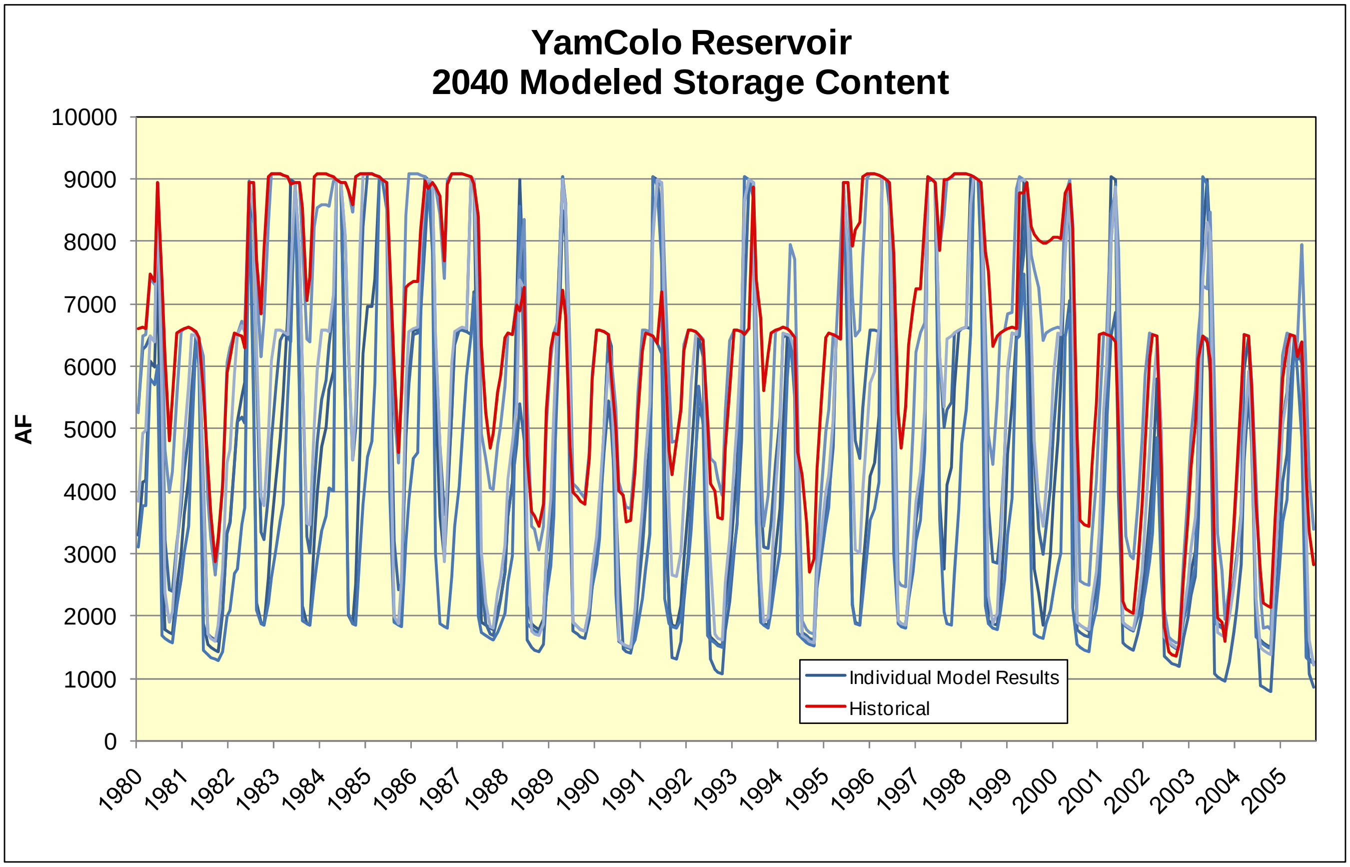


Figure 3-24 – Yamcolo Reservoir - 2040 Modeled Storage Content

As discussed in previous sections, the Yampa River basin shows increases in average annual modeled streamflow for the five climate projections. However, the increased flow is associated with an earlier peak runoff, and flows are below historical during the late irrigation season. Decreased late irrigation season flows, coupled with increased irrigation demands due to increased temperatures, results in more reservoir releases required to meet the demands. Figure 3-24 shows that Yamcolo Reservoir draws down more than historical levels during the 1980s and the late 1990s. Increased spring flows result in the reservoir filling more than historical for some of the model projections.

Figure 3-25 shows average monthly modeled Yamcolo Reservoir content over the 1950 through 2005 study period for historical climate conditions, and average monthly content for each of the 2040 climate projections. As shown, the reservoir is drawn down more with the climate projection hydrology and demands than under historical climate conditions. Note that Yamcolo Reservoir has a conservation pool plus a municipal and industrial account that is not modeled with increased demand under climate projections.

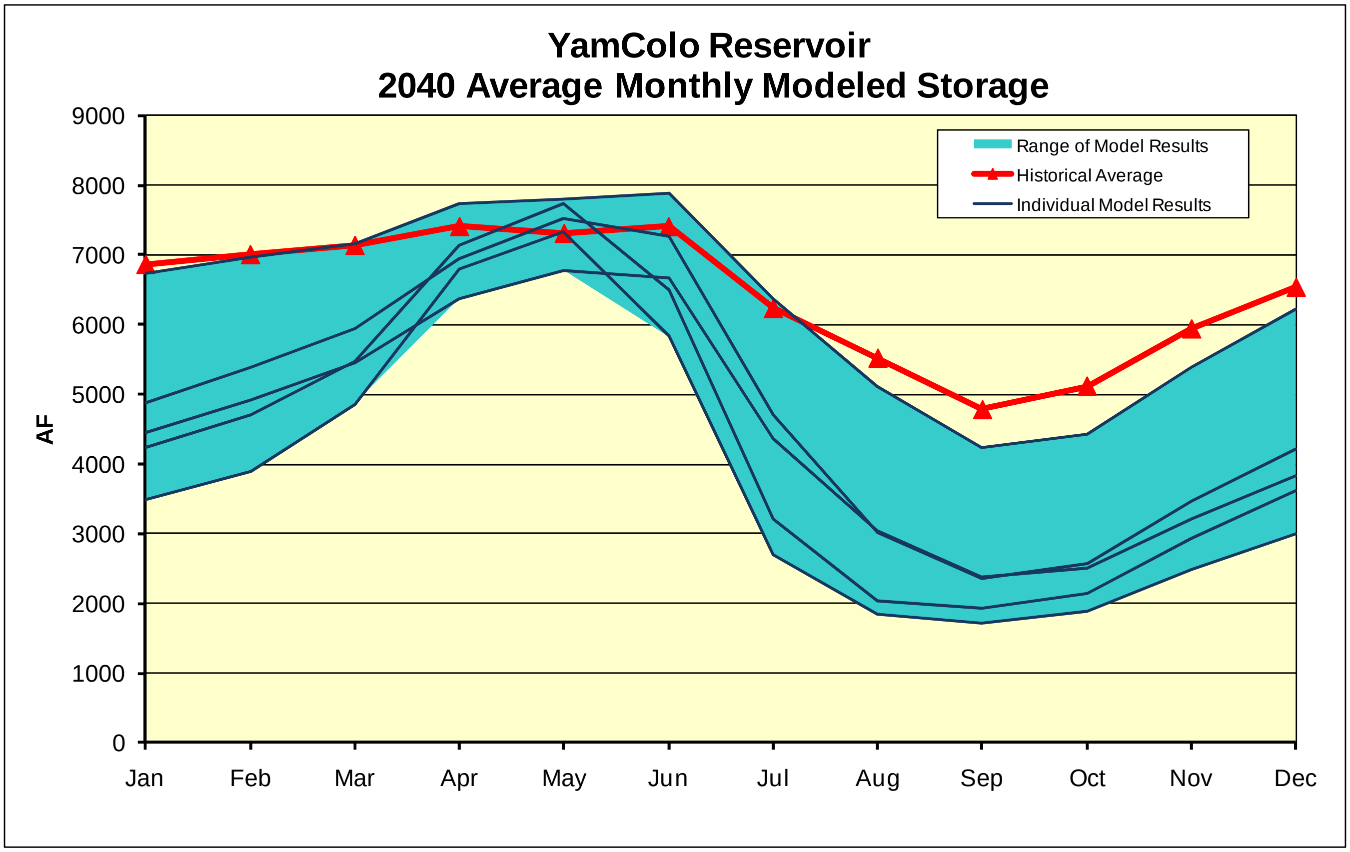


Figure 3-25 – Yamcolo Reservoir - 2040 Average Monthly Modeled Storage Content

Figure 3-26 shows the time series of modeled reservoir end-of-month contents based on historical climate and 2040 climate projections for Vega Reservoir, located in the upper reaches of the Plateau Creek, tributary to the Colorado River. Vega Reservoir is primarily used to meet irrigation demands.

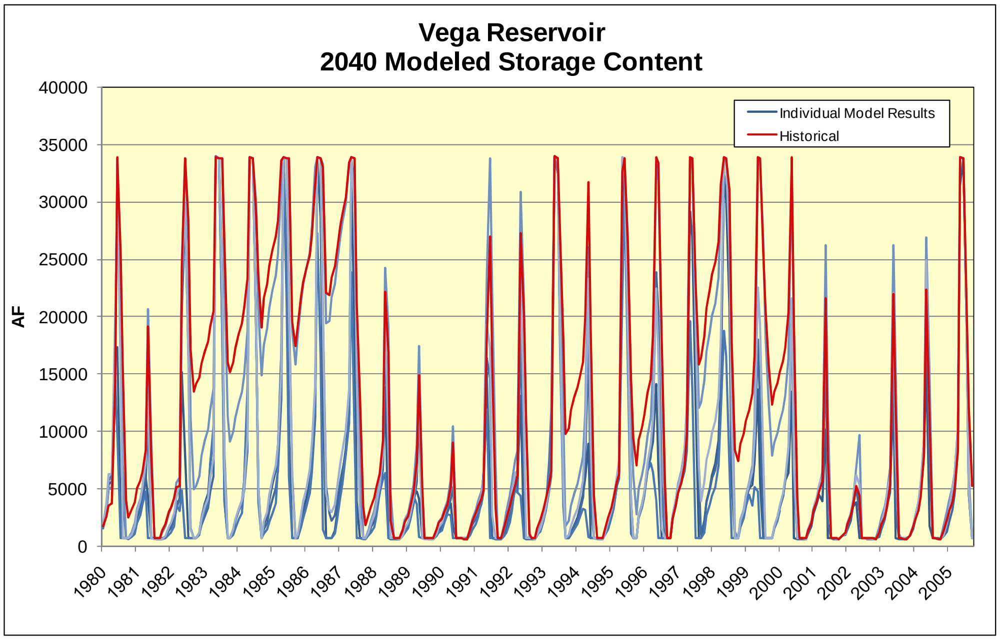


Figure 3-26 – Vega Reservoir - 2040 Modeled Storage Content

Figure 3-27 shows average monthly modeled Vega Reservoir content over the 1950 through 2005 study period for historical climate conditions, and average monthly content for each of the 2040 climate projections. Similar to Yamcolo Reservoir, Vega Reservoir is drawn down more with the climate projection hydrology and demands than under historical climate conditions. One of the climate projections show more water available to refill the reservoir than historical conditions allowed.

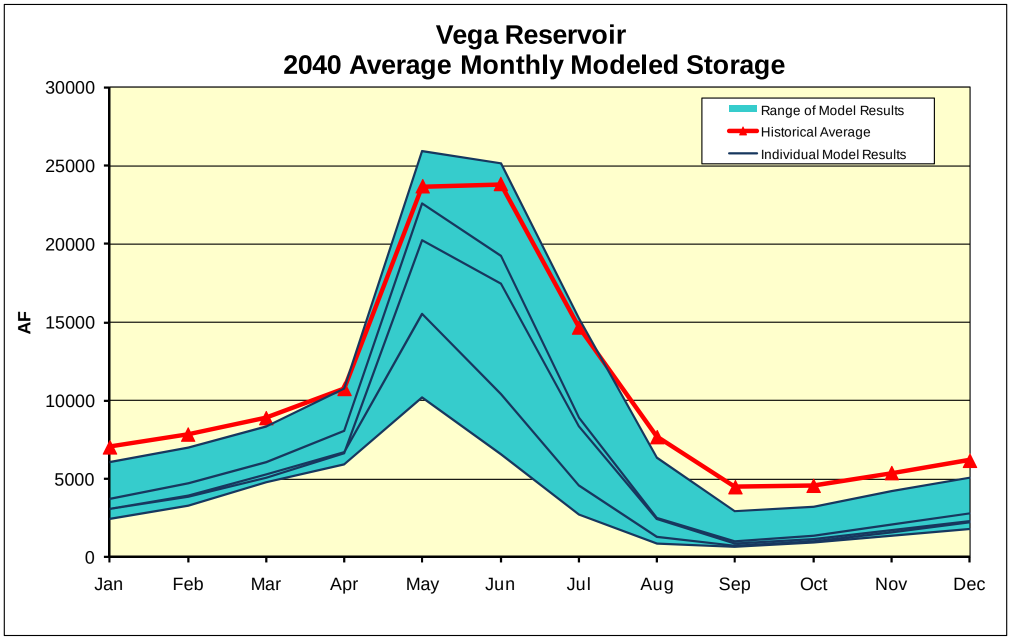


Figure 3-27 – Vega Reservoir - 2040 Average Monthly Modeled Storage Content

Figure 3-28 shows the time series of modeled reservoir end-of-month contents based on historical climate and 2040 climate projections for Ridgway Reservoir, located on a tributary to the Uncompahgre River in the Gunnison basin. Ridgway Reservoir includes an irrigation account that provides supplemental water to the Uncompahgre Valley Water Users. The remaining reservoir is allocated to recreation and municipal use. In addition, there is a 25,000 acre-feet pool below the release outlet.

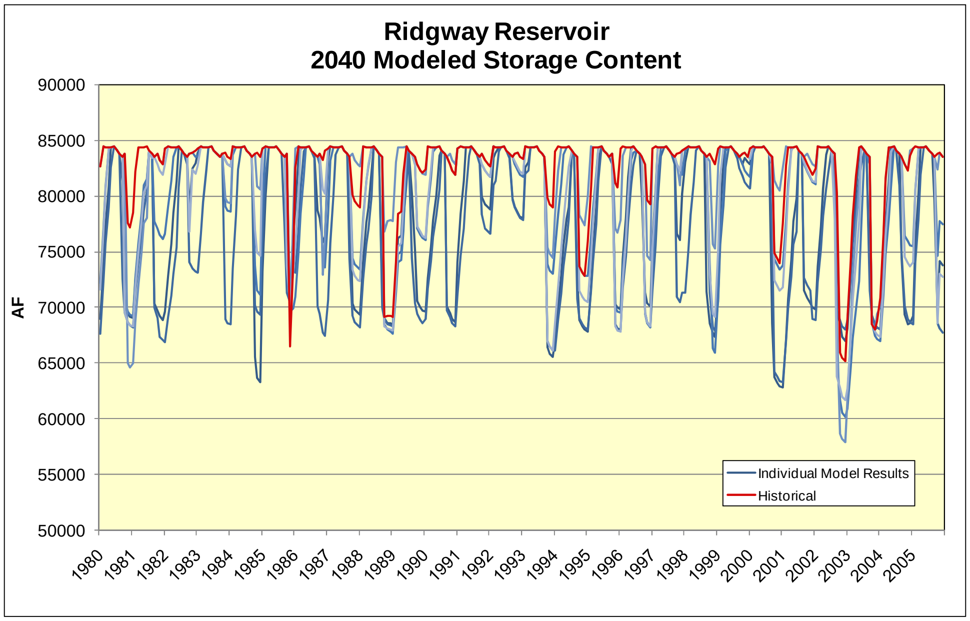


Figure 3-28 – Ridgway Reservoir - 2040 Modeled Storage Content

Figure 3-29 shows average monthly modeled Ridgeway Reservoir content over the 1950 through 2005 study period for historical climate conditions, and average monthly content for each of the 2040 climate projections. Ridgway Reservoir is drawn down more with the climate projection hydrology and demands than under historical climate conditions, but is able to fill to capacity in each year of simulation for every climate projection.

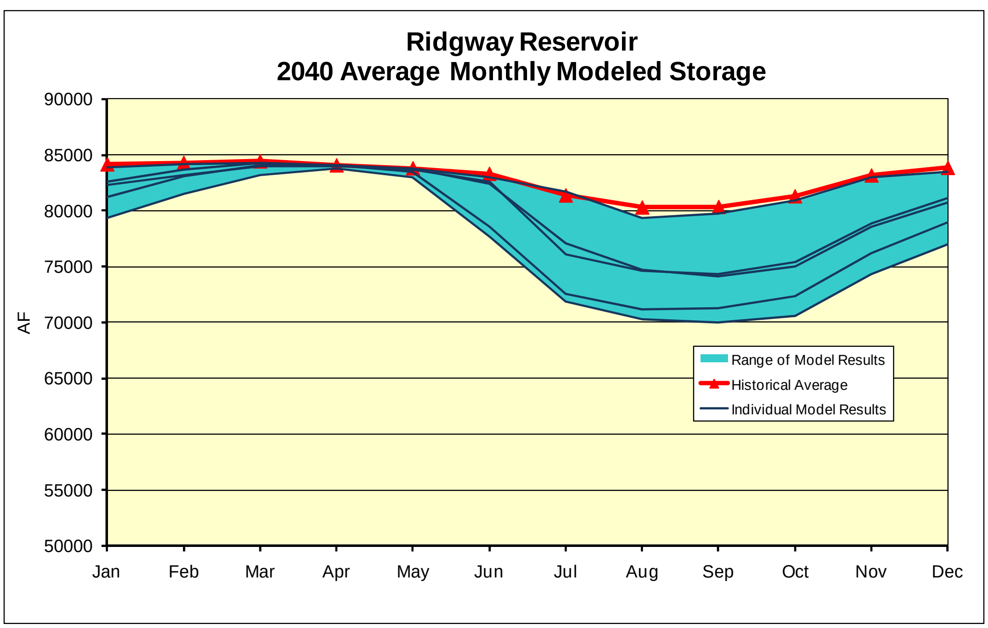


Figure 3-29 – Ridgeway Reservoir - 2040 Average Monthly Modeled Storage Content

Figure 3-30 shows the time series of modeled reservoir end-of-month contents based on historical climate and 2040 climate projections for McPhee Reservoir, located on the Dolores River. McPhee Reservoir is used to supplement irrigation demands primarily in the McElmo Creek tributary. McPhee includes a large inactive pool (150,000 AF) that cannot be used to deliver water to the irrigation uses.

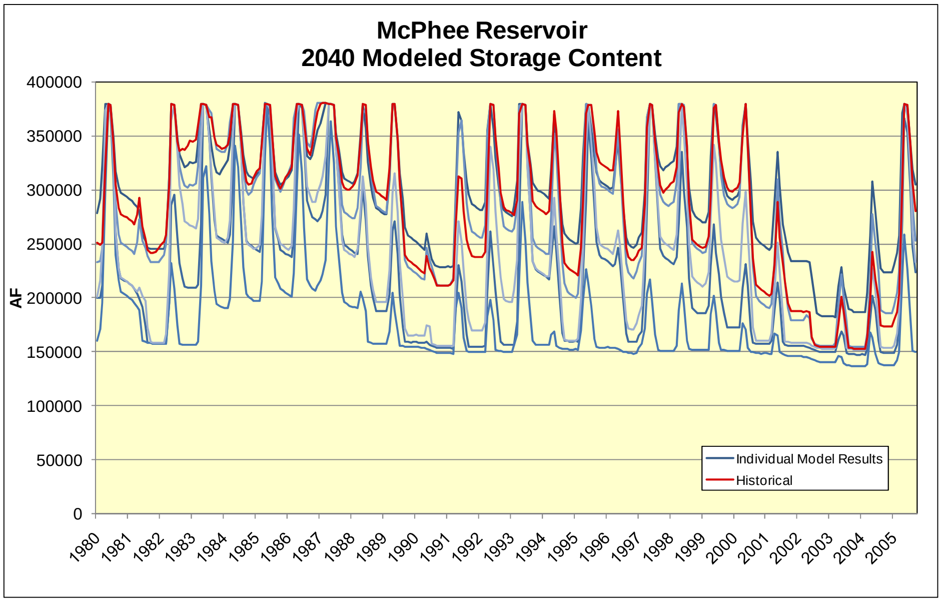


Figure 3-30 – McPhee Reservoir - 2040 Modeled Storage Content

Figure 3-31 shows average monthly modeled McPhee Reservoir content over the 1950 through 2005 study period for historical climate conditions, and average monthly content for each of the 2040 climate projections. McPhee Reservoir is drawn down more with the climate projection hydrology and demands than under historical climate conditions, and is able to refill the irrigation account in many years. One of the climate projections shows more water available to refill the reservoir than historical conditions. As shown in both Figures 3-30 and 3-31, current McPhee Reservoir operations restrict irrigation diversions from the 150,000 acre-feet inactive pool.

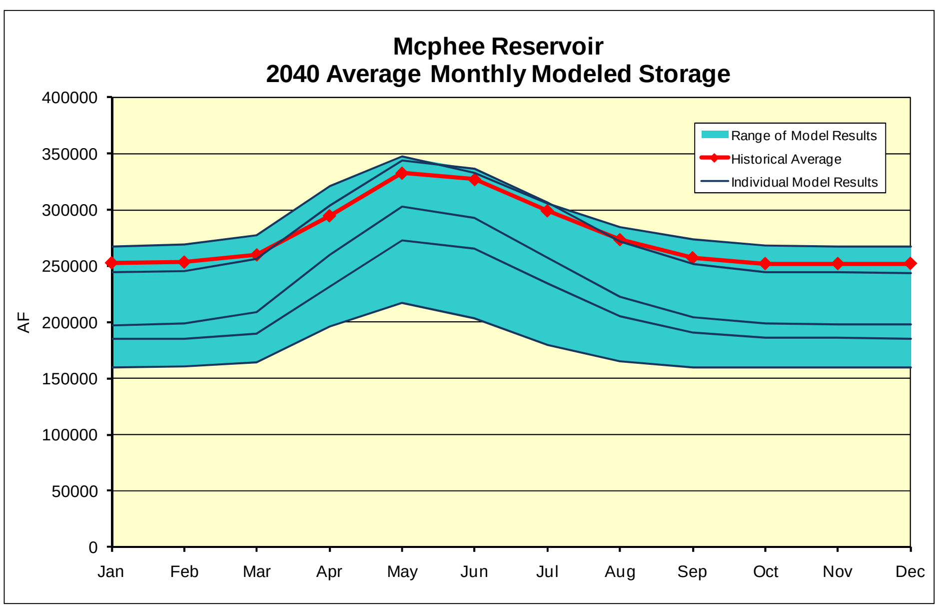


Figure 3-31 – McPhee Reservoir - 2040 Average Monthly Modeled Storage Content

Modeled end-of-month content time-series based on historical climate and climate projections, and average monthly reservoir storage figures for the four selected reservoirs are presented in Appendix G for the 2040 and 2070 projections. The following observations can be made based on the review of reservoirs supplementing irrigation demands in the Study basins:

- Each of the reservoirs investigated show more fluctuation in reservoir storage, indicating increased use of the reservoirs

- Earlier peak runoff, reduced flows during the peak irrigation season, and increased crop demands results in more use of existing reservoir storage

3.8 Modeled Consumptive Use

Crop irrigation demands for the climate projections increased in each study basin, due to increases in temperature and decreases in irrigation season precipitation. As discussed in Section 2.4.6, StateMod headgate demands for irrigation structures were adjusted for each climate projection. Transbasin diversion demands, demands for municipal and industrial use, and instream flow demands, with the exceptions noted in Section 2.4.6, were not revised.

Yampa River Basin Consumptive Use

Figure 3-32 shows the average monthly modeled consumptive uses and losses in the Yampa River basin for each of the five 2040 climate projections and for historical climate conditions. Values are the total modeled depletions in the basin and include irrigation, municipal, and industrial consumptive uses plus reservoir evaporation. As shown, the consumptive use in the Yampa River basin increased every month during the irrigation season for most of the 2040 climate projections.

- Modeled combined average annual consumptive use (including evaporation) increased by 5 percent for the climate projections.
- Combined average annual crop irrigation requirement increased by 15 percent for the climate projections.
- The agricultural-use reservoirs, for example Yamcolo Reservoir discussed in Section 3.7, Stillwater Reservoir and Allen Basin Reservoir, supply more water to meet the increased agricultural demand for the climate projections.
- Although consumptive use increased, not all crop demands were met. Similar to historical climate results, there continue to be water shortages on tributaries to the Yampa River in the late irrigation season for the climate projections. Basin-wide combined crop consumptive use shortage associated with the climate projections is 10 percent, whereas crop consumptive use shortage associated with historical climate conditions is 5 percent. Note that historical and climate projection crop shortages are difficult to compare directly, since the crop demands are not the same.

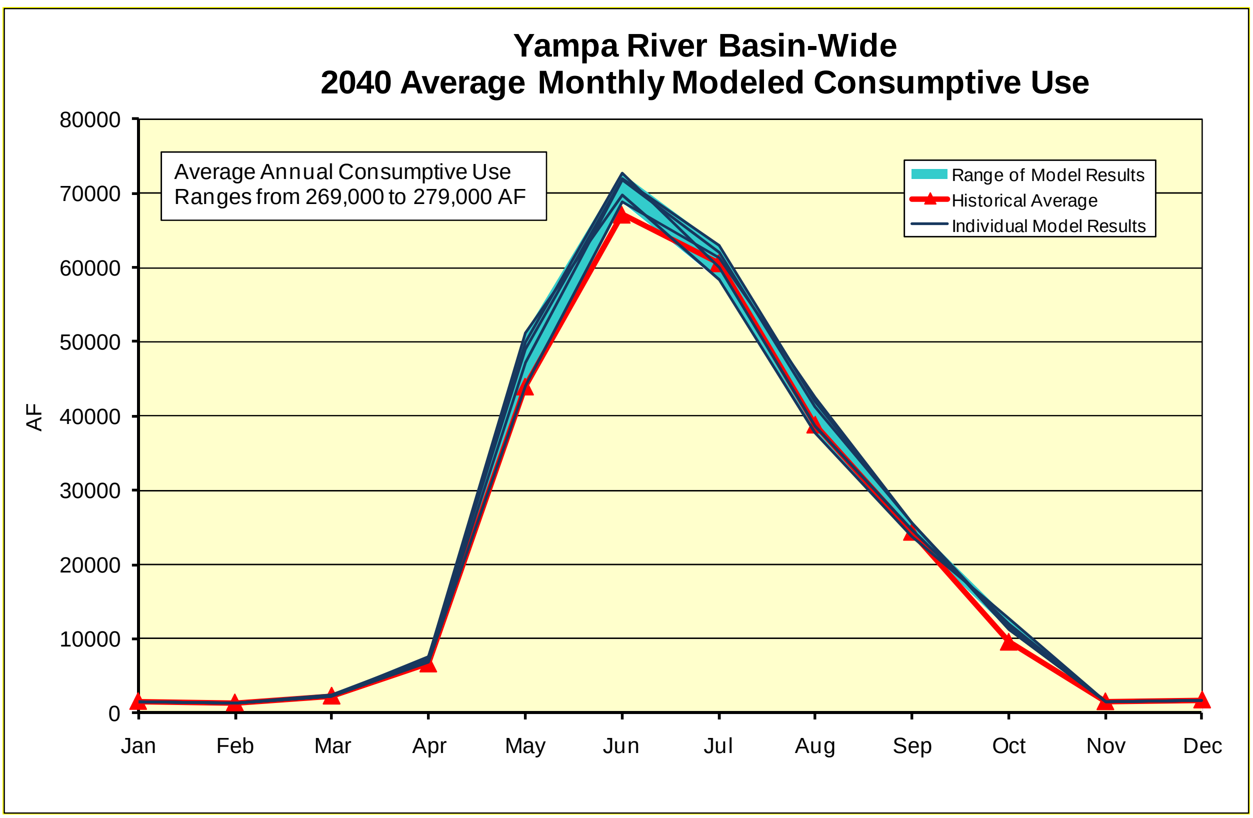


Figure 3-32 – Yampa River Basin-Wide - 2040 Average Monthly Modeled Consumptive Use

White River Basin Consumptive Use

Figure 3-33 shows the average monthly modeled consumptive uses and losses in the White River basin for each of the five 2040 climate projections and for historical climate conditions. Values are the total modeled depletions in the basin and include irrigation, municipal, and industrial consumptive uses plus reservoir evaporation. As shown, the consumptive use in the White River basin increased every month for each of the 2040 climate projections.

- Modeled annual consumptive use (including evaporation) increased by 18 percent for the climate projections combined.
- Average annual crop irrigation requirements increased by 23 percent for the climate projections combined.
- The increase in crop irrigation demand was able to be met during spring and early summer months, even though there is not significant reservoir storage for agricultural use in the White River basin.
- Although crop consumptive use increased, not all crop demands were met. Similar to historical climate results, there continue to be water shortages on tributaries to the White River in the late irrigation season for the climate projections. Basin-wide combined crop consumptive use shortage associated with the climate projections is 5 percent, whereas crop consumptive use shortage associated with historical climate conditions is 2 percent. Note that historical and climate projection crop shortages are difficult to compare directly, since the crop demands are not the same

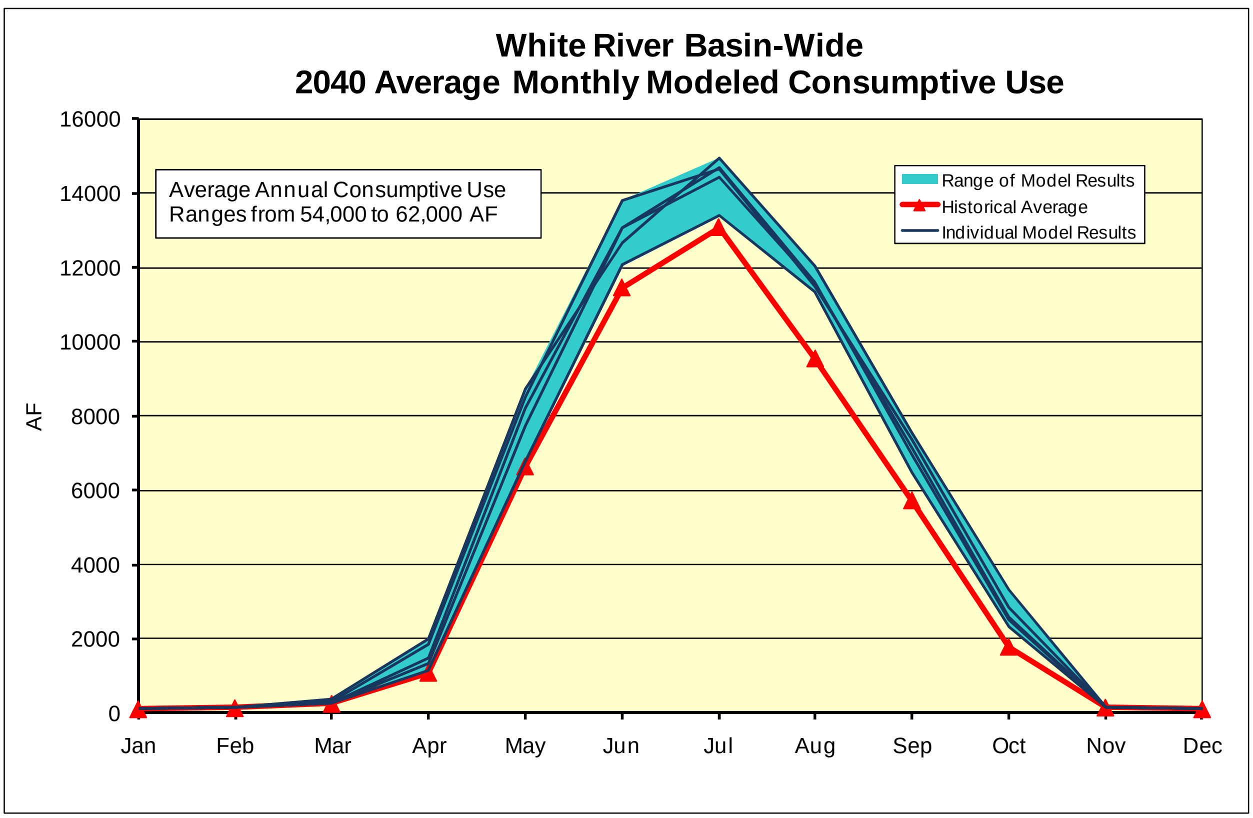


Figure 3-33 – White River Basin-Wide - 2040 Average Monthly Modeled Consumptive Use

Upper Colorado River Basin Consumptive Use

Figure 3-34 shows the average monthly modeled consumptive uses and losses in the Upper Colorado River basin for each of the five 2040 climate projections and for historical climate conditions. Values are the total modeled depletions in the basin and include irrigation, municipal and industrial consumptive uses, basin exports, plus reservoir evaporation. As shown, the consumptive use in the Upper Colorado River basin increased every month for most of the 2040 climate projections.

- Modeled annual consumptive uses and losses increased by 4% for climate projections combined.
- Average annual crop irrigation requirements increased by 19% for climate projections combined.
- The increase in crop irrigation demand was able to be partially met during spring and early summer months, even though there is not significant reservoir storage for agricultural use on most tributaries to the Colorado River.
- Although consumptive use slightly increased for most climate projections, not all crop demands were met. Crop consumptive use of the large irrigation diversions on the main stem Colorado River, including those associated with the Grand Valley Project and Grand Valley Irrigation Canal, were often shorted due to existing structure capacity and water rights limitations - not available water limitations. Tributary demands continued to be shorted in the late irrigation season due to water availability. Basin-wide combined crop consumptive use shortage associated with the climate projections is 10 percent, whereas to crop consumptive use shortage associated with historical climate conditions is 7 percent. Note that historical and climate projection crop shortages are difficult to compare directly, since the crop demands are not the same.
- Although transbasin diversion demands were not revised as part of CRWAS Phase I modeling efforts, existing demands cannot be fully met due to the impact of climate projections including decreased natural flows and increased senior downstream demands. On average, 5% less water is exported from the basin for the climate projections compared to historical climate conditions.

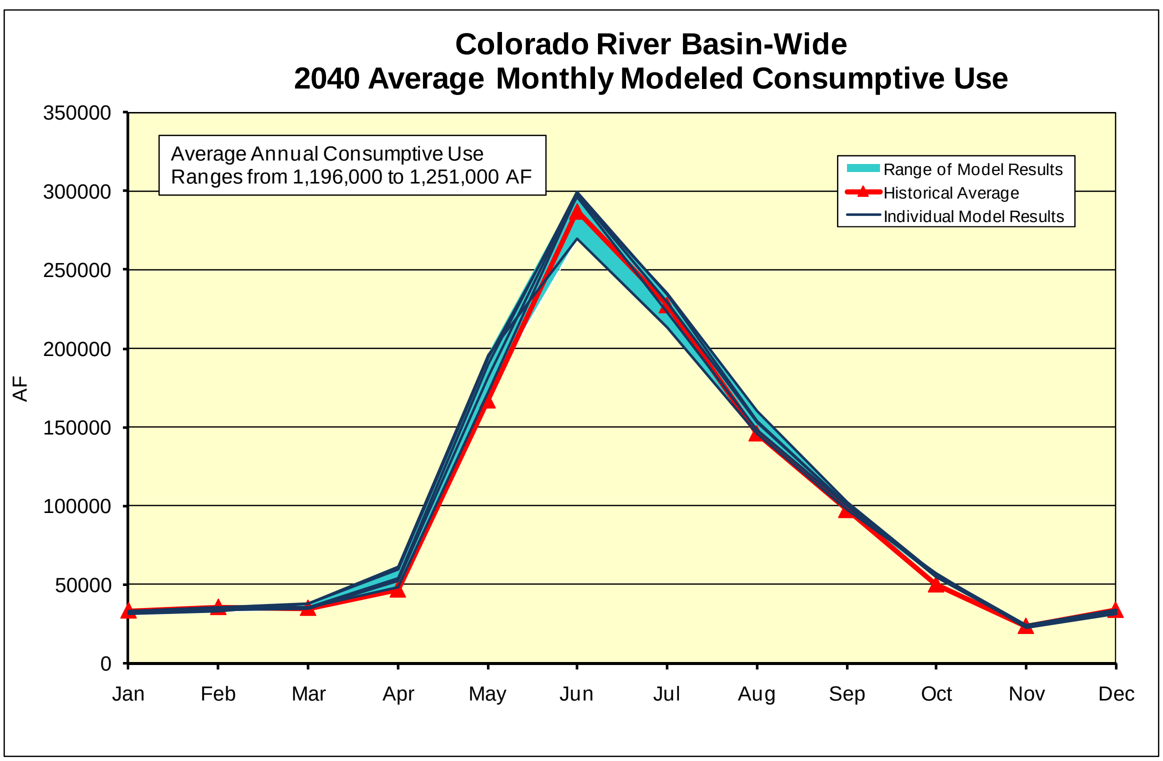


Figure 3-34 – Upper Colorado River Basin-Wide - 2040 Average Monthly Modeled Consumptive Use

Gunnison River Basin Consumptive Use

Figure 3-35 shows the average monthly modeled consumptive use in the Gunnison River basin for each of the five 2040 climate projections and for historical climate conditions. Values are the total modeled depletions in the basin and include irrigation, municipal, and industrial consumptive uses plus reservoir evaporation (note, does not include evaporation from the Aspinall Unit). As shown, the consumptive use in the Gunnison River basin increased every month for each of the 2040 climate projections.

- Modeled annual consumptive use (including evaporation on reservoirs except Blue Mesa and Morrow Point) increased by 10 percent for the climate projections combined.
- Average annual crop irrigation requirements increased by 17 percent for the climate projections combined.
- The agricultural-use reservoirs, for example Ridgway Reservoir discussed in Section 3.7, and the reservoirs in the North Fork Gunnison tributaries, supply more water to meet the increased agricultural demand for the climate projections.
- Although consumptive use increased, not all crop demands were met. Similar to historical climate results, there continue to be water shortages on tributaries in the Gunnison River basin in the late irrigation season for the climate projections. These shortages are greater for structures diverting off smaller tributaries and structures without supplemental storage than, for instance, structures in the Uncompahgre River valley. Basin-wide combined crop consumptive use shortage associated with the climate projections is 17 percent, whereas crop consumptive use shortage associated with historical climate conditions is 12 percent. Note that historical and climate projection crop shortages are difficult to compare directly, since the crop demands are not the same.

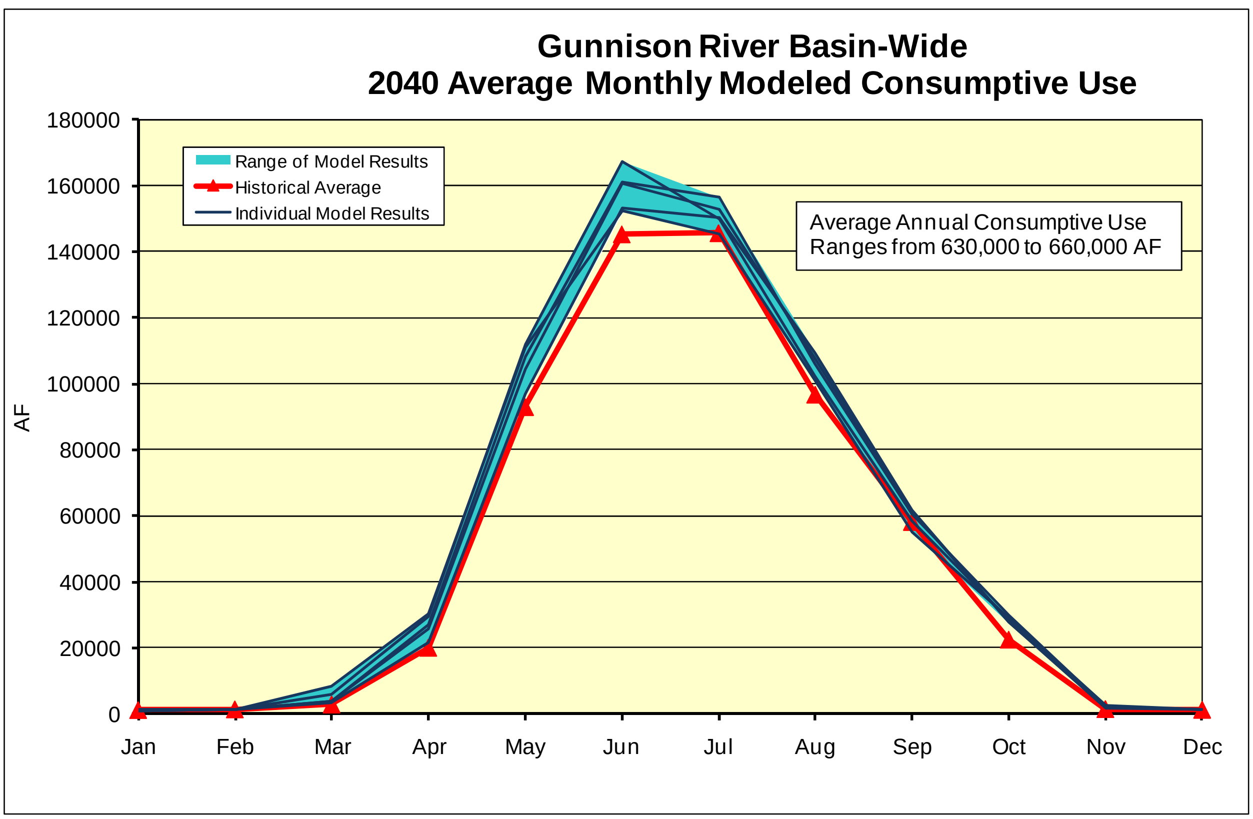


Figure 3-35 – Gunnison River Basin-Wide - 2040 Average Monthly Modeled Consumptive Use

San Juan River Basin Consumptive Use

Figure 3-36 shows the average monthly modeled consumptive use in the San Juan and Dolores River basins for each of the five 2040 climate projections and for historical climate conditions. Values are the total modeled depletions in the basin in Colorado and include irrigation, municipal, and industrial consumptive uses plus reservoir evaporation. Note that San Juan-Chama project diversions, other New Mexico uses represented in the model, and evaporation from Navajo Reservoir are not included. Figure 3-36 shows that, unlike the other study basins, the consumptive use in the San Juan and Dolores basins decreased for most of the 2040 climate projections.

- Modeled annual consumptive use (including evaporation in Colorado) decreased by 8 percent for the climate projections combined.
- Three of the five individual climate projections showed a significant decrease in consumptive use, and two showed a slight increase in consumptive use. The wide range between the climate projections shown in Figure 3-35 is similar to the wide range of natural flows seen at locations in the southwestern portion of the State.
- Average annual crop irrigation requirement increased by 17 percent for the climate projections combined. As previously discussed, this is a higher increase in crop irrigation requirement than projections indicated in the other study basins.
- The agricultural-use reservoirs, for example McPhee Reservoir discussed in Section 3.7, Lemon Reservoir, and Vallecito Reservoir, supplied more water to meet increased agricultural demand for the climate projections.
- As consumptive use decreased, basin-wide shortages increased for historical climate conditions. This is a result of both increased demand and significantly decreased natural flow for most of the climate projections, especially in the southwestern area of the basin where a significant percentage of the irrigation occurs. Basin-wide combined crop consumptive use shortage associated with the climate projections is 37 percent, whereas crop consumptive use shortage associated with historical climate conditions is 23 percent. Note that historical and climate projection crop shortages are difficult to compare directly, since the crop demands are not the same.

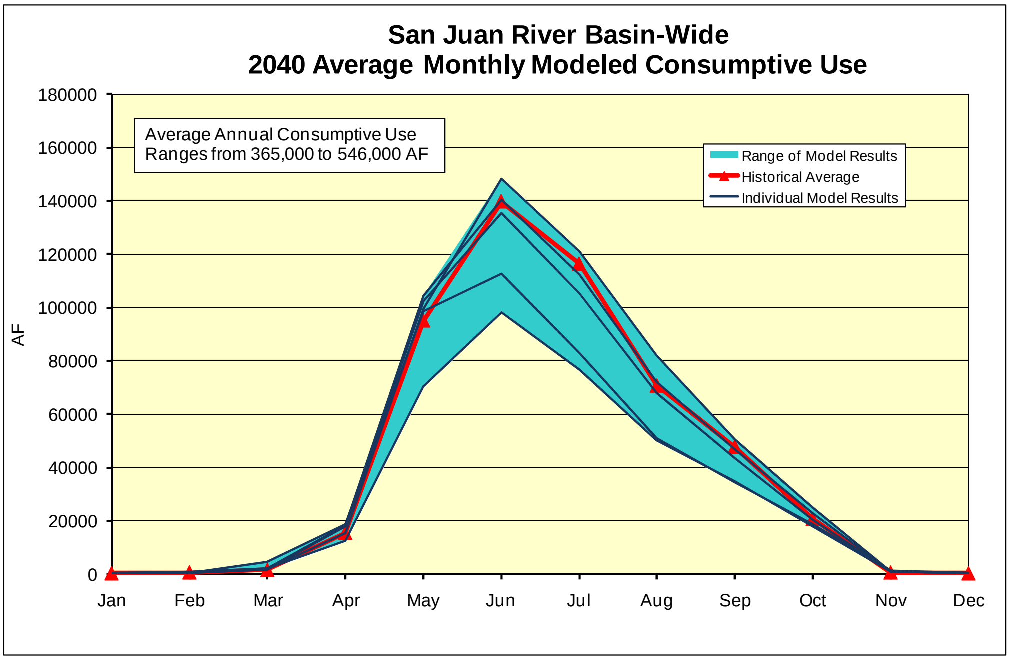


Figure 3-36 – San Juan River Basin-Wide - 2040 Average Monthly Modeled Consumptive Use

3.9 Water Available for Future Consumptive Use by Colorado

Figure 3-37 shows, for different hydrologic cases and for the two bounding values of the compact assumptions used for purposes of this study, the range of potential outcomes of the amount of water available for future consumptive use. Consistent with previous analyses, the values in Figure 3-37 include Colorado's share of CRSP evaporation, which is part of the Upper Basin's right to use Colorado River water. The previous analysis referred to in Figure 3-37 was conducted by Randy Seaholm, of the CWCB staff (CWCB, 2009).

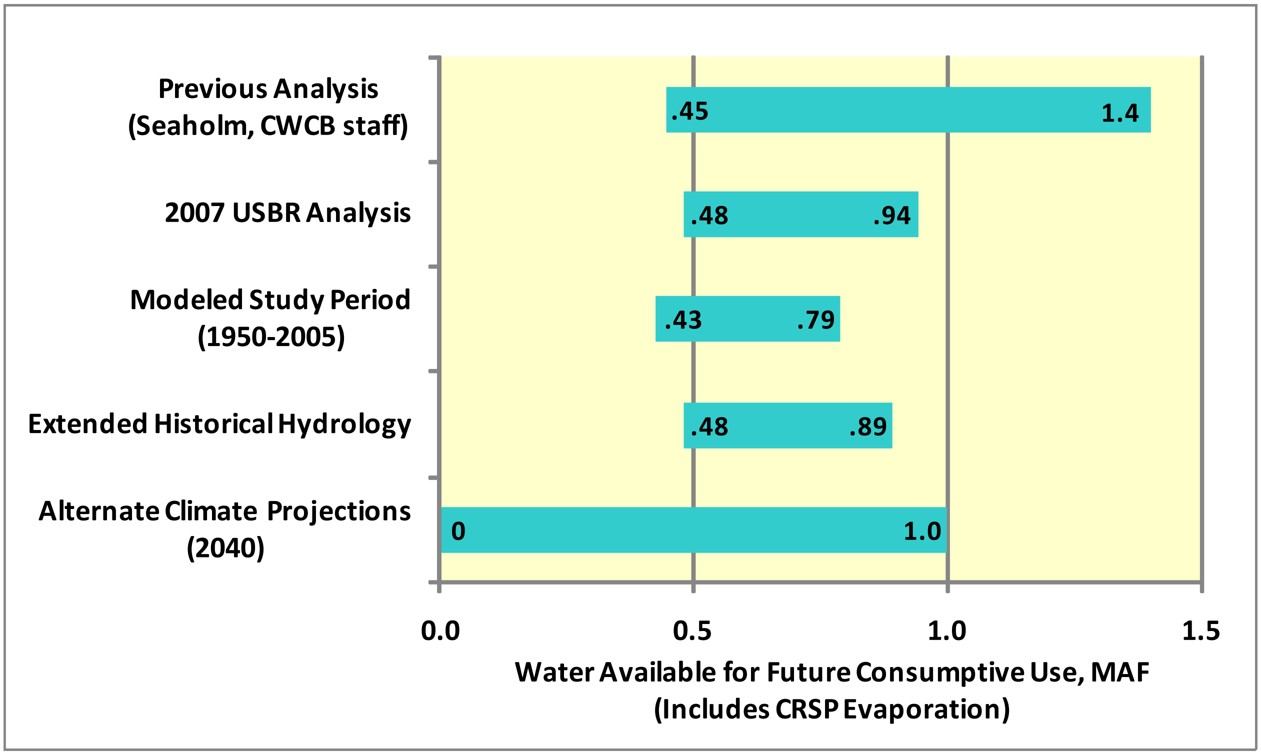


Figure 3-37 –Water Available for Future Consumptive Use by Colorado (MAF)
Revised from preliminary charts presented from January through March 2010 to CWCB, IBCC, Joint Agriculture Committee, and Colorado Water Congress

The analyses presented above provide a useful first step in characterizing the general magnitude of possible outcomes regarding the amount of water available for future consumptive use in Colorado. Assumptions as to the Law of the River used for purposes of this Study do not constitute Colorado's interpretation of any law or policy. The results demonstrate the broad uncertainty inherent in projections of future hydrologic conditions and in future interpretations of the terms of the compacts and the Law of the River. Consideration of the limitations of the current state of scientific knowledge regarding future climate and, to a lesser degree, regarding the methods and computer tools currently being used to support inter-state Colorado River basin water management decisions will help the State focus future phases of the CRWAS and other studies of Colorado's water availability.

3.10 General Findings

The Study involved a substantial evaluation of alternative methodological approaches to the elements of the Study, followed by selection of the preferred approach for each element. These evaluations provided the following general findings:

- GCMs do not reliably simulate year-to-year sequences of hydrologic state (wet/dry) or wet or dry spells, but they do a reasonable job of simulating average changes in climate at a monthly level. Impact studies, like CRWAS, typically use climate projections to establish the mean monthly change in climate.
- The information most commonly taken from the output of GCMs for impact studies like CRWAS is the projected change in monthly, seasonal or annual average climate conditions. In CRWAS the projected *change* in monthly mean temperature and precipitation is applied to the observed values of temperature and precipitation to obtain a *climate-adjusted* weather record.
- Impact studies like CRWAS most commonly “inherit” inter-annual variability (the sequence of years and distribution of spells) from the “baseline” period. In the case of CRWAS this would mean that the sequence of years and the distribution of spells would be that which had occurred over the observed period from 1950 through 2005.
- Paleo hydrology provides information that can be used to evaluate water availability and system performance under droughts and wet spells that are more intense and more sustained than those experienced in the historical record.
- Recognizing these factors, the CWCB specified that the CRWAS would incorporate information from the paleo-record into the water availability analyses. Reliable methods were identified that could combine information from paleo hydrology about the frequency of droughts and wet spells with information about impacts of projected climate on mean monthly flows.
- Physical hydrology models are the most common method for quantifying the impact on streamflow of projected changes in climate. A number of physical hydrology models are available for such impact studies. The Variable Infiltration Capacity (VIC) model was selected for use in CRWAS based on its relative advantage over the other available models for this application.
- At this time the availability of observed weather data, which is required for hydrology modeling, is the factor that limits the length of the historical hydrology period. The historical hydrology period for CRWAS is of adequate length and contains sufficient variability for the purpose of the Study.
- The range of hydrologic impacts of climate change on streamflow is very large, and includes the possibility of significant increases in streamflow and the possibility of significant decreases in streamflow. If it is not practical to analyze the impact of all available projections, a valid approach is to select a subset of climate projections that represent a sufficient portion of the range of uncertainty inherent in the climate projections (projection-to-projection variability).
- The projections selected by FRCCVS and CRWAS for 2040 represent about 75% of the range of uncertainty in the climate projections. The projections selected for 2040 better characterize the range of projected impacts on streamflow from future climate for both 2040 and 2070 than do the projections selected for 2070.
- The wide range of flow conditions simulated in CRWAS could be simulated in the CDSS models without significant problems related to either model execution or operating rules.
- Compared to the CRSS model, the CDSS models, which represent the water supply systems in Colorado with a greater degree of detail, and which have been calibrated against observed water use, show a higher level of water use under dry conditions.

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Conclusions and Recommendations

4 CONCLUSIONS AND RECOMMENDATIONS

The CRWAS responds to the General Assembly's direction to the CWCB to provide information on how much water is available from the Colorado River basin to meet the State's water needs. As a starting point, the Phase I work presented in this report provides a water availability assessment based on existing levels of water use (also referred to as water demands) served by water rights that are currently being used ("perfected" or "absolute" water rights) and by interpretations of current operating and management practices for water diversion, storage and conveyance facilities. Assessments of water availability to meet future water needs are reserved for Phase II of the CRWAS.

Conclusions of the Phase I Study are summarized below:

- Interaction with the BRTs provided essential information to update and refine the State's hydrologic planning tools (including CDSS); improving model calibration and enhancing the representation of current water management.

- Computer models used in Phase I (including CDSS) proved appropriate to simulate current water uses (demands) and alternate hydrologic scenarios (historical, paleohydrology, and a broad range of equally-probable climate projections). The models were effective in simulating a broad range of possible future conditions associated with crop irrigation requirement, streamflow, consumptive use, and water availability that vary (in magnitude and time) with elevation and geographic region of the state.

- Phase I demonstrates a broad range of water availability for future Colorado consumptive use under various compact assumptions used for purposes of this Study. The upper end of this range lies within the range of previous studies, while the corresponding lower range suggests that Colorado may have no or limited additional water available for development.

- The primary underlying drivers for the broad range of Phase I results are 1) the inherent uncertainties in the available global climate models in projecting the magnitude and nature of future greenhouse gas emissions; 2) the complexity of modeling atmospheric circulation; and 3) down-scaling the resulting effects of changed temperature and precipitation on natural flows in an area the size of the Colorado River basin.

- Phase I results are based only on current water uses (consumptive and non-consumptive water demands). Stakeholders demonstrated strong interest in more than 30 Study presentations to expand analysis to include future demands and operating conditions.

The following recommendations are offered for consideration:

- *Continue refinements to the CDSS* – This Study, with its large geographic scale and detailed analysis, would not have been possible without the availability of the CDSS system. The process of presenting the Study's approach and tools in Phase I through the use of BRT meetings should continue in Phase II in close collaboration with the processes and programs of the CWCB Water Supply Protection Section and the Bureau of Reclamation's Colorado River Basin Study. A key element in developing additional CRWAS refinements is demonstrating openness and transparency in displaying hydrologic data, modeling procedures and calibration results. Specific CDSS refinements that should be considered include the following:
    - Revise baseflows in Plateau Creek based on information currently being developed by Collbran Water Conservancy District and the Division of Water Resources. Delivery of water from Vega Reservoir through the Southside Canal has a significant effect on both baseflows and the ability to meet future demands in Plateau Creek basin. Historical delivery records and locations of direct delivery to irrigated lands are being compiled and provided to the CRWAS study team. Incorporating this information into the Upper Colorado River StateMod model will greatly improve calibration and, therefore, confidence in simulated results.
    - Consider alternatives to representing the USFWS fish flow recommendations for the 15-mile reach in the Upper Colorado River model. As discussed in this report, the USFWS recommendations are modeled as an instream flow agreement. Although the flows are modeled as junior to other basin demands (therefore they cannot "place a call" on the river), the approach used in the current modeling effort allocates water to the demands, thereby decreasing the reported water available for future uses upstream.
    - Revise current release rules for reservoirs that operate for flood control to account for changes in timing of peak runoff. Four reservoirs in the Study basin (Green Mountain, Ruedi, Lemon, and Vallecito reservoir) release water for flood control based on target rules that reflect current inflow hydrographs. The climate projections indicate a shift in the peak runoff that would likely result in a change to flood control operations.
    - Consider revisions to Aspinall Unit reservoir operations. The Aspinall Unit reservoirs (Blue Mesa, Morrow Point, and Crystal) operate primarily for non-consumptive uses within and outside of Colorado. An EIS is currently in draft form that will revise reservoir operations.
    - Incorporate alternative transbasin demands affected by climate change. In Phase I, transbasin demands were not revised to reflect the effects climate change may have on current levels of demands in the South Platte River and Arkansas River basins. In addition, transbasin demands are dependent on eastern slope supplies. The State should continue their efforts to develop a South Platte StateMod model that can be used, along with the current western slope models, to better represent the basin inter-dependence. Combined with an Arkansas River StateMod model, the entire State could be modeled together to better understand how future statewide demands will be met under climate change.
    - Remove New Mexico structures from the San Juan/Dolores StateMod model. The current StateMod model for the San Juan and Dolores basins includes structures that divert and consume water in New Mexico. These structures, along with Navajo Reservoir, were included in the model to assist the State in identifying options to meet recommended fish flows for the San Juan Recovery Program. New Mexico structures are modeled as junior to Colorado demands, therefore, they cannot "place a call" on the river. However, the current modeling effort allocates water to these demands, thereby decreasing the reported water available for future uses upstream.

- *Incorporate new water management strategies and interpretations of existing operating rules and agreements* – Stakeholder input (in Phase I) shows that there are many potential interpretations of the methods in which water can be managed in accordance with state water law. Phase II should identify additional interpretations to compare the effects of additional future consumptive and non-consumptive water demands.

- *Use the CRWAS to support the CWCB / IBCC programs and continue use of the CCTAG* – The data and models used in Phase I should be used to support the many on-going programs of the CWCB and the IBCC. Phase I demonstrated the benefits of independent input from these groups. Colorado is in an enviable position in terms of its resident professional expertise in water resources planning and management, including climate change expertise in the state. Future studies should take advantage of the multiple CWCB / IBCC programs and the CCTAG as a cost-effective source of key technical review and enhanced credibility.

- *Recommendation to Stakeholders* – Phase I results help Colorado River stakeholders better understand potential effects of climate change on water available for future uses in Colorado. These results can be used by stakeholders to prepare for a range of future hydrologic conditions, to better deal with uncertainty in their water management decisions and to support development of their individual policies and programs. It is recommended that each stakeholder interpret the broad range of future water availability from its own perspective, considering its own assessment of the possible future conditions, its role in water management, the resources it has to adapt to alternative potential futures, and its tolerance for risk.

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Where to find more detailed information:

A concise list of documents most pertinent to CRWAS and summaries of those documents are provided in CRWAS Task 2.1 – *Pertinent Document List* and CRWAS Task 2.2 – *Summary Briefs*; comprehensive reference lists and literature reviews are provided in technical memoranda and modeling briefs associated with CRWAS Tasks 3.1, 4.1, 6.1, 6.2, 6.3, 6.4, 6.7, 7.2, 7.3, 7.4, 7.5, 7.12, 8.1, 8.2, and 8.6; available at http://cwcb.state.co.us/.

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Appendices

APPENDICES

As noted in the Executive Summary, Phase I of CRWAS provides a range of water availability based on superimposing current water uses (water demands) on historical hydrology, paleohydrology, and climate-adjusted hydrology that will help Colorado River stakeholders to be prepared for a range of future hydrologic conditions and better deal with uncertainty in their water management decisions.

The five 2040 projections selected for CRWAS proved to be representative of the distribution of the 112 available global climate projections(see Figure 2-11), while the five 2070 projections selected for CRWAS proved to be not as representative of the distribution of the 112 available global climate projections as they are clustered on the low end of the distribution of 112 climate projections (see Figure 2-12). Comparison of the distribution of 2040 and 2070 projections show that climate-induced effects on streamflow are very similar for the two time frames (see Figure 2-10). Therefore, results presented in the Executive Summary and in the body of the report focus on the 2040 time frame. Results associated with the 2070 time frame are included here in the appendices.

A. Temperature

Contents

Table A1
Average Annual Projected Temperature Compared to Historical Temperature

Climate Station	Elevation	Designation	Location	2040		2070	
				Delta Temperature Degree Fahrenheit	Chart Page	Delta Temperature Degree Fahrenheit	Chart Page
Fruita 1W	4480	Lower	North	3.8	A-5	6.0	A-12
Glenwood Springs No2	5880	Mid	North	3.5	A-5	5.8	A-12
Grand Lake 6SSW	8288	Higher	North	3.3	A-6	5.5	A-13
Rangely 1E	5290	Lower	North	3.6	A-6	6.0	A-13
Meeker 3W	6180	Mid	North	3.6	A-7	5.9	A-14
Maybell	5908	Lower	North	3.5	A-7	5.9	A-14
Hayden	6440	Mid	North	3.4	A-8	5.7	A-15
Yampa	7890	Higher	North	3.5	A-8	5.8	A-15
Delta 3E	5010	Lower	South	3.7	A-9	5.9	A-16
Montrose No 2	5785	Mid	South	3.6	A-9	5.9	A-16
Gunnison 3SW	7640	Higher	South	3.5	A-10	5.7	A-17
Cortez	6153	Lower	South	3.6	A-10	5.9	A-17
Durango	6592	Mid	South	3.5	A-11	5.8	A-18
Norwood	7020	Higher	South	3.6	A-11	5.9	A-18
Basin-wide Average				**3.6**		**5.8**	

Figure A1 - 2040 Average Annual Temperature Increase from Historical (deg F)

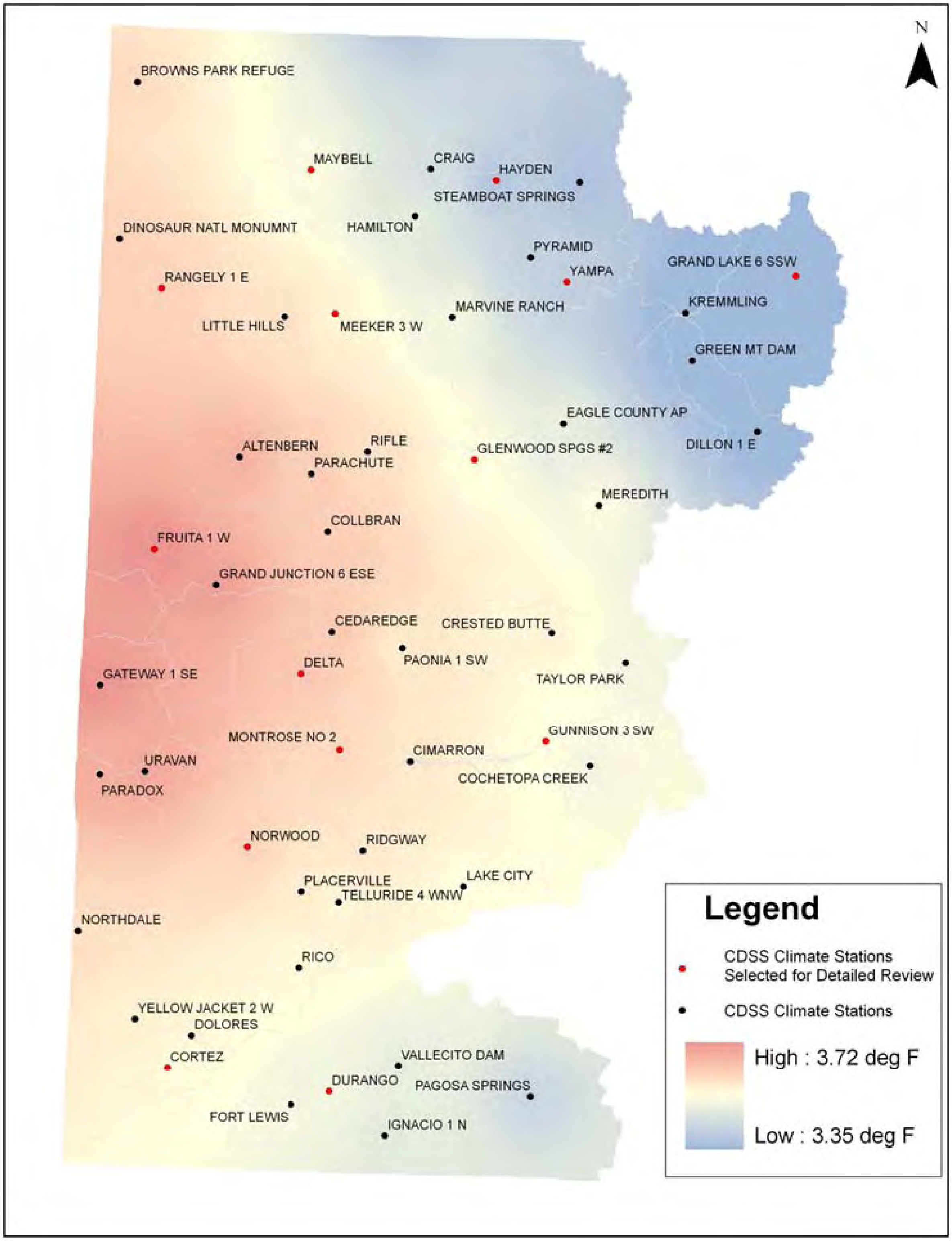


Figure A2 - 2070 Average Annual Temperature Increase from Historical (deg F)

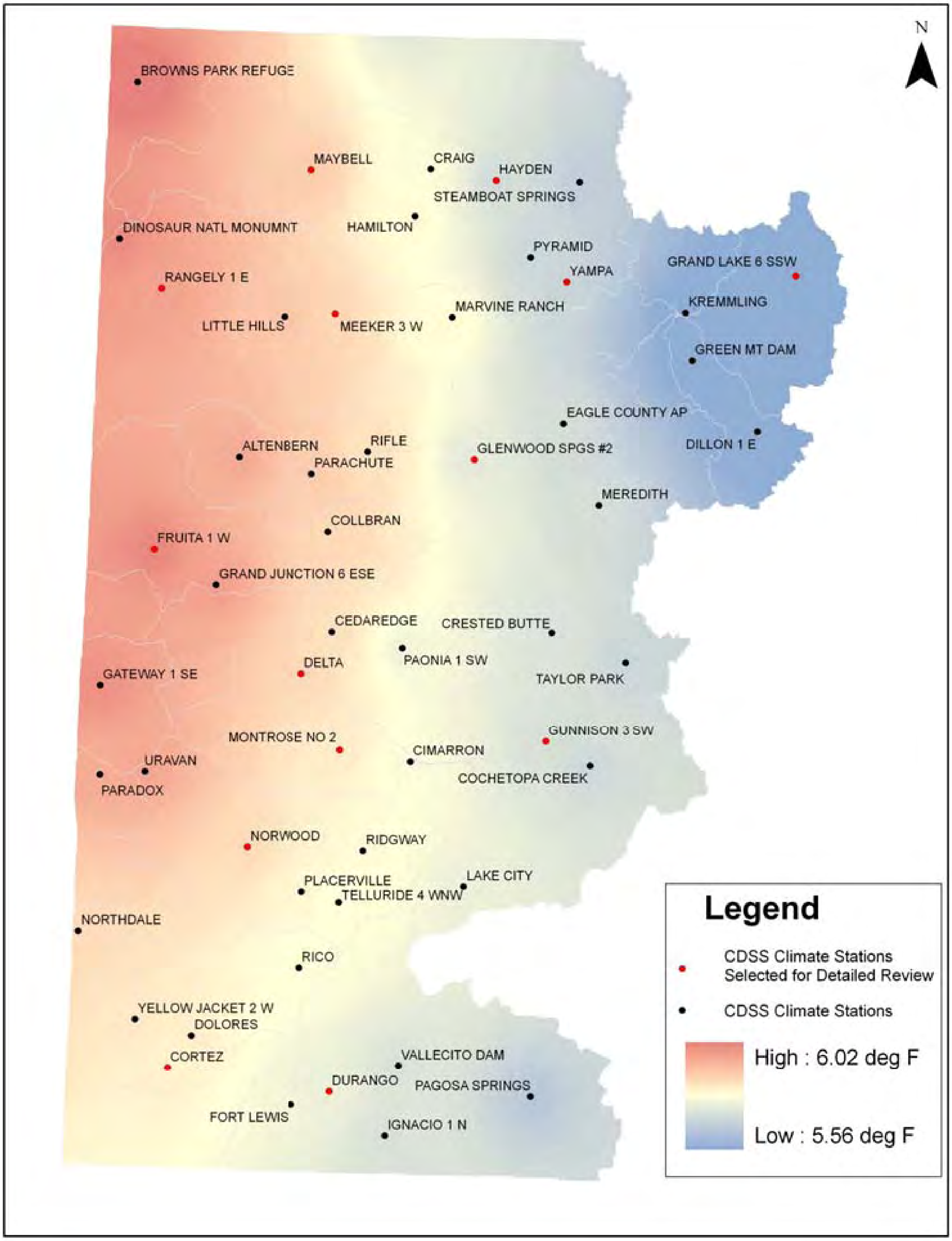


Figure A3 – Fruita 2040 Average Monthly Temperature Comparison

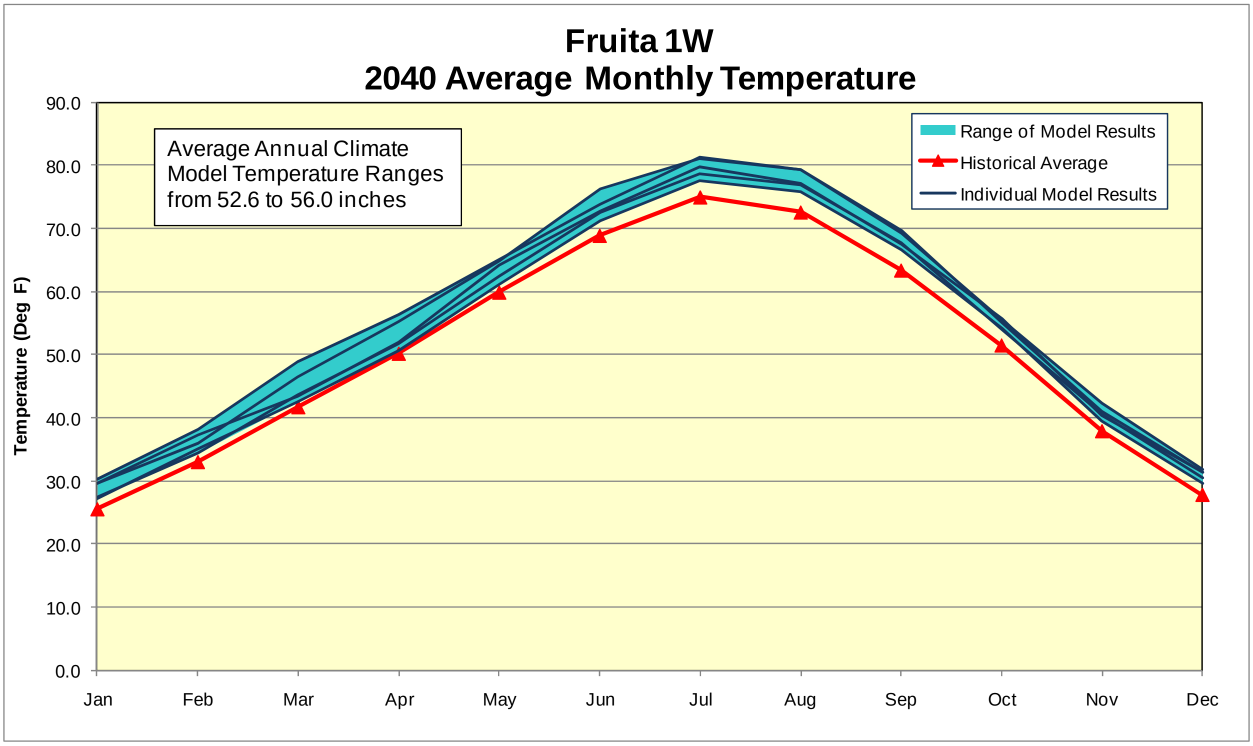


Figure A4 – Glenwood Springs 2040 Average Monthly Temperature Comparison

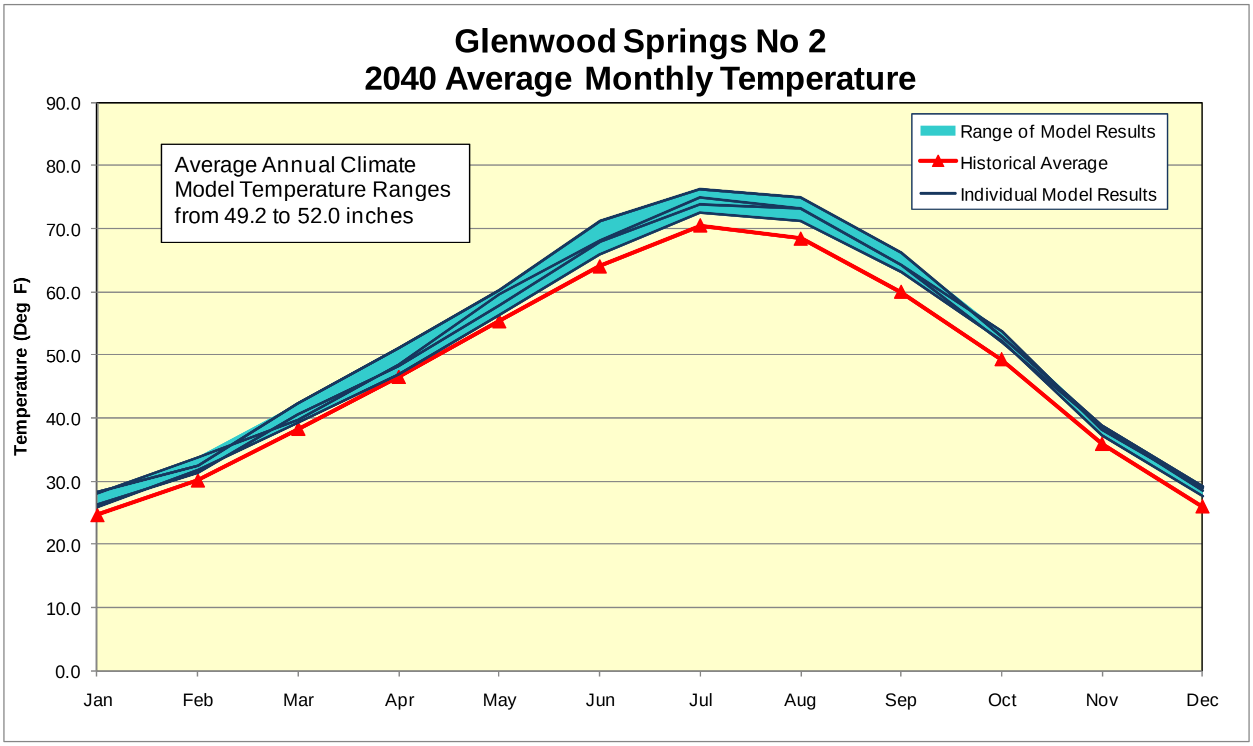


Figure A5 – Grand Lake 2040 Average Monthly Temperature Comparison

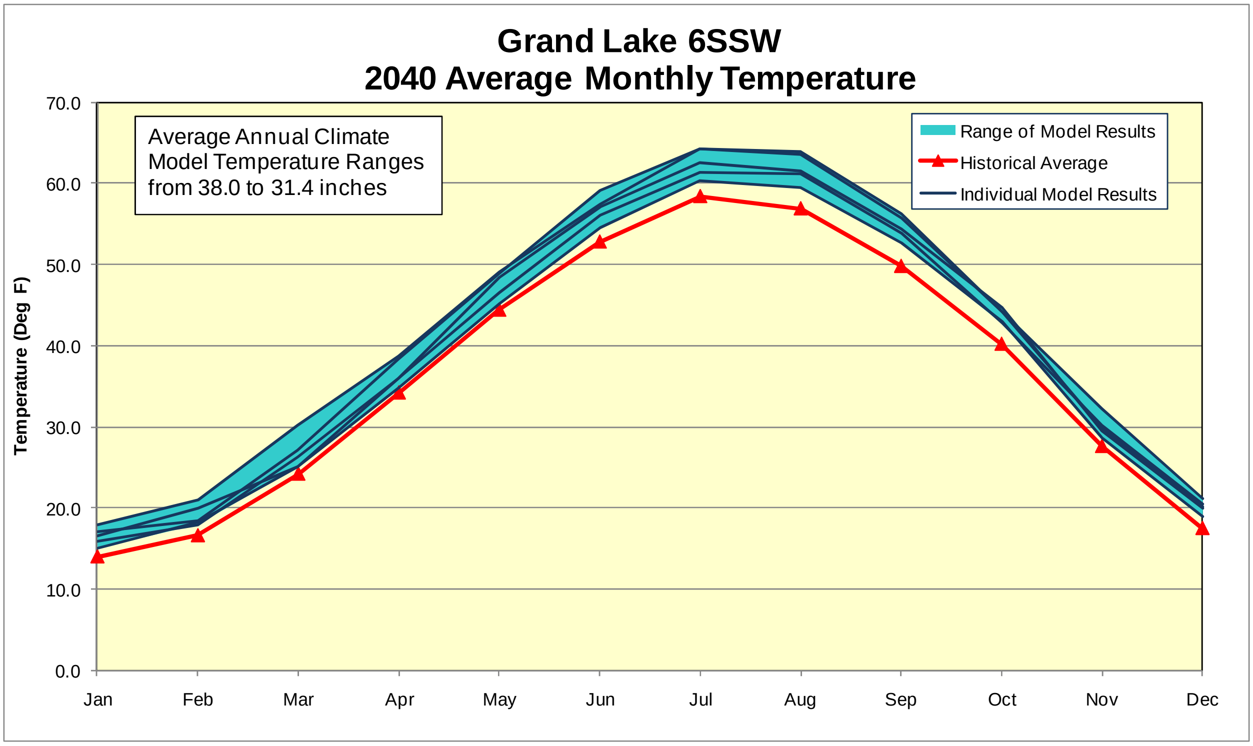


Figure A6 – Rangely 2040 Average Monthly Temperature Comparison

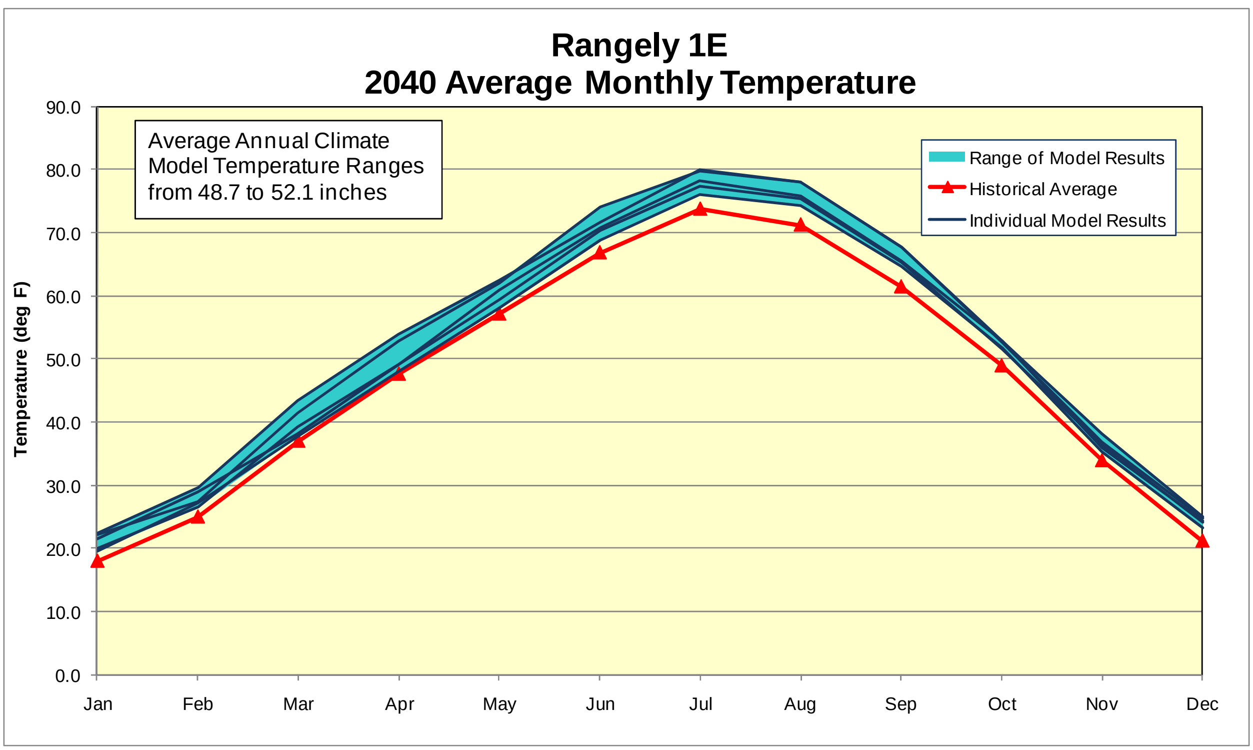


Figure A7 – Meeker 2040 Average Monthly Temperature Comparison

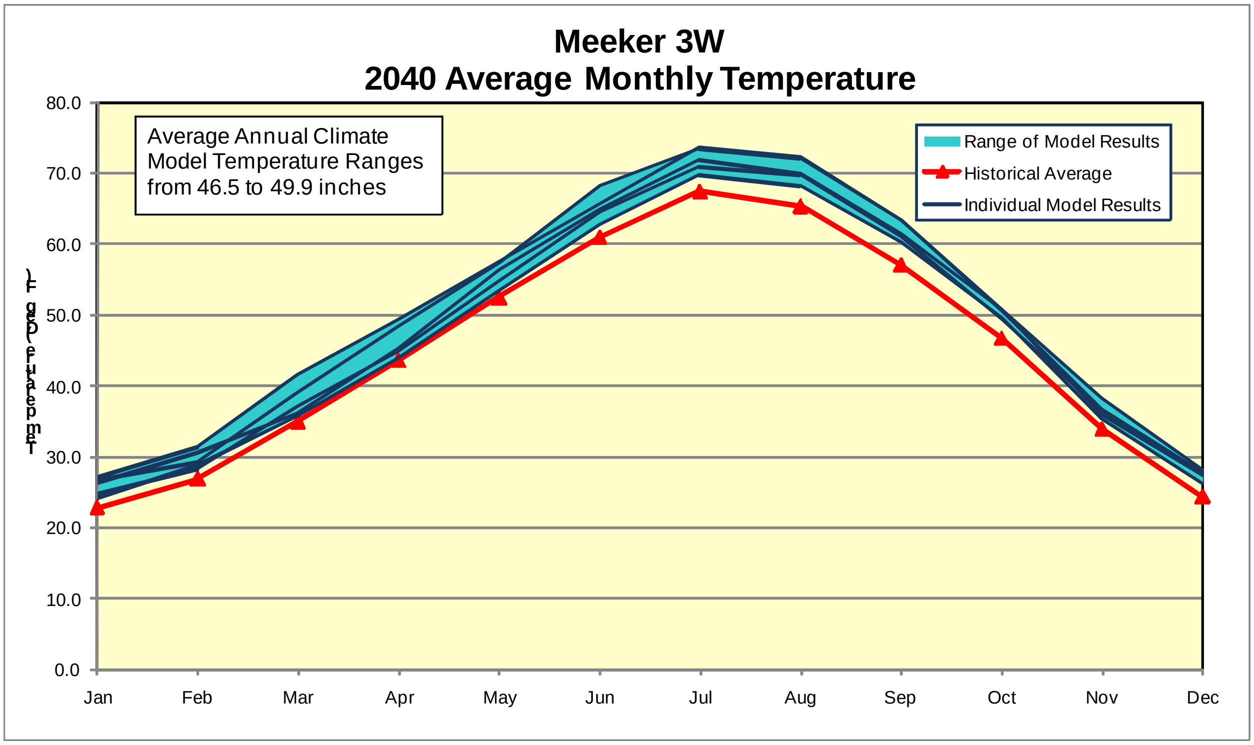


Figure A8 – Maybell 2040 Average Monthly Temperature Comparison

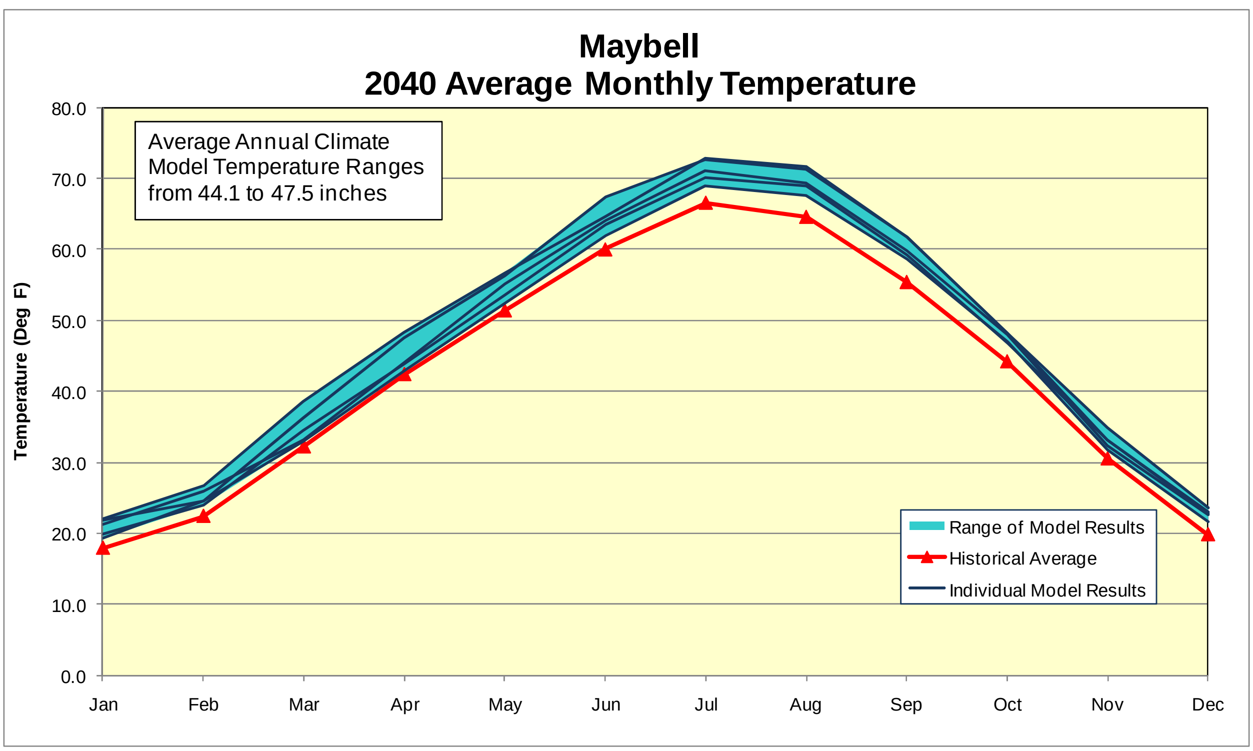


Figure A9 – Hayden 2040 Average Monthly Temperature Comparison

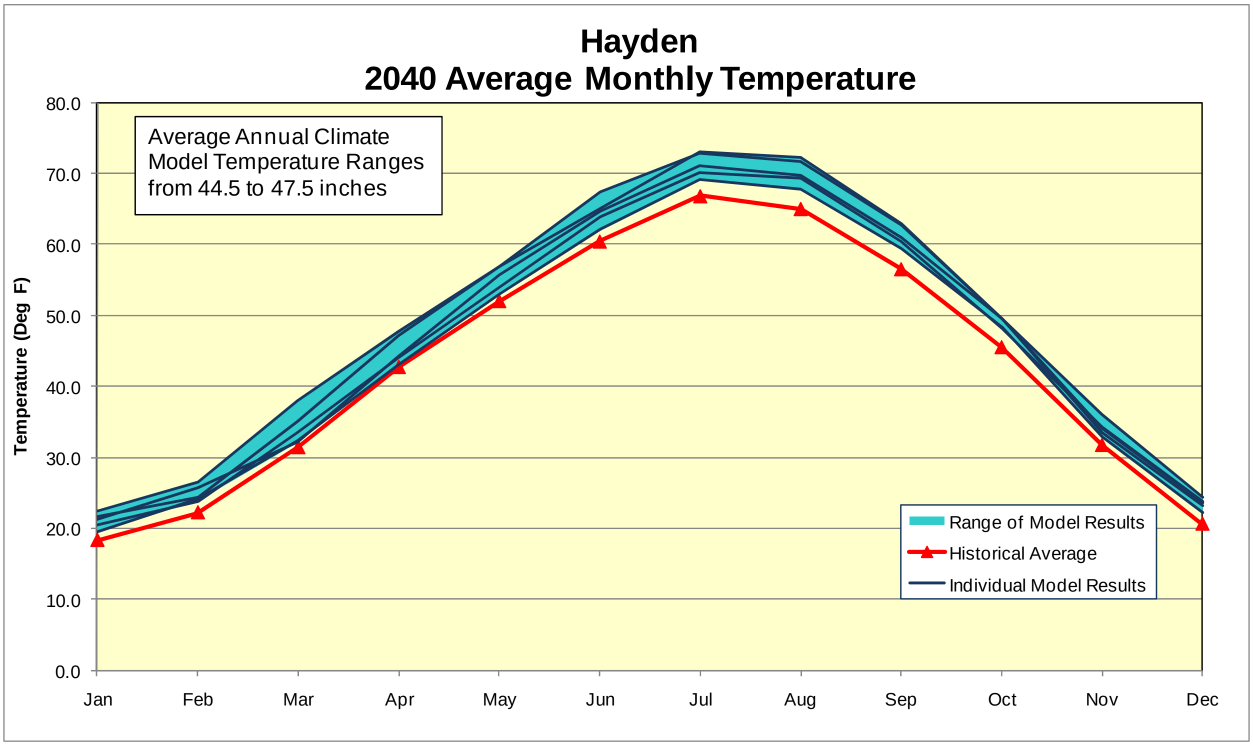


Figure A10 – Yampa 2040 Average Monthly Temperature Comparison

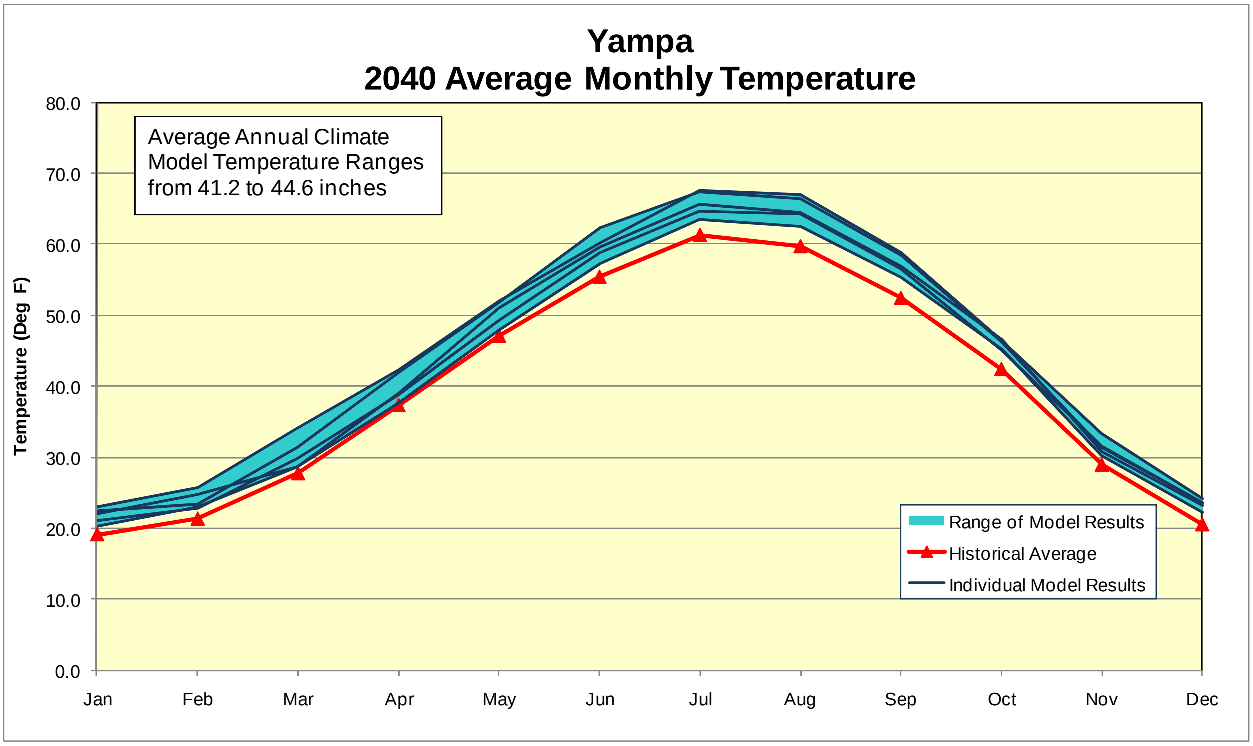


Figure A11 – Delta 2040 Average Monthly Temperature Comparison

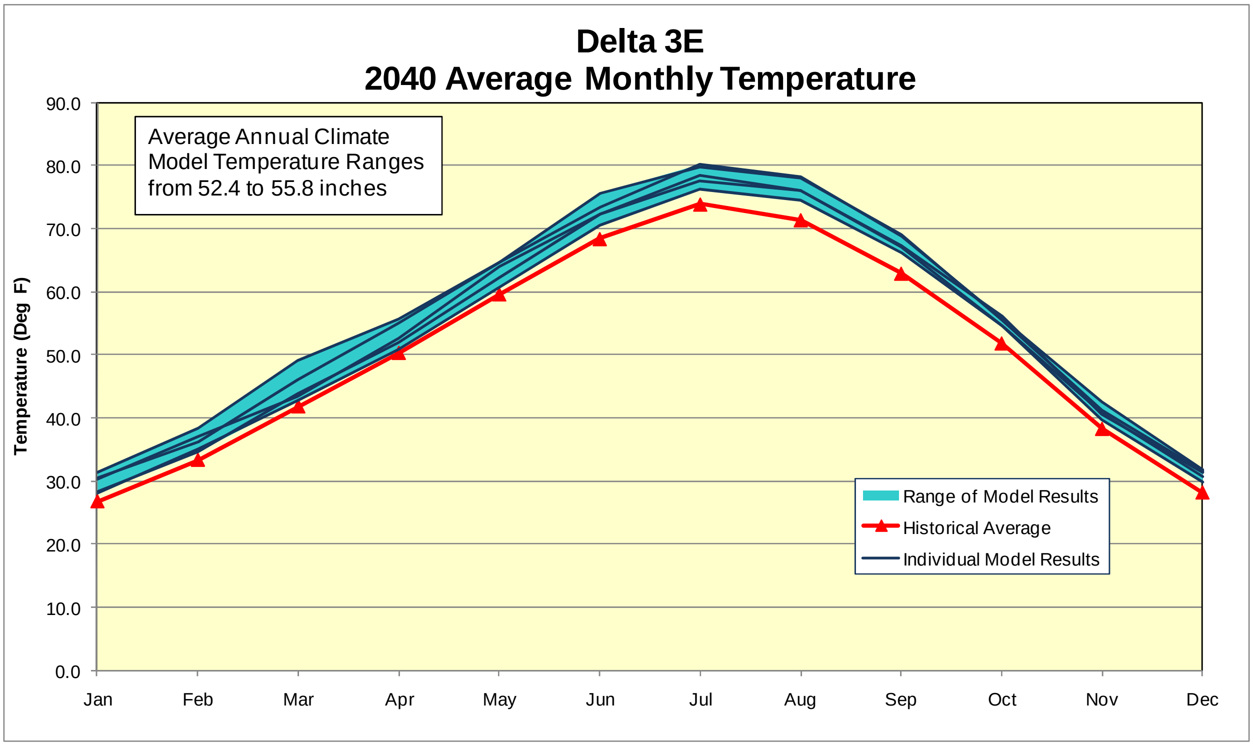


Figure A12 – Montrose 2040 Average Monthly Temperature Comparison

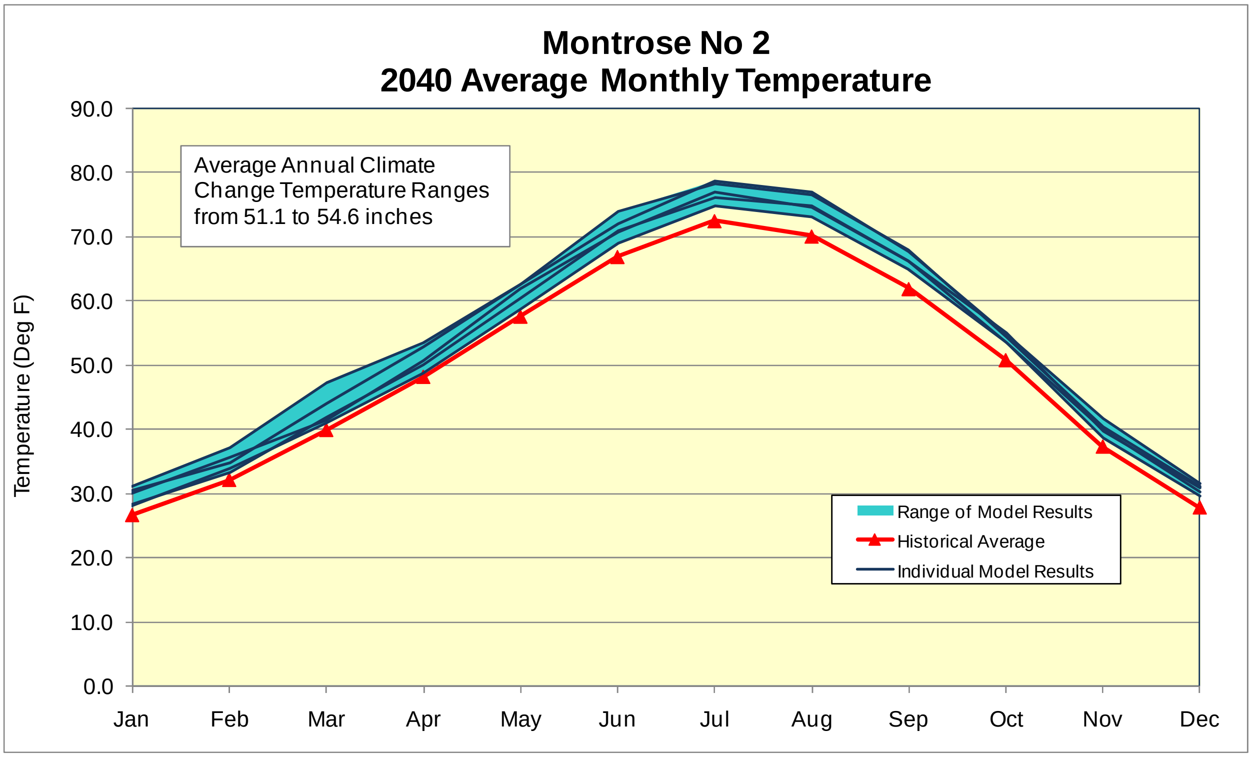


Figure A13 – Gunnison 2040 Average Monthly Temperature Comparison

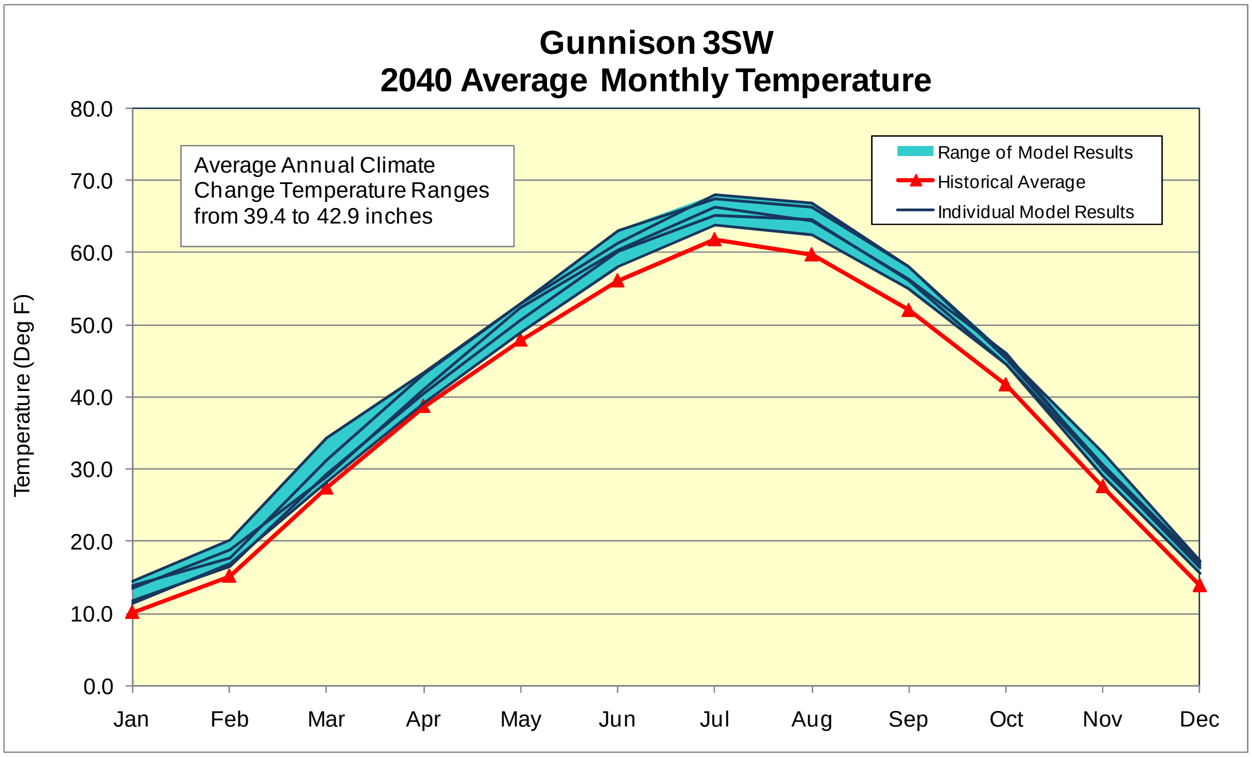


Figure A14 – Cortez 2040 Average Monthly Temperature Comparison

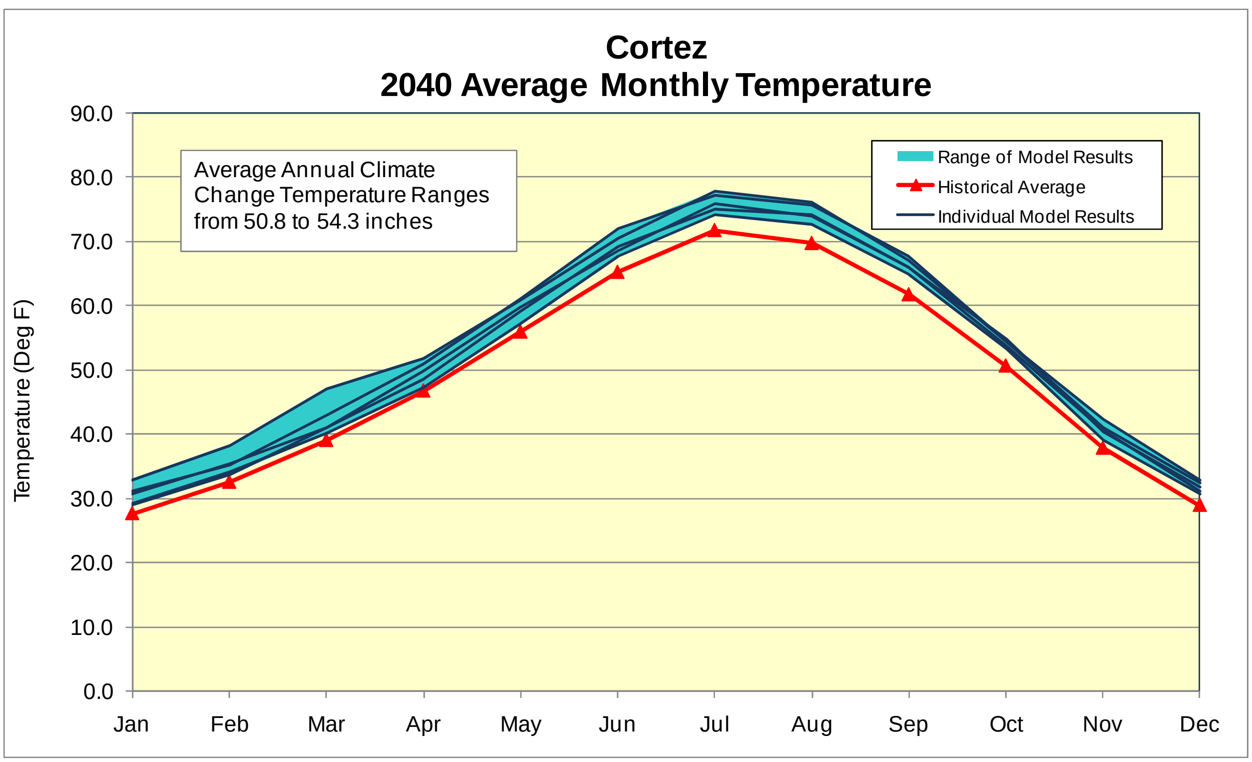


Figure A15 – Durango 2040 Average Monthly Temperature Comparison

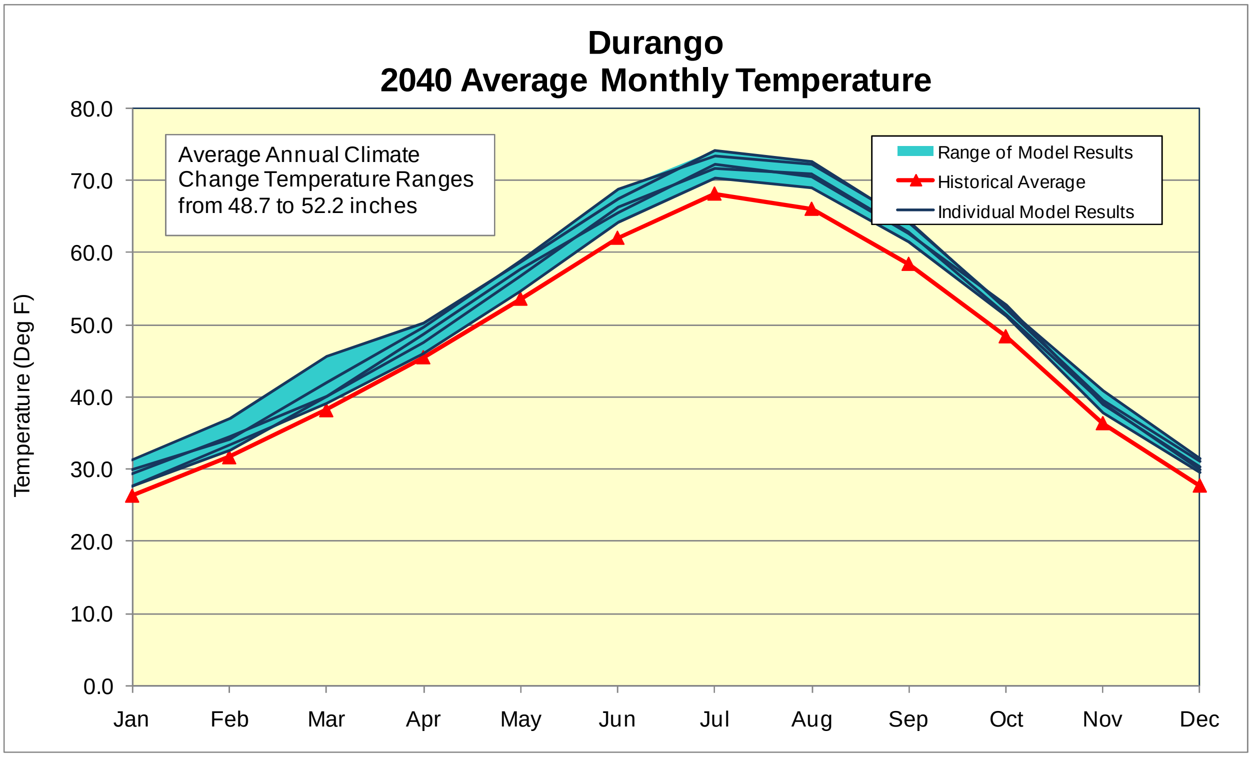


Figure A16 – Norwood 2040 Average Monthly Temperature Comparison

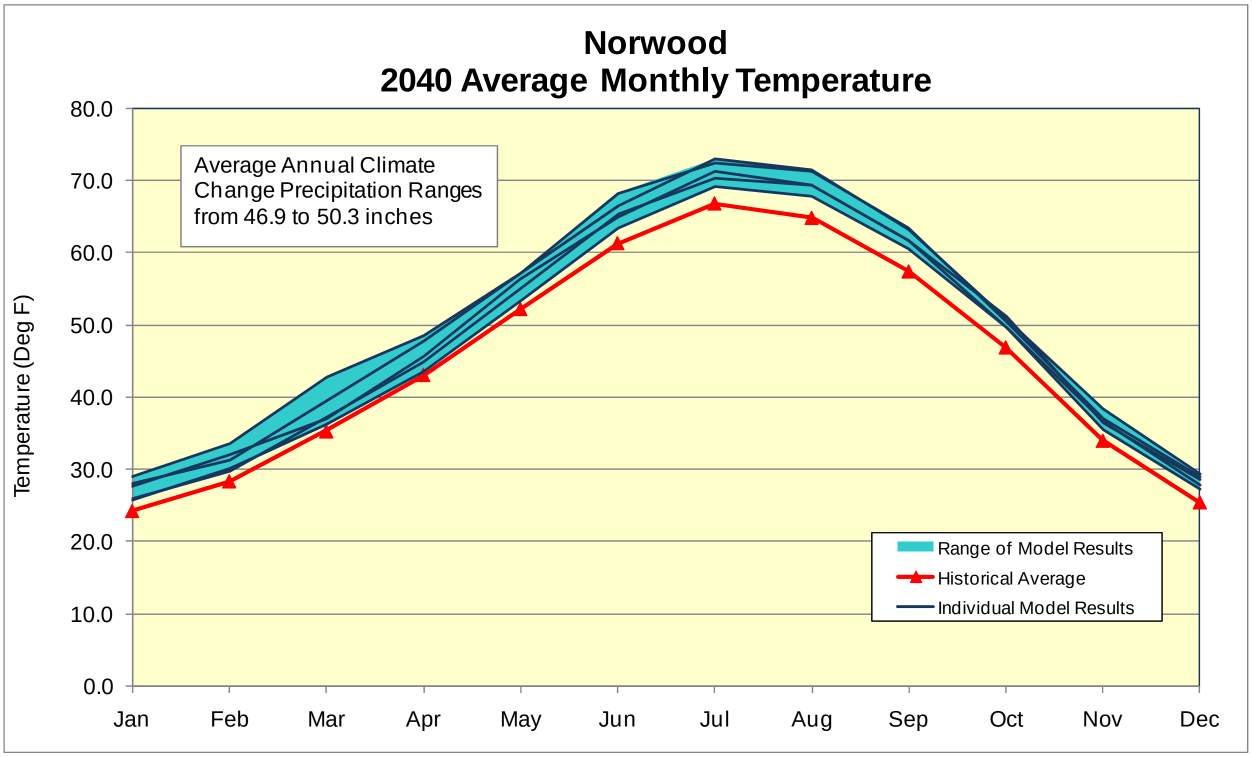


Figure A17 – Fruita 2070 Average Monthly Temperature Comparison

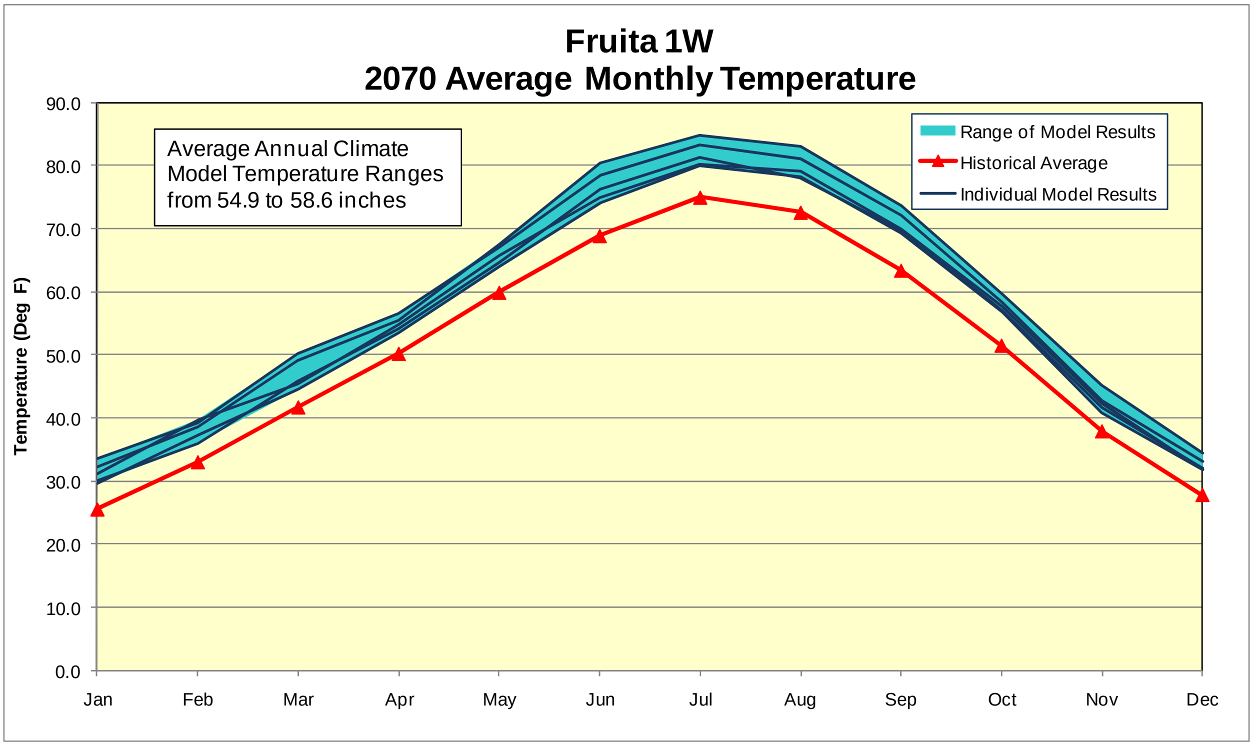


Figure A18 – Glenwood Springs 2070 Average Monthly Temperature Comparison

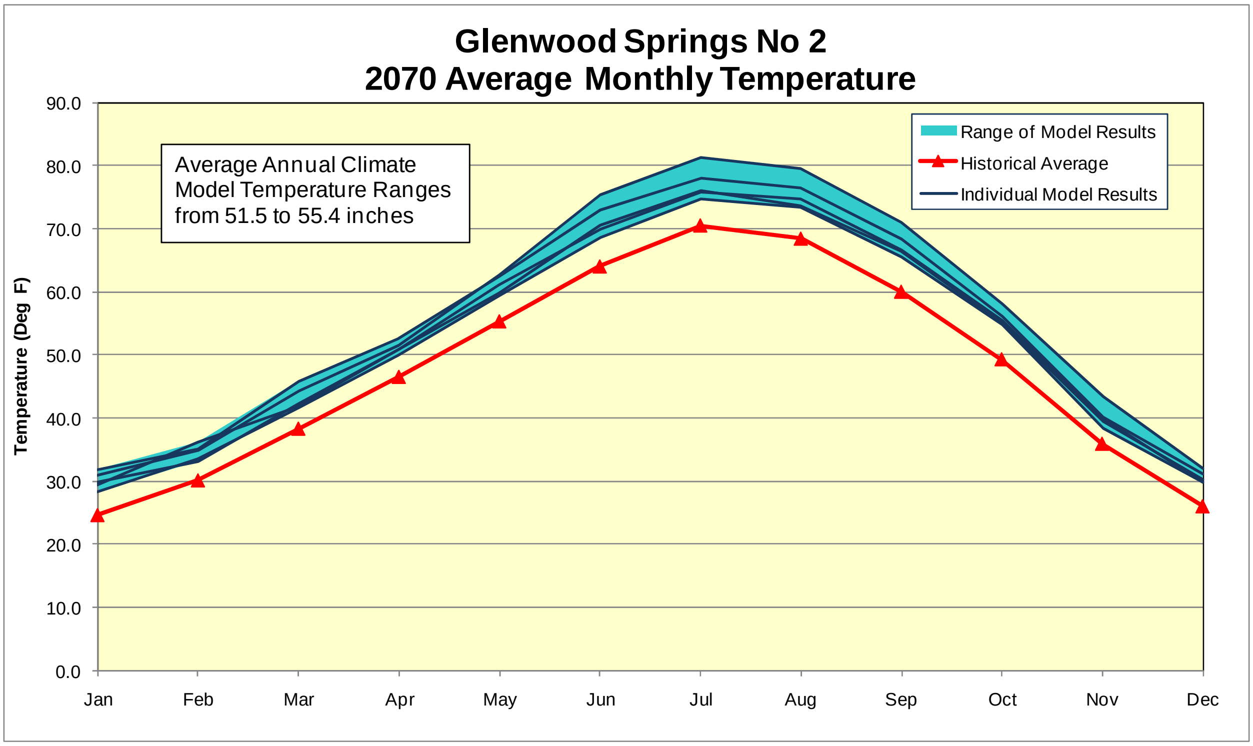


Figure A19 – Grand Lake 2070 Average Monthly Temperature Comparison

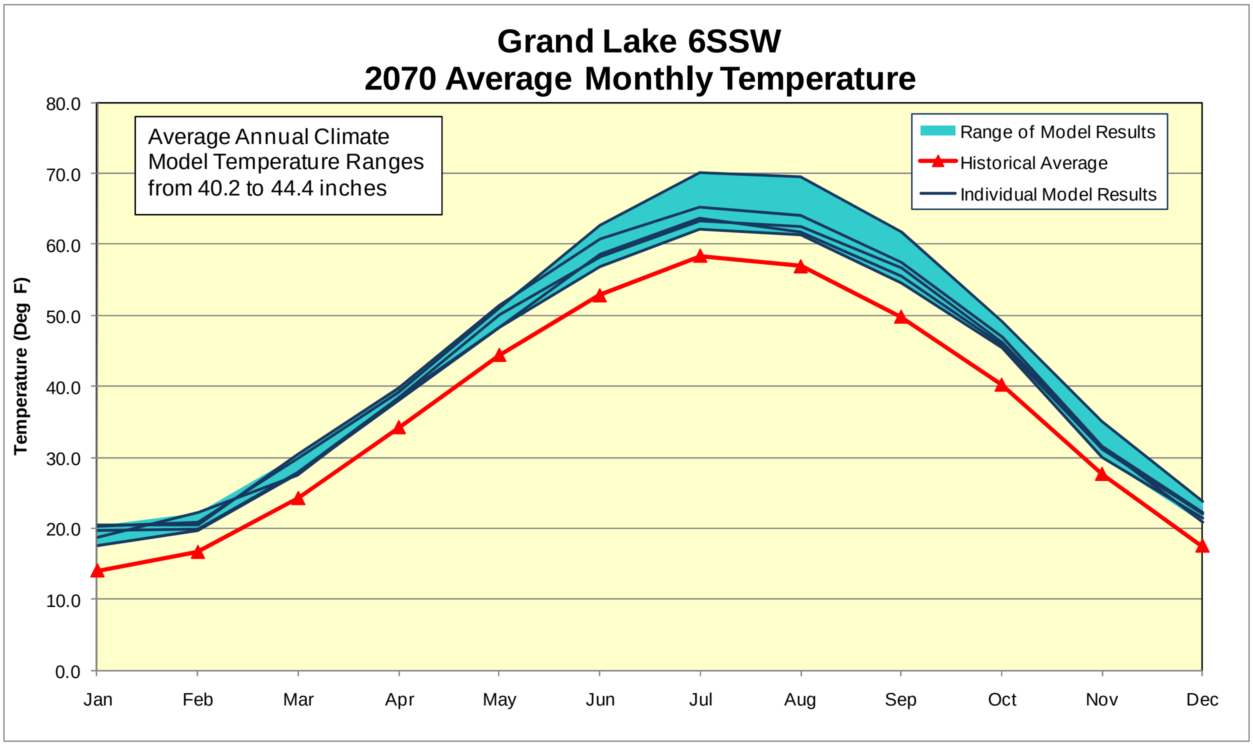


Figure A20 – Rangely 2070 Average Monthly Temperature Comparison

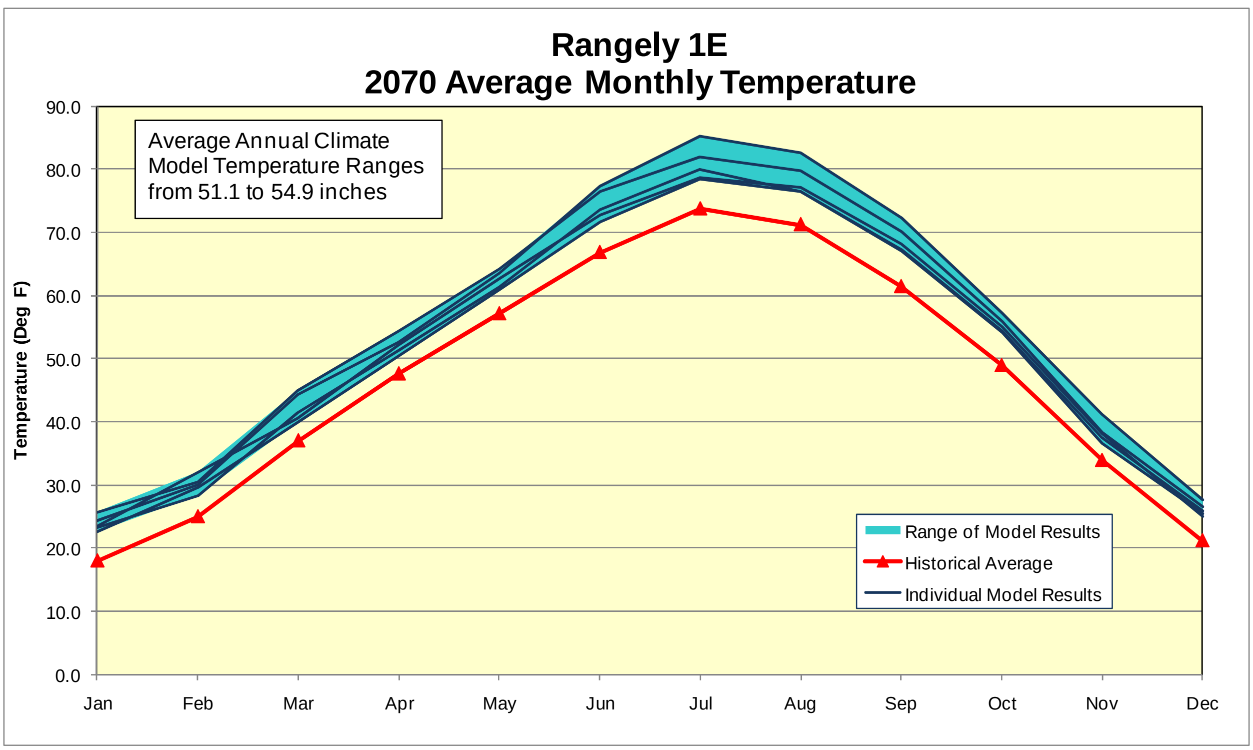


Figure A21 – Meeker 2070 Average Monthly Temperature Comparison

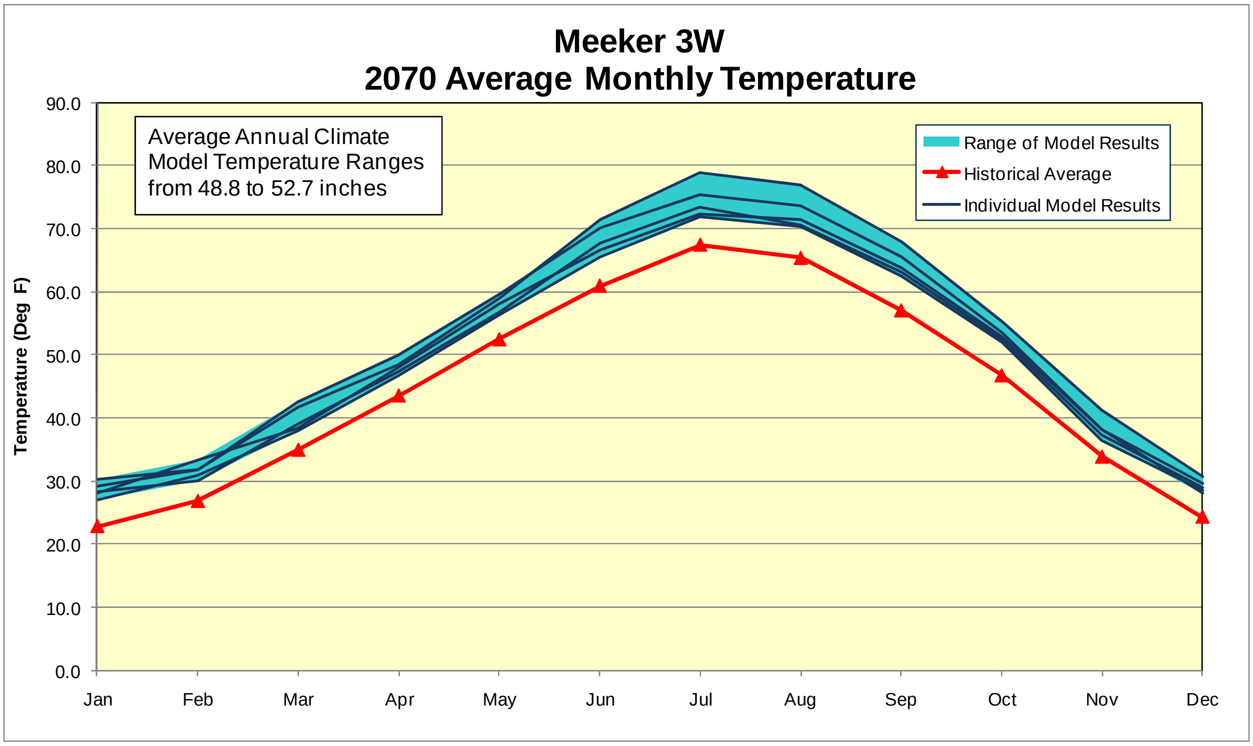


Figure A22 – Maybell 2070 Average Monthly Temperature Comparison

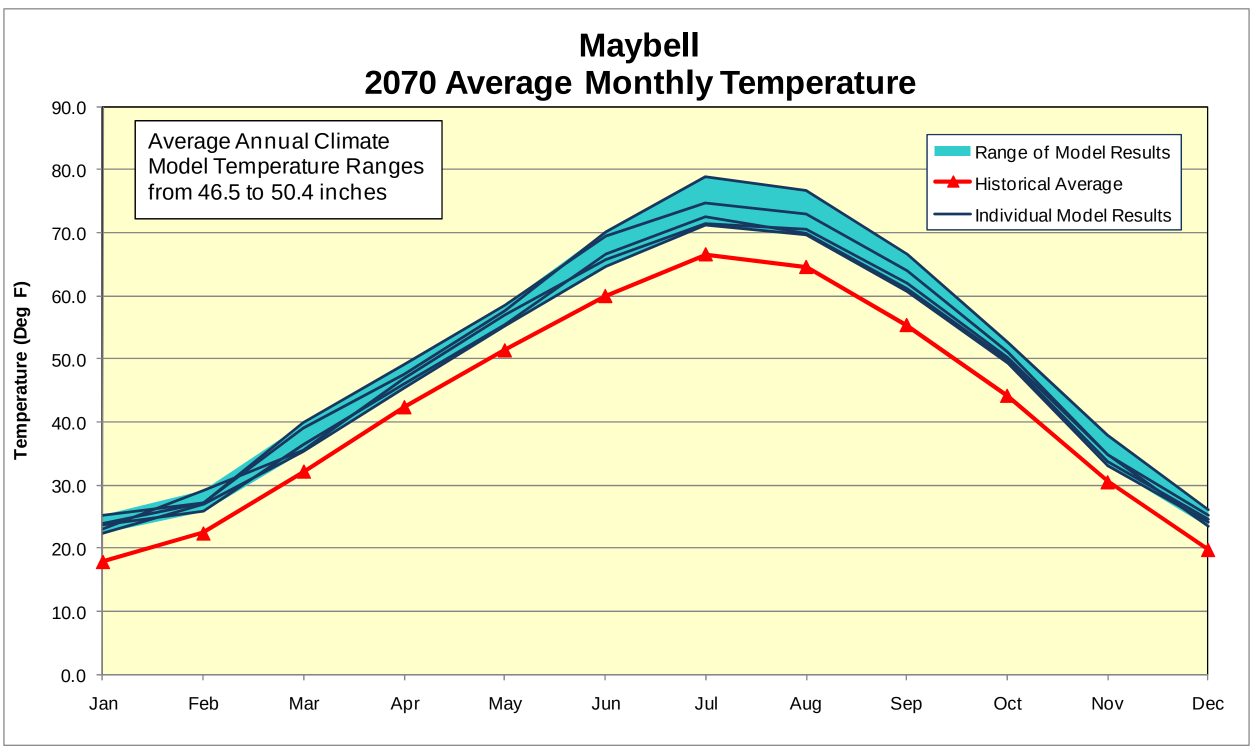


Figure A23 – Hayden 2070 Average Monthly Temperature Comparison

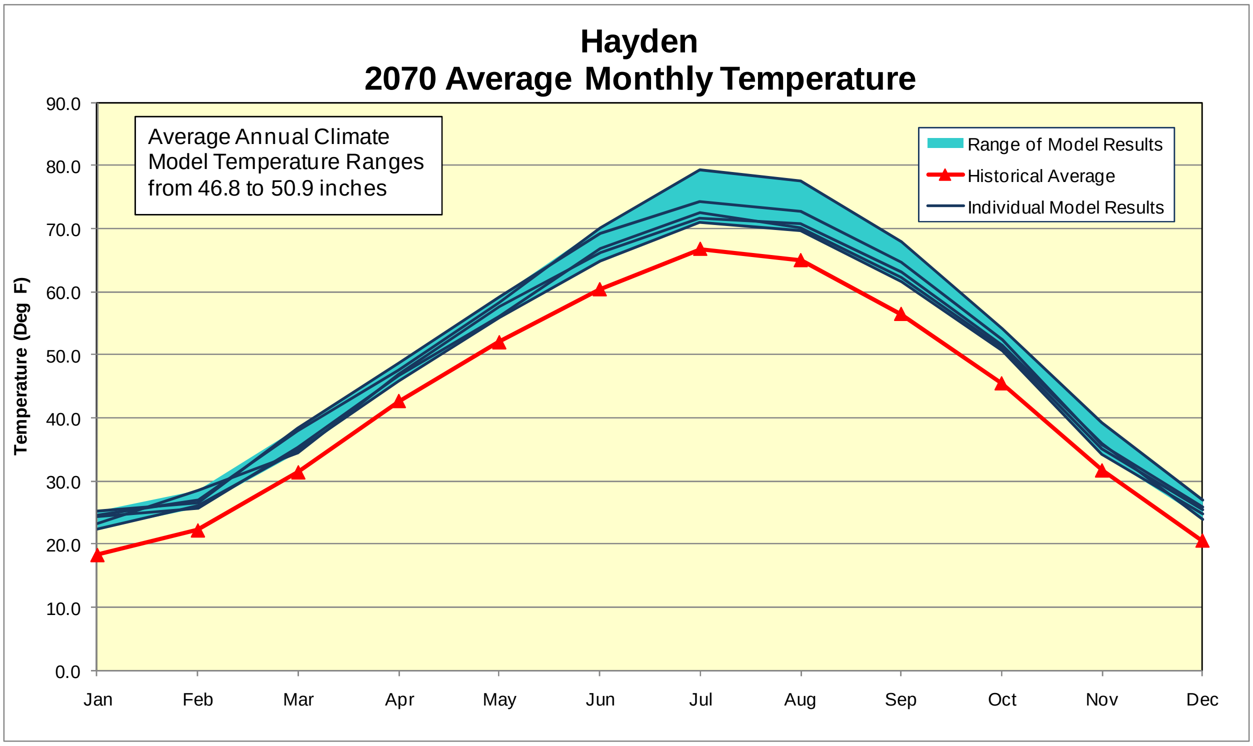


Figure A24 – Yampa 2070 Average Monthly Temperature Comparison

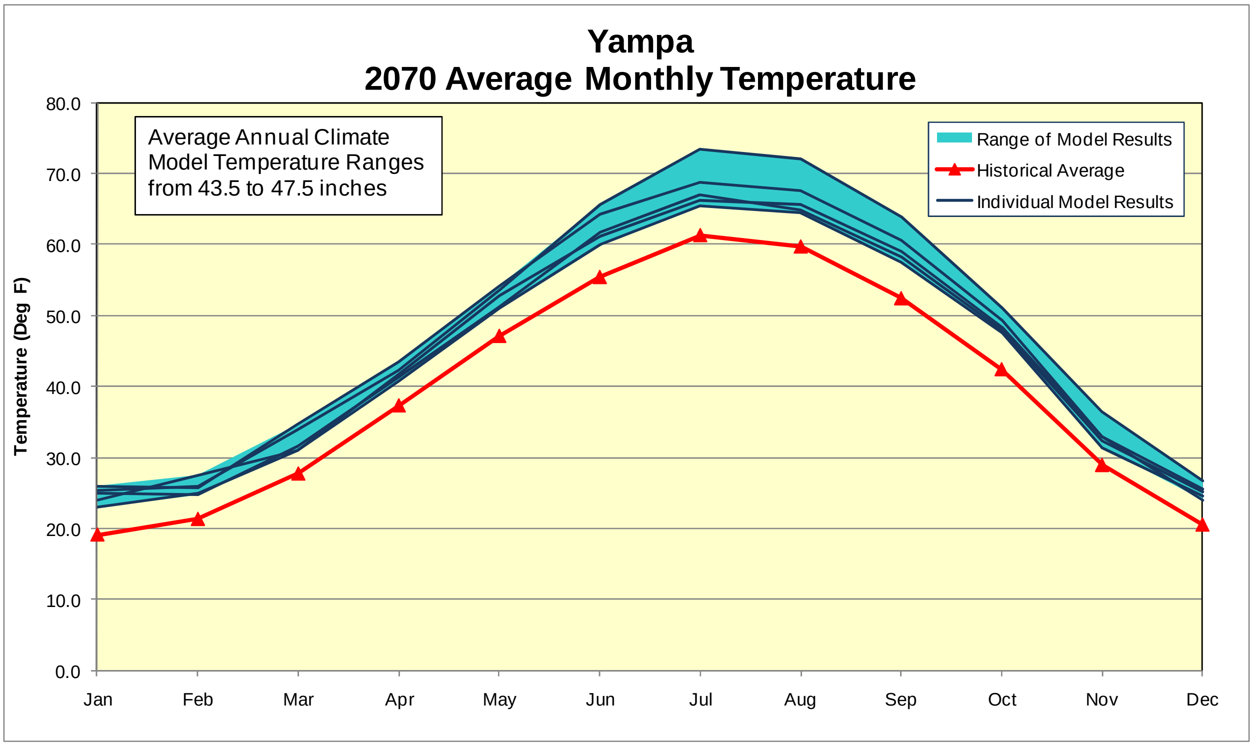


Figure A25 – Delta 2070 Average Monthly Temperature Comparison

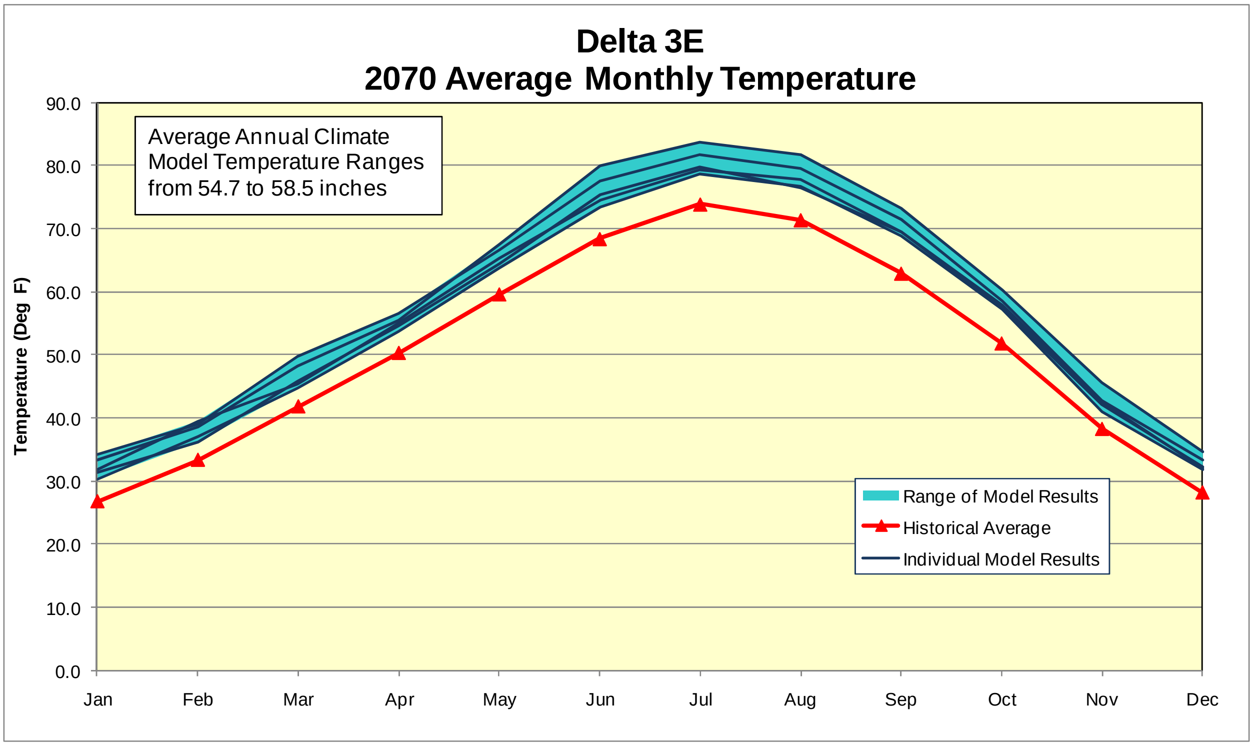


Figure A26 – Montrose 2070 Average Monthly Temperature Comparison

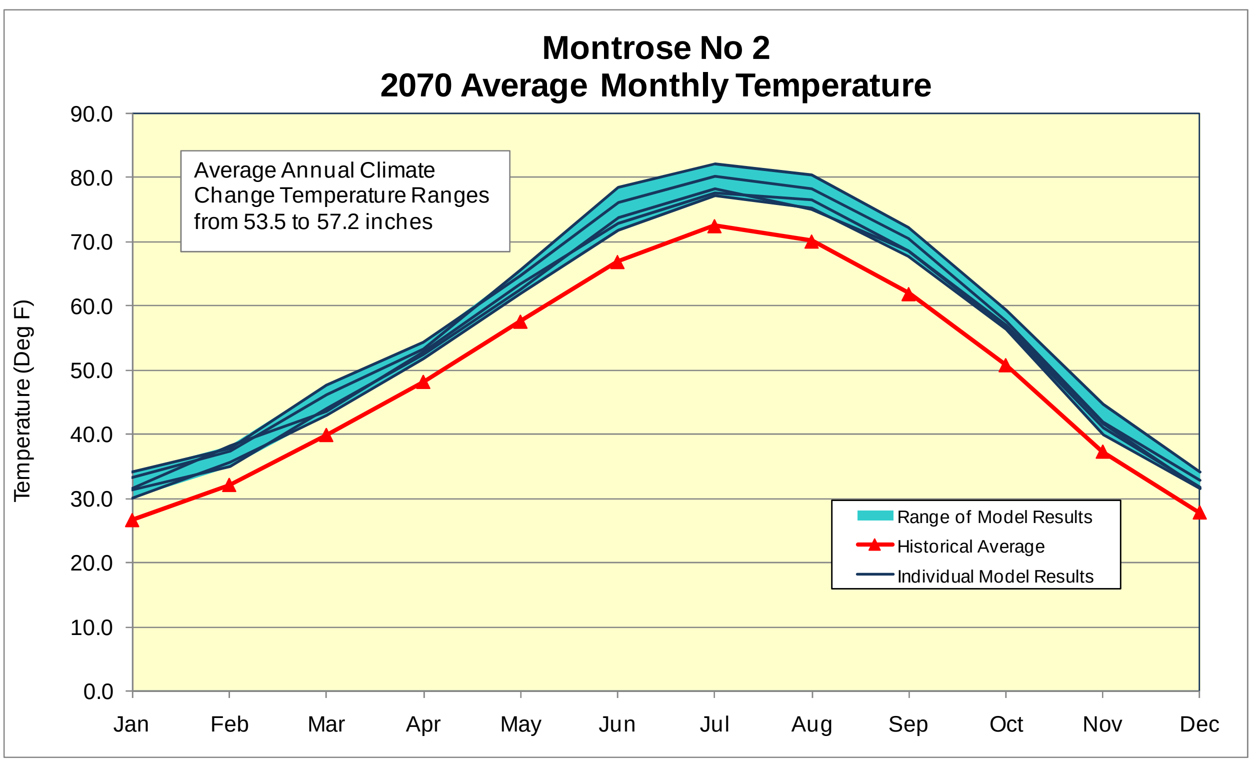


Figure A27 – Gunnison 2070 Average Monthly Temperature Comparison

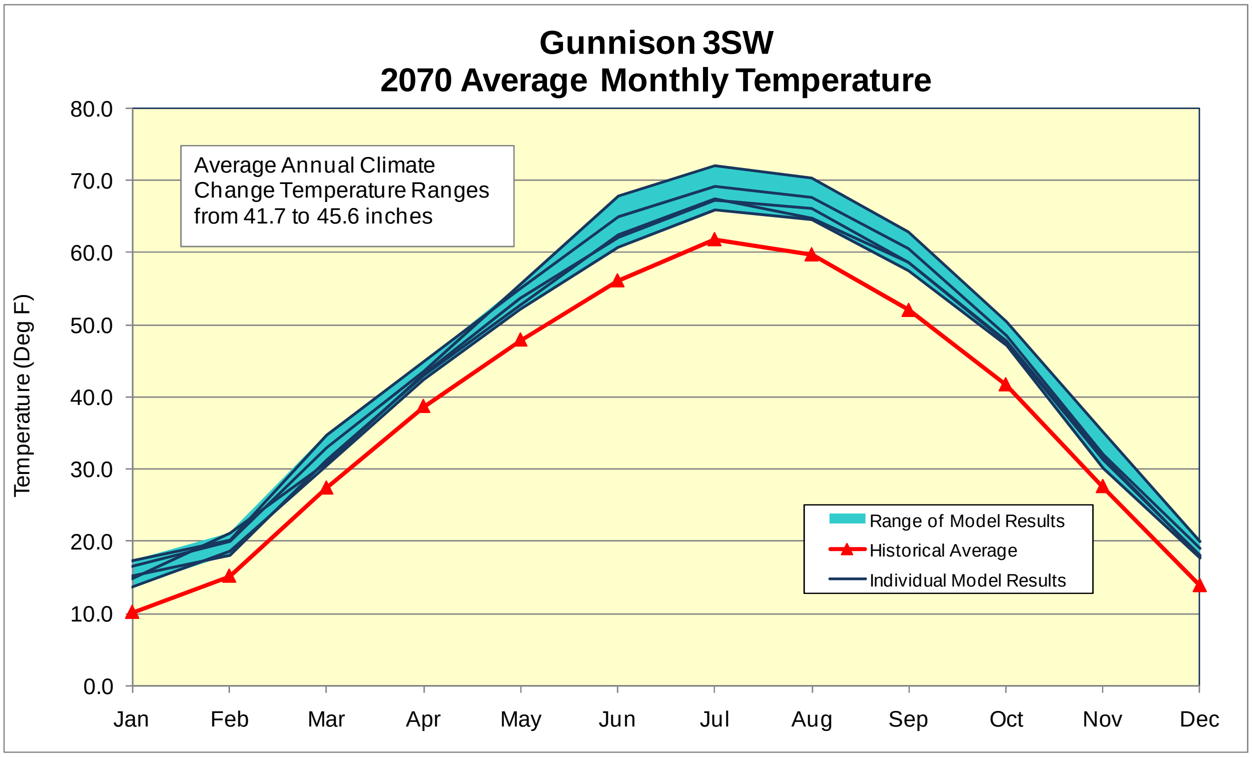


Figure A28 – Cortez 2070 Average Monthly Temperature Comparison

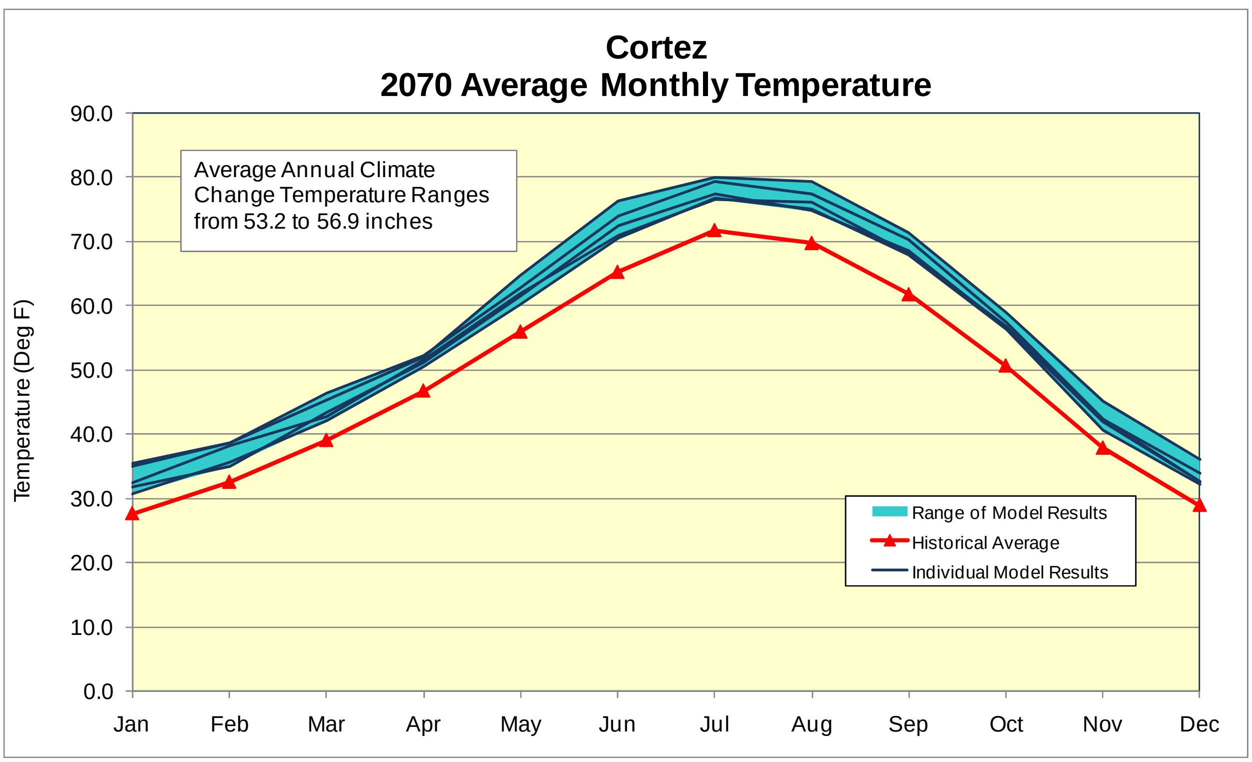


Figure A29 – Durango 2070 Average Monthly Temperature Comparison

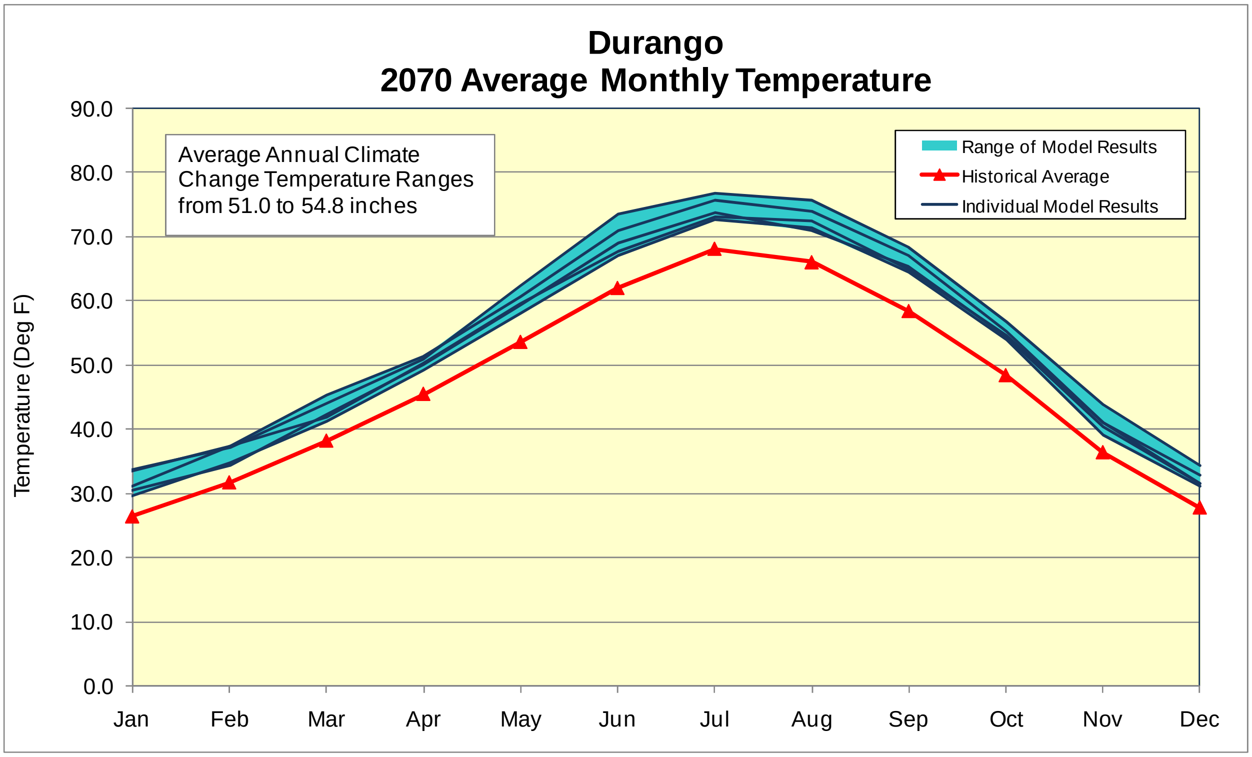
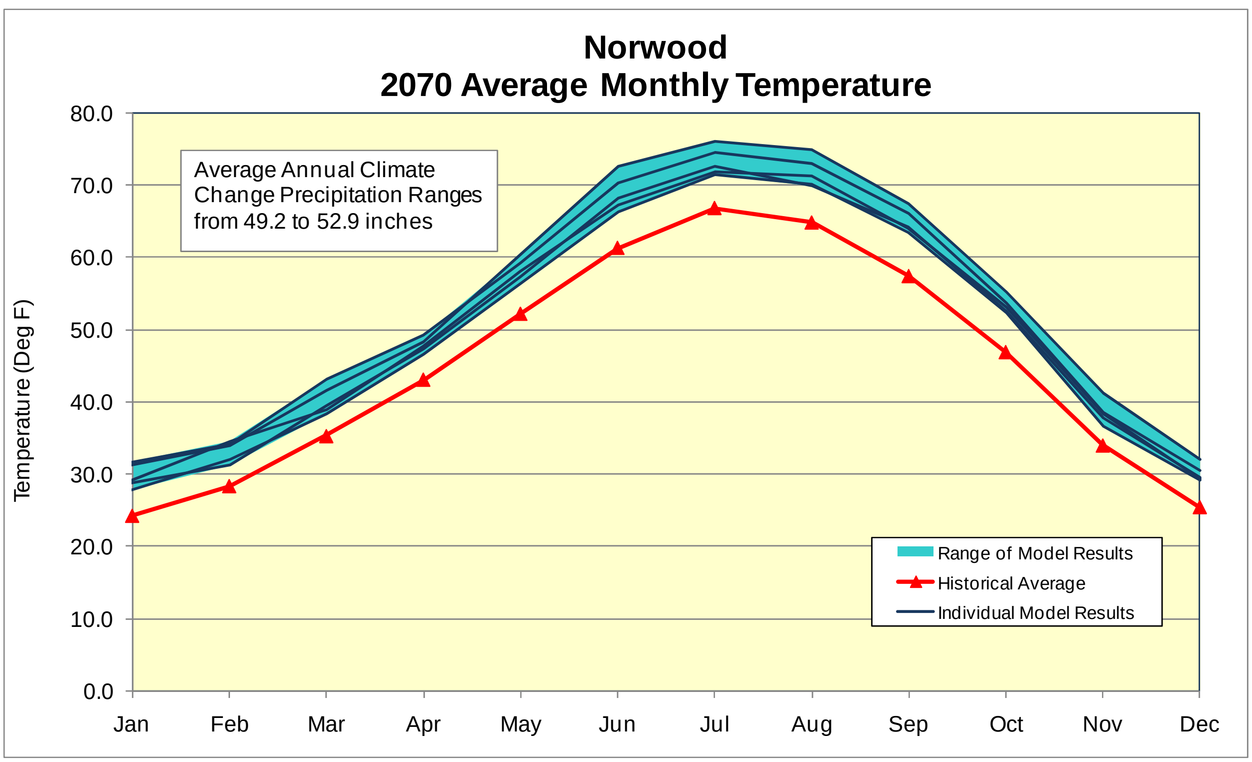


Figure A30 – Norwood 2070 Average Monthly Temperature Comparison



B. Precipitation

Contents

Table B1
Average Annual Projected Precipitation Compared to Historical Precipitation

Climate Station	Elevation	Designation	Location	2040 % Difference Precipitation*	2040 Chart Page	2070 % Difference Precipitation*	2070 Chart Page
Fruita 1W	4480	Lower	North	- 3.1%	B-7	- 3.7%	B-14
Glenwood Springs No 2	5880	Mid	North	- 0.9%	B-7	- 1.4%	B-14
Grand Lake 6SSW	8288	Higher	North	+ 1.3%	B-8	+ 3.6%	B-15
Rangely 1E	5290	Lower	North	- 1.5%	B-8	- 2.4%	B-15
Meeker 3W	6180	Mid	North	- 0.7%	B-9	- 1.1%	B-16
Maybell	5908	Lower	North	+ 1.0%	B-9	0.0%	B-16
Hayden	6440	Mid	North	+ 2.1%	B-10	+ 2.6%	B-17
Yampa	7890	Higher	North	+ 0.7%	B-10	+ 1.8%	B-17
Delta 3E	5010	Lower	South	- 4.0%	B-11	- 4.5%	B-18
Montrose No 2	5785	Mid	South	- 3.6%	B-11	- 4.8%	B-18
Gunnison 3SW	7640	Higher	South	- 1.8%	B-12	- 1.0%	B-19
Cortez	6153	Lower	South	- 3.4%	B-12	- 6.7%	B-19
Durango	6592	Mid	South	- 2.0%	B-13	- 4.7%	B-20
Norwood	7020	Higher	South	- 3.6%	B-13	- 4.8%	B-20
Basin-wide Average				**- 1.4%**		**-1.9%**	

* Negative percent difference indicates less annual projected rainfall than historical

Figure B1 - 2040 Percent of Historical Winter (November – March) Precipitation

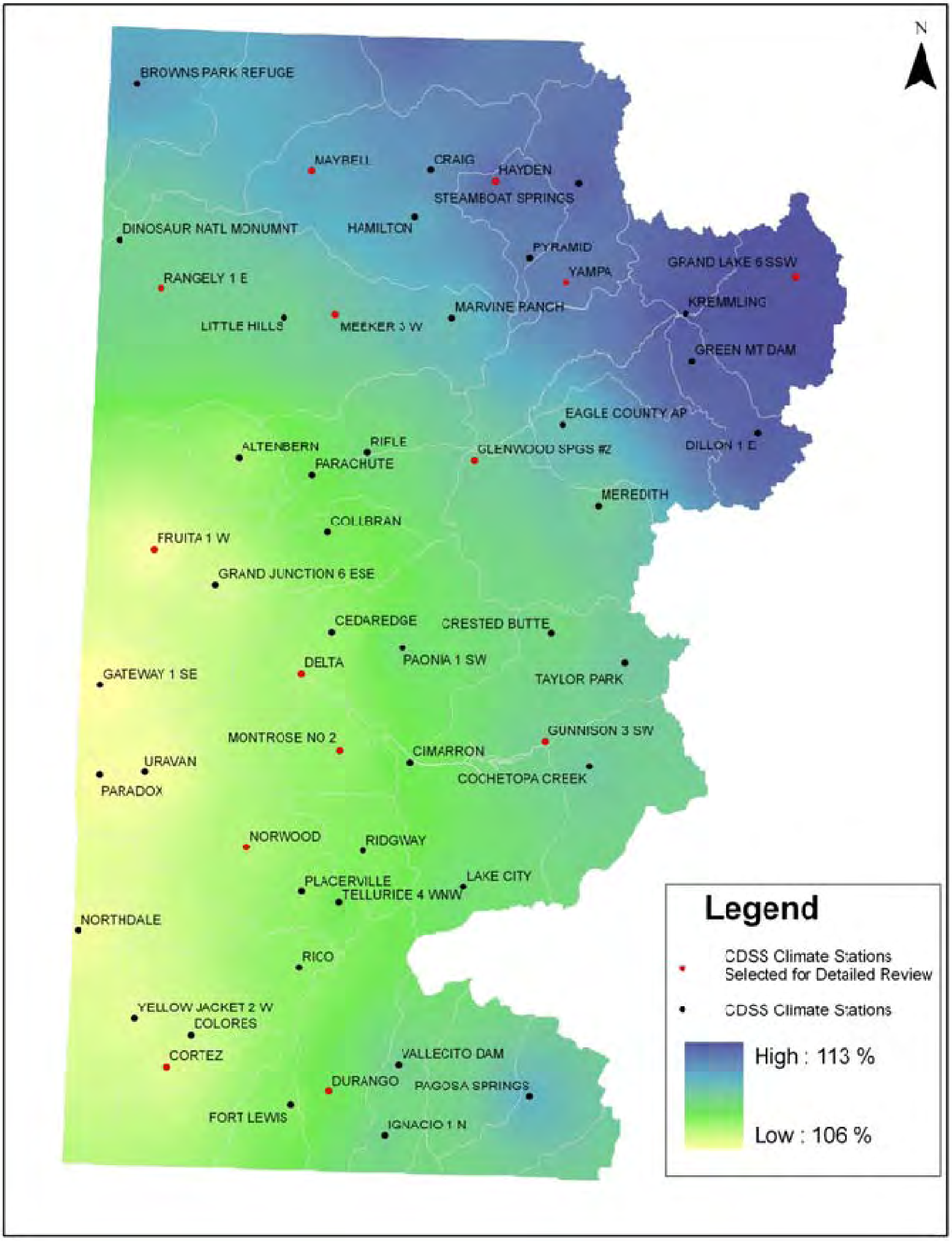


Figure B2 - 2040 Percent of Historical April through October Precipitation

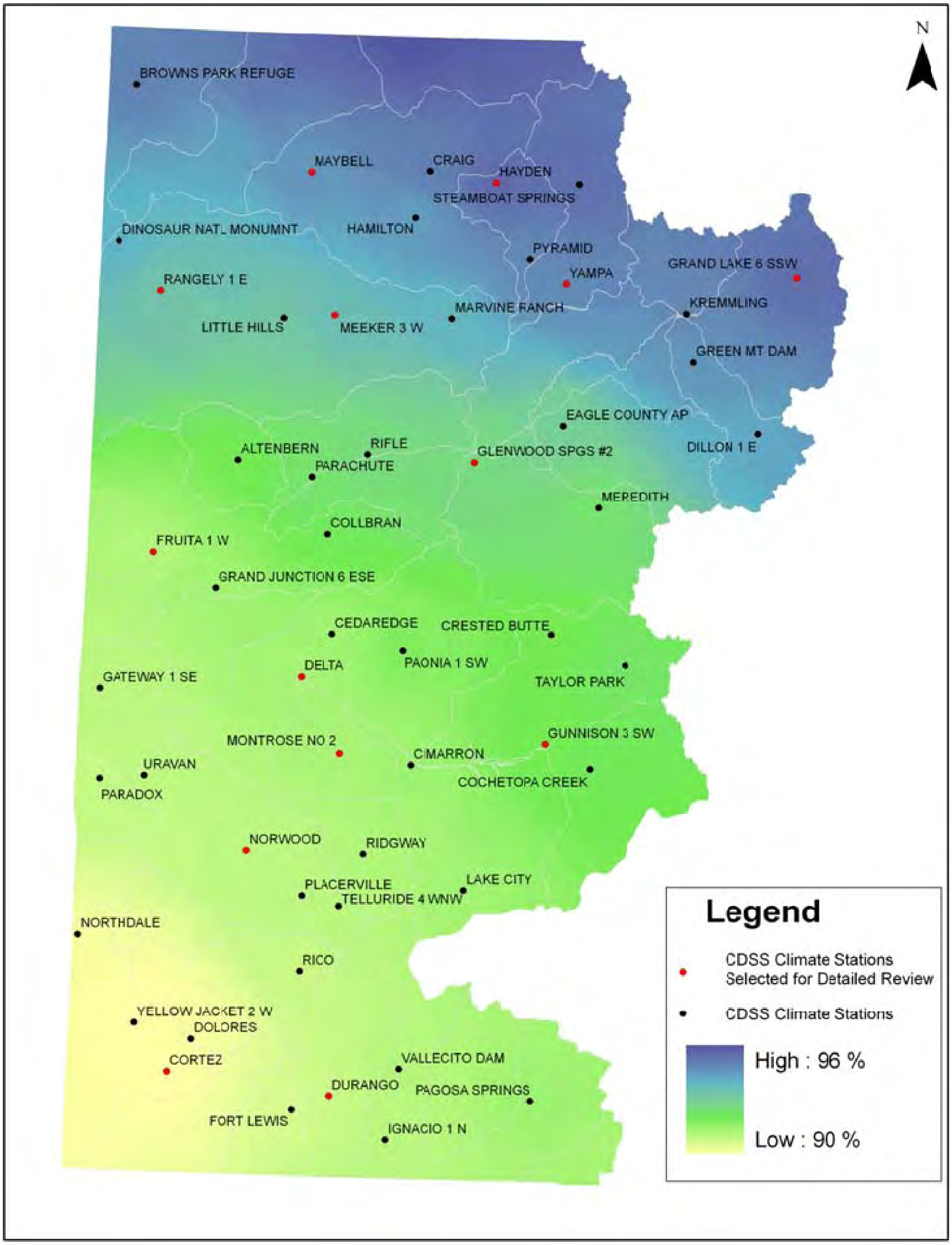


Figure B3 - 2070 Percent of Historical Winter (November – March) Precipitation

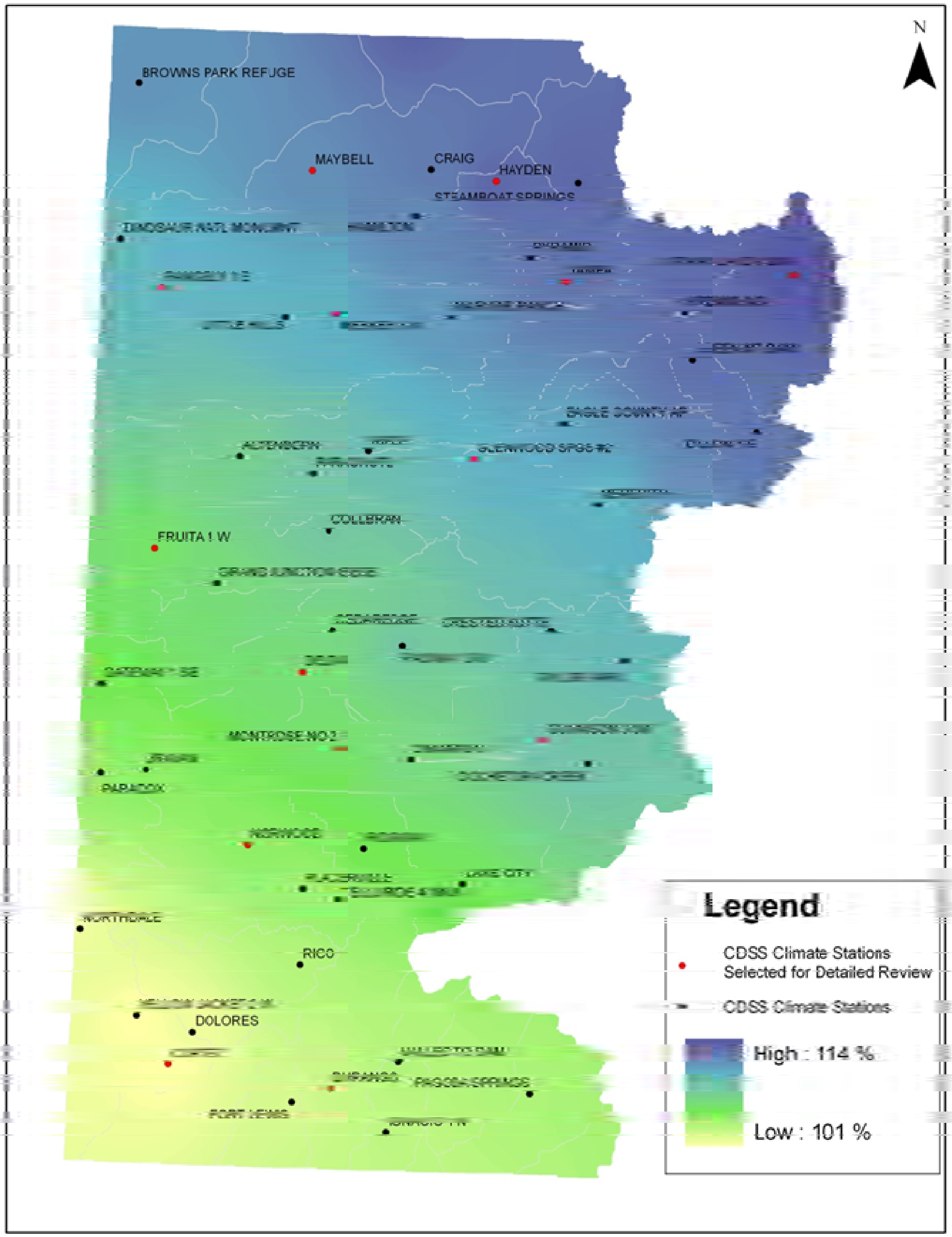


Figure B4 - 2070 Percent of Historical April through October Precipitation

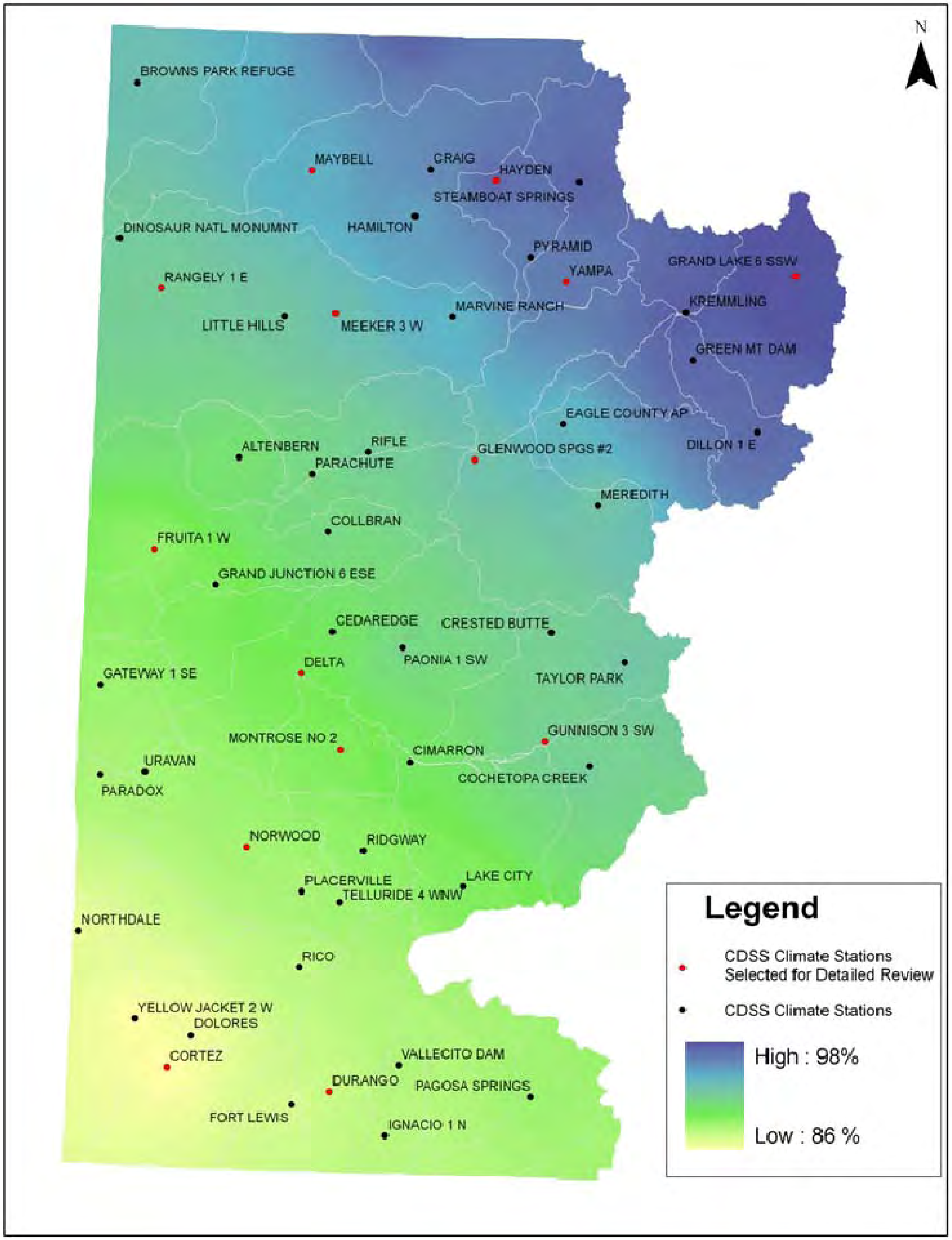


Figure B5 – Fruita 2040 Average Monthly Precipitation Comparison

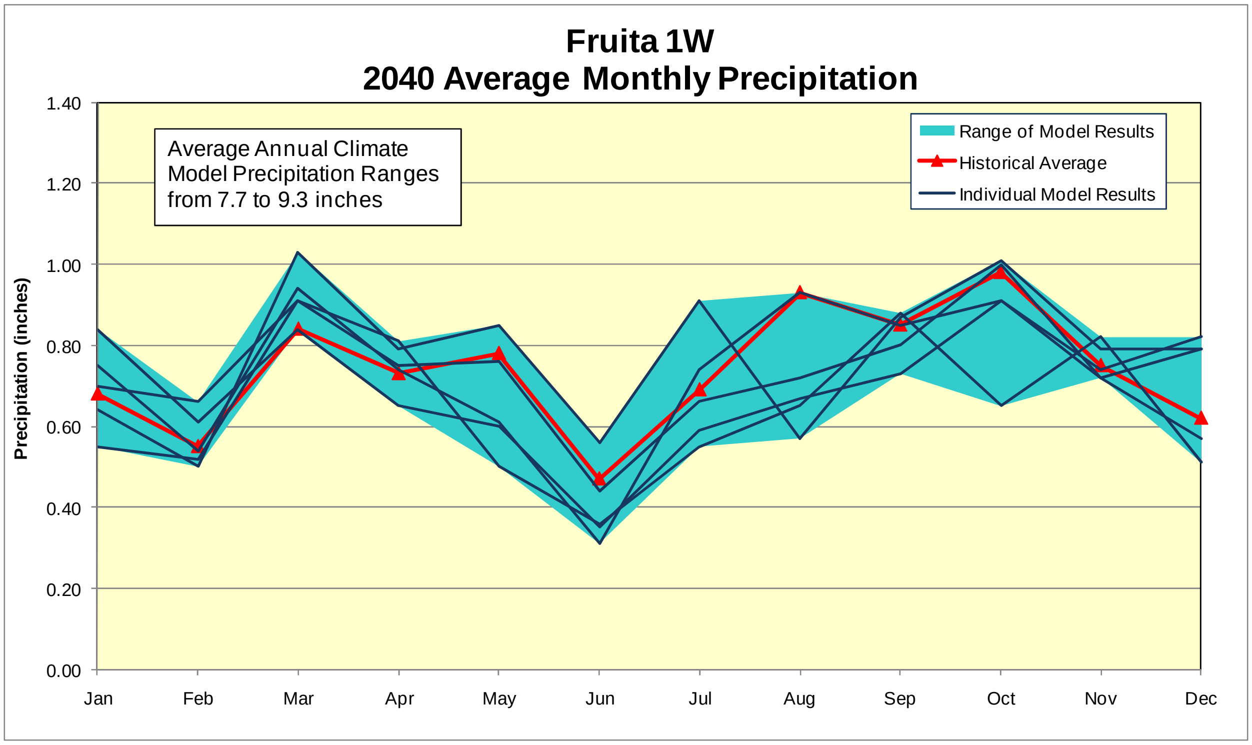


Figure B6 – Glenwood Springs 2040 Average Monthly Precipitation Comparison

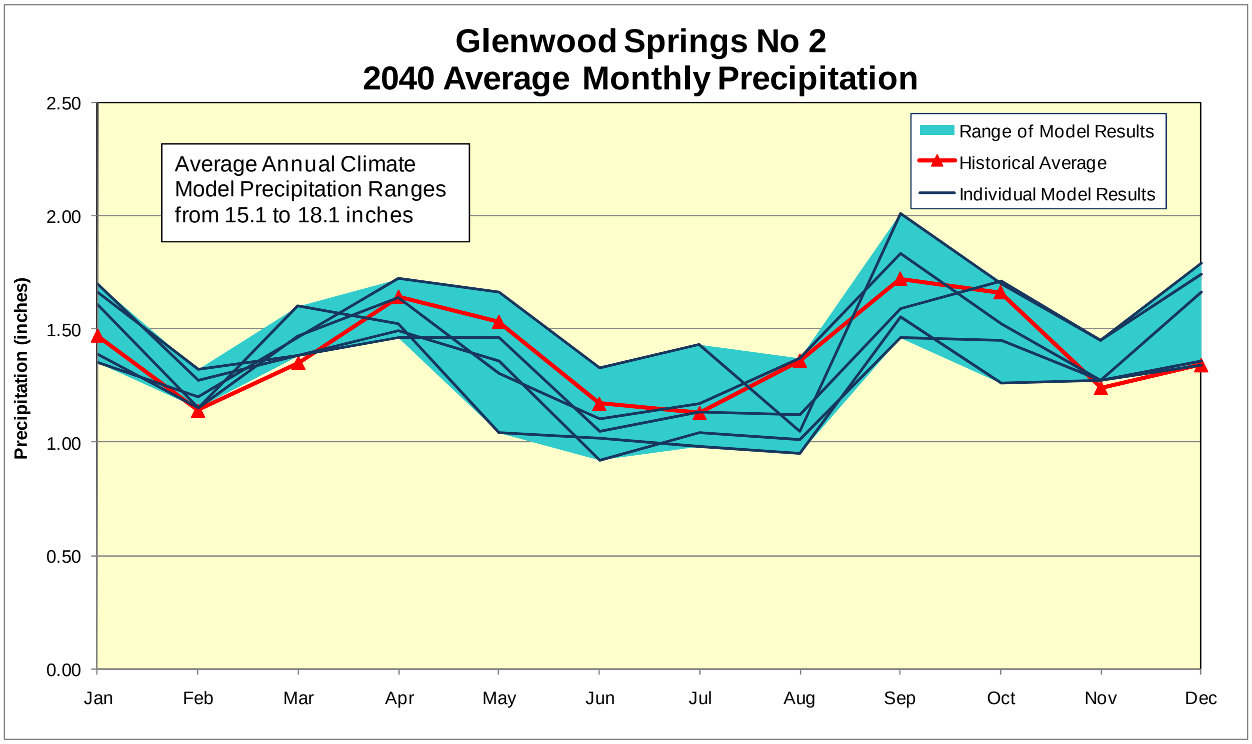


Figure B7 – Grand Lake 2040 Average Monthly Precipitation Comparison

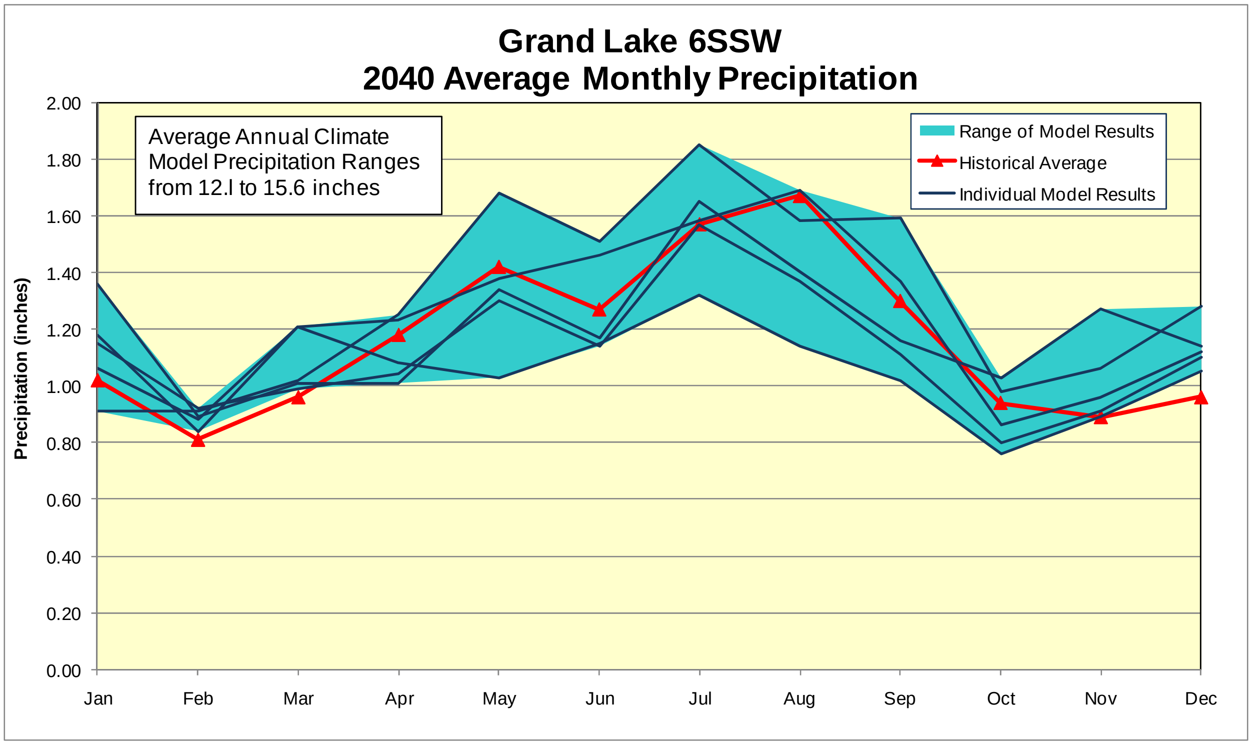


Figure B8 – Rangely 2040 Average Monthly Precipitation Comparison

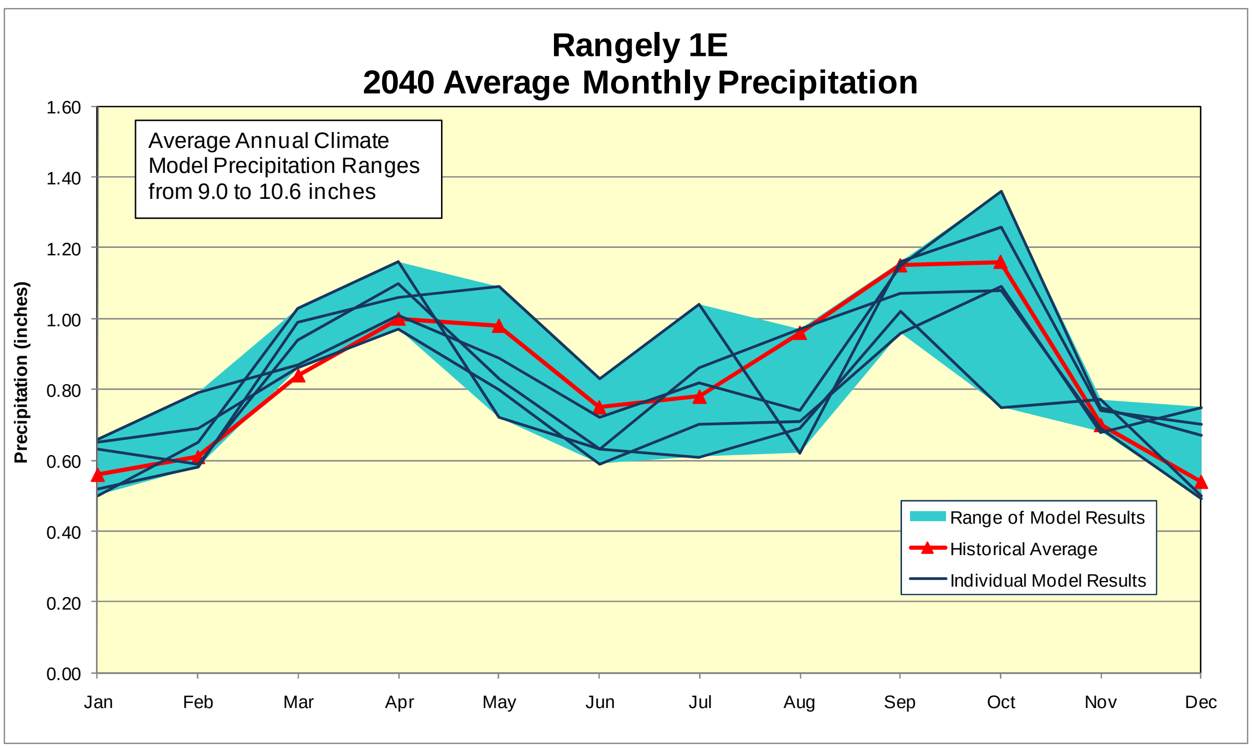


Figure B9 – Meeker 2040 Average Monthly Precipitation Comparison

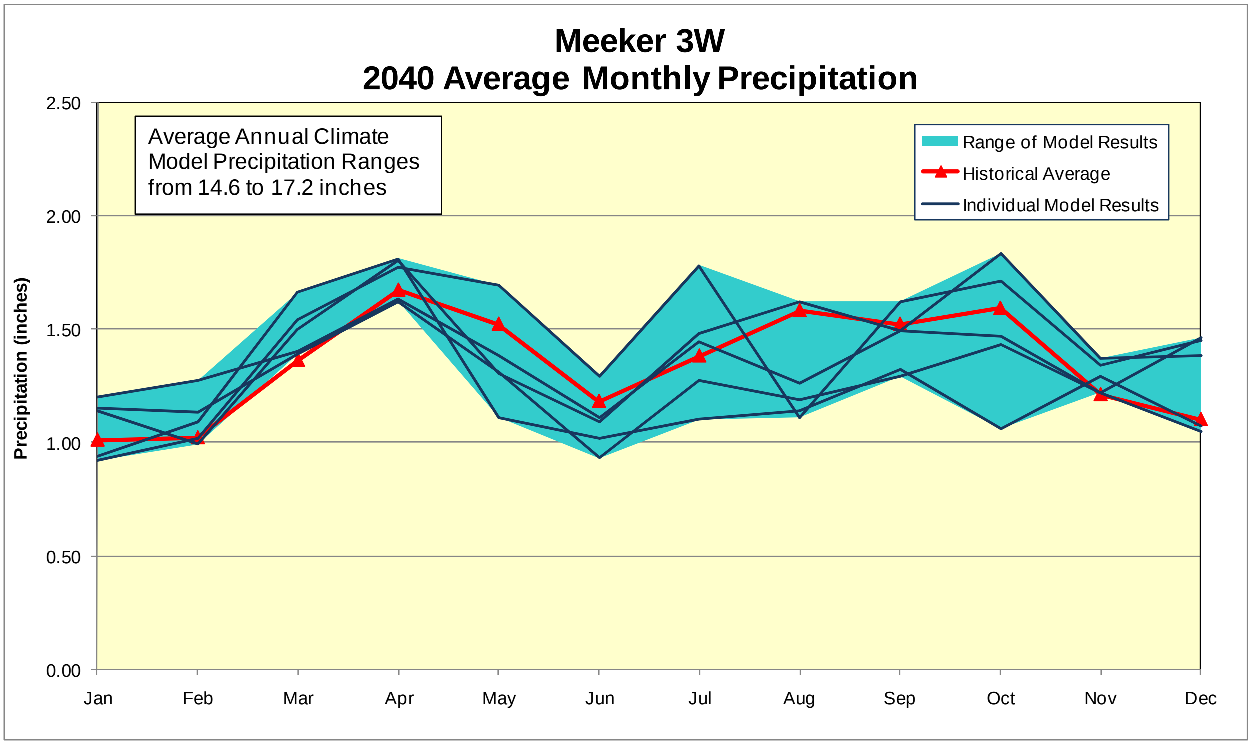


Figure B10 – Maybell 2040 Average Monthly Precipitation Comparison

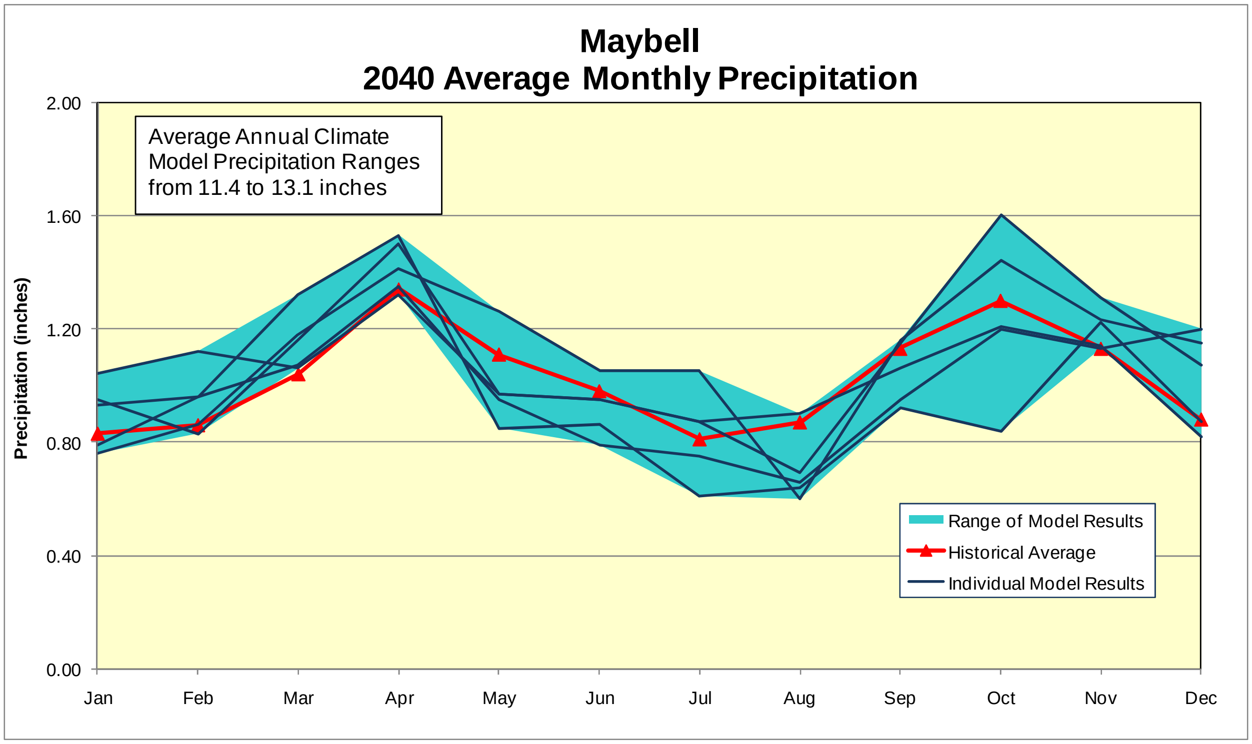


Figure B11 – Hayden 2040 Average Monthly Precipitation Comparison

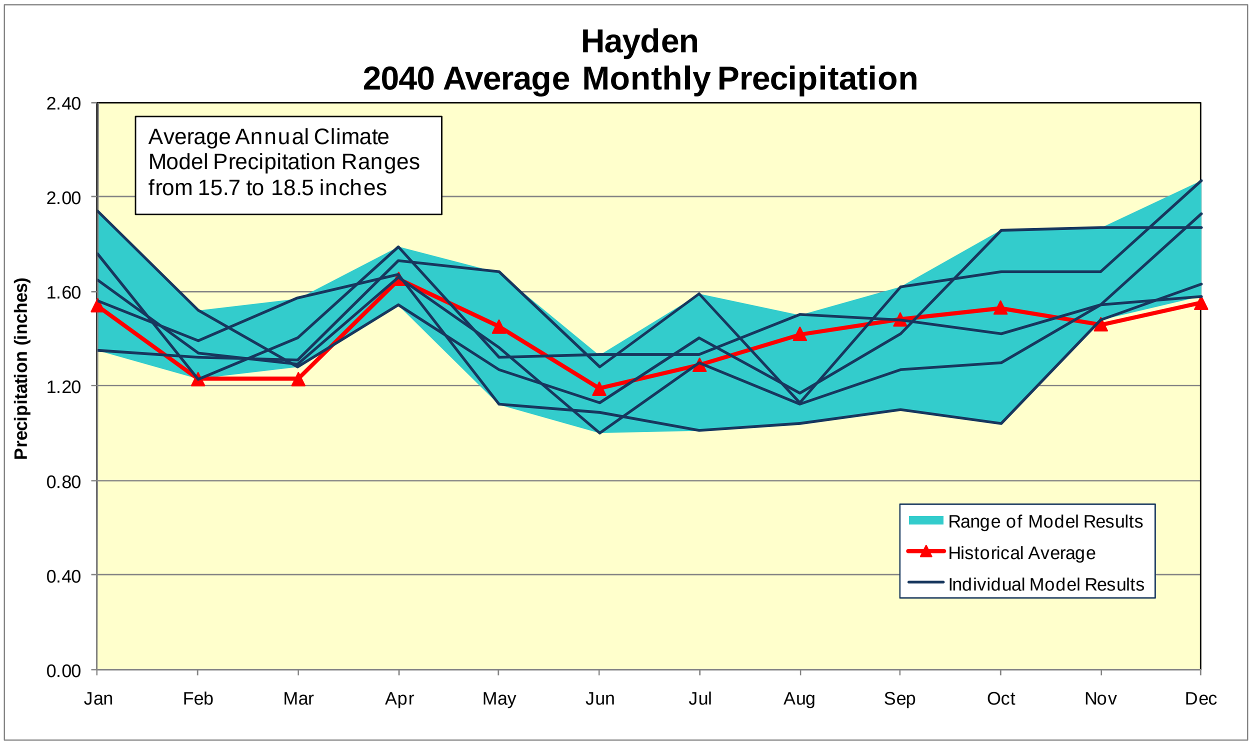


Figure B12 – Yampa 2040 Average Monthly Precipitation Comparison

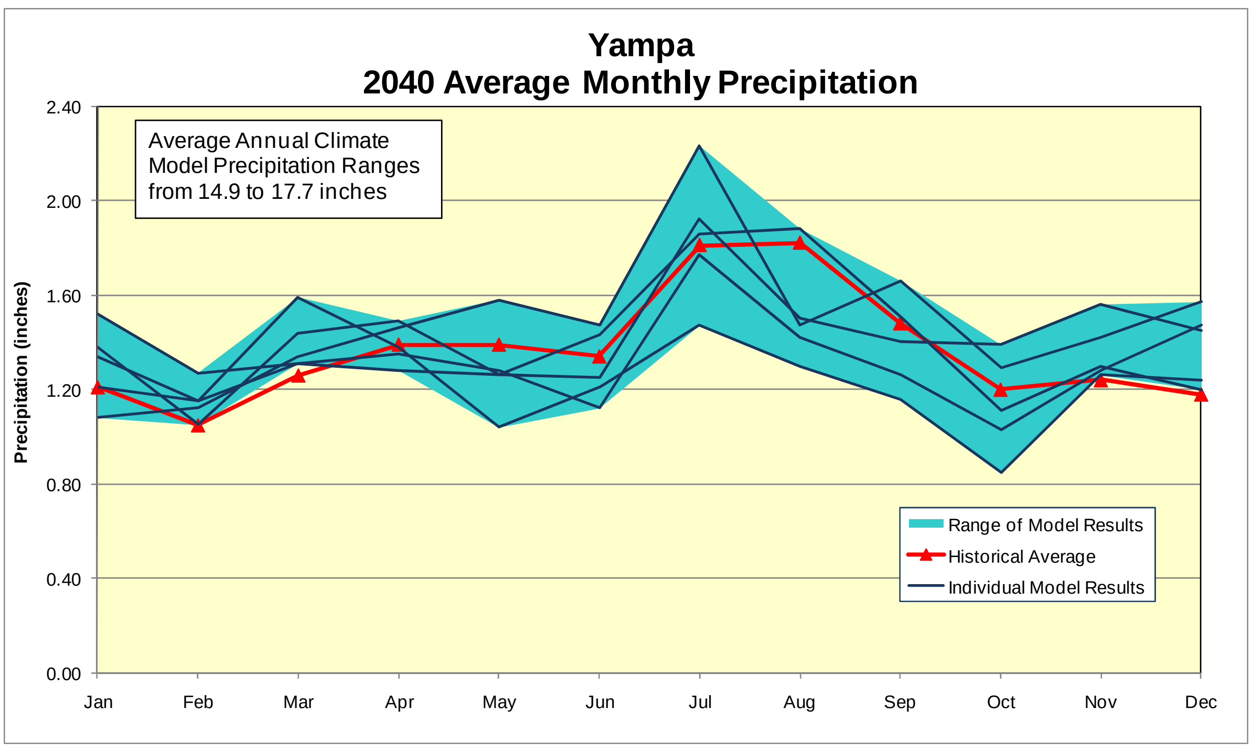


Figure B13 – Delta 2040 Average Monthly Precipitation Comparison

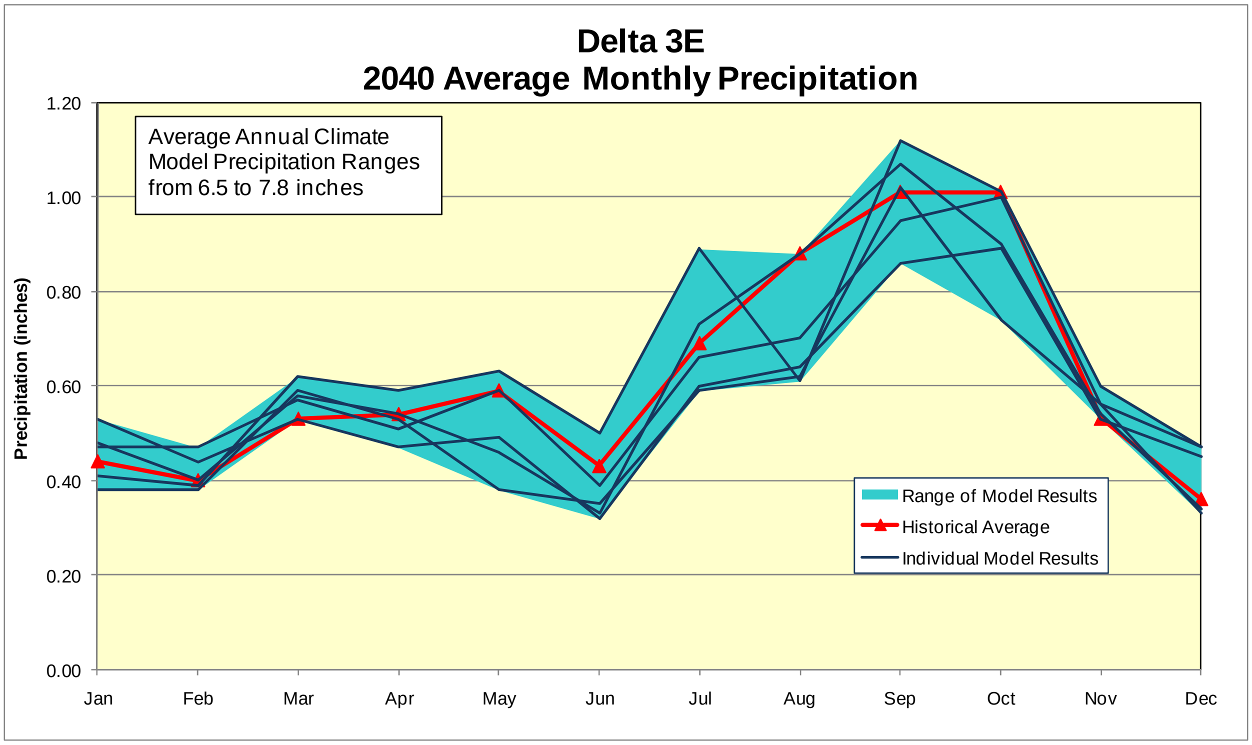


Figure B14 – Montrose 2040 Average Monthly Precipitation Comparison

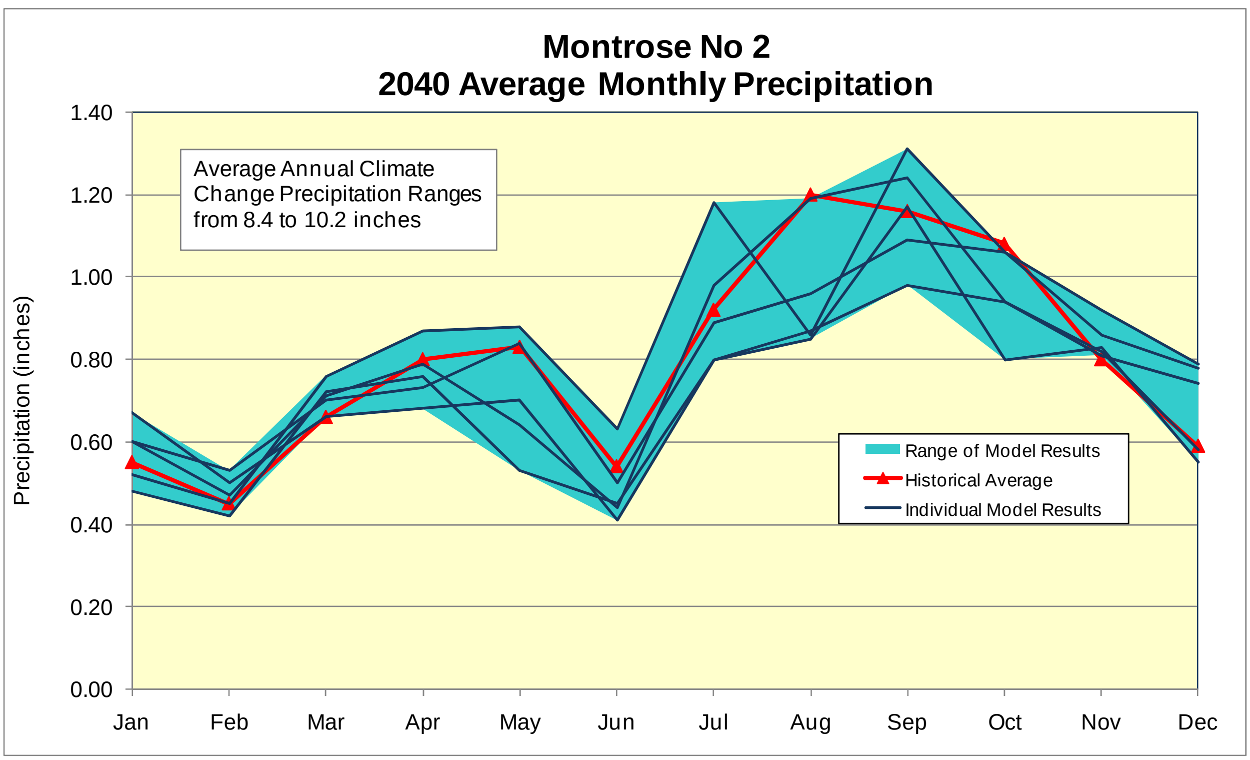


Figure B15 – Gunnison 2040 Average Monthly Precipitation Comparison

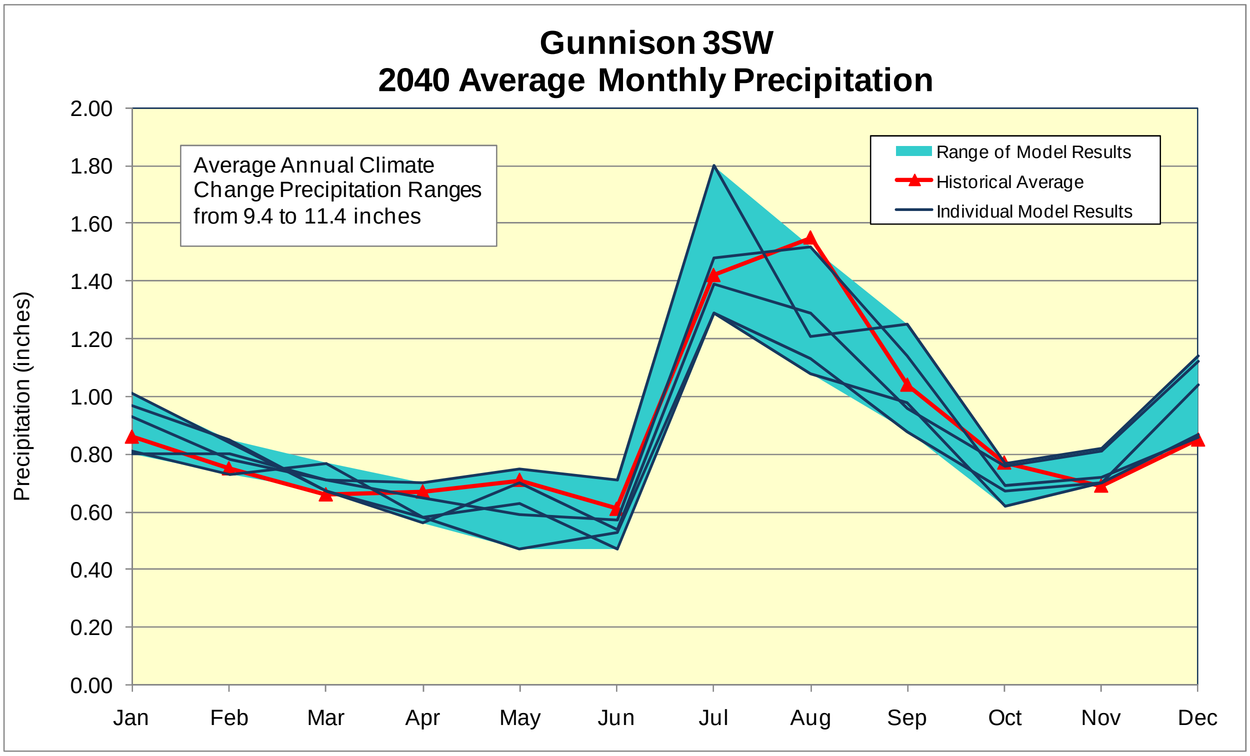


Figure B16 – Cortez 2040 Average Monthly Precipitation Comparison

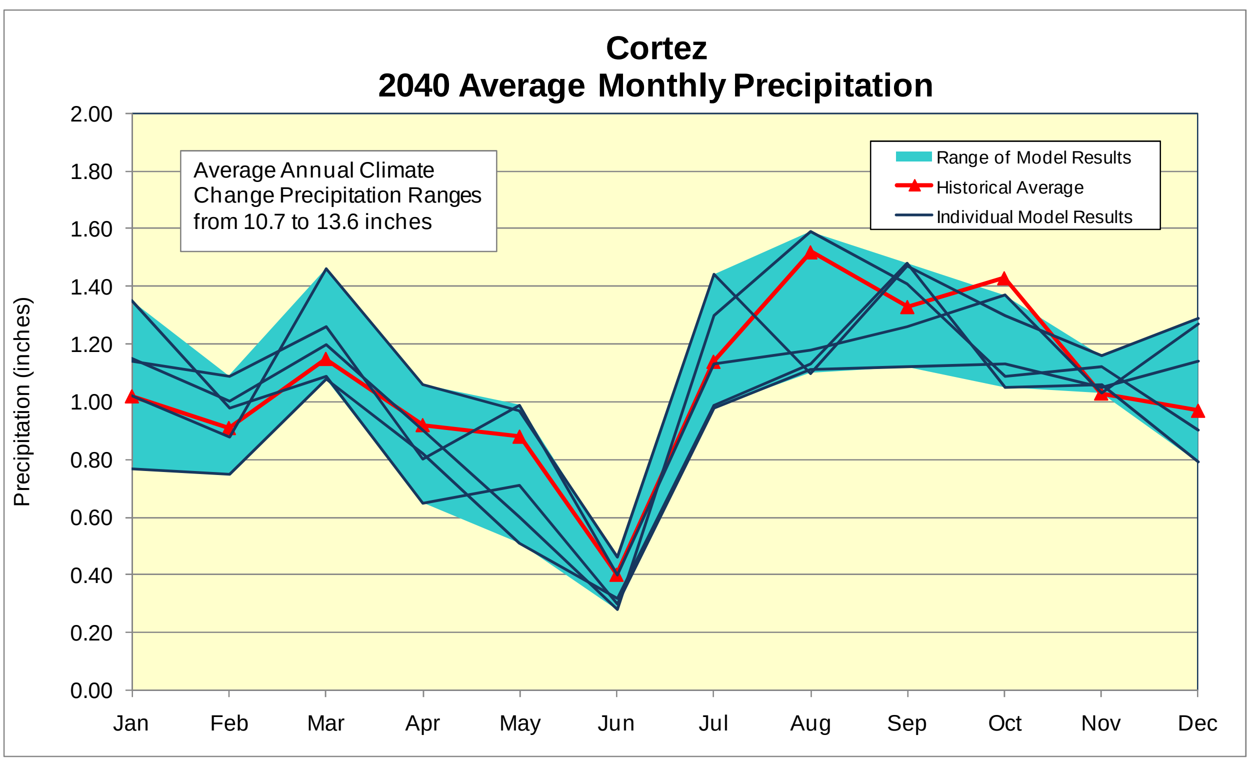


Figure B17 – Durango 2040 Average Monthly Precipitation Comparison

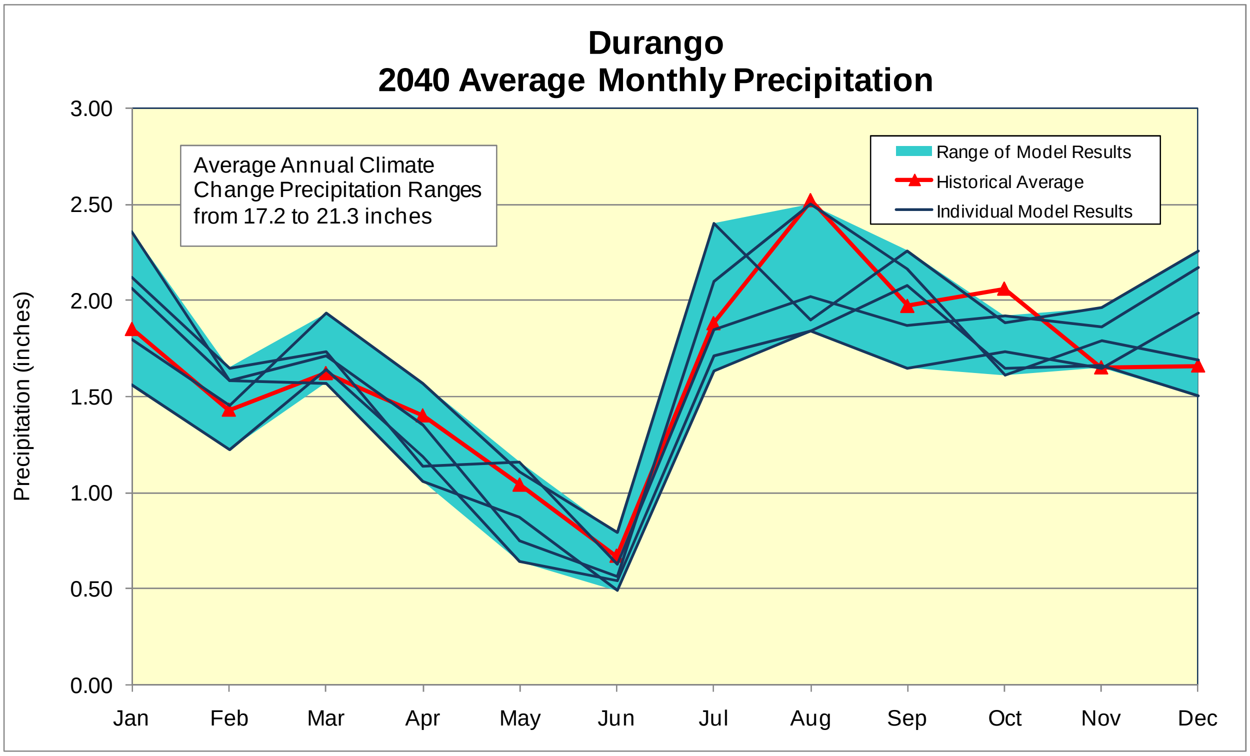


Figure B18 – Norwood 2040 Average Monthly Precipitation Comparison

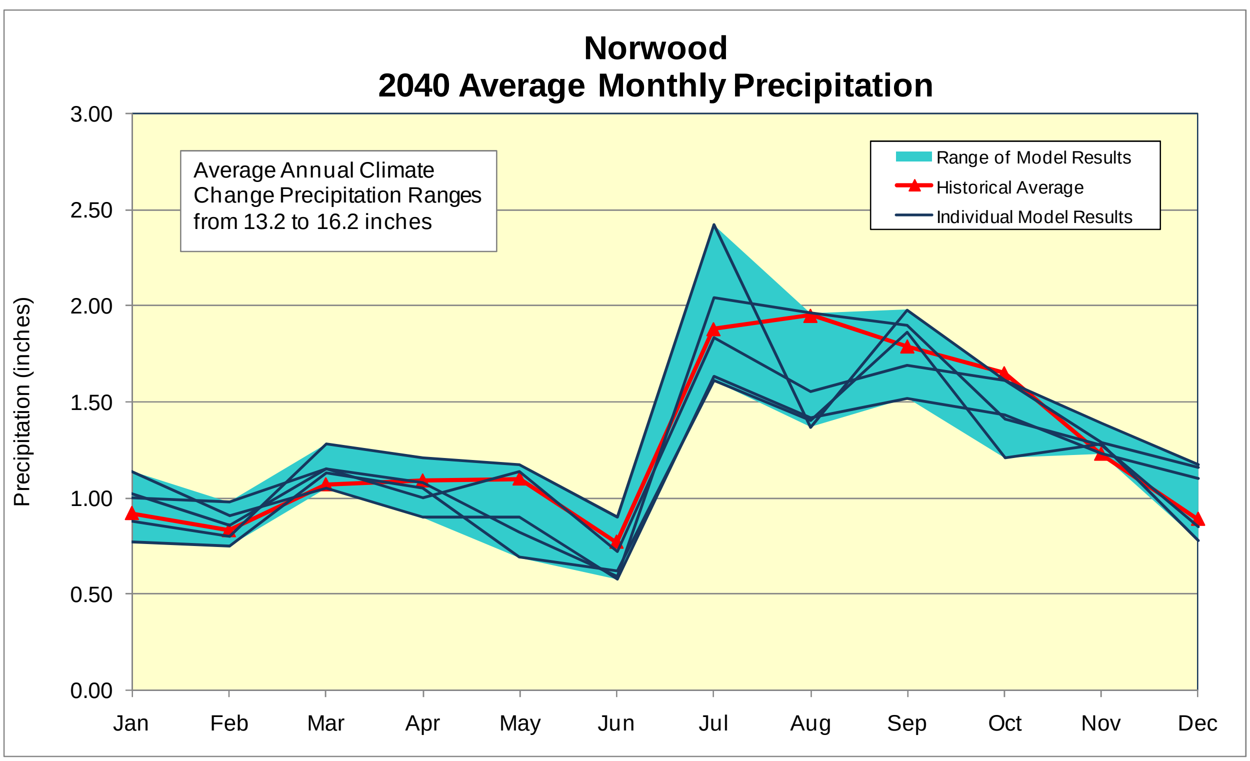


Figure B19 – Fruita 2070 Average Monthly Precipitation Comparison

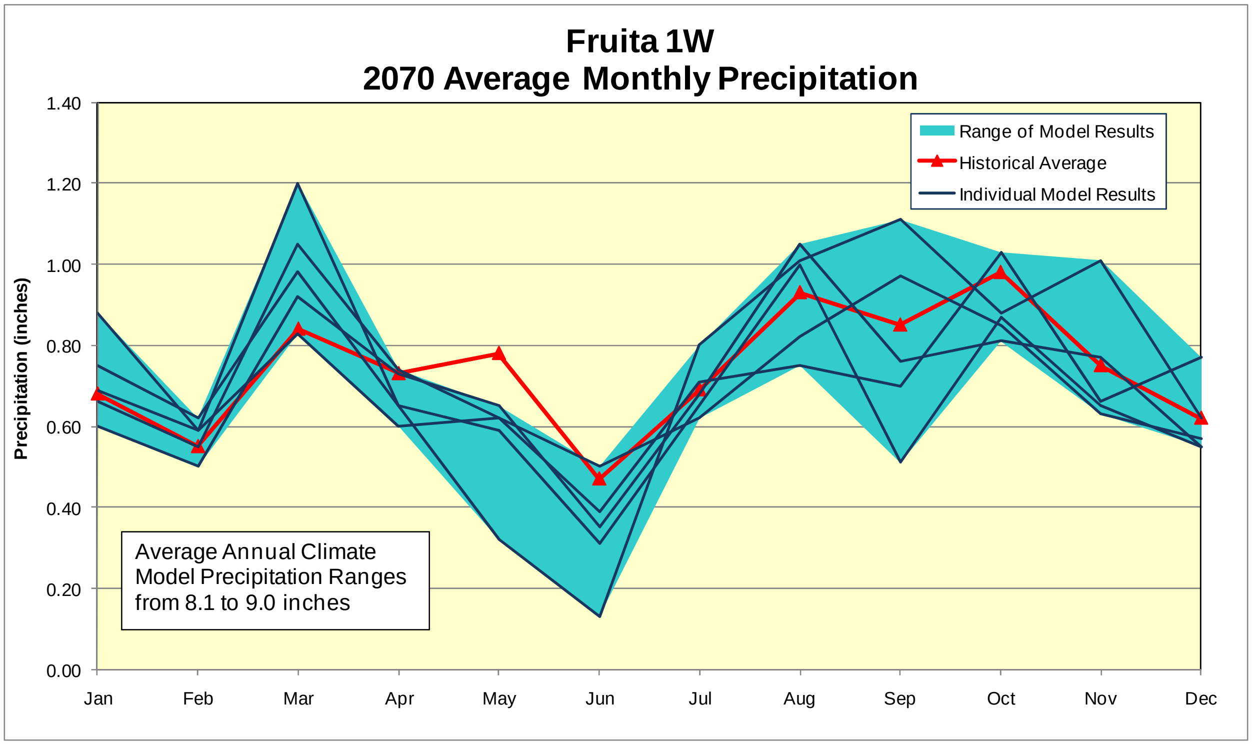


Figure B20 – Glenwood Springs 2070 Average Monthly Precipitation Comparison

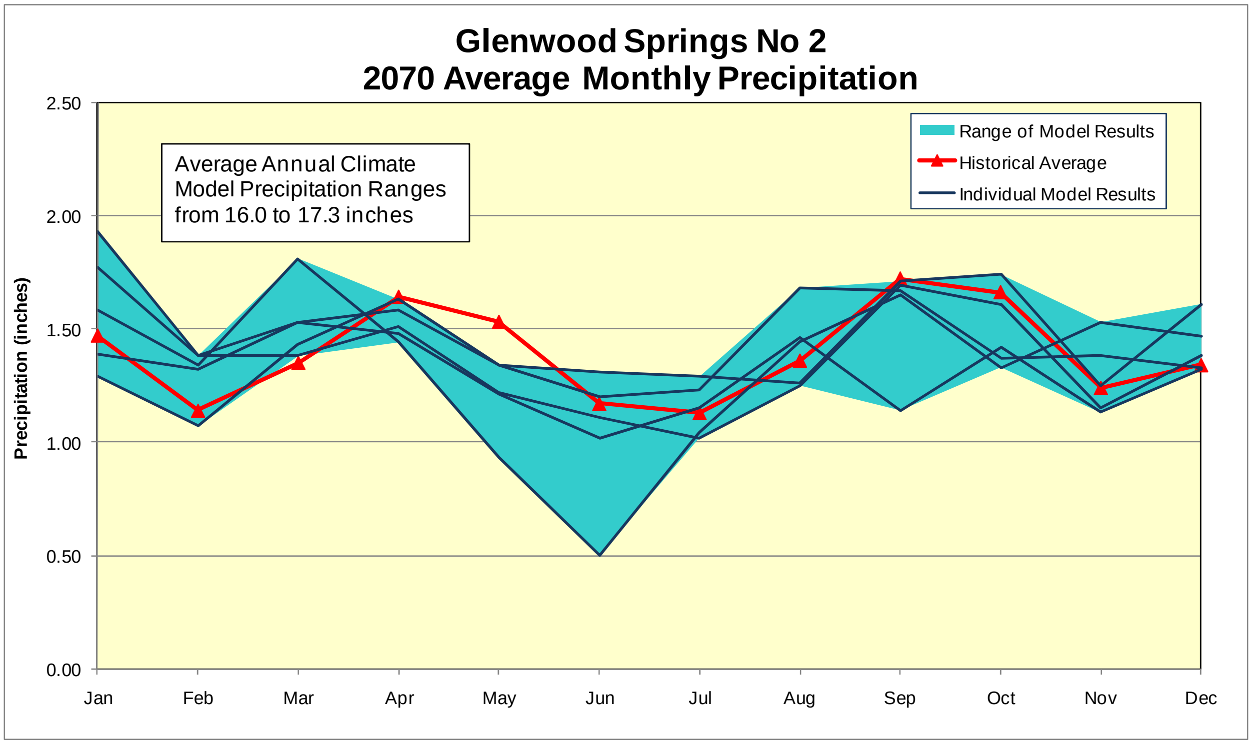


Figure B21 – Grand Lake 2070 Average Monthly Precipitation Comparison

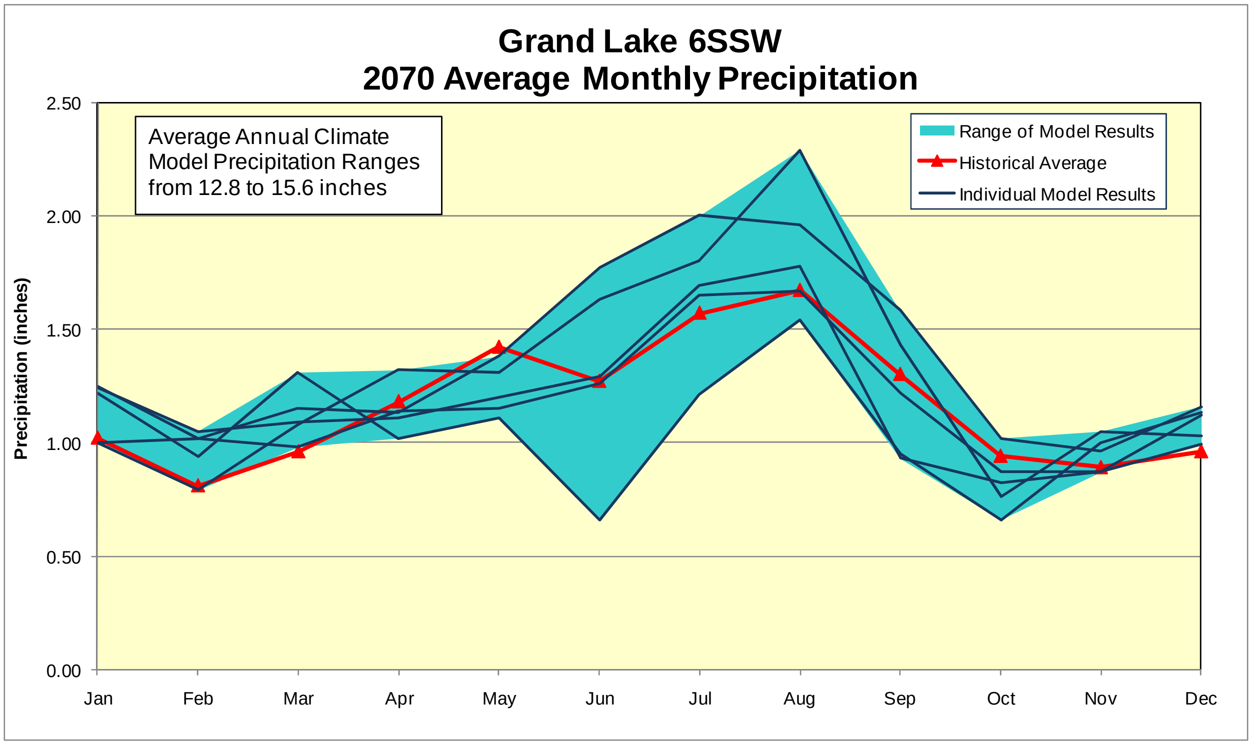


Figure B22 – Rangely 2070 Average Monthly Precipitation Comparison

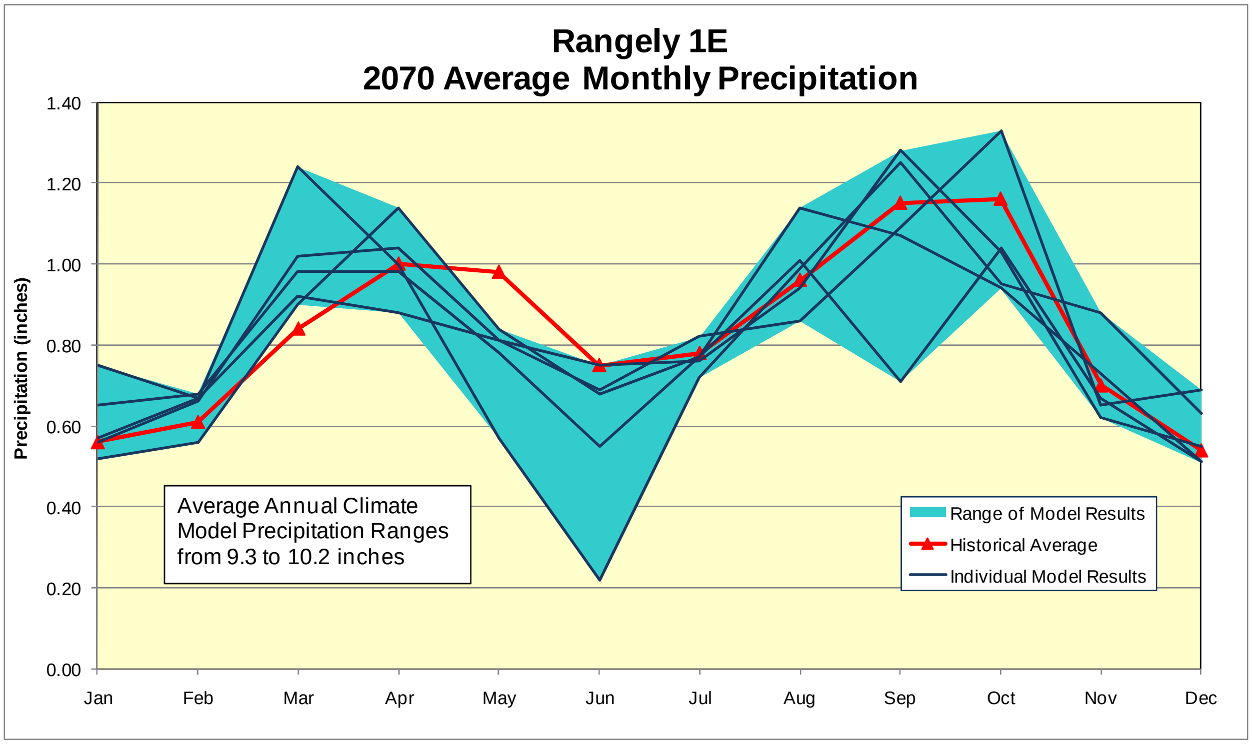


Figure B23 – Meeker 2070 Average Monthly Precipitation Comparison

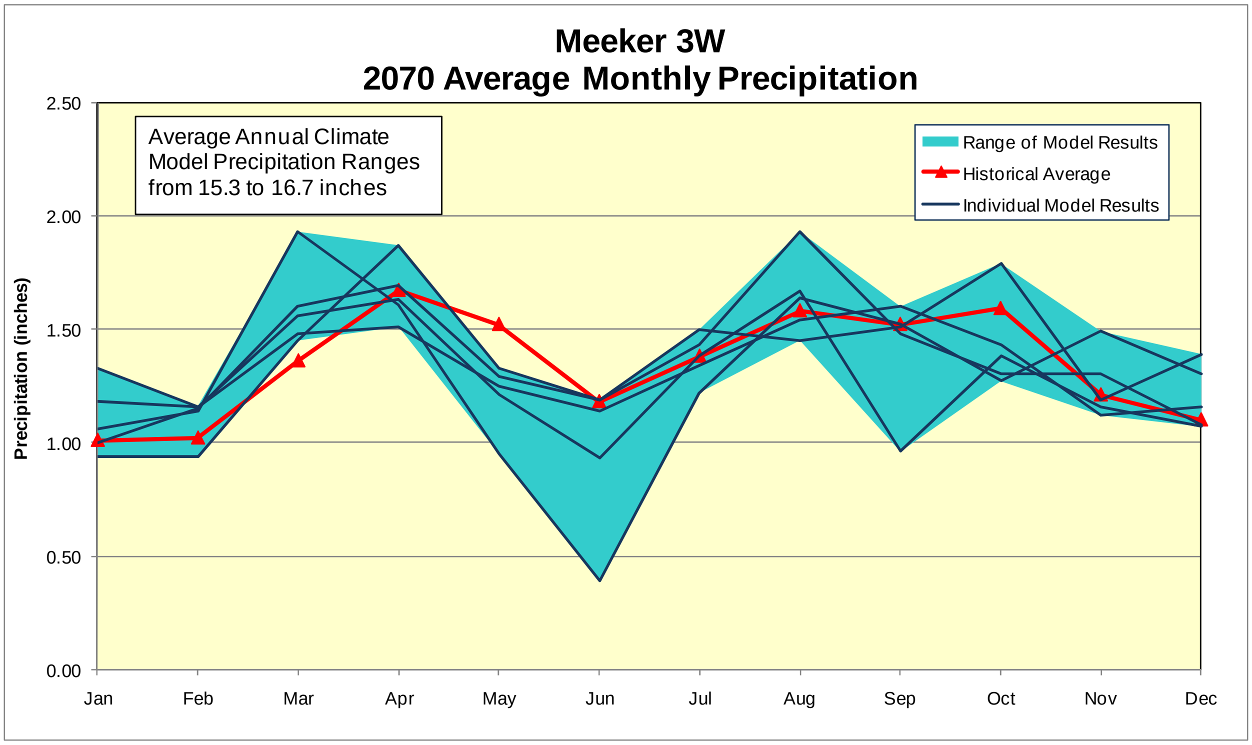


Figure B24 – Maybell 2070 Average Monthly Precipitation Comparison

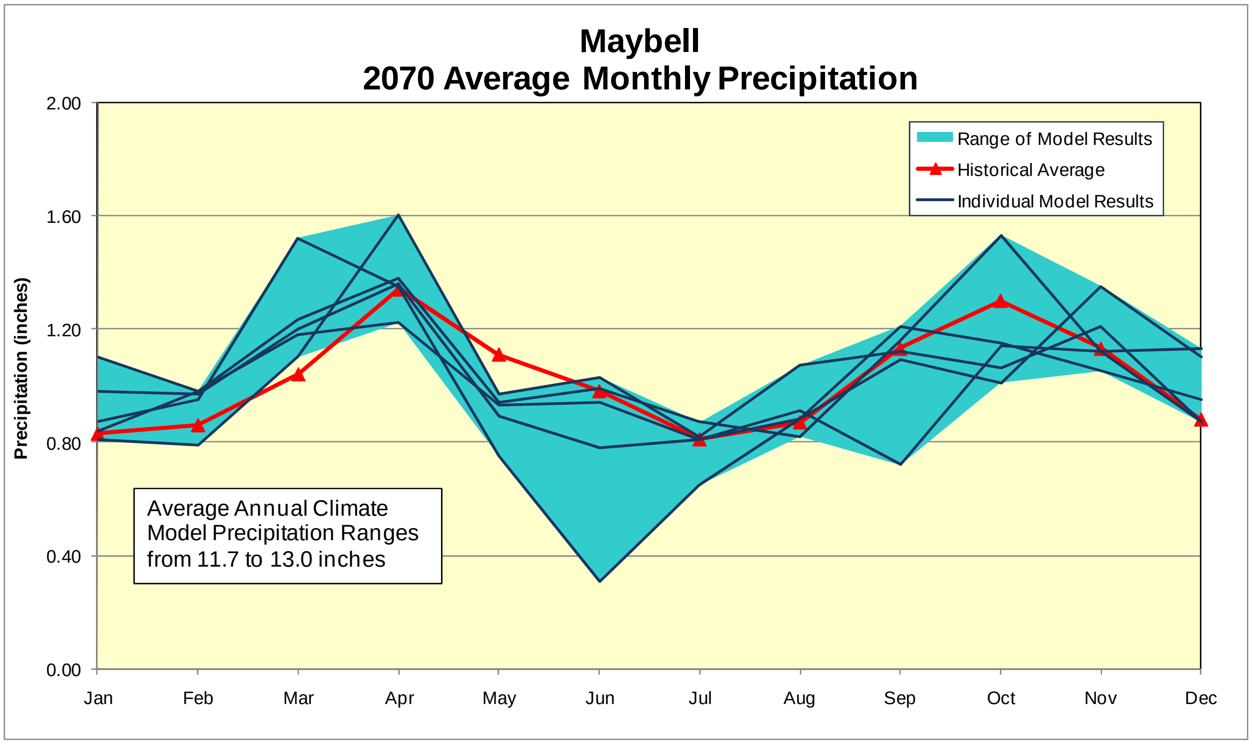


Figure B25 – Hayden 2070 Average Monthly Precipitation Comparison

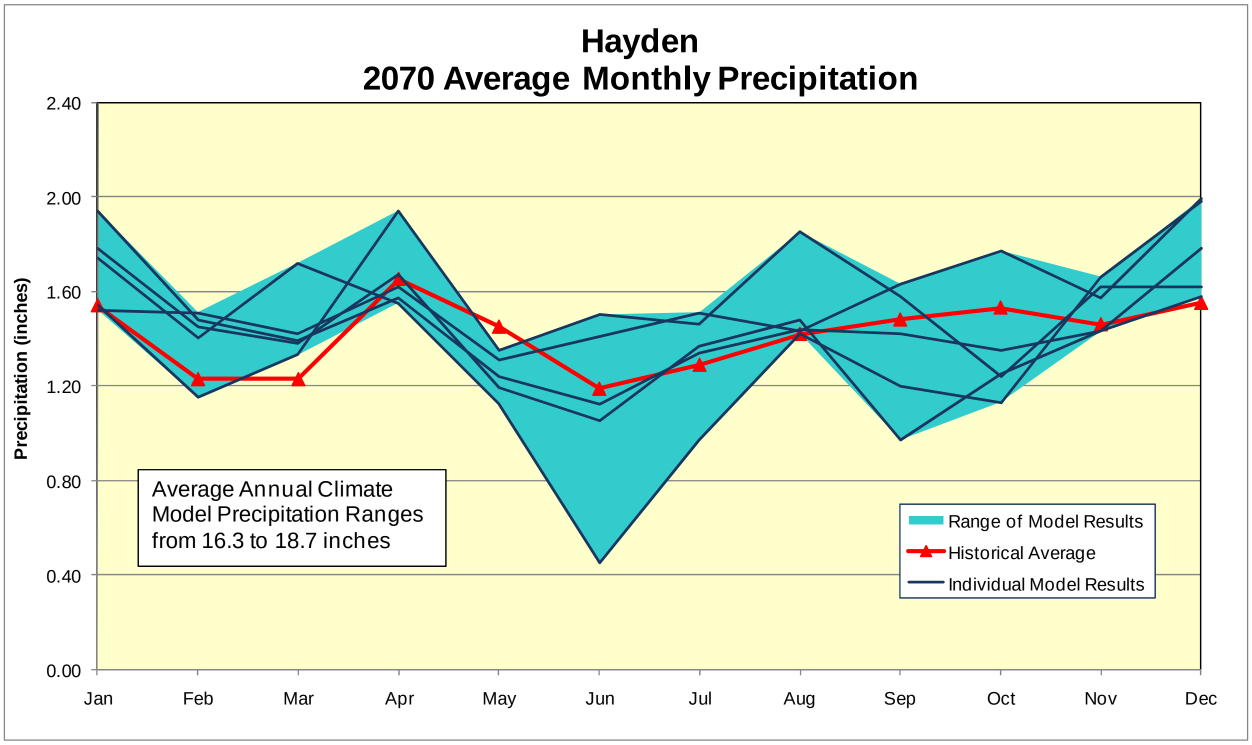


Figure B26 – Yampa 2070 Average Monthly Precipitation Comparison

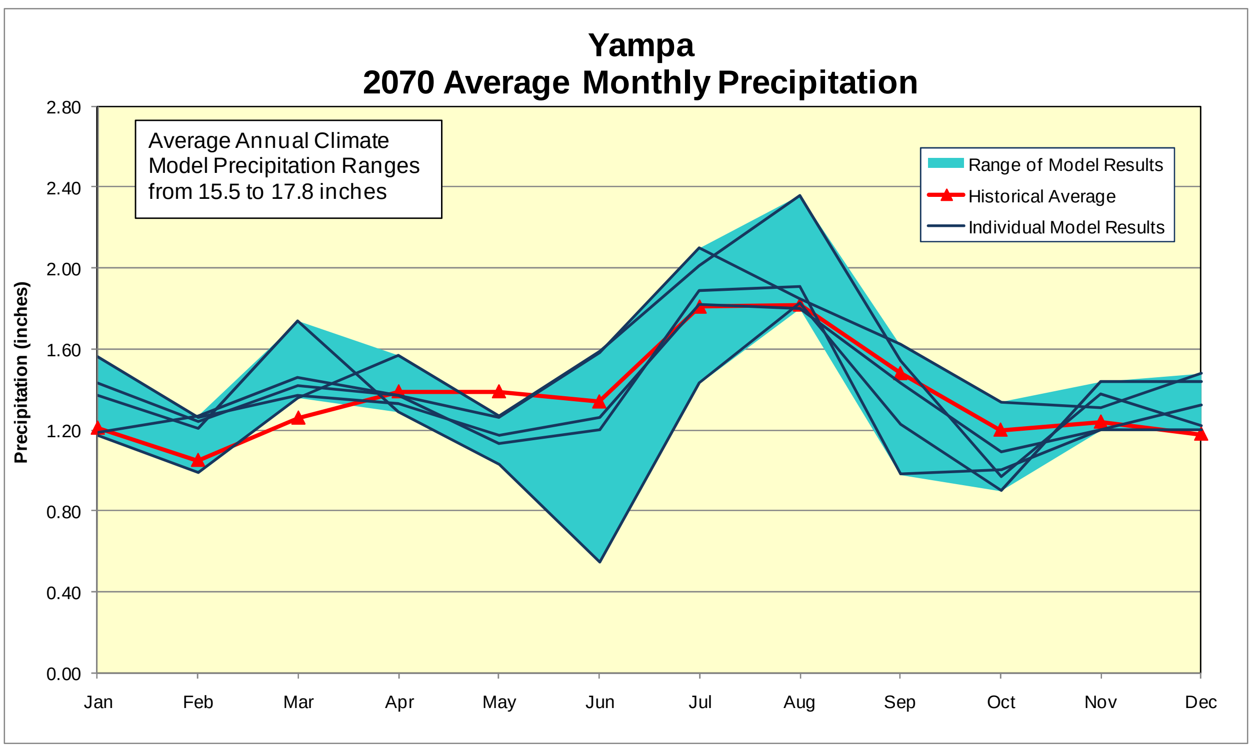


Figure B27 – Delta 2070 Average Monthly Precipitation Comparison

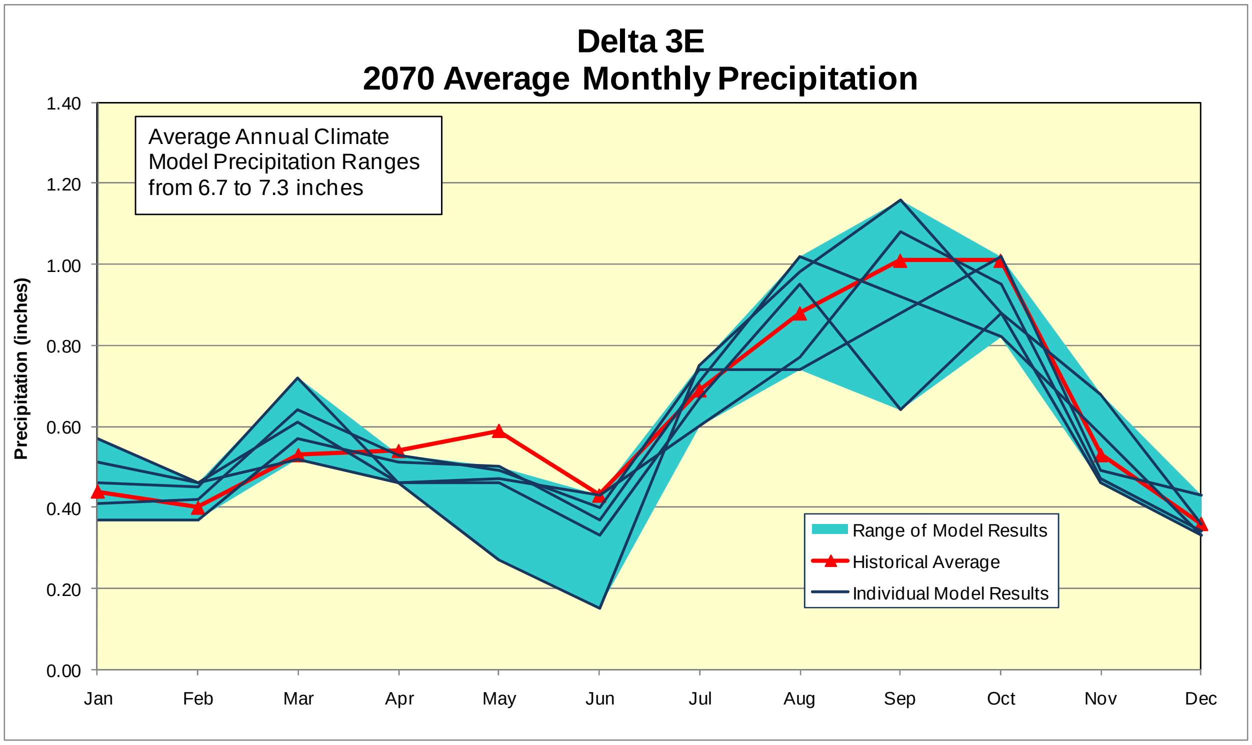


Figure B28 – Montrose 2070 Average Monthly Precipitation Comparison

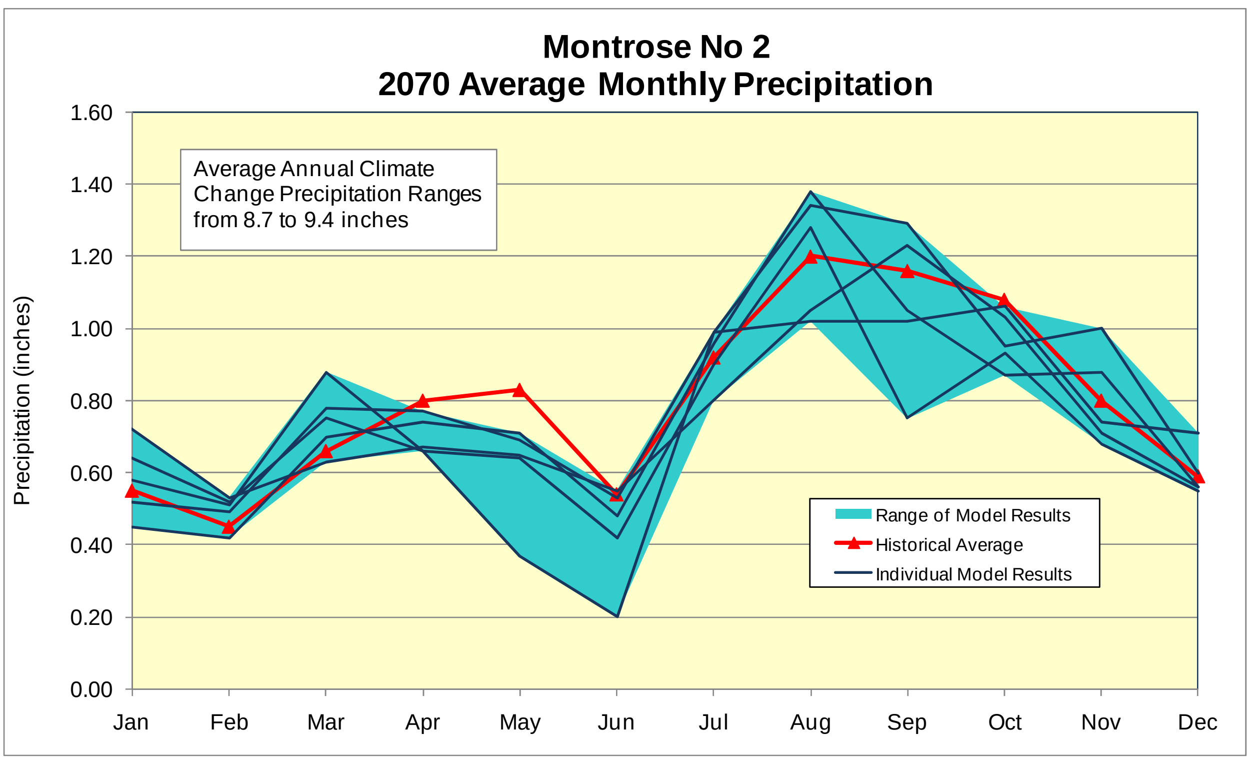


Figure B29 – Gunnison 2070 Average Monthly Precipitation Comparison

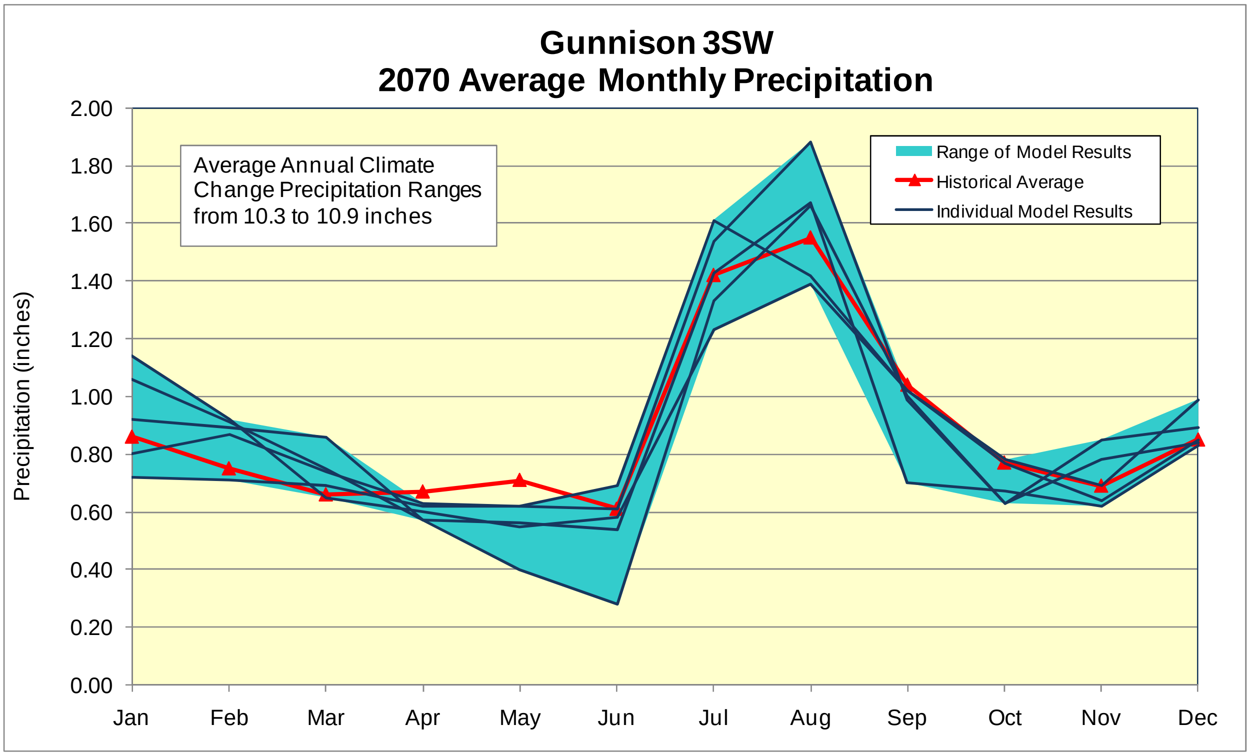


Figure B30 – Cortez 2070 Average Monthly Precipitation Comparison

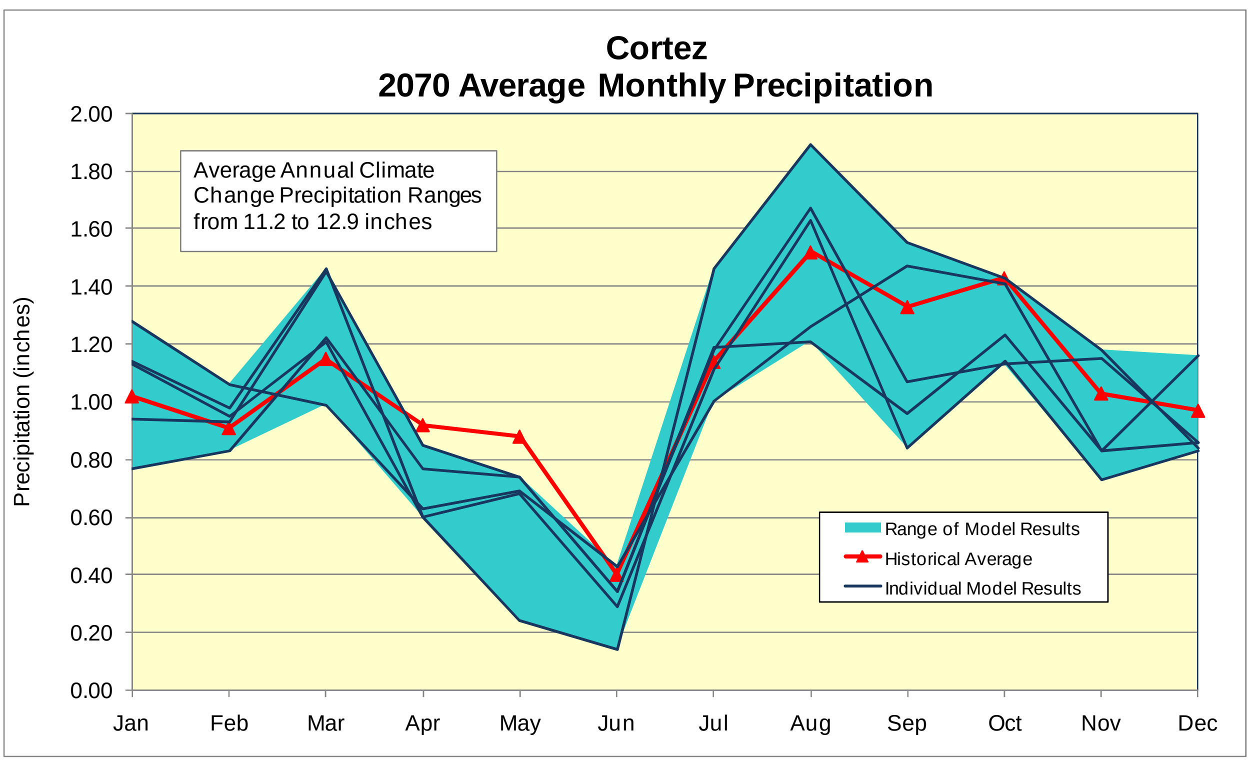


Figure B31 – Durango 2070 Average Monthly Precipitation Comparison

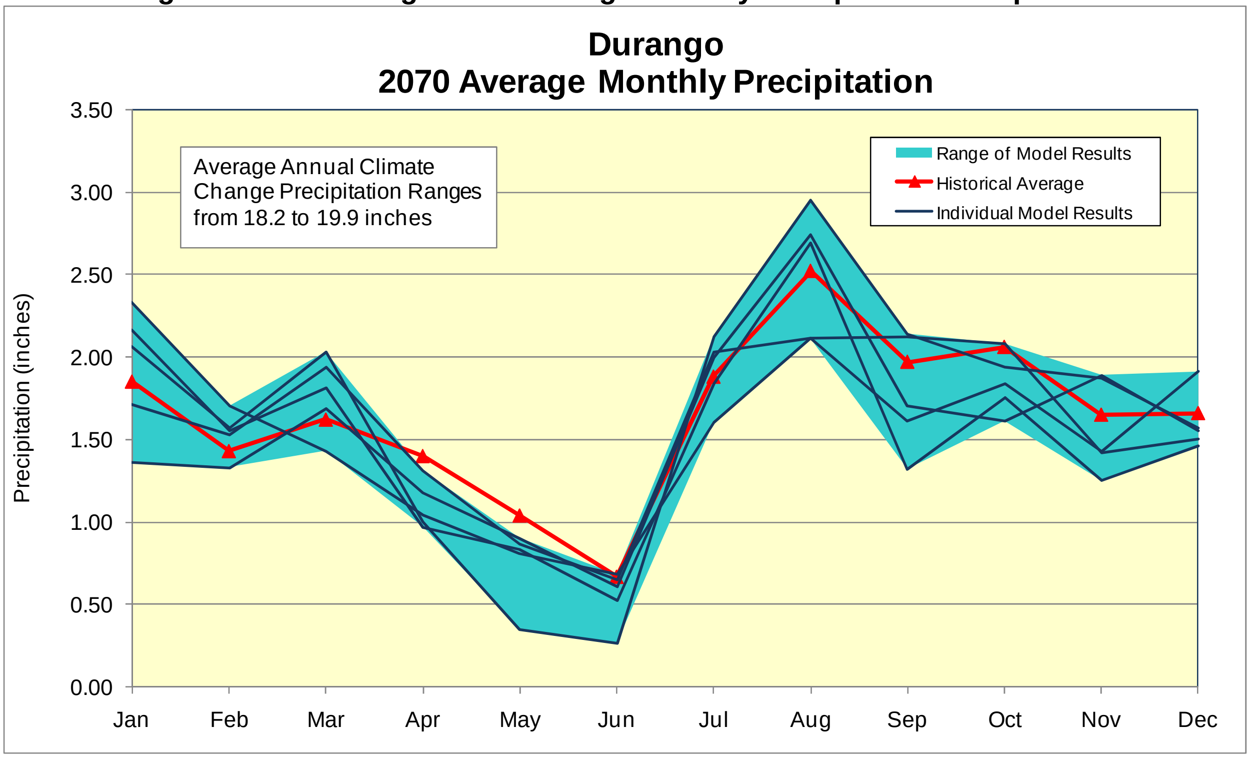
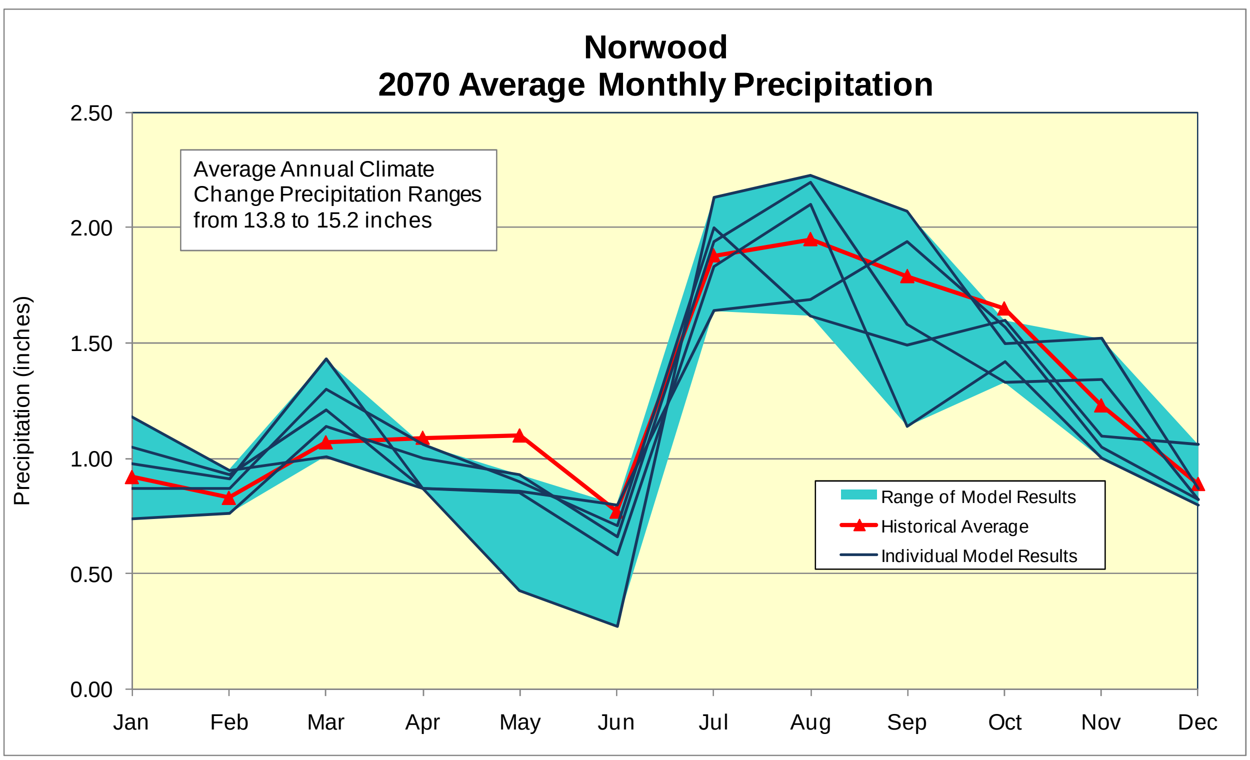


Figure B32 – Norwood 2070 Average Monthly Precipitation Comparison



C. Crop Irrigation Requirement

Contents

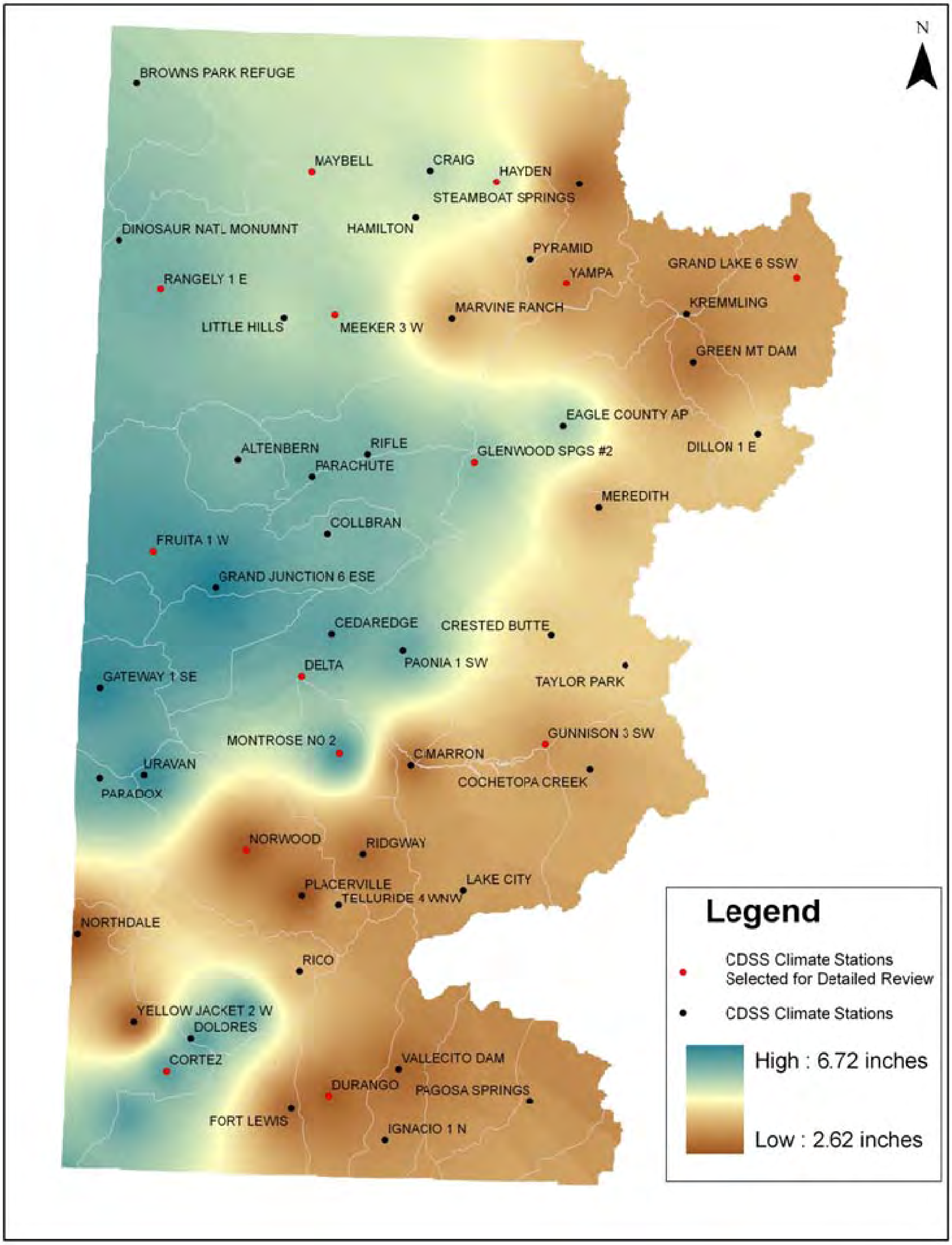
Table C1
2040 Average Annual Grass Pasture Crop Irrigation Requirement (CIR) and Growing Season Length Compared to Historical

Climate Station	% Difference CIR	Increase in CIR (inches)	# Days Increase Start Growing Season	# Days Increase End Growing Season	# Days Increase Growing Season	Chart Page
Fruita 1W	21%	6.38	11	7	18	C-6
Glenwood Springs	25%	5.81	11	8	19	C-6
Grand Lake 6SSW	16%	3.67	9	9	18	C-7
Rangely 1E	22%	6.02	9	7	16	C-7
Meeker 3W	28%	5.47	10	8	18	C-8
Maybell	26%	5.16	9	7	16	C-8
Hayden	25%	4.75	8	7	15	C-9
Yampa	13%	3.29	9	8	17	C-9
Delta 3E	21%	6.43	11	7	18	C-10
Montrose No 2	23%	6.36	12	8	20	C-10
Gunnison 3SW	13%	3.5	9	7	16	C-11
Cortez	24%	6.24	14	8	22	C-11
Durango	10%	2.81	13	8	21	C-12
Norwood	10%	2.74	9	8	16	C-12
Average	**20%**	**4.90**	**10.5**	**7.6**	**18.1**	

Table C2
2070 Average Annual Grass Pasture Crop Irrigation Requirement (CIR) and Growing Season Length Compared to Historical

Climate Station	% Difference CIR	Increase in CIR (inches)	# Days Increase Start Growing Season	# Days Increase End Growing Season	# Days Increase Growing Season	Chart Page
Fruita 1W	34%	10.15	18	12	30	C-13
Glenwood Springs	40%	9.14	19	13	32	C-13
Grand Lake 6SSW	24%	5.47	15	15	30	C-14
Rangely 1E	36%	9.67	16	12	28	C-14
Meeker 3W	44%	8.59	17	14	31	C-15
Maybell	42%	8.45	15	13	28	C-15
Hayden	42%	8.11	14	13	27	C-16
Yampa	20%	4.87	14	13	27	C-16
Delta 3E	34%	10.18	17	12	28	C-17
Montrose No 2	36%	10.01	18	13	31	C-17
Gunnison 3SW	19%	5.09	14	13	27	C-18
Cortez	38%	9.89	21	13	34	C-18
Durango	15%	4.15	20	13	23	C-19
Norwood	14%	4.08	19	13	32	C-19
Average	**31%**	**7.7**	**17.0**	**13.0**	**29.0**	

Figure C1 - 2040 Increase in Grass Pasture CIR from Historical (inches)



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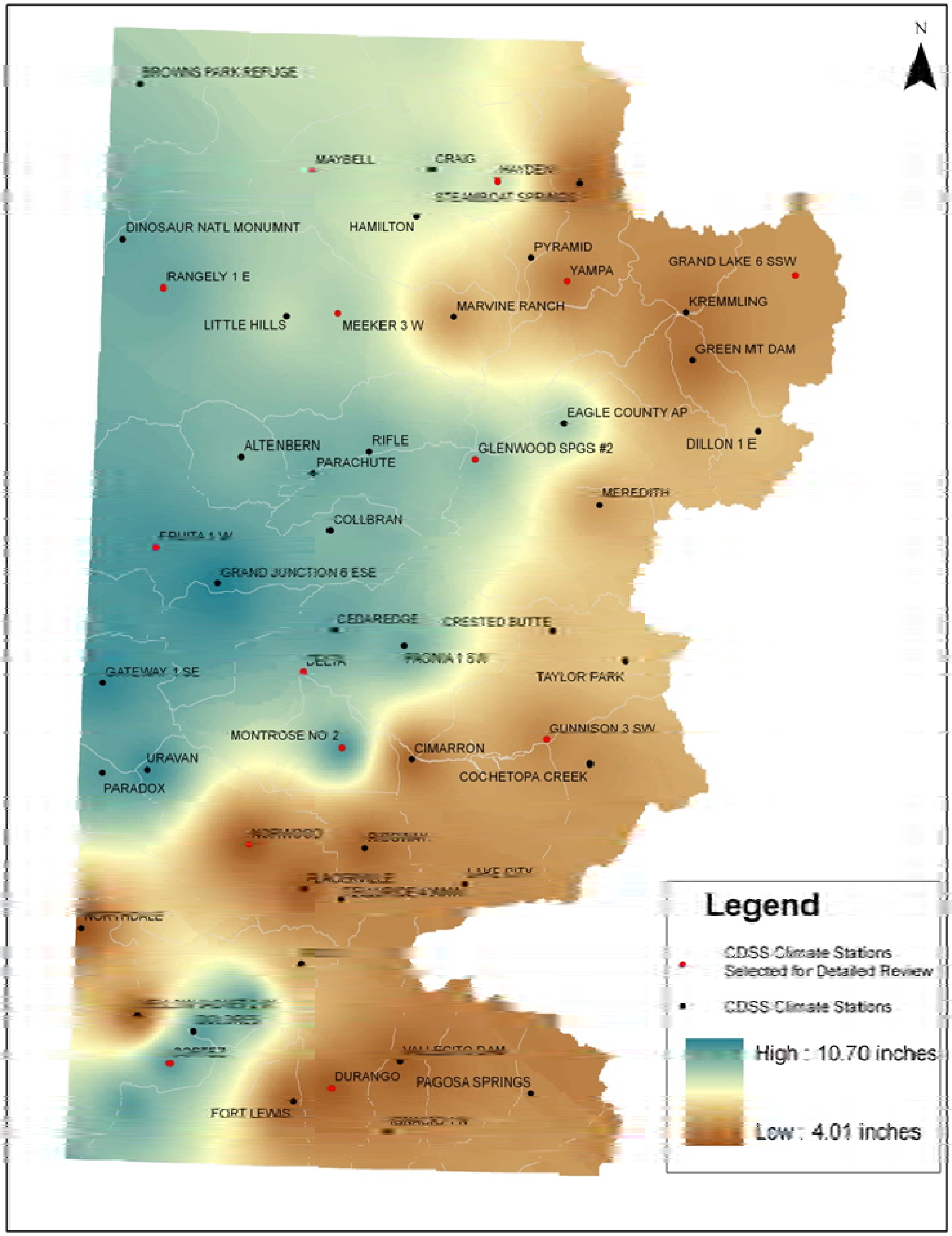

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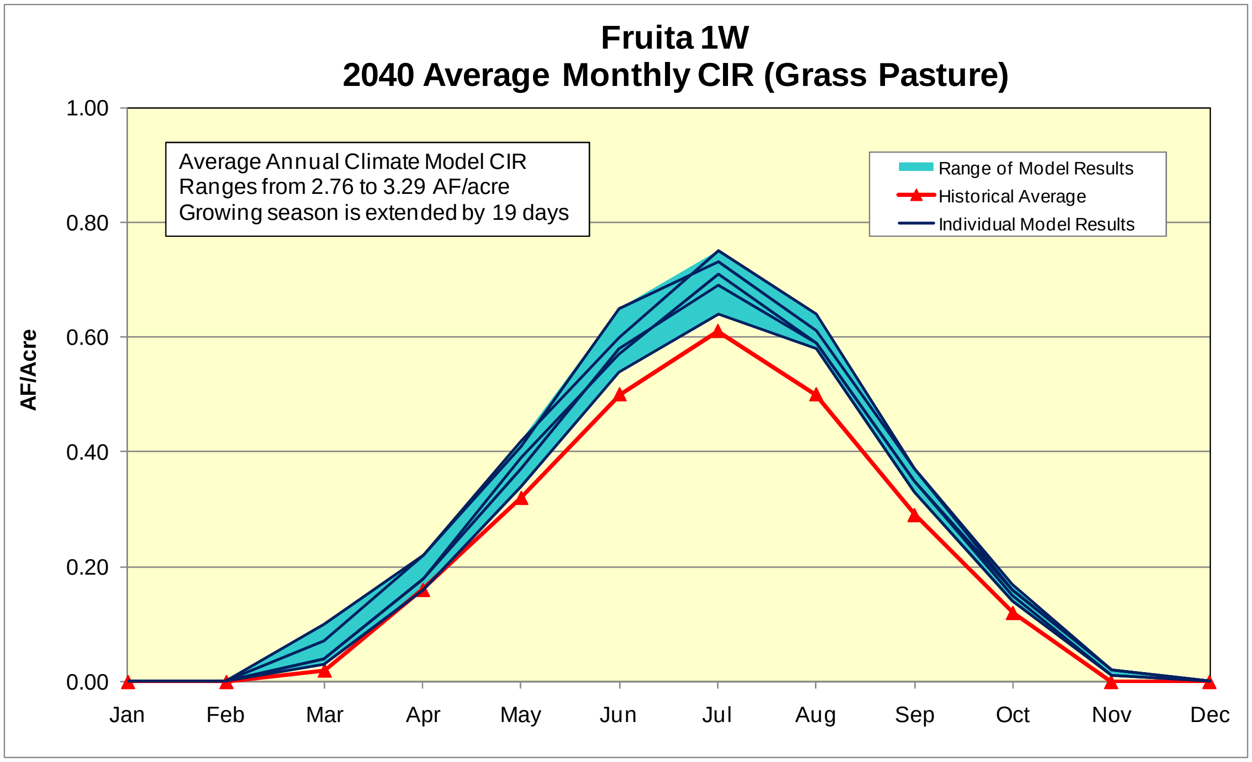

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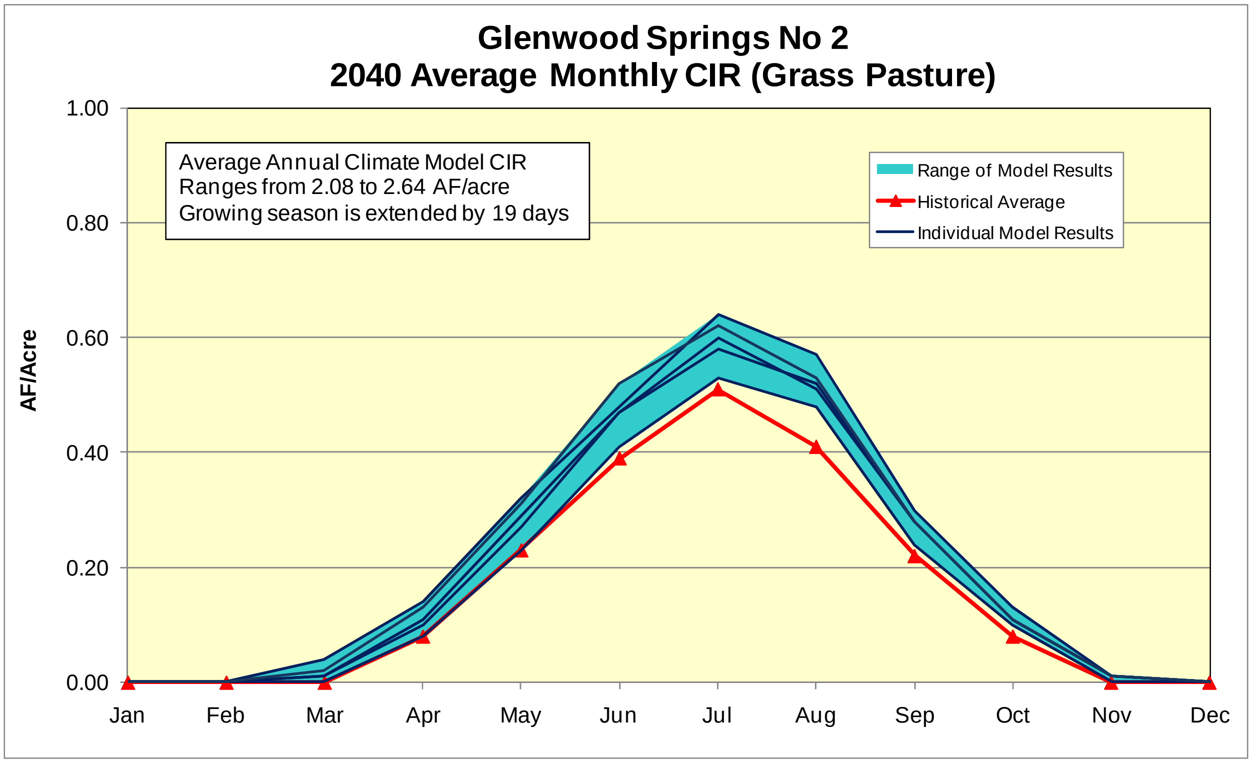

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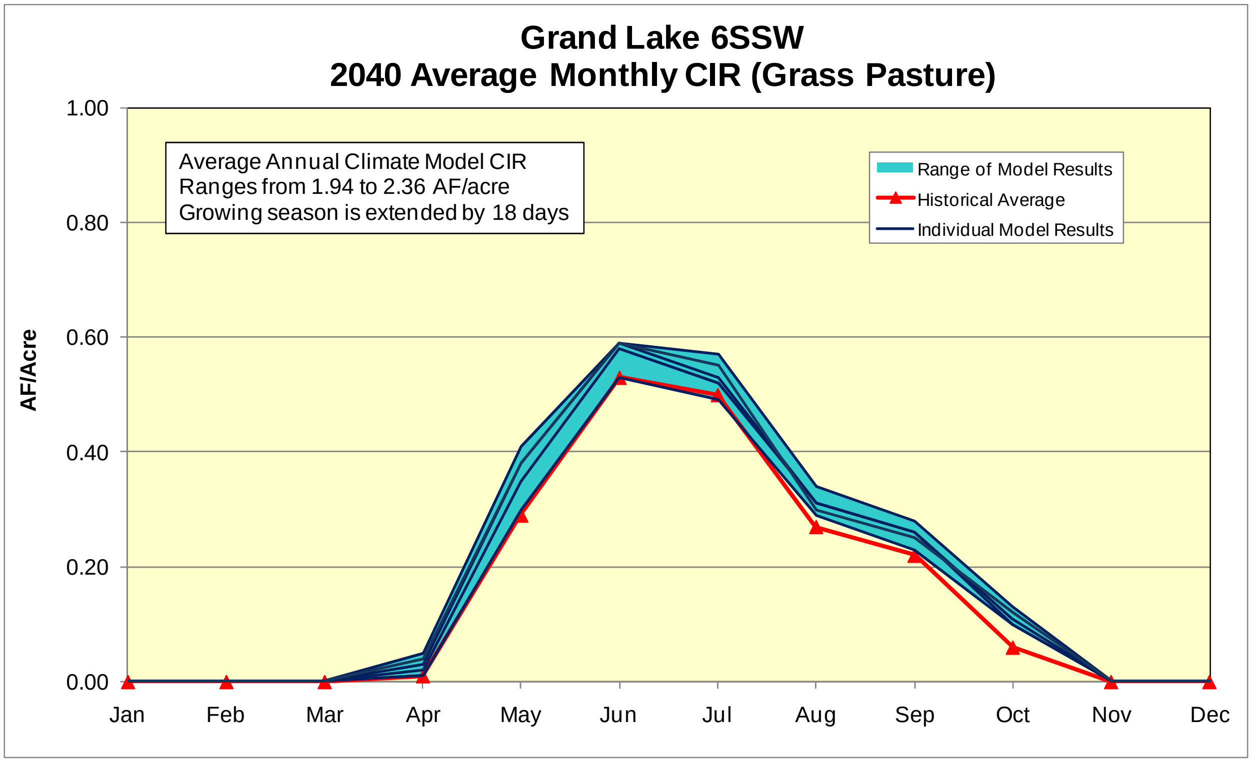

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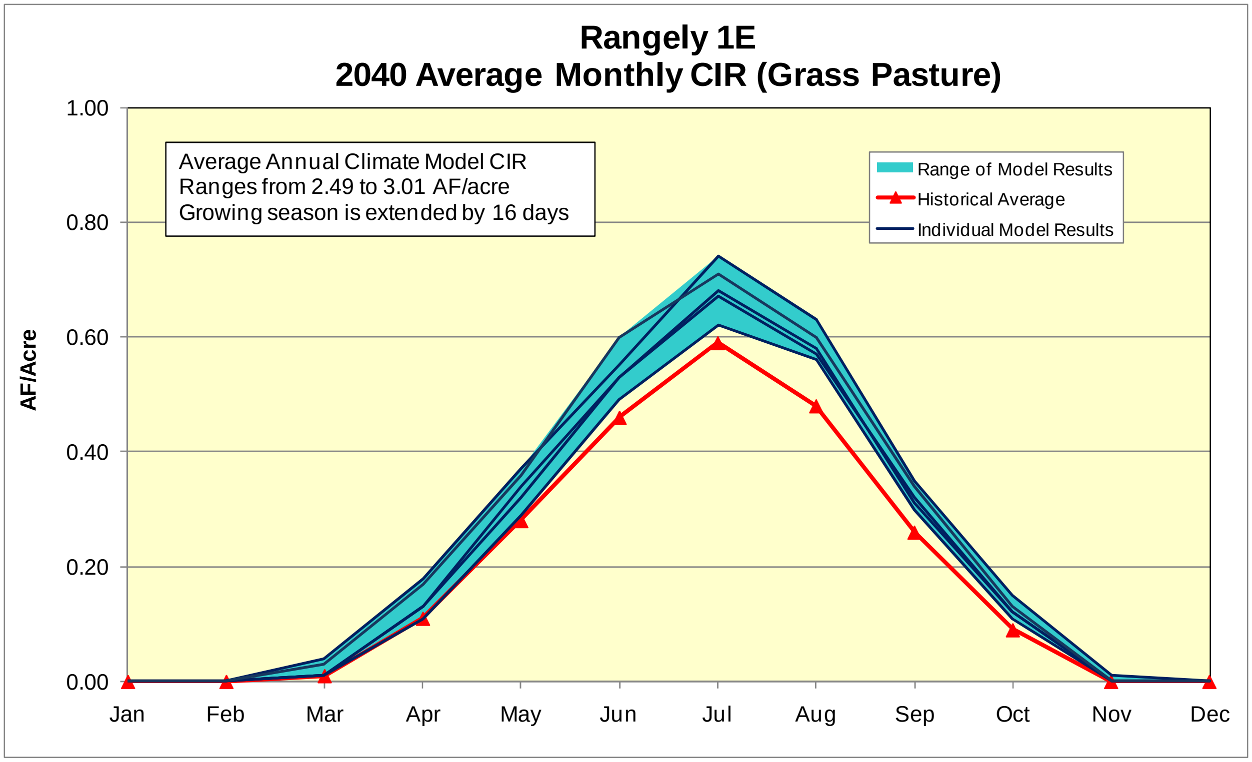

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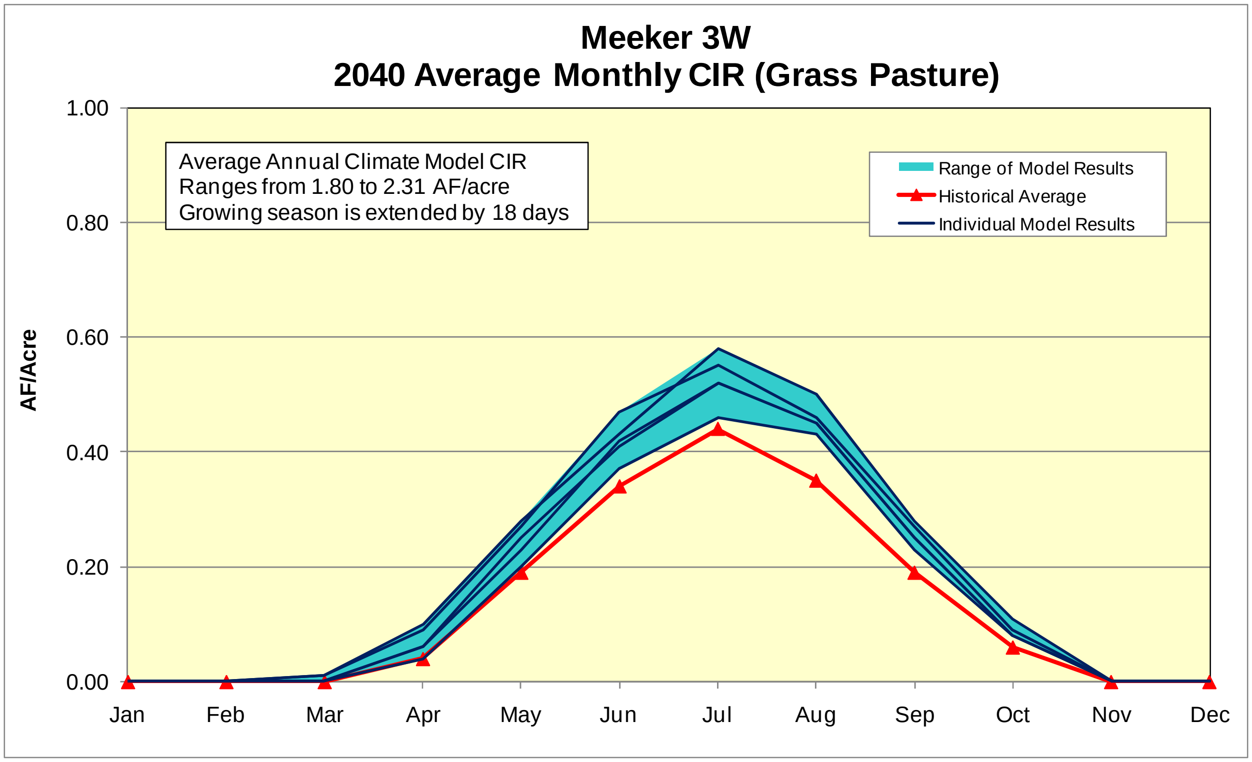

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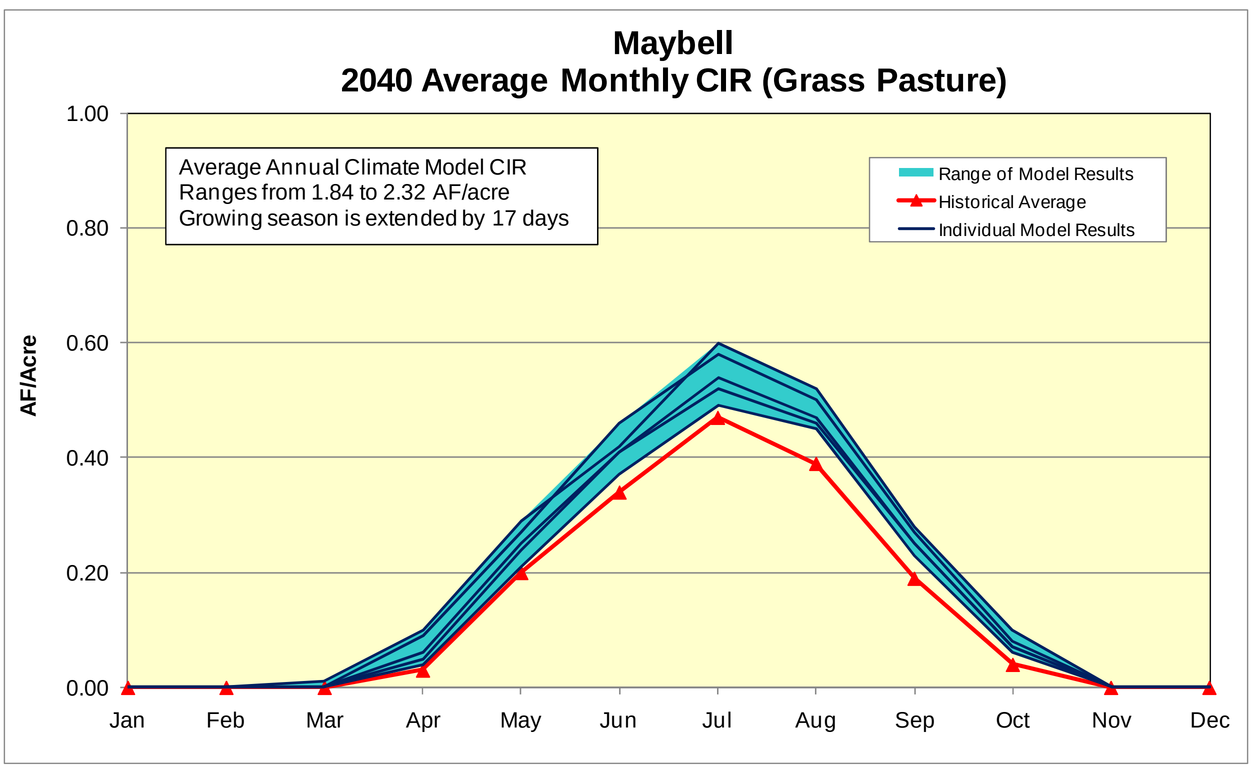

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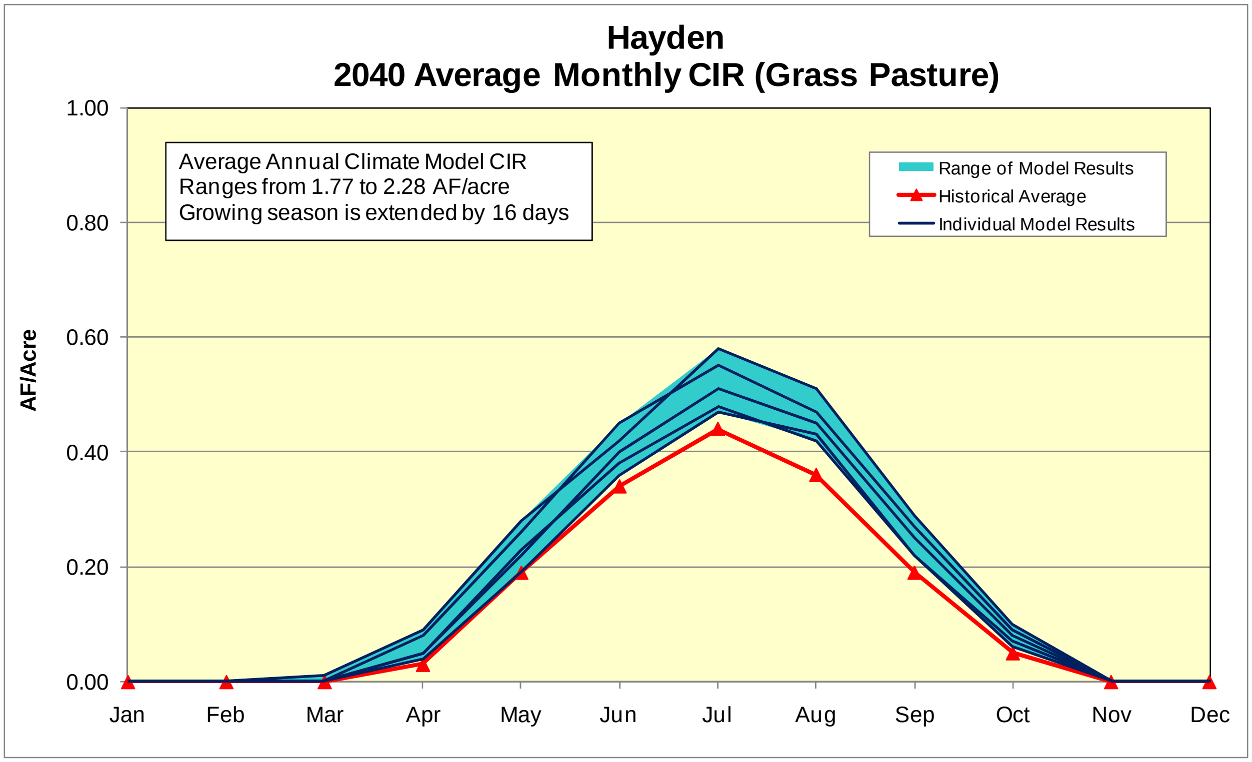

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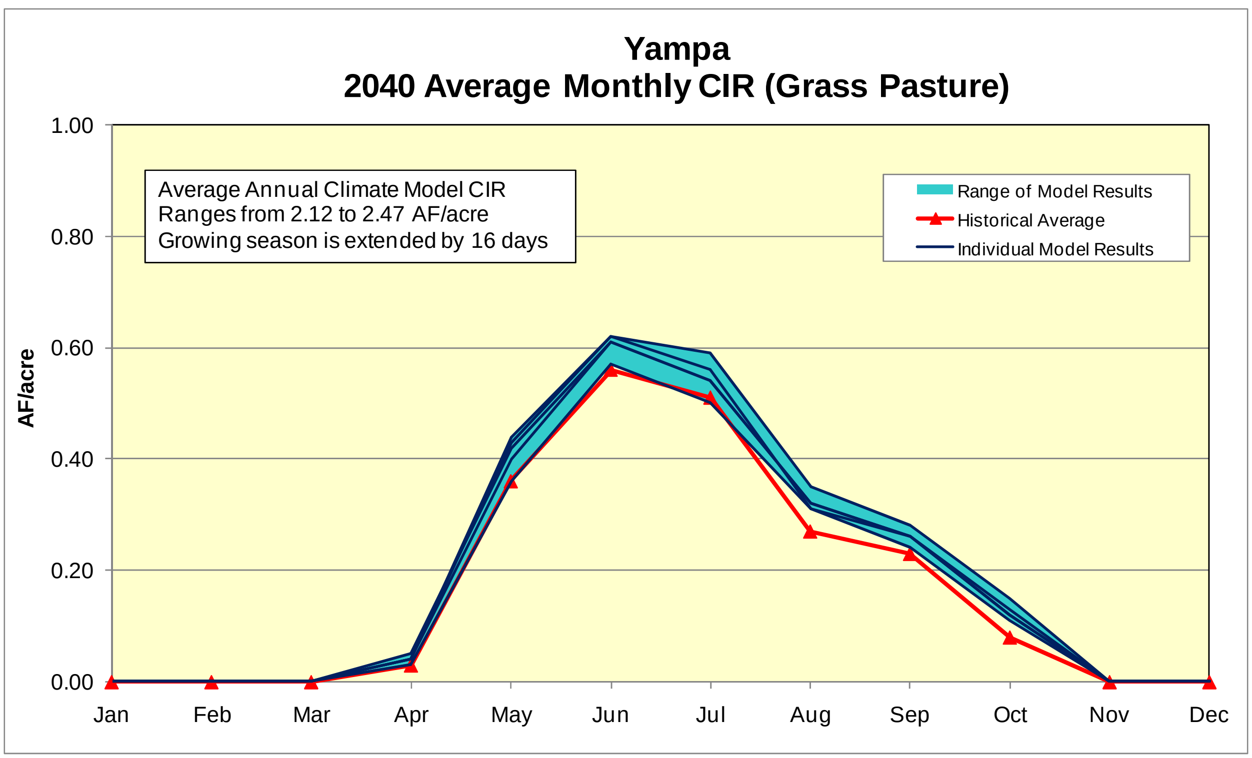

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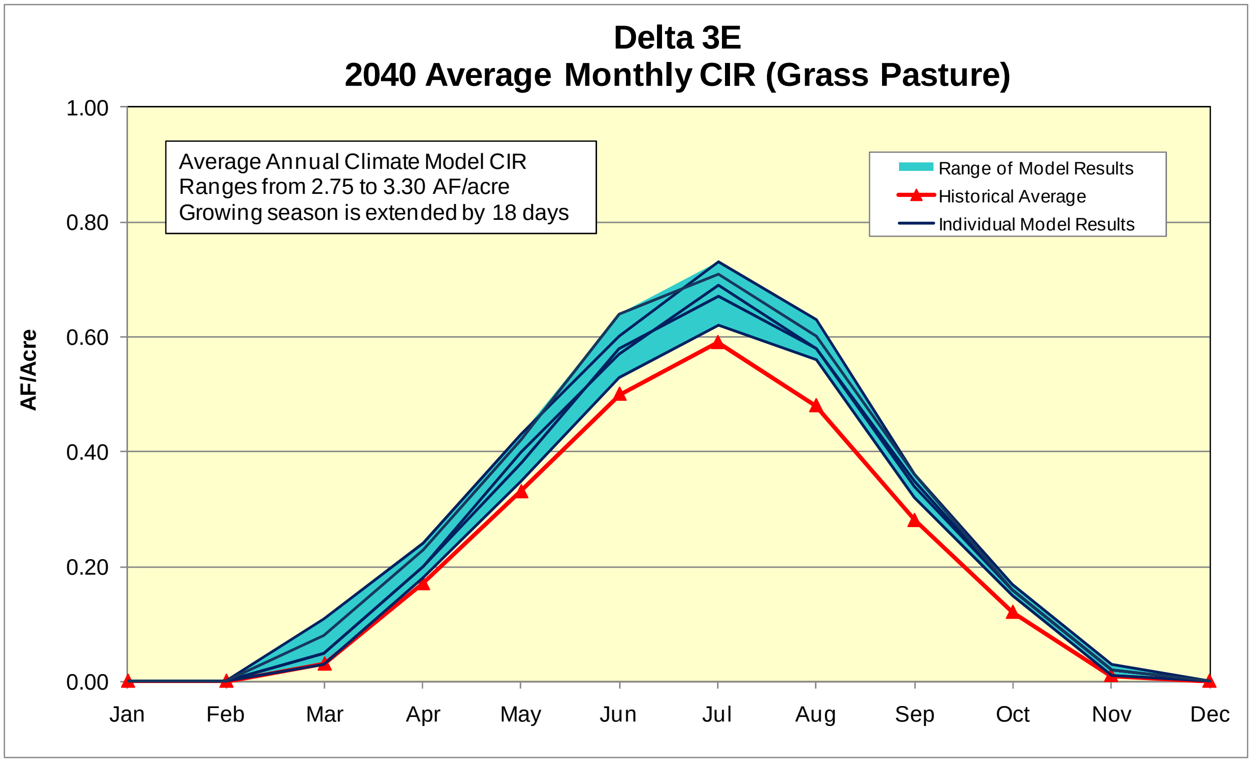

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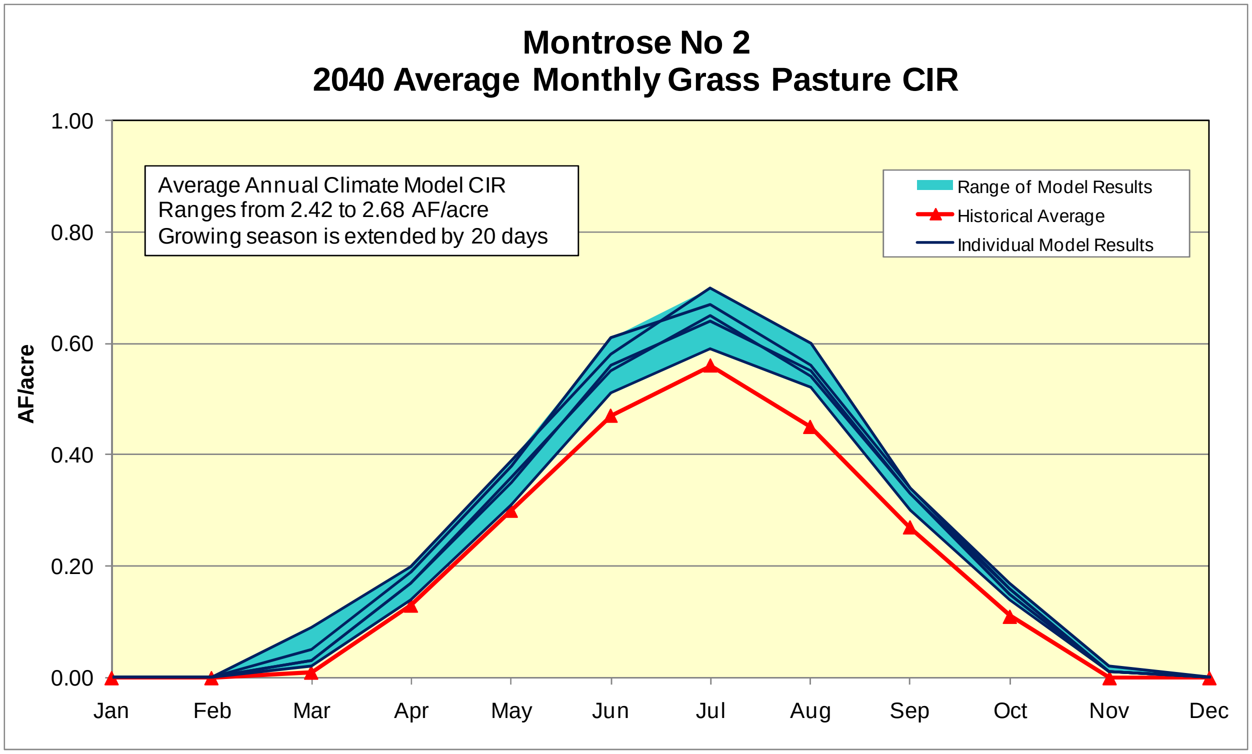

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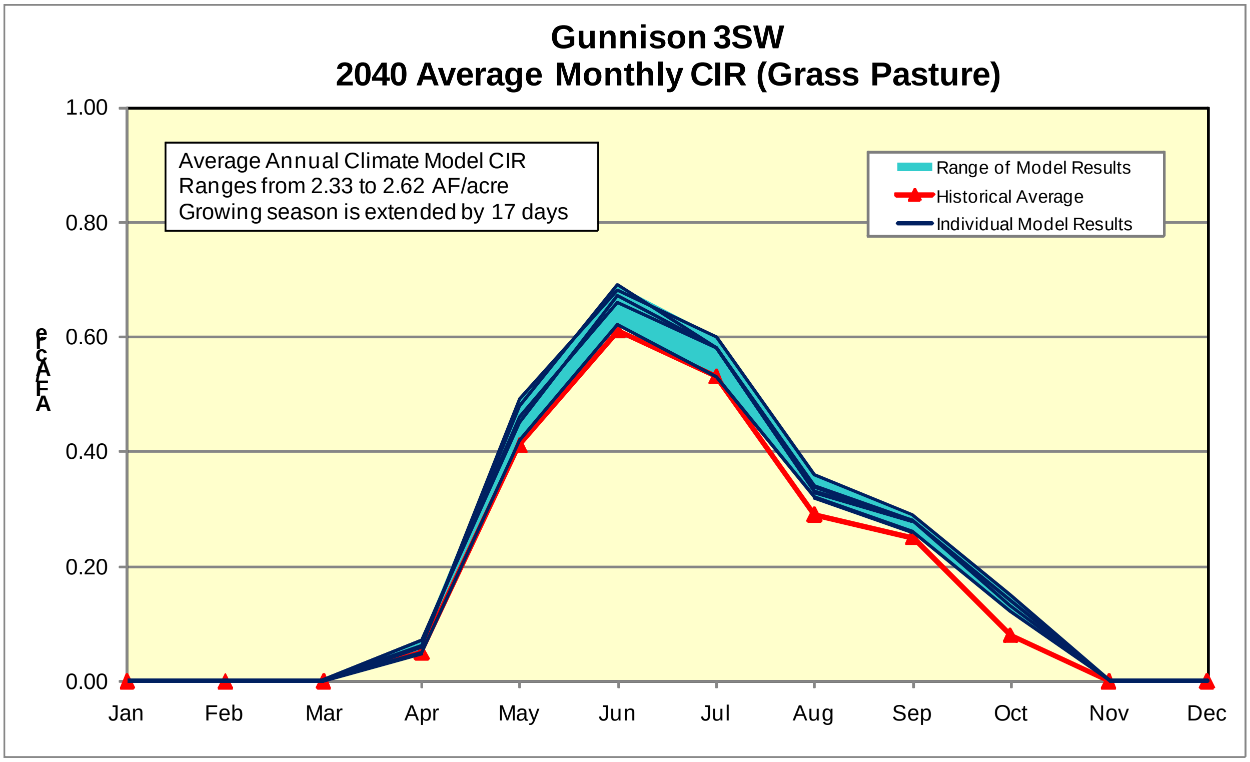

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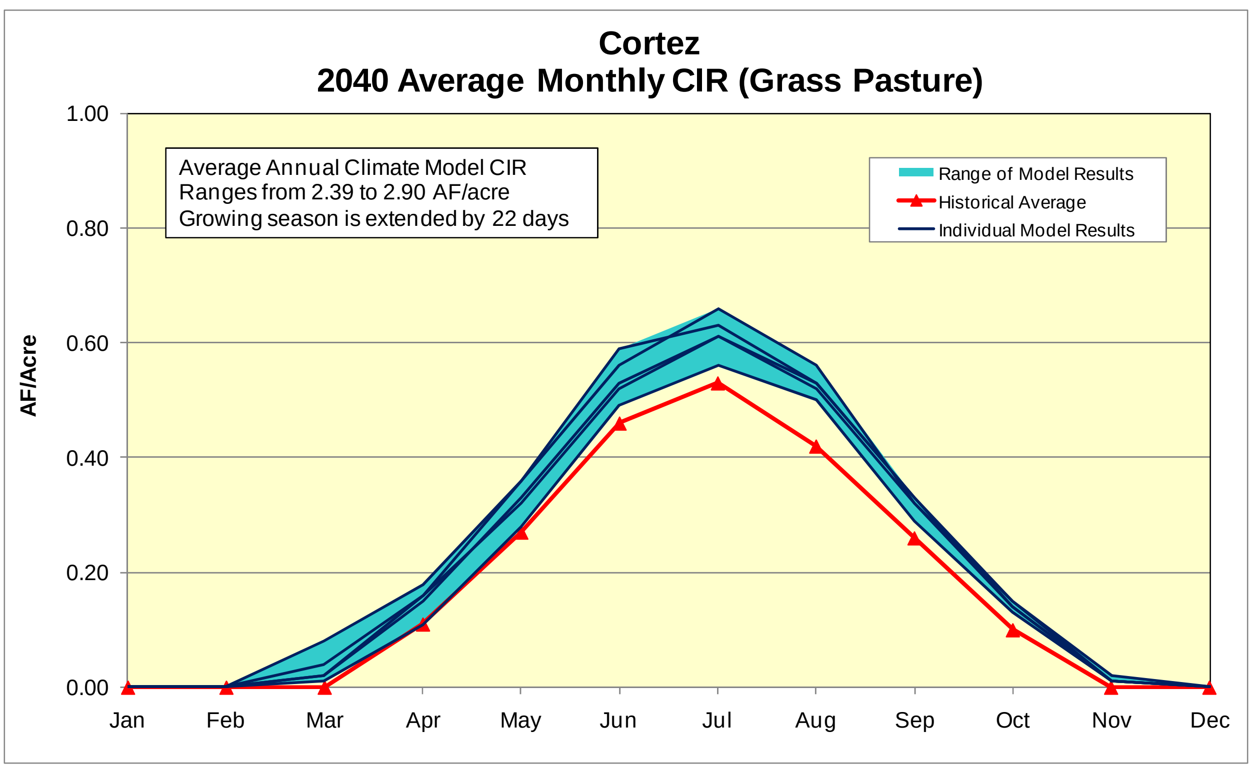

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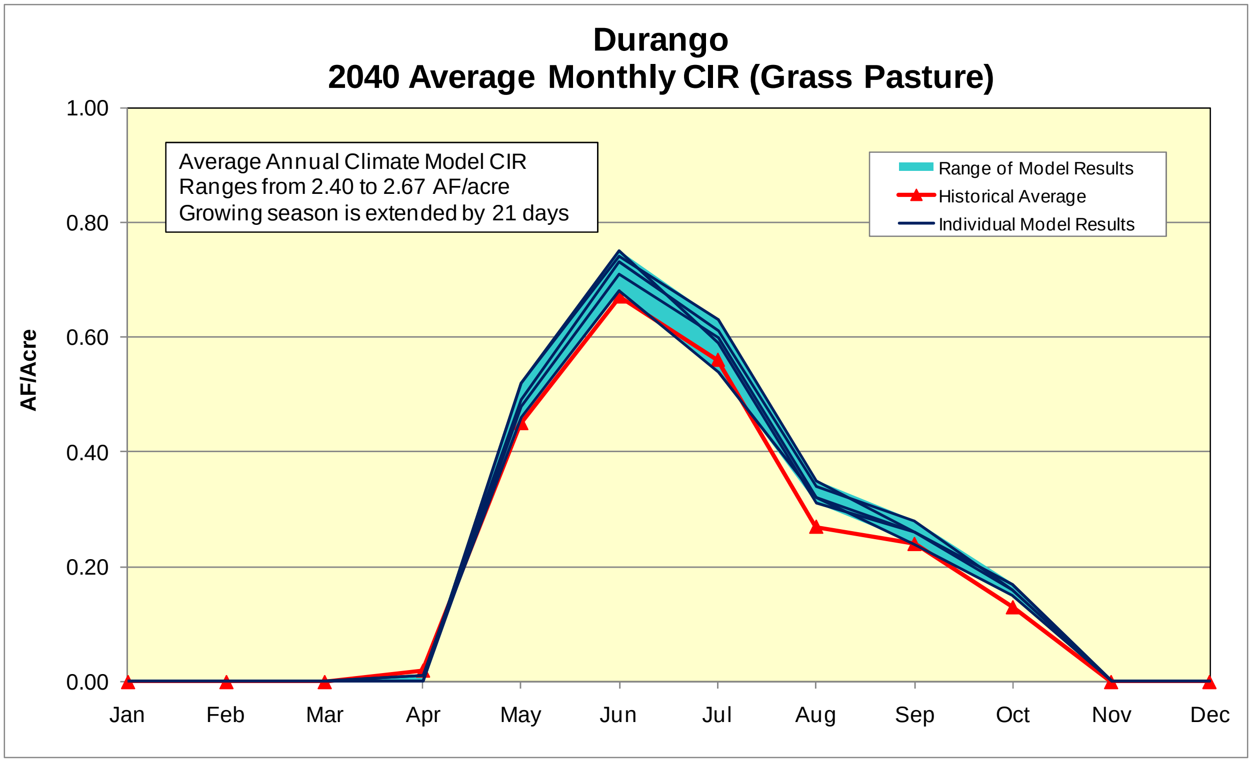

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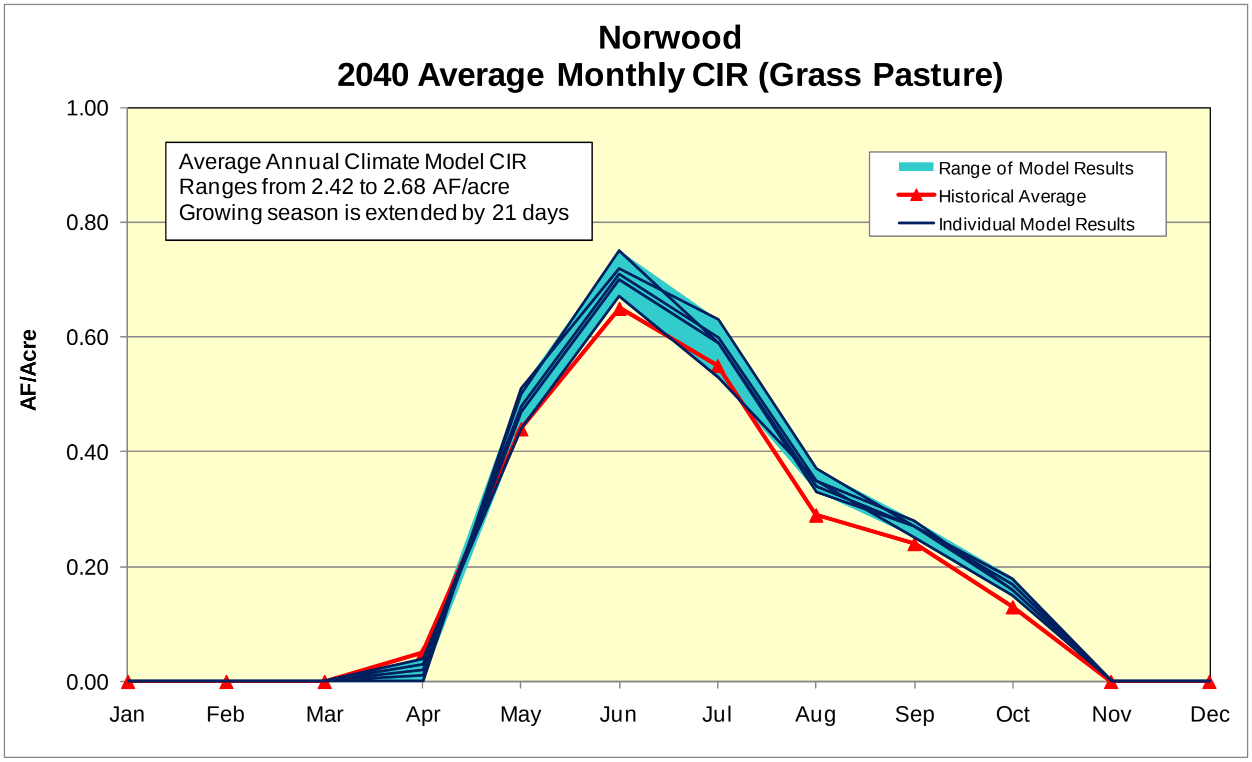

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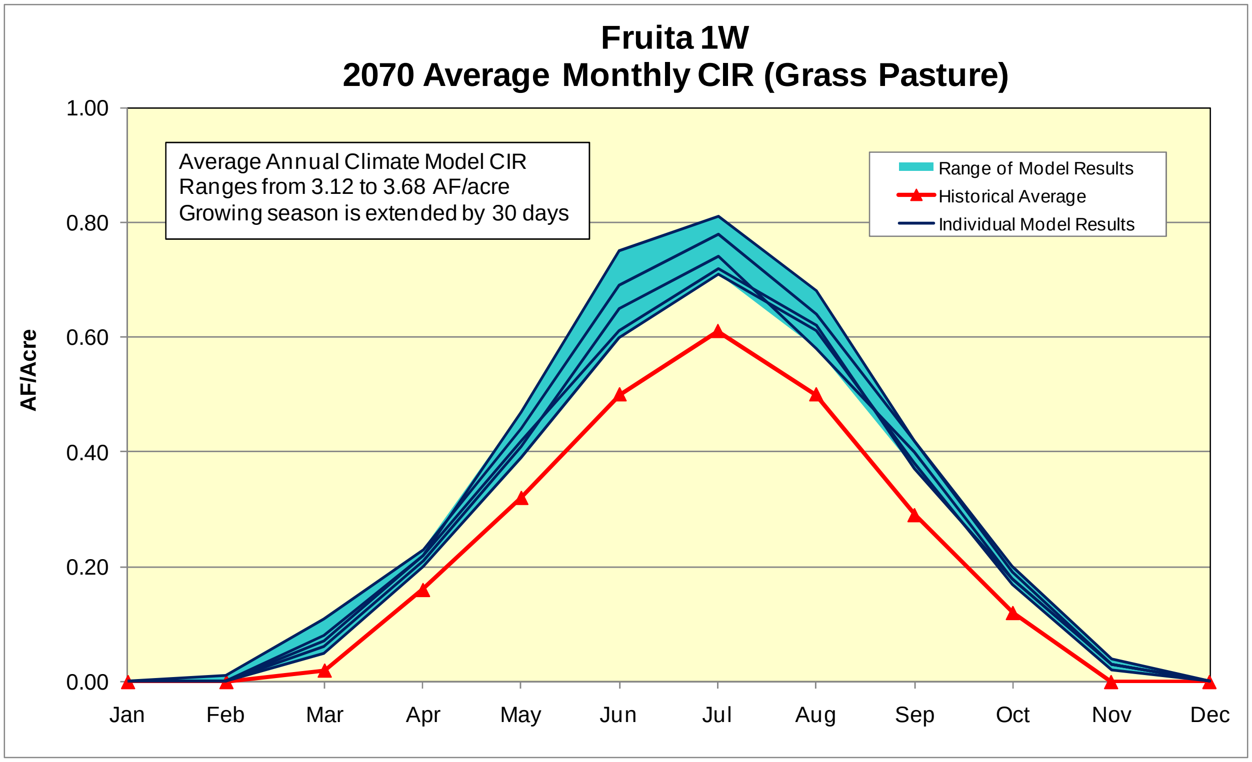

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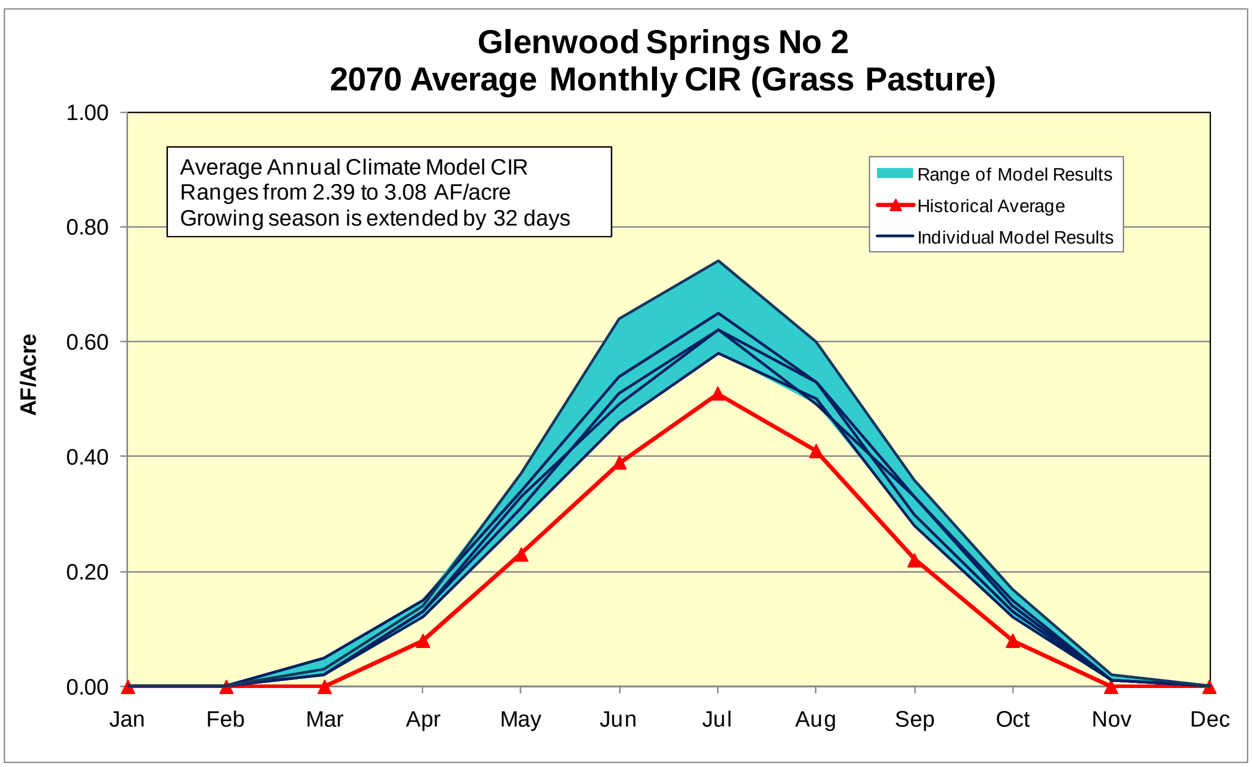

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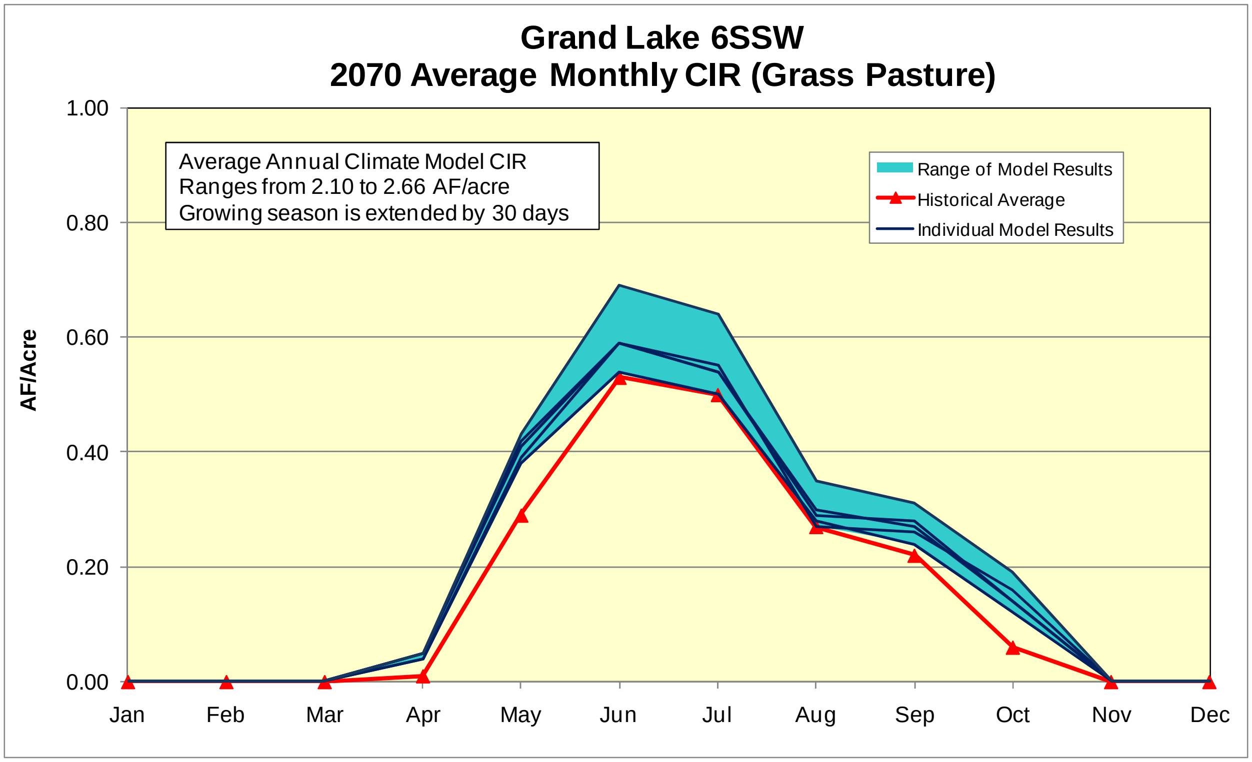

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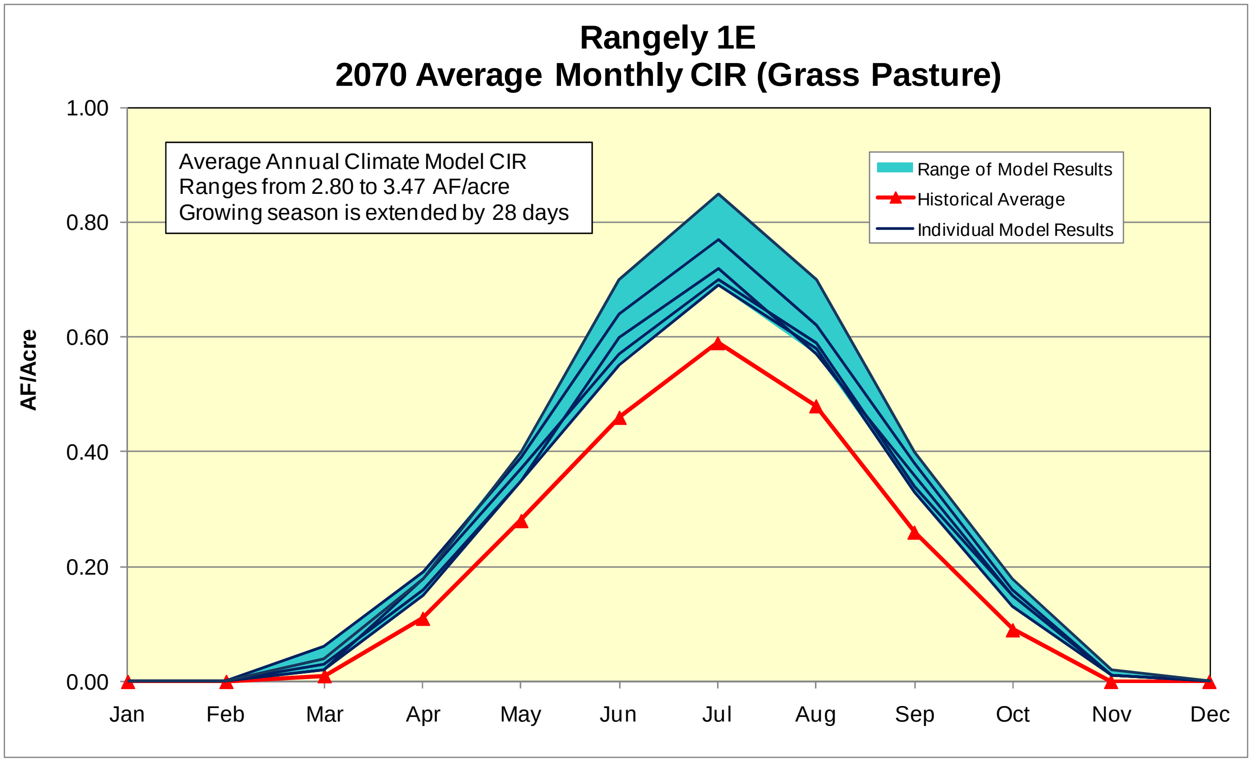

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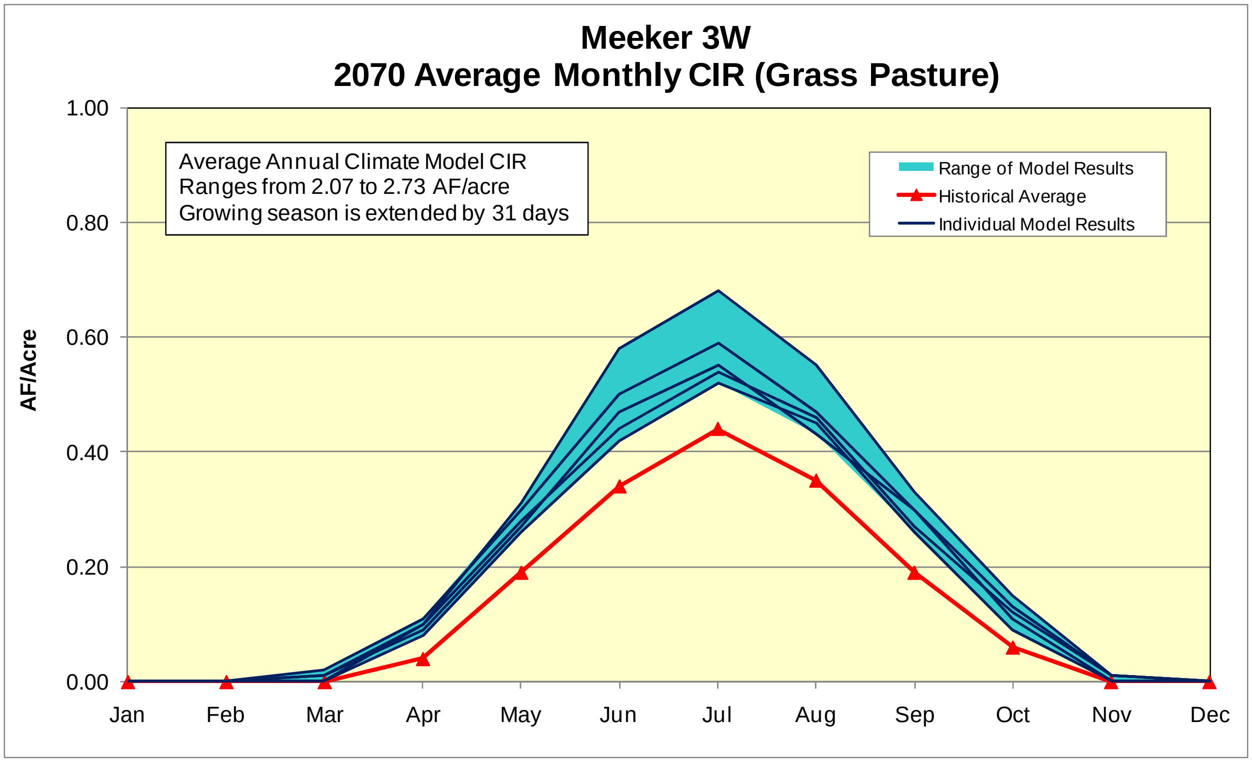

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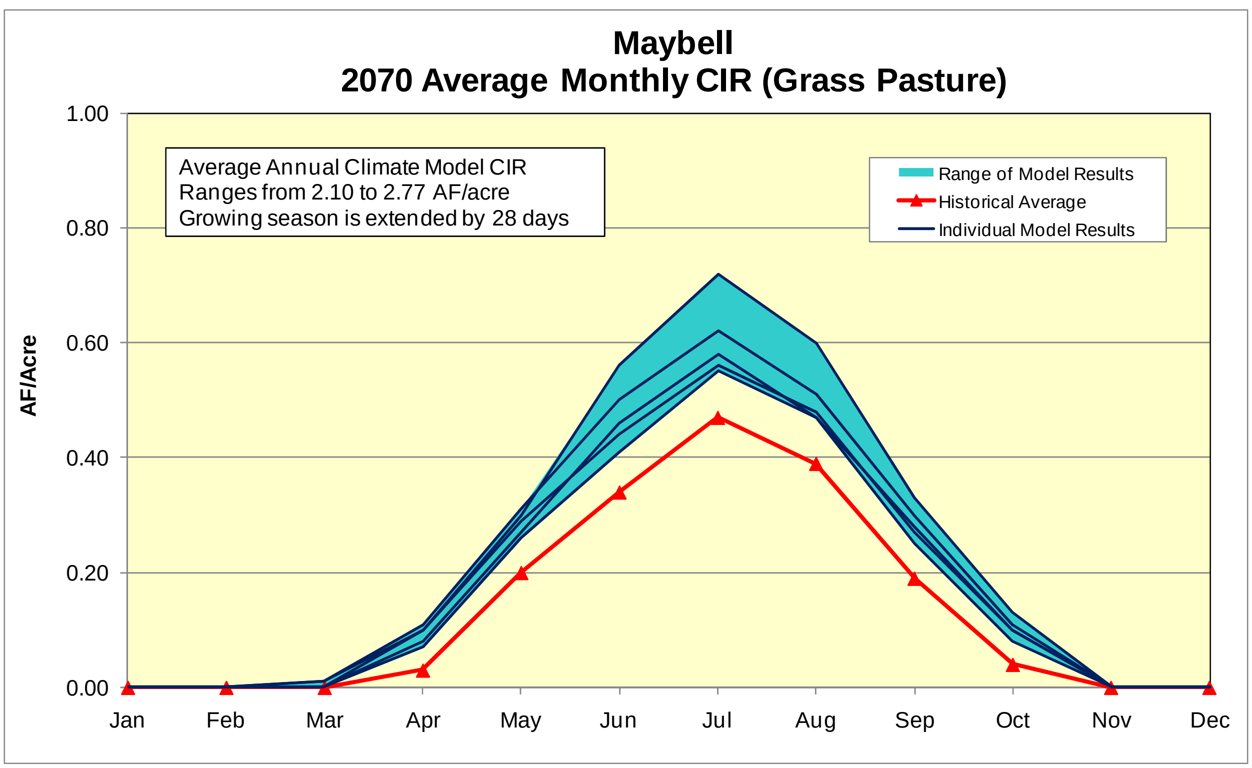

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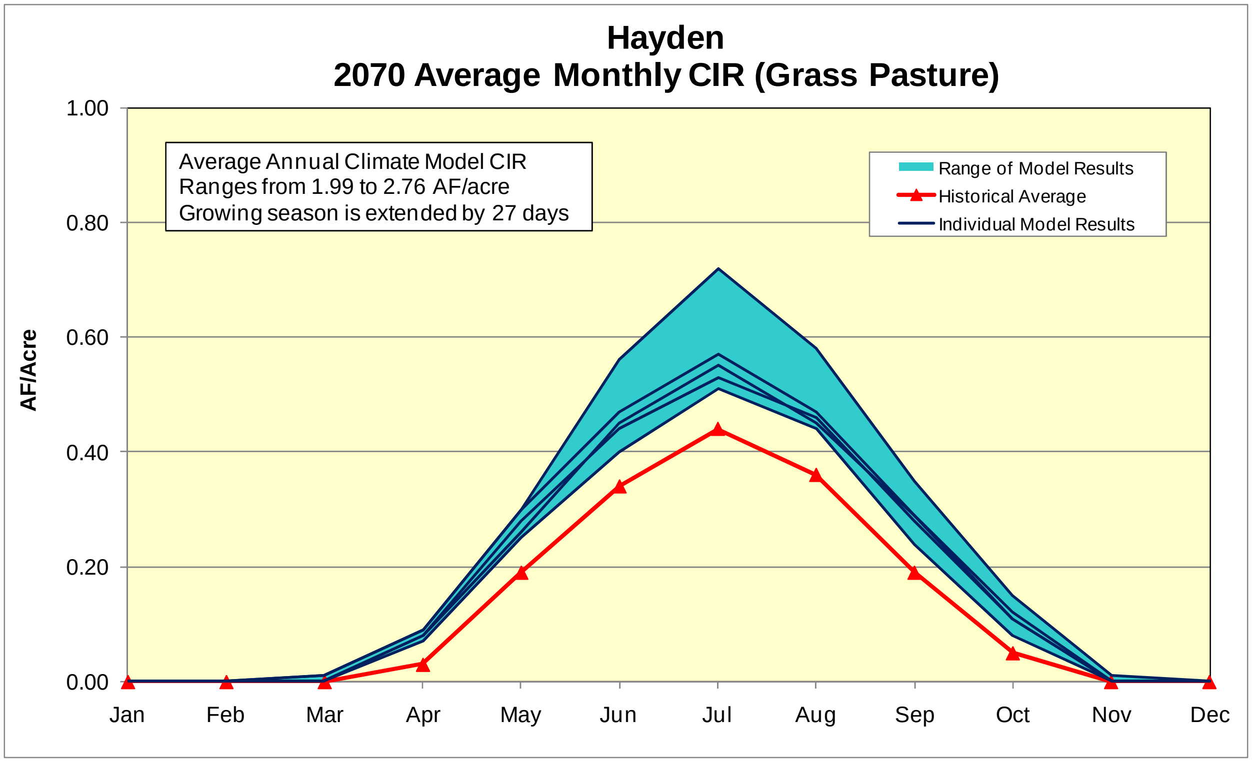

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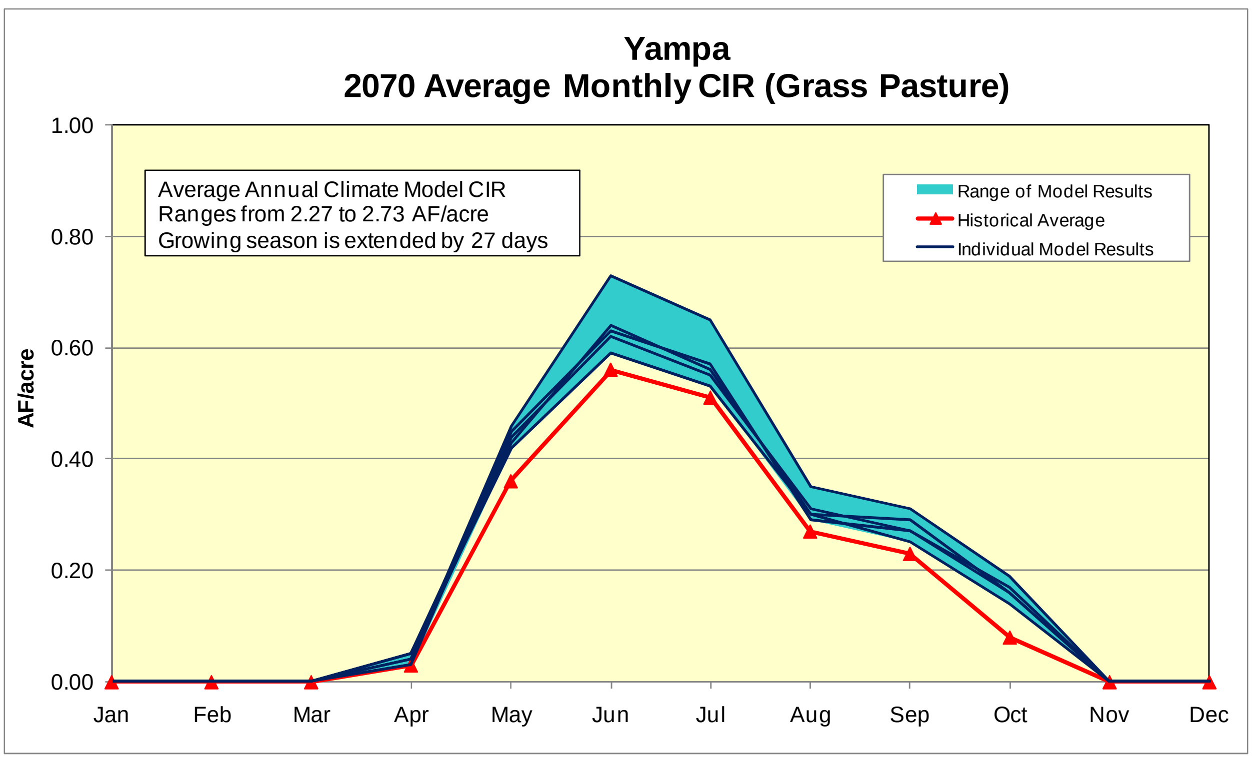

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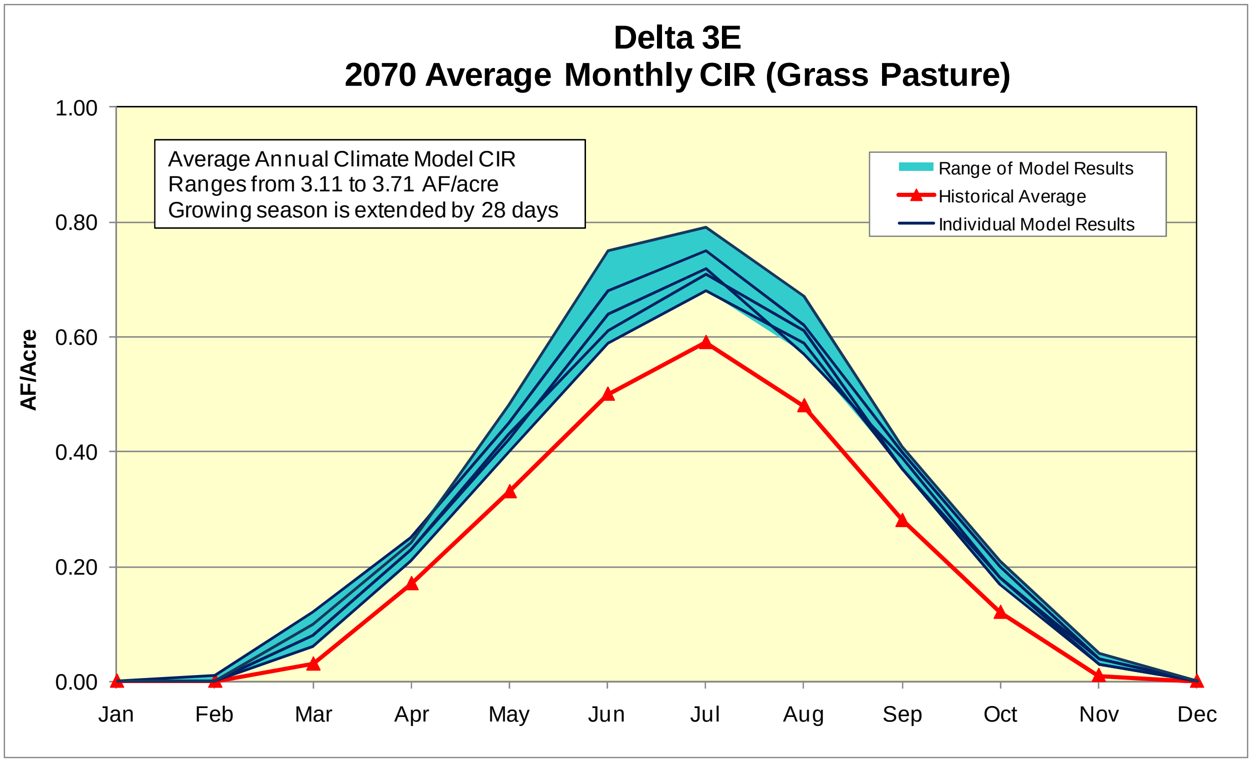

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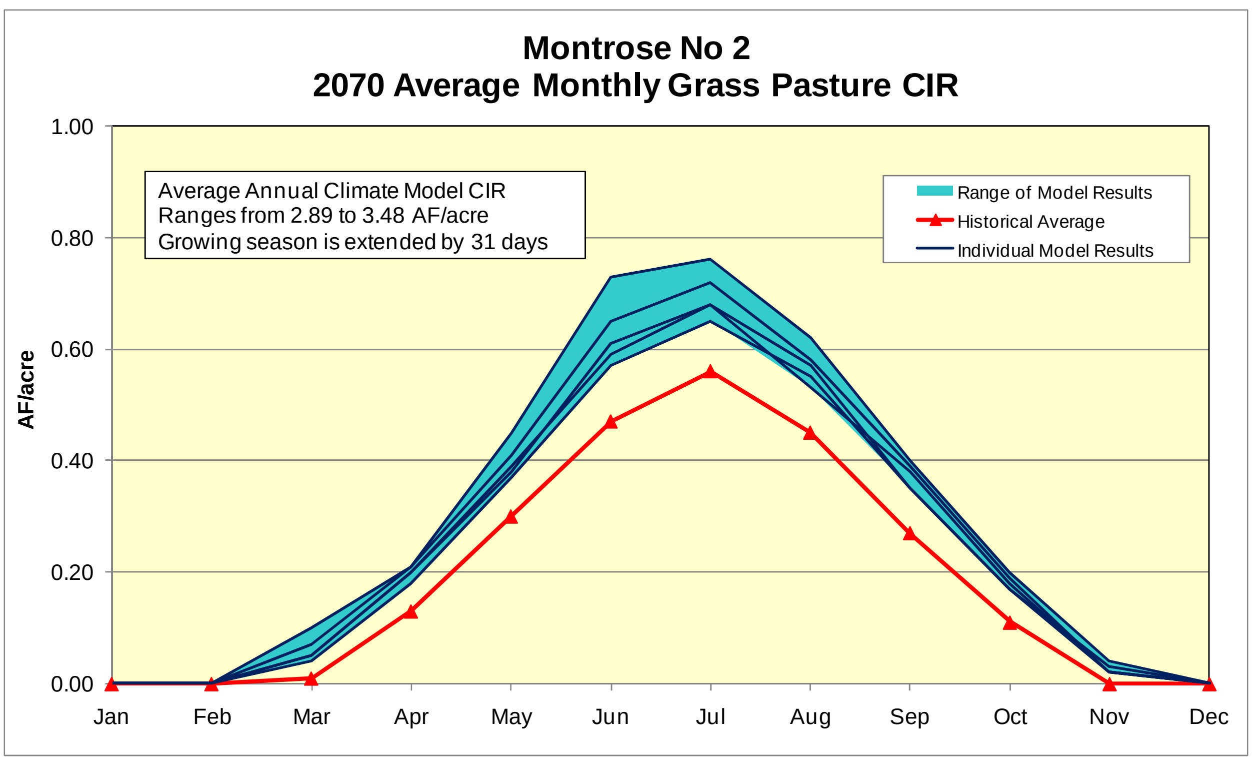

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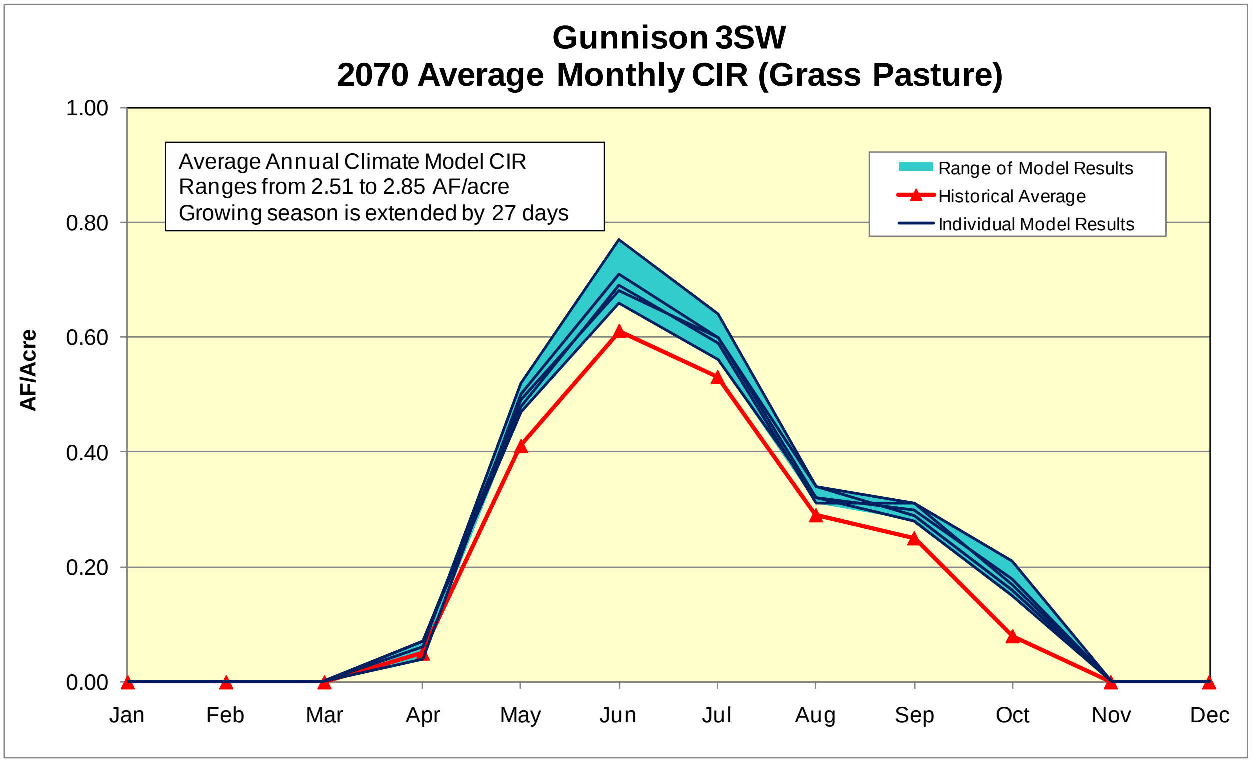

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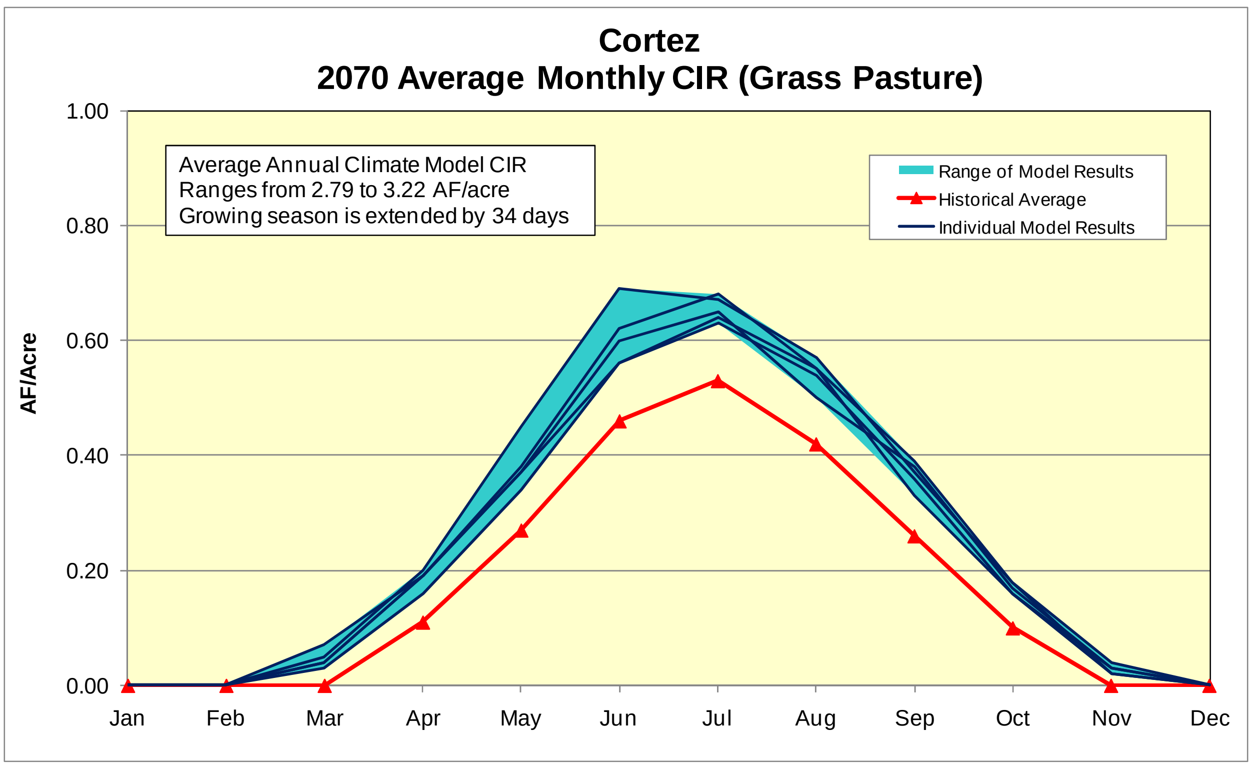

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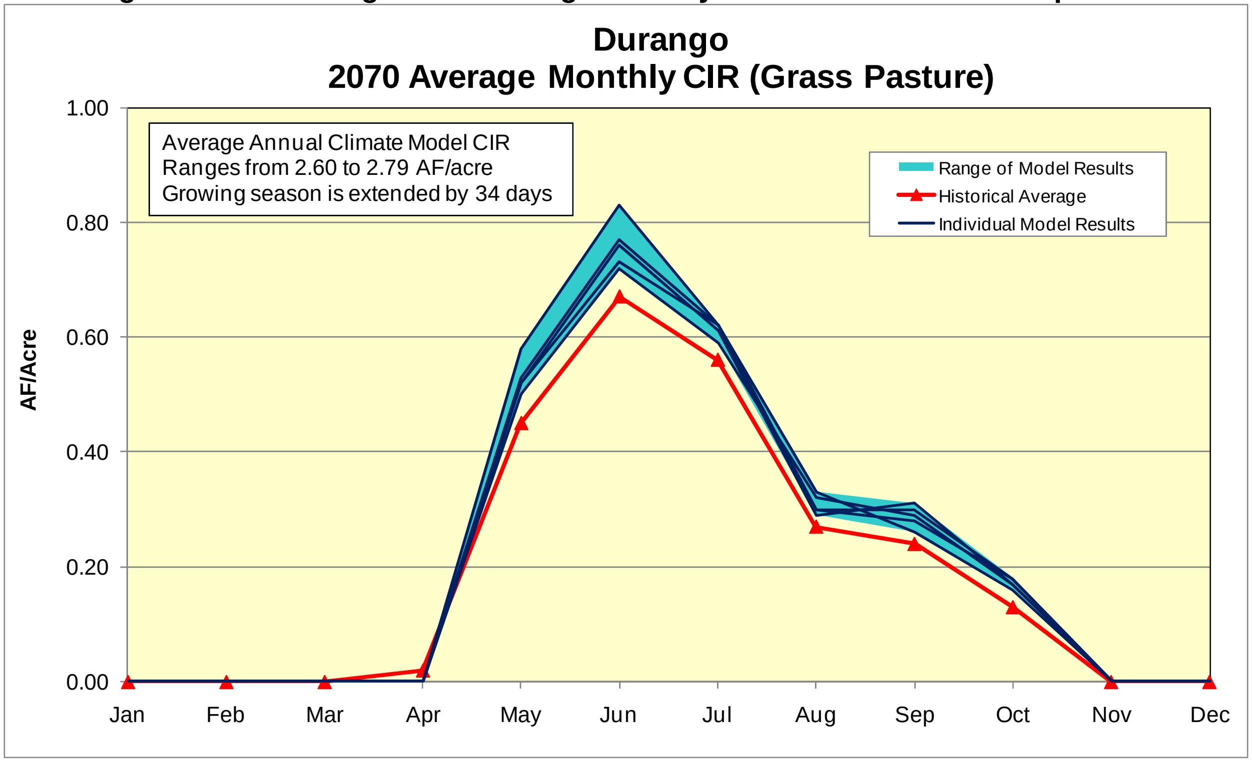

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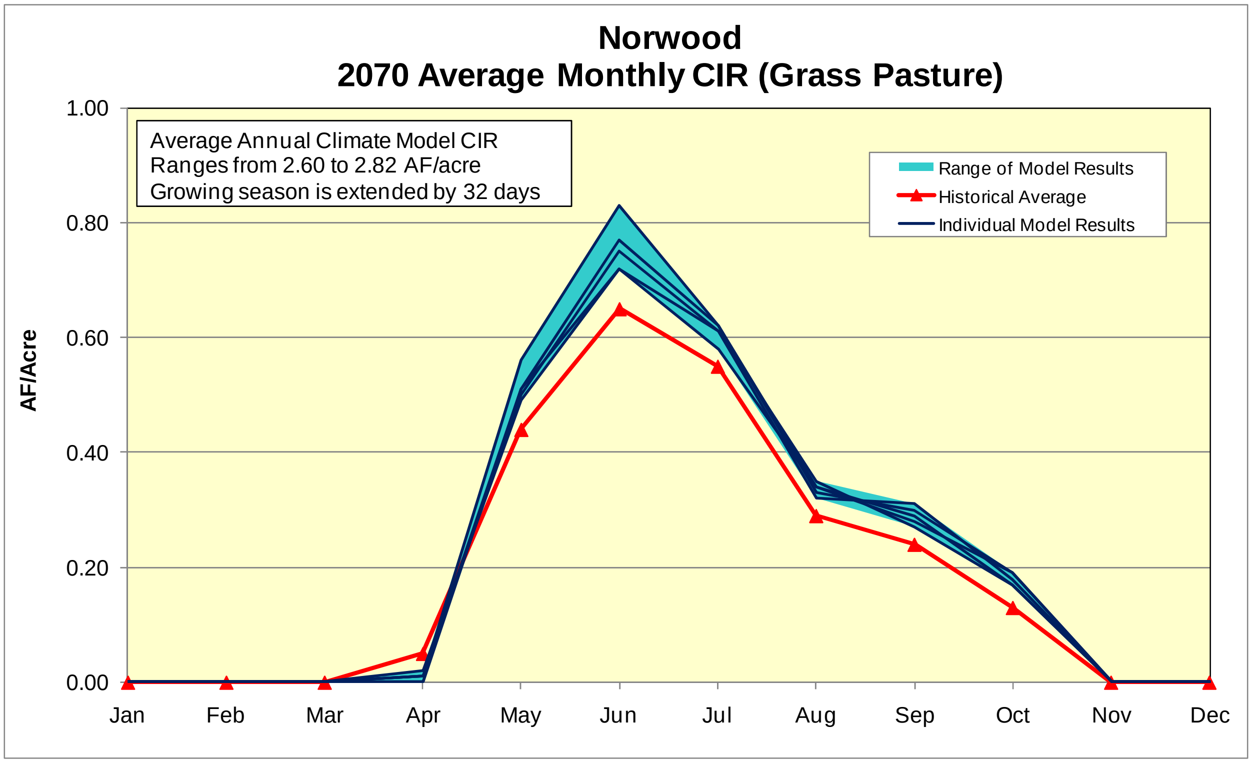

D. Natural Streamflow

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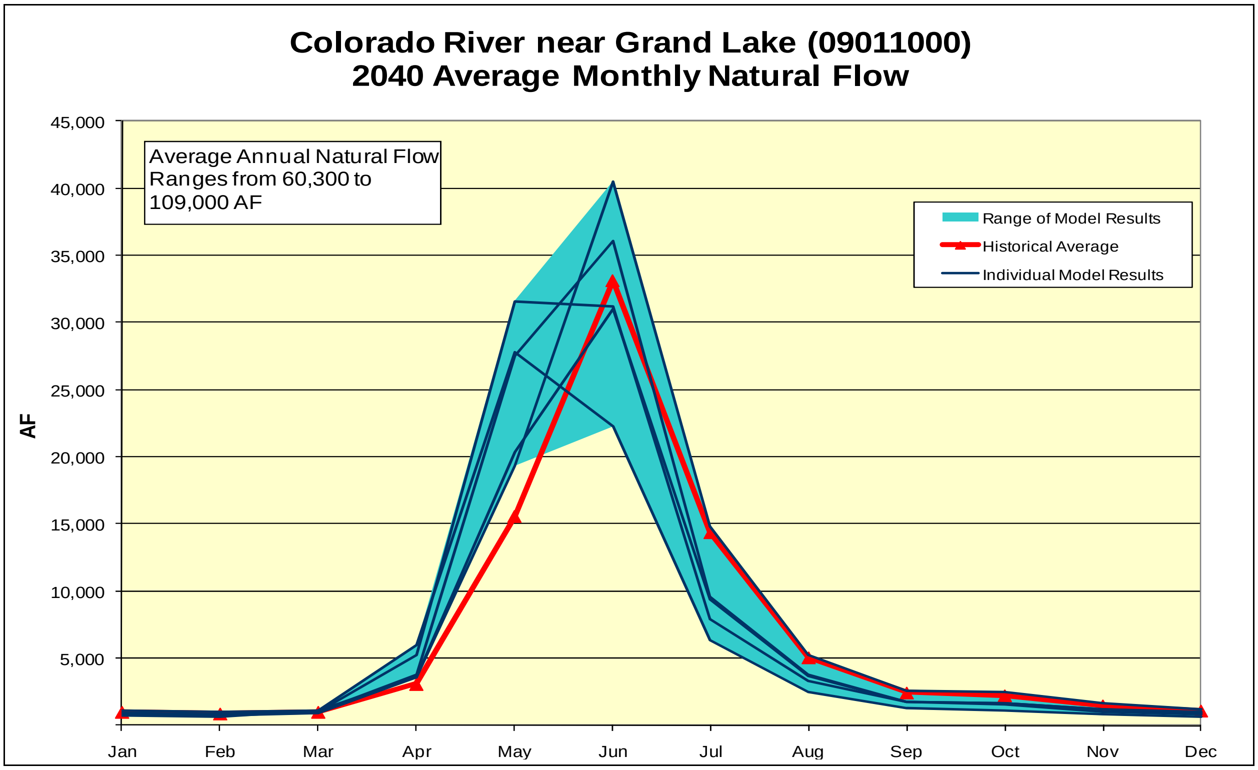

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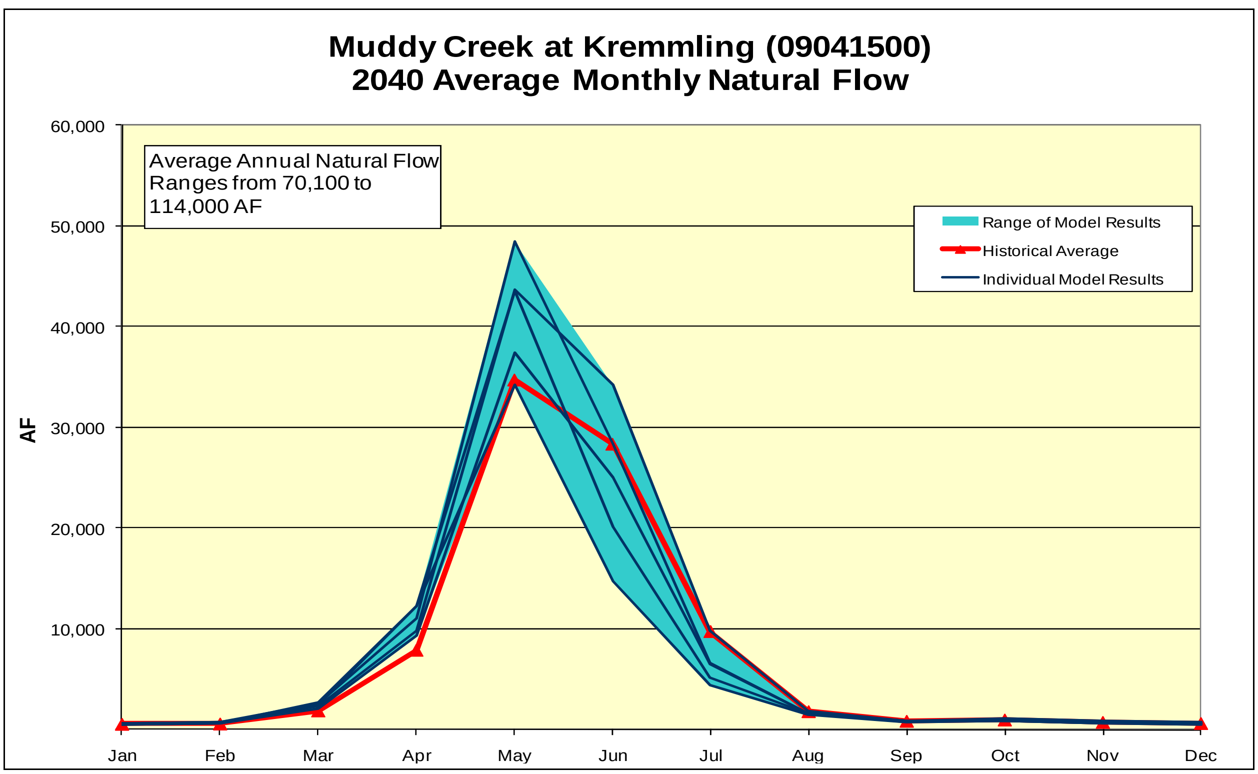

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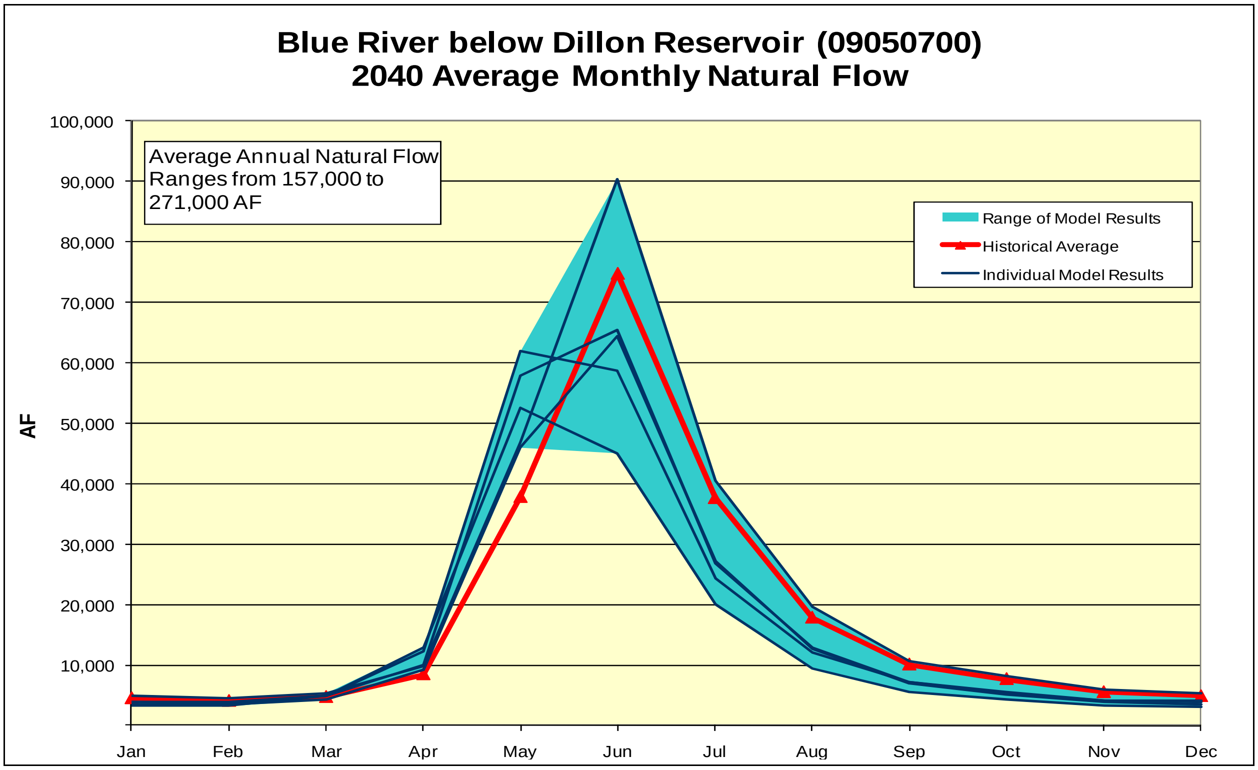

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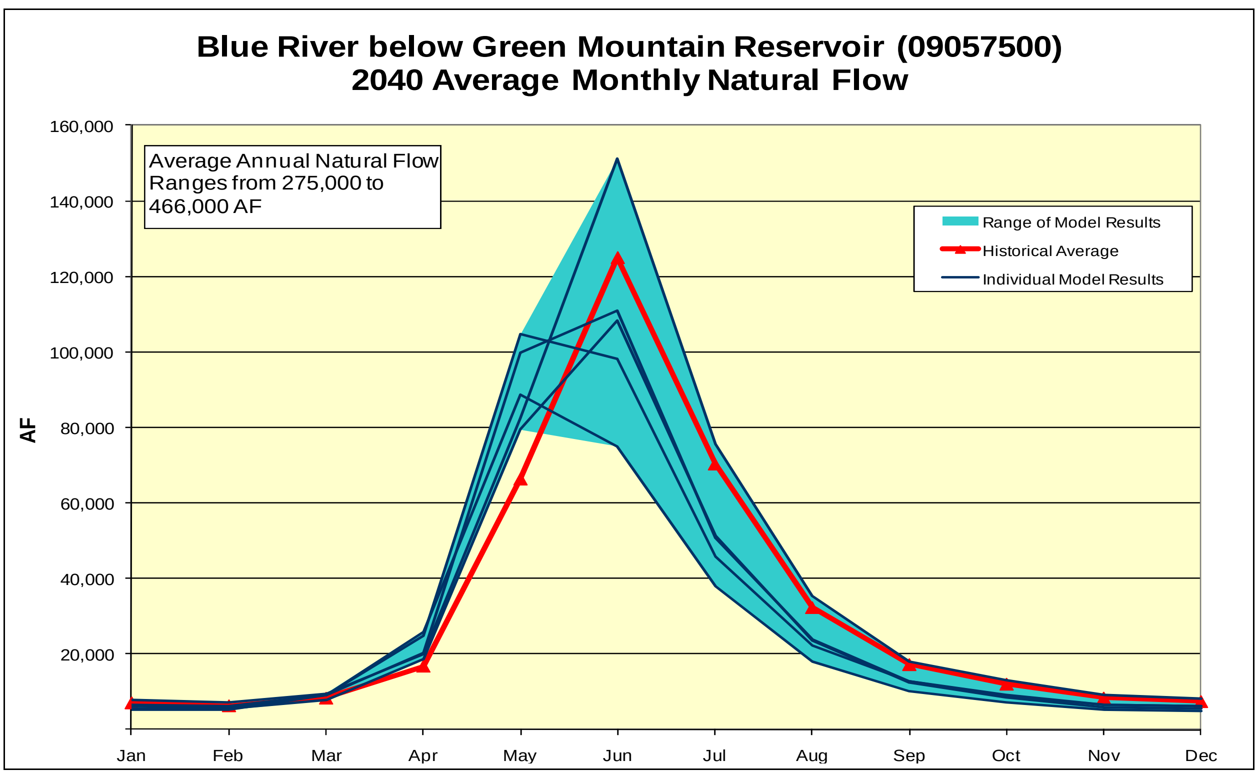

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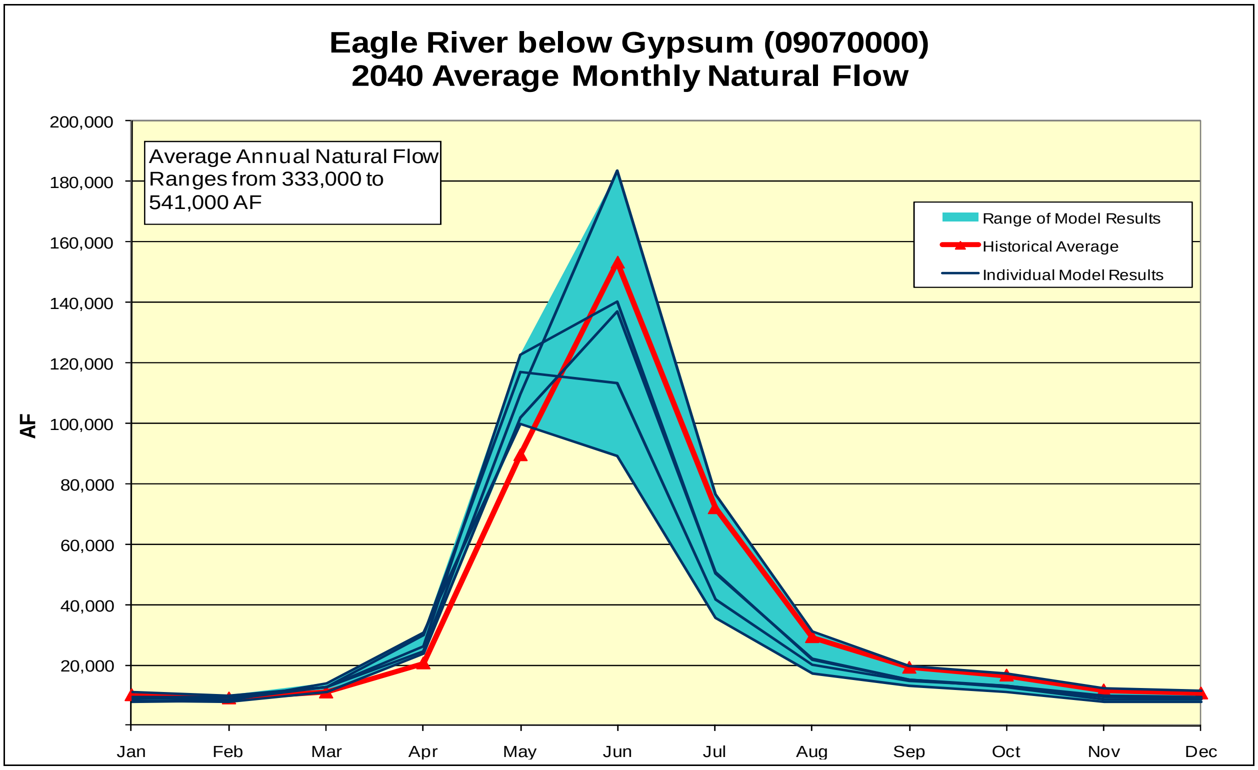

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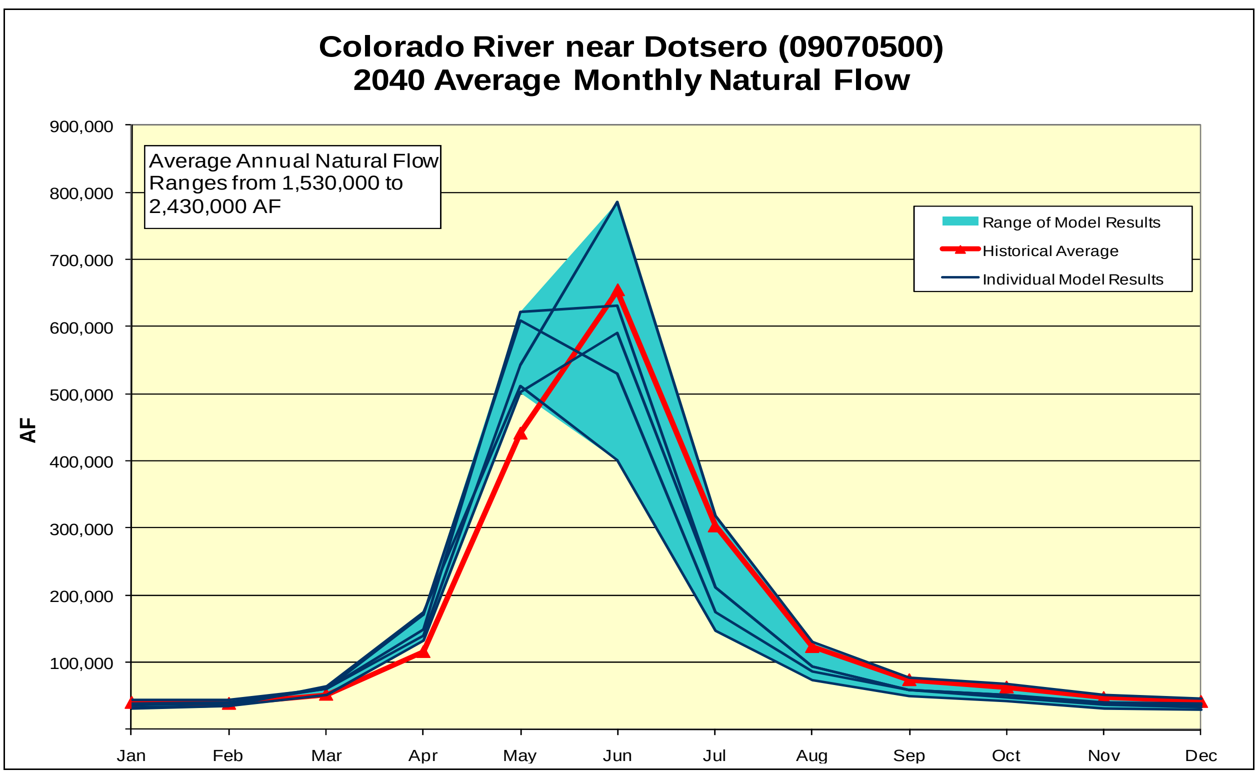

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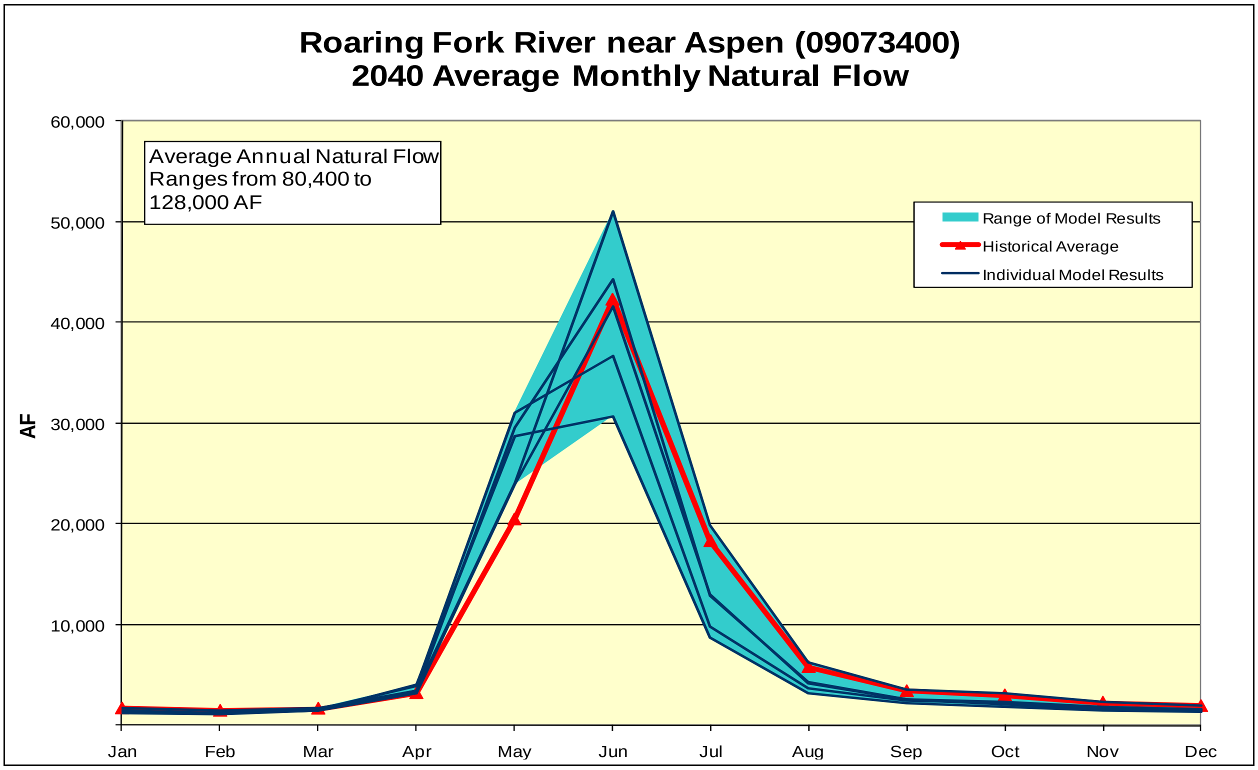

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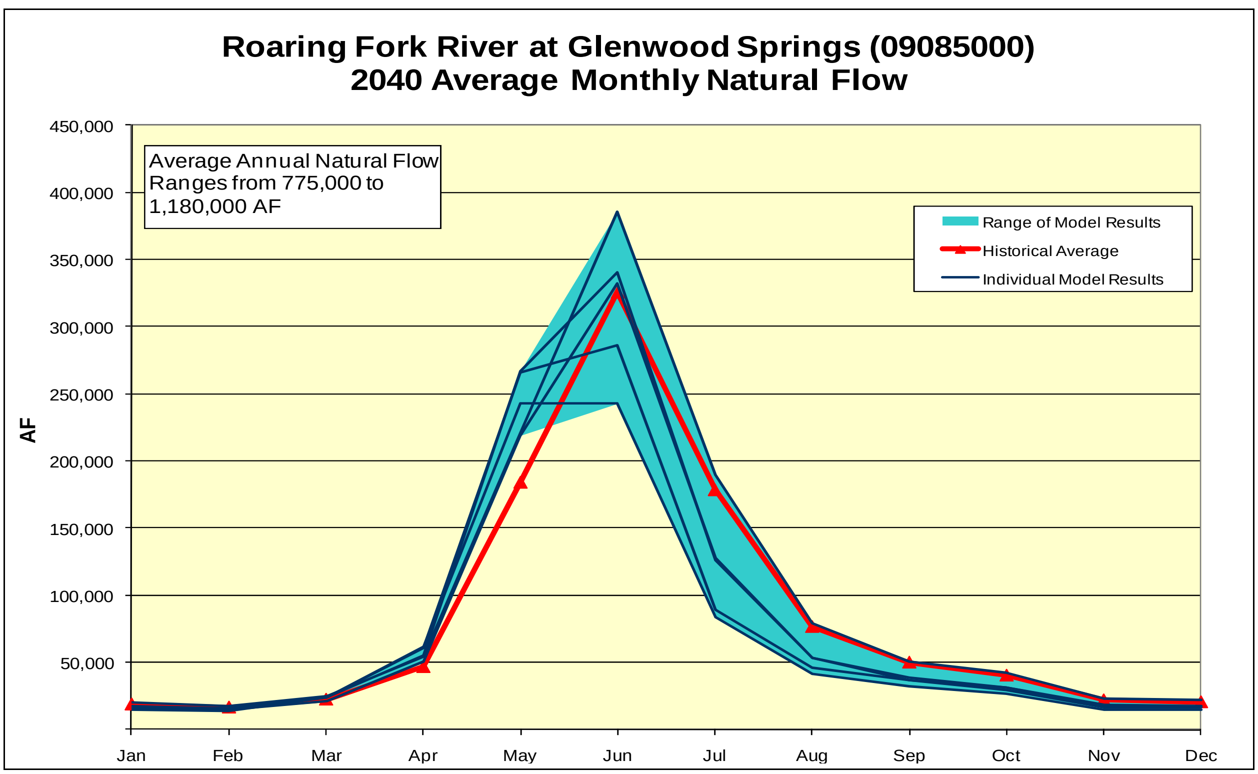

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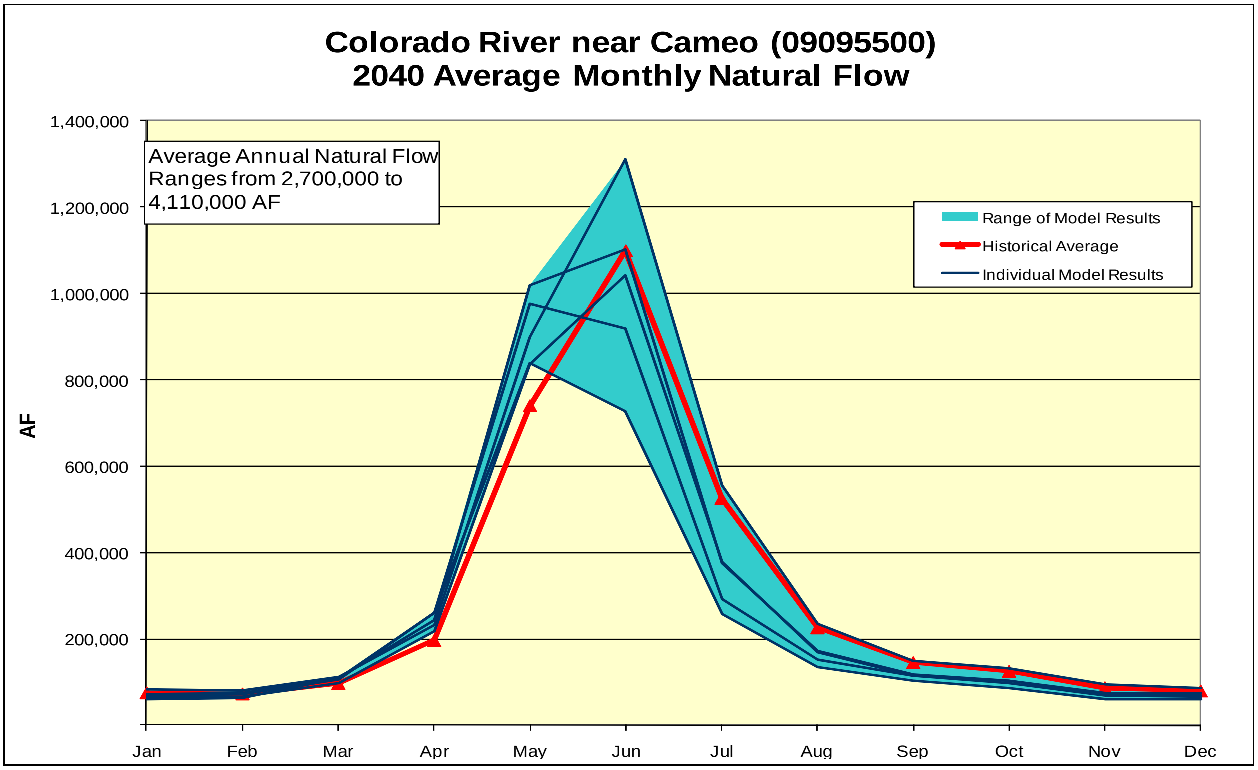

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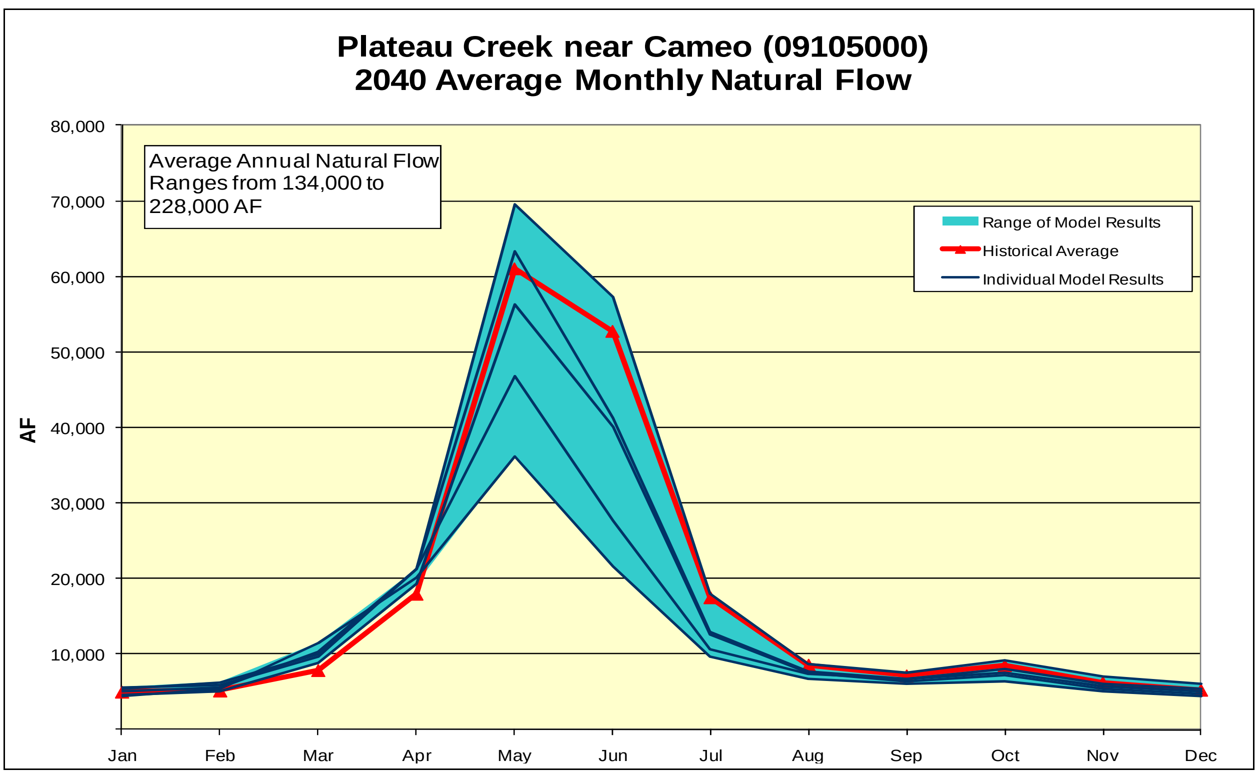

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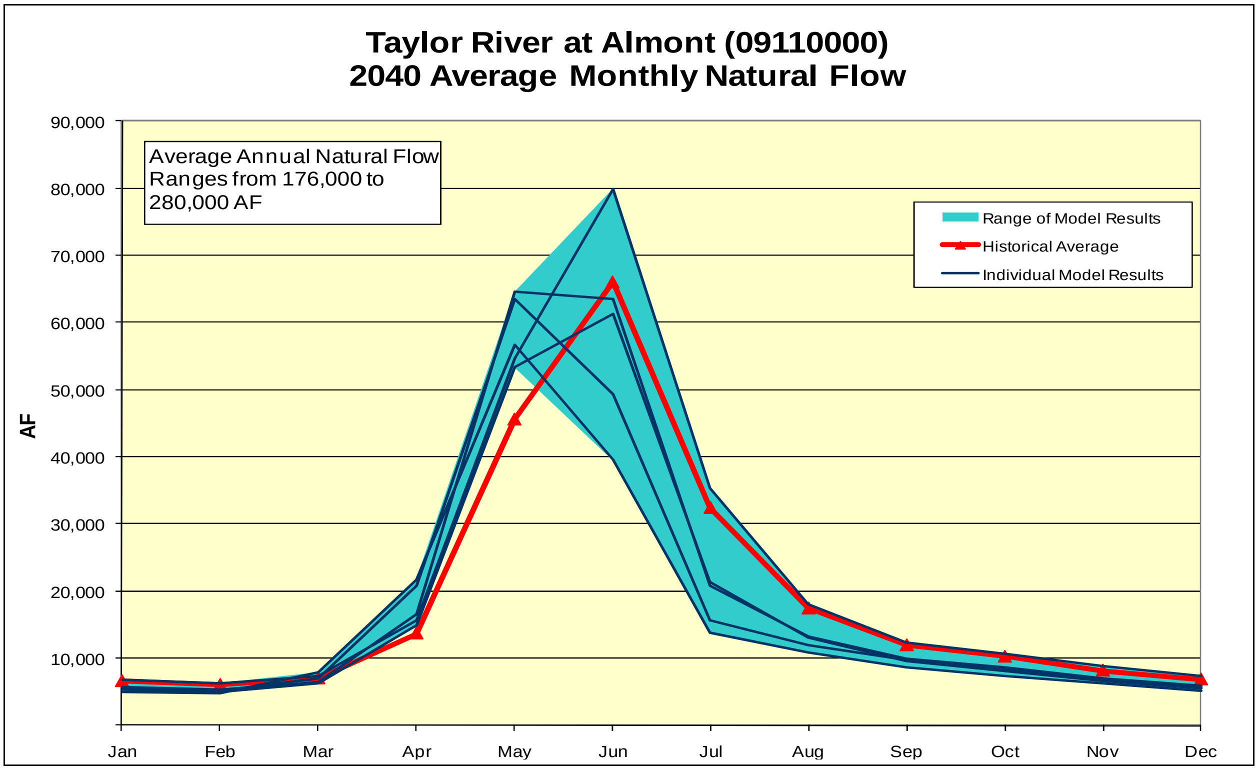

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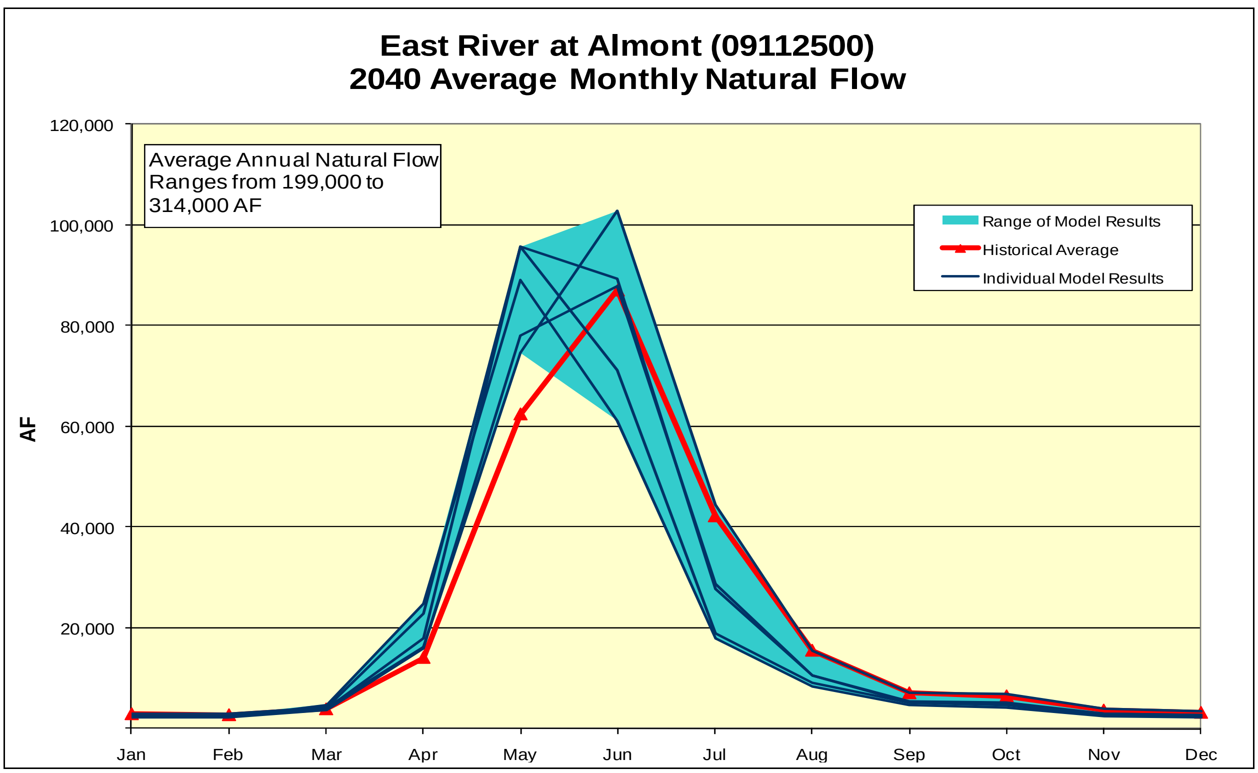

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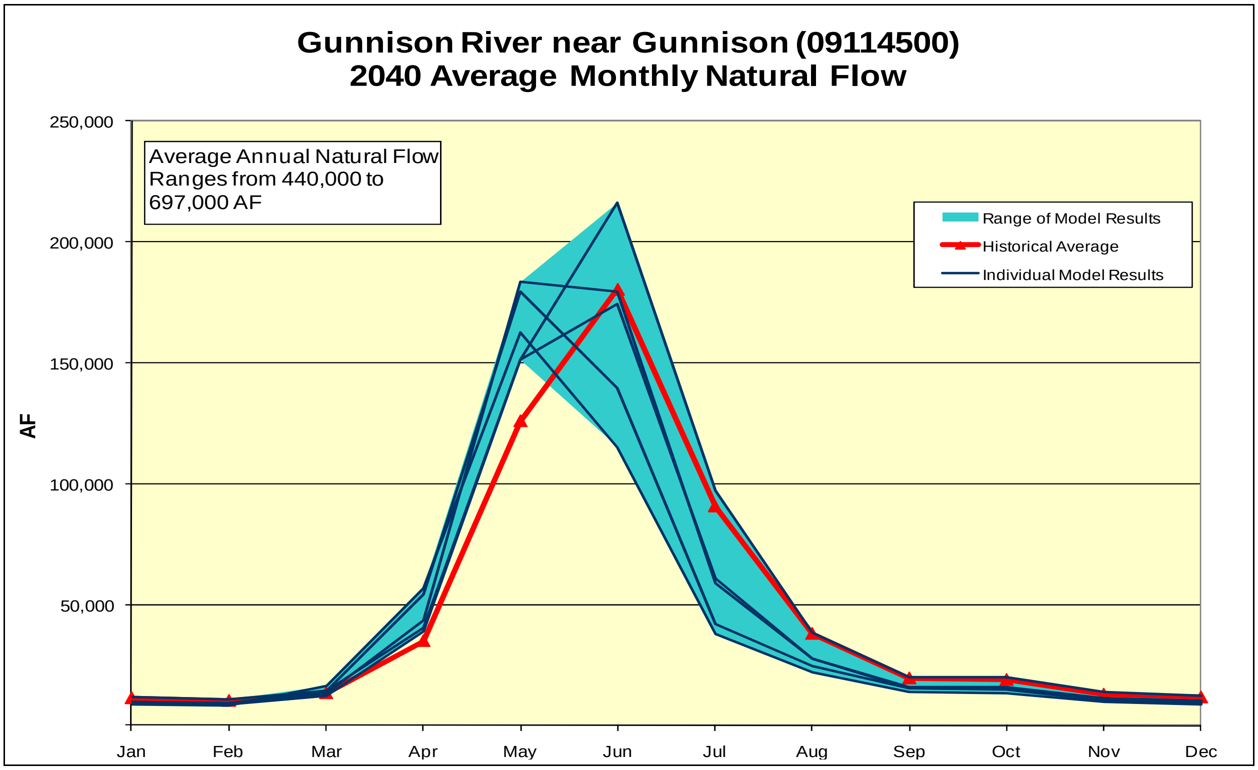

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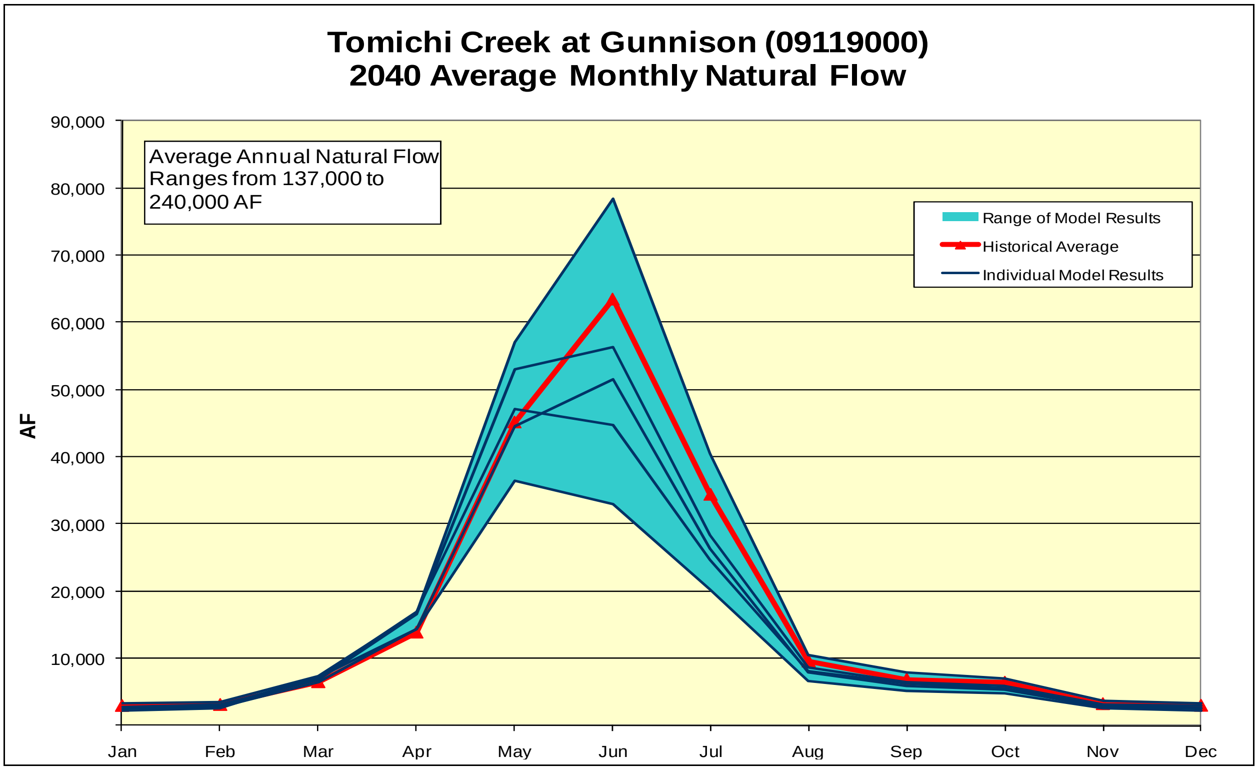

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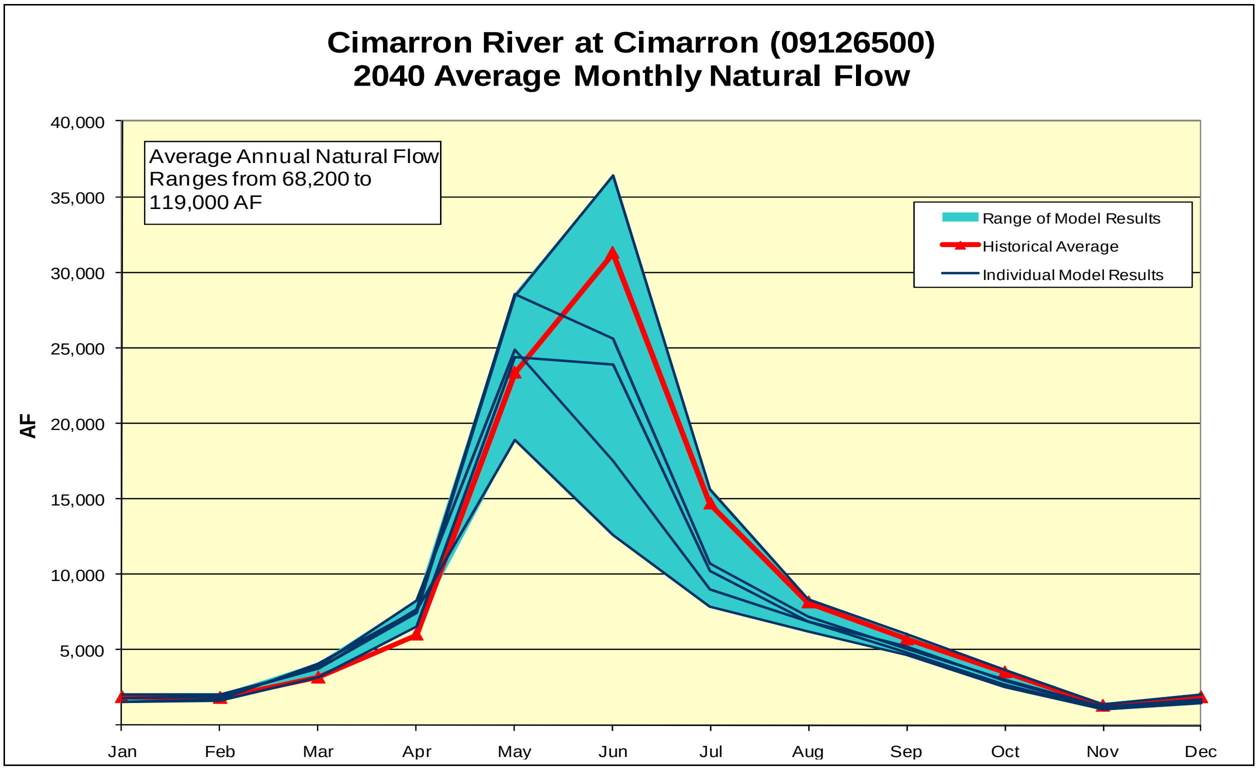

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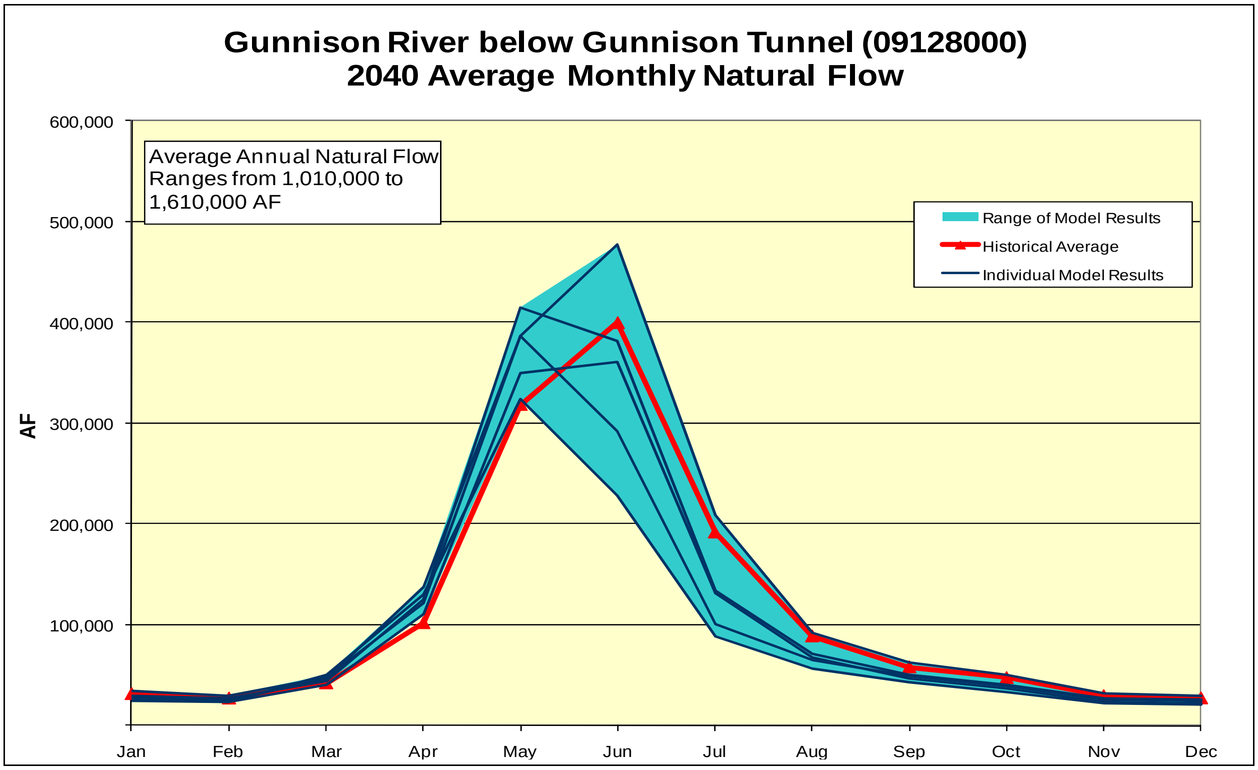

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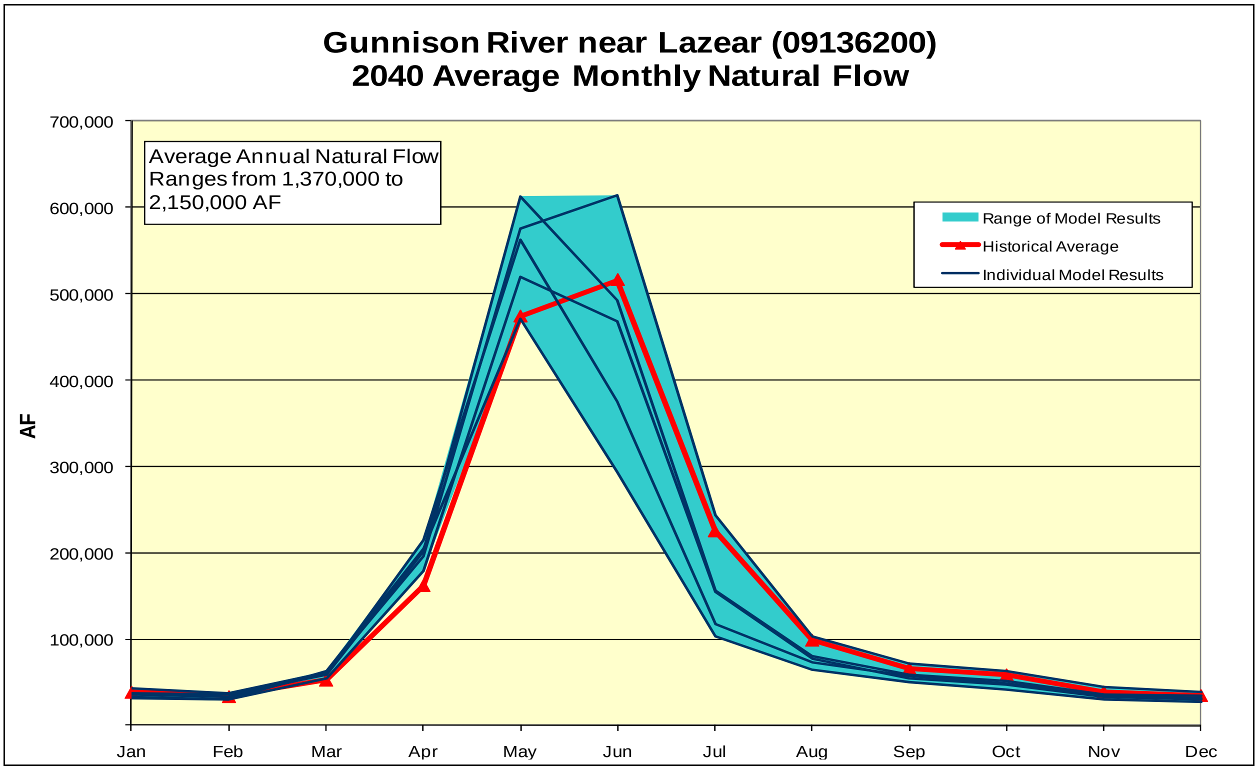

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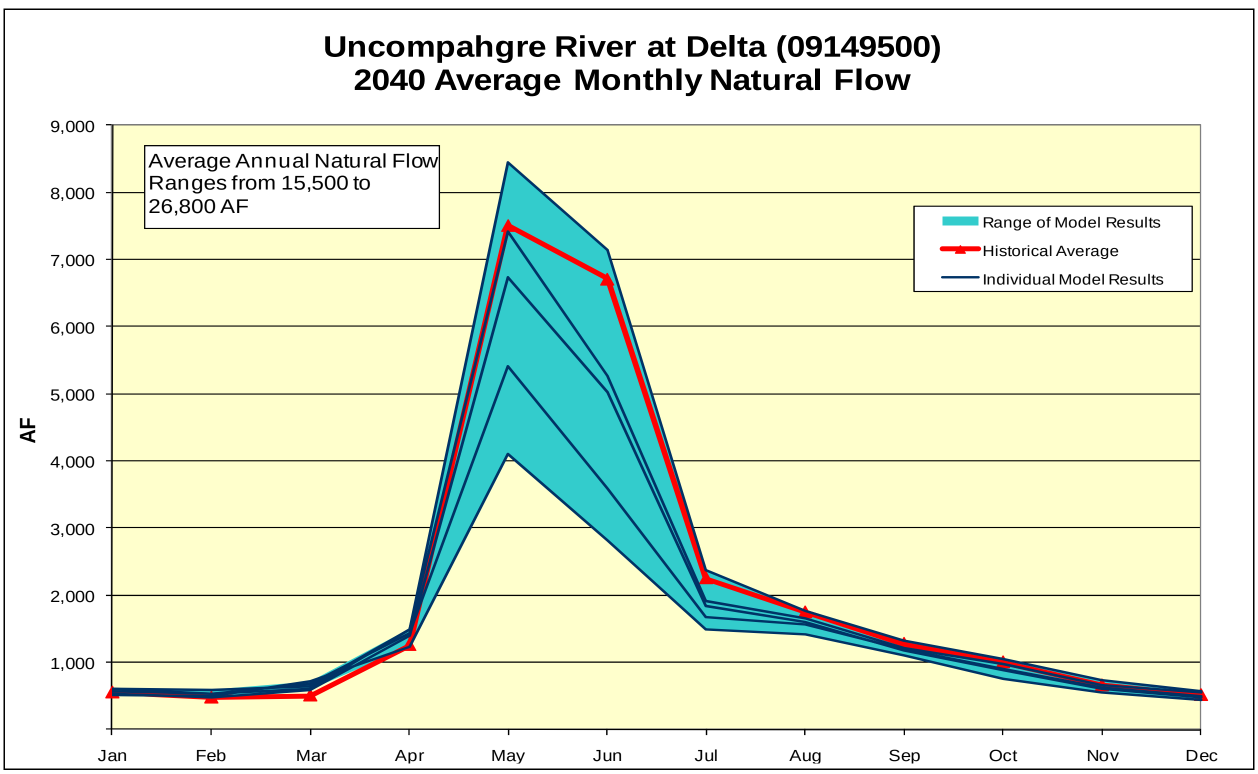

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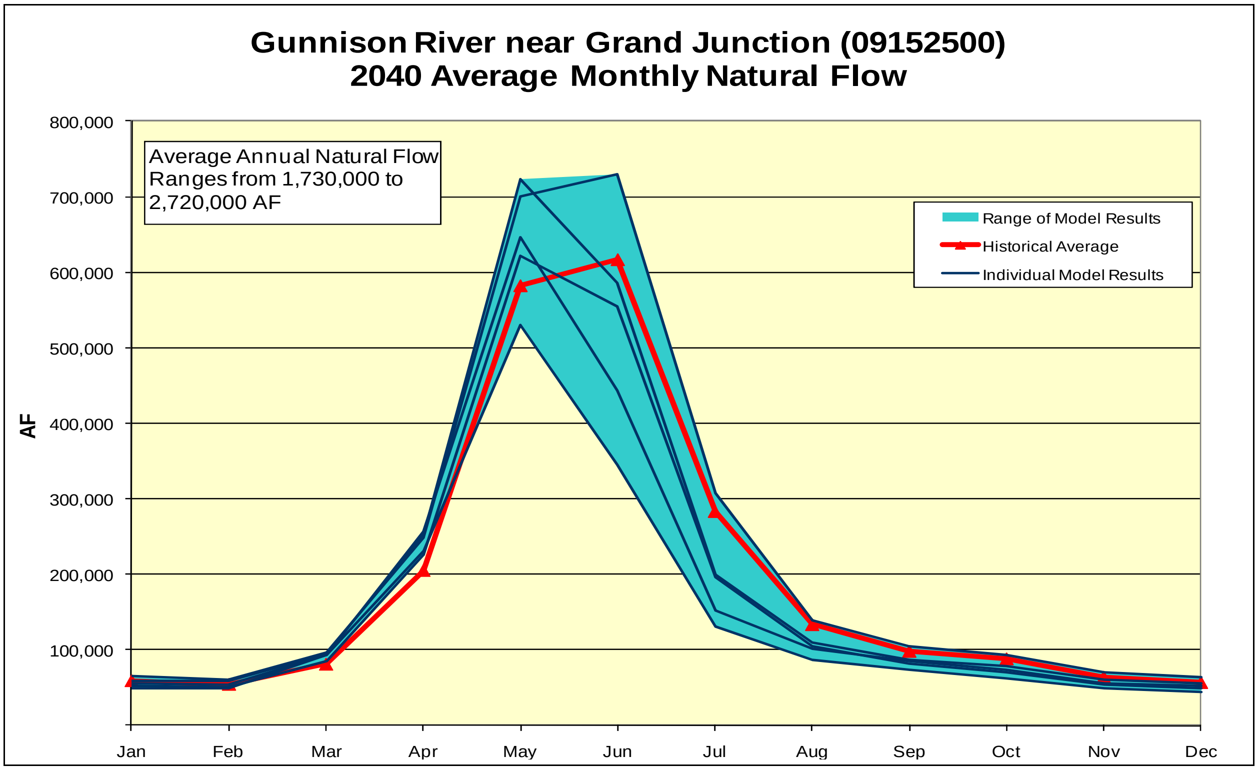

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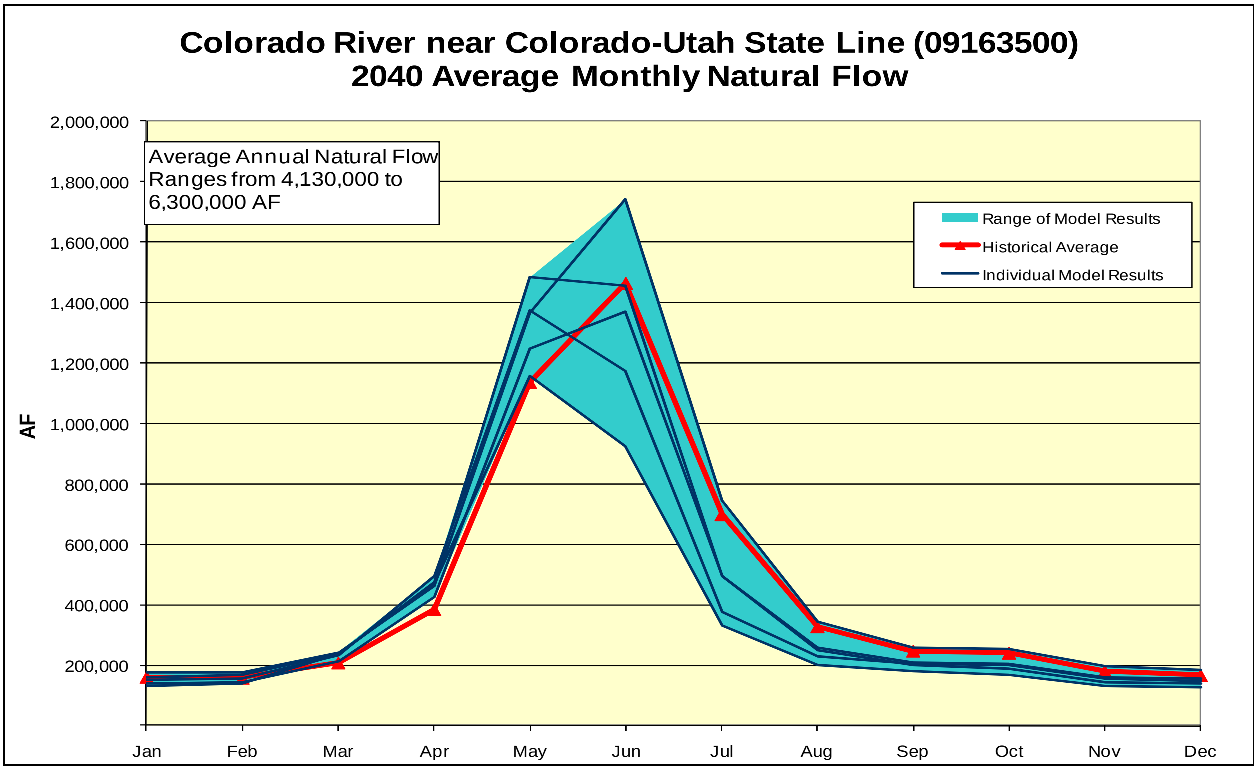

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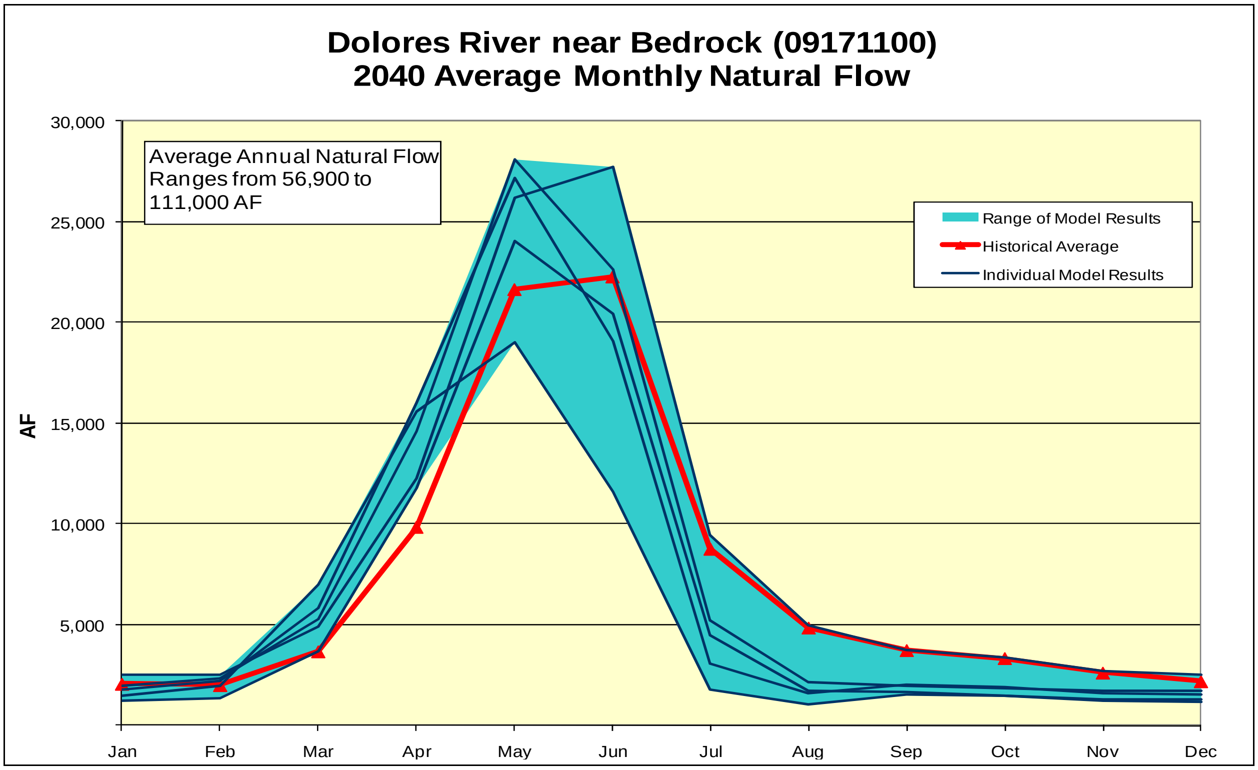

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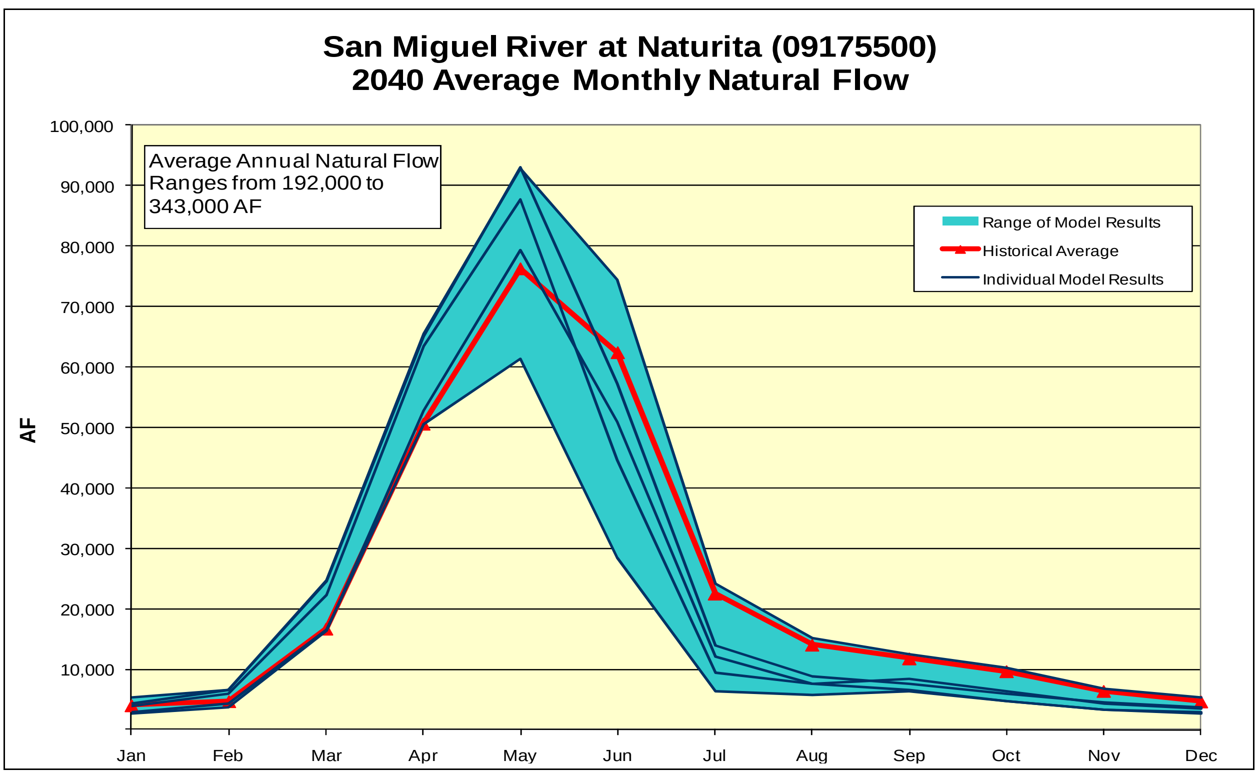

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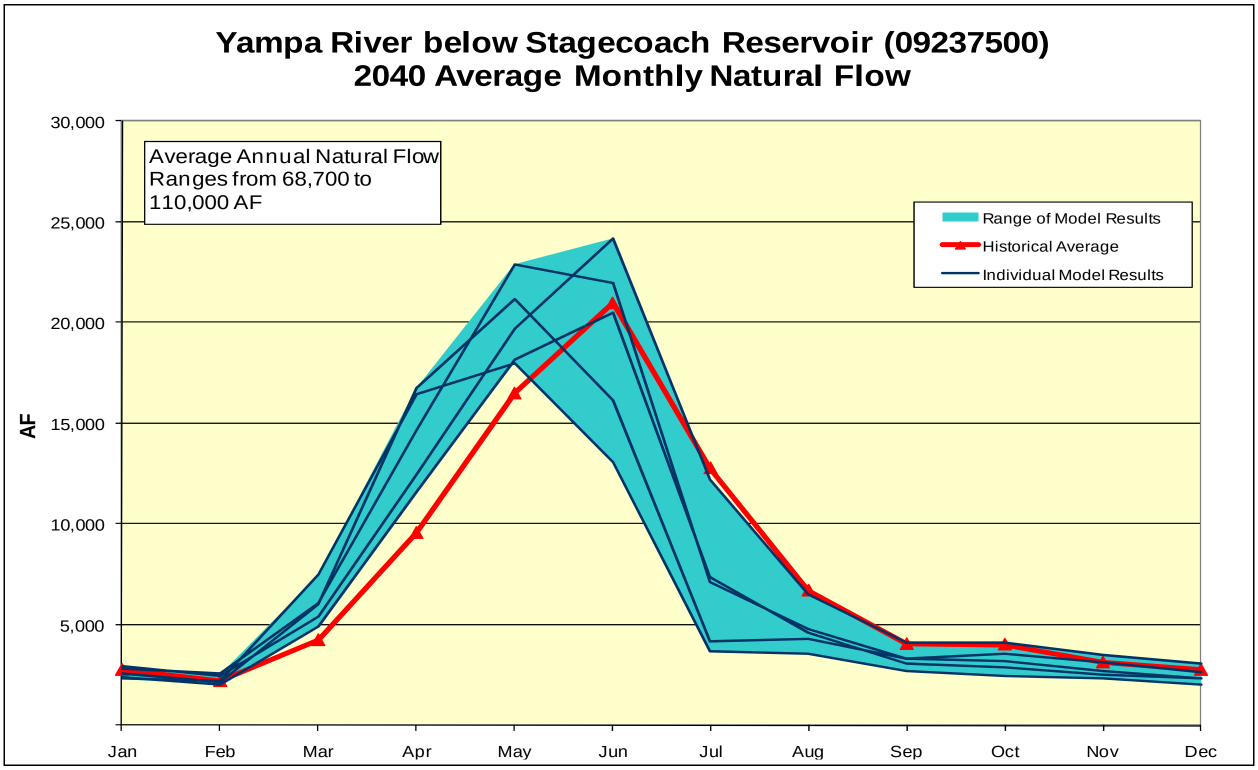

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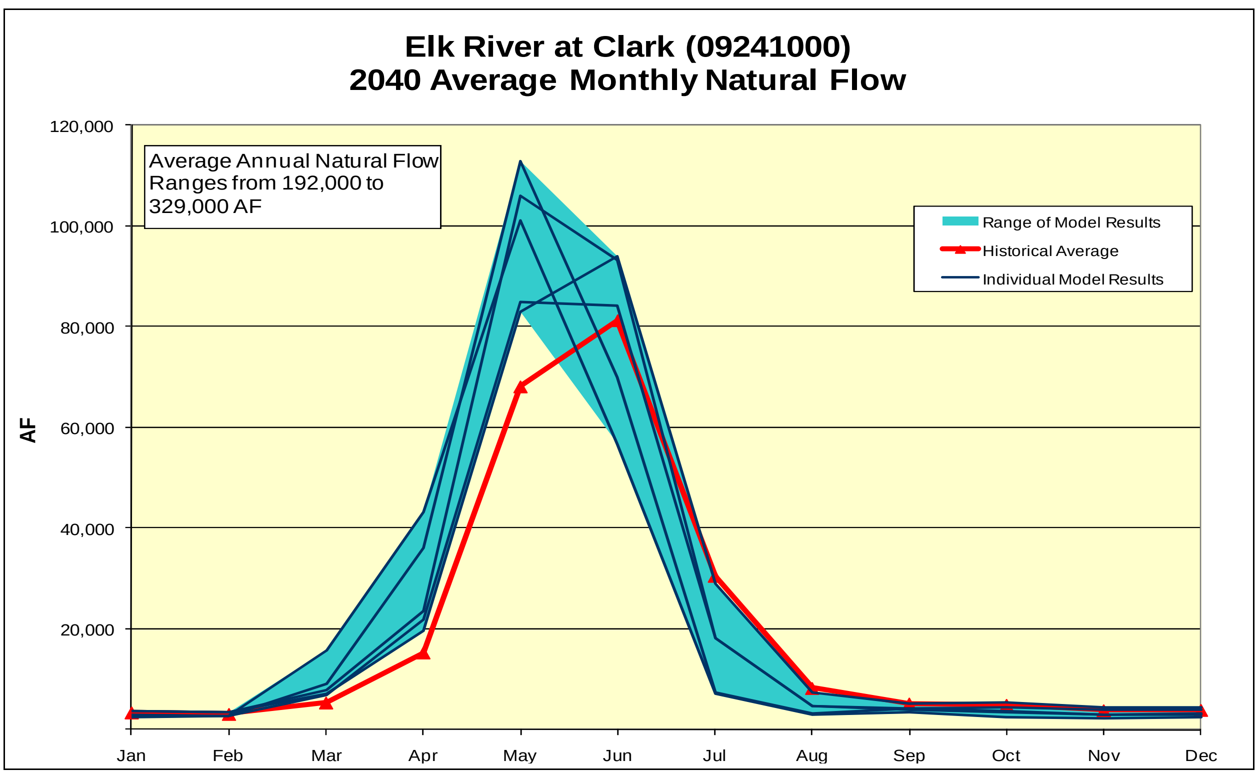

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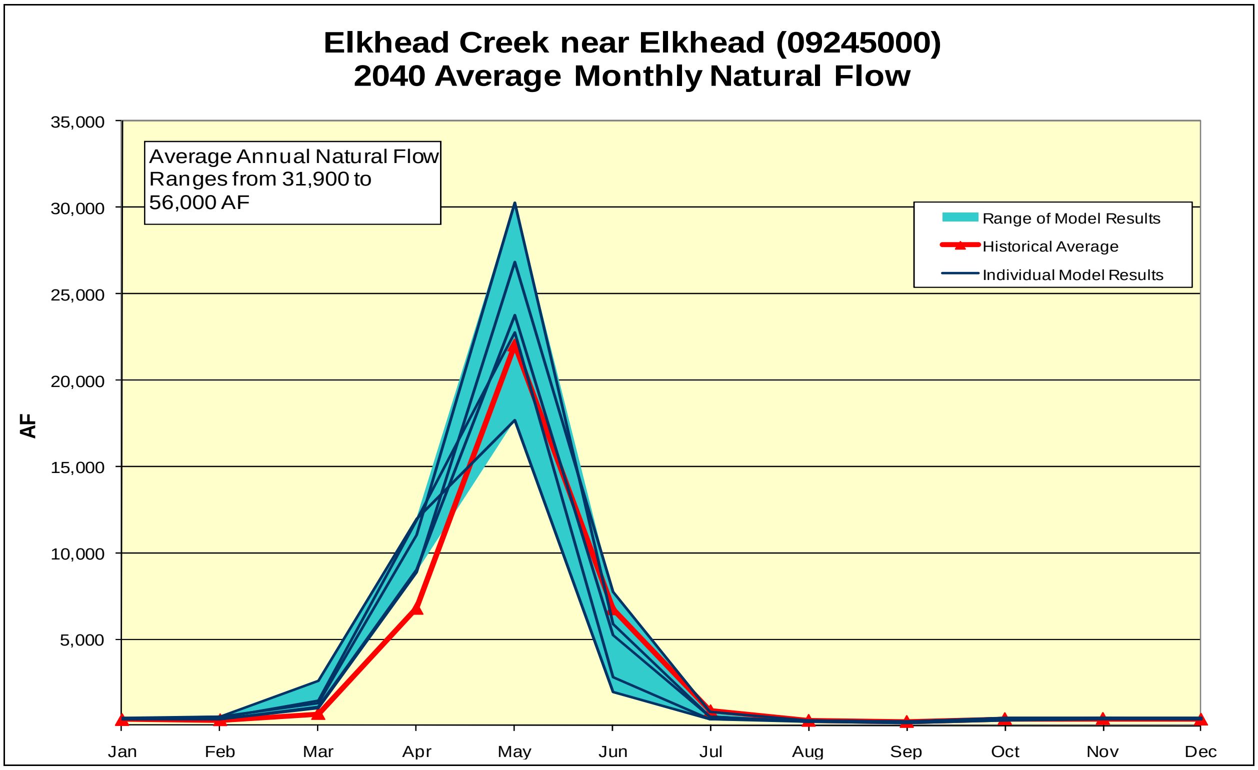

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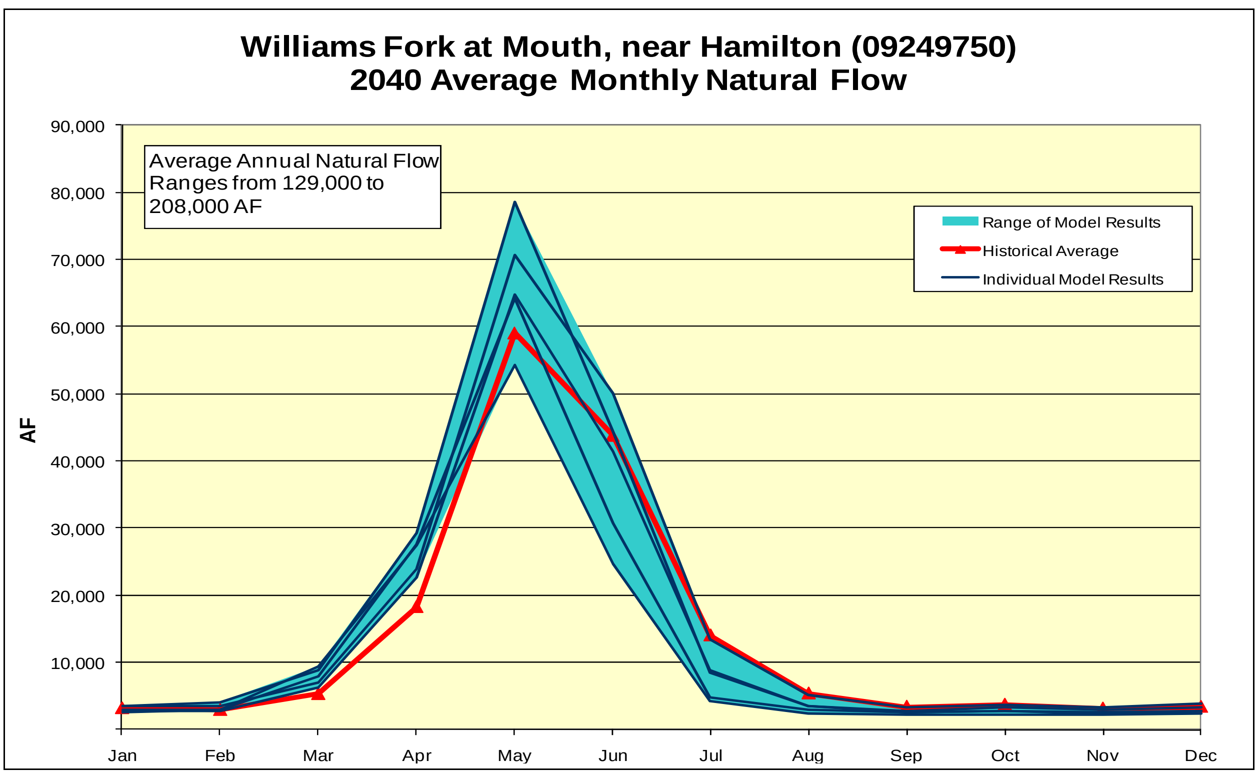

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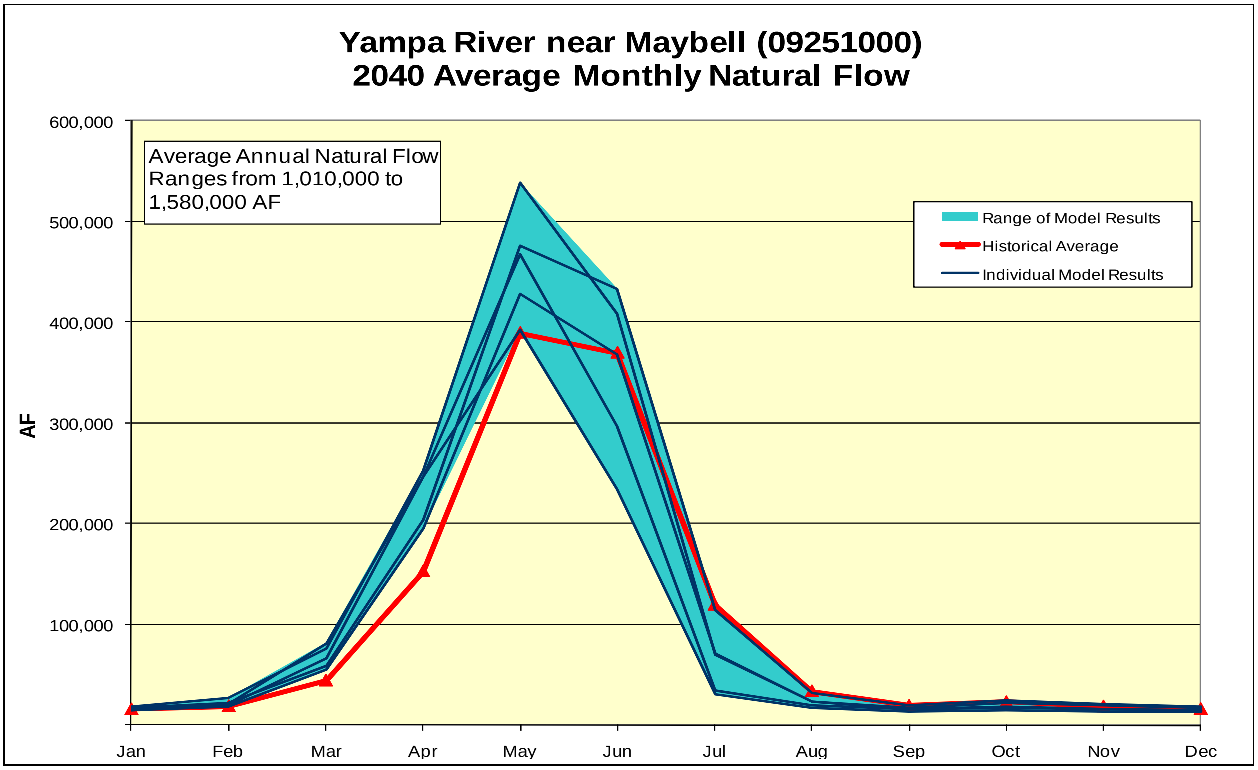

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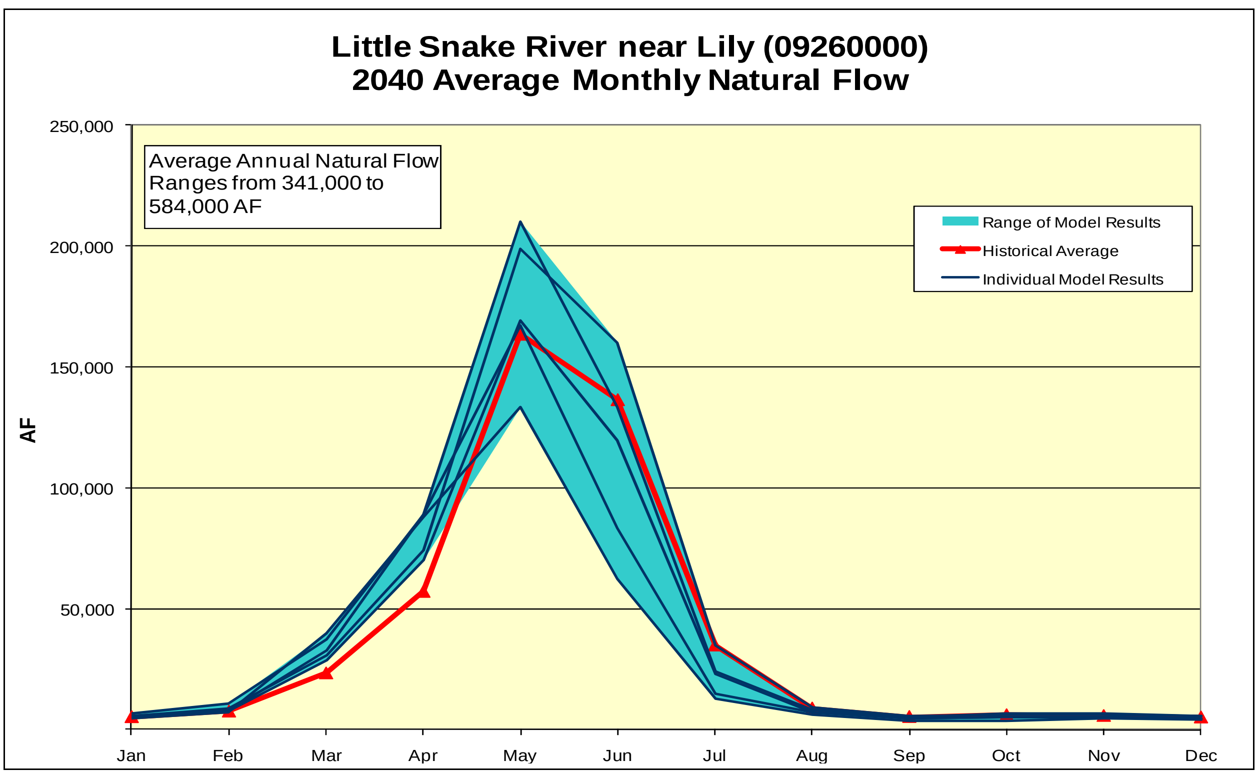

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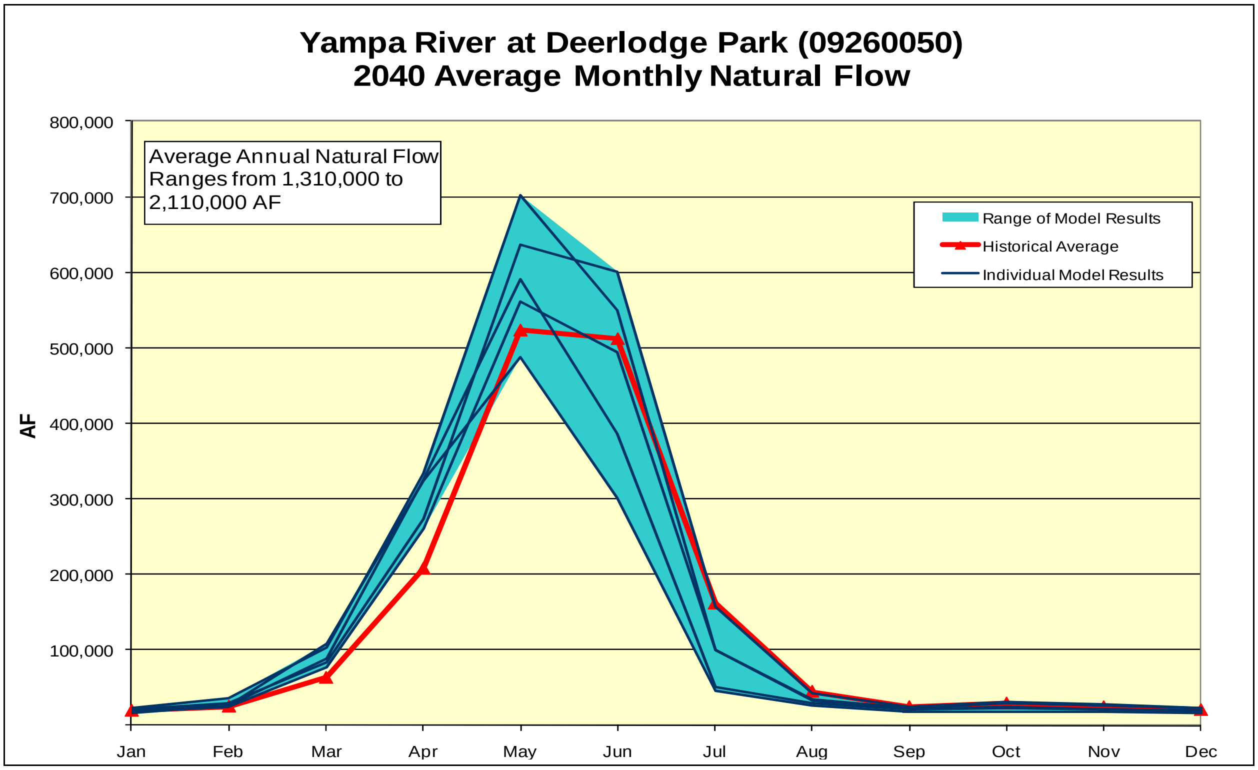

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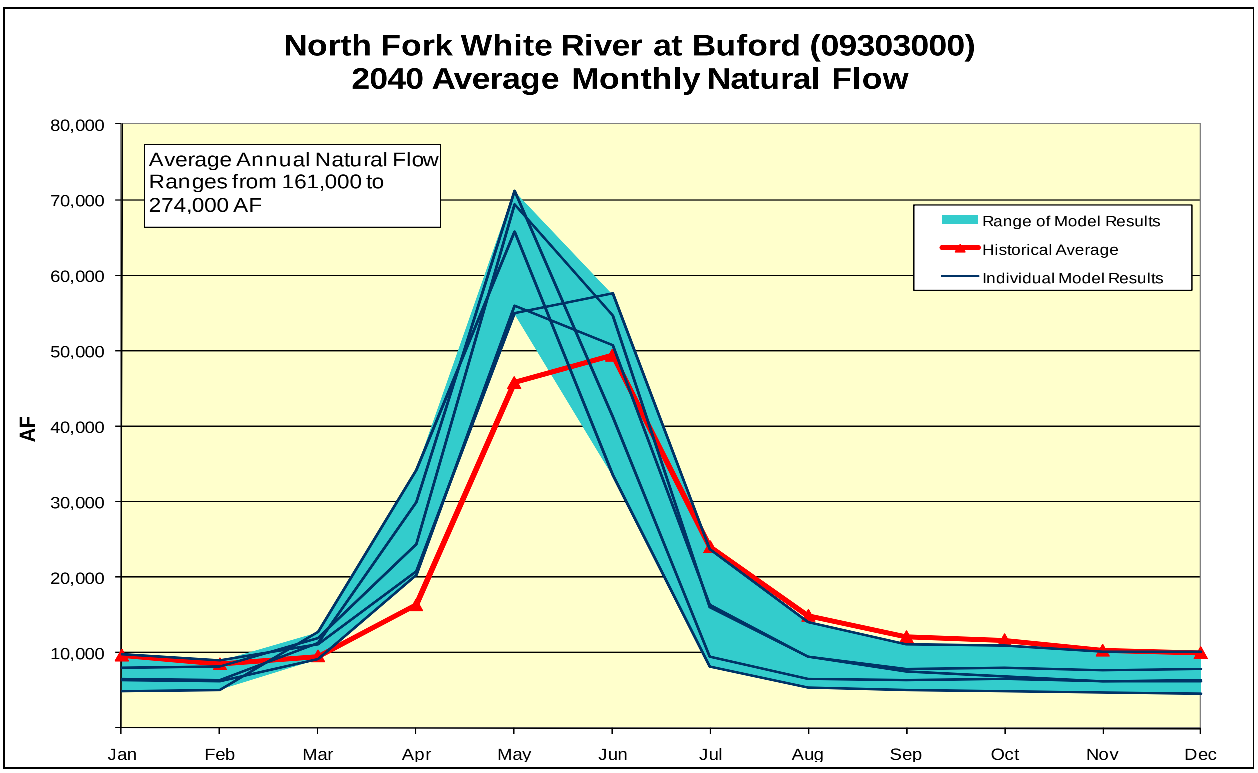

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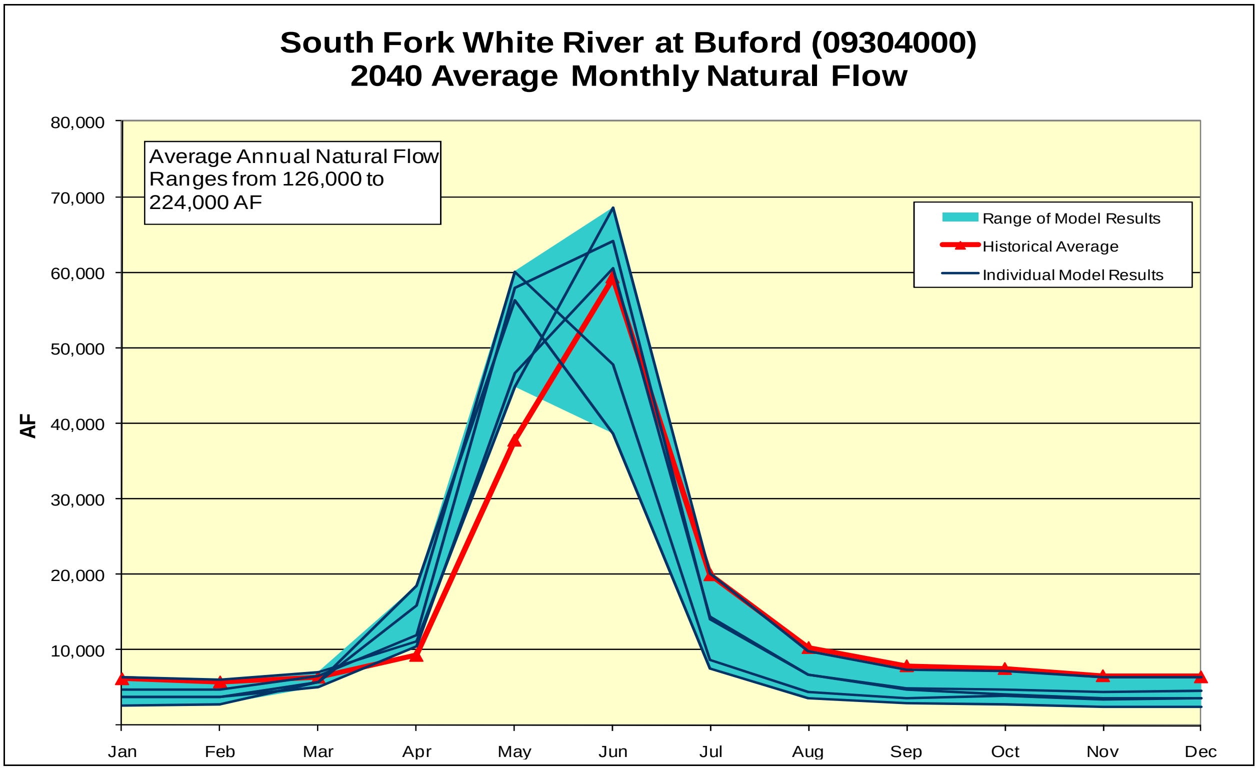

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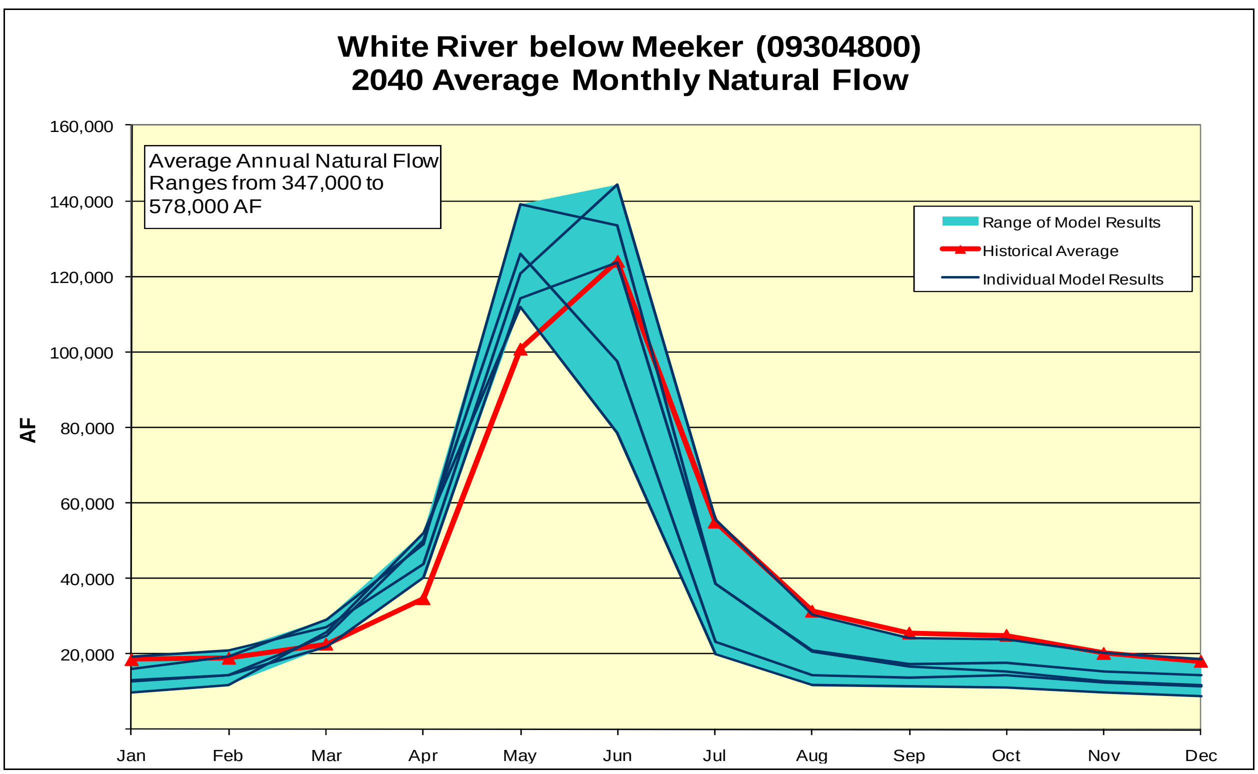

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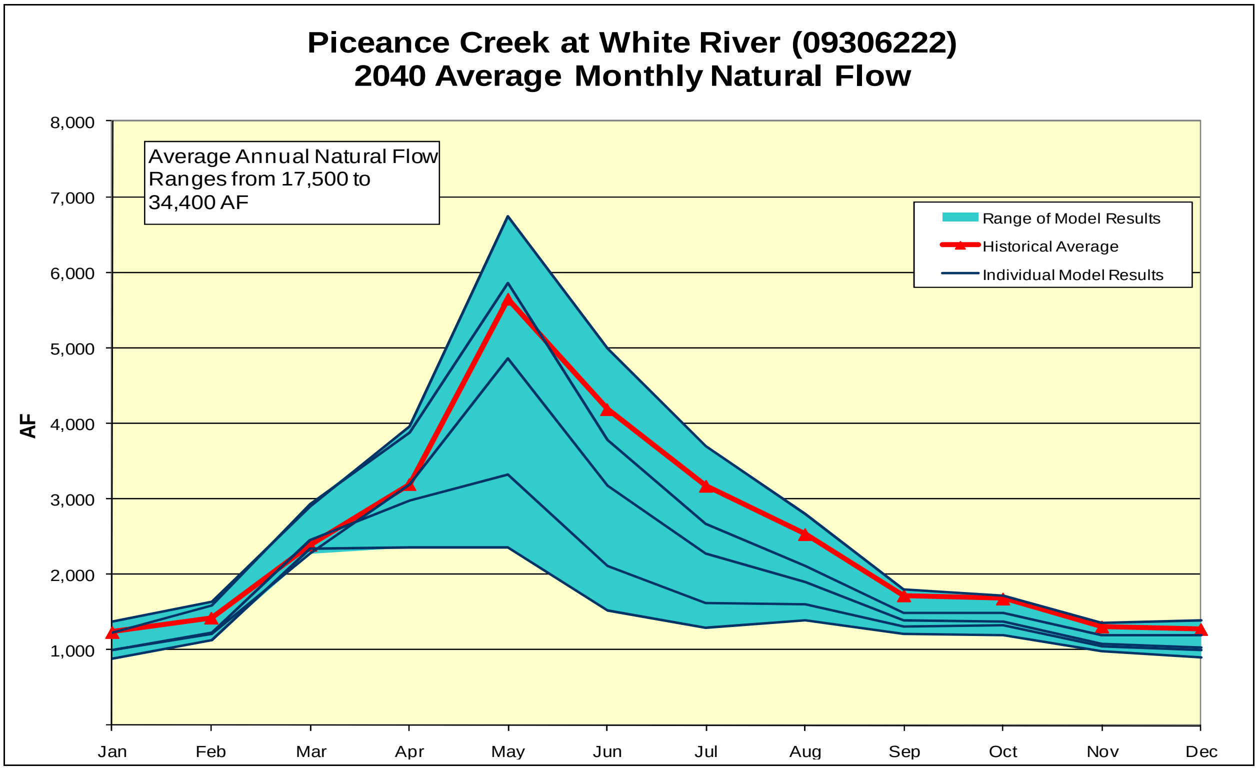

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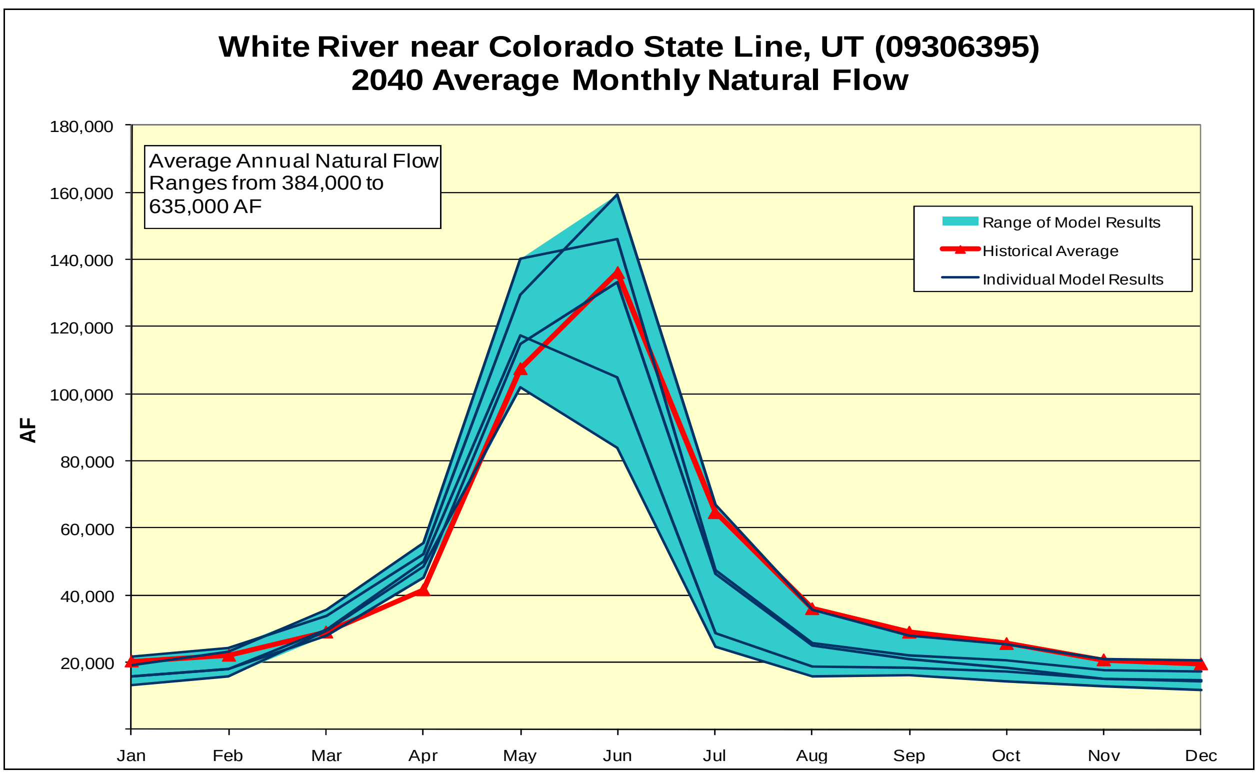

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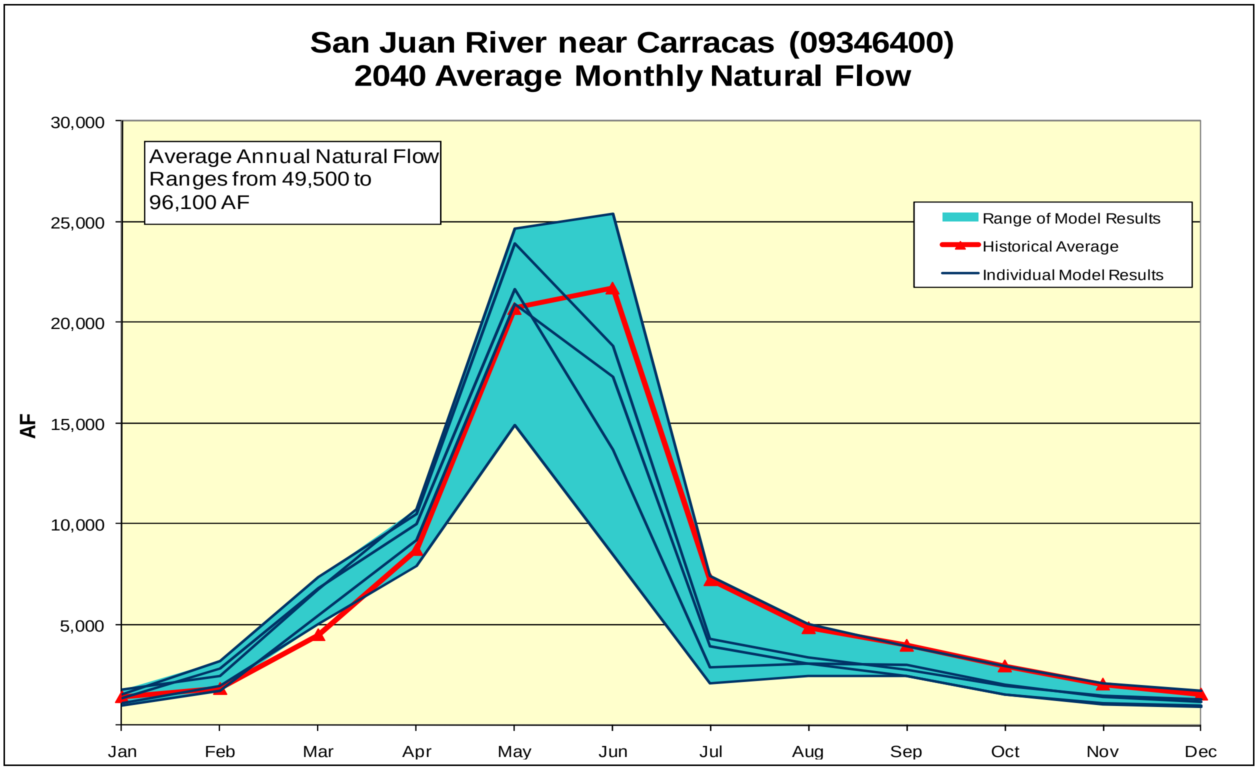

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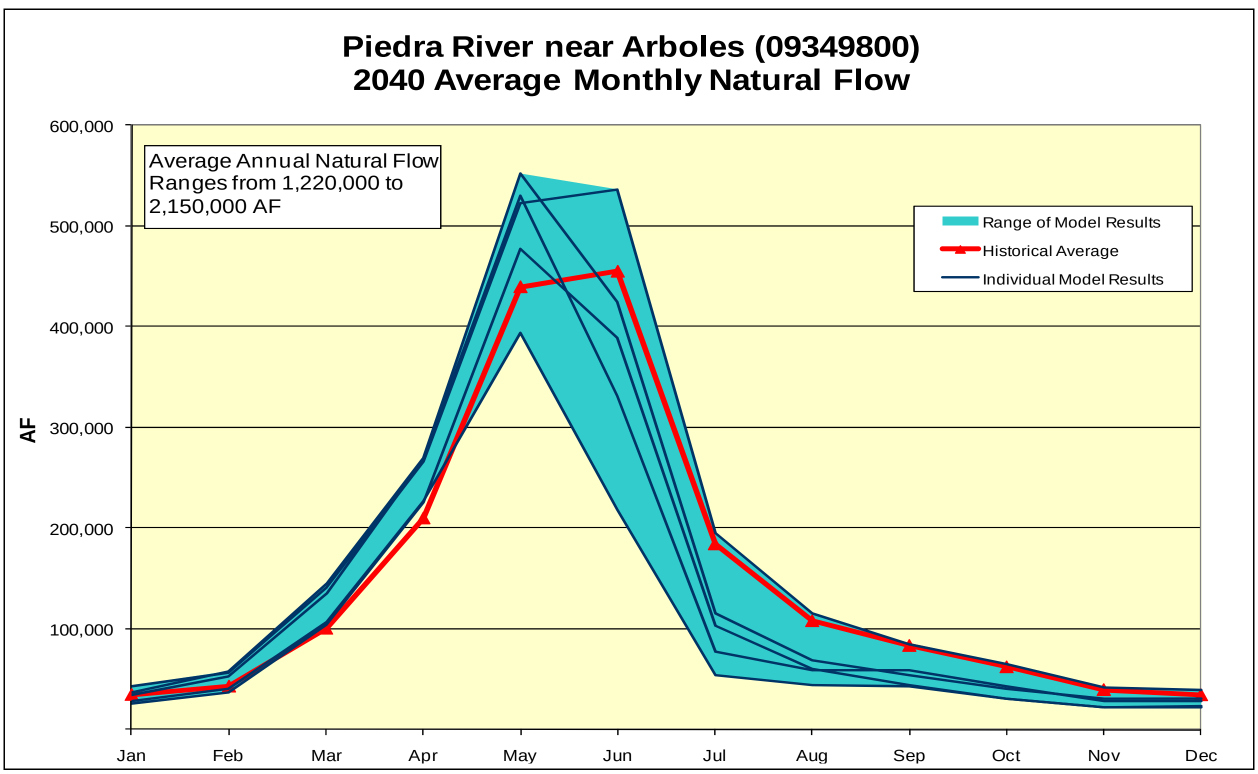


Figure D37 – 2040 Los Pinos River at La Boca Average Monthly Natural Flow Comparison

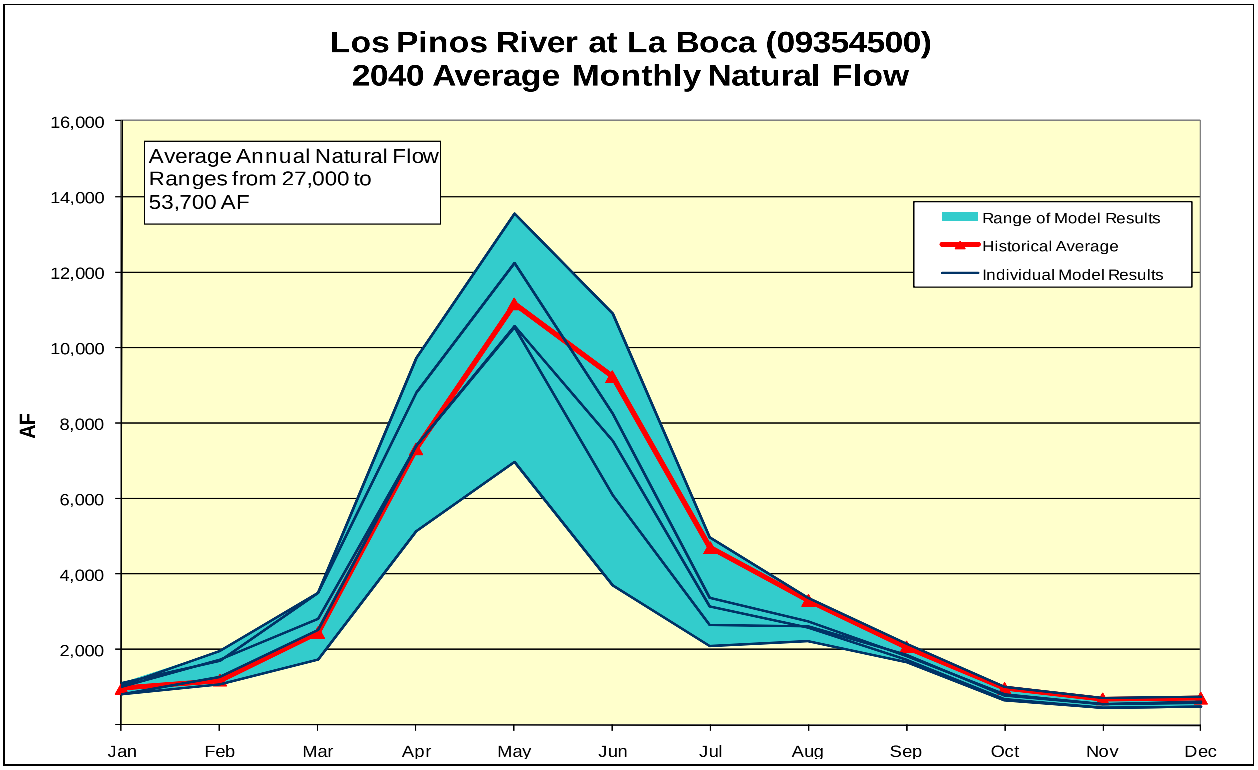


Figure D38 – 2040 Florida River at Bondad Average Monthly Natural Flow Comparison

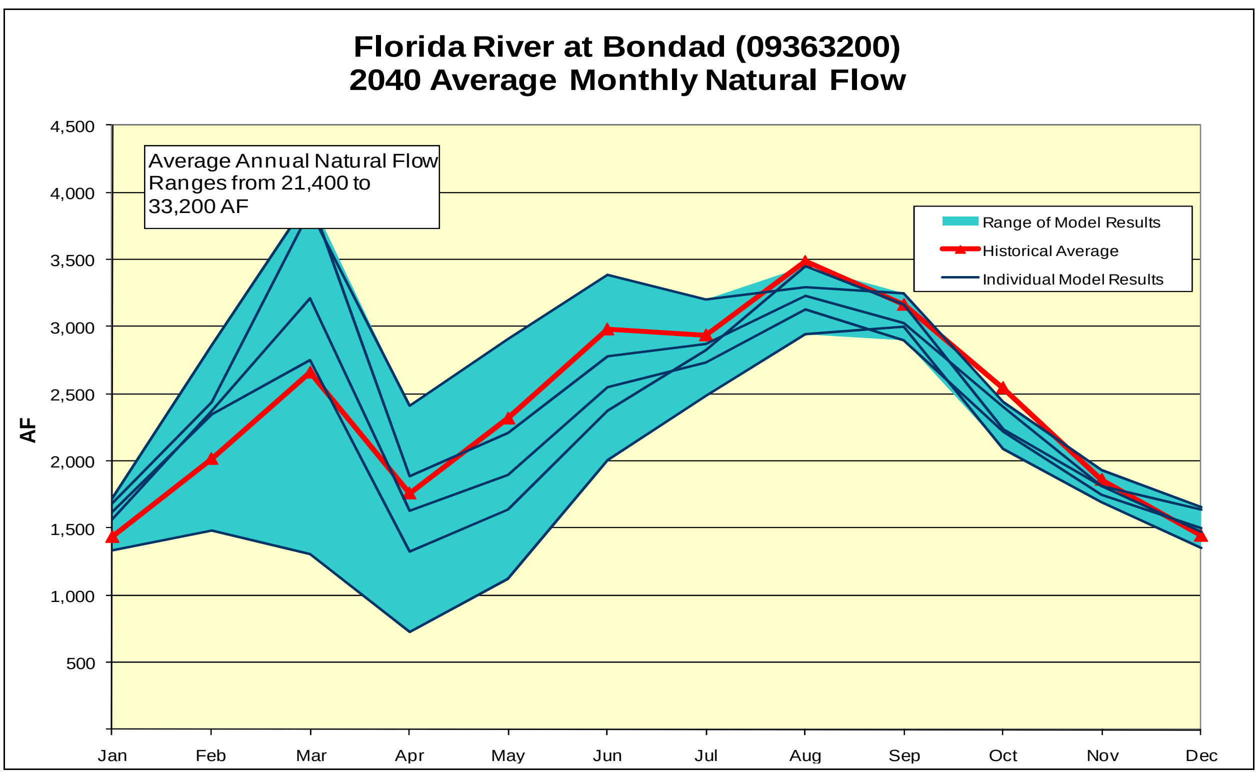


Figure D39 – 2040 Animas River near Cedar Hill, Nm Average Monthly Natural Flow Comparison

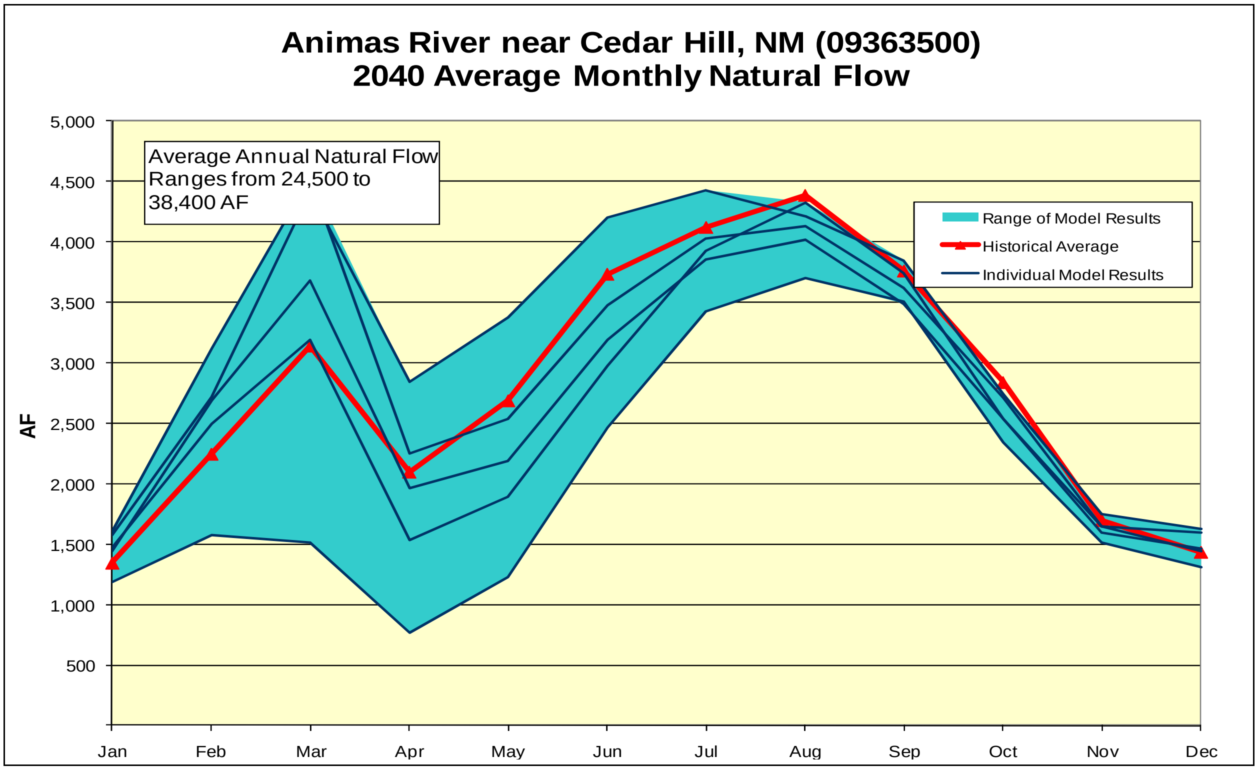


Figure D40 – 2040 La Plata River at Hesperus Average Monthly Natural Flow Comparison

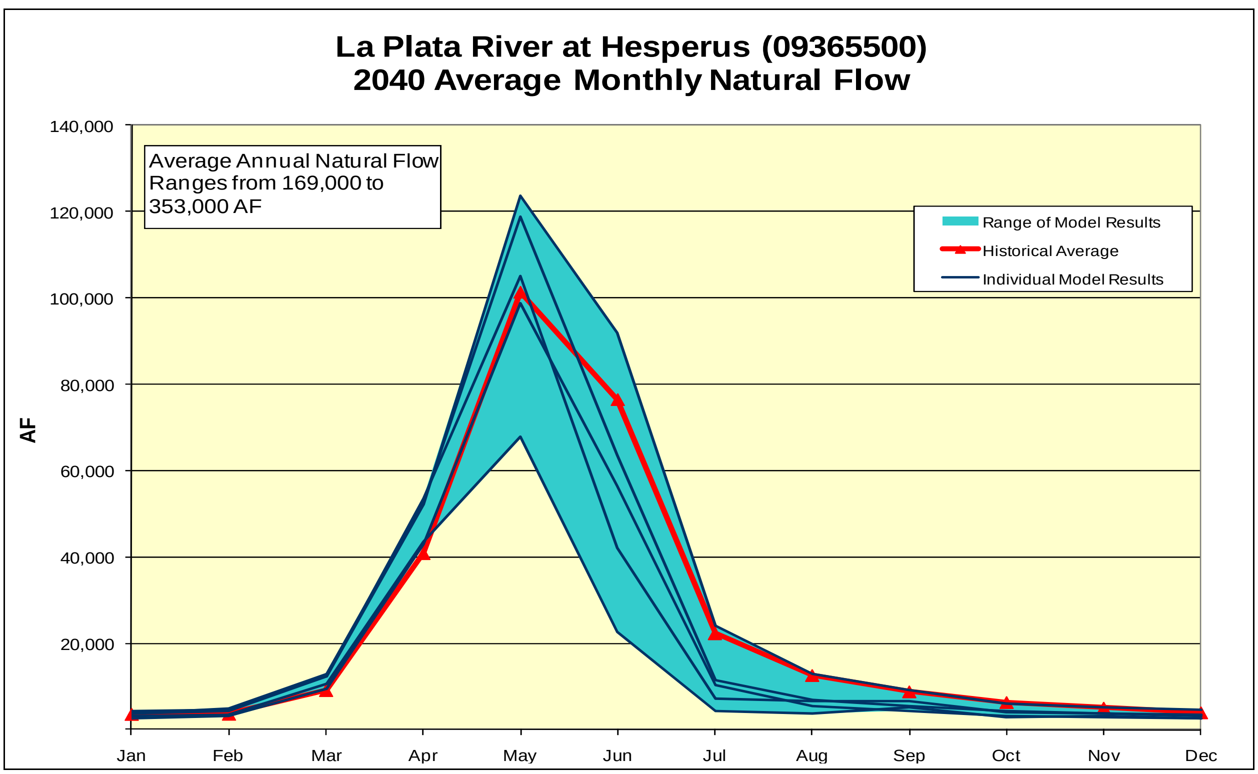


Figure D41 – 2040 La Plata River at Colorado-New Mexico State Line Average Monthly Natural Flow Comparison

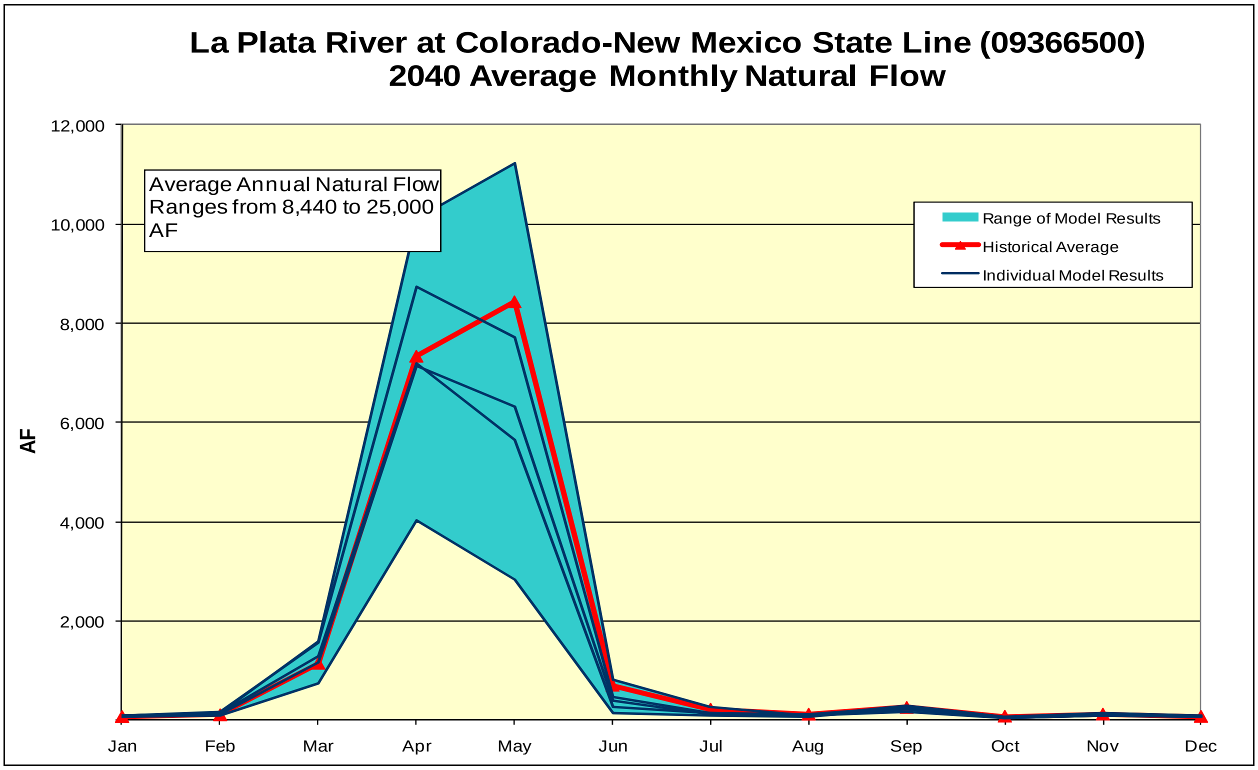


Figure D42 – 2040 Mancos River near Towaoc Average Monthly Natural Flow Comparison

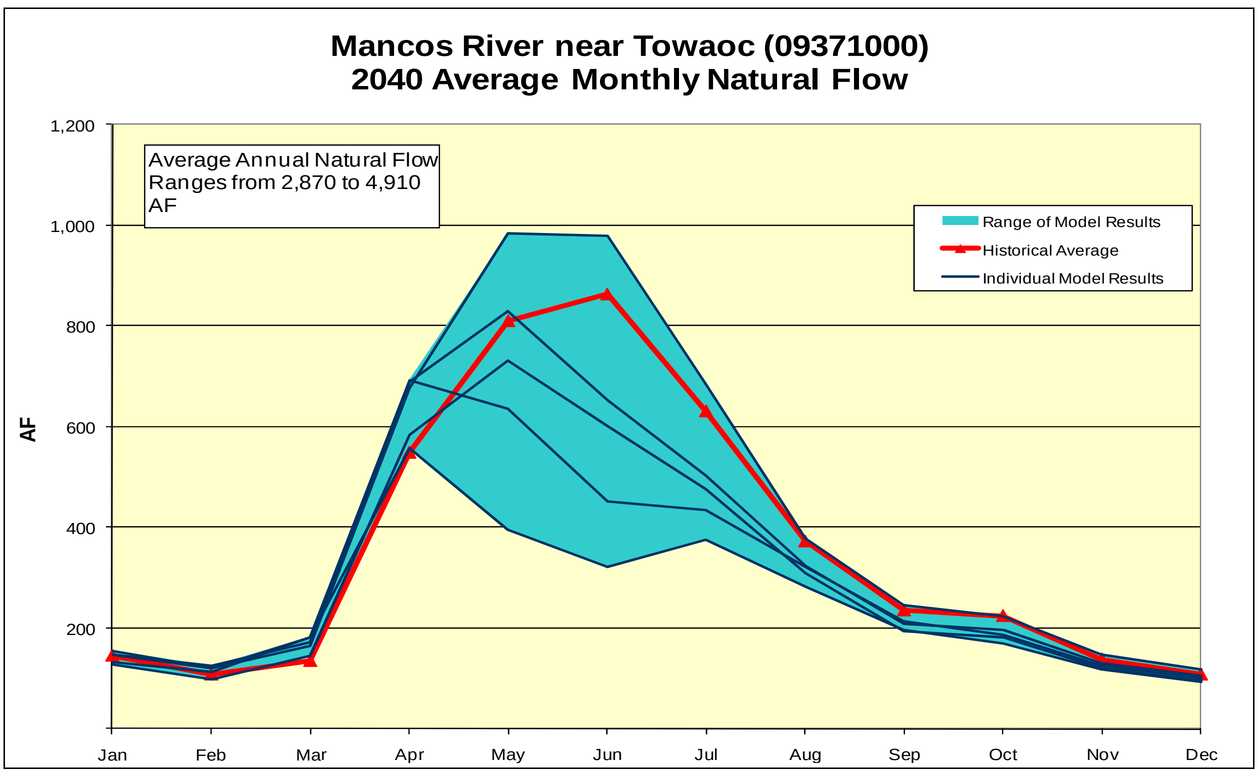


Figure D43 – 2040 McElmo Creek near Colorado-Utah State Line Average Monthly Natural Flow Comparison

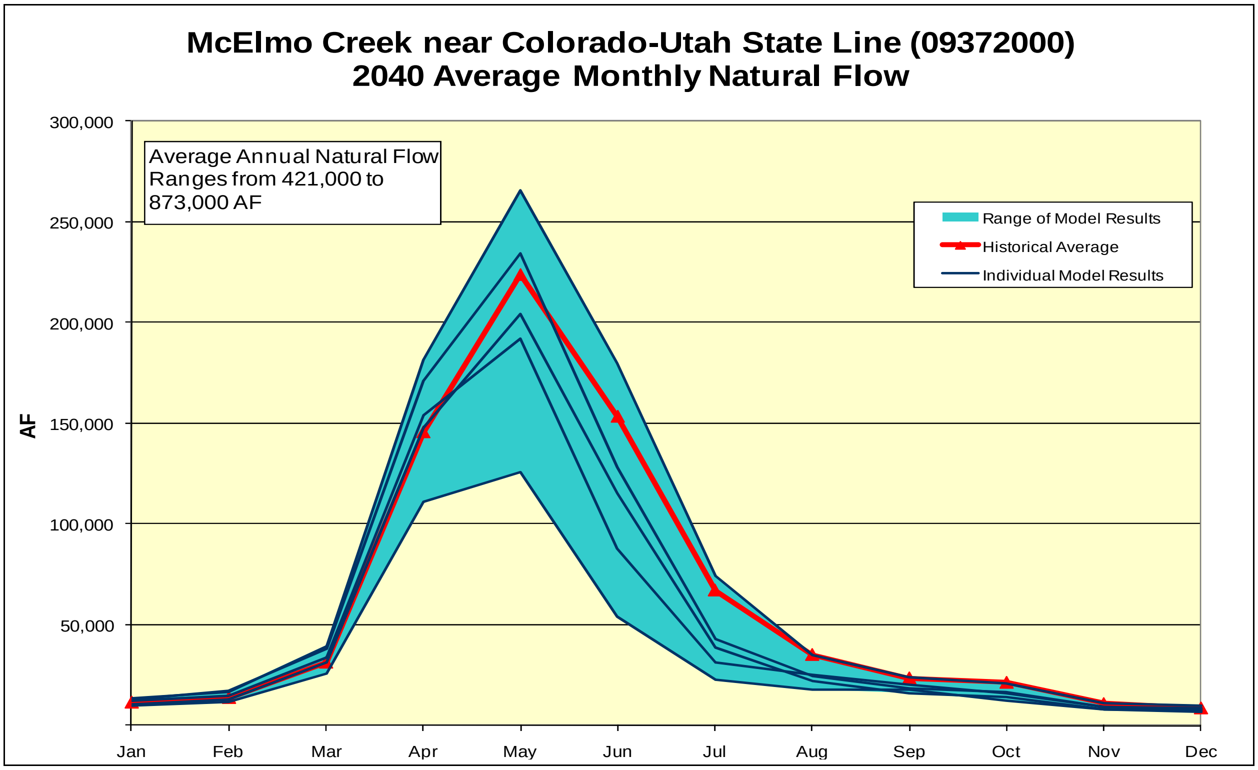


Figure D44 – 2070 Colorado River near Grand Lake Average Monthly Natural Flow Comparison

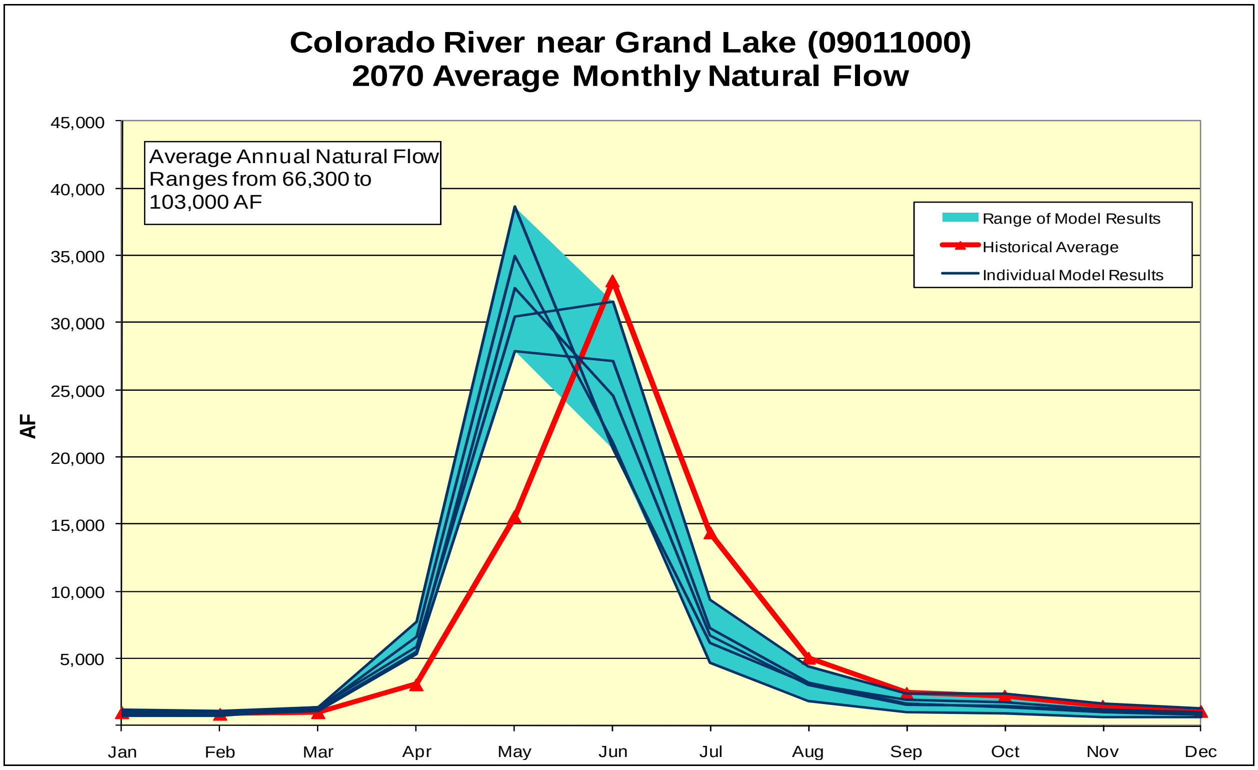


Figure D45 – 2070 Muddy Creek at Kremmling Average Monthly Natural Flow Comparison

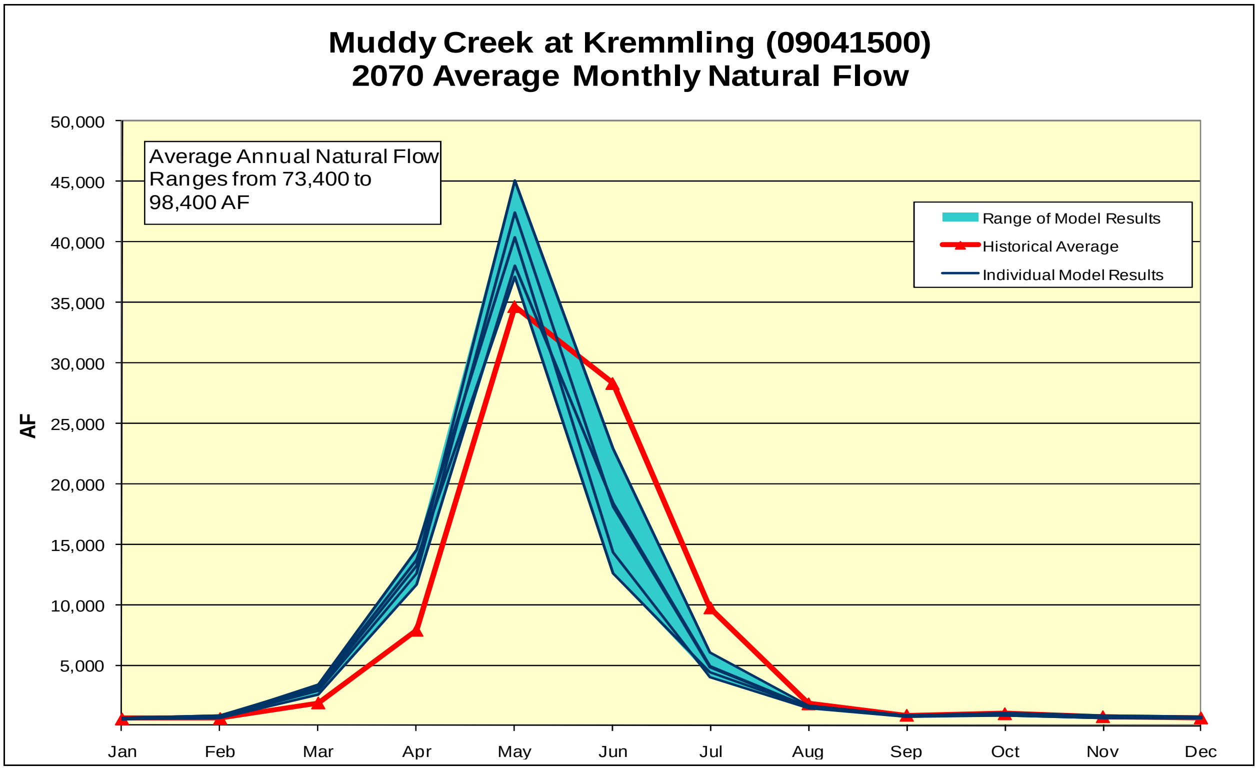


Figure D46 – 2070 Blue River below Dillon Average Monthly Natural Flow Comparison

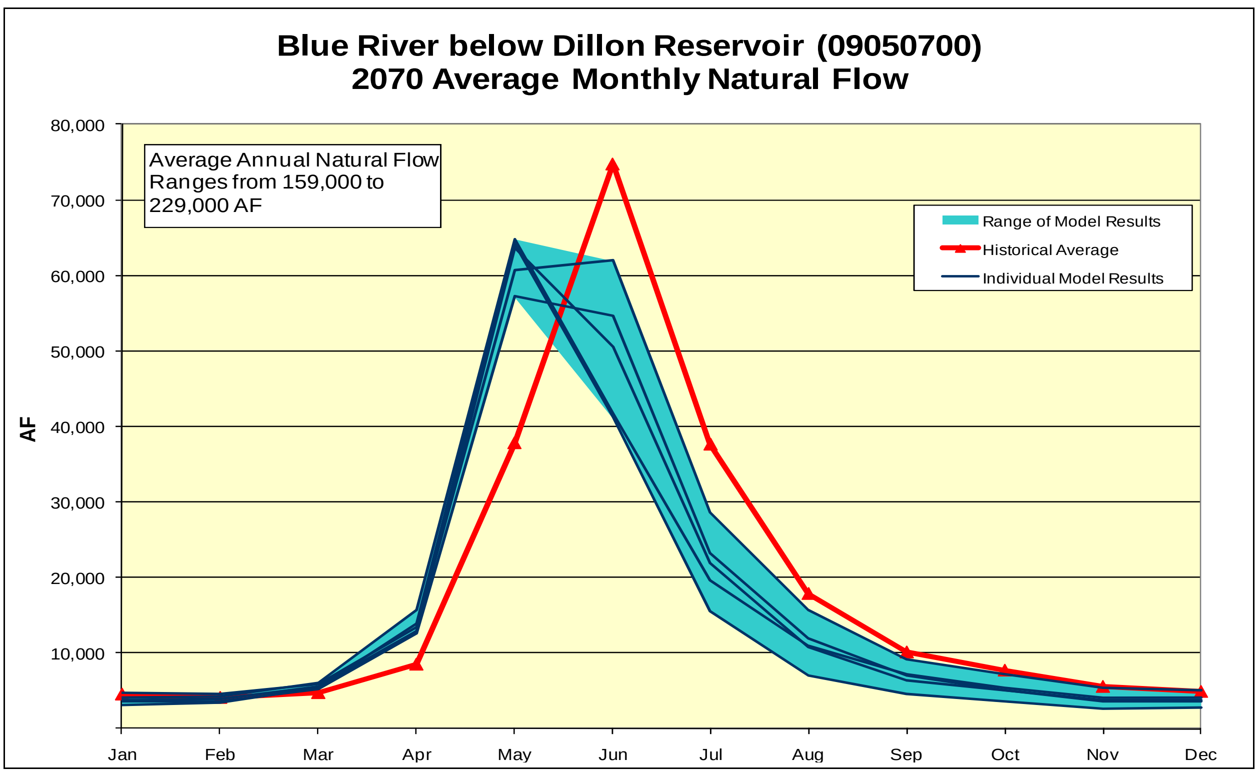


Figure D47 – 2070 Blue River below Green Mountain Reservoir Average Monthly Natural Flow Comparison

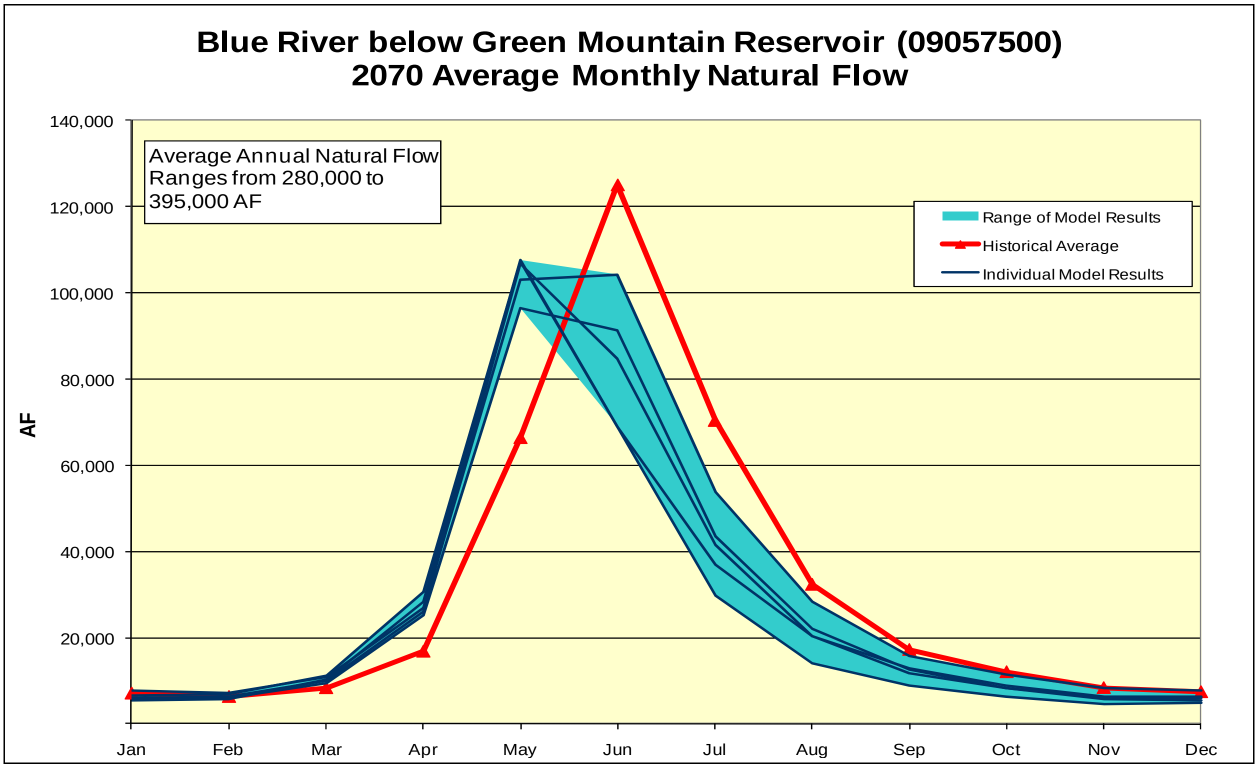


Figure D48 – 2070 Eagle River below Gypsum Average Monthly Natural Flow Comparison

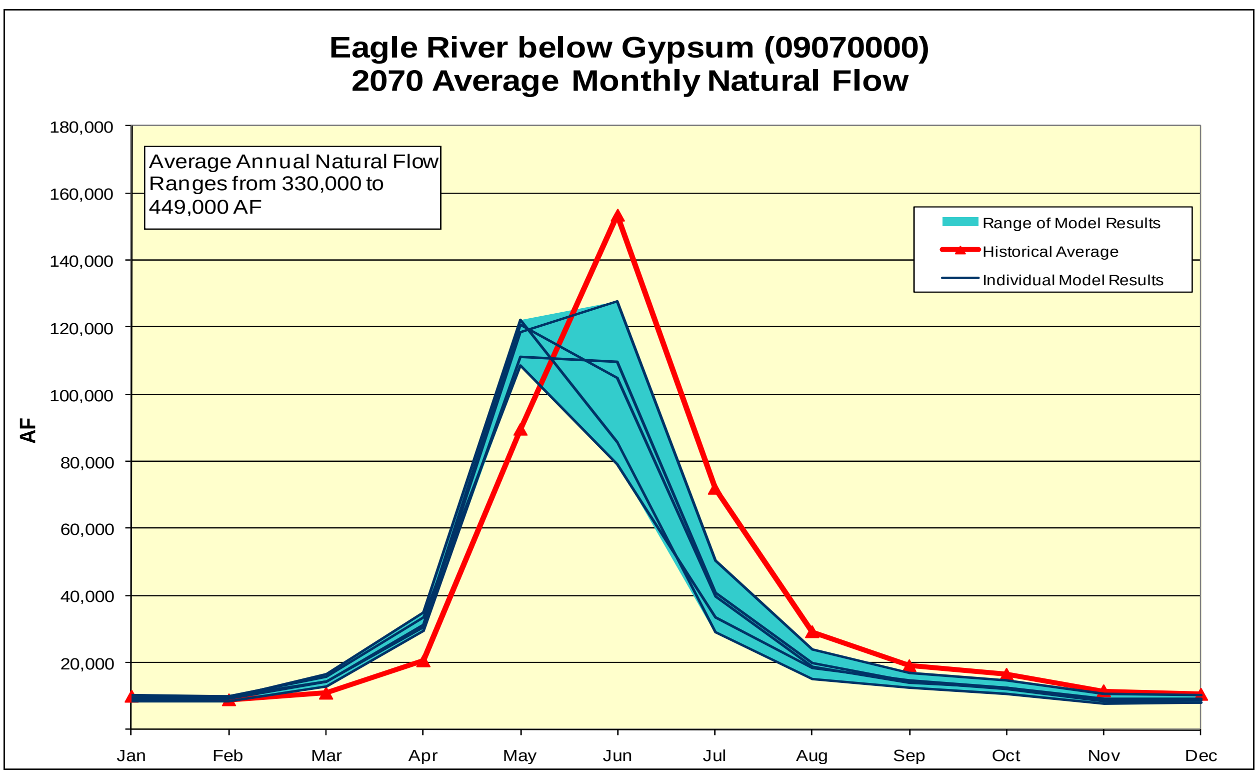


Figure D49 – 2070 Colorado River at Dotsero Average Monthly Natural Flow Comparison

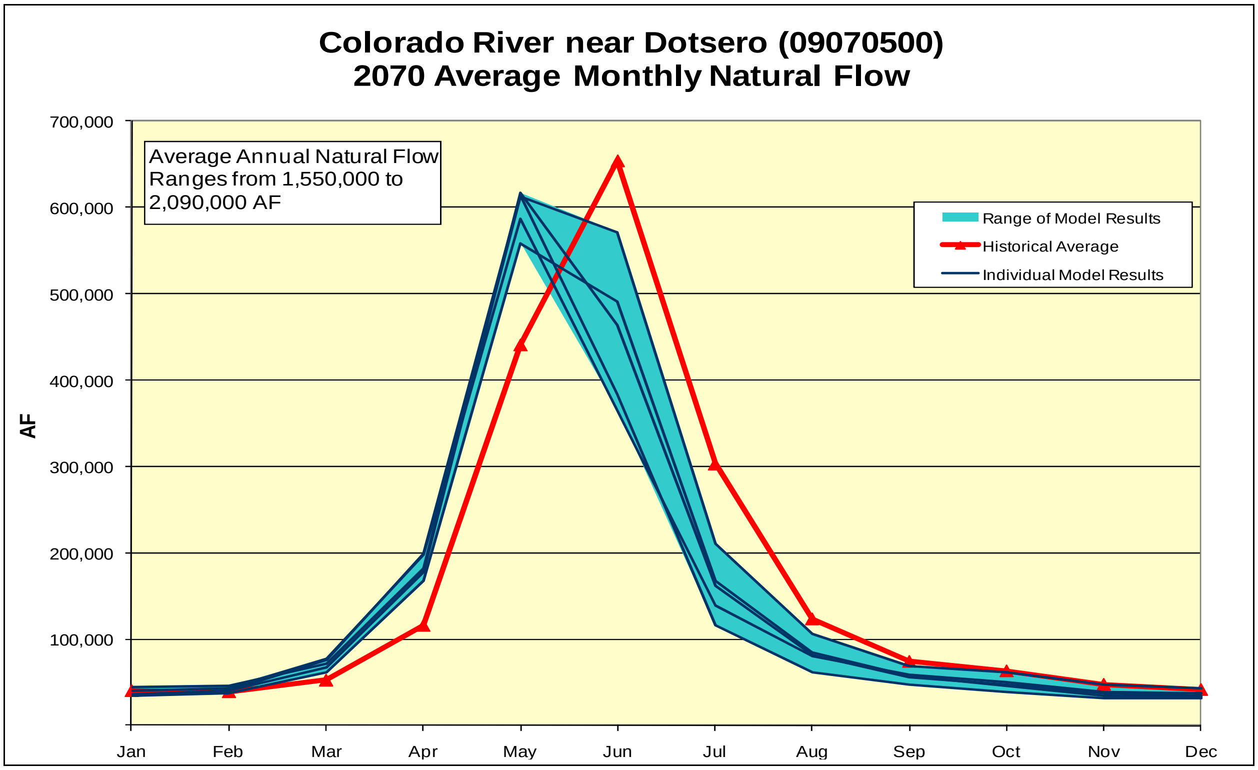


Figure D50 – 2070 Roaring Fork River near Aspen Average Monthly Natural Flow Comparison

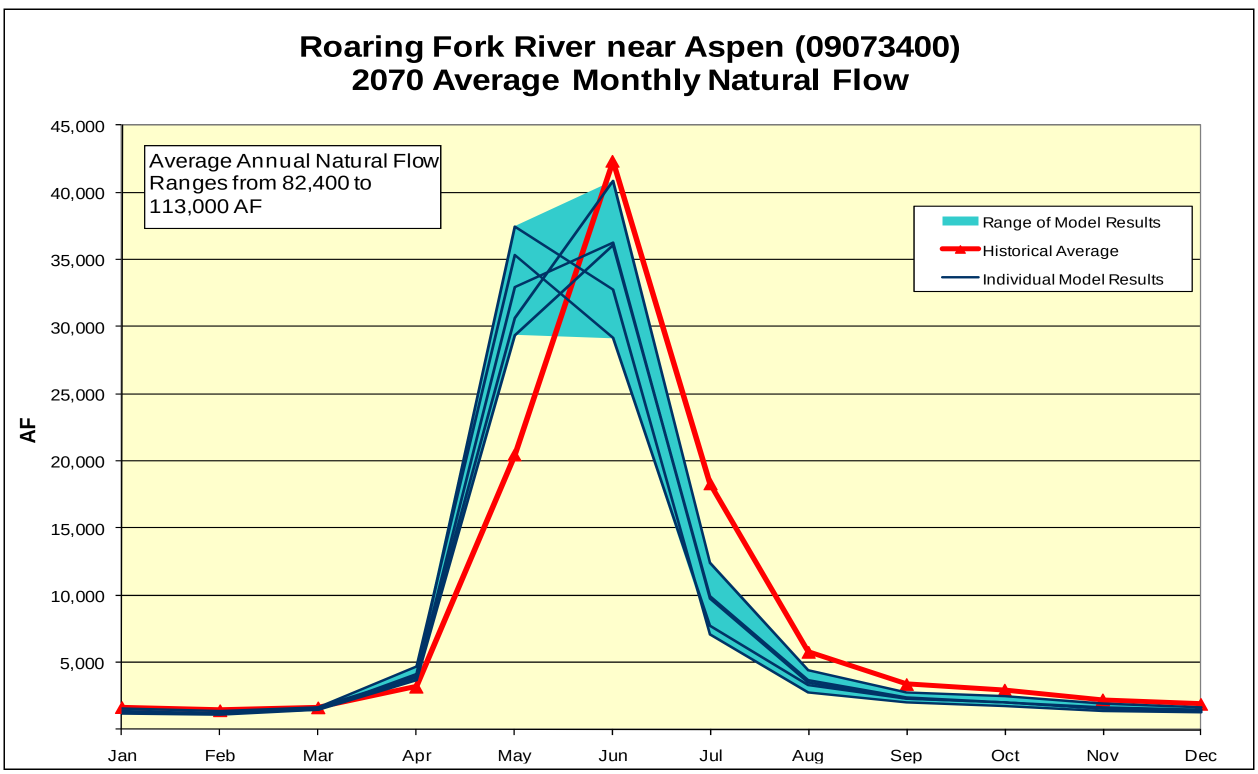


Figure D51 – 2070 Roaring Fork River at Glenwood Average Monthly Natural Flow Comparison

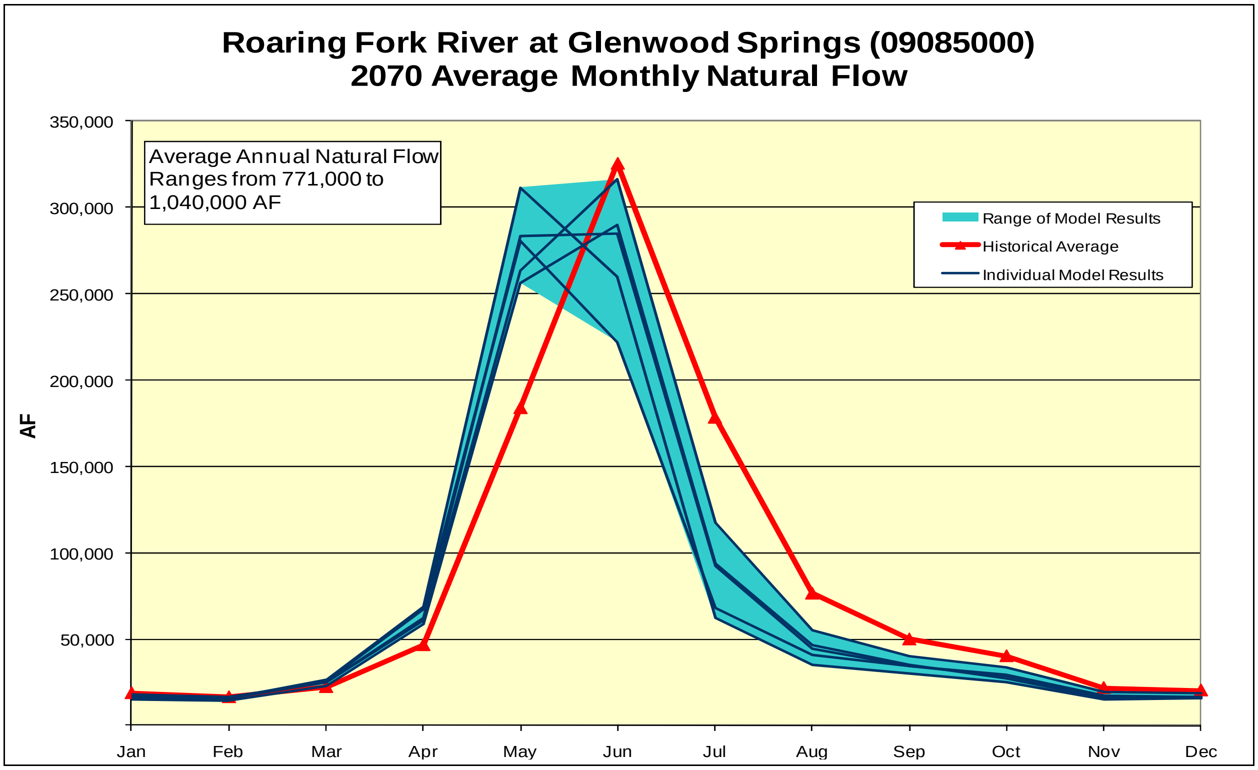


Figure D52 – 2070 Colorado River near Cameo Average Monthly Natural Flow Comparison

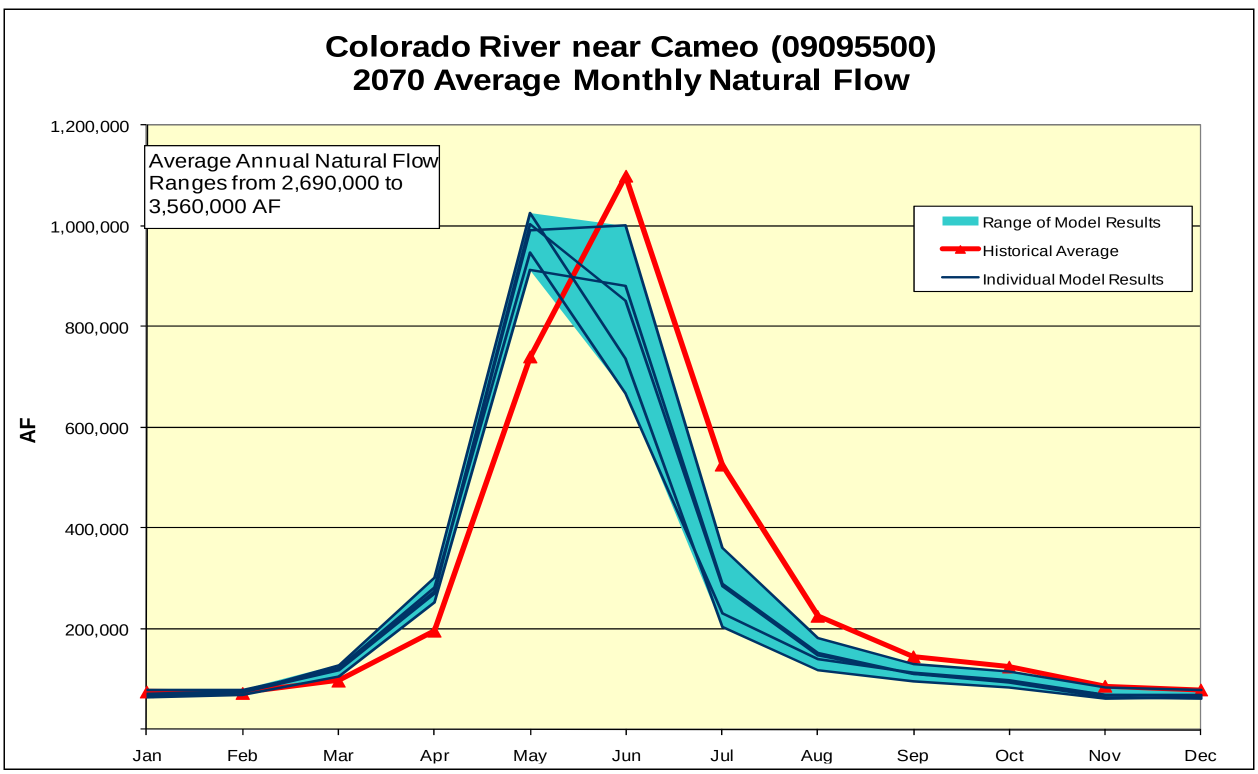


Figure D53 – 2070 Plateau Creek near Cameo Average Monthly Natural Flow Comparison

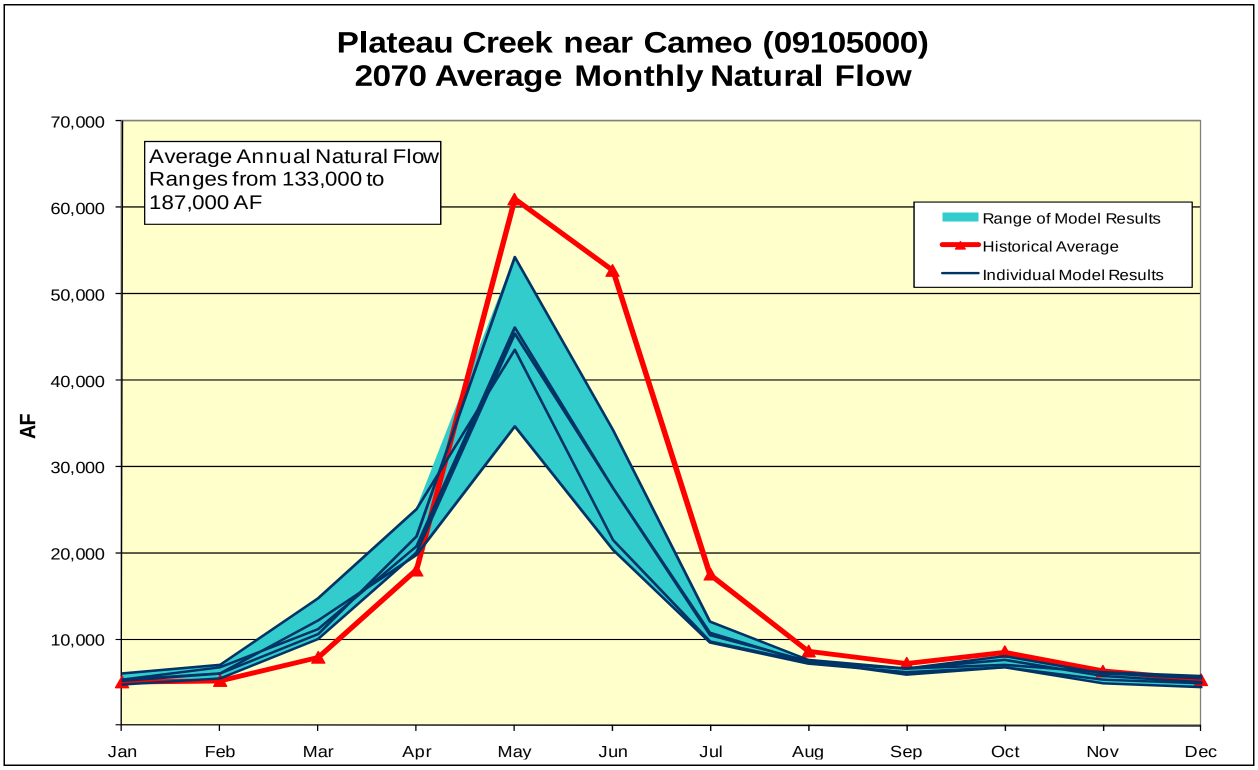


Figure D54 – 2070 Taylor River at Almont Average Monthly Natural Flow Comparison

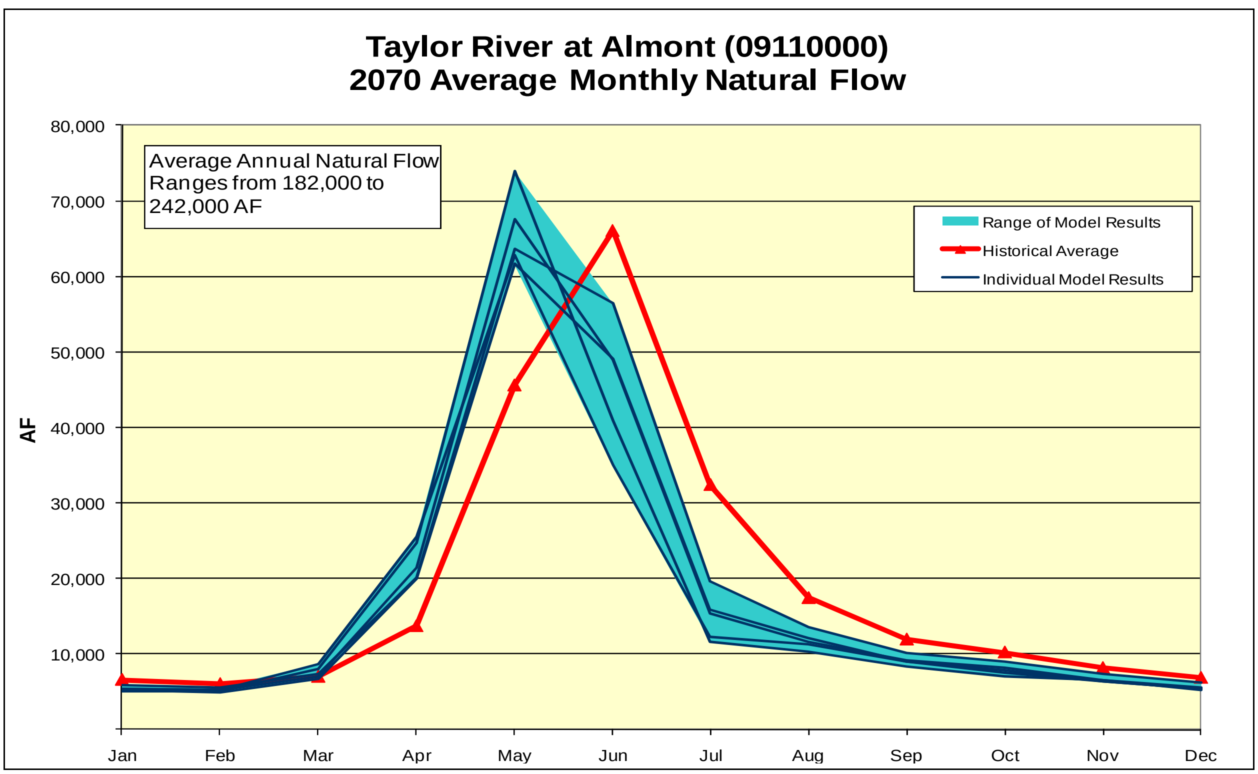


Figure D55 – 2070 East River at Almont Average Monthly Natural Flow Comparison

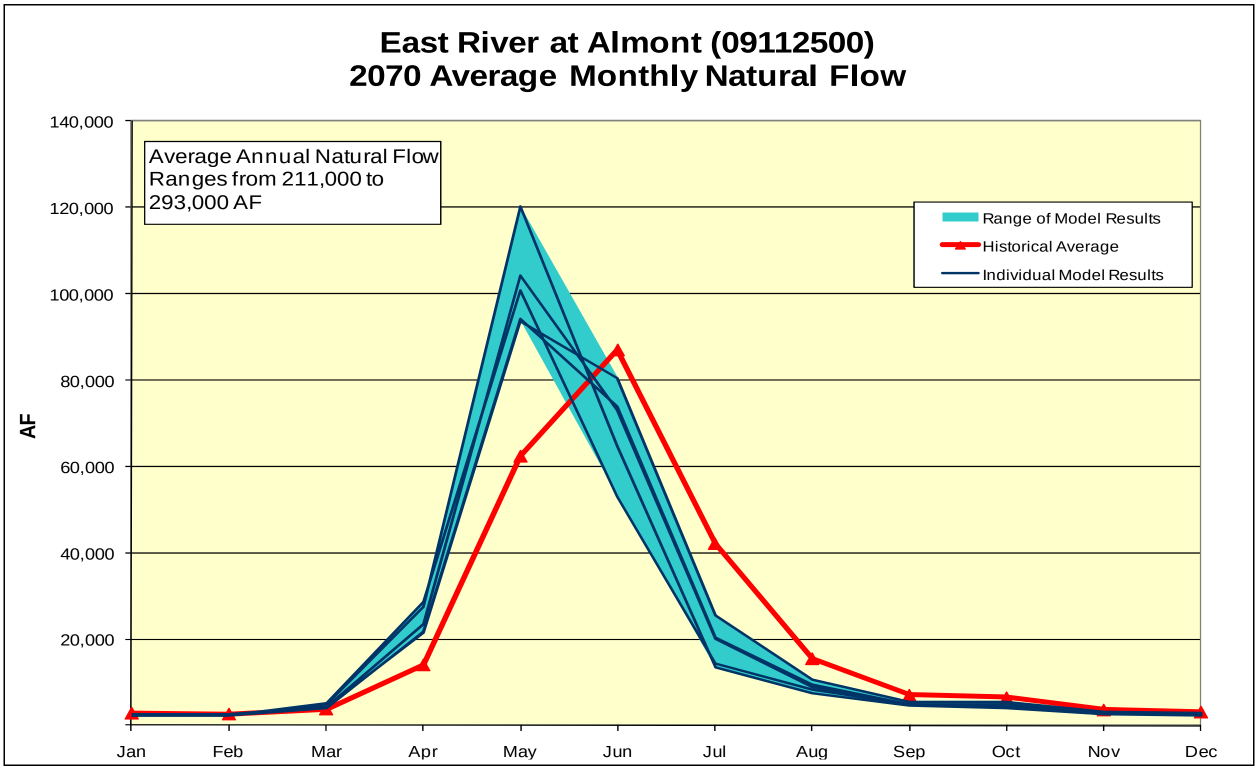


Figure D56 – 2070 Gunnison River near Gunnison Average Monthly Natural Flow Comparison

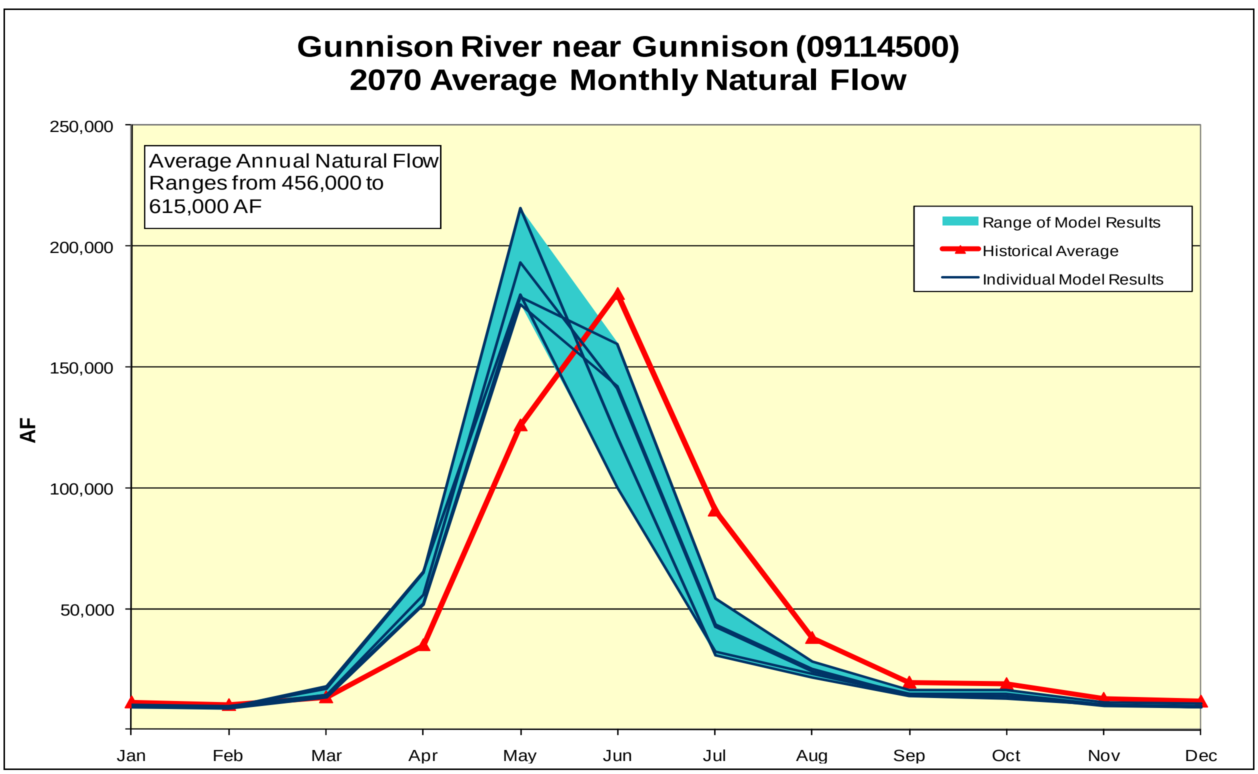


Figure D57 – 2070 Tomichi Creek at Gunnison Average Monthly Natural Flow Comparison

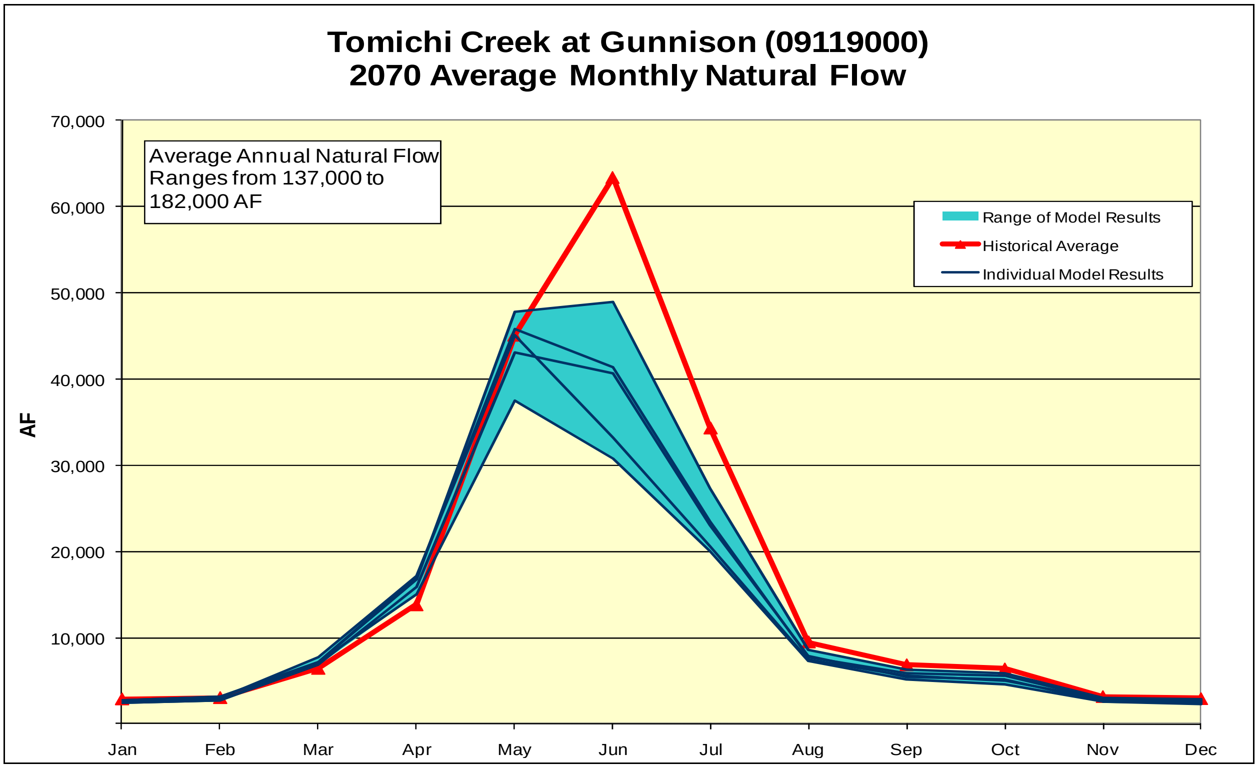


Figure D58 – 2070 Cimarron River at Cimarron Average Monthly Natural Flow Comparison

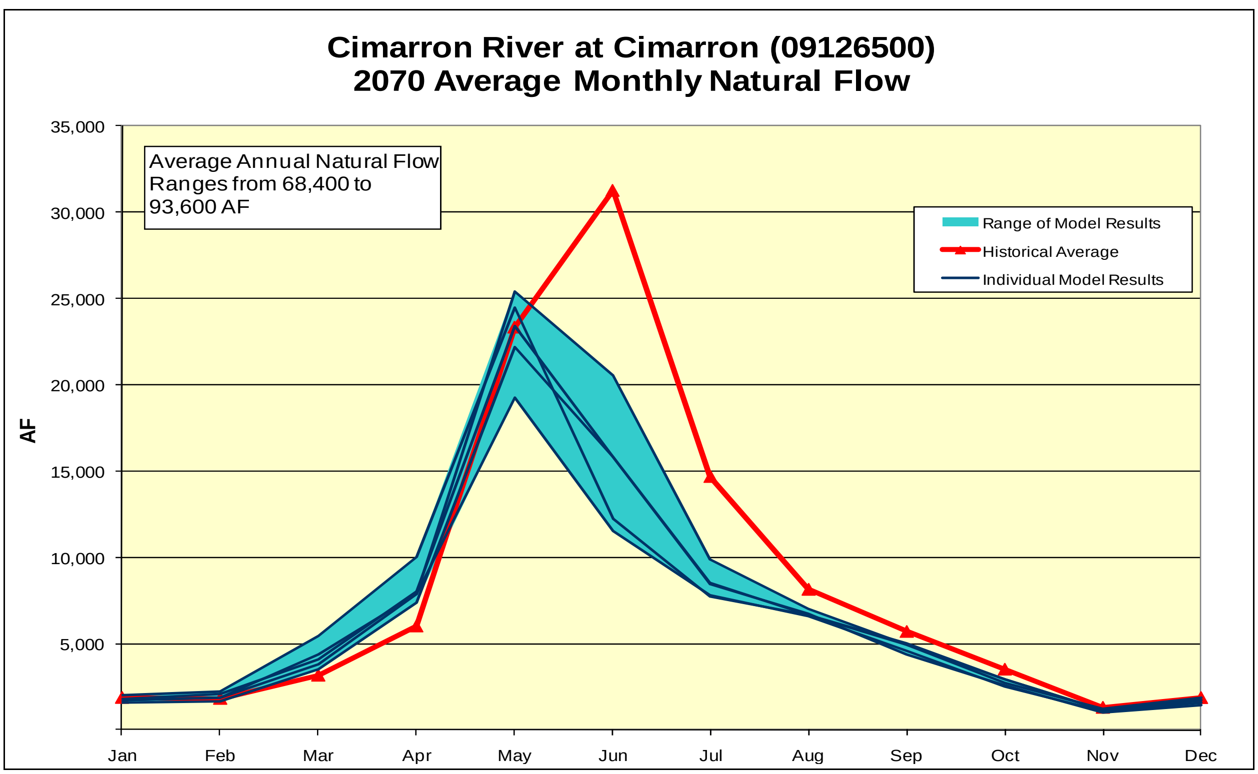


Figure D59 – 2070 Gunnison River below Gunnison Tunnel Average Monthly Natural Flow Comparison

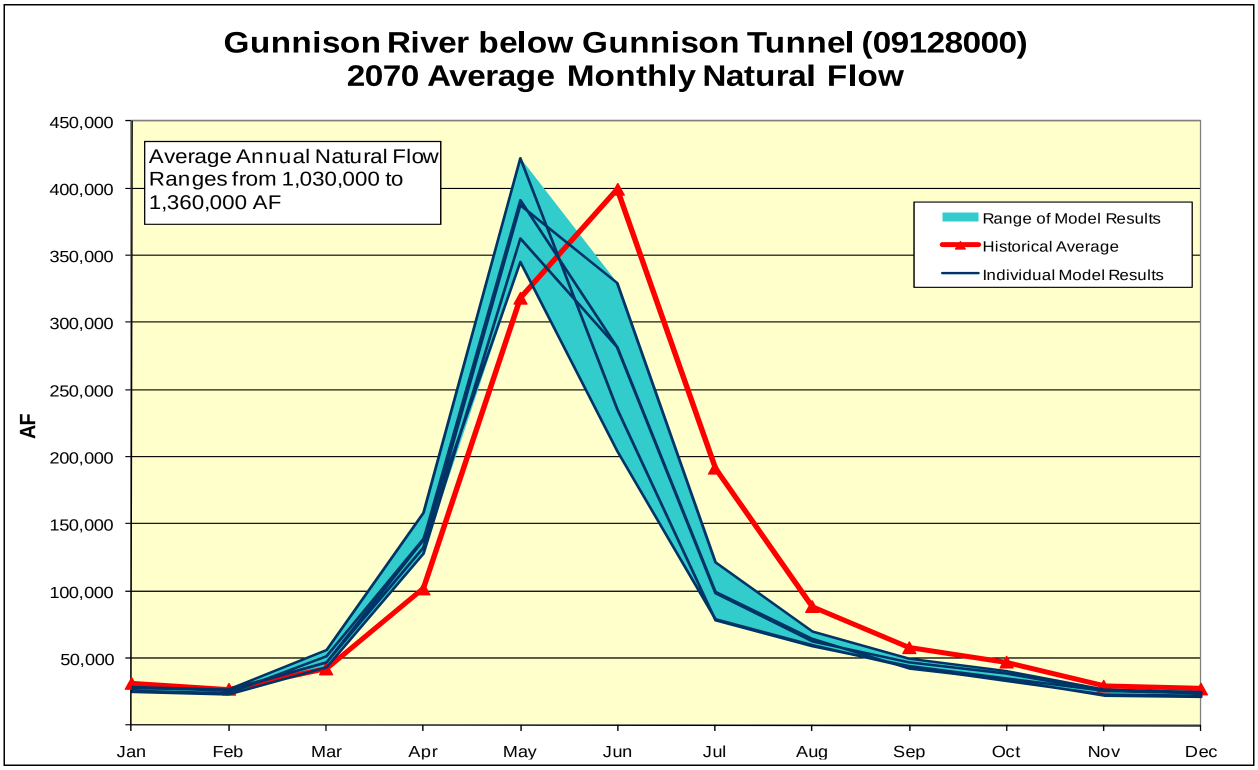


Figure D60 – 2070 Gunnison River near Lazear Average Monthly Natural Flow Comparison

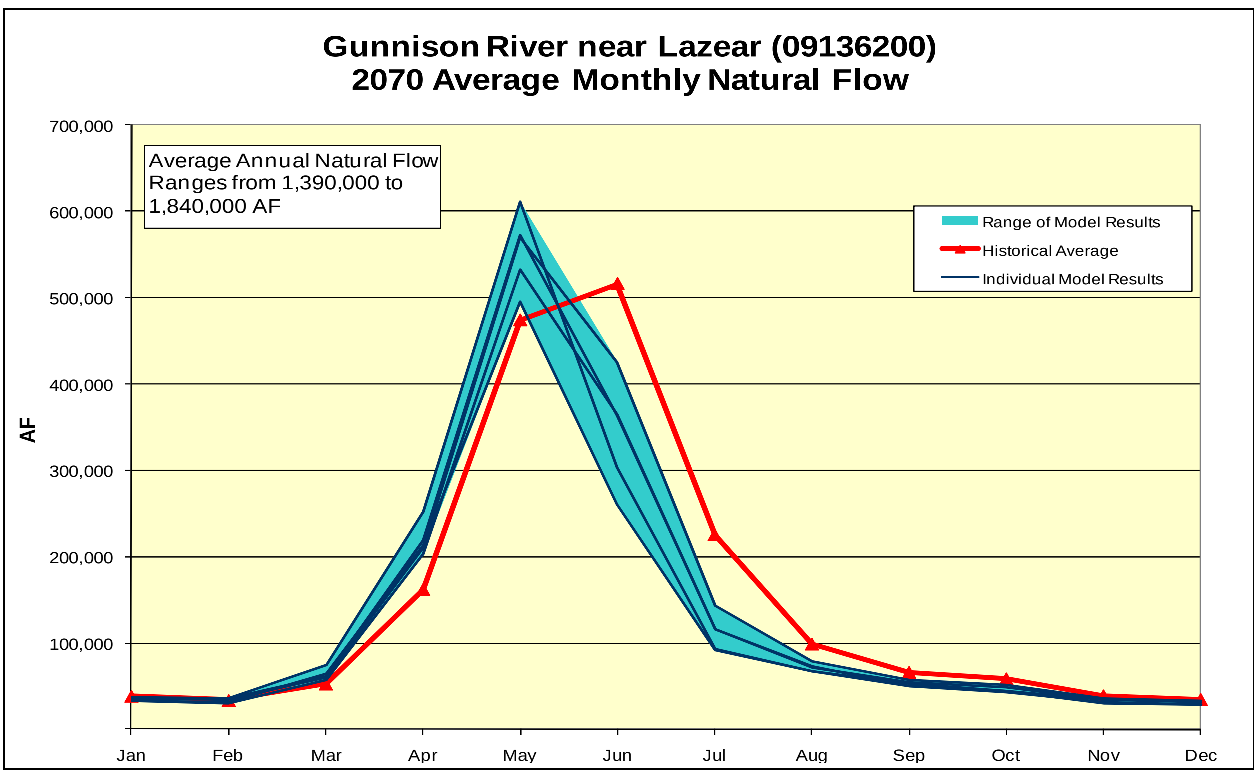


Figure D61 – 2070 Uncompahgre River at Delta Average Monthly Natural Flow Comparison

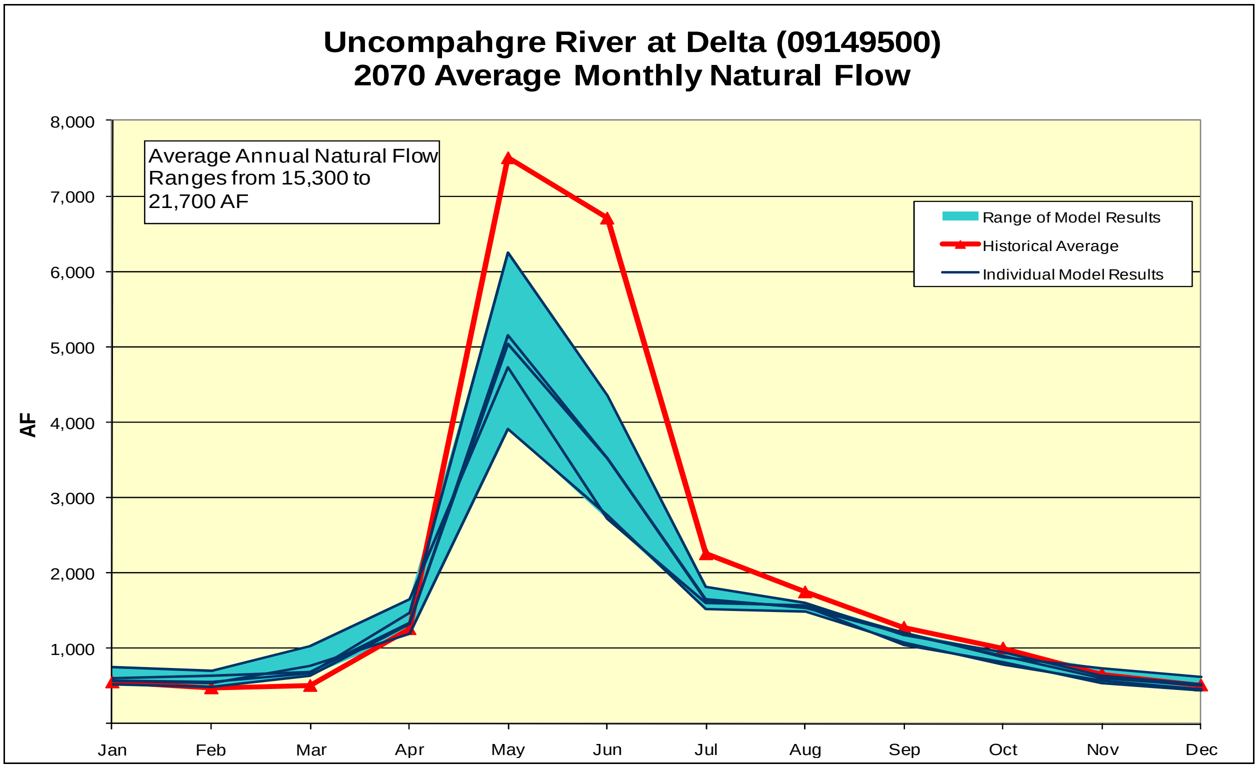


Figure D62 – 2070 Gunnison River near Grand Junction Average Monthly Natural Flow Comparison

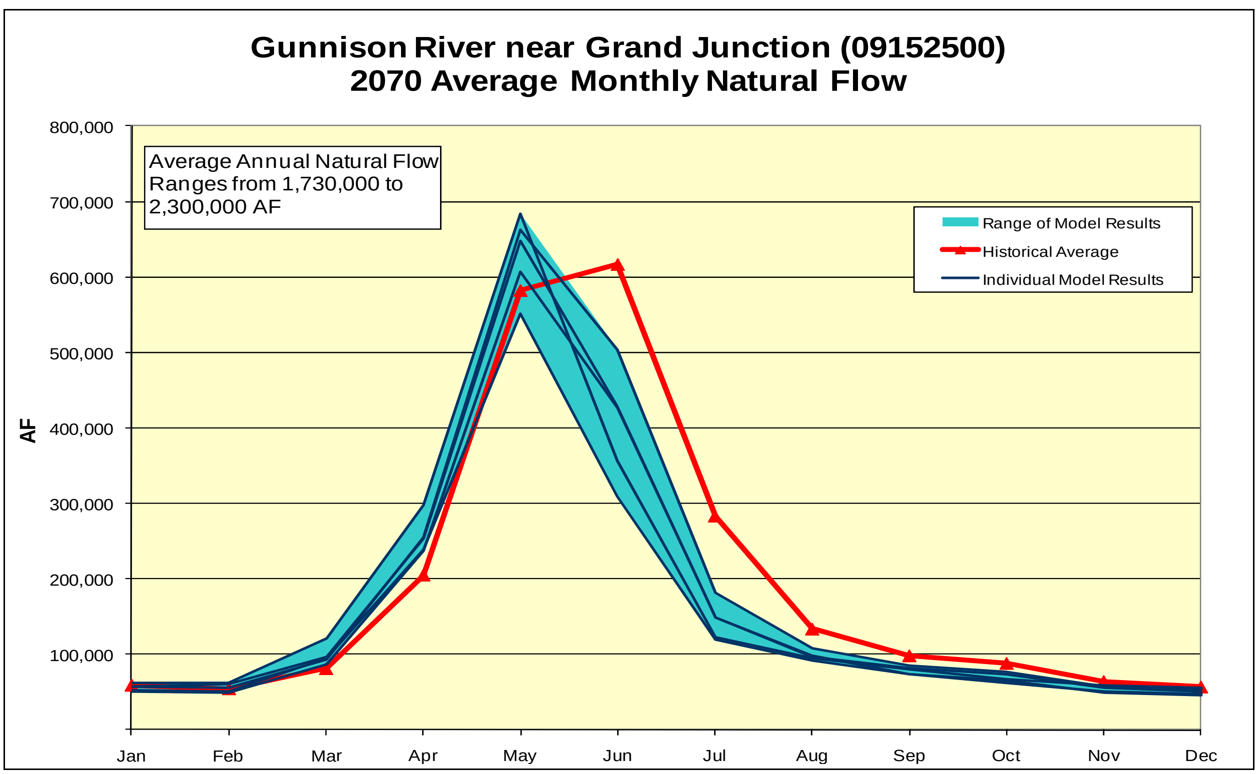


Figure D63 – 2070 Colorado River near Colorado-Utah State Line Average Monthly Natural Flow Comparison

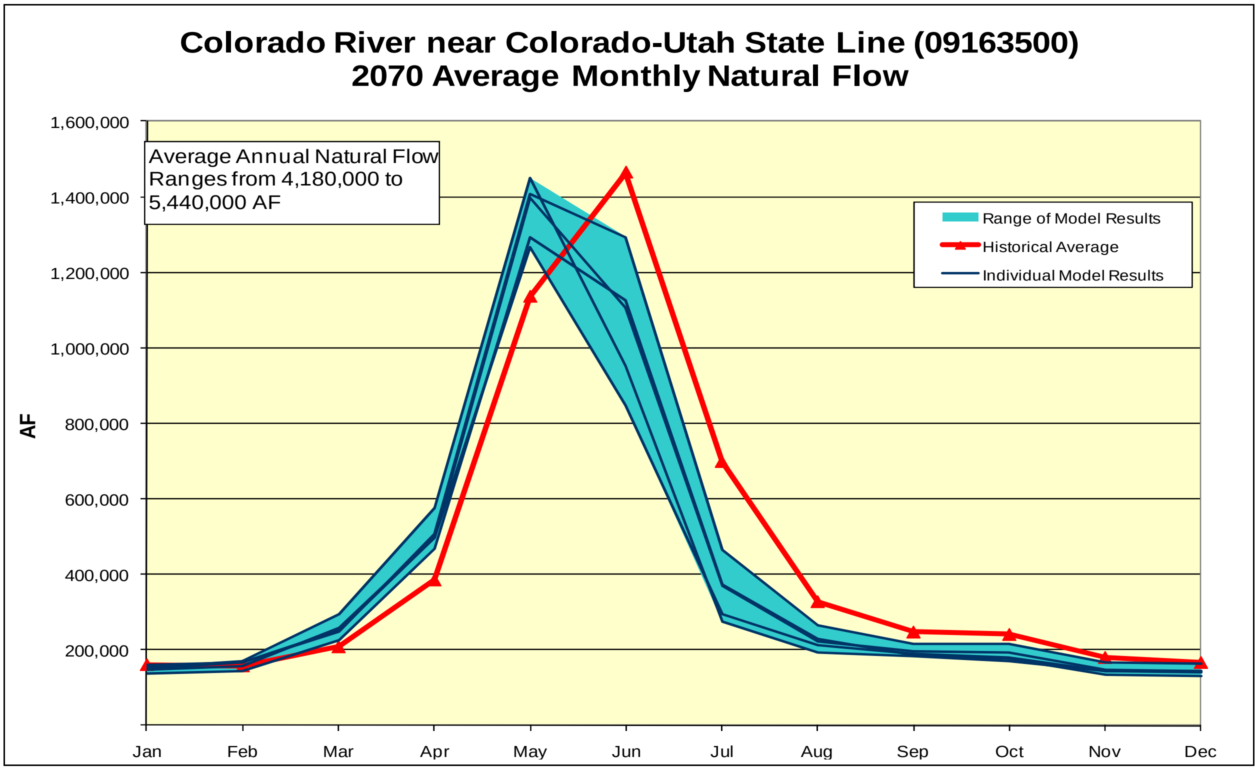


Figure D64 – 2070 Dolores River near Bedrock Average Monthly Natural Flow Comparison

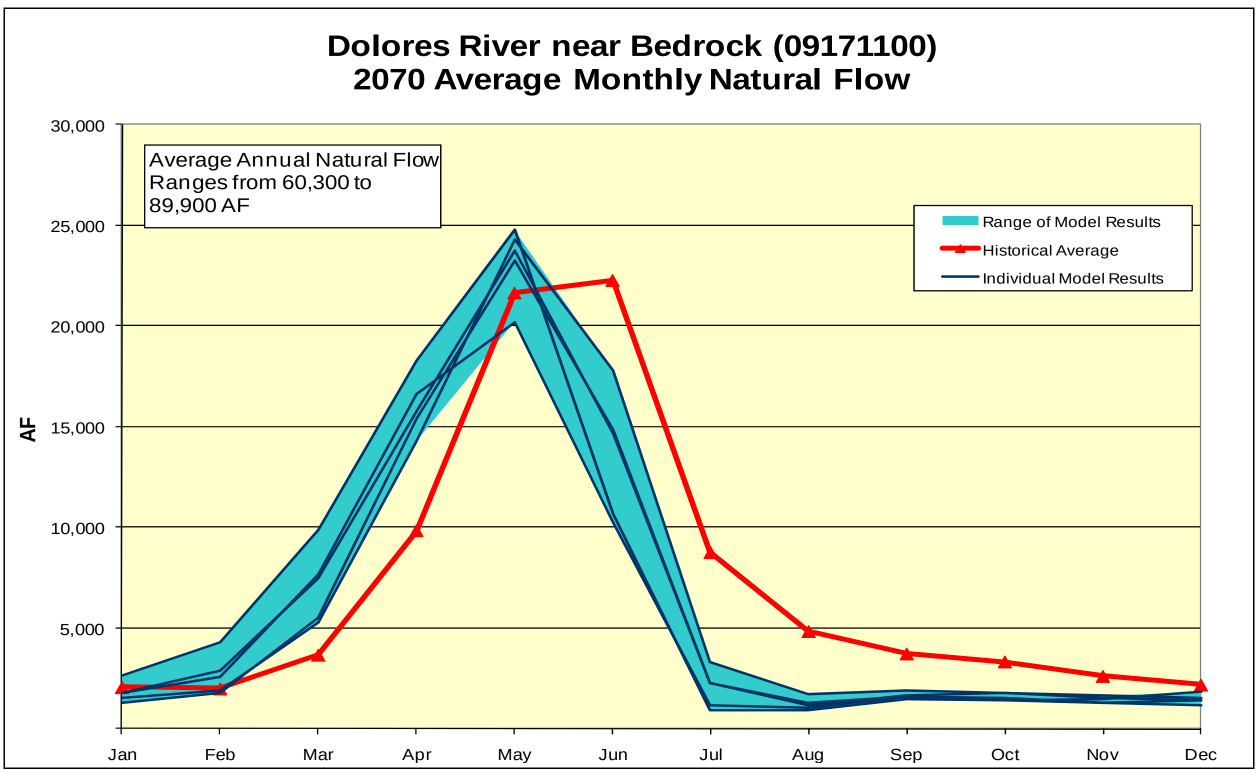


Figure D65 – 2070 San Miguel River at Naturita Average Monthly Natural Flow Comparison

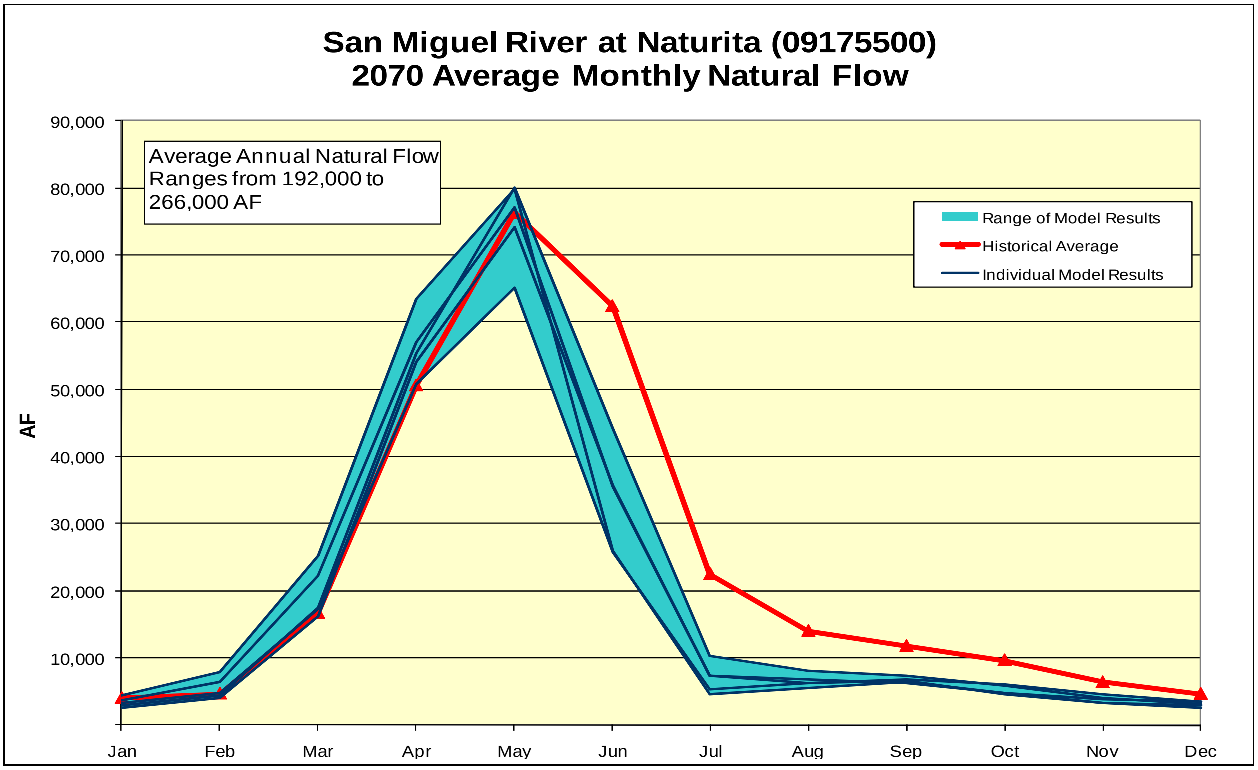


Figure D66 – 2070 Yampa River below Stagecoach Reservoir Average Monthly Natural Flow Comparison

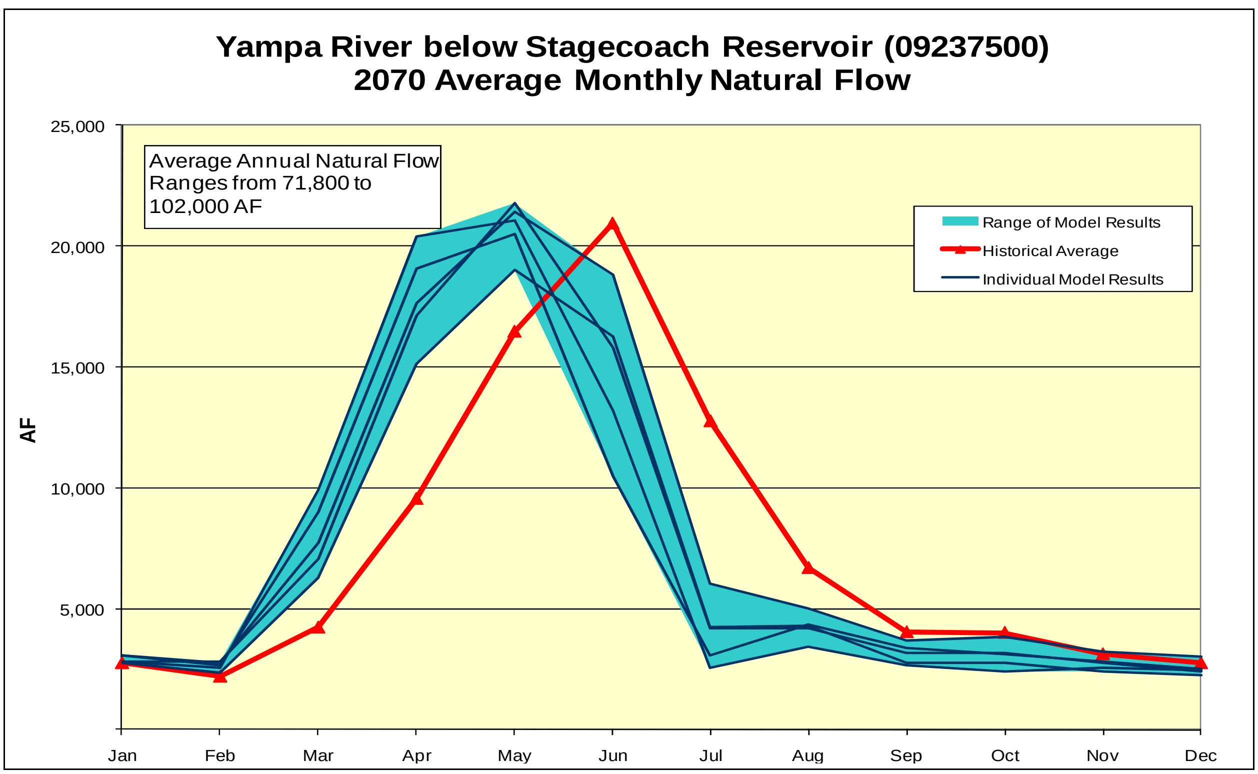


Figure D67 – 2070 Elk River at Clark Average Monthly Natural Flow Comparison

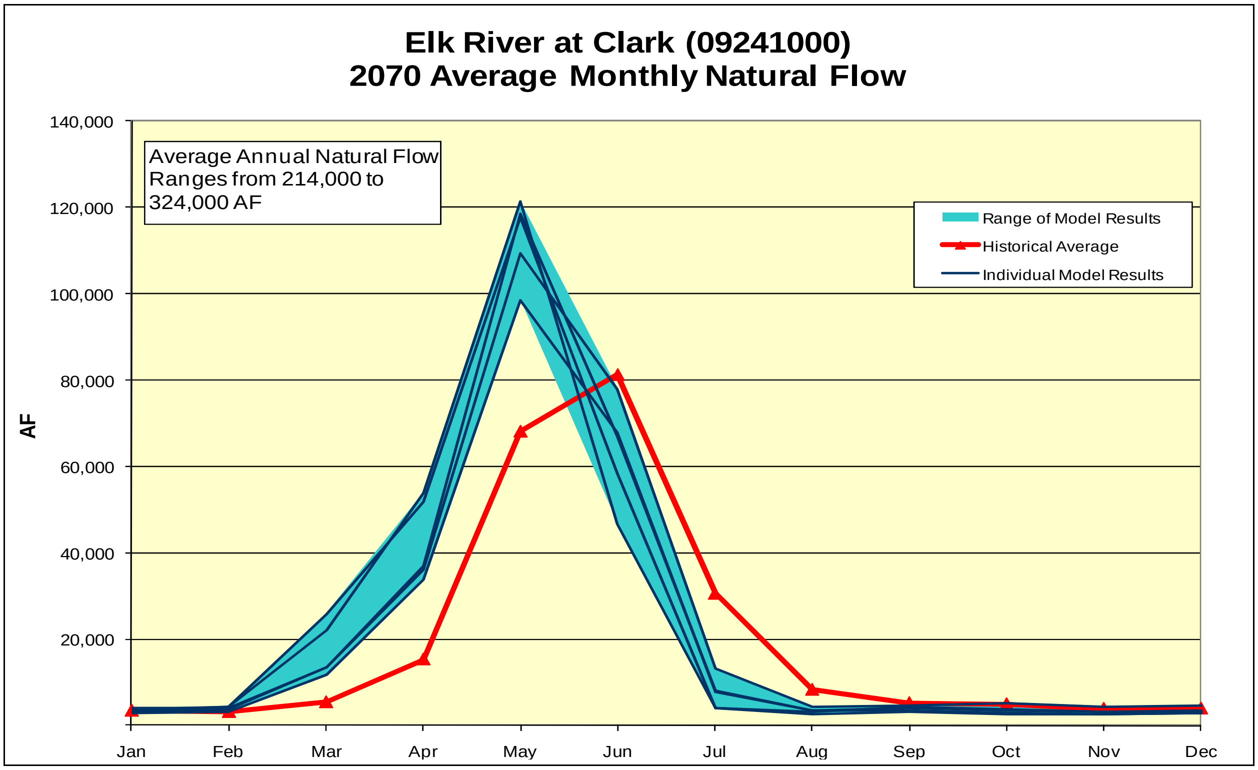


Figure D68 – 2070 Elkhead Creek near Elkhead Average Monthly Natural Flow Comparison

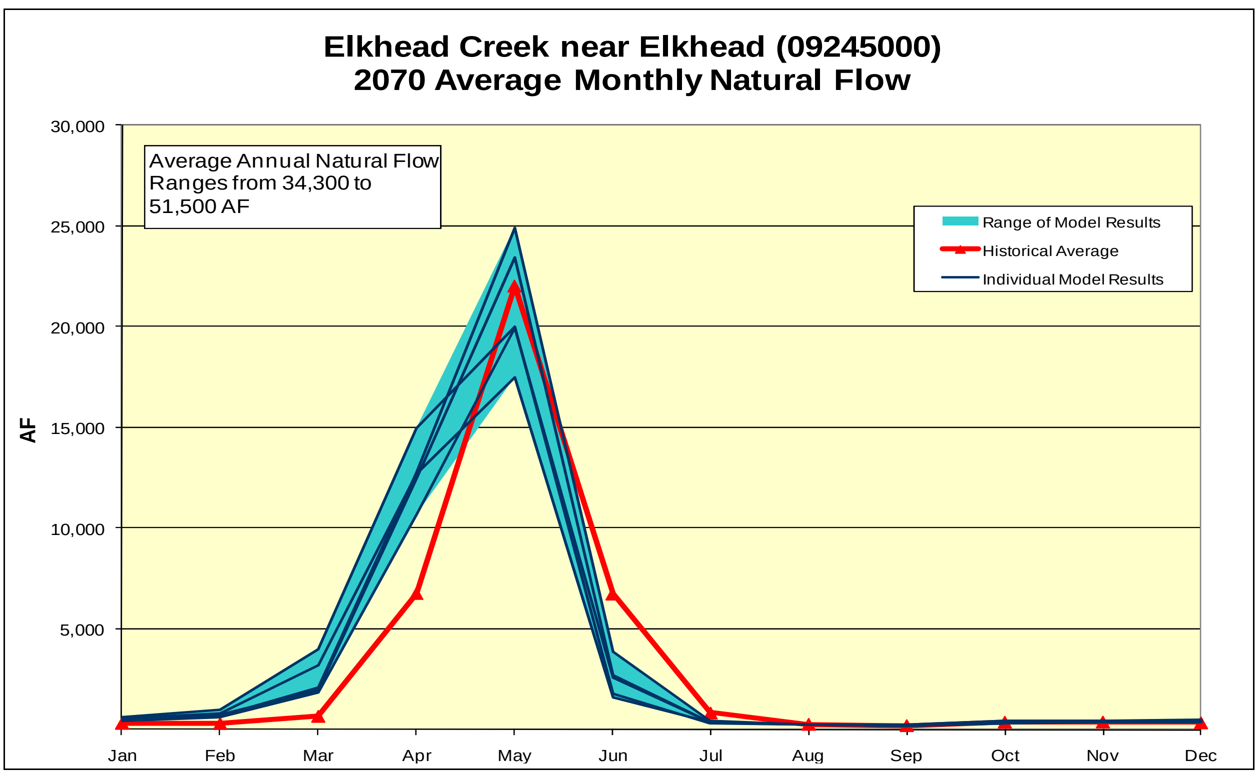


Figure D69 – 2070 Williams Fork at Mouth, near Hamilton Average Monthly Natural Flow Comparison

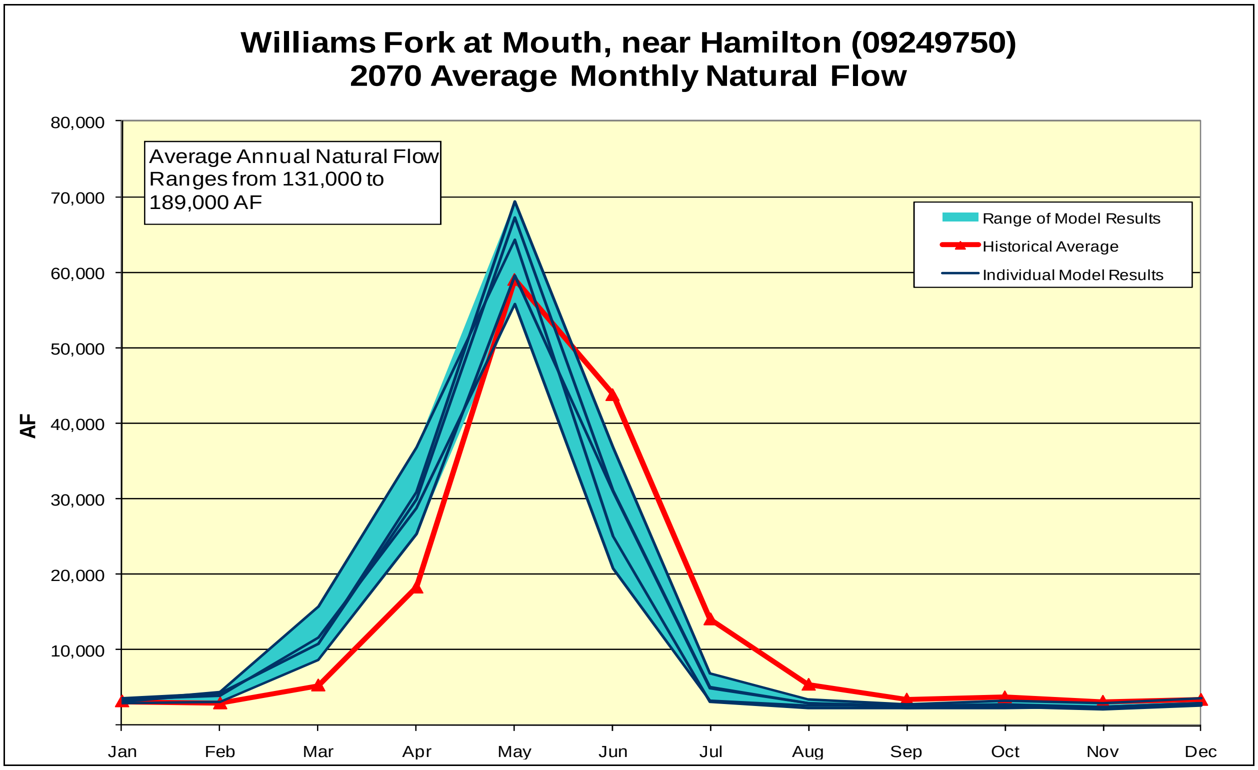


Figure D70 – 2070 Yampa River near Maybell Average Monthly Natural Flow Comparison

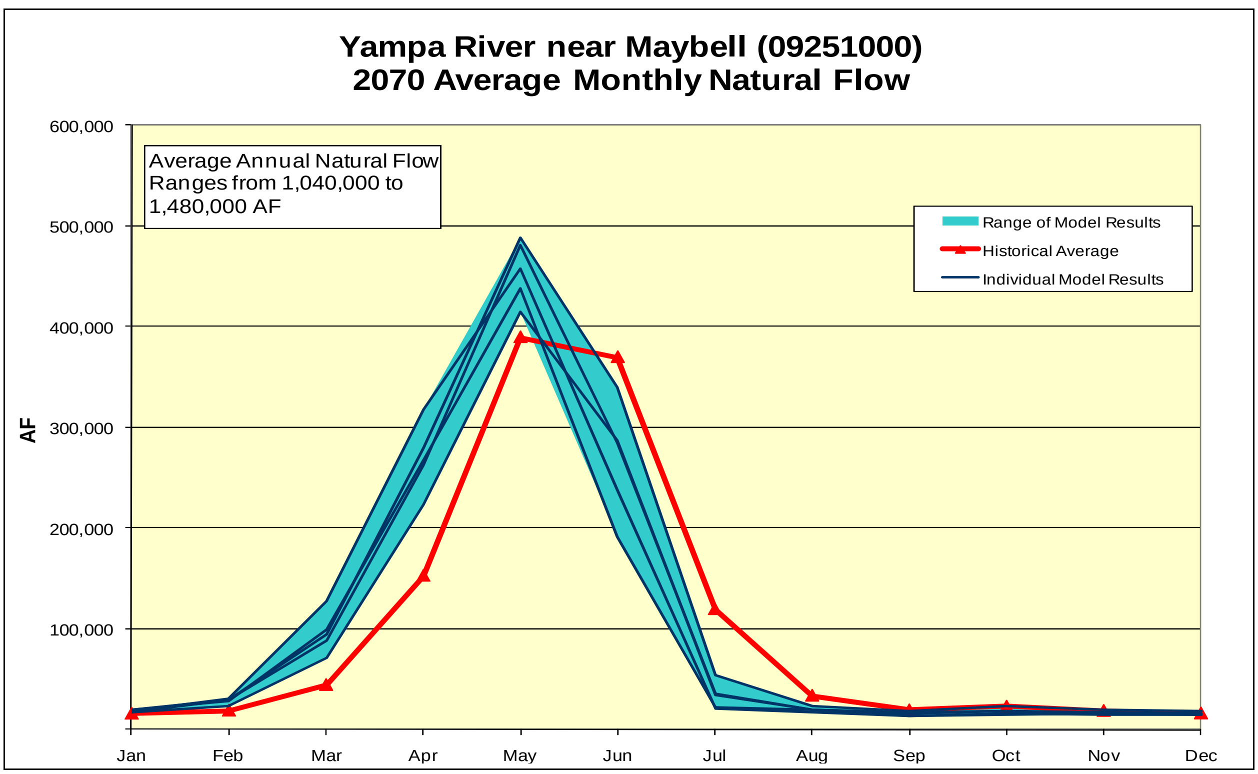


Figure D71 – 2070 Little Snake River near Lily Average Monthly Natural Flow Comparison

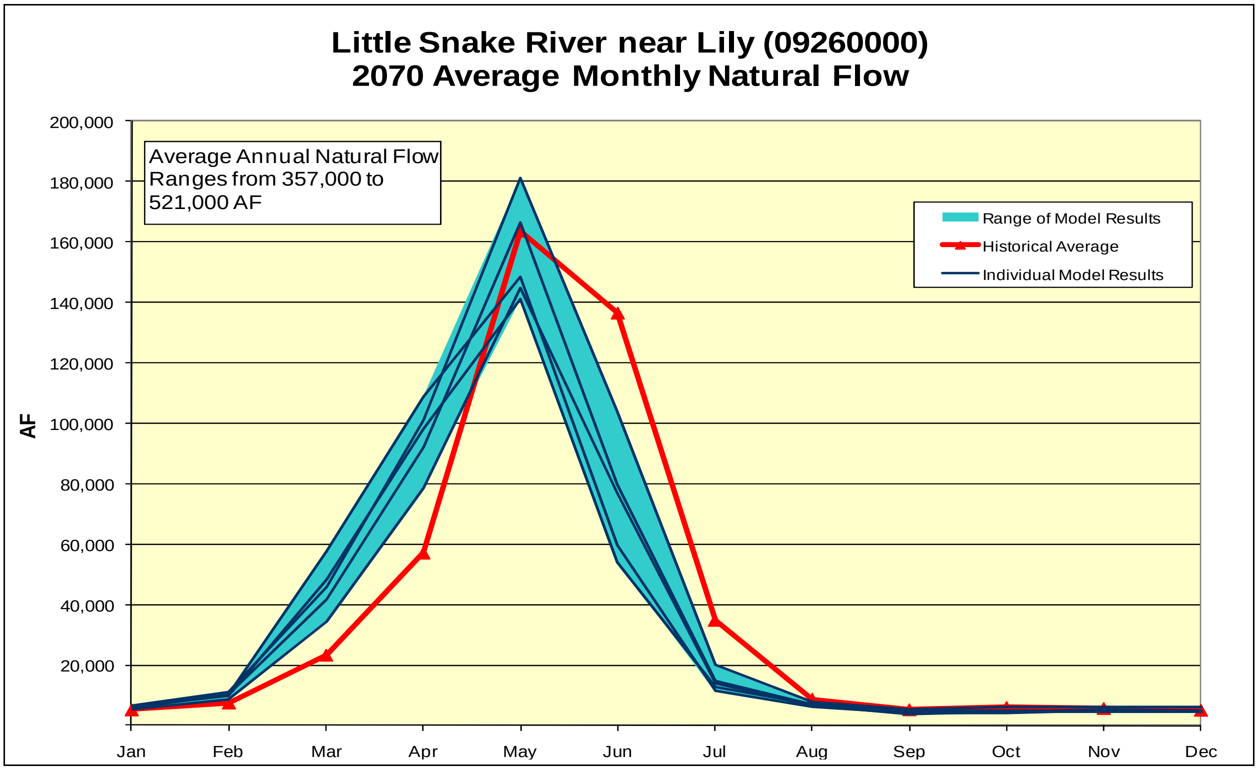


Figure D72 – 2070 Yampa River at Deerlodge Park Average Monthly Natural Flow Comparison

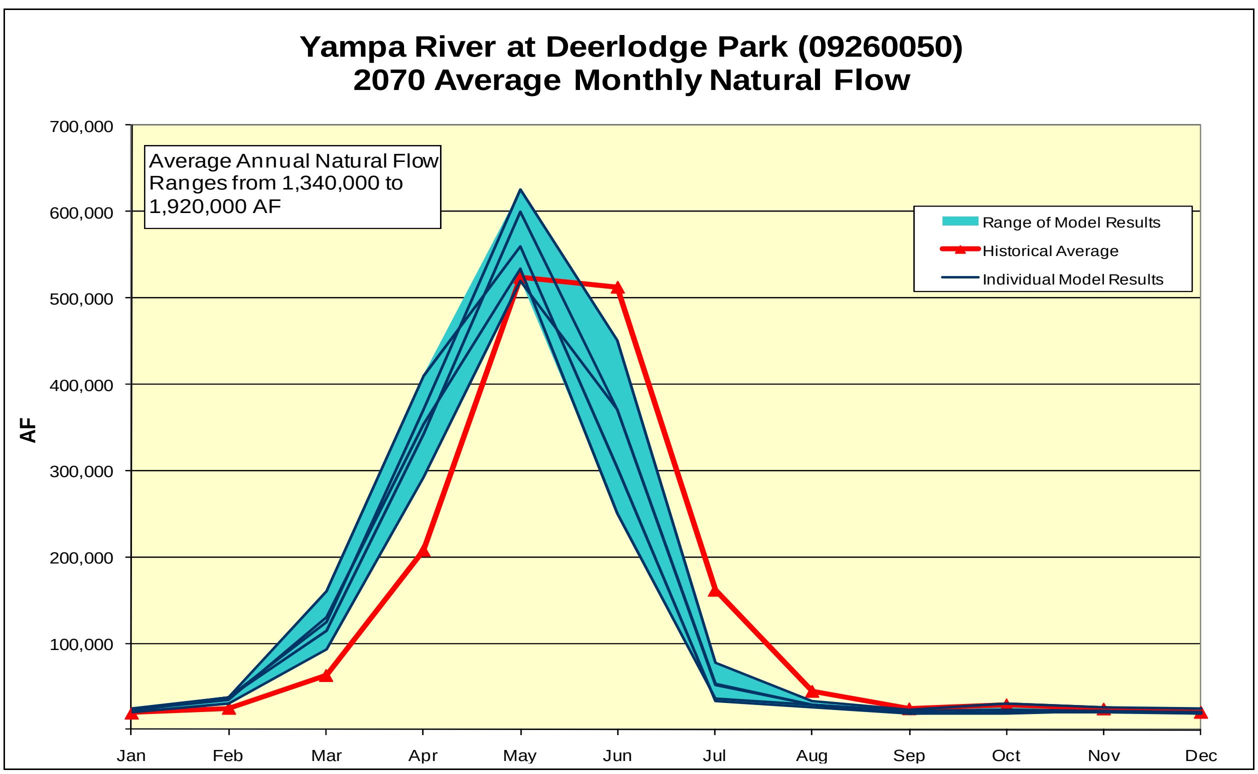


Figure D73 – 2070 North Fork White River at Buford, Co Average Monthly Natural Flow Comparison

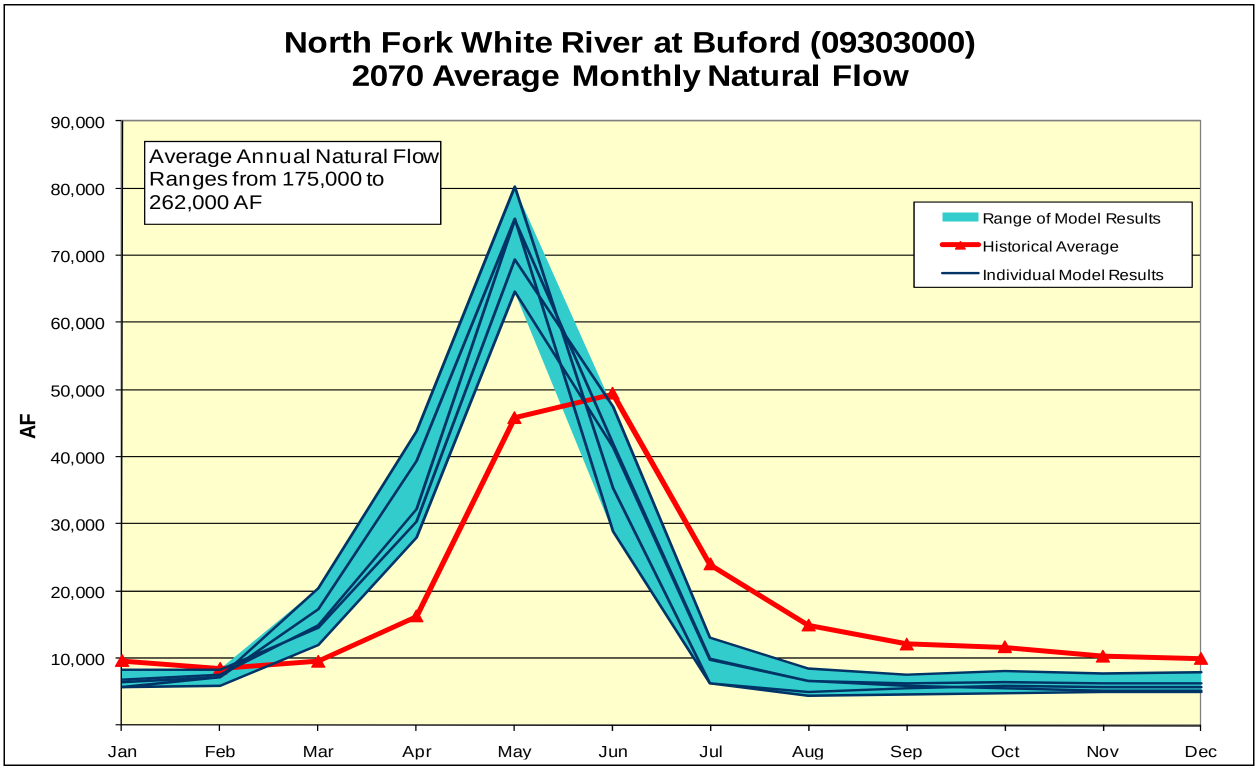


Figure D74 – 2070 South Fork White River at Buford Average Monthly Natural Flow Comparison

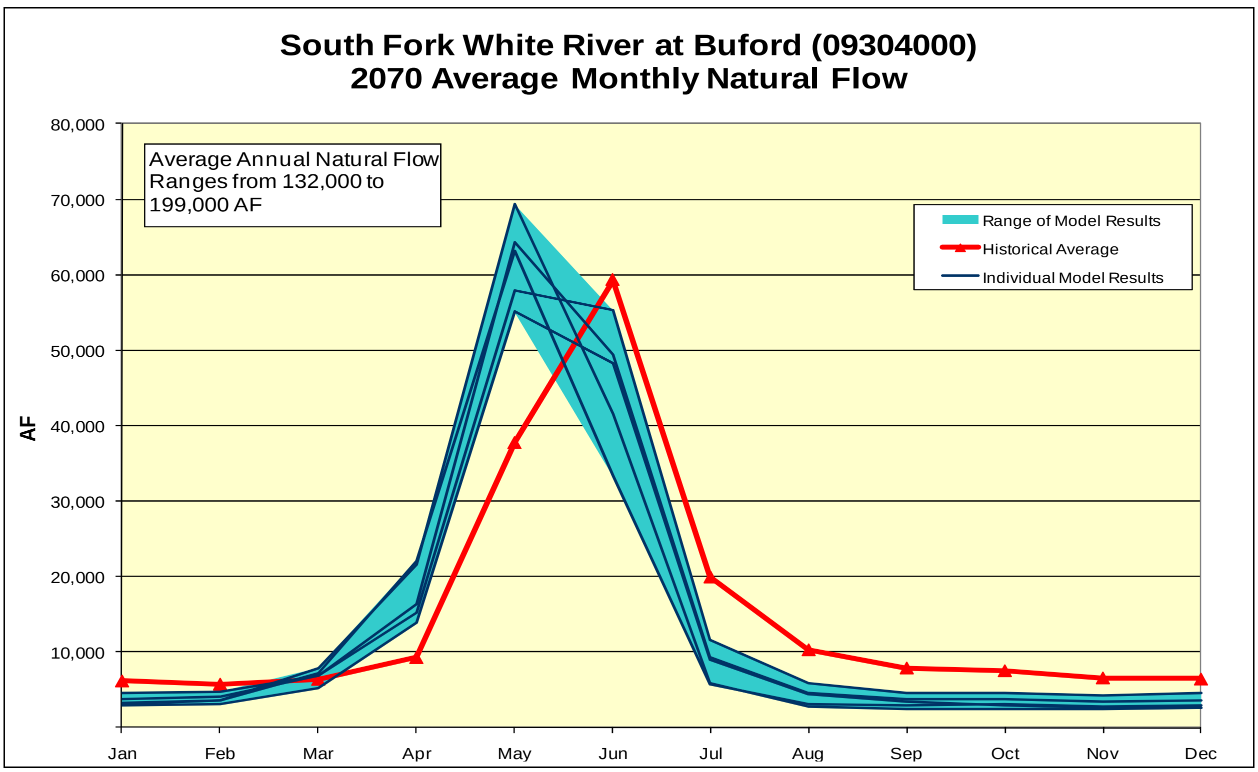


Figure D75 – 2070 White River below Meeker Average Monthly Natural Flow Comparison

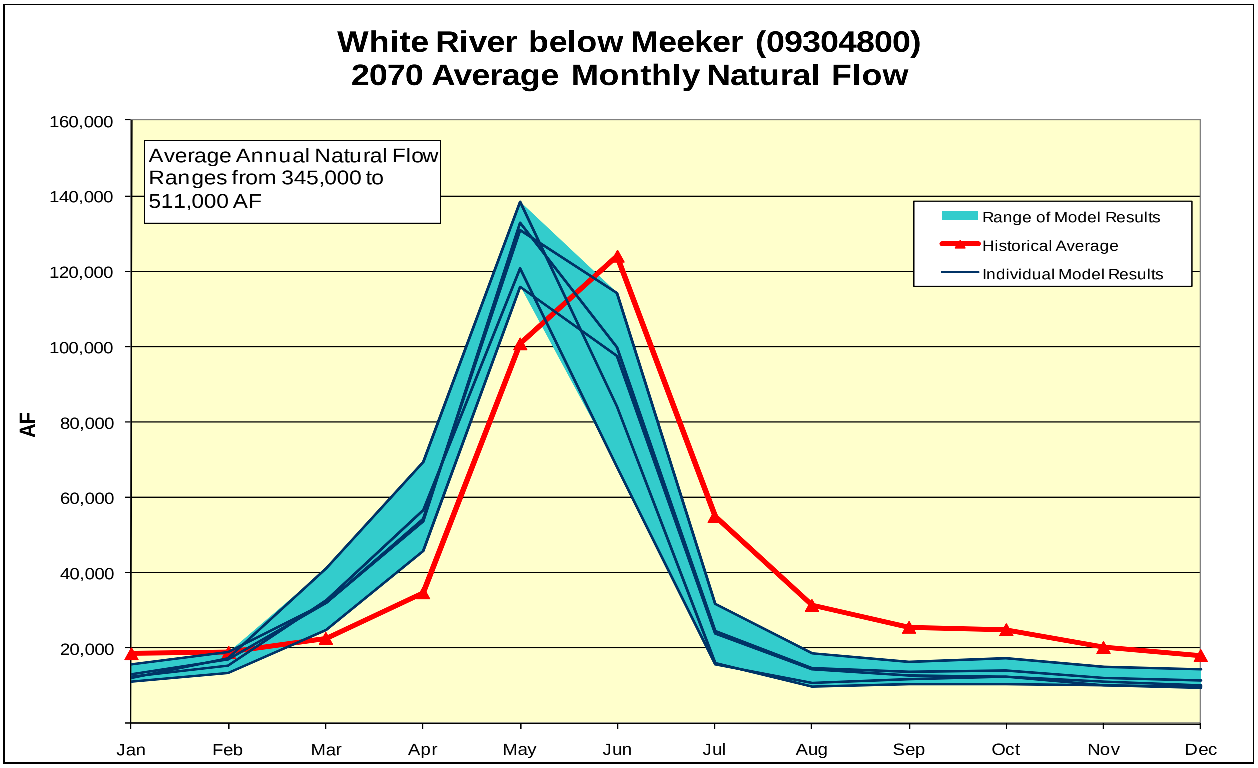


Figure D76 – 2070 Piceance Creek at White River Average Monthly Natural Flow Comparison

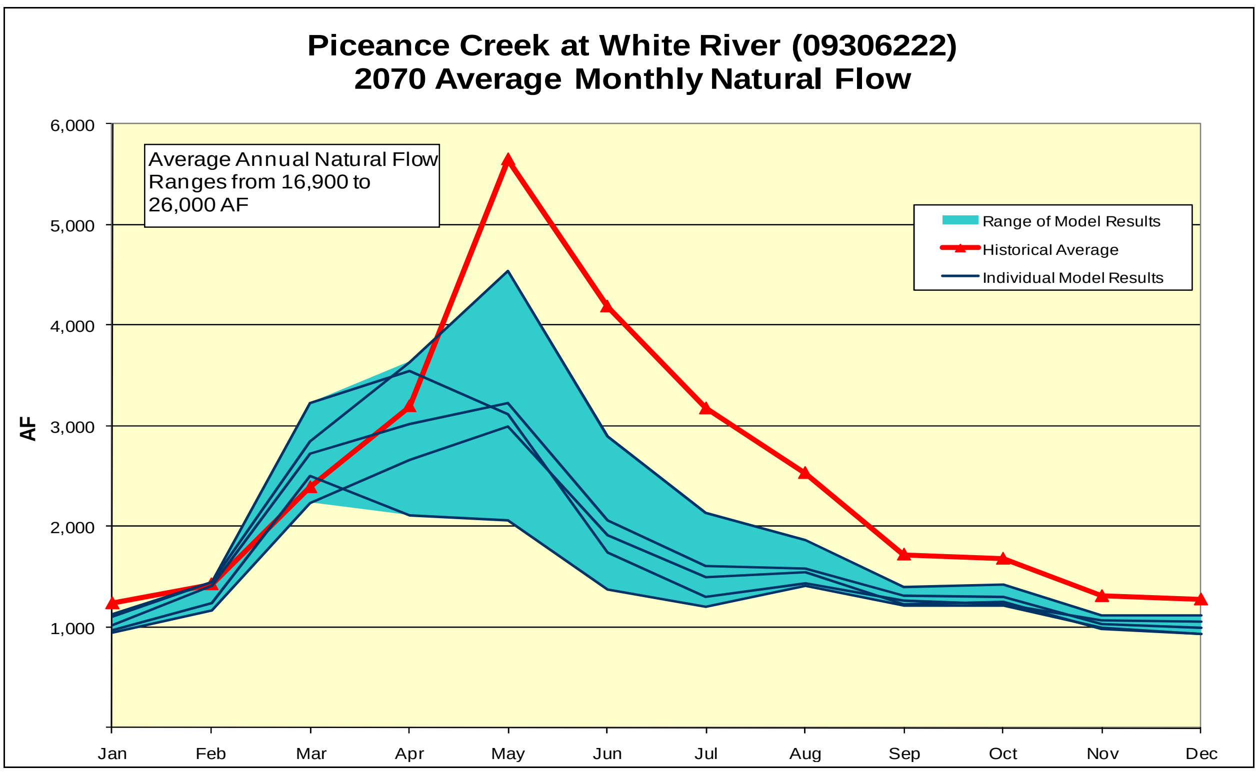


Figure D77 – 2070 White River near Colorado-Utah State Line Average Monthly Natural Flow Comparison

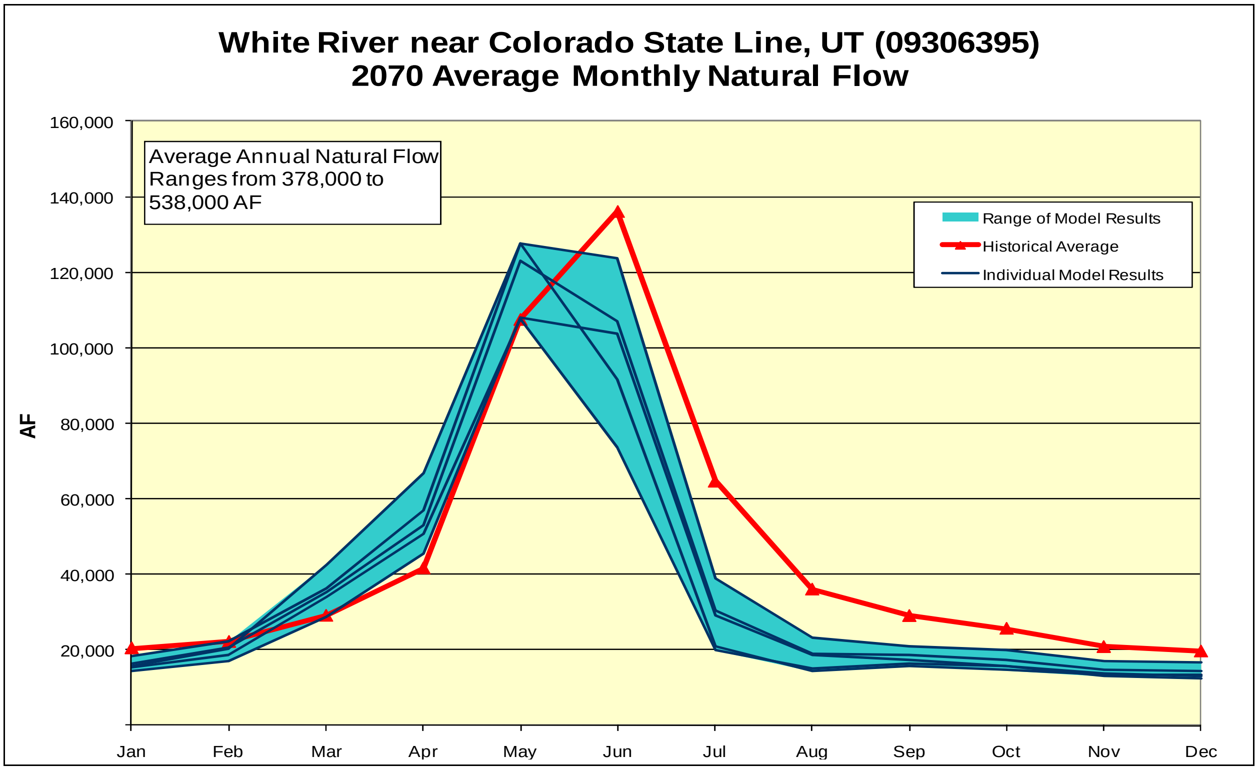


Figure D78 – 2070 San Juan River near Carracas Average Monthly Natural Flow Comparison

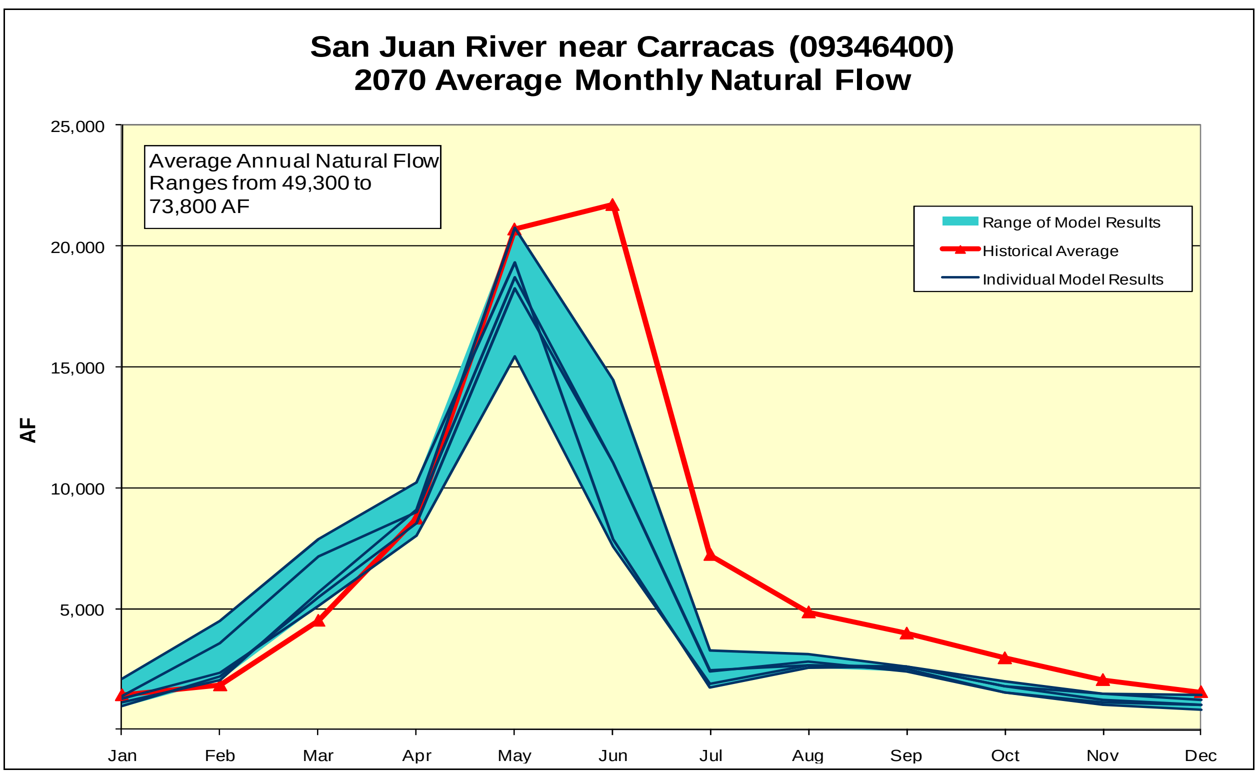


Figure D79 – 2070 Piedra River near Arboles Average Monthly Natural Flow Comparison

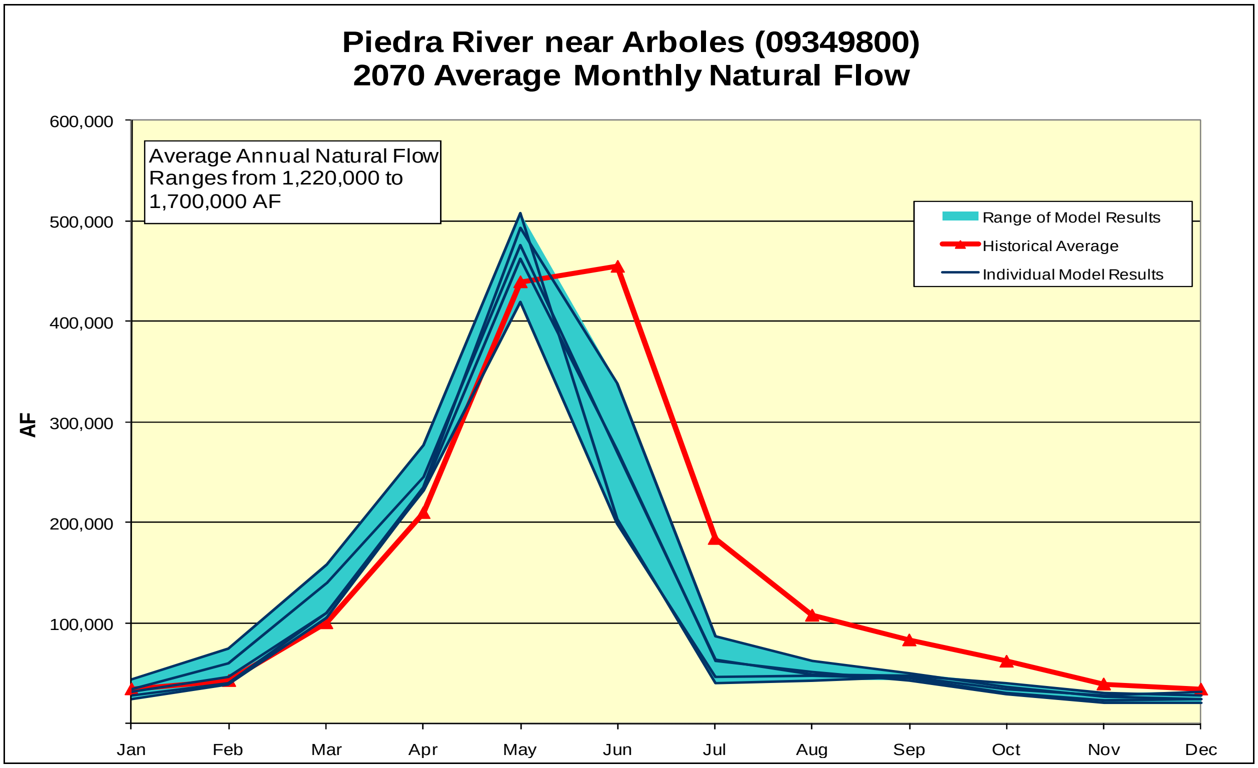


Figure D80 – 2070 Los Pinos River at La Boca Average Monthly Natural Flow Comparison

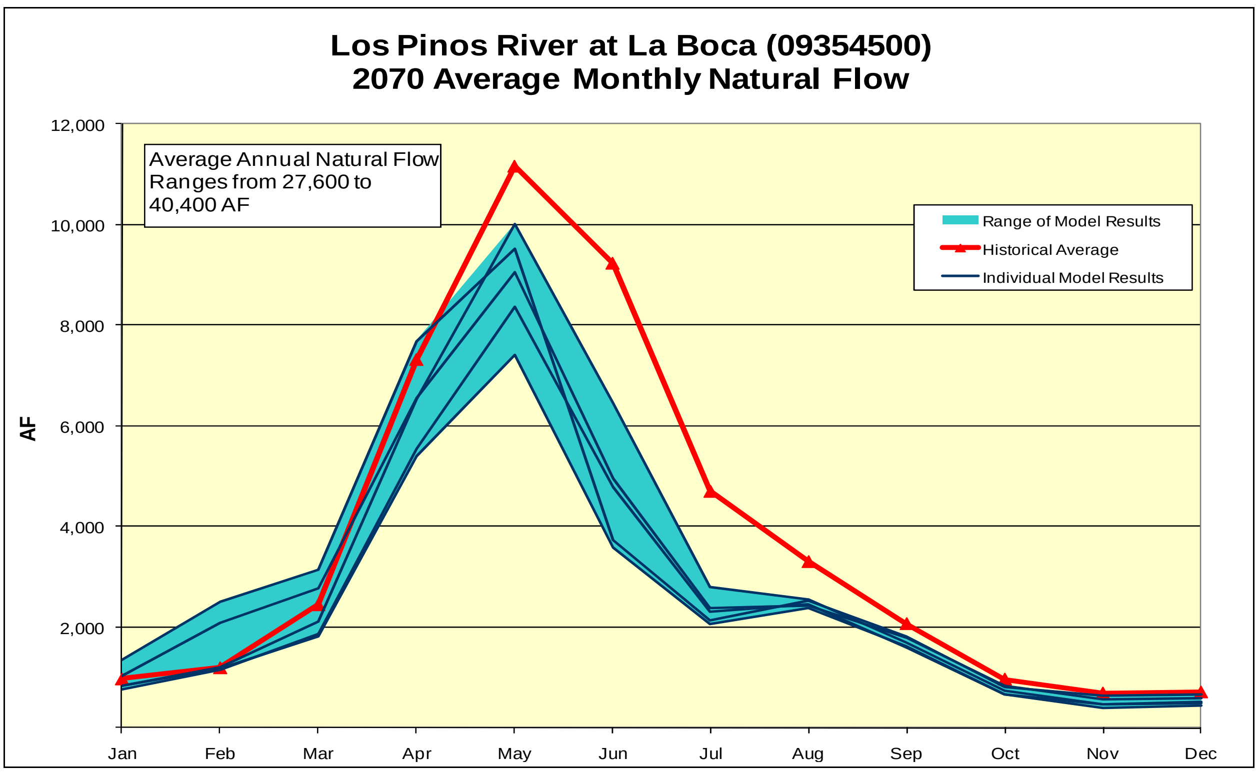


Figure D81 – 2070 Florida River at Bondad Average Monthly Natural Flow Comparison

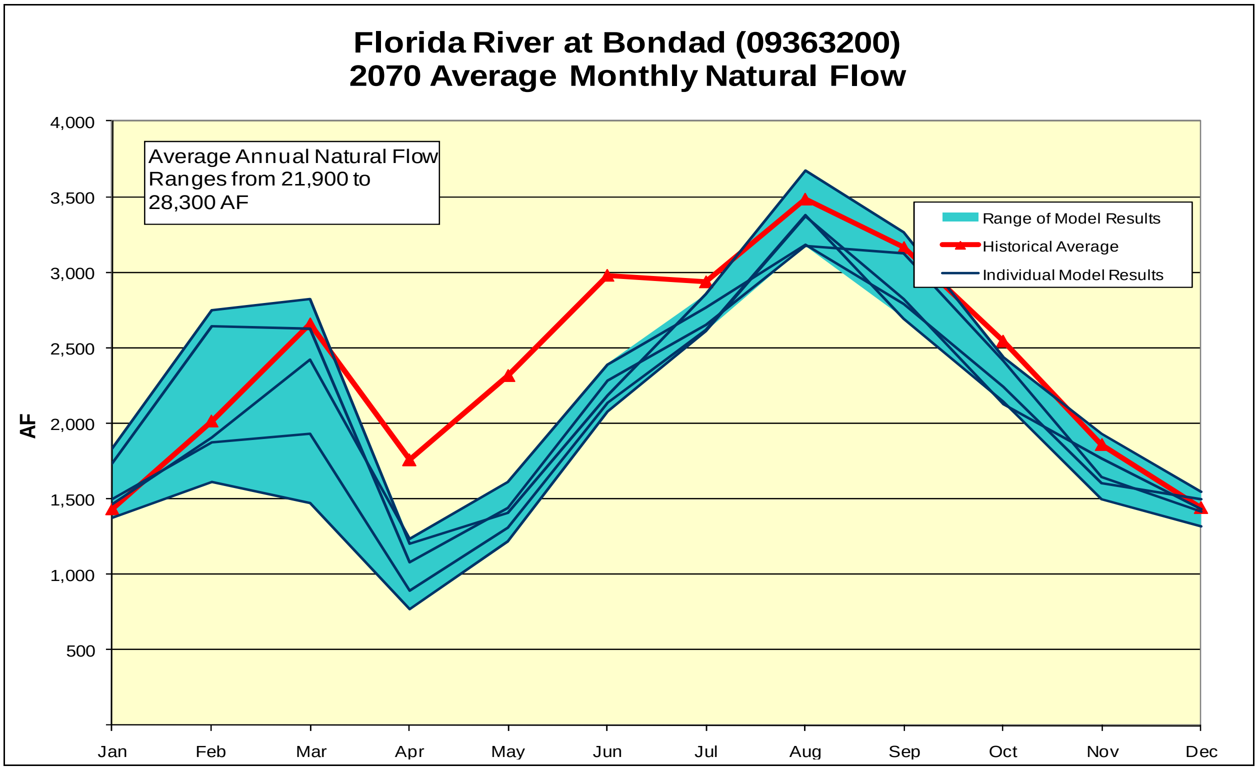


Figure D82 – 2070 Animas River near Cedar Hill, Nm Average Monthly Natural Flow Comparison

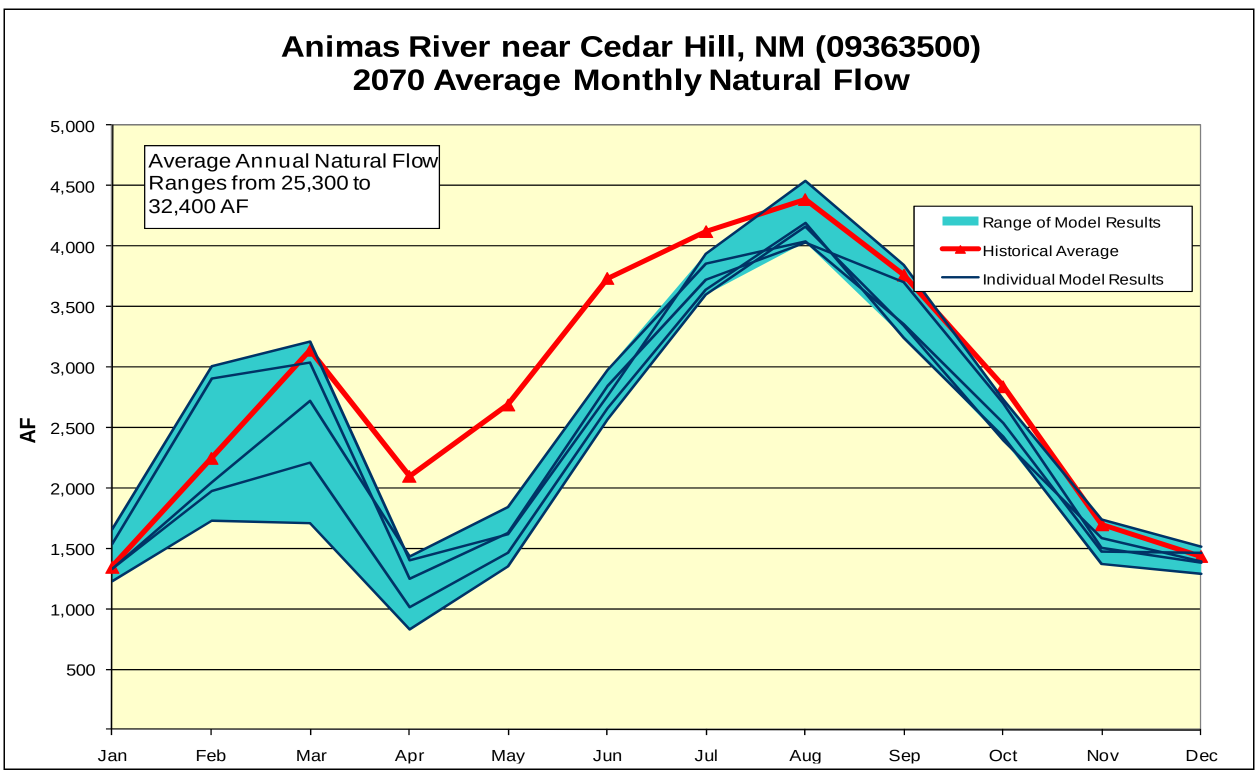


Figure D83 – 2070 La Plata River at Hesperus Average Monthly Natural Flow Comparison

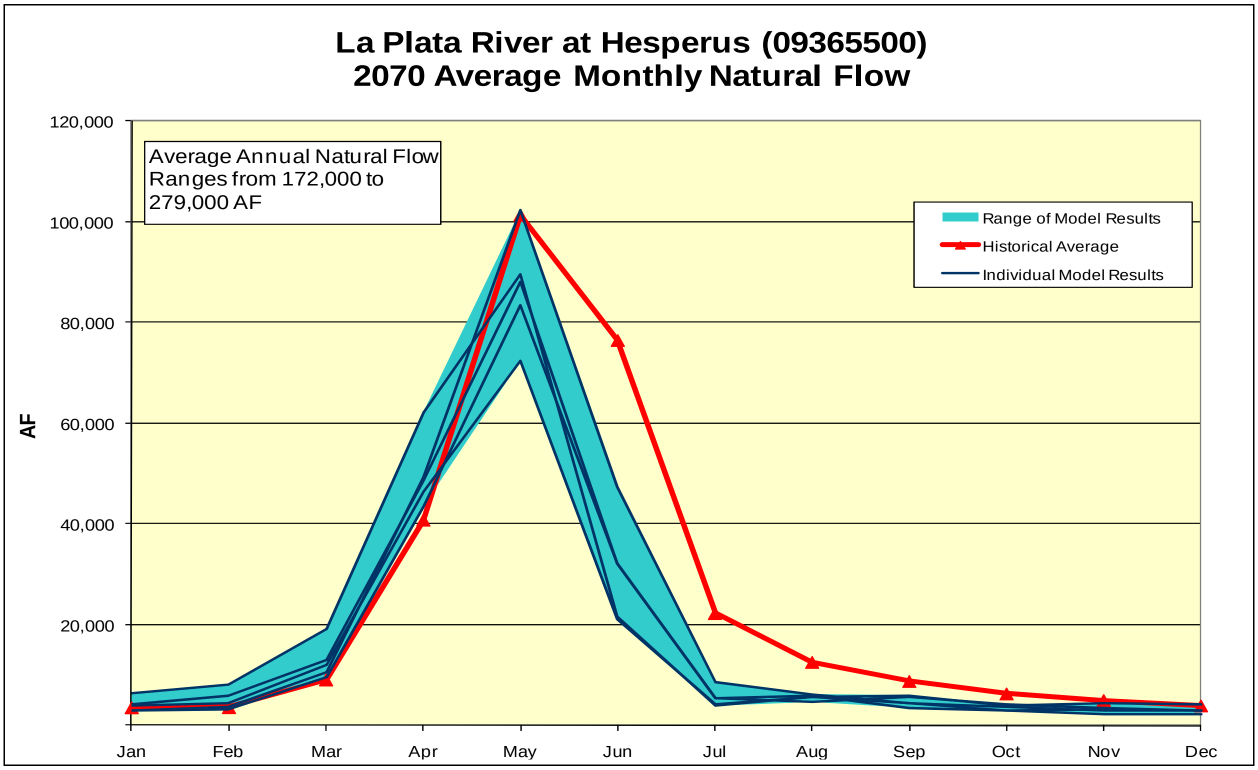


Figure D84 – 2070 La Plata River at Colorado-New Mexico State Line Average Monthly Natural Flow Comparison

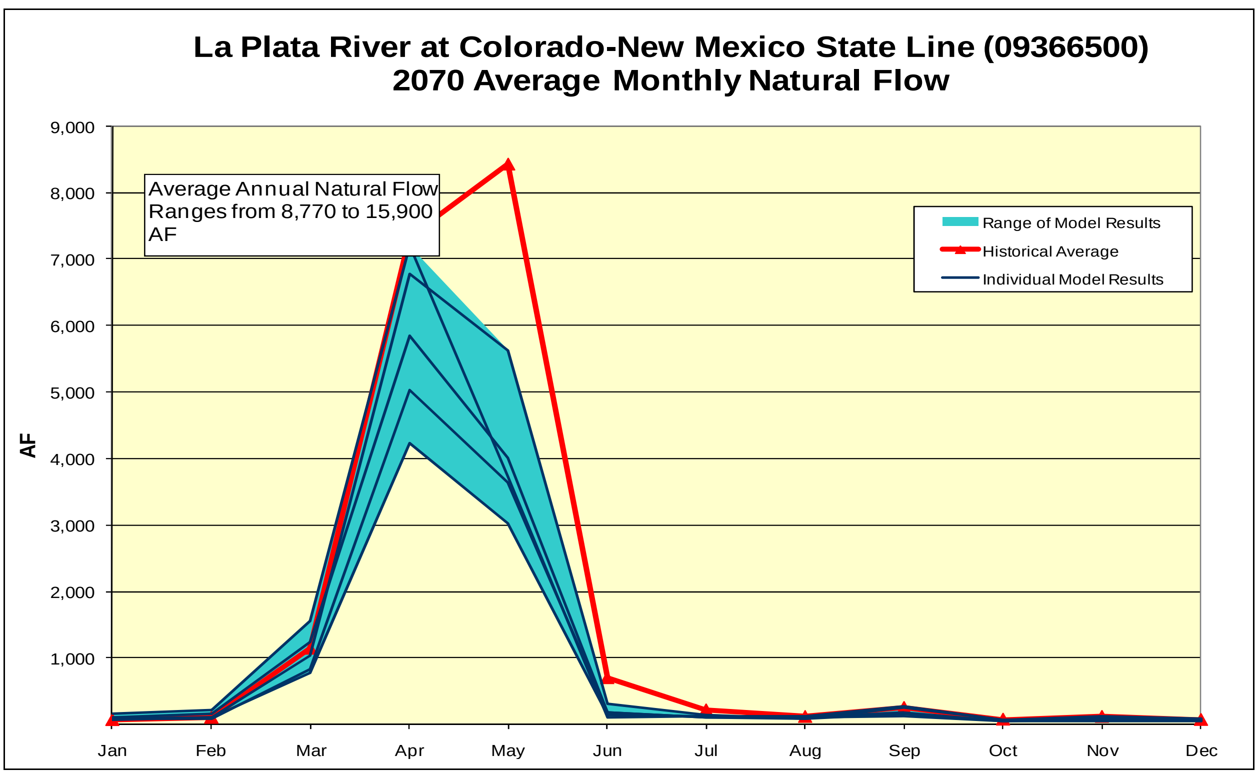


Figure D85 – 2070 Mancos River near Towaoc Average Monthly Natural Flow Comparison

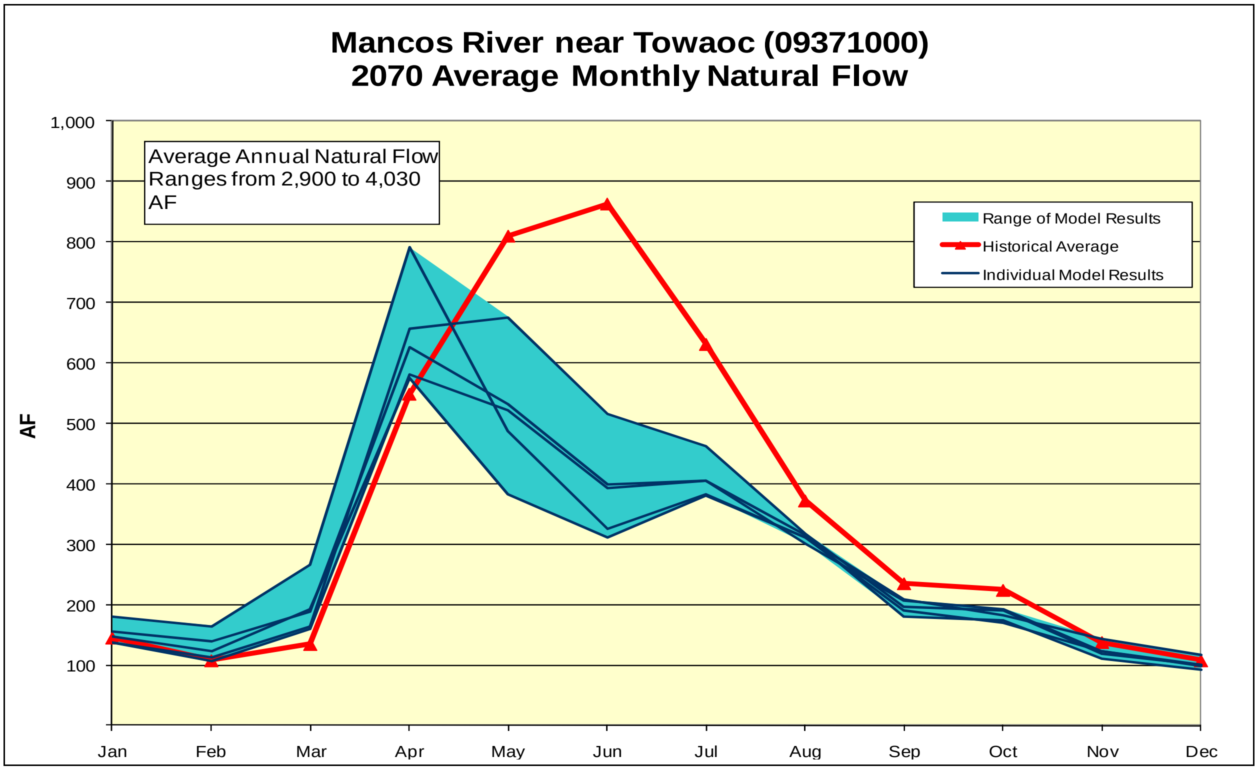


Figure D86 – 2070 McElmo Creek near Colorado-Utah State Line Average Monthly Natural Flow Comparison

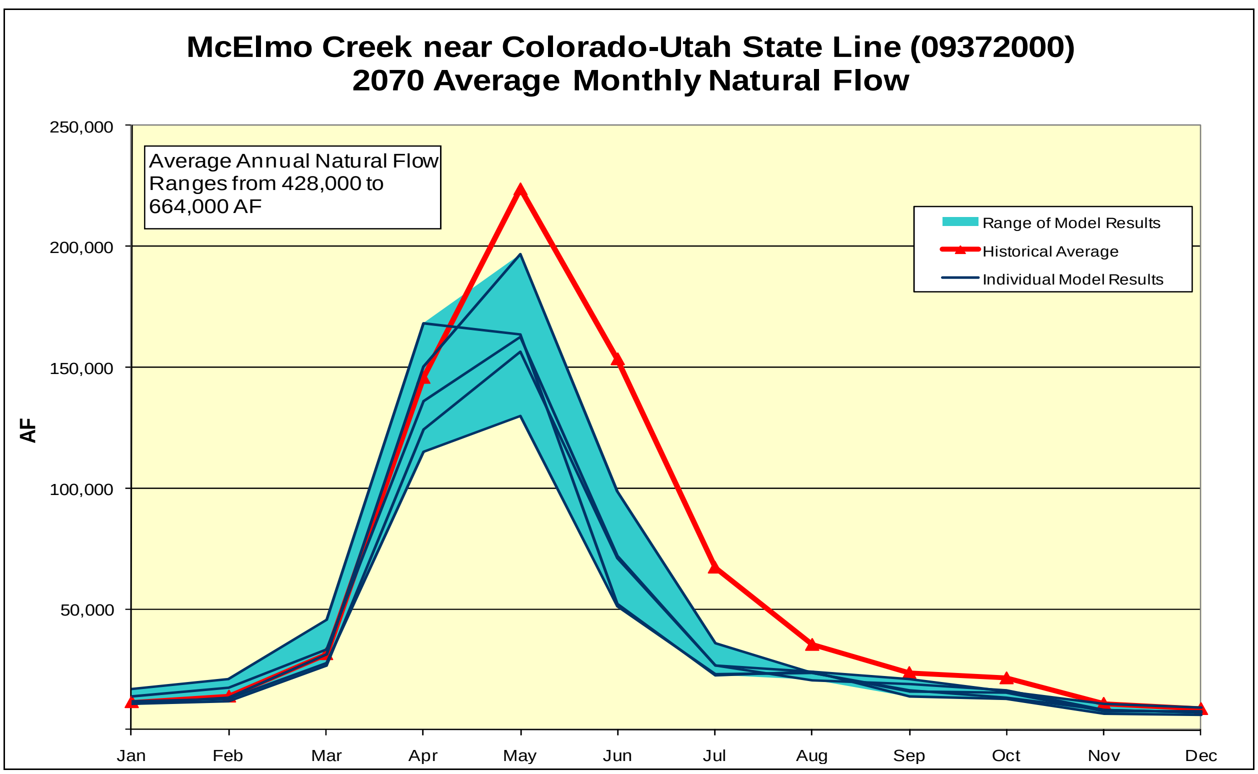


Figure D87 – 2040 Colorado River near Grand Lake Natural Flow Low-Flow Comparison

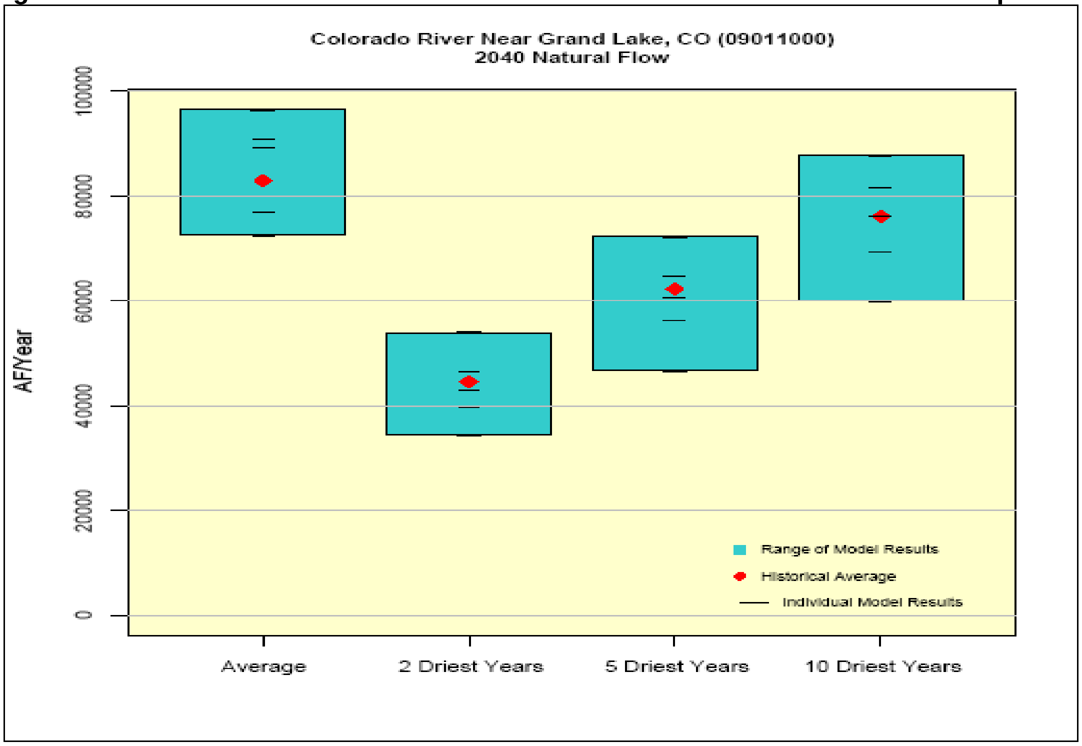


Figure D88 – 2040 Muddy Creek at Kremmling Natural Flow Low-Flow Comparison

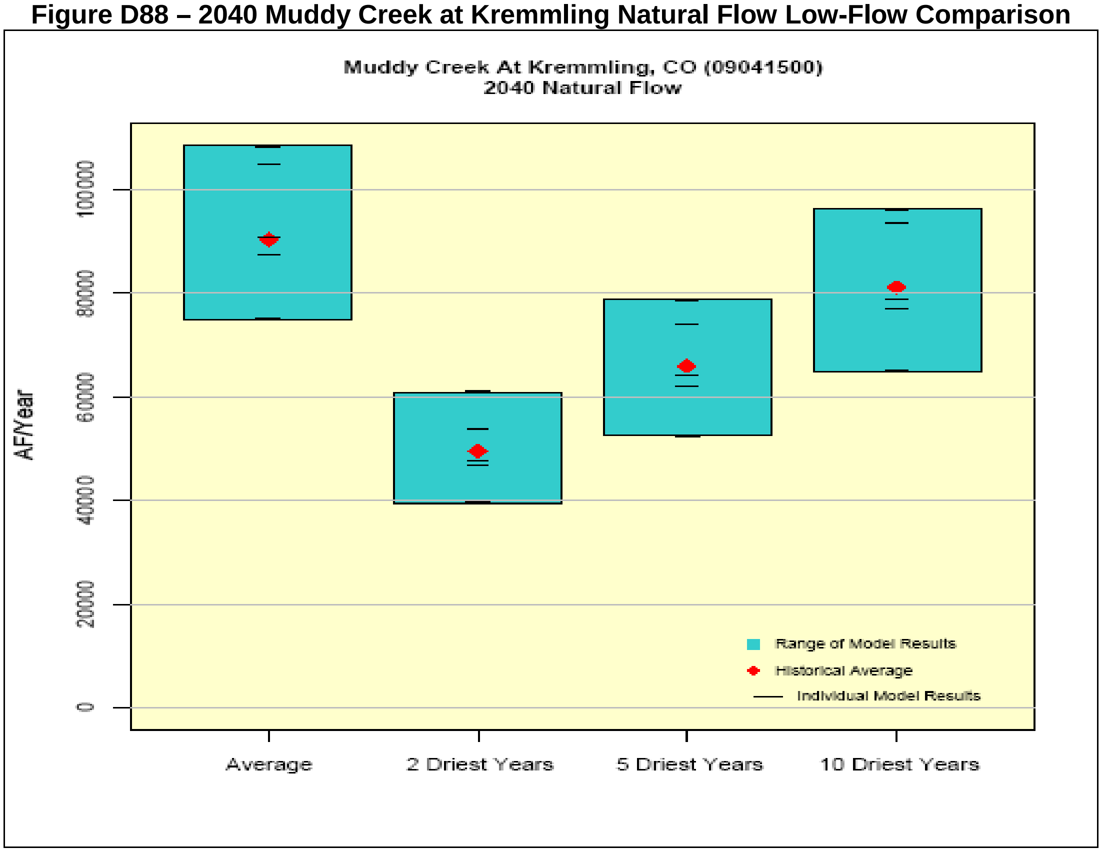


Figure D89 – 2040 Blue River below Dillon Natural Flow Low-Flow Comparison

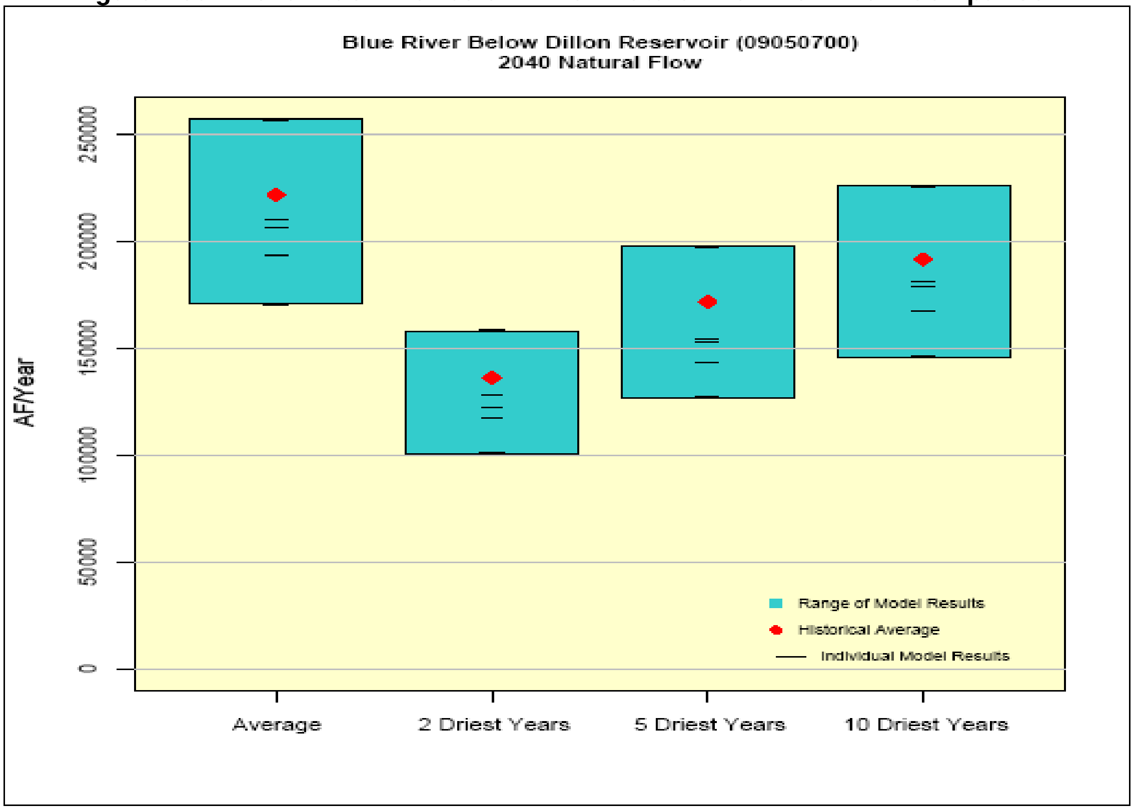


Figure D90 – 2040 Blue River below Green Mountain Reservoir Natural Flow Low-Flow Comparison

Figure D91 – 2040 Eagle River below Gypsum Natural Flow Low-Flow Comparison

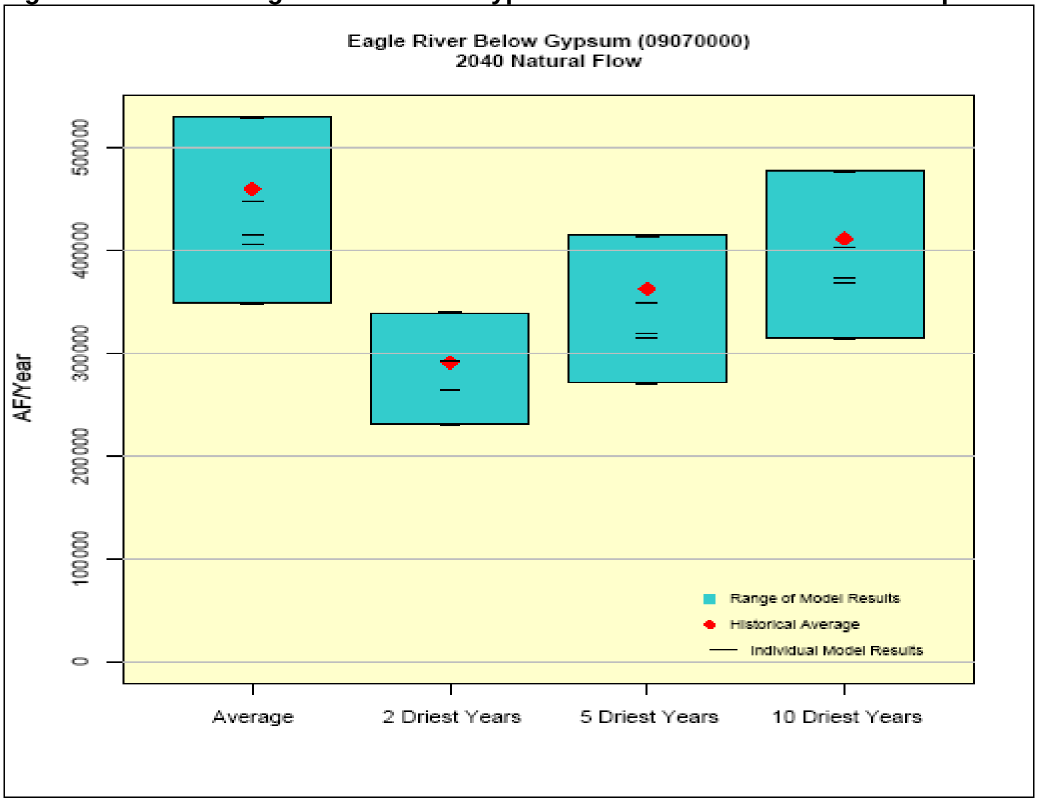


Figure D92 – 2040 Colorado River at Dotsero Natural Flow Low-Flow Comparison

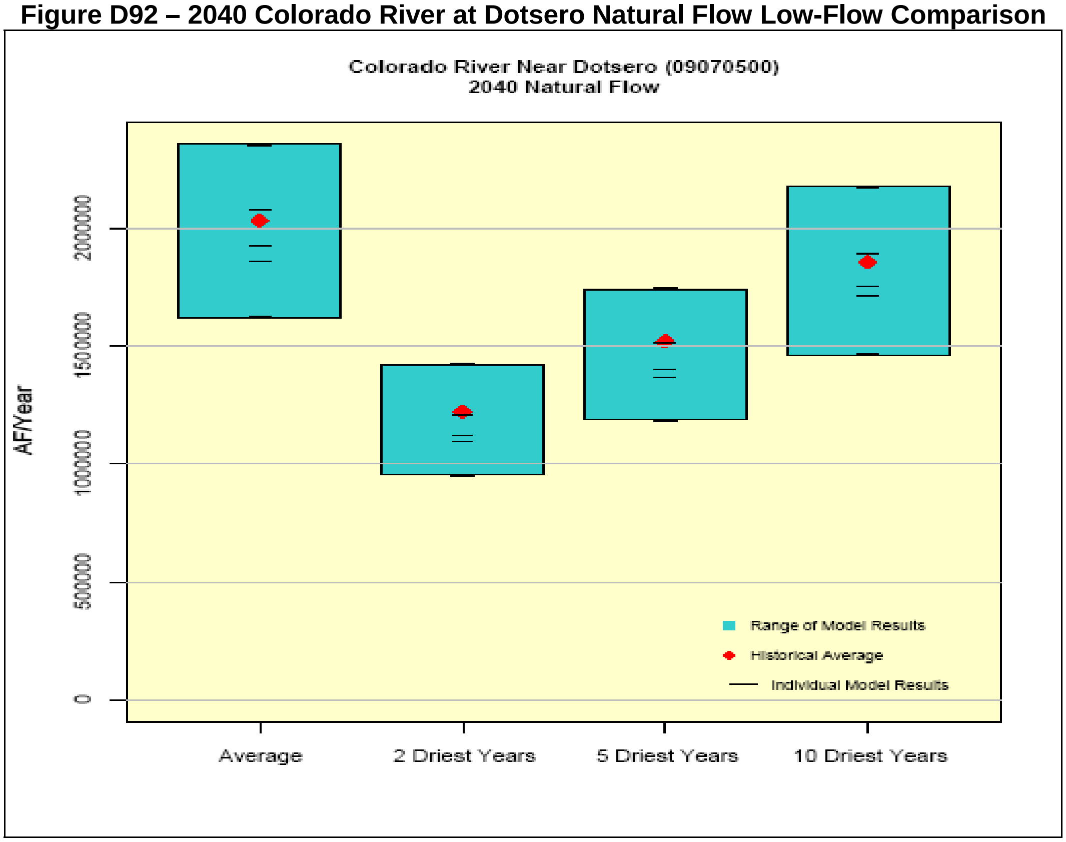


Figure D93 – 2040 Roaring Fork River near Aspen Natural Flow Low-Flow Comparison

Figure D94 – 2040 Roaring Fork River at Glenwood Natural Flow Low-Flow Comparison

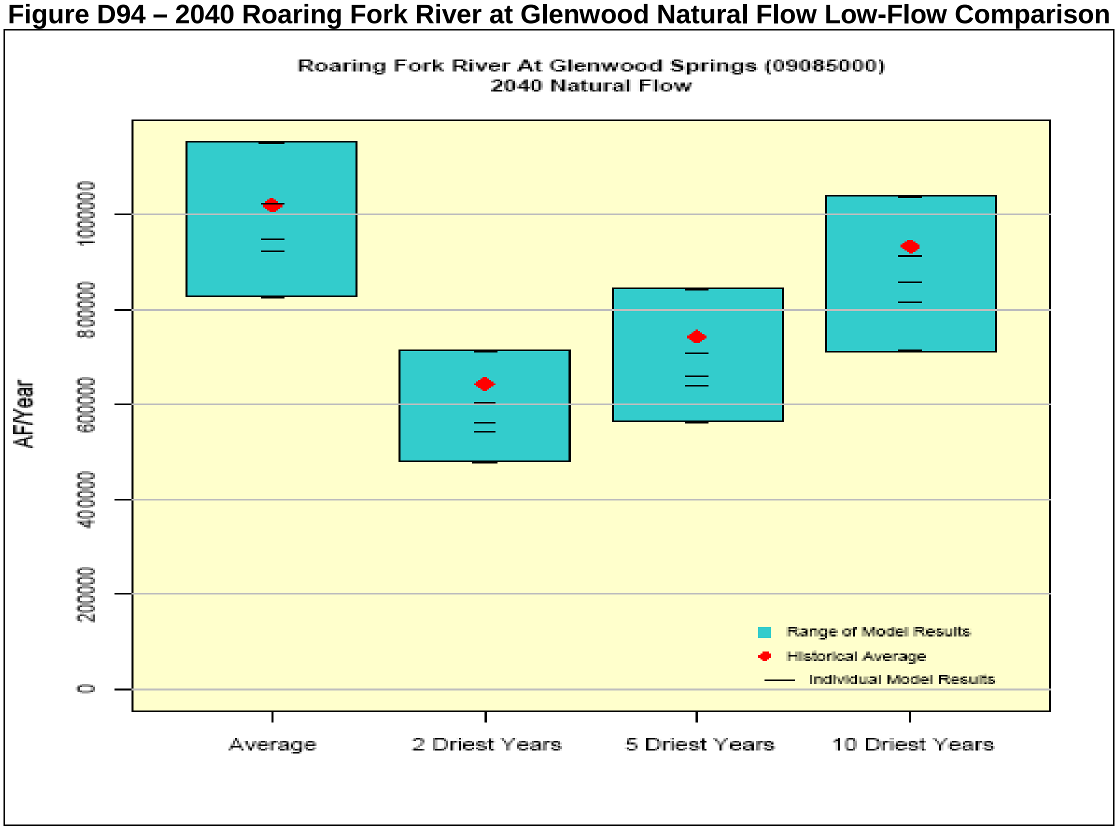


Figure D95 – 2040 Colorado River near Cameo Natural Flow Low-Flow Comparison

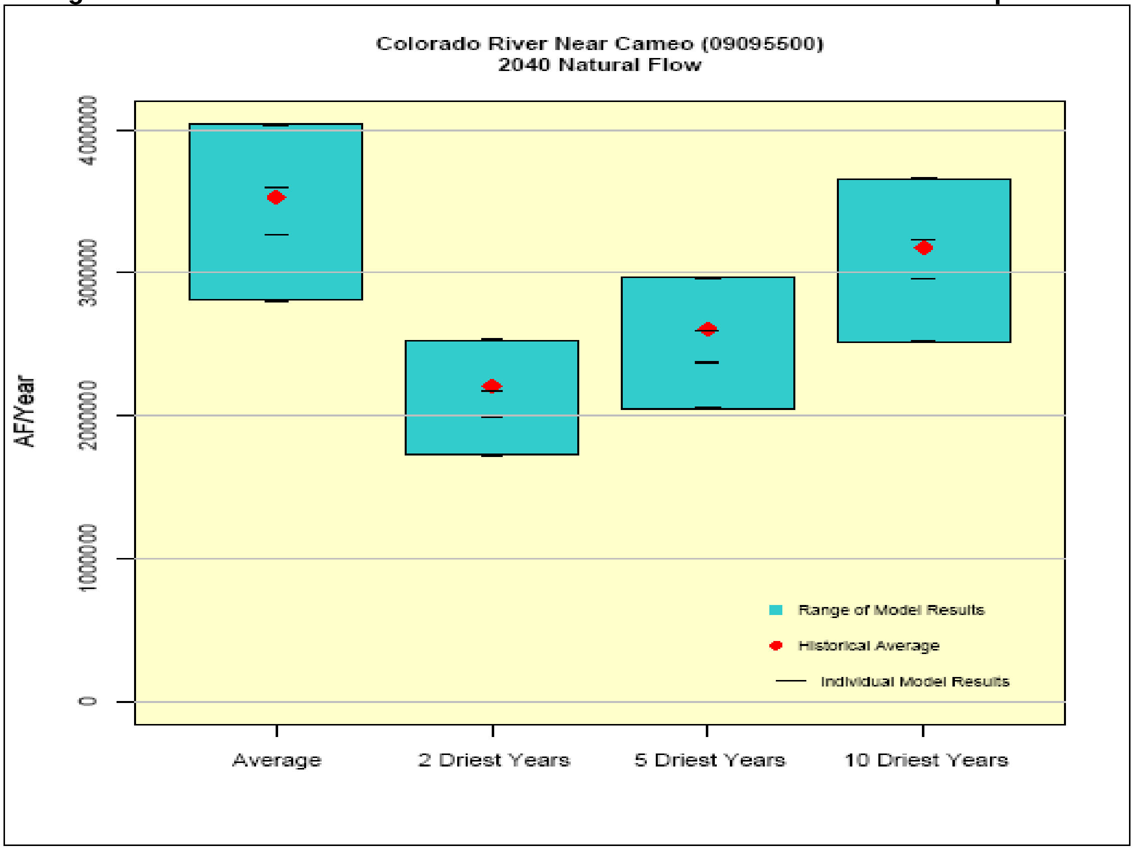


Figure D96 – 2040 Plateau Creek near Cameo Natural Flow Low-Flow Comparison

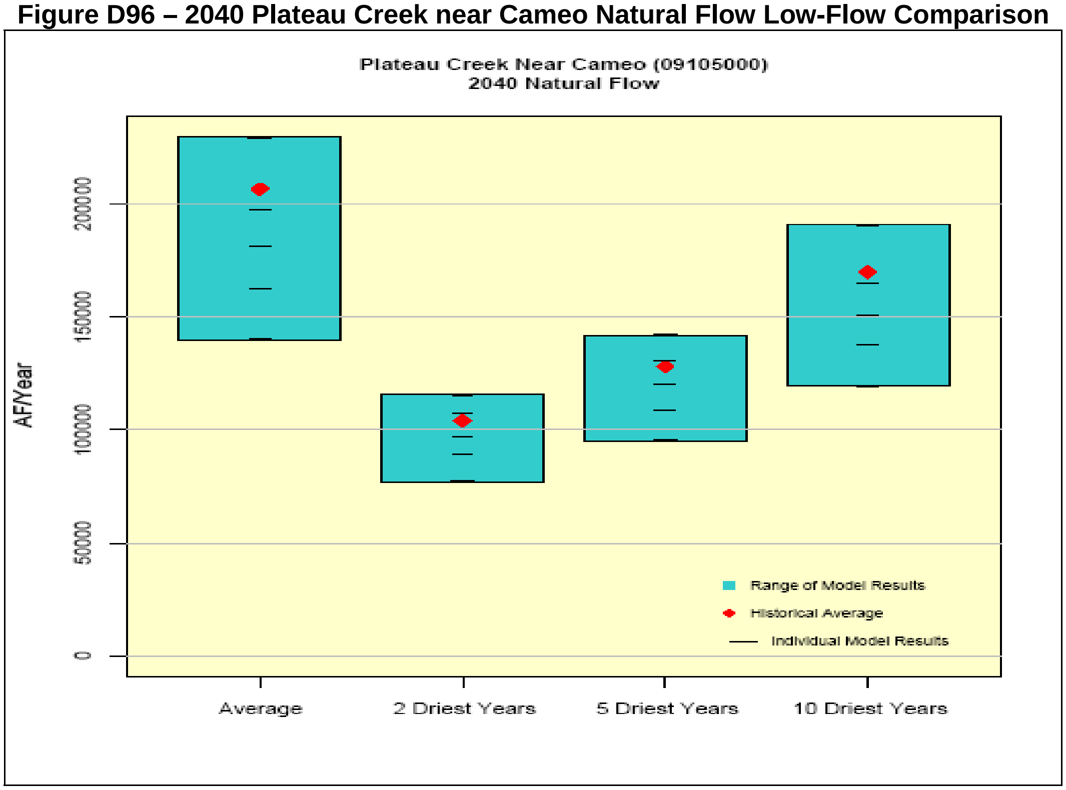


Figure D97 – 2040 Taylor River at Almont Natural Flow Low-Flow Comparison

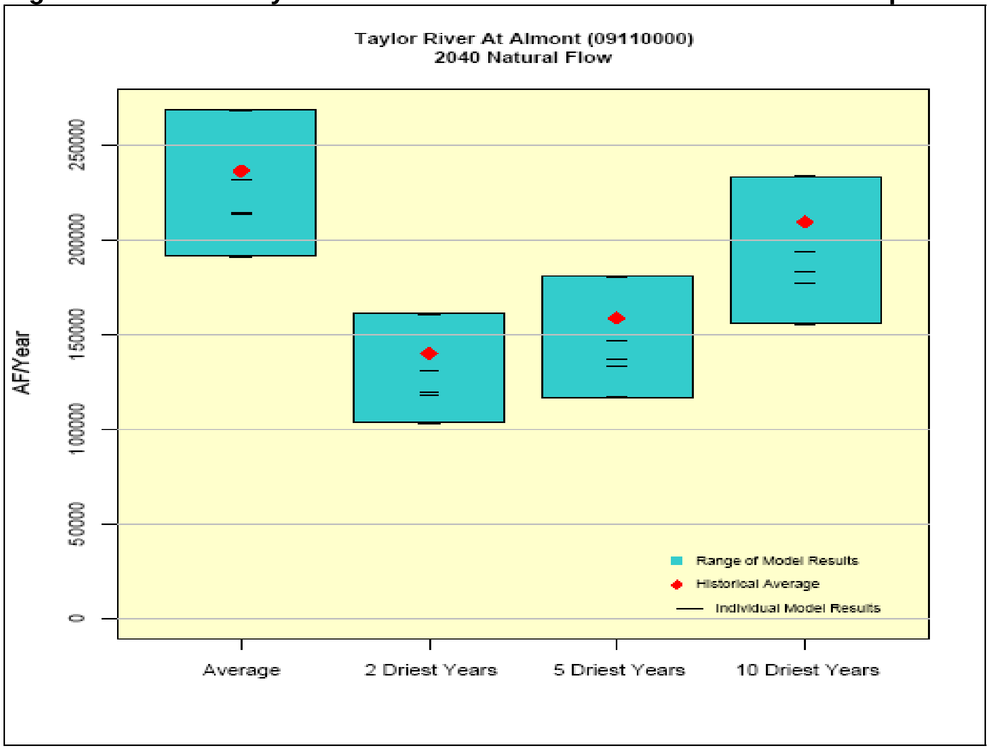


Figure D98 – 2040 East River at Almont Natural Flow Low-Flow Comparison

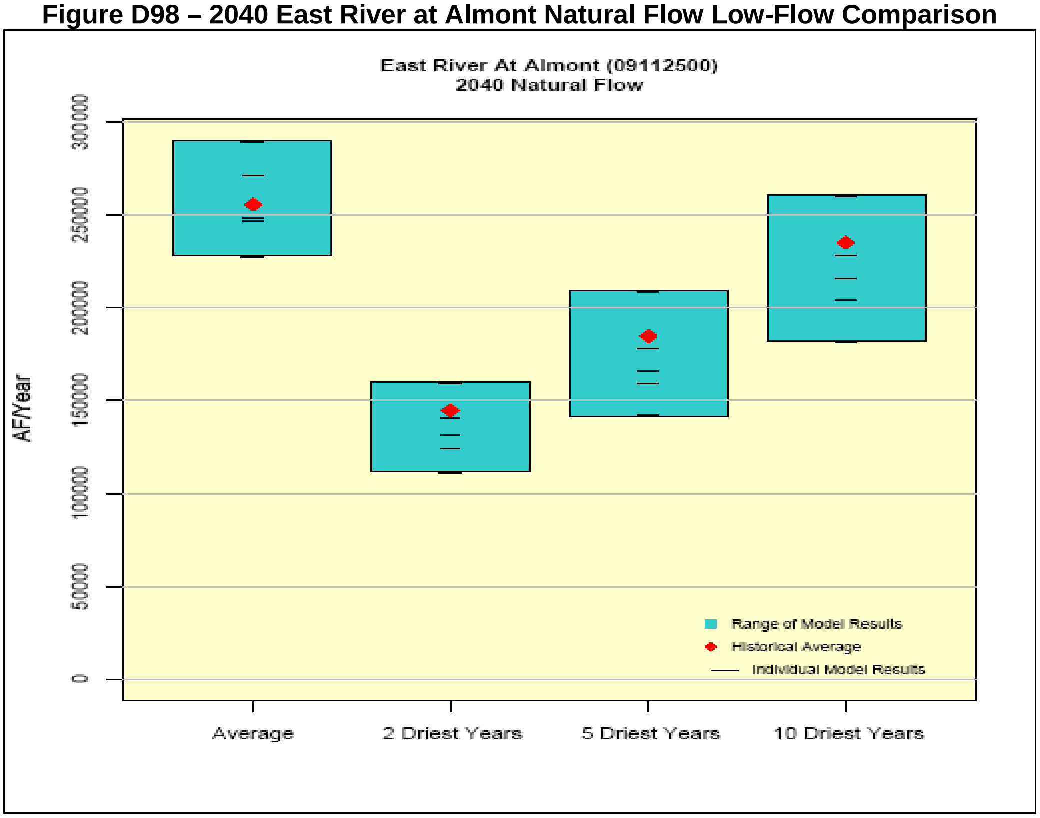


Figure D99 – 2040 Gunnison River near Gunnison Natural Flow Low-Flow Comparison

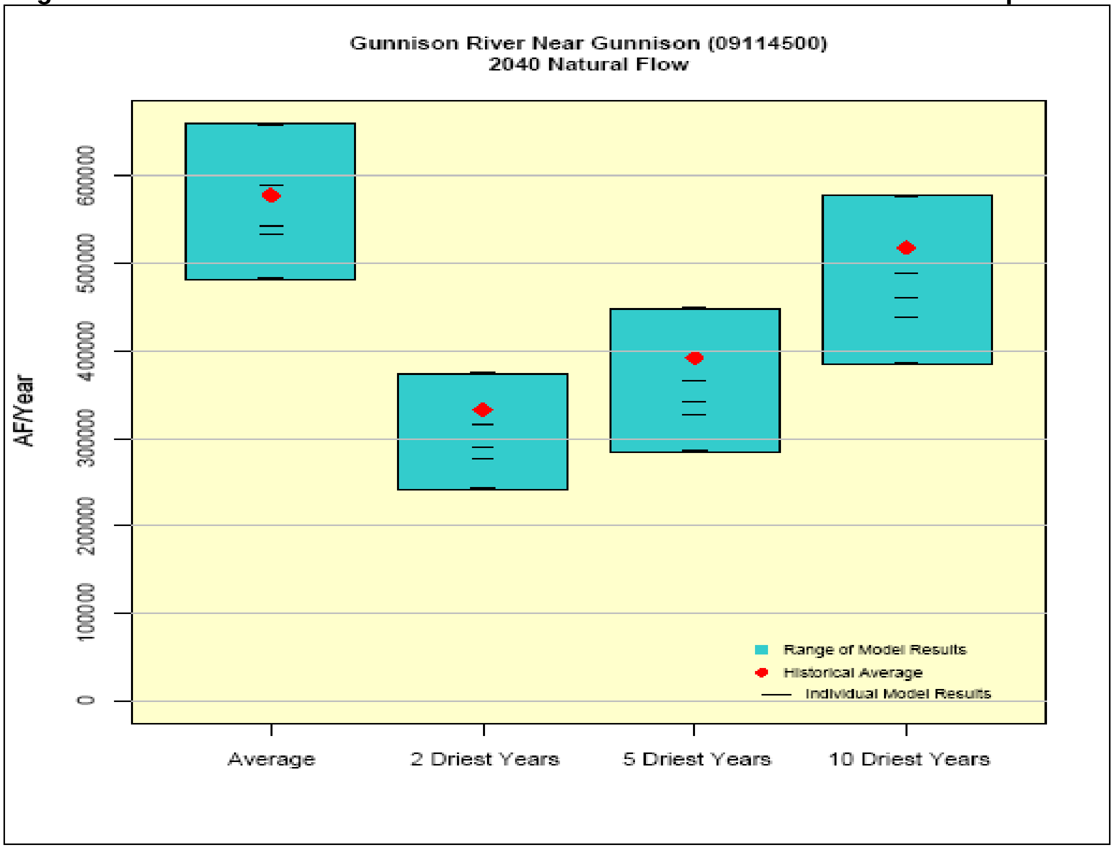


Figure D100 – 2040 Tomichi Creek at Gunnison Natural Flow Low-Flow Comparison

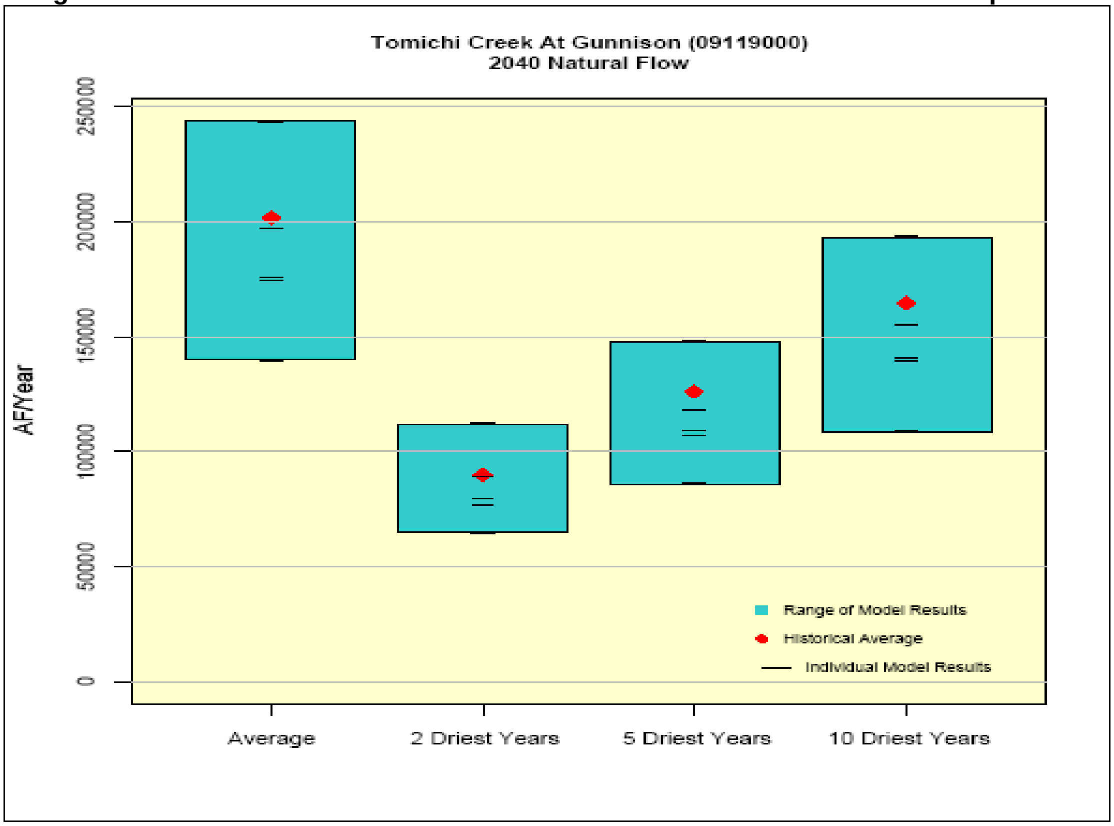


Figure D101 – 2040 Cimarron River at Cimarron Natural Flow Low-Flow Comparison

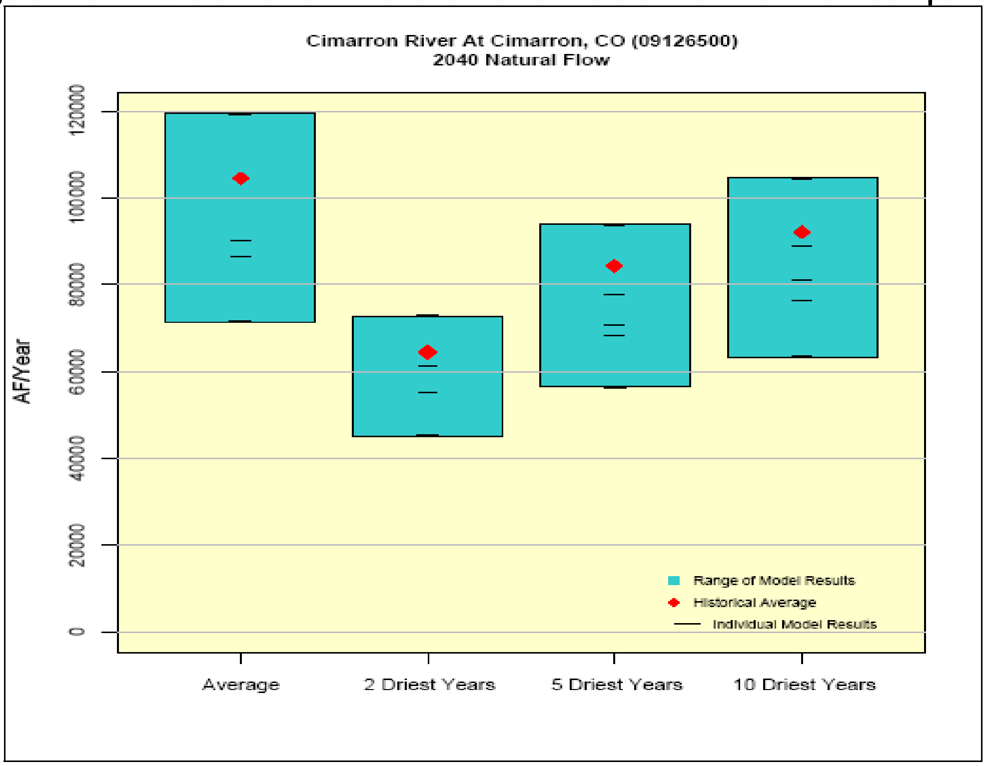


Figure D102 – 2040 Gunnison River below Gunnison Tunnel Natural Flow Low-Flow Comparison

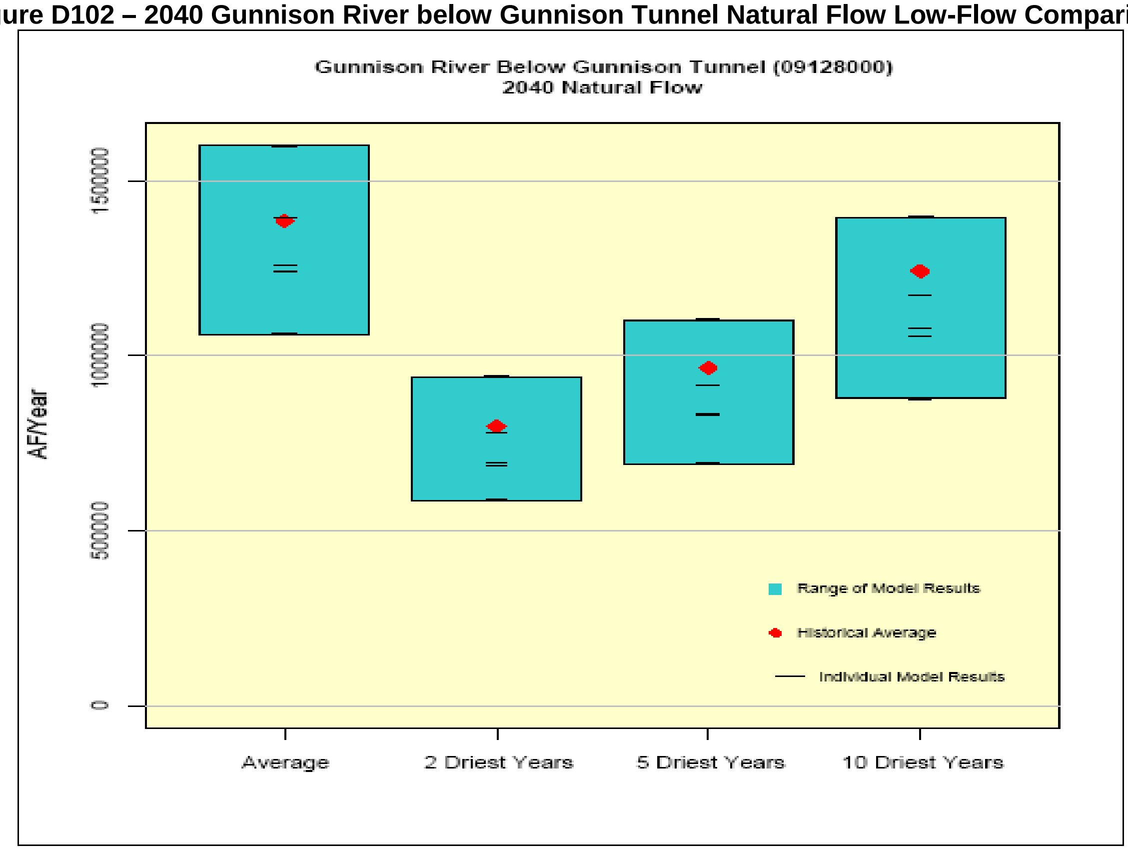


Figure D103 – 2040 Gunnison River near Lazear Natural Flow Low-Flow Comparison

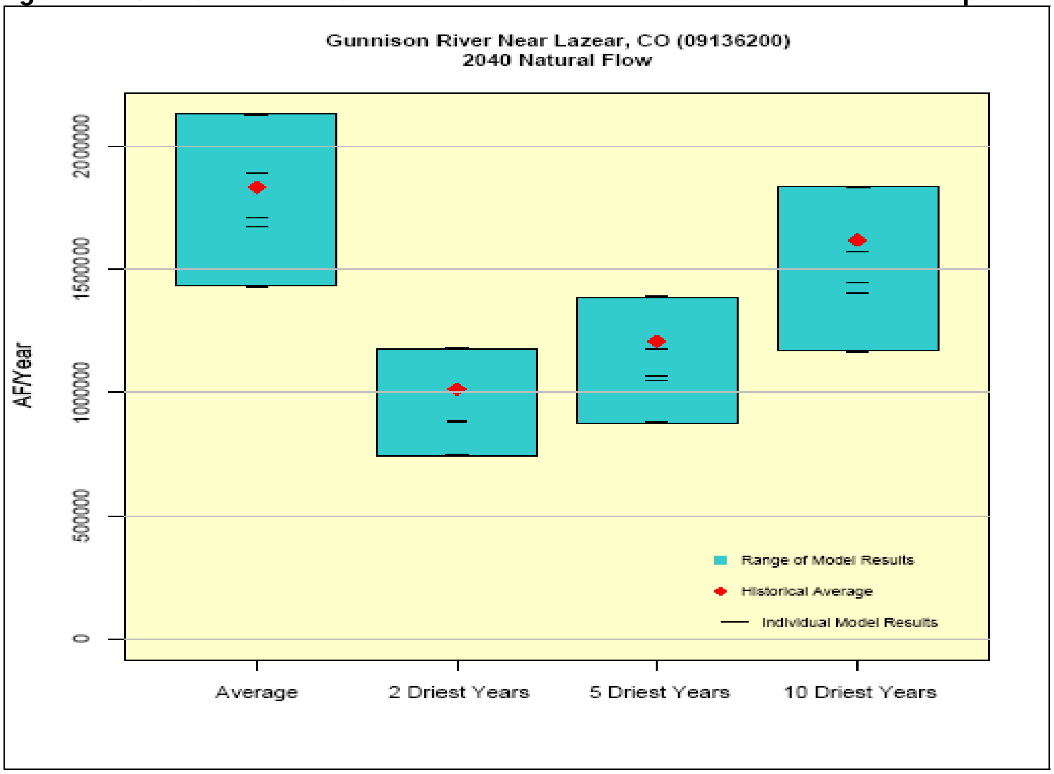


Figure D104 – 2040 Uncompahgre River at Delta Natural Flow Low-Flow Comparison

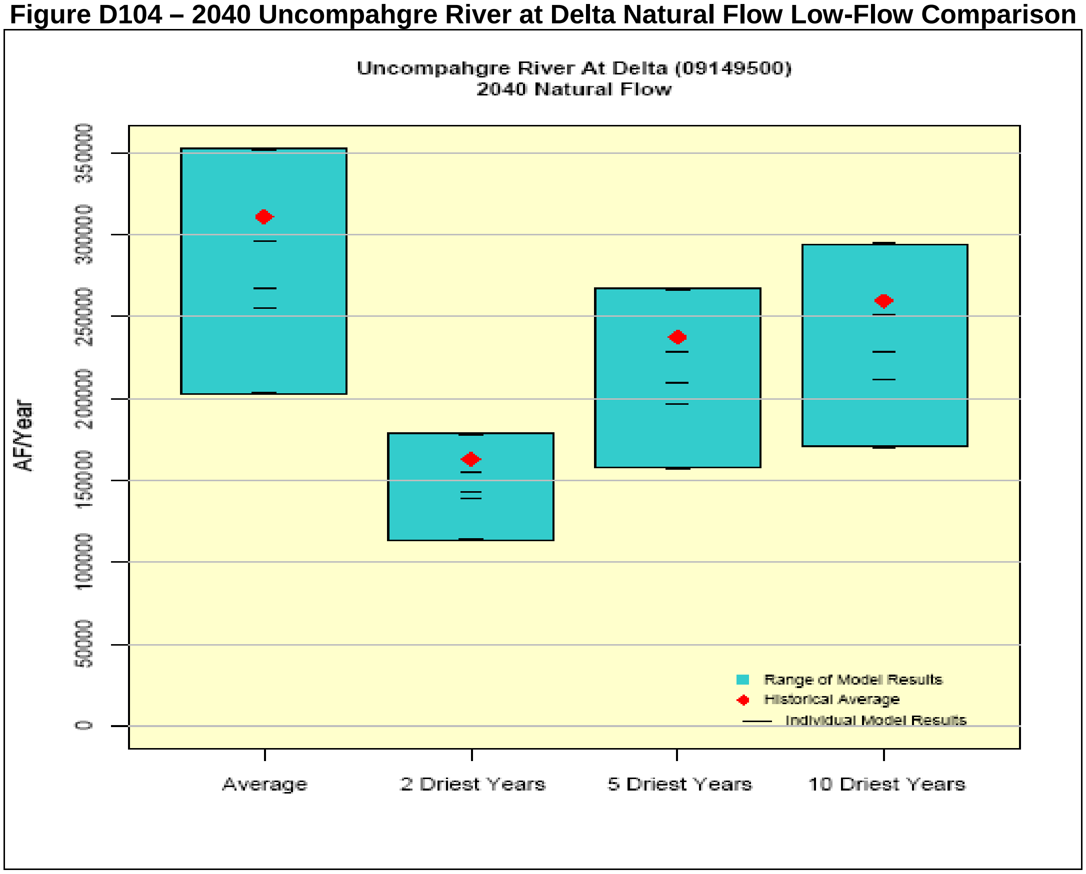


Figure D105 – 2040 Gunnison River near Grand Junction Natural Flow Low-Flow Comparison

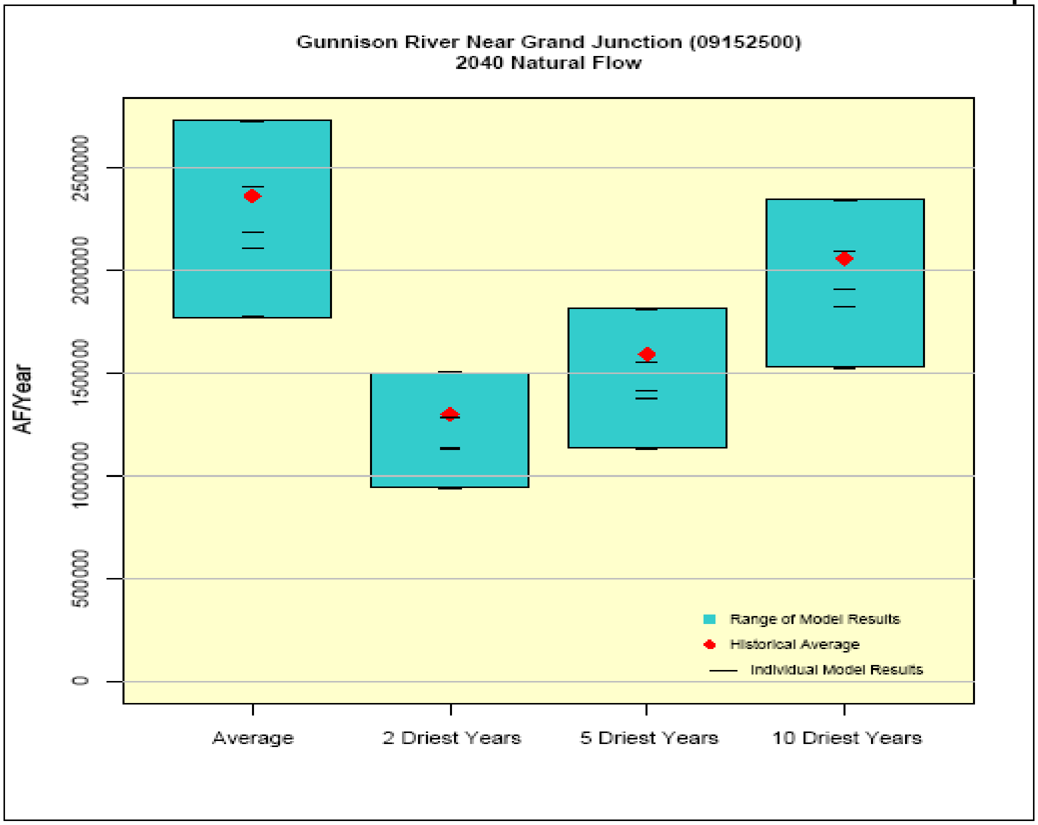


Figure D106 – 2040 Colorado River near CO-UT State Line Natural Flow Low-Flow Comparison

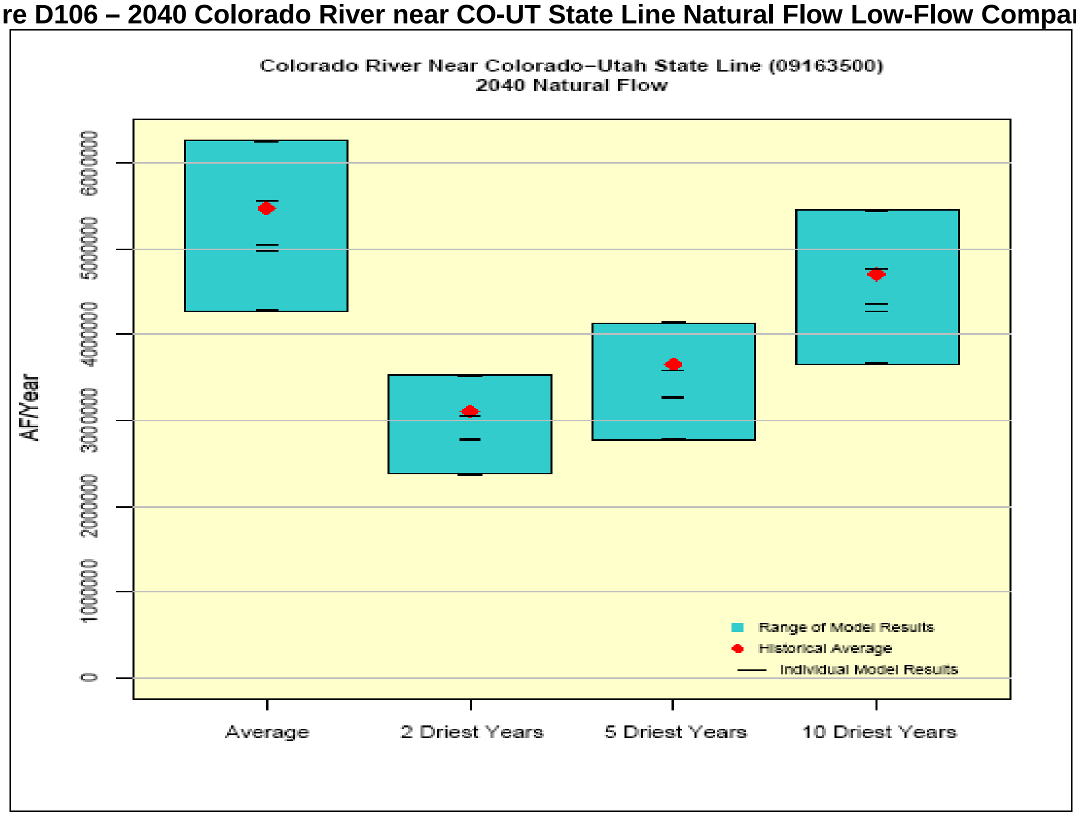


Figure D107 – 2040 Dolores River near Bedrock Natural Flow Low-Flow Comparison

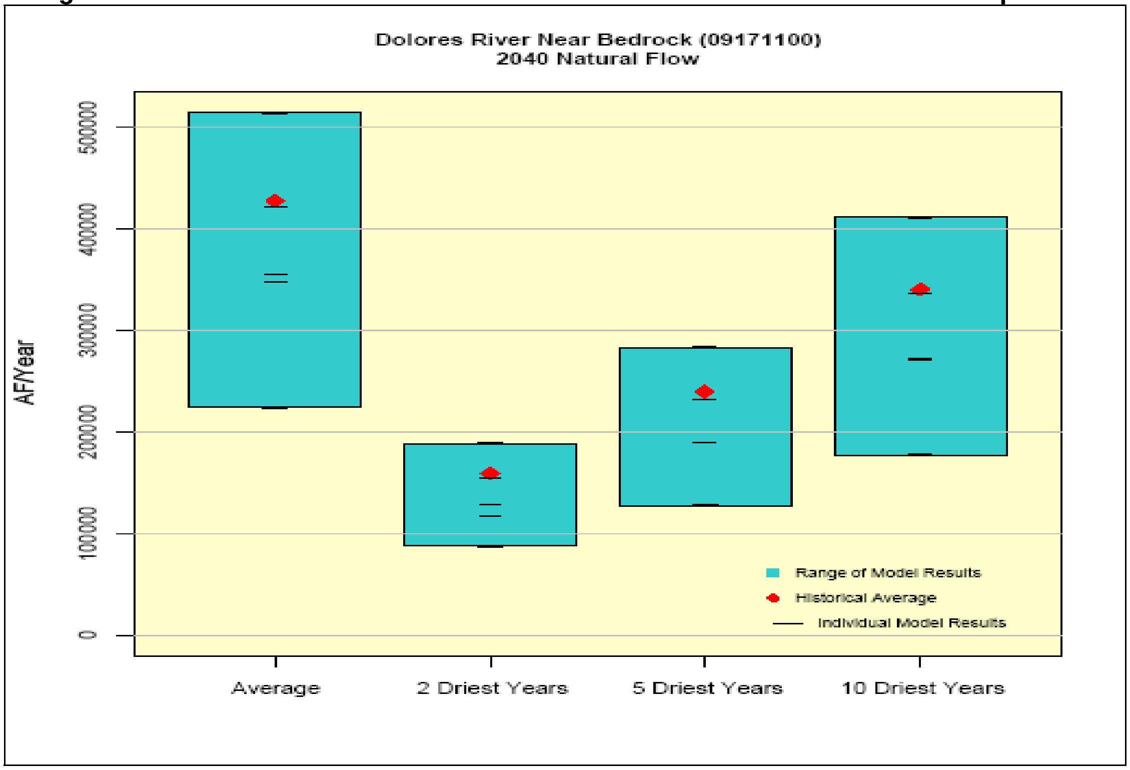


Figure D108 – 2040 San Miguel River at Naturita Natural Flow Low-Flow Comparison

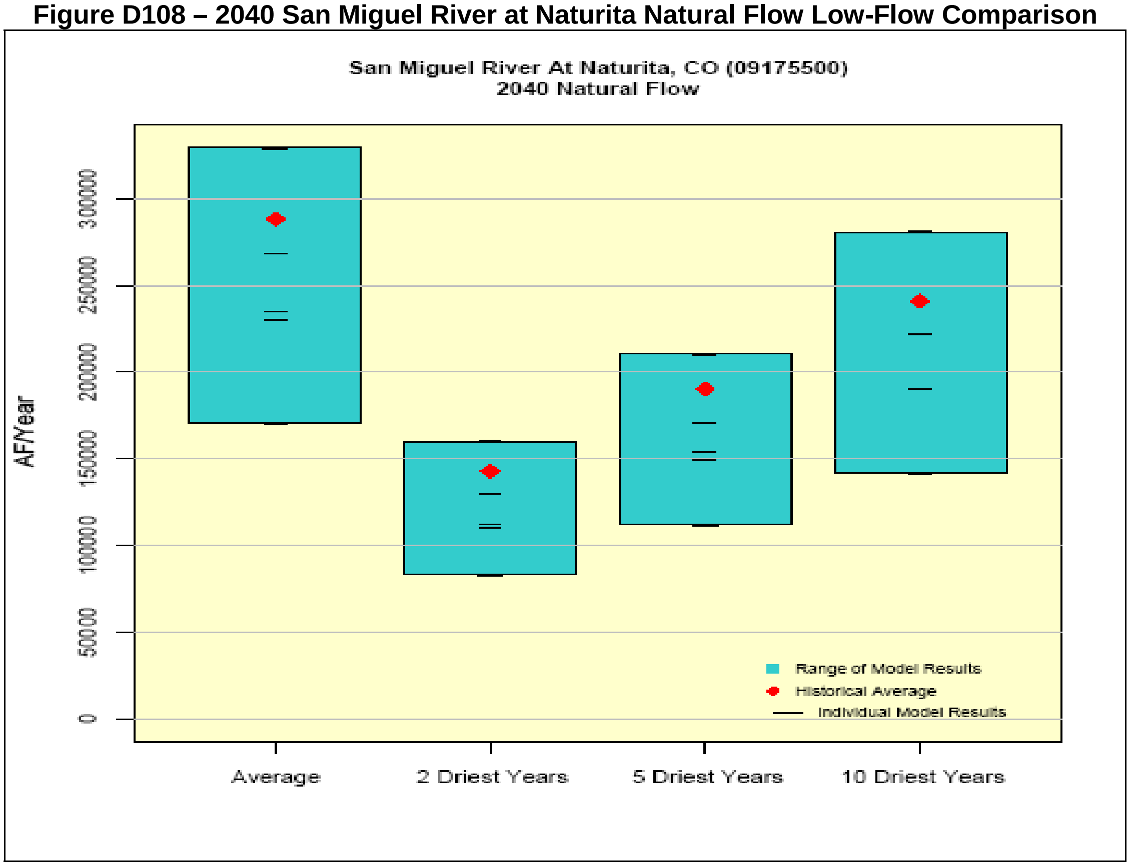


Figure D109 – 2040 Yampa River below Stagecoach Reservoir Natural Flow Low-Flow Comparison

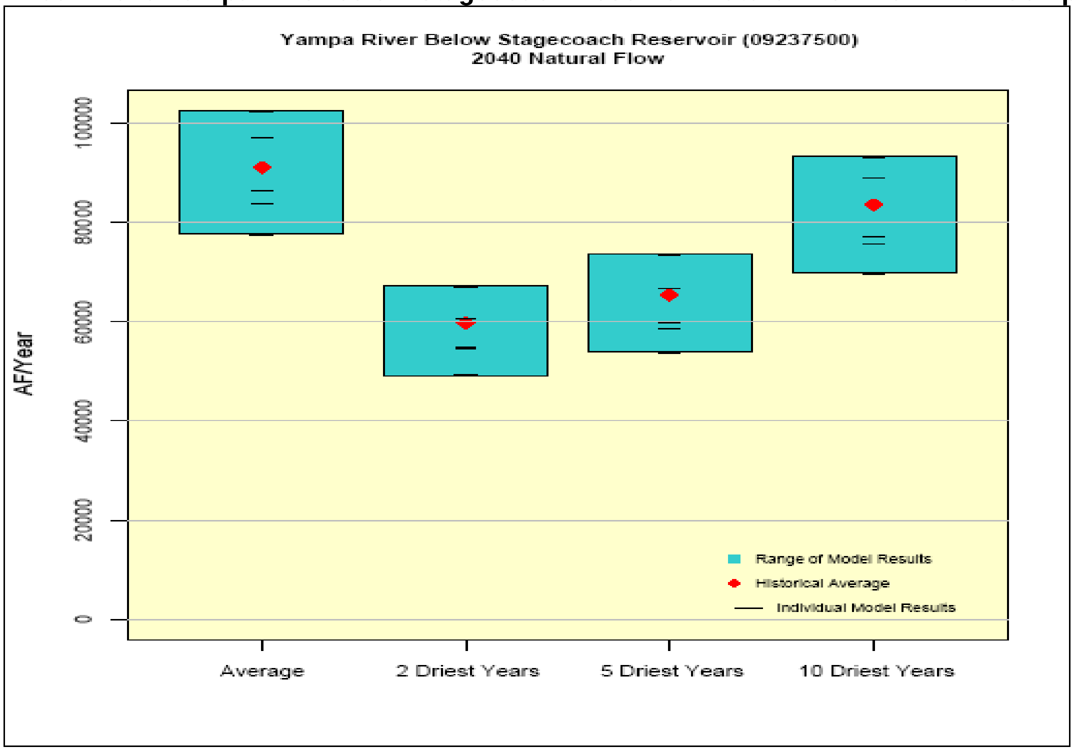


Figure D110 – 2040 Elk River at Clark Natural Flow Low-Flow Comparison

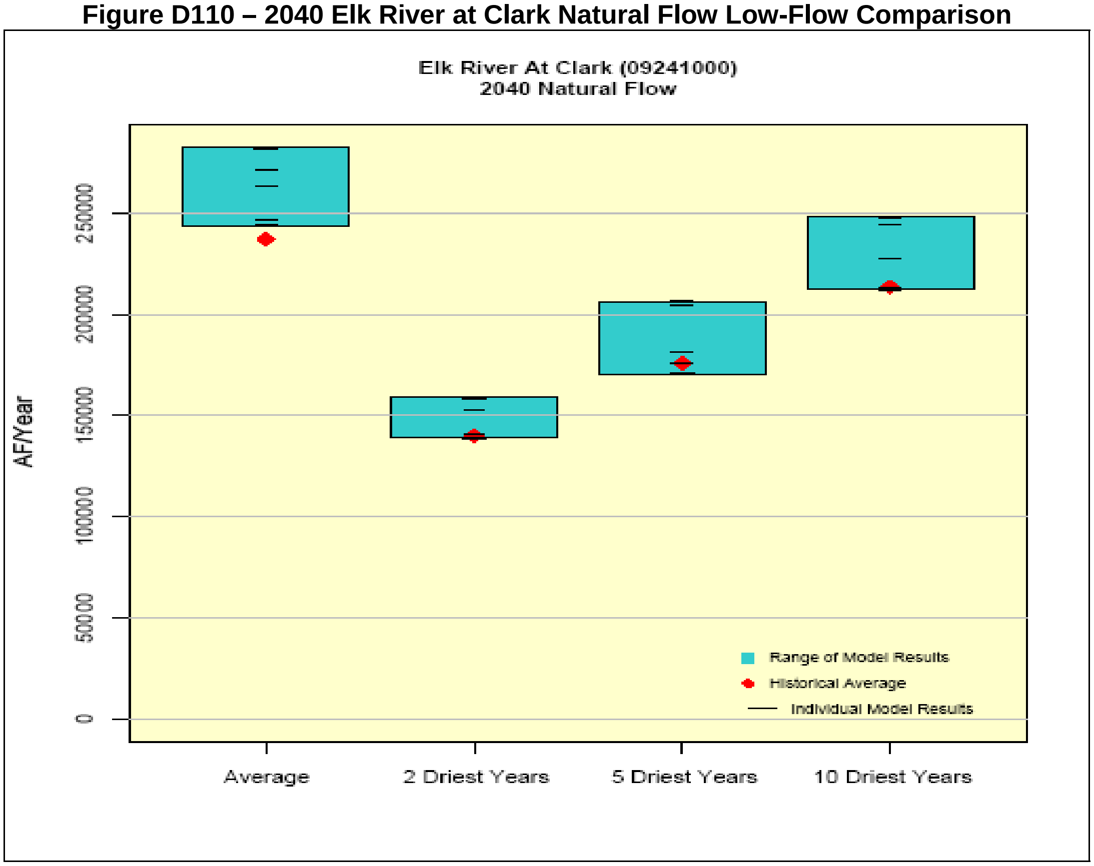


Figure D111 – 2040 Elkhead Creek near Elkhead Natural Flow Low-Flow Comparison

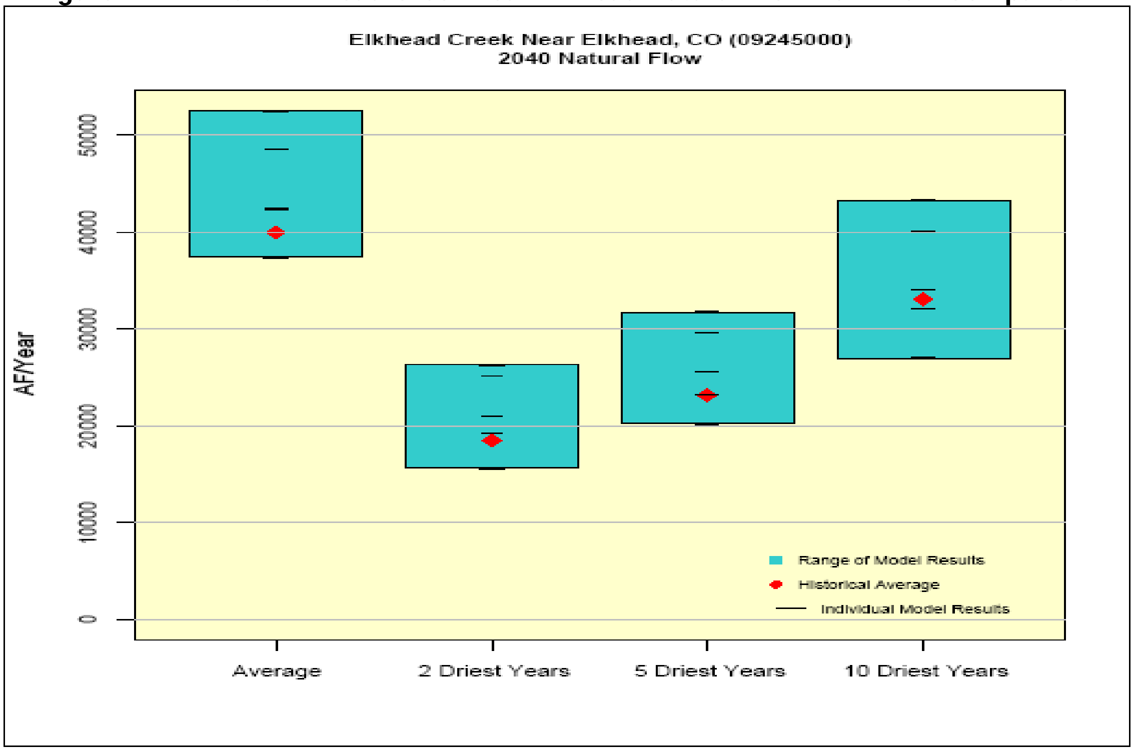


Figure D112 – 2040 Williams Fork at Mouth, near Hamilton Natural Flow Low-Flow Comparison

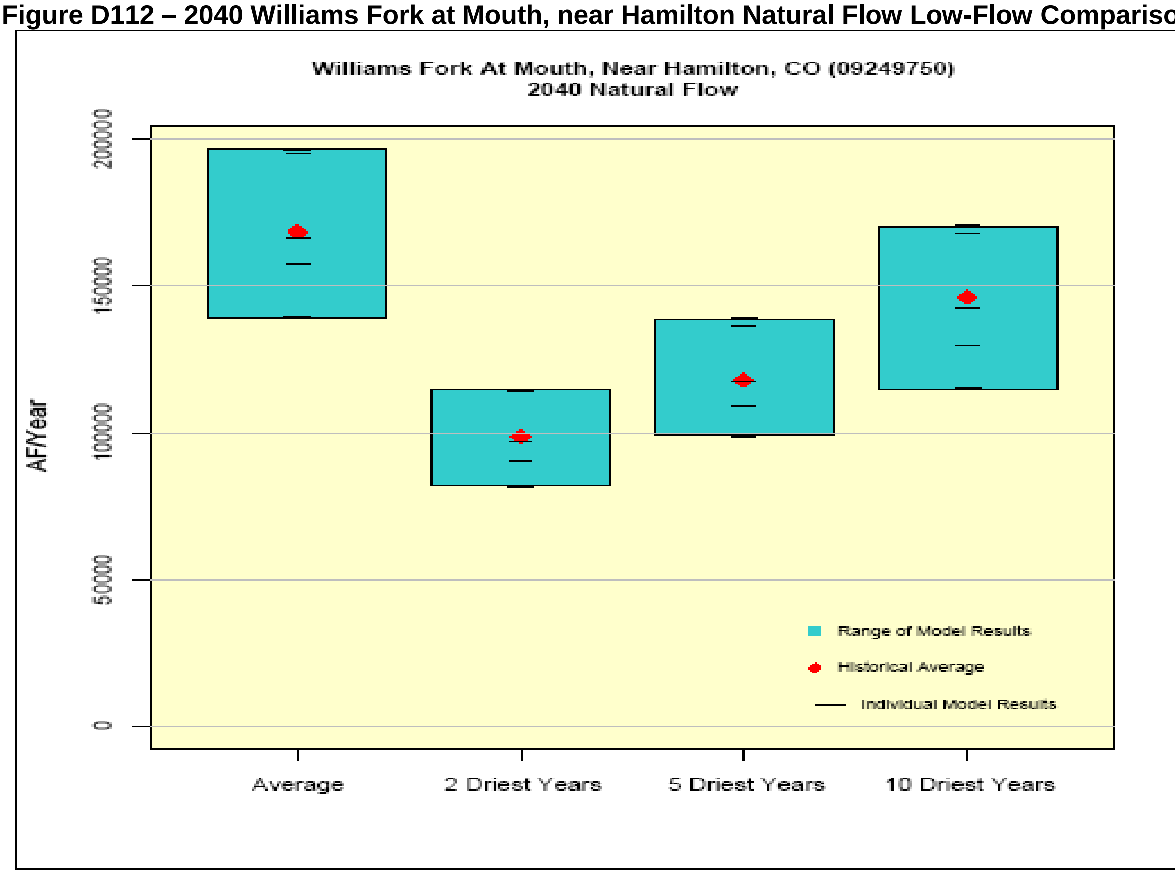


Figure D113 – 2040 Yampa River near Maybell Natural Flow Low-Flow Comparison

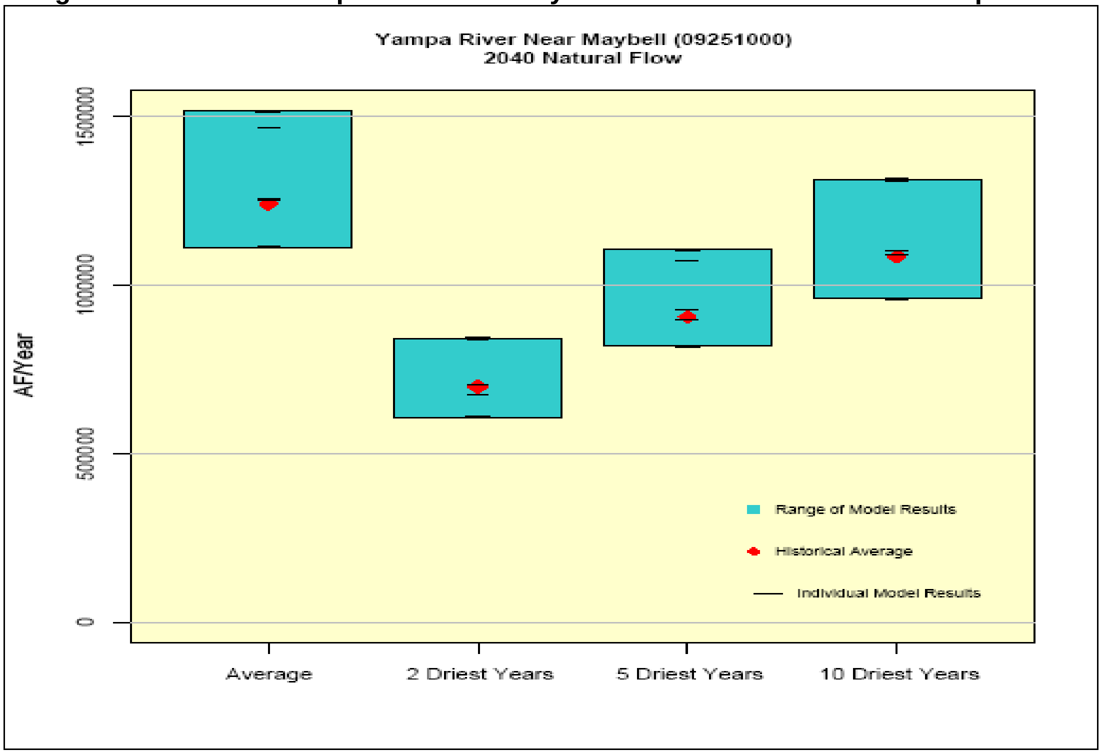


Figure D114 – 2040 Little Snake River near Lily Natural Flow Low-Flow Comparison

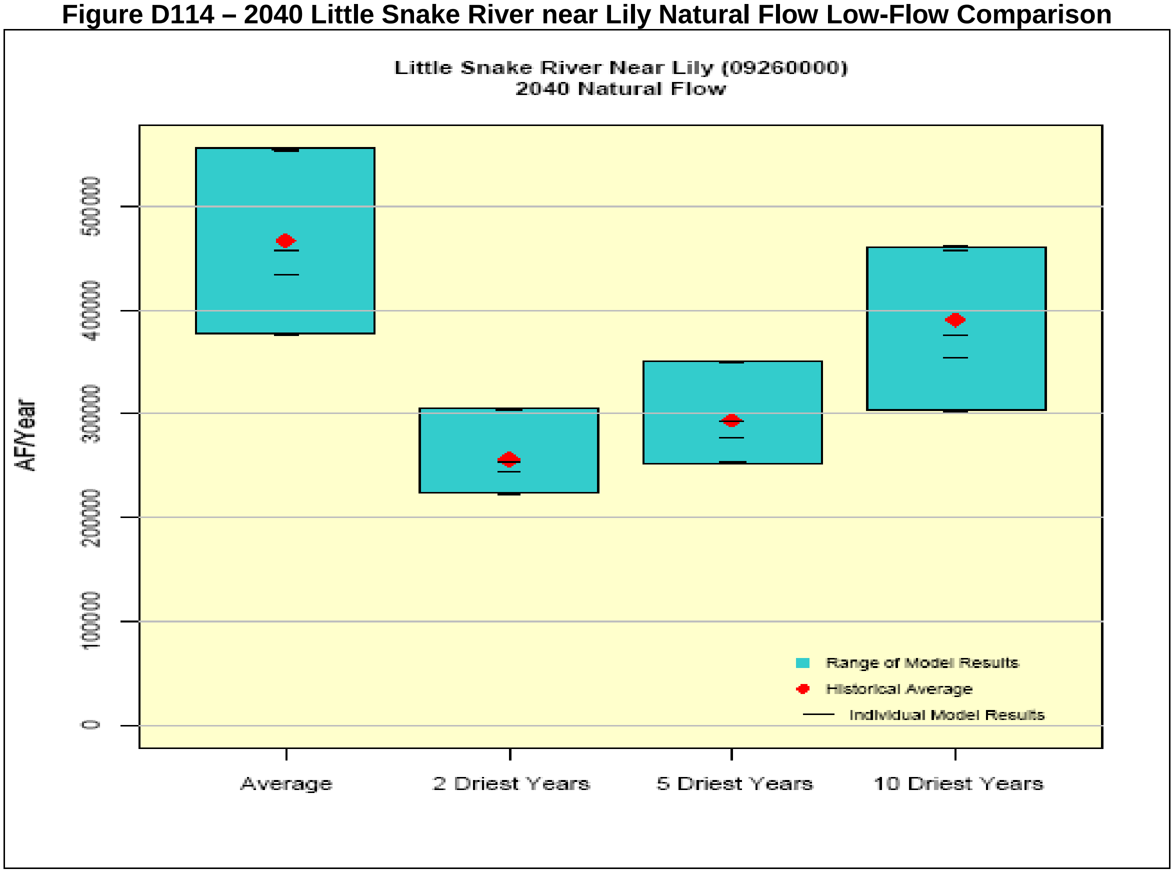


Figure D115 – 2040 Yampa River at Deerlodge Park Natural Flow Low-Flow Comparison

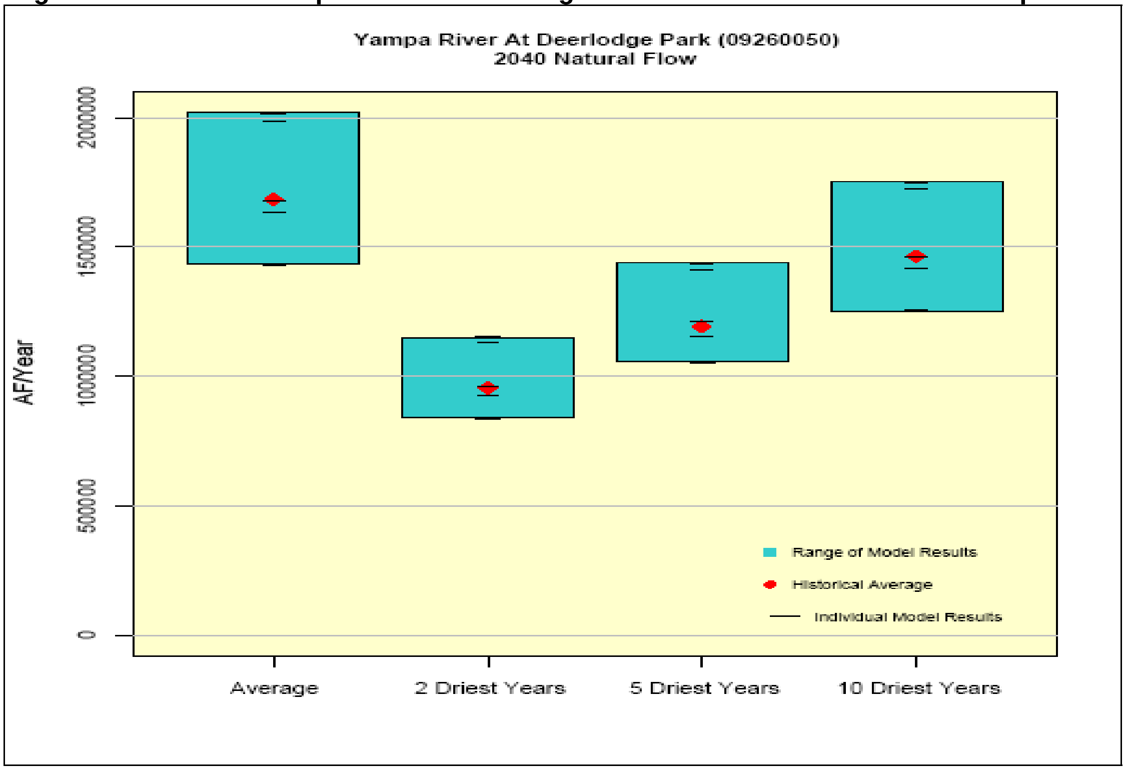


Figure D116 – 2040 North Fork White River at Buford, Co Natural Flow Low-Flow Comparison

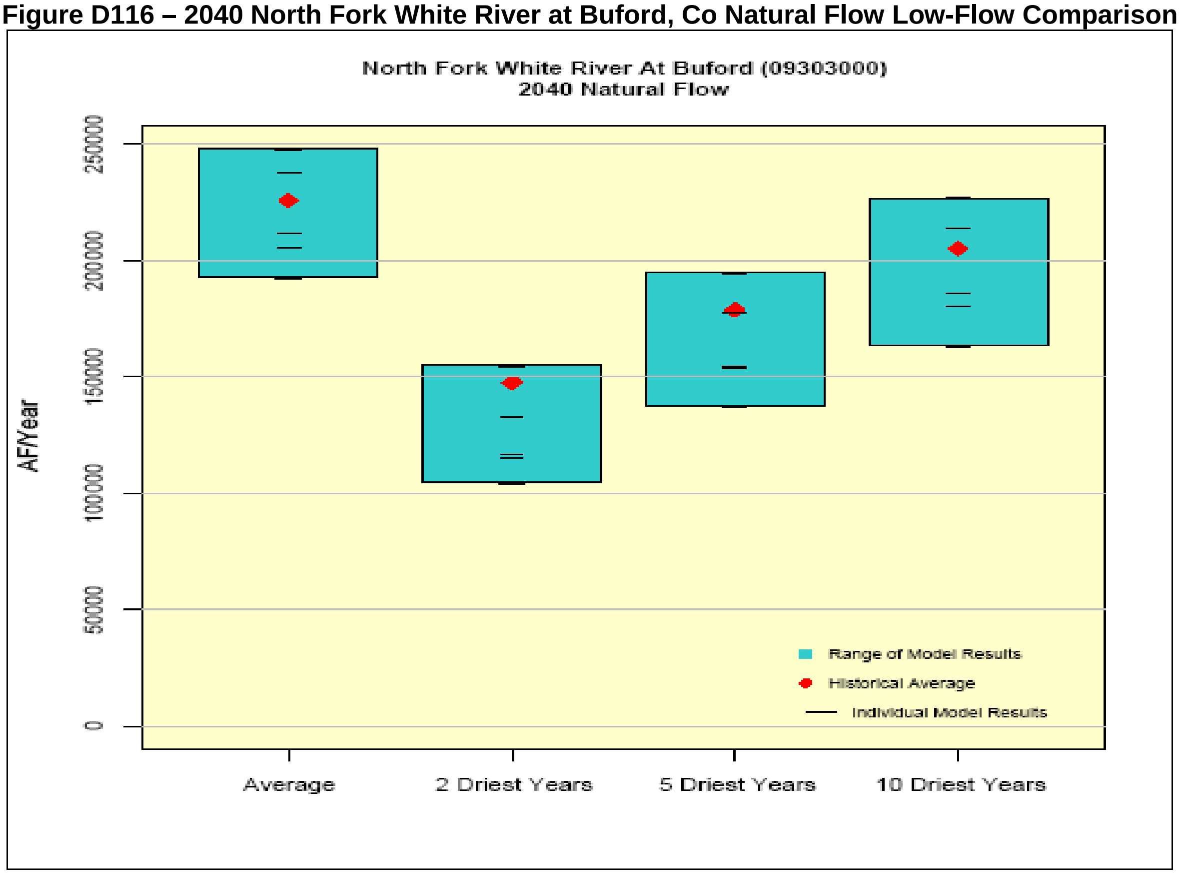


Figure D117 – 2040 South Fork White River at Buford Natural Flow Low-Flow Comparison

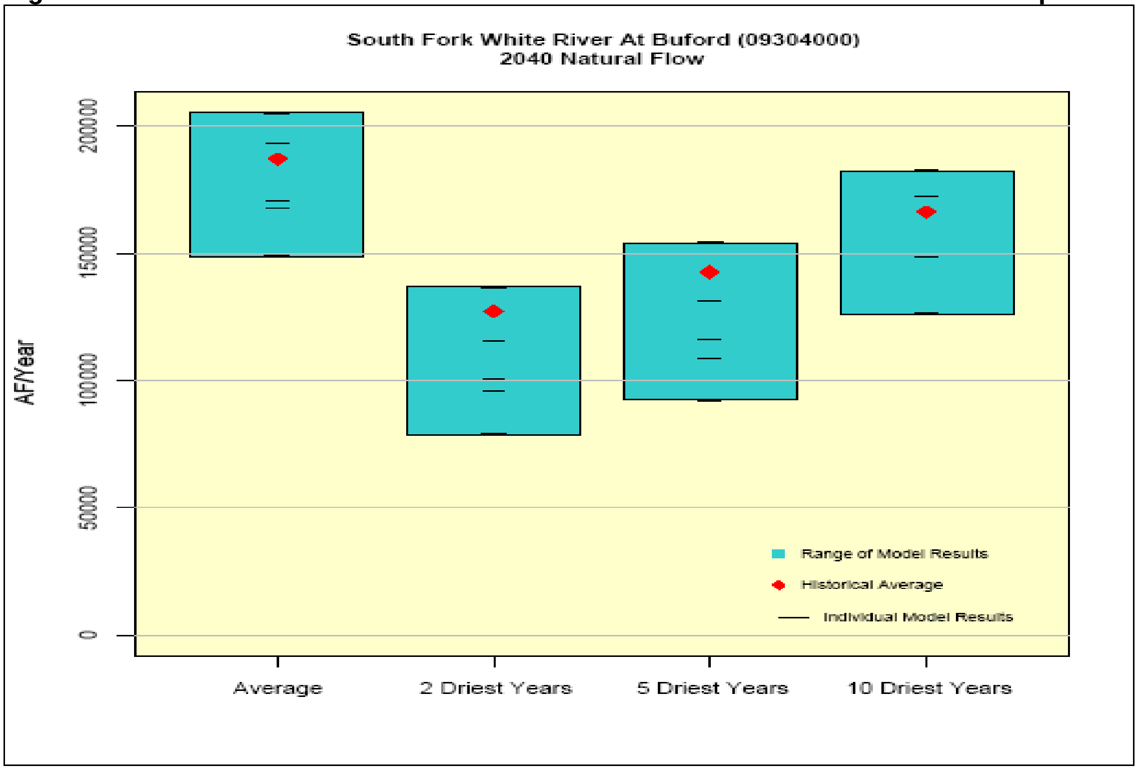


Figure D118 – 2040 White River below Meeker Natural Flow Low-Flow Comparison

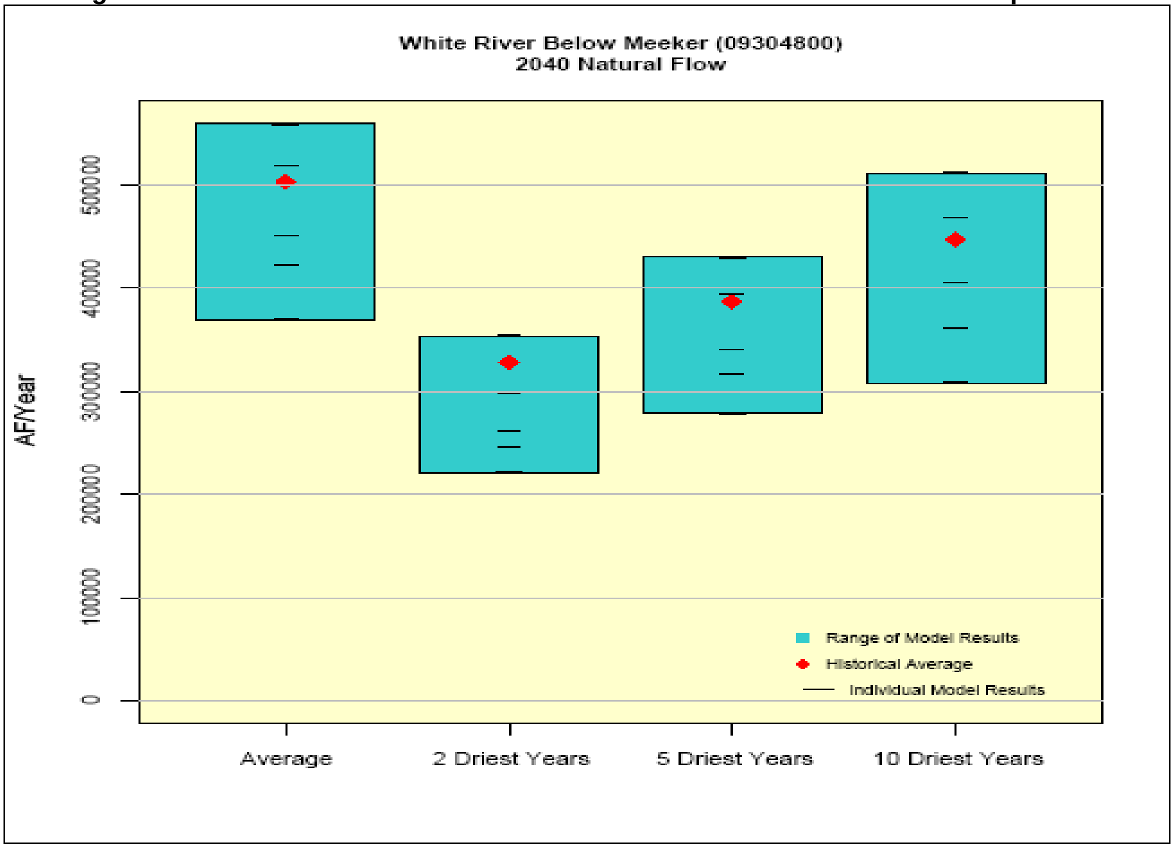


Figure D119 – 2040 Piceance Creek at White River Natural Flow Low-Flow Comparison

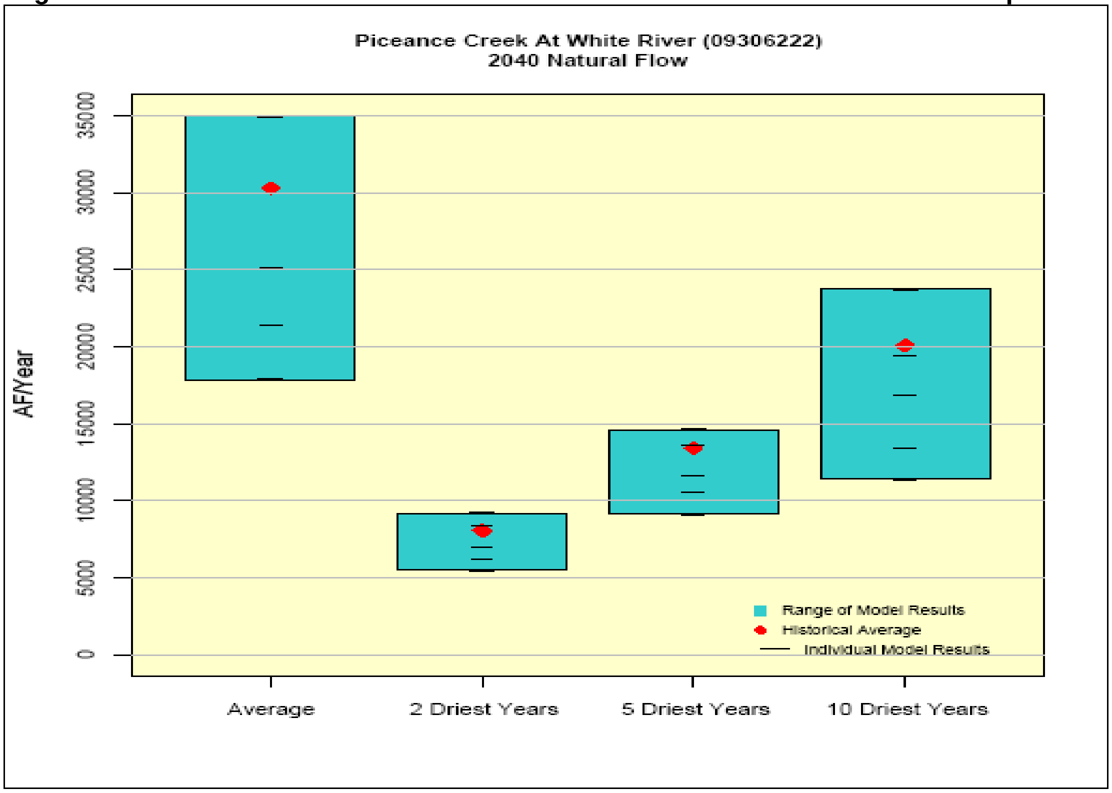


Figure D120 – 2040 White River near CO-UT State Line Natural Flow Low-Flow Comparison

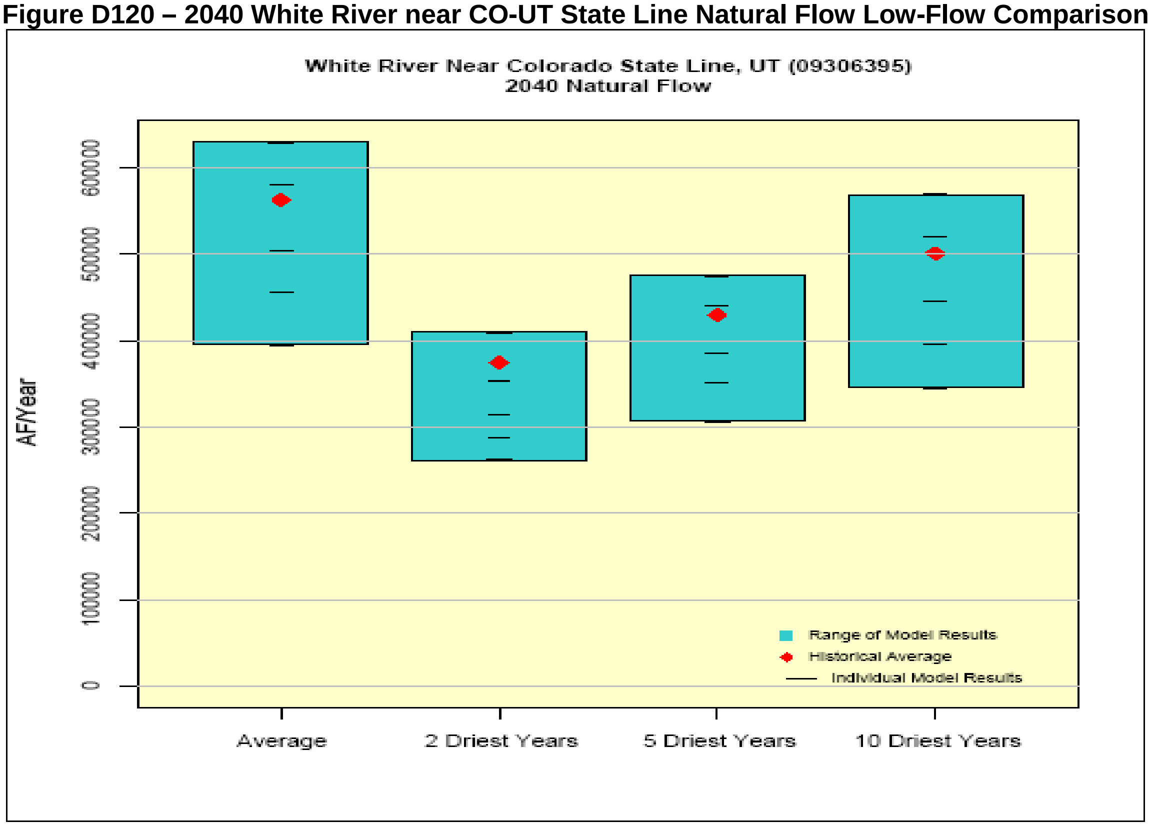


Figure D121 – 2040 San Juan River near Carracas Natural Flow Low-Flow Comparison

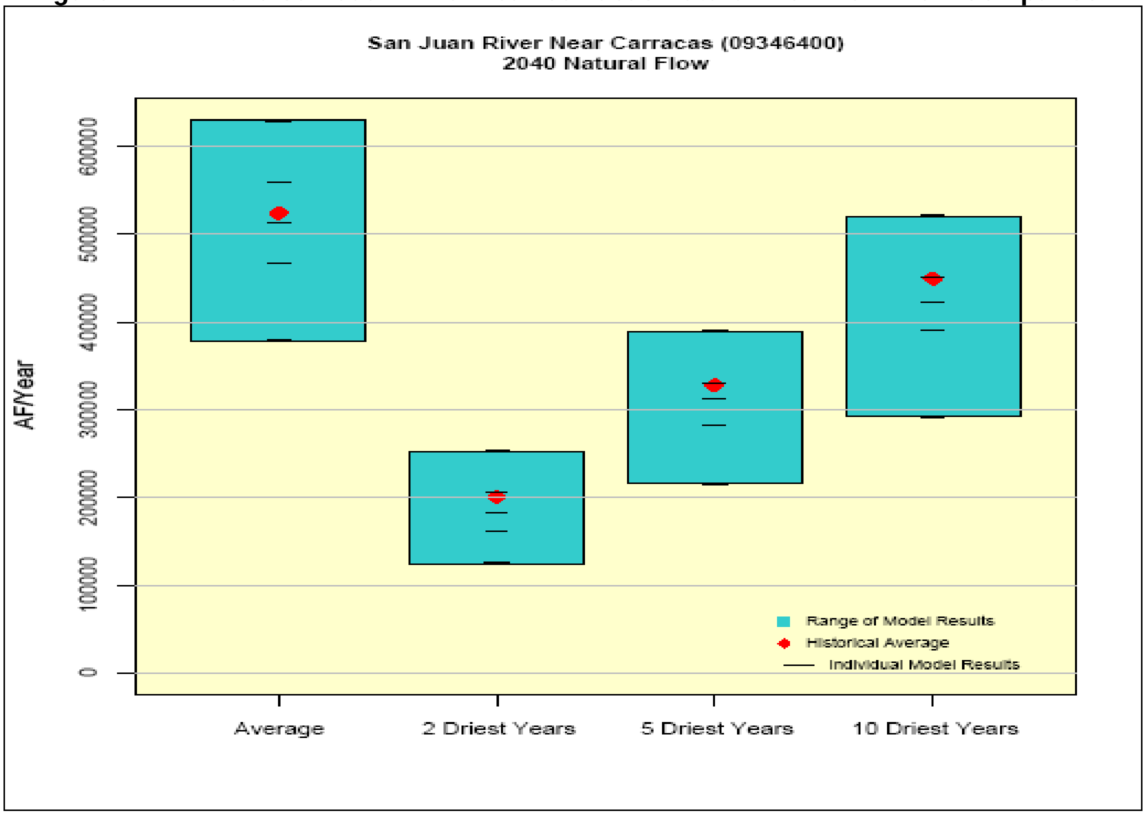


Figure D122 – 2040 Piedra River near Arboles Natural Flow Low-Flow Comparison

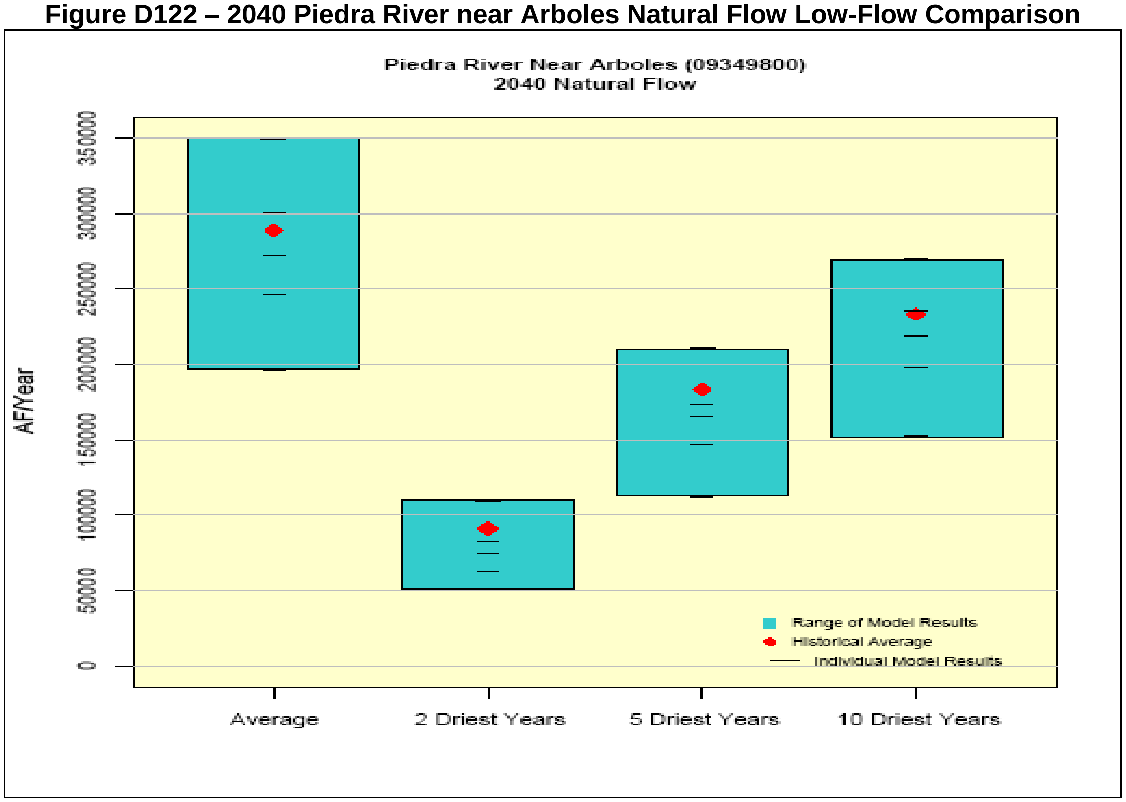


Figure D123 – 2040 Los Pinos River at La Boca Natural Flow Low-Flow Comparison

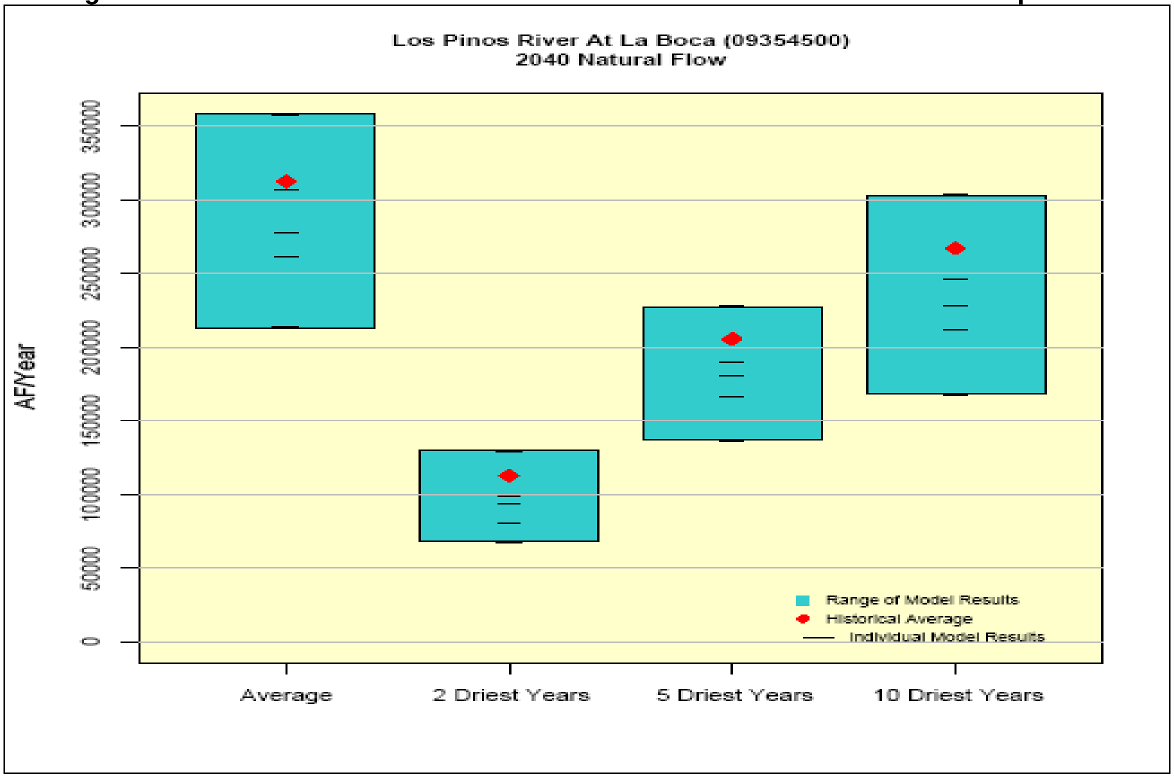


Figure D124 – 2040 Florida River at Bondad Natural Flow Low-Flow Comparison

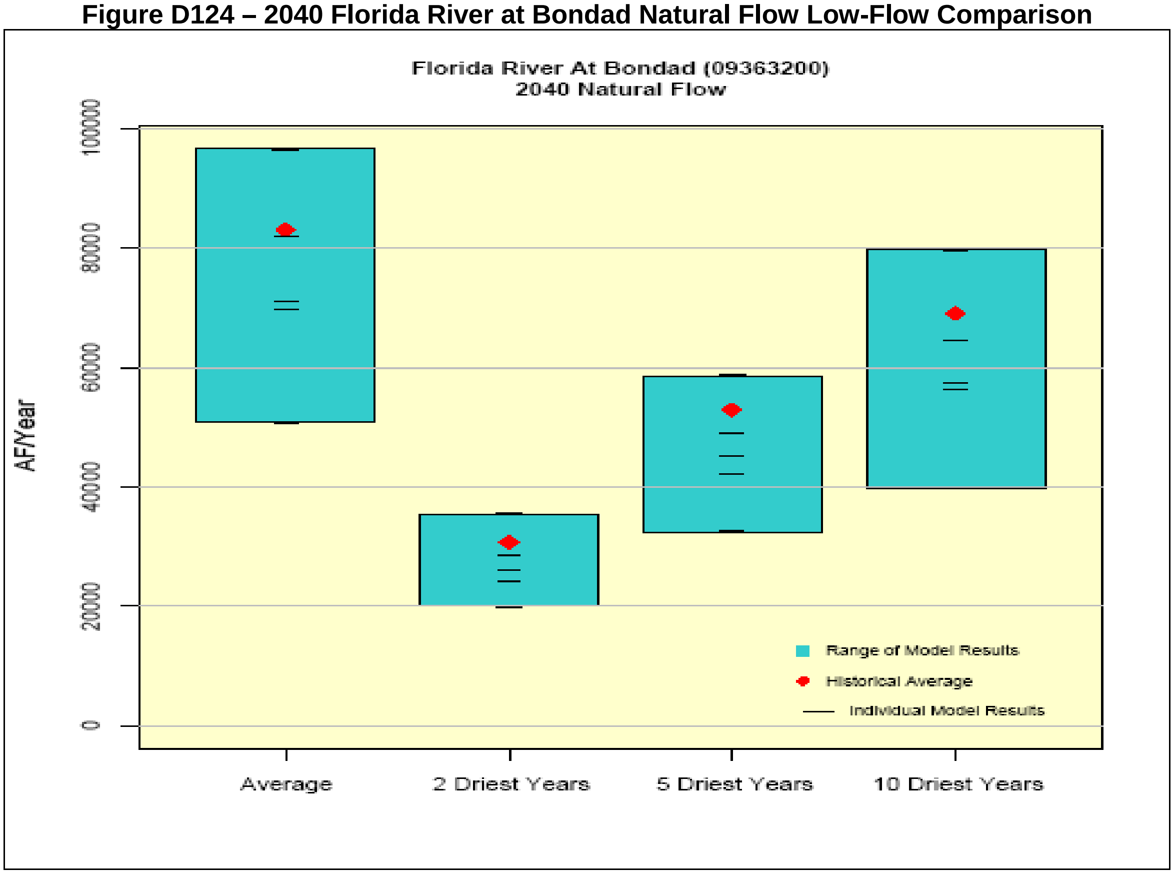


Figure D125 – 2040 Animas River near Cedar Hill, NM Natural Flow Low-Flow Comparison

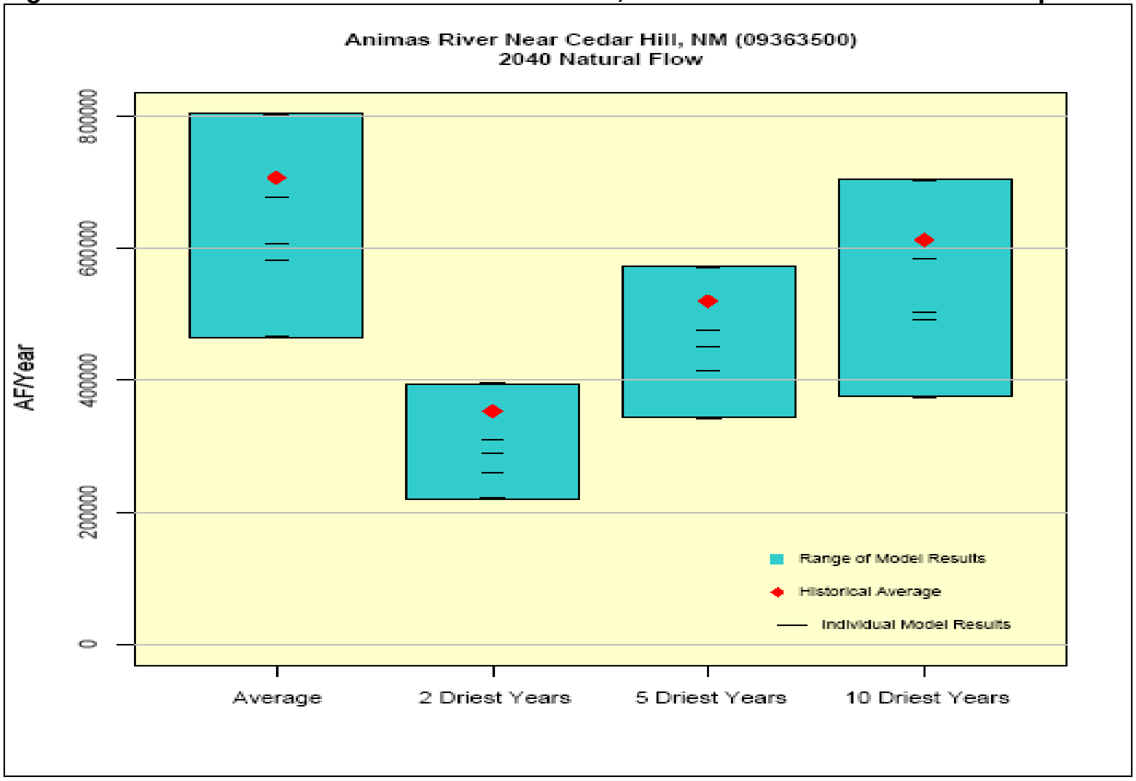


Figure D126 – 2040 La Plata River at Hesperus Natural Flow Low-Flow Comparison

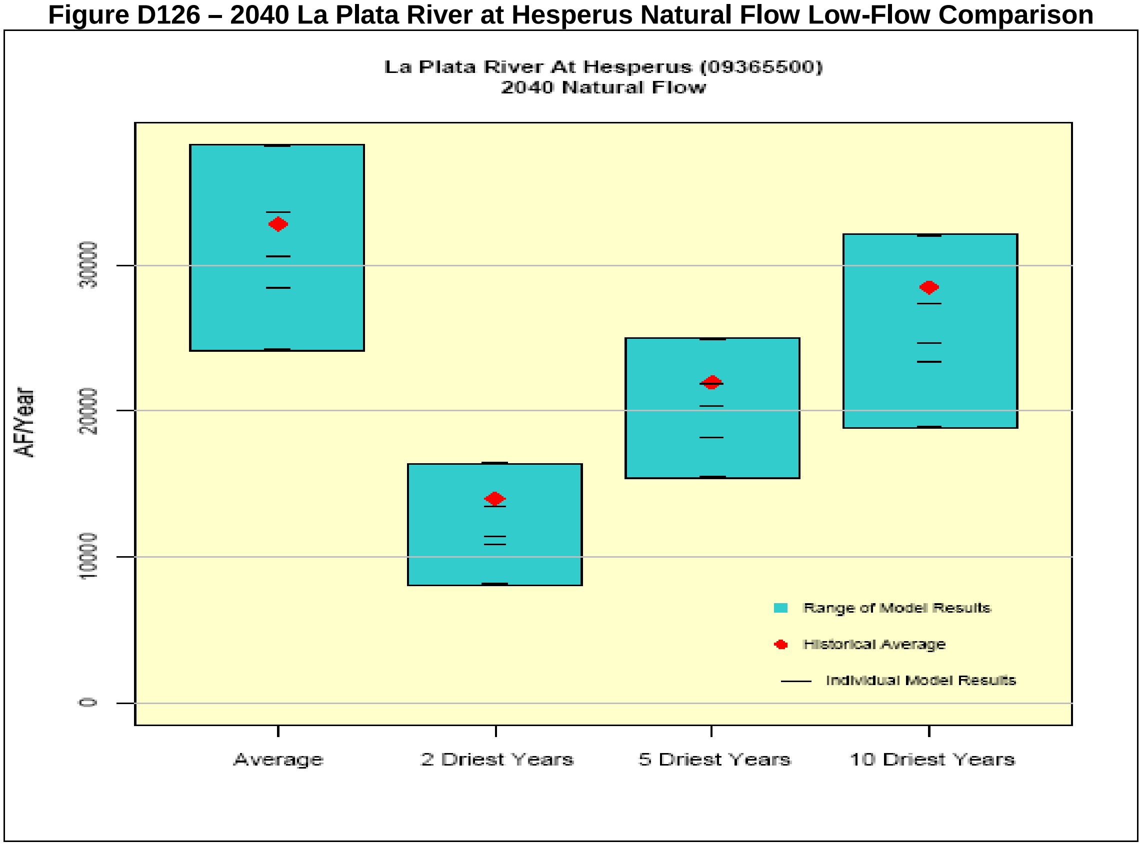


Figure D127 – 2040 La Plata River at CO-NM State Line Natural Flow Low-Flow Comparison

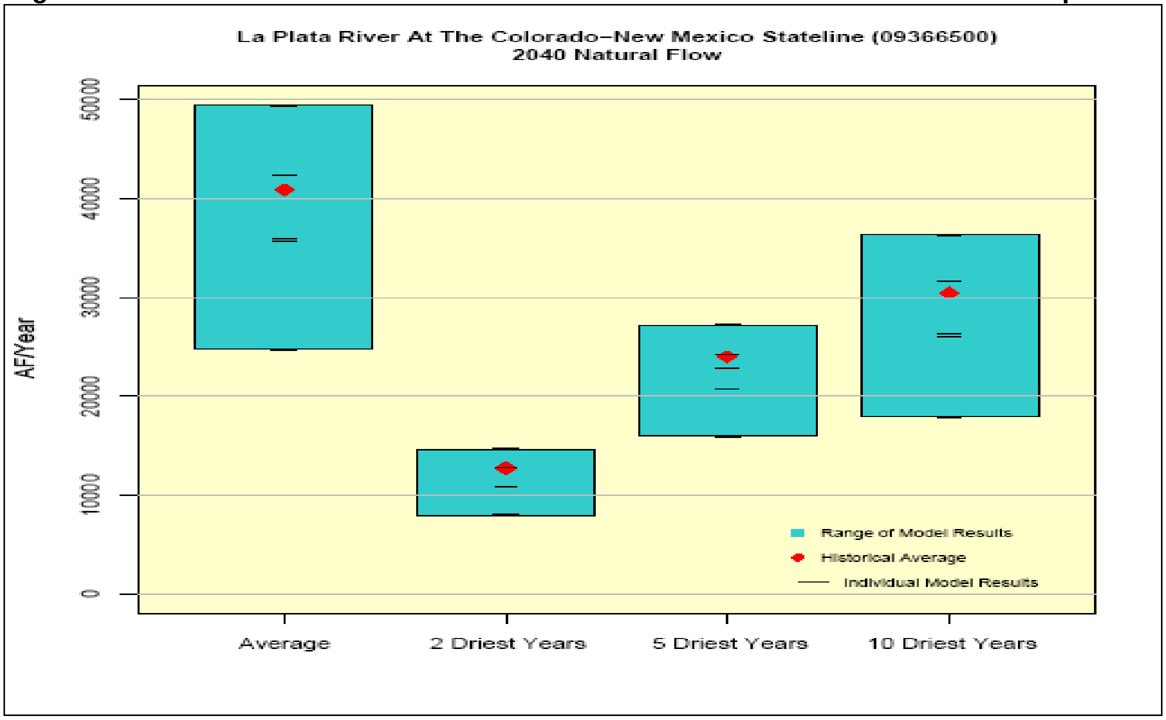


Figure D128 – 2040 Mancos River near Towaoc Natural Flow Low-Flow Comparison

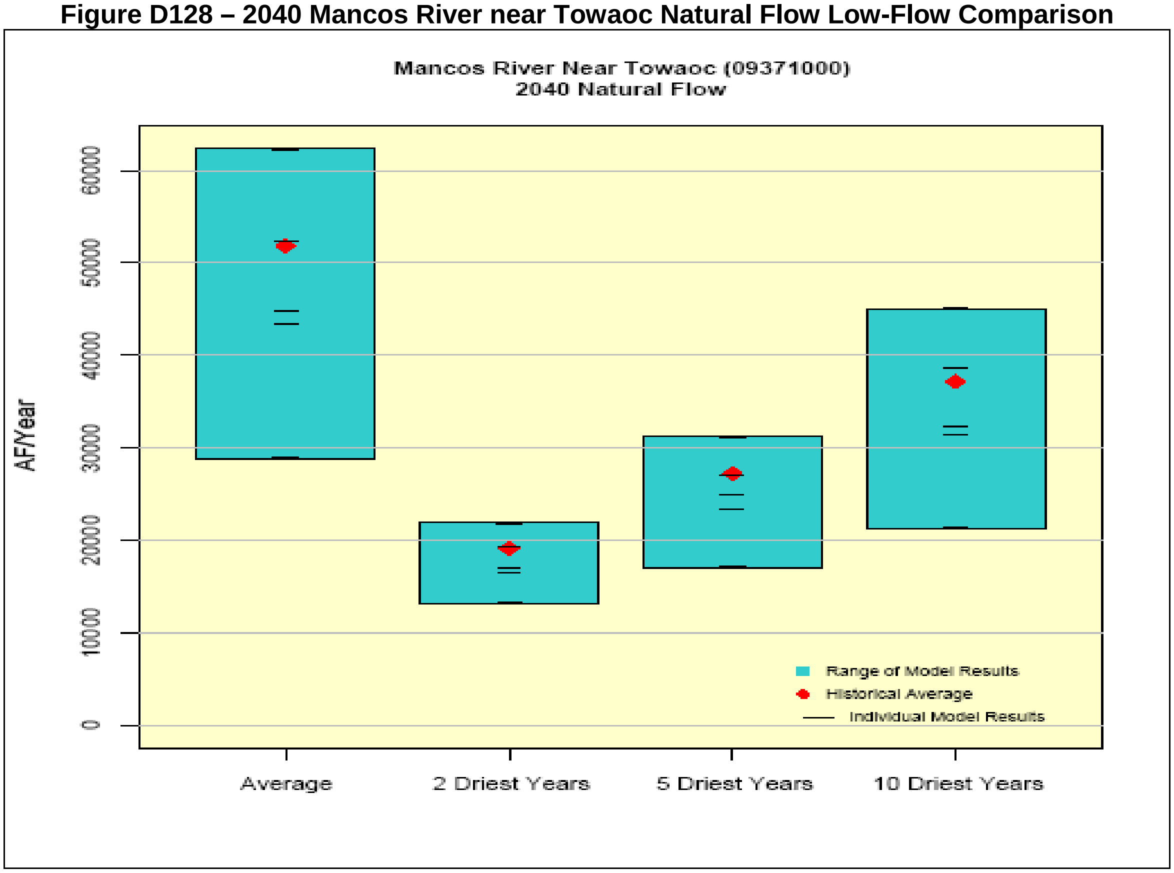


Figure D129 – 2040 McElmo Creek near CO-UT State Line Natural Flow Low-Flow Comparison

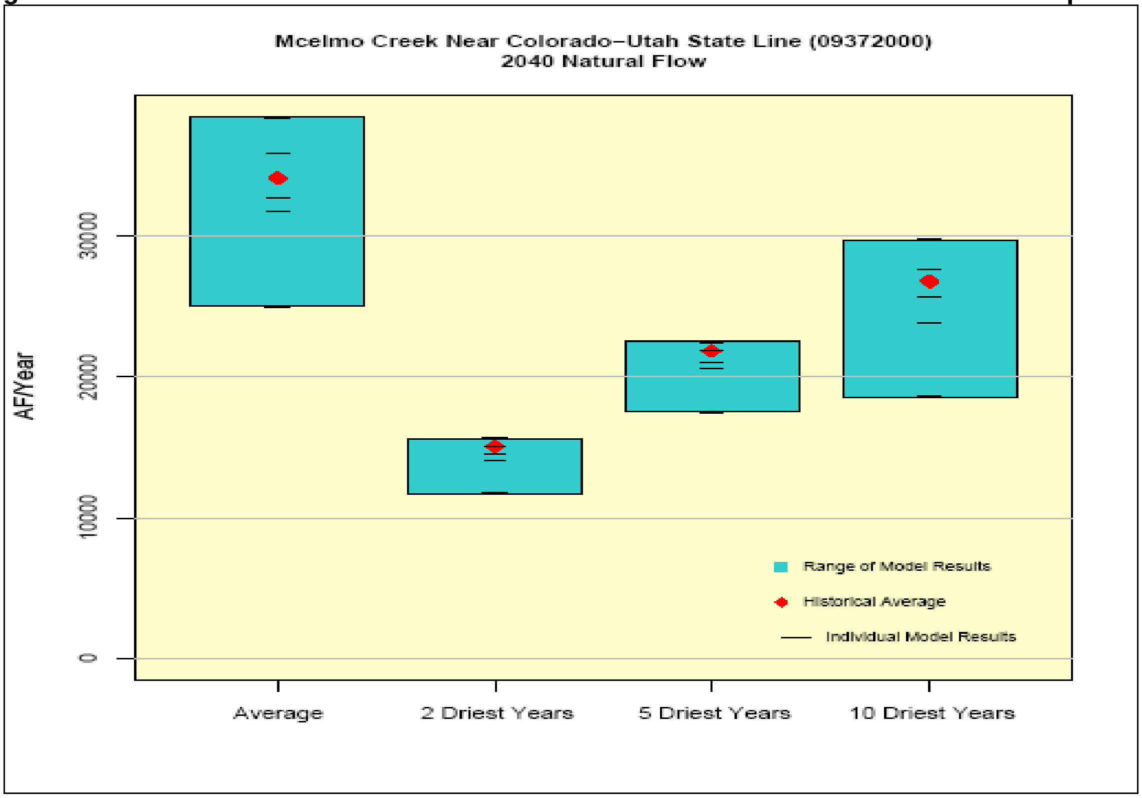


Figure D130 – 2070 Colorado River near Grand Lake Natural Flow Low-Flow Comparison

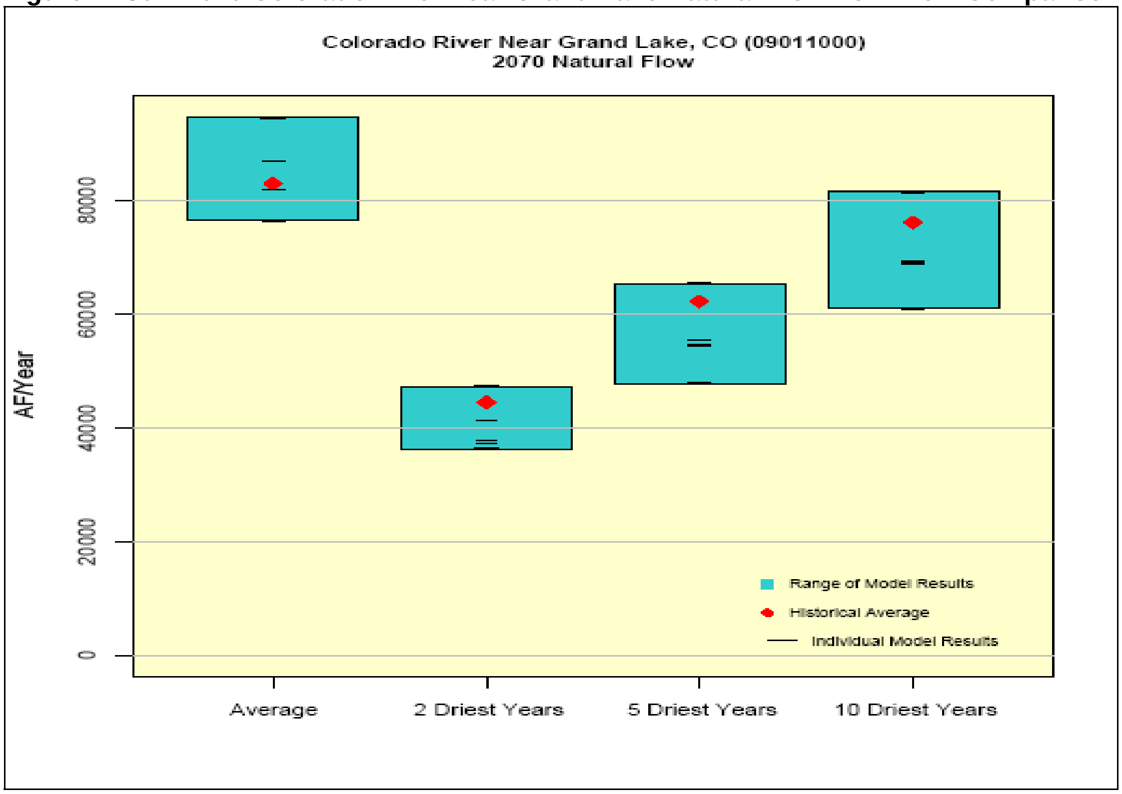


Figure D131 – 2070 Muddy Creek at Kremmling Natural Flow Low-Flow Comparison

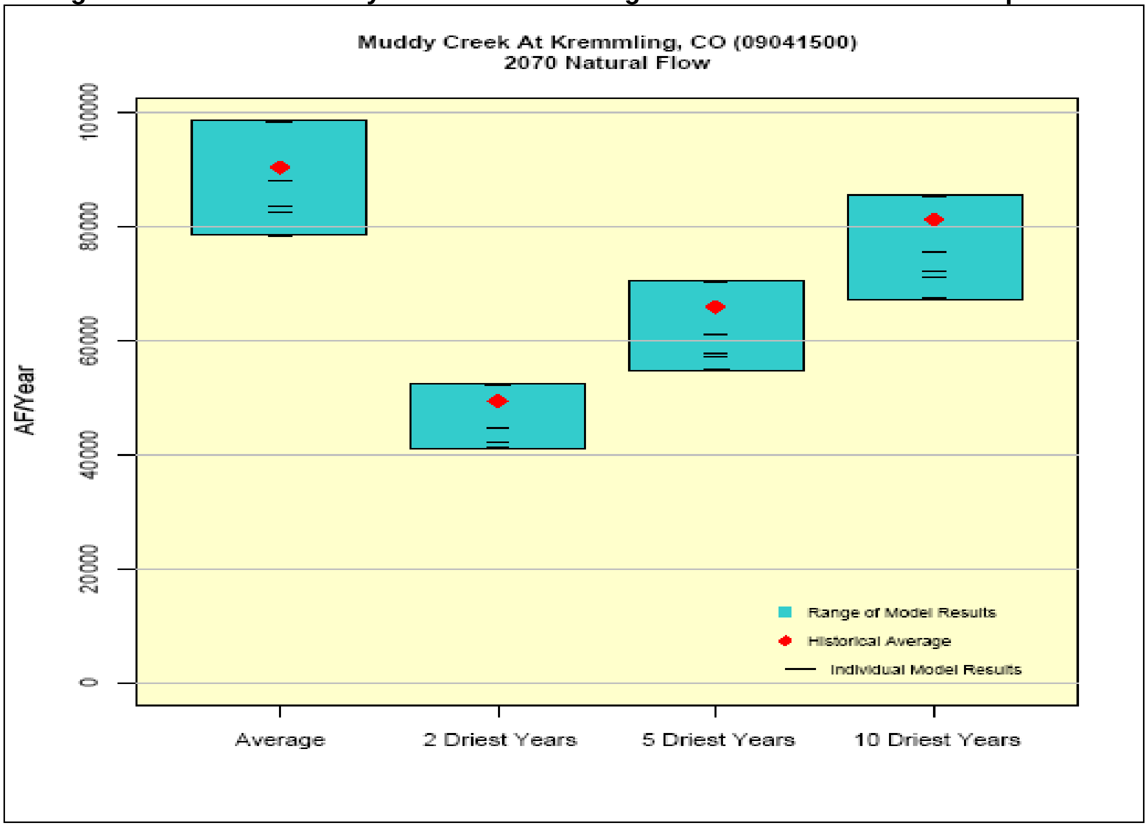


Figure D132 – 2070 Blue River below Dillon Natural Flow Low-Flow Comparison

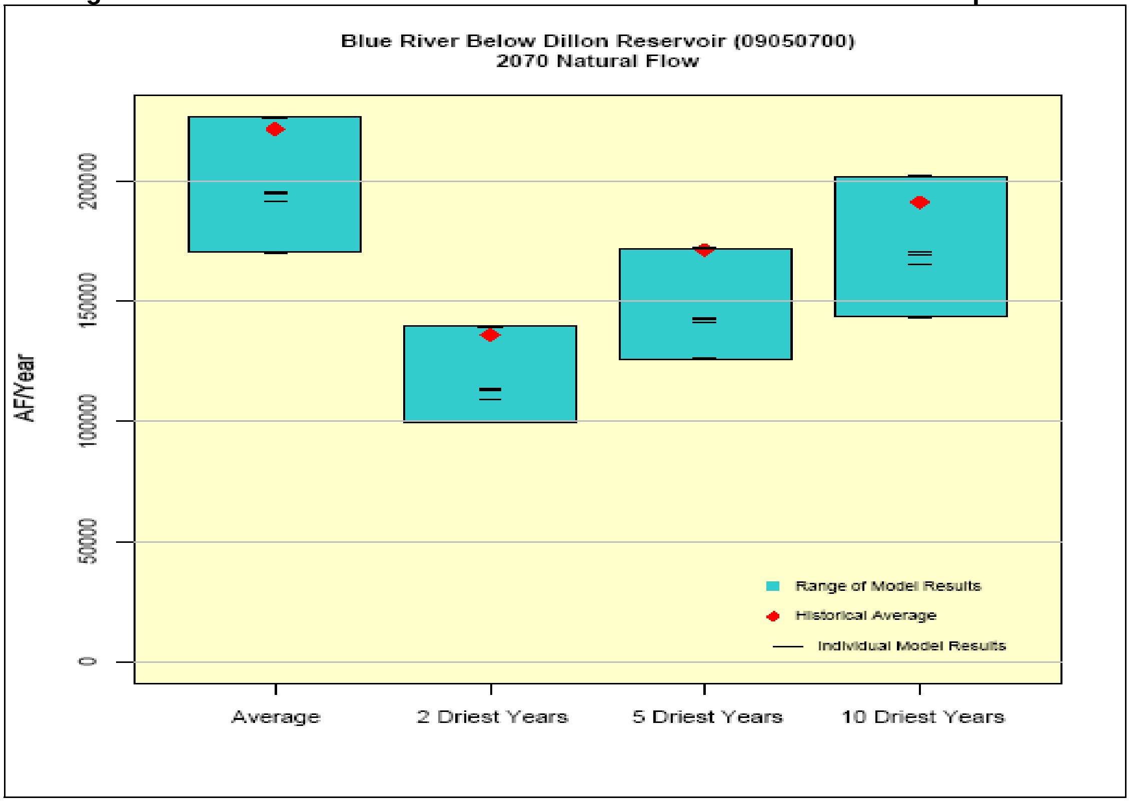


Figure D133 – 2070 Blue River below Green Mountain Reservoir Natural Flow Low-Flow Comparison

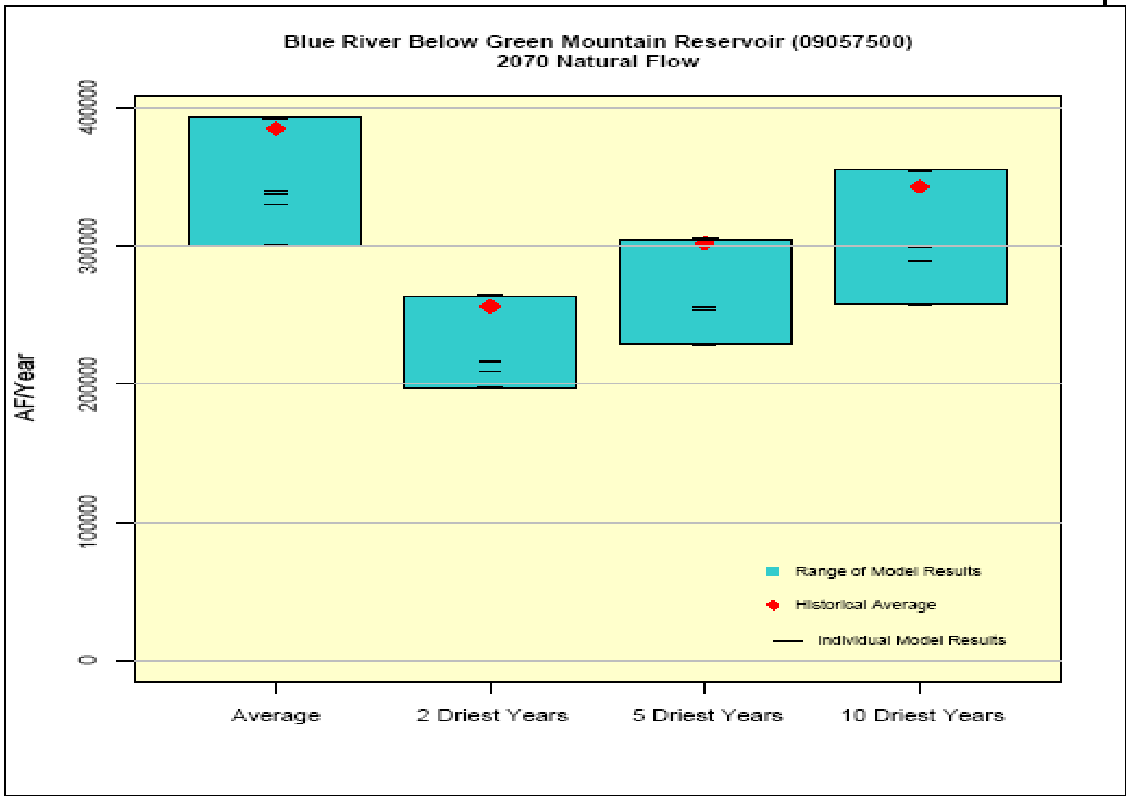


Figure D134 – 2070 Eagle River below Gypsum Natural Flow Low-Flow Comparison

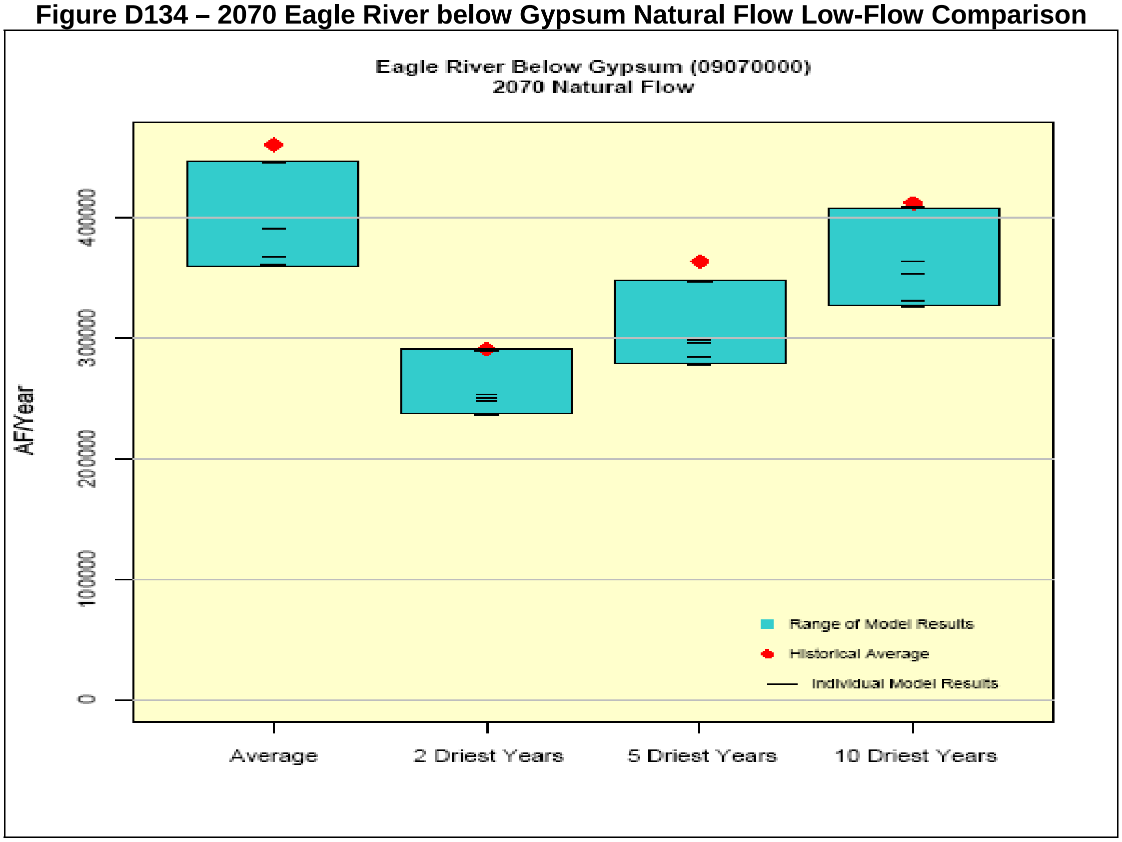


Figure D135 – 2070 Colorado River at Dotsero Natural Flow Low-Flow Comparison

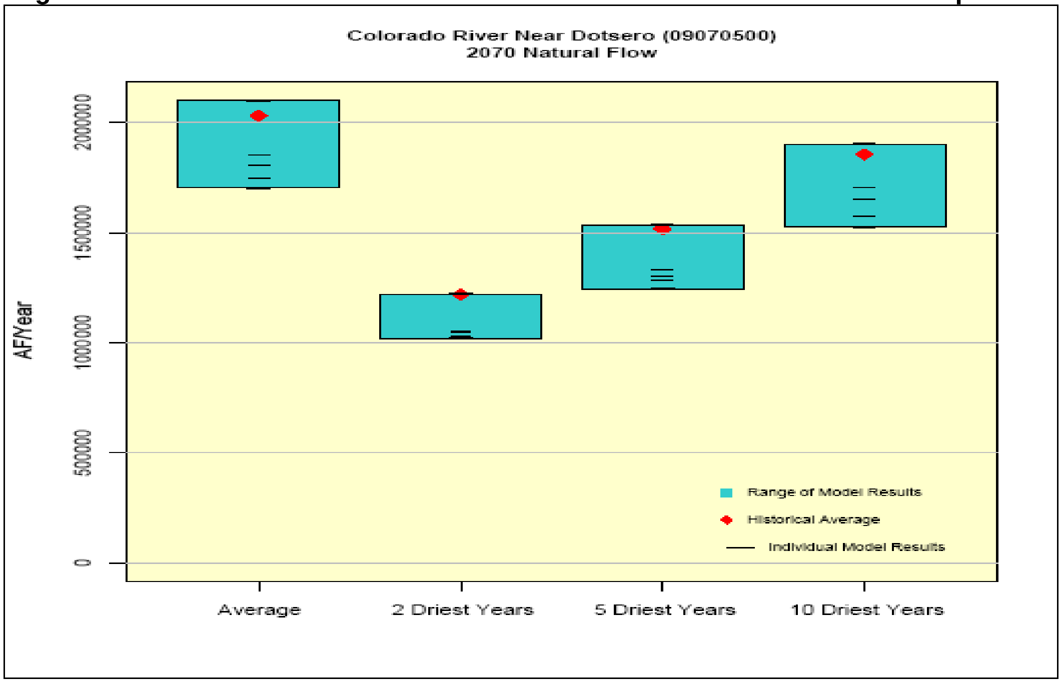


Figure D136 – 2070 Roaring Fork River near Aspen Natural Flow Low-Flow Comparison

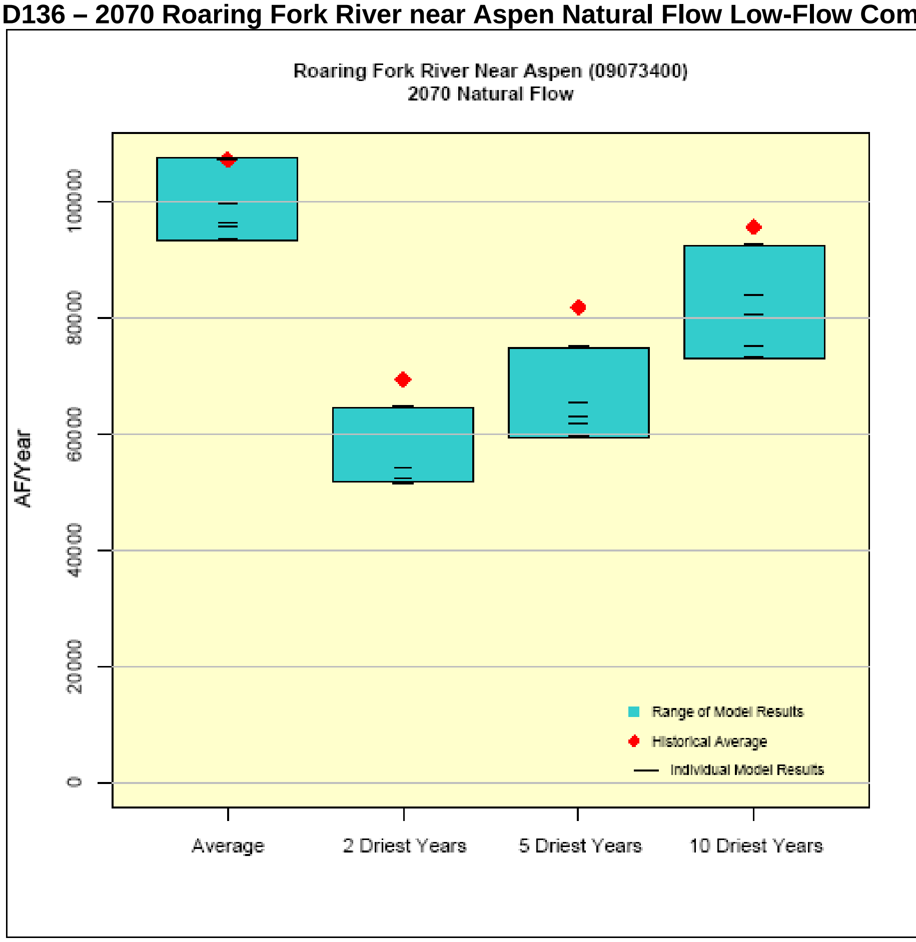


Figure D137 – 2070 Roaring Fork River at Glenwood Natural Flow Low-Flow Comparison

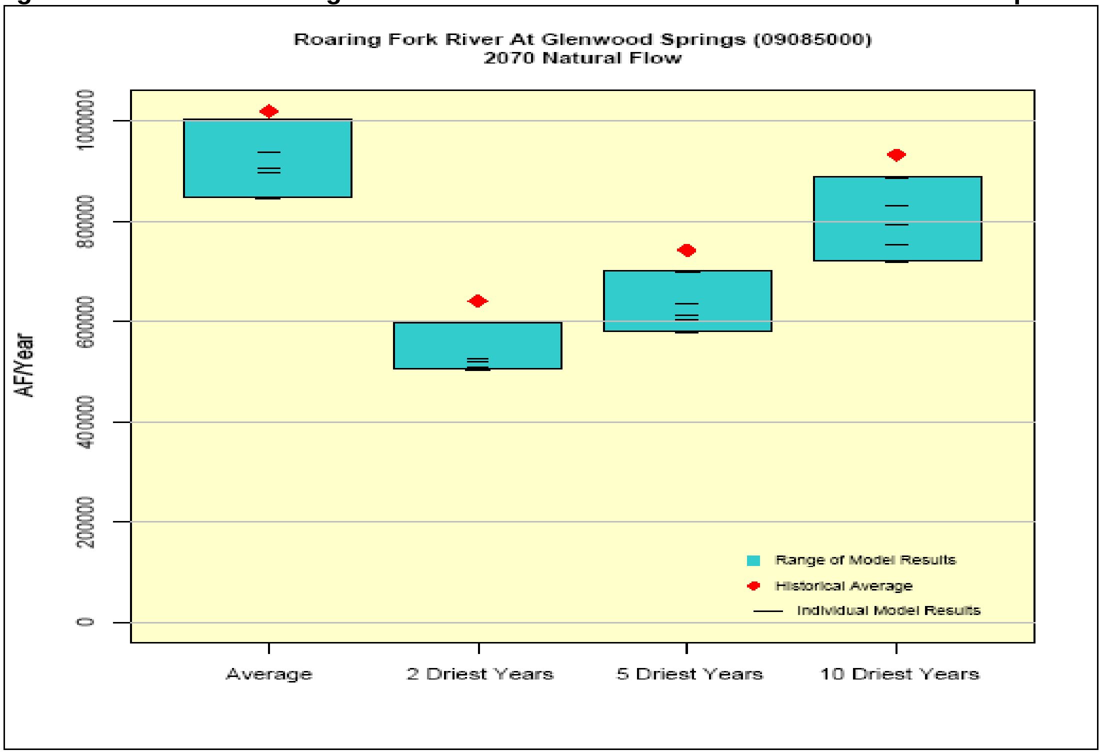


Figure D138 – 2070 Colorado River near Cameo Natural Flow Low-Flow Comparison

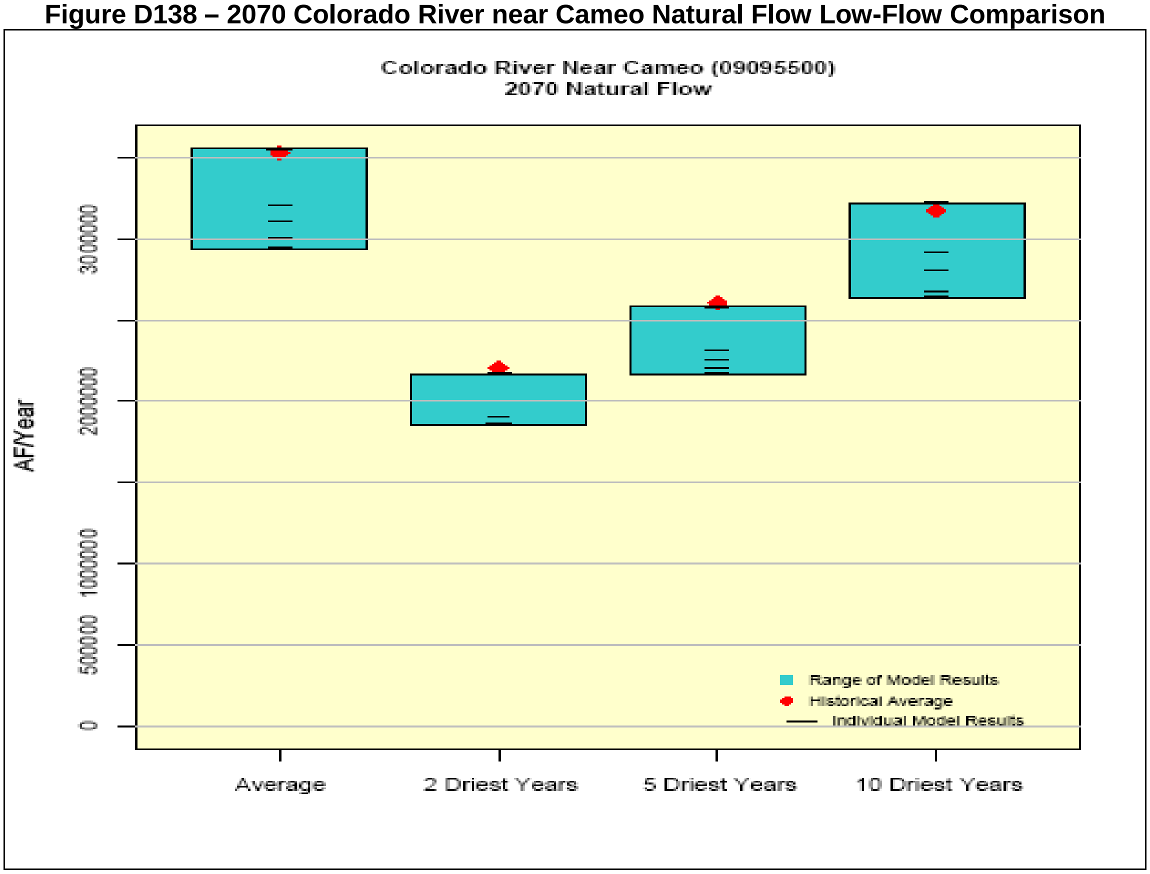


Figure D139 – 2070 Plateau Creek near Cameo Natural Flow Low-Flow Comparison

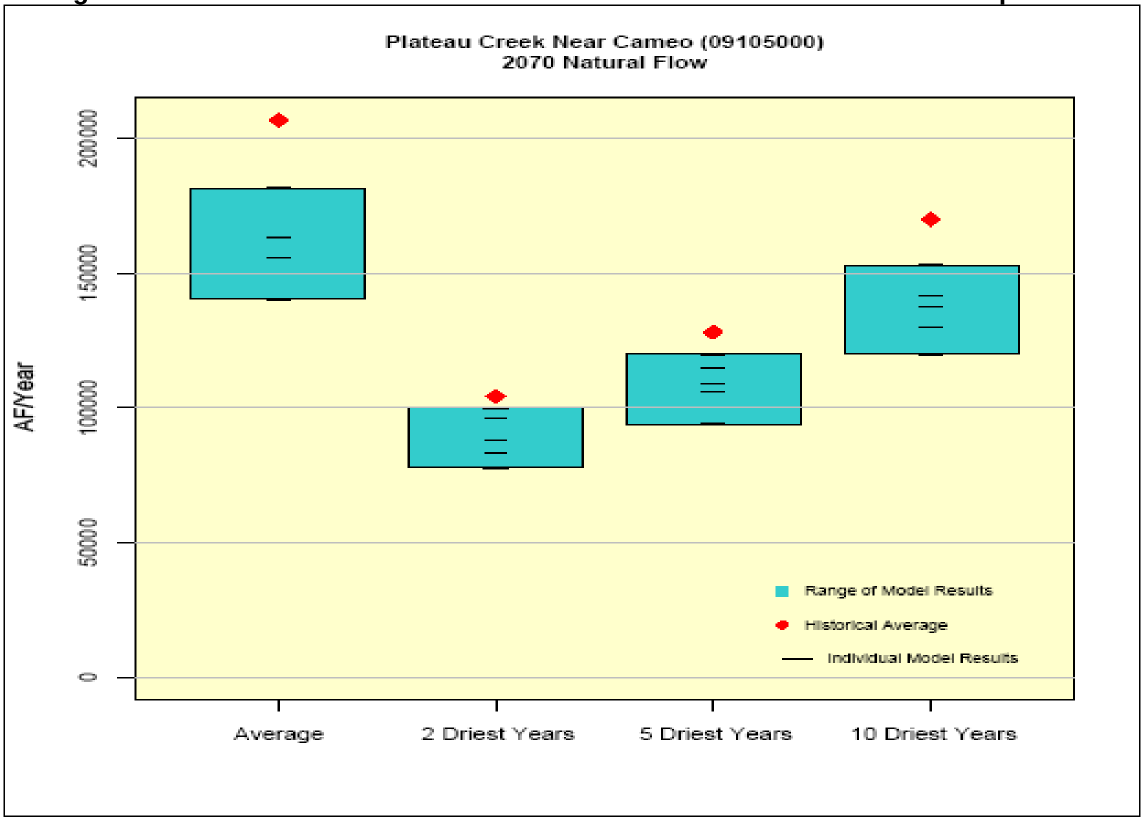


Figure D140 – 2070 Taylor River at Almont Natural Flow Low-Flow Comparison

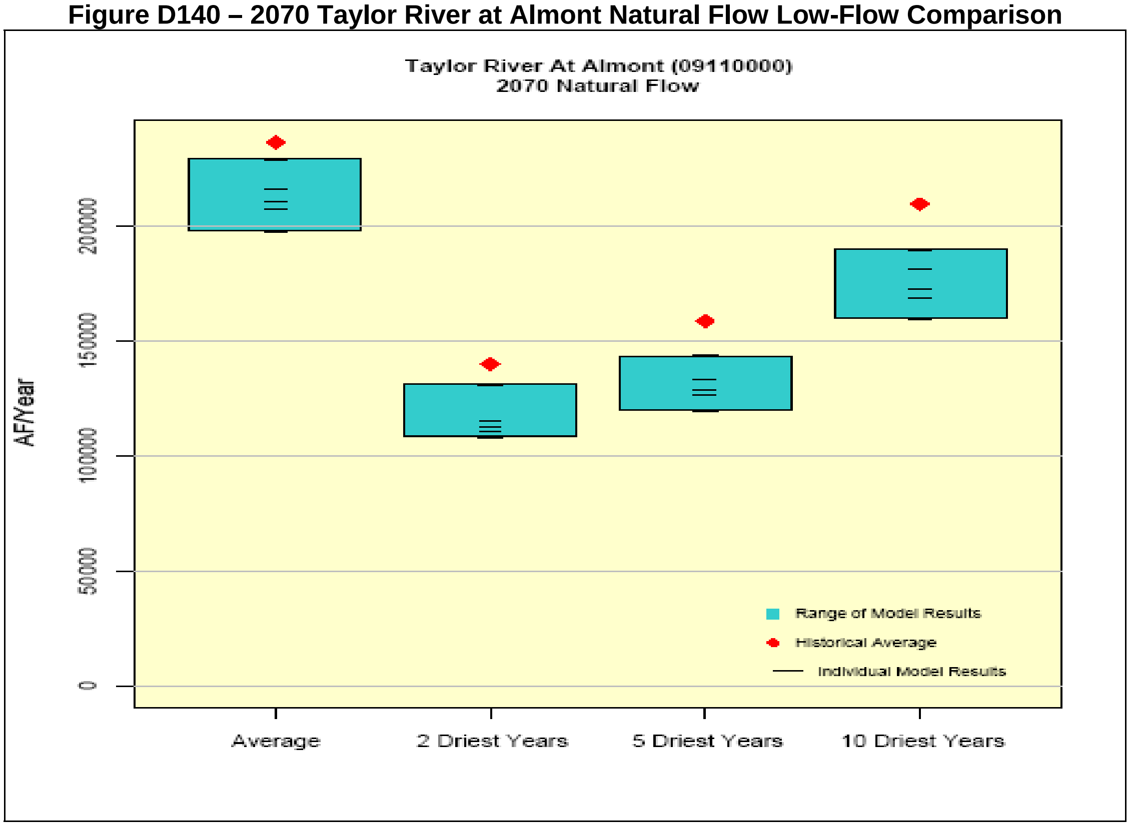


Figure D141 – 2070 East River at Almont Natural Flow Low-Flow Comparison

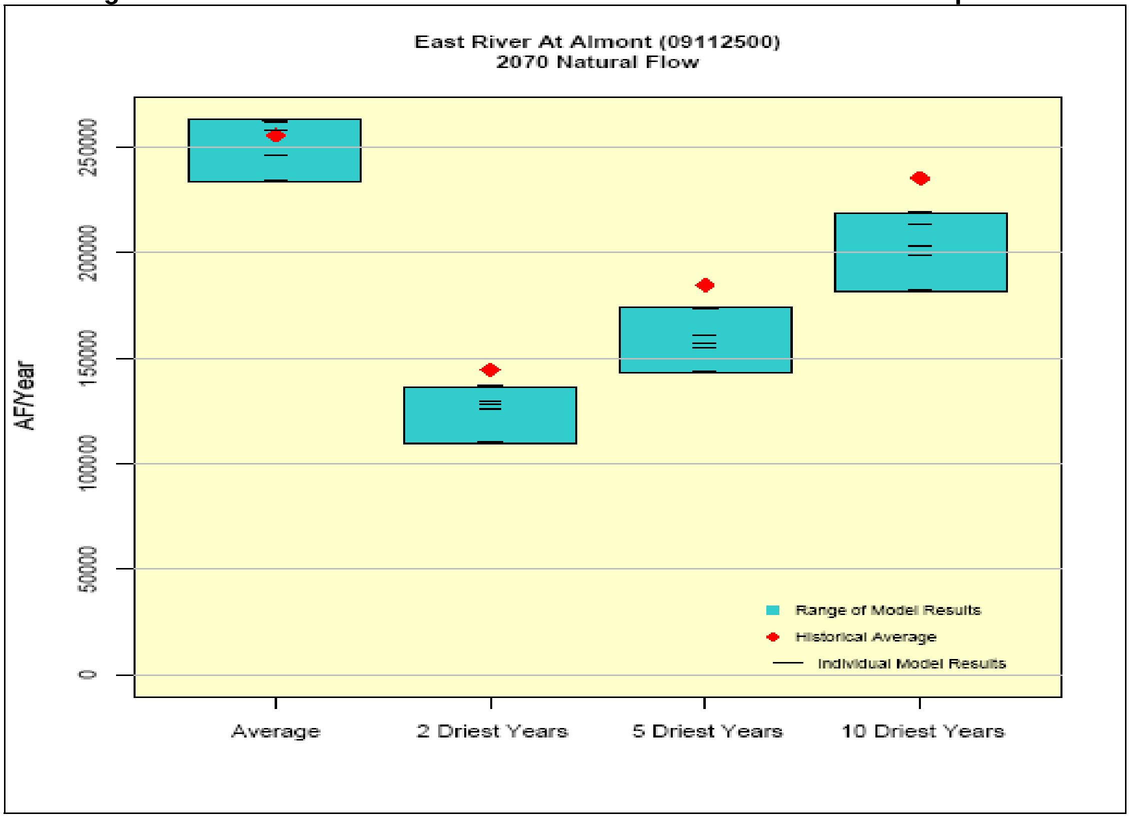


Figure D142 – 2070 Gunnison River near Gunnison Natural Flow Low-Flow Comparison

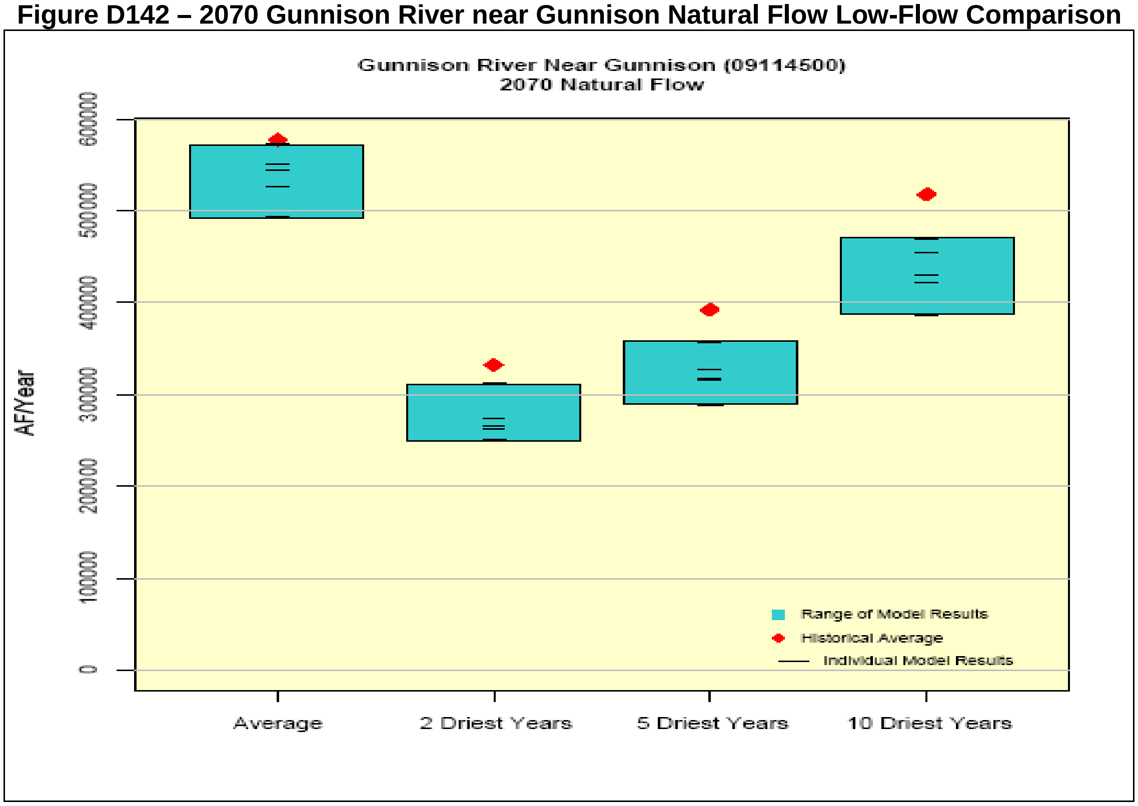


Figure D143 – 2070 Tomichi Creek at Gunnison Natural Flow Low-Flow Comparison

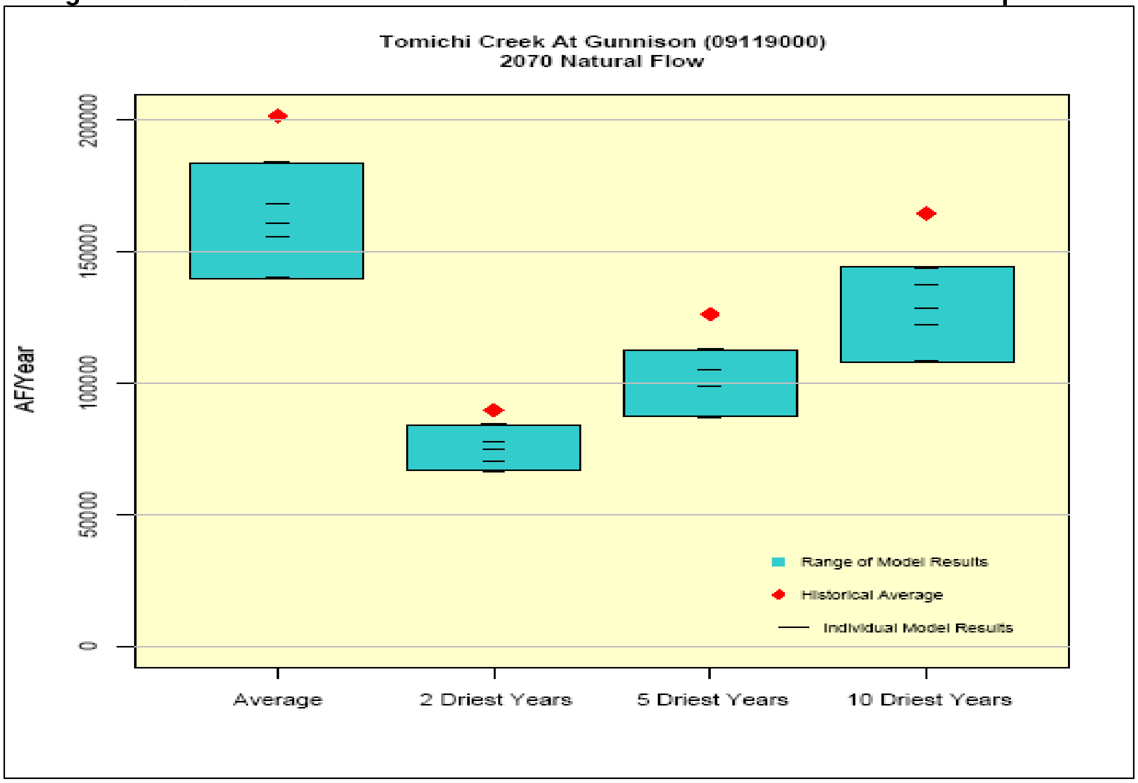


Figure D144 – 2070 Cimarron River at Cimarron Natural Flow Low-Flow Comparison

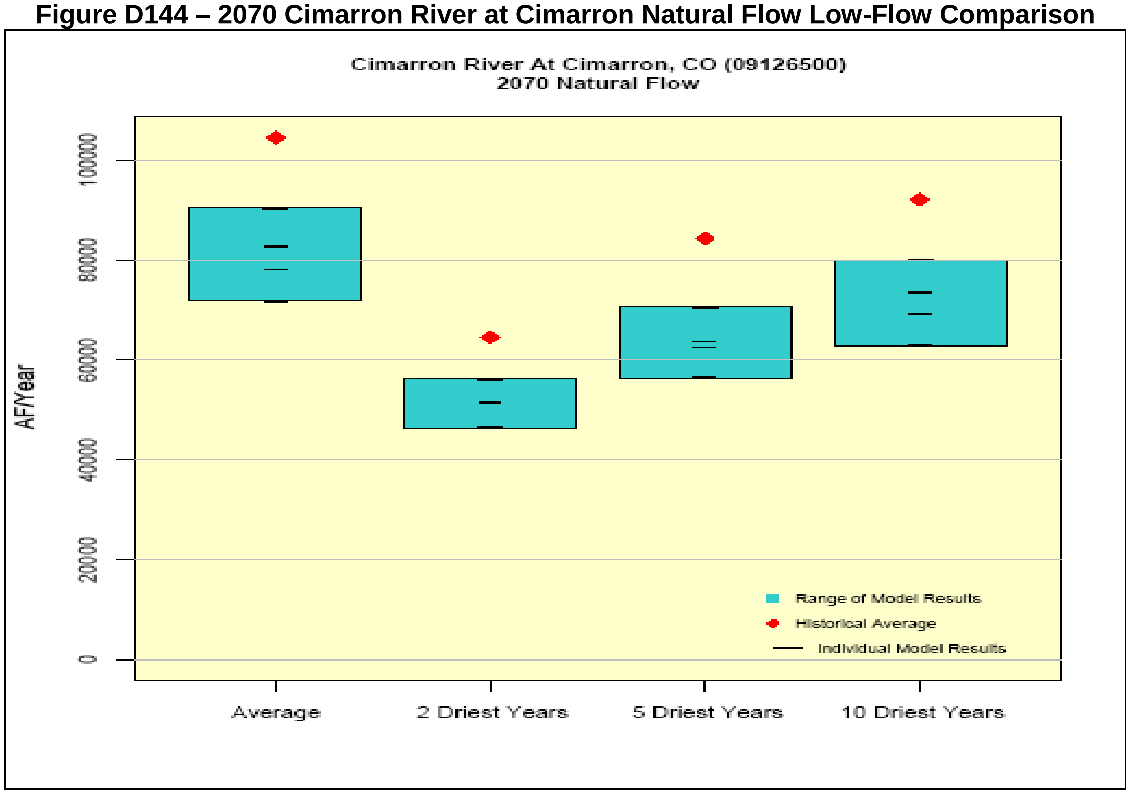


Figure D145 – 2070 Gunnison River below Gunnison Tunnel Natural Flow Low-Flow Comparison

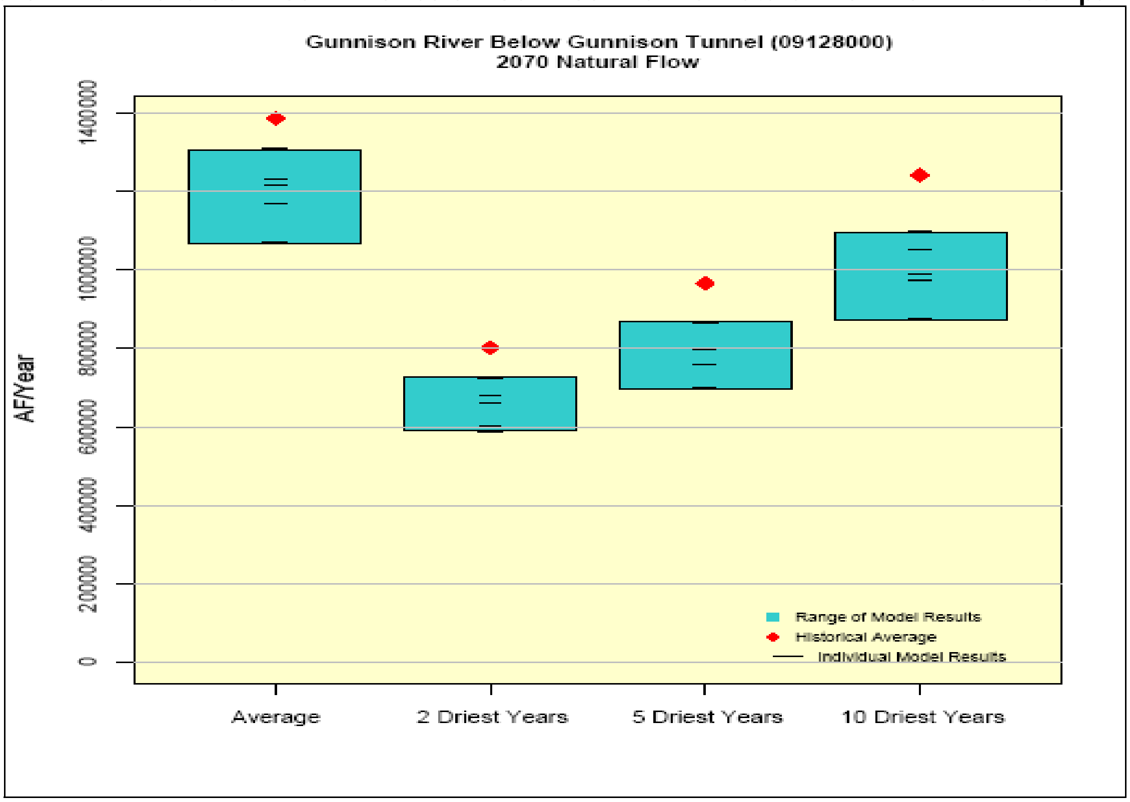


Figure D146 – 2070 Gunnison River near Lazear Natural Flow Low-Flow Comparison

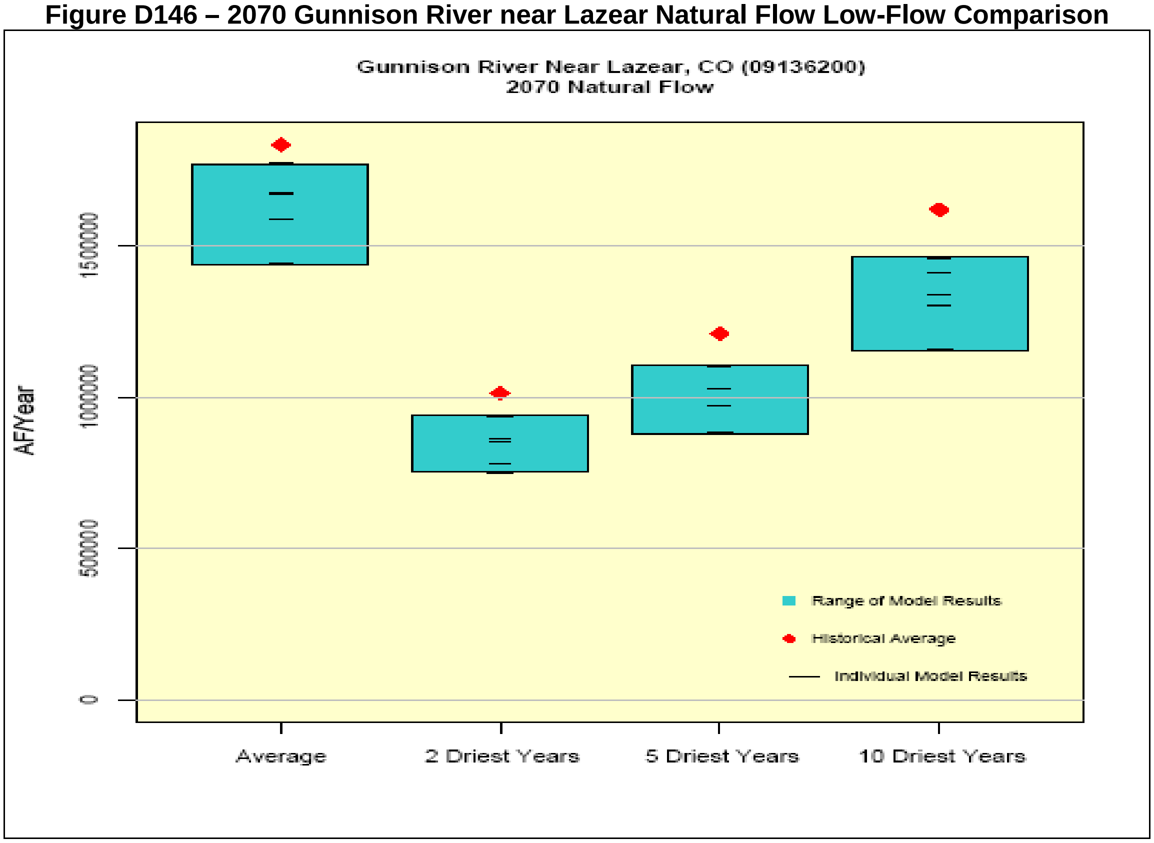


Figure D147 – 2070 Uncompahgre River at Delta Natural Flow Low-Flow Comparison

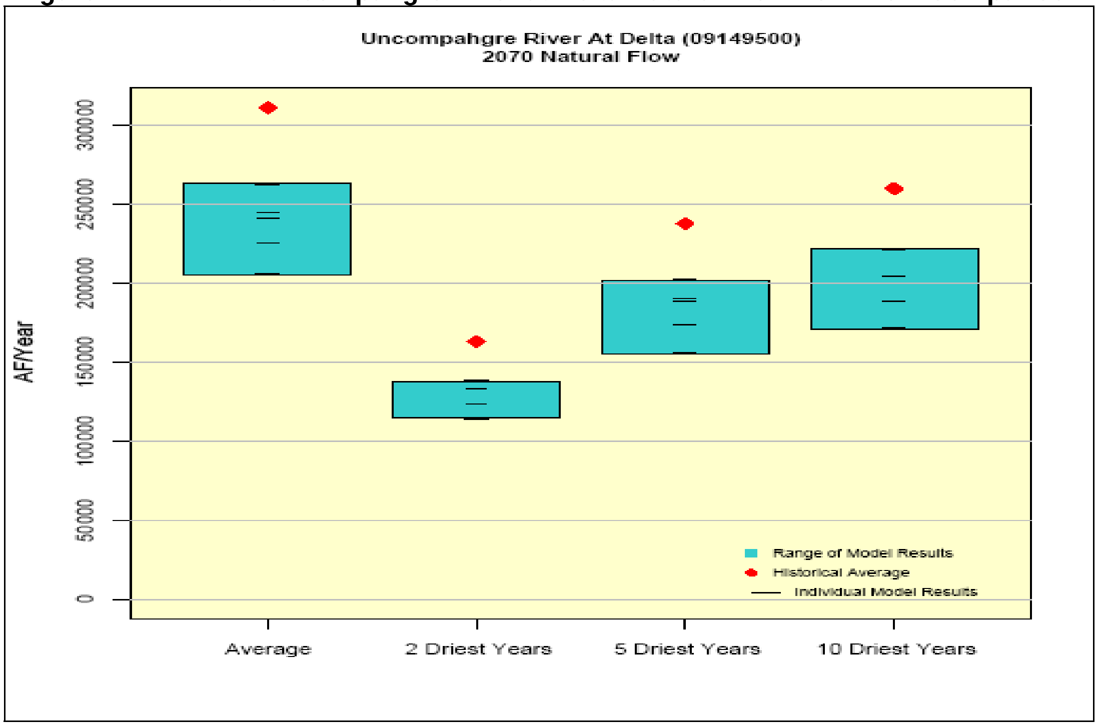


Figure D148 – 2070 Gunnison River near Grand Junction Natural Flow Low-Flow Comparison

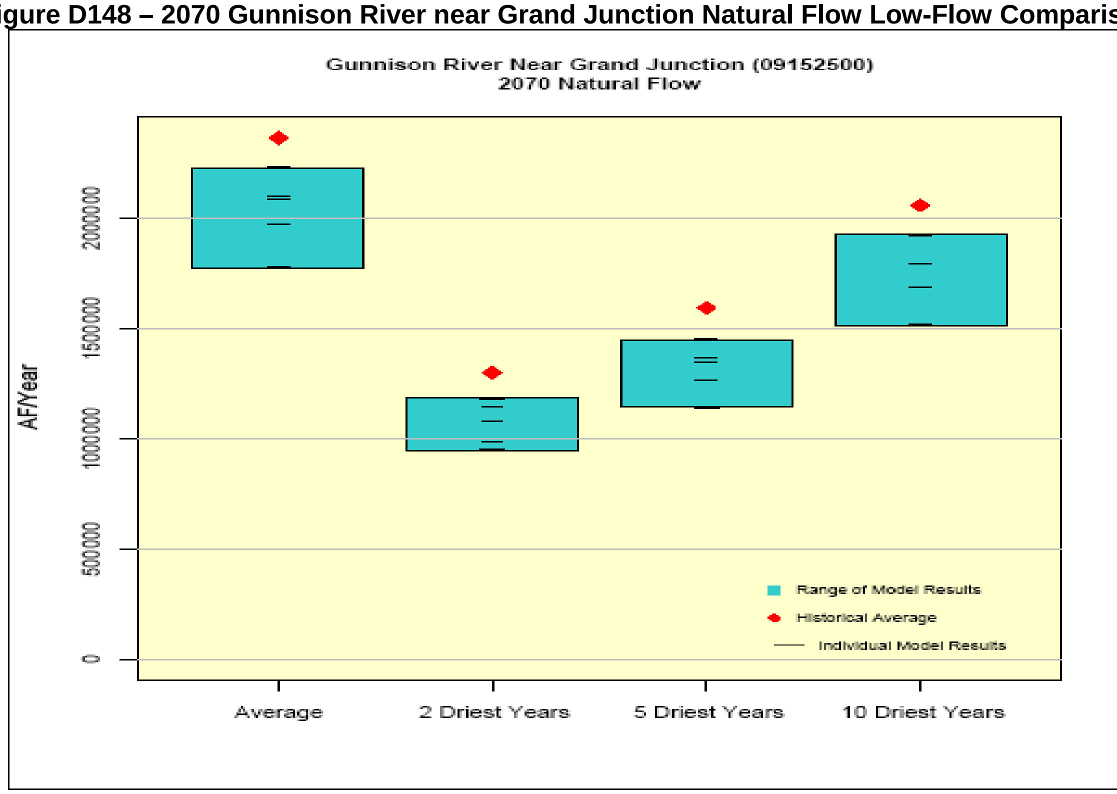


Figure D149 – 2070 Colorado River near CO-UT State Line Natural Flow Low-Flow Comparison

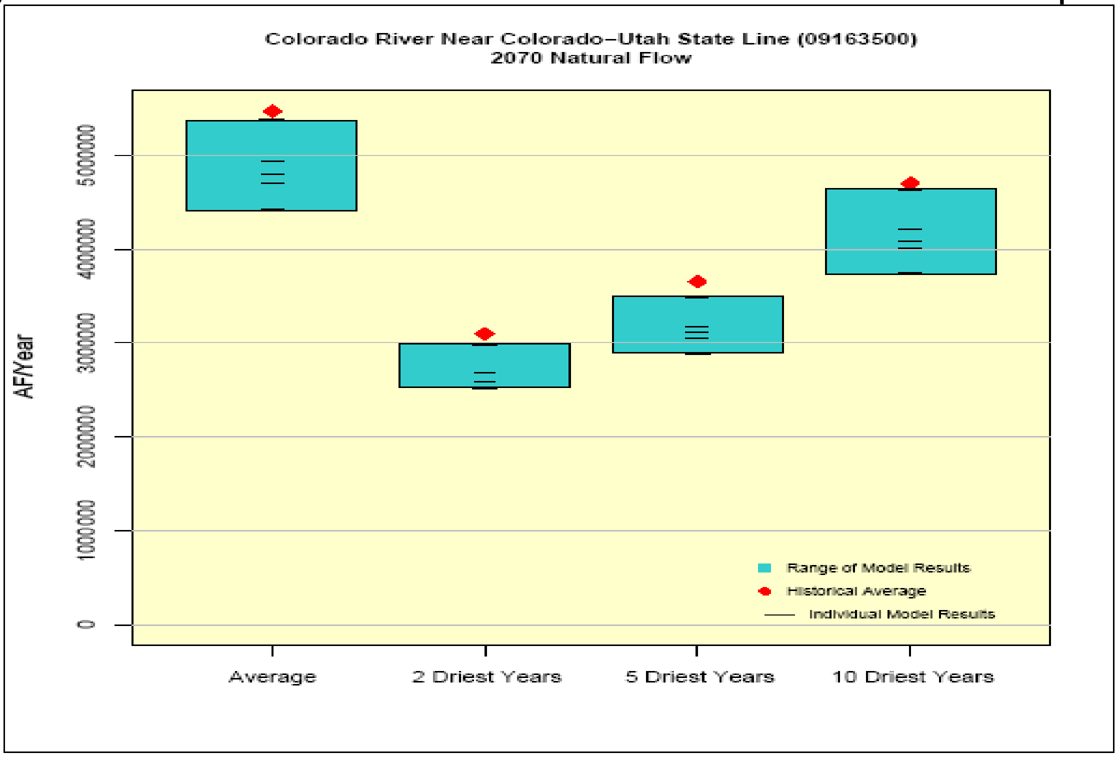


Figure D150 – 2070 Dolores River near Bedrock Natural Flow Low-Flow Comparison

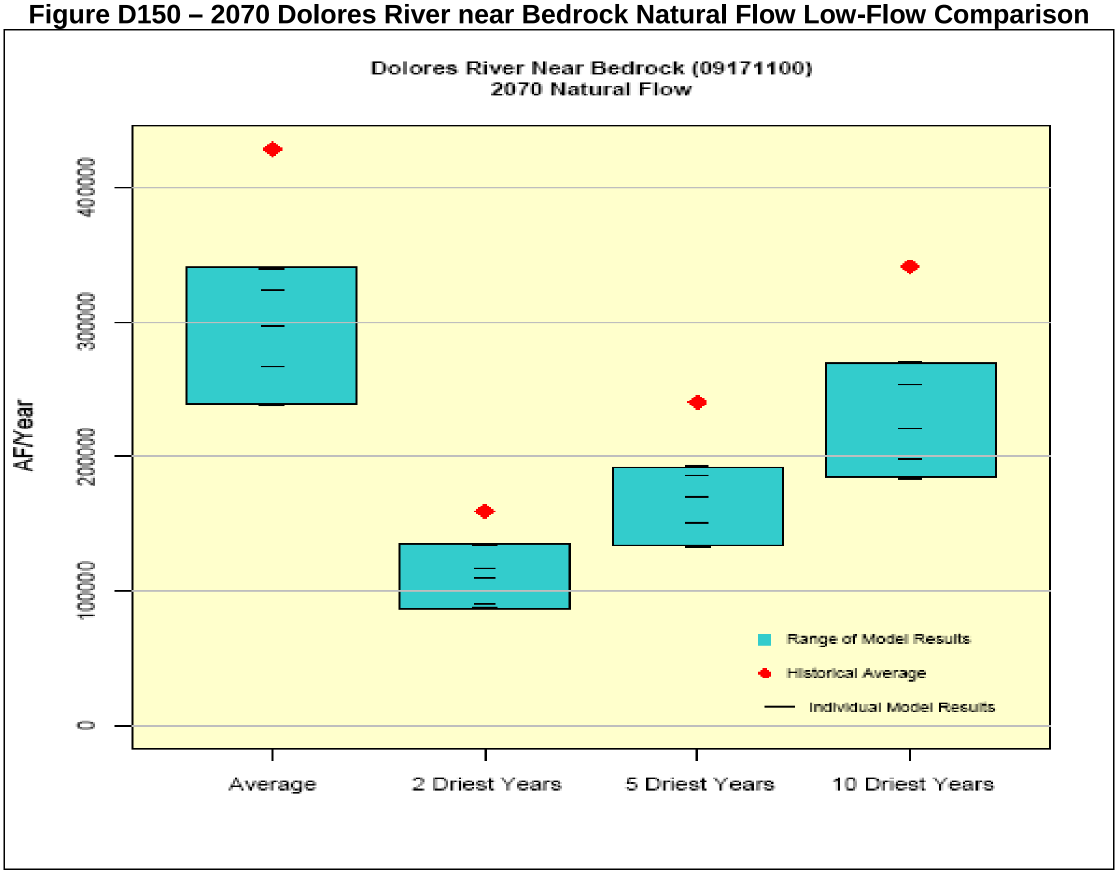


Figure D151 – 2070 San Miguel River at Naturita Natural Flow Low-Flow Comparison

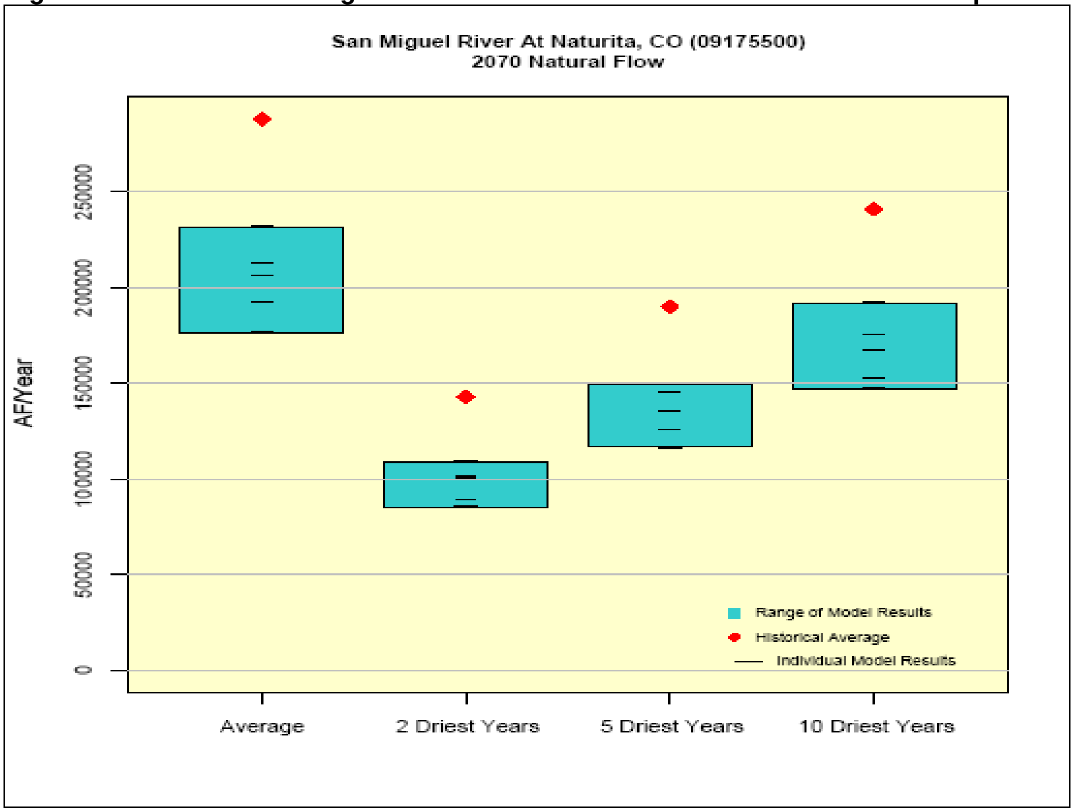


Figure D152 – 2070 Yampa River below Stagecoach Reservoir Natural Flow Low-Flow Comparison

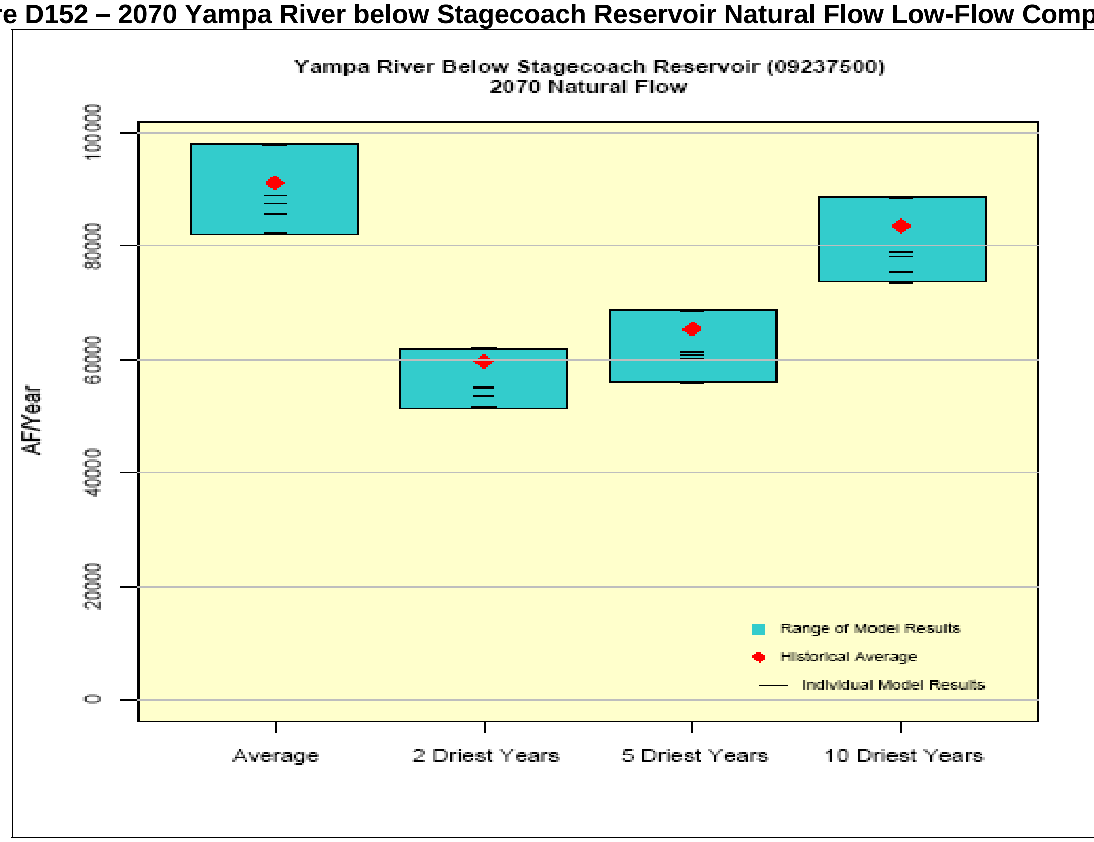


Figure D153 – 2070 Elk River at Clark Natural Flow Low-Flow Comparison

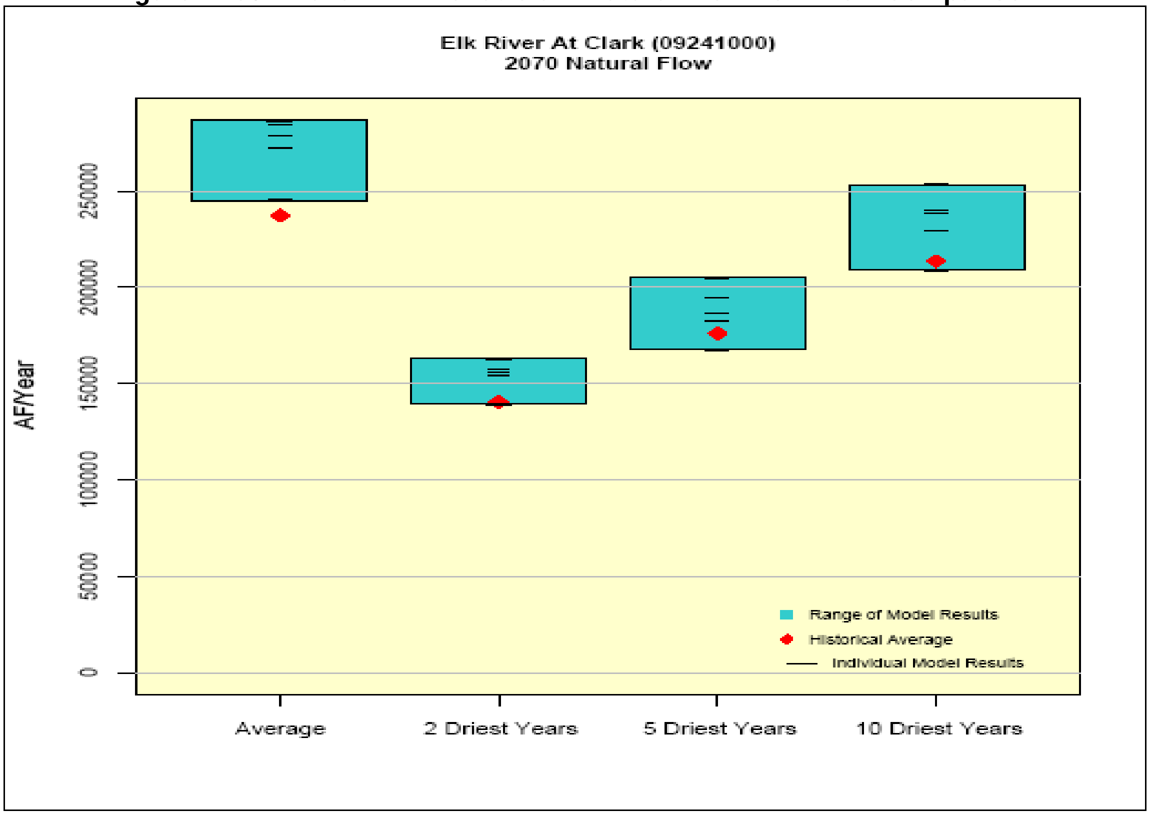


Figure D154 – 2070 Elkhead Creek near Elkhead Natural Flow Low-Flow Comparison

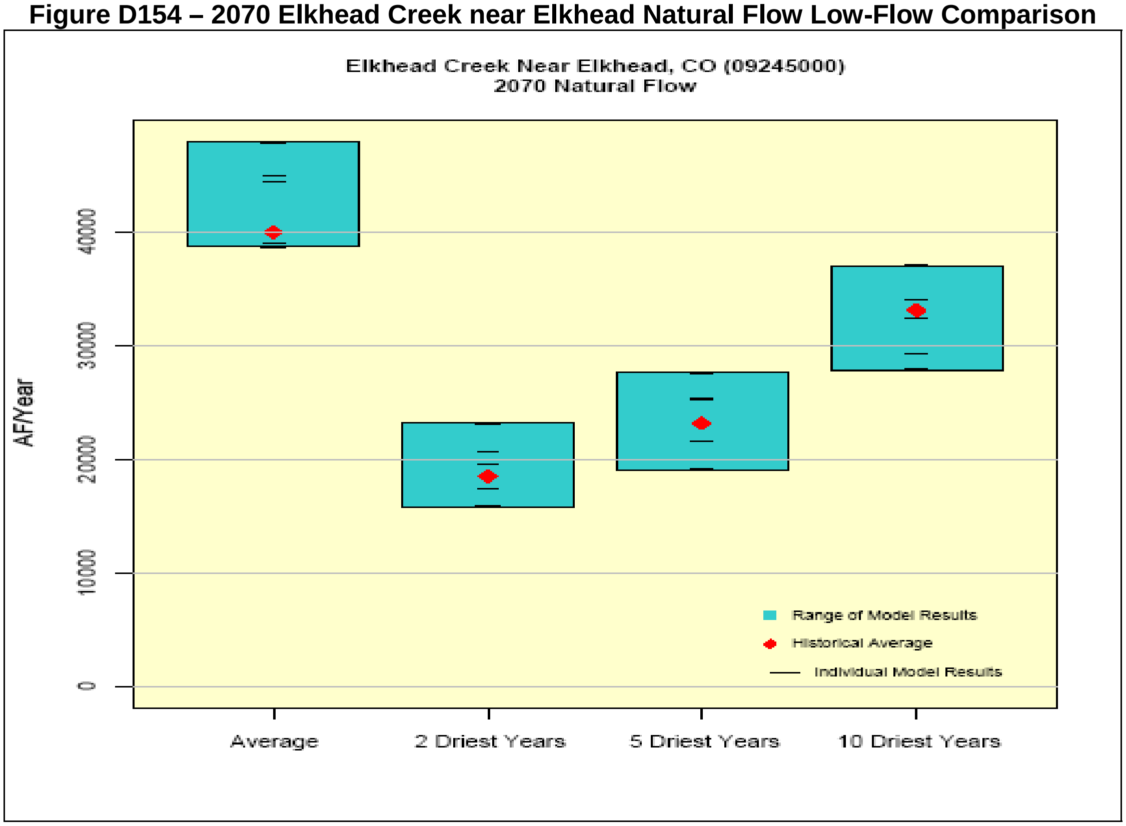


Figure D155 – 2070 Williams Fork at Mouth, near Hamilton Natural Flow Low-Flow Comparison

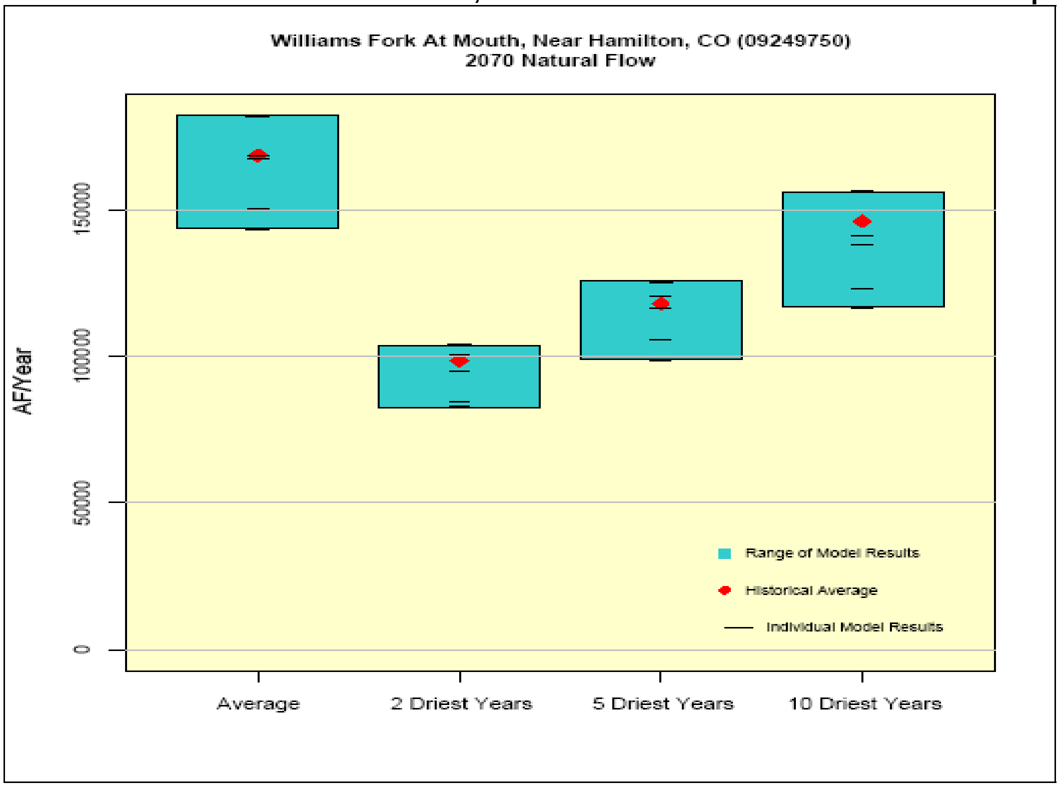


Figure D156 – 2070 Yampa River near Maybell Natural Flow Low-Flow Comparison

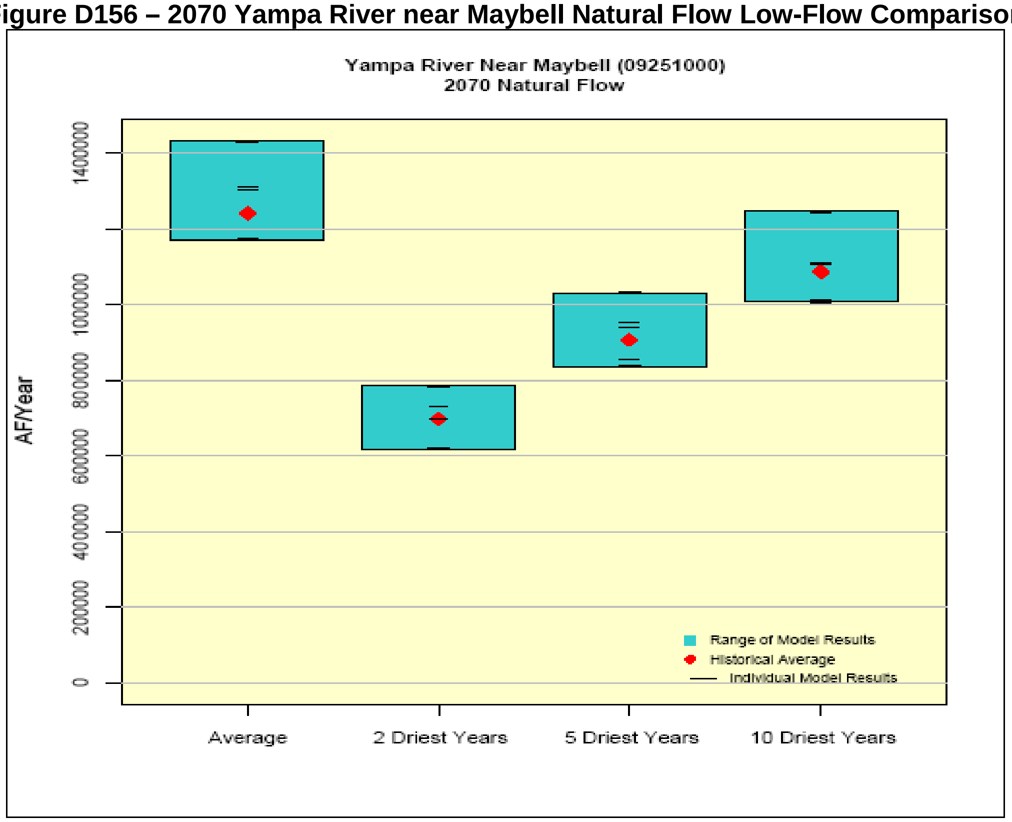


Figure D157 – 2070 Little Snake River near Lily Natural Flow Low-Flow Comparison

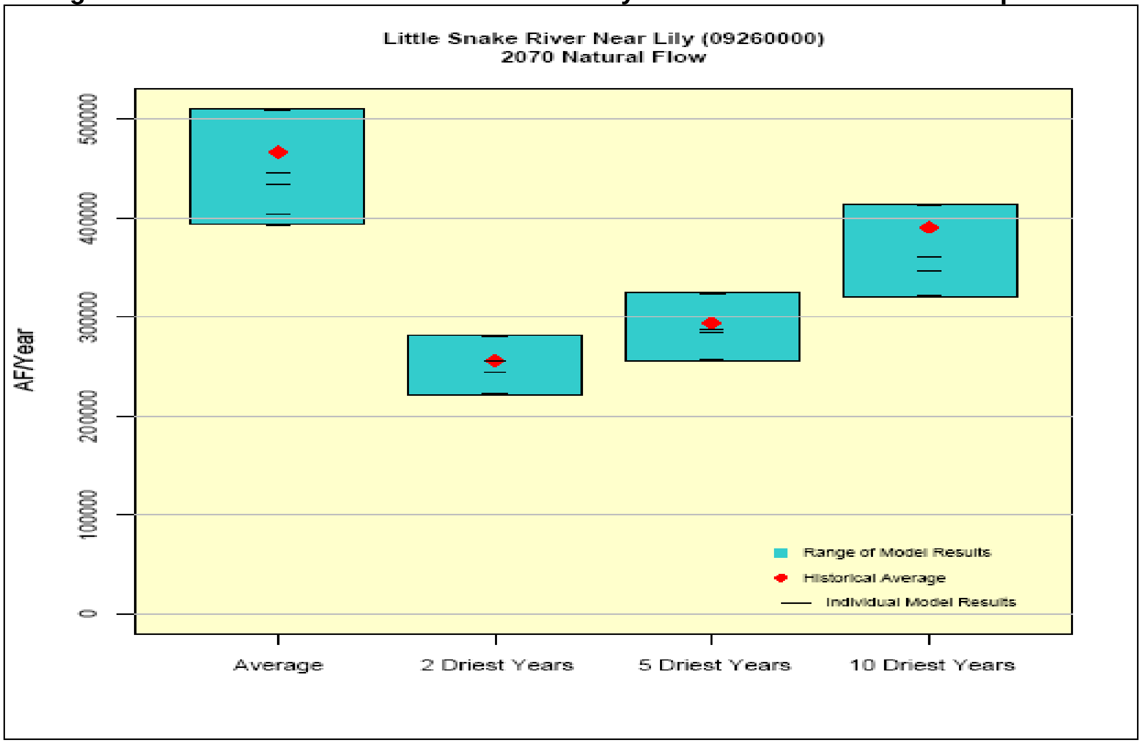


Figure D158 – 2070 Yampa River at Deerlodge Park Natural Flow Low-Flow Comparison

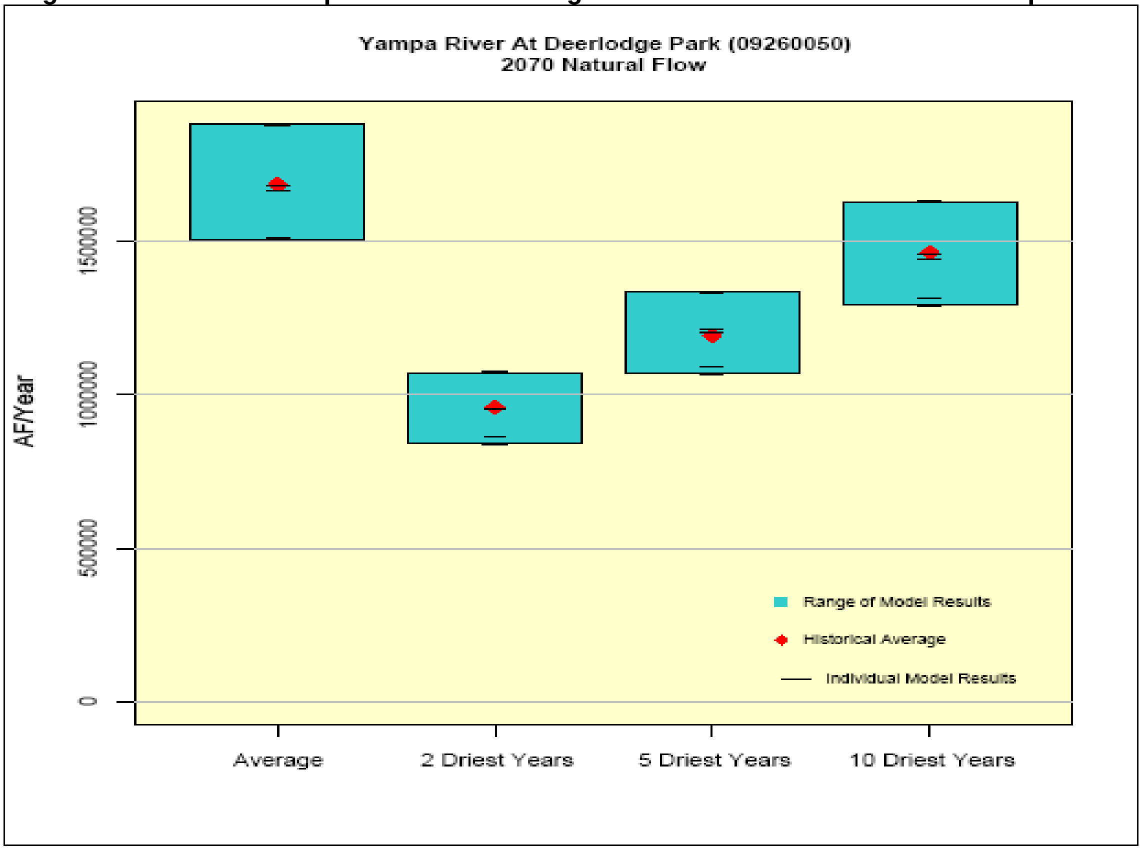


Figure D159 – 2070 North Fork White River at Buford, CO Natural Flow Low-Flow Comparison

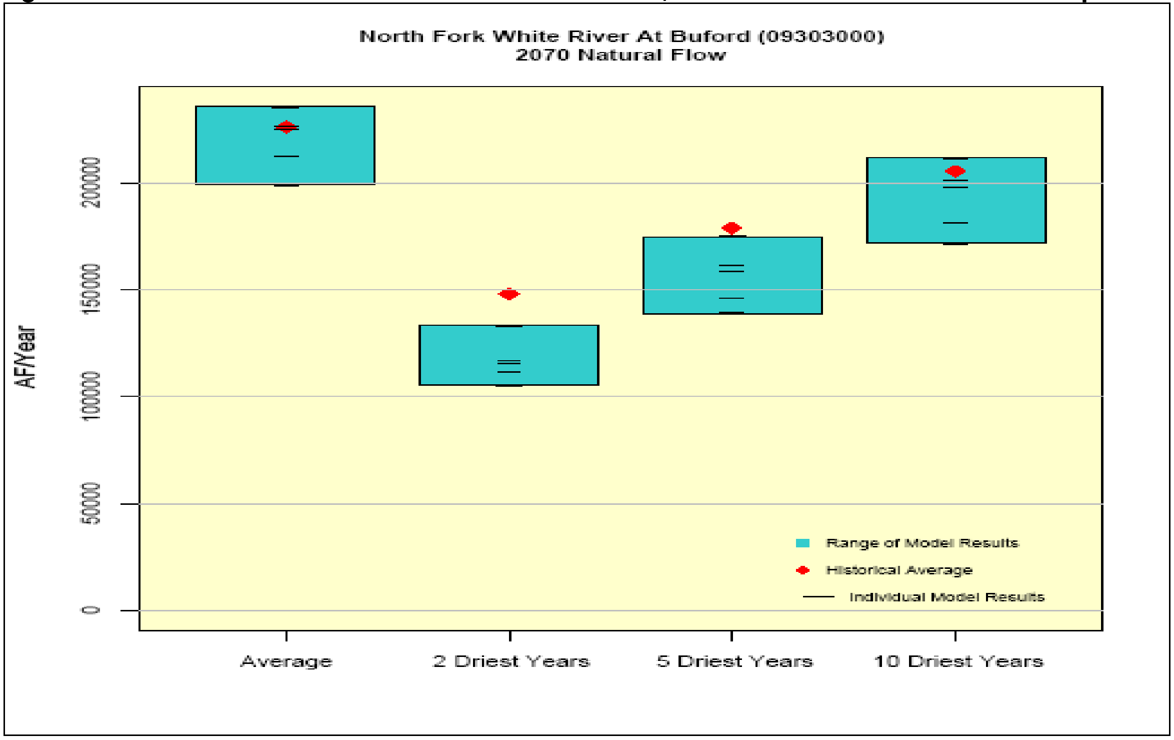


Figure D160 – 2070 South Fork White River at Buford Natural Flow Low-Flow Comparison

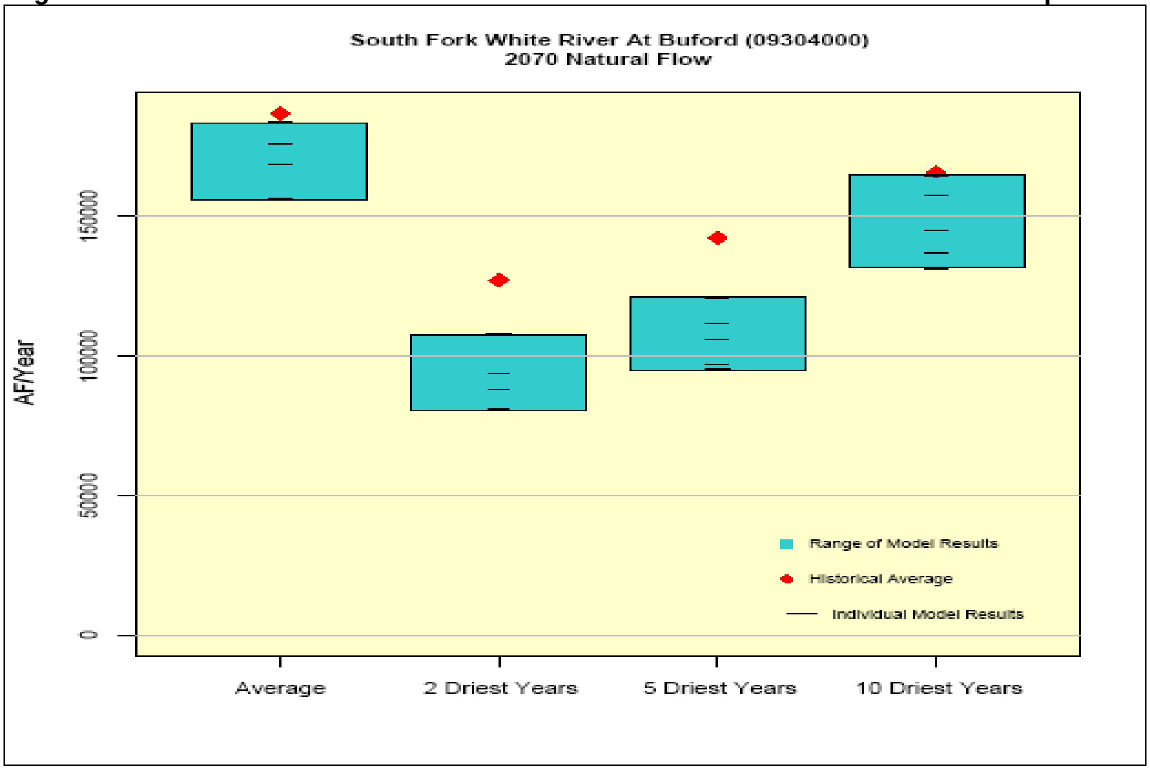


Figure D161 – 2070 White River below Meeker Natural Flow Low-Flow Comparison

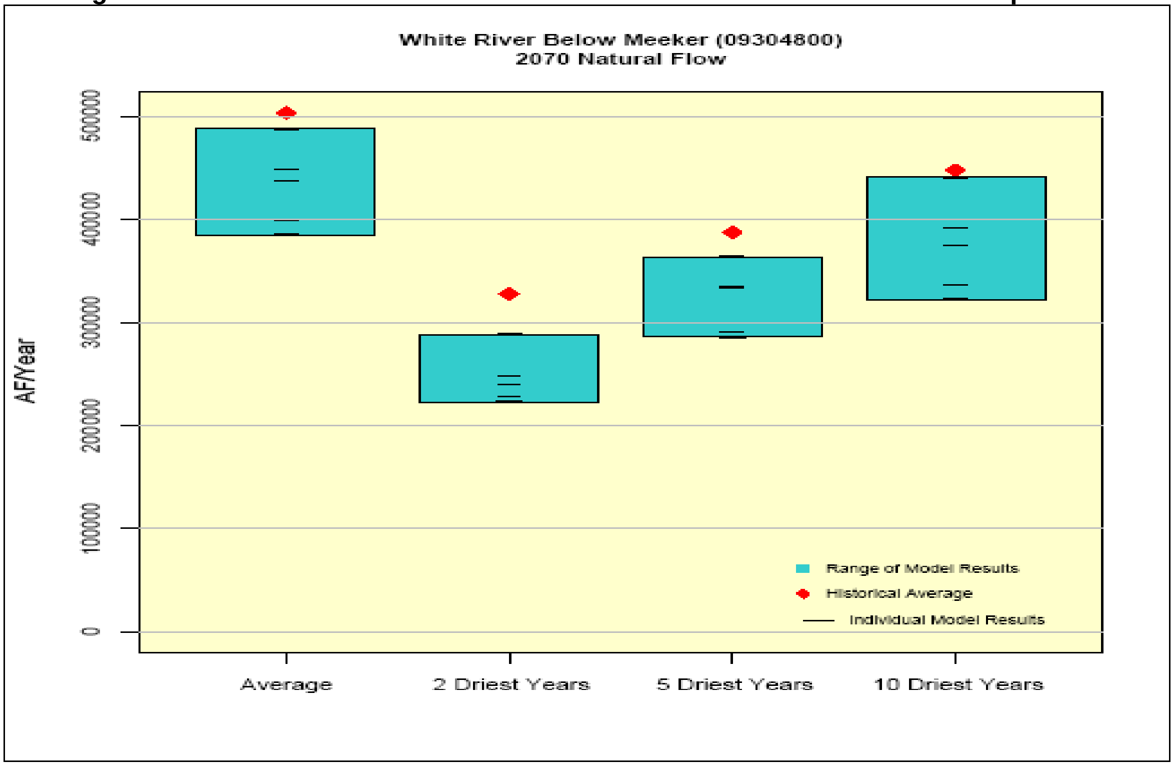


Figure D162 – 2070 Piceance Creek at White River Natural Flow Low-Flow Comparison

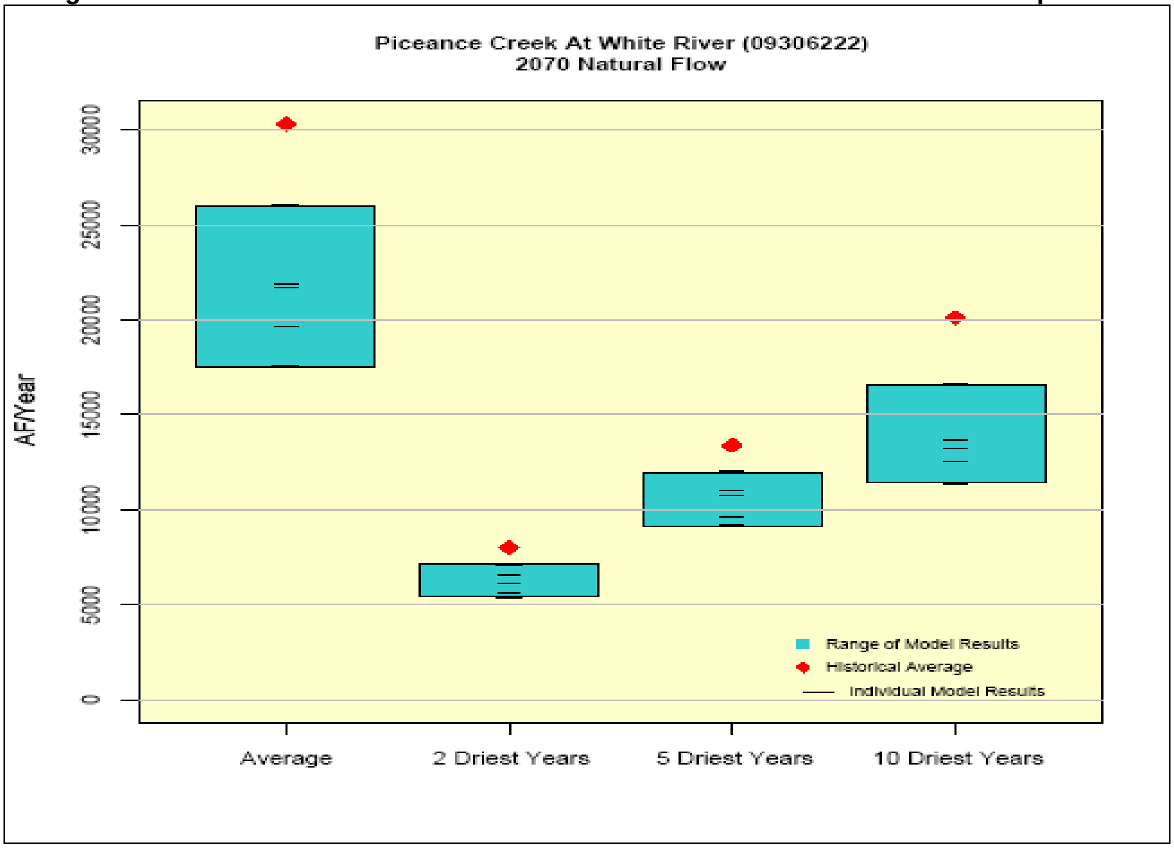


Figure D163 – 2070 White River near CO-UT State Line Natural Flow Low-Flow Comparison

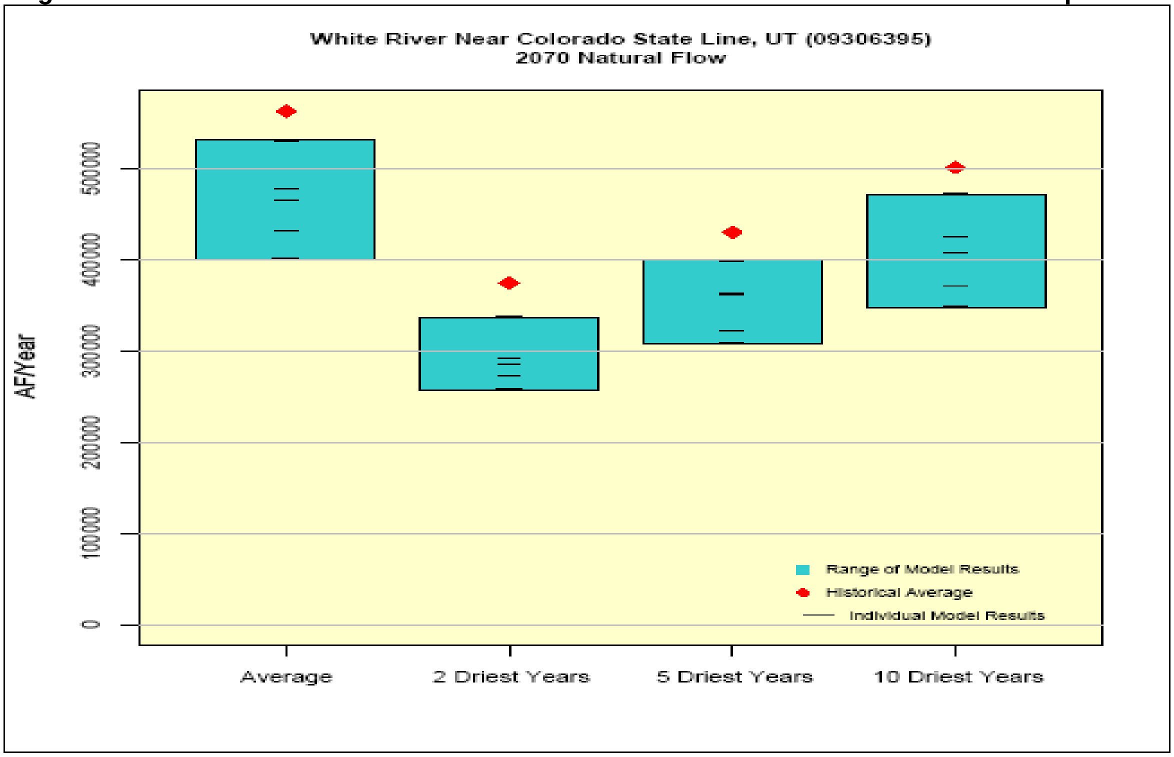


Figure D164 – 2070 San Juan River near Carracas Natural Flow Low-Flow Comparison

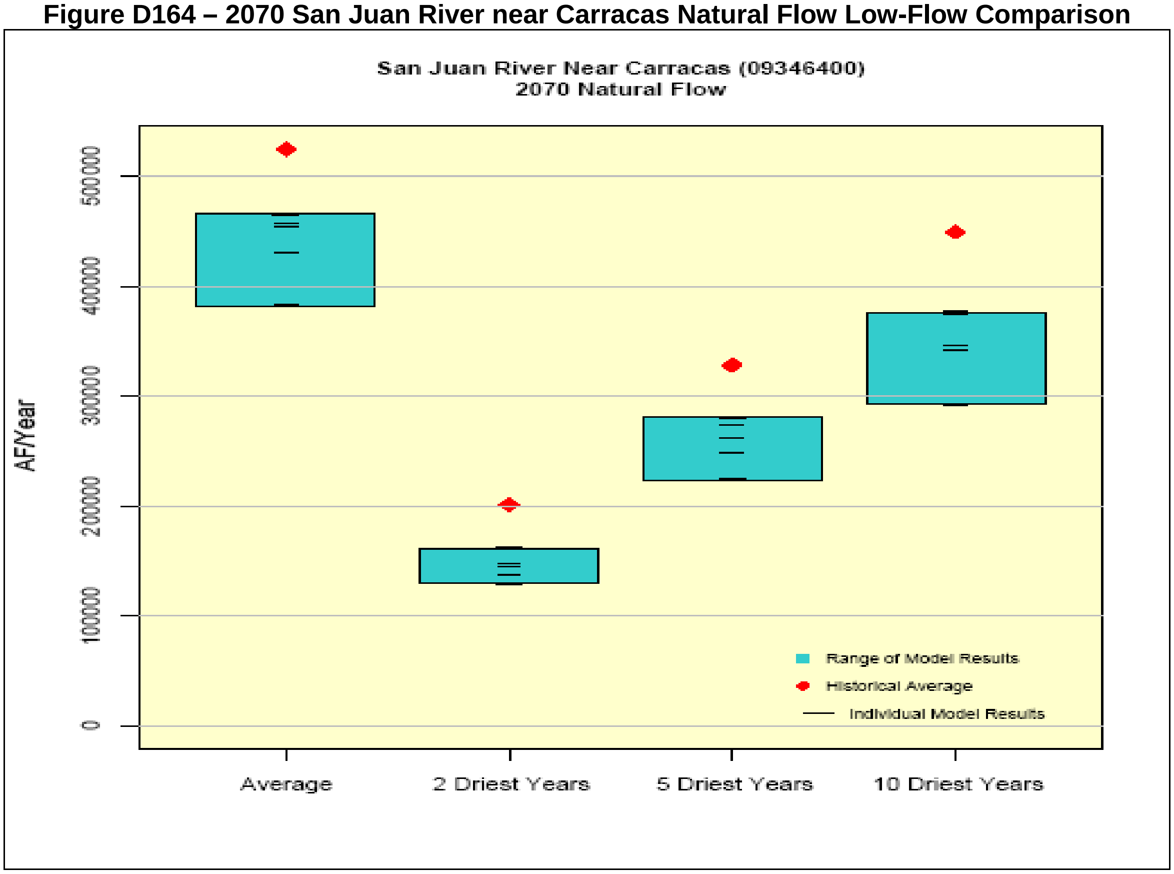


Figure D165 – 2070 Piedra River near Arboles Natural Flow Low-Flow Comparison

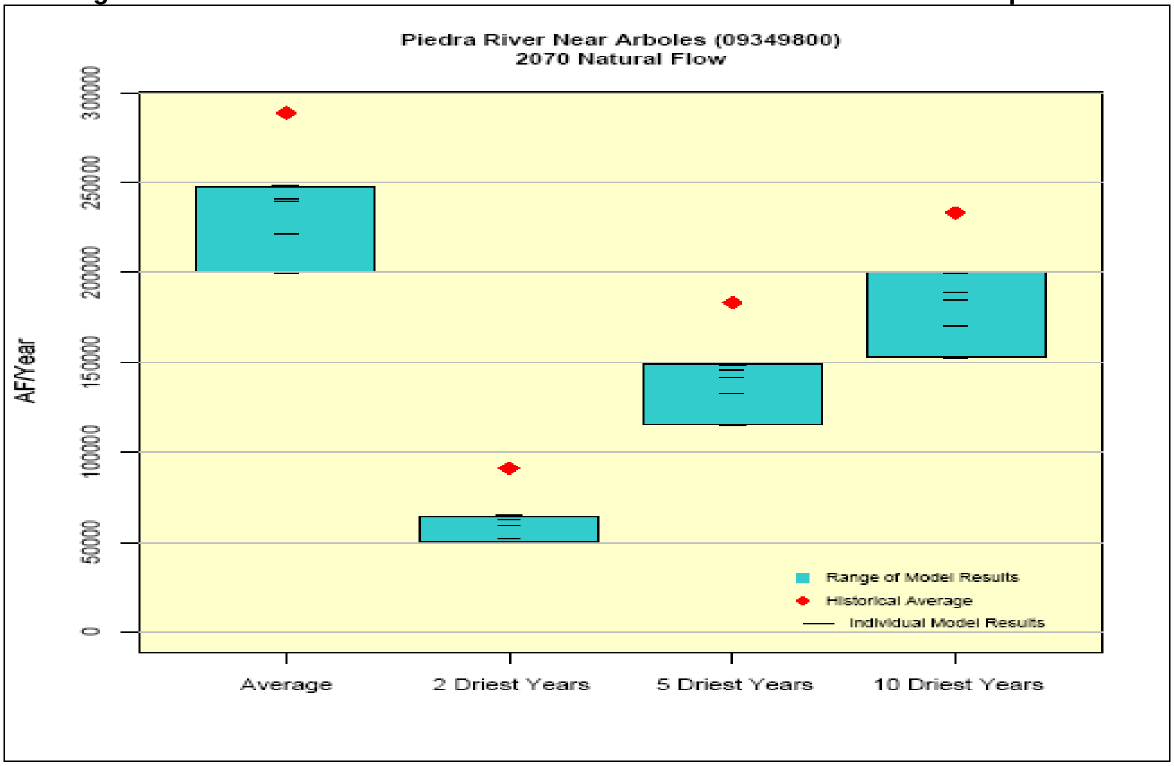


Figure D166 – 2070 Los Pinos River at La Boca Natural Flow Low-Flow Comparison

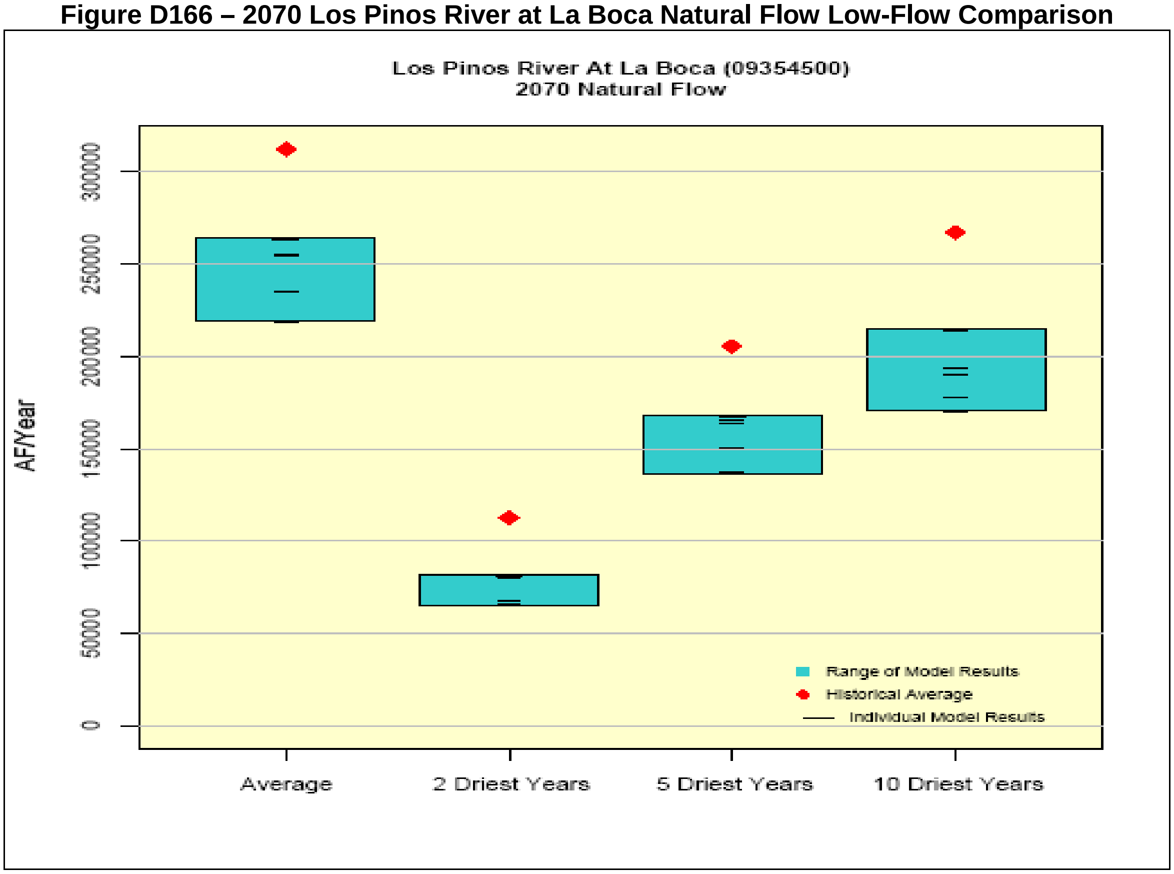


Figure D167 – 2070 Florida River at Bondad Natural Flow Low-Flow Comparison

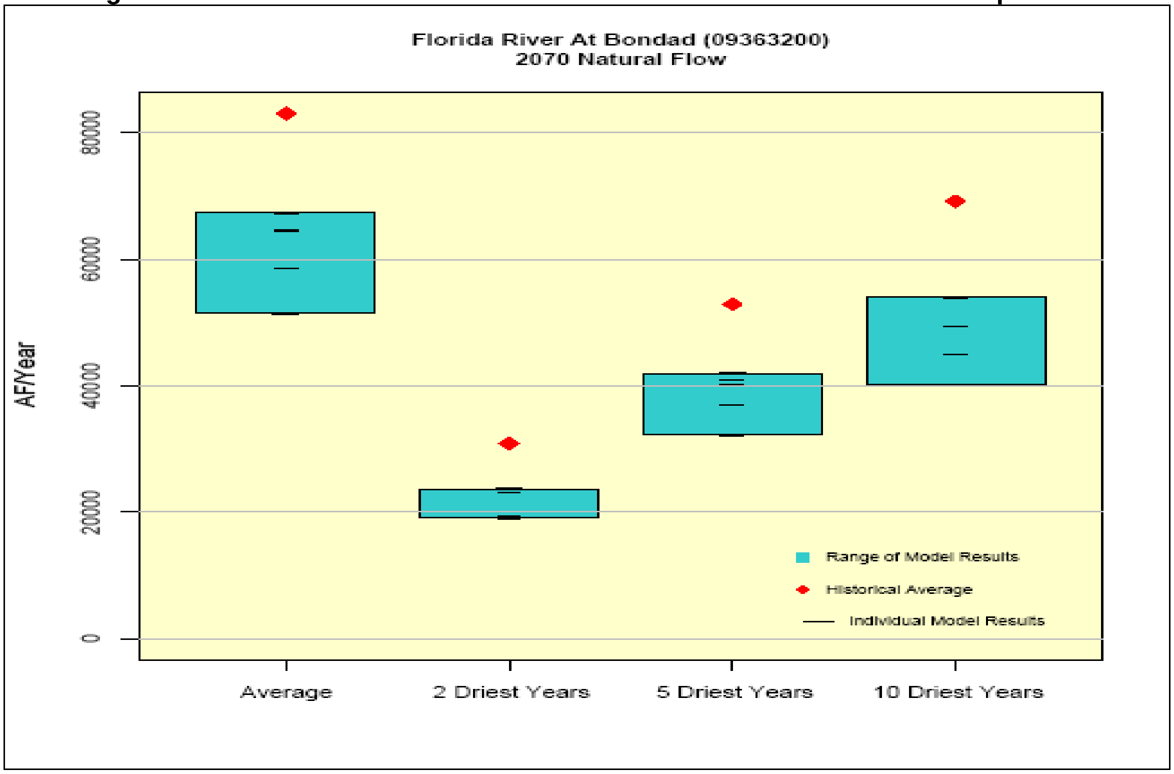


Figure D168 – 2070 Animas River near Cedar Hill, NM Natural Flow Low-Flow Comparison

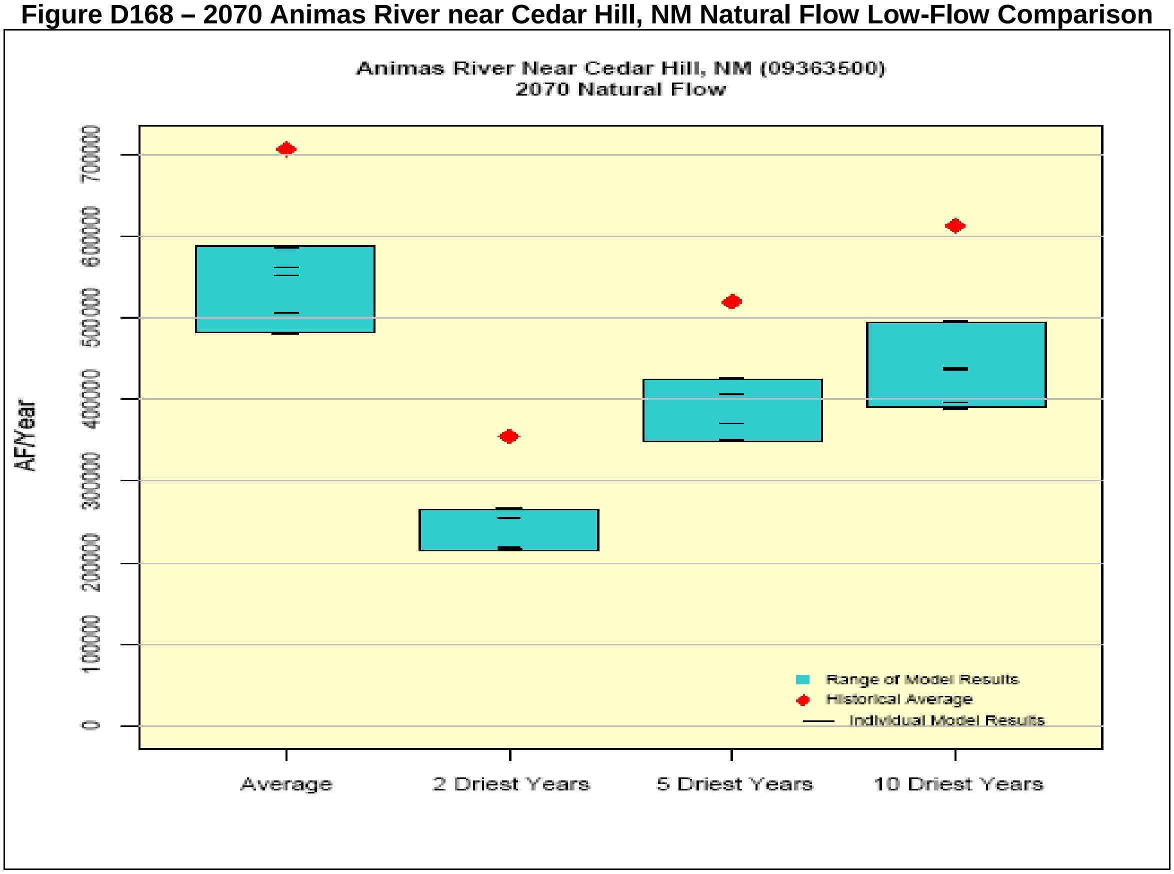


Figure D169 – 2070 La Plata River at Hesperus Natural Flow Low-Flow Comparison

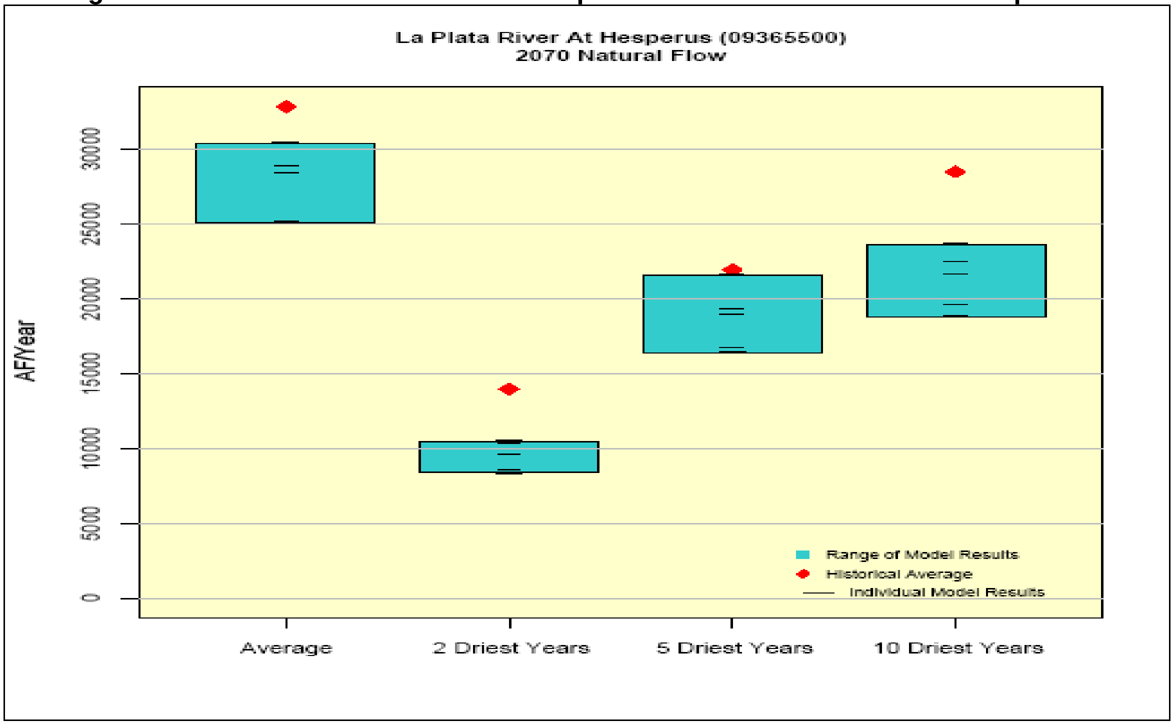


Figure D170 – 2070 La Plata River at CO-NM State Line Natural Flow Low-Flow Comparison

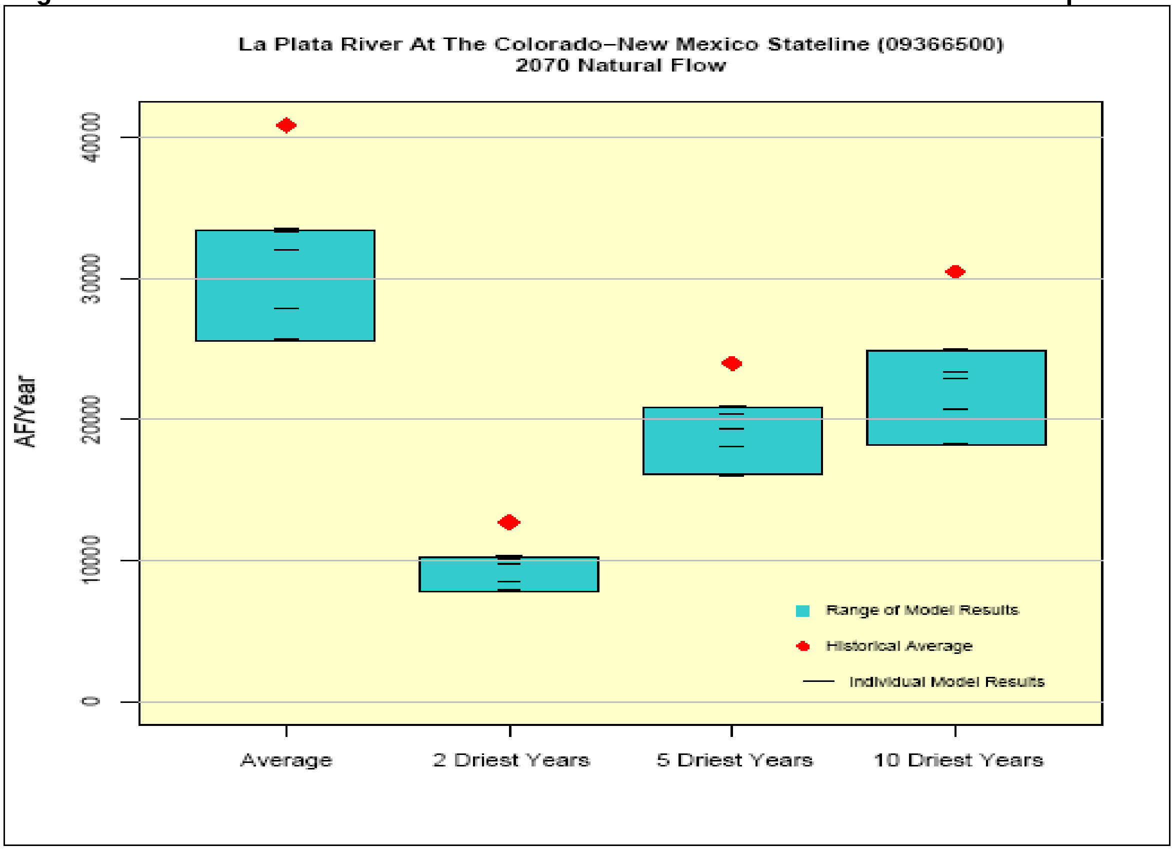


Figure D171 – 2070 Mancos River near Towaoc Natural Flow Low-Flow Comparison

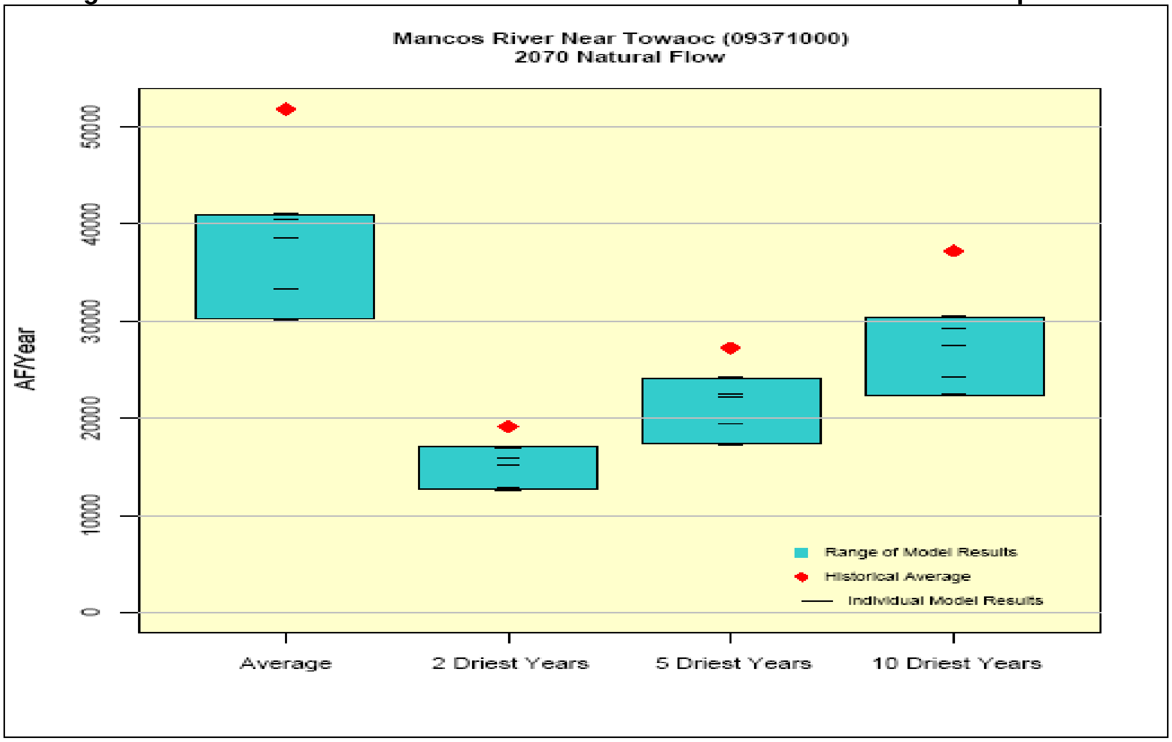
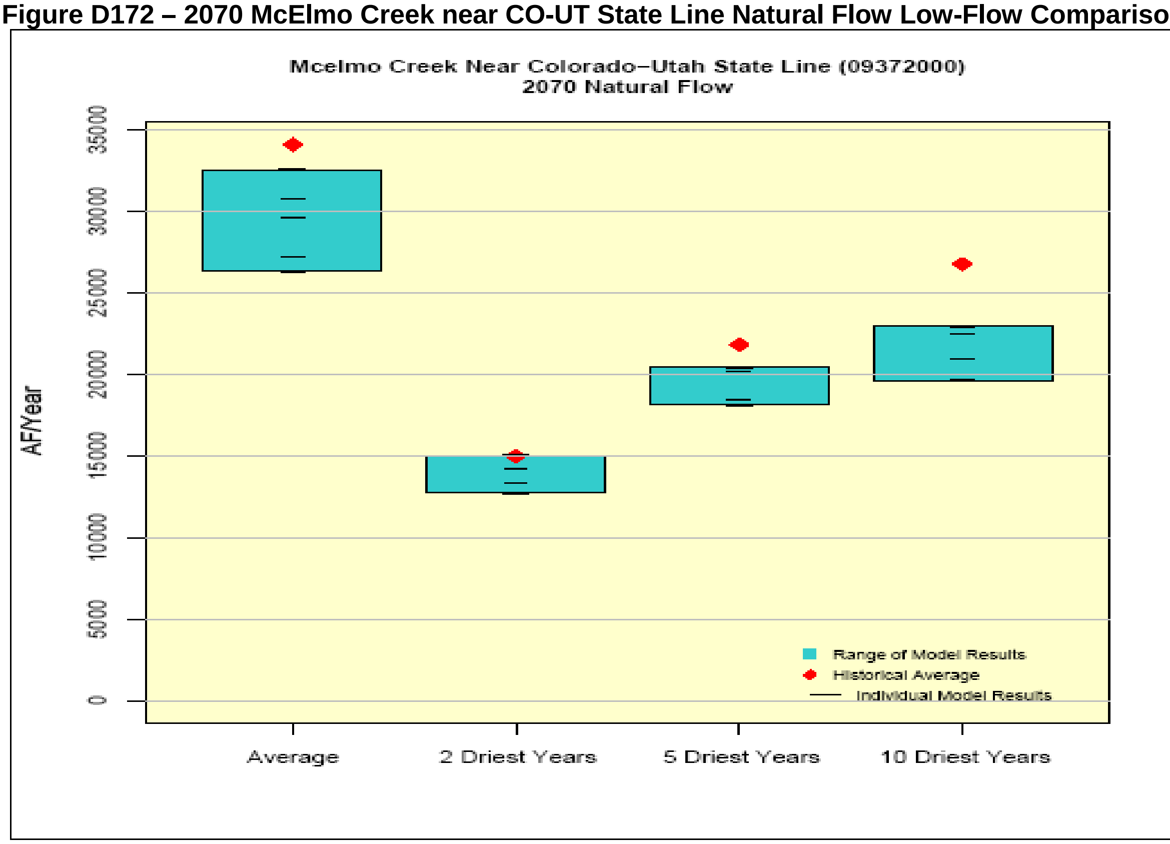


Figure D172 – 2070 McElmo Creek near CO-UT State Line Natural Flow Low-Flow Comparison



E. Modeled Streamflow

Contents

Table E1 - 2040 Upper Colorado River Basin Average Modeled Streamflow

2040 Climate Projections		Average Monthly Modeled Streamflow (AF)*												Range** in Average Annual Modeled Streamflow (AF)		Reduction*** in Avg Annual Modeled Streamflow	
USGS #	Location Name	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Low*	*High*	*KAF*	*Percent*
09011000	Colorado River Near Grand Lake	910	838	1,071	4,364	22,698	21,224	1,925	975	641	1,318	1,208	957	48,300	68,100	-2,927	-5%
09041500	Muddy Creek At Kremmling	763	782	2,099	5,334	25,007	13,848	5,087	9,914	1,353	323	940	866	49,400	80,800	-2,635	-4%
09050700	Blue River Below Dillon	3,840	3,602	4,869	3,764	20,158	42,658	18,534	9,264	4,174	3,750	3,901	3,858	90,000	168,500	11,509	9%
09057500	Blue River Below Green Mountain Reservoir	14,478	14,044	17,058	6,121	12,851	56,278	46,905	29,124	19,857	15,749	14,797	14,422	202,100	342,700	20,796	7%
09070000	Eagle River Below Gypsum	9,939	9,325	12,971	26,216	93,264	111,106	38,803	16,526	12,186	12,193	11,105	10,200	288,200	459,200	32,655	8%
09070500	Colorado River At Dotsero	48,355	47,207	66,395	100,724	276,548	344,663	141,116	91,406	55,776	53,845	53,737	48,847	1,013,700	1,694,300	63,665	5%
09073400	Roaring Fork River Near Aspen	1,285	1,157	1,429	3,138	17,811	17,532	5,589	2,755	2,081	1,826	1,385	1,364	49,800	69,500	-2,355	-4%
09085000	Roaring Fork River At Glenwood	20,847	18,846	26,014	53,183	185,535	222,049	91,287	44,501	34,567	33,135	23,835	22,253	644,200	942,500	40,915	5%
09095500	Colorado River Near Cameo	82,874	82,138	113,192	175,205	548,538	650,808	241,623	138,039	98,600	101,444	91,965	84,891	1,867,000	3,026,500	145,512	6%
09105000	Plateau Creek Near Cameo	4,255	4,656	7,807	10,297	25,997	20,876	6,926	4,640	4,294	5,579	5,158	4,566	71,100	147,700	24,095	19%
09163500	Colorado River Near Colorado-Utah State Line	171,706	172,690	241,525	376,727	898,039	895,048	296,197	169,024	172,019	205,698	189,074	175,785	3,052,100	4,986,500	286,233	7%

* Average for the five 2040 climate models
** Annual range for the five 2040 climate models
*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Table E2 - 2040 Gunnison River Basin Average Modeled Streamflow

2040 Climate Projectios		Average Monthly Modeled Streamflow (AF)*												Range** in Average Annual Modeled Streamflow (AF)		Reduction*** in Avg Annual Modeled Streamflow	
USGS #	Location Name	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Low*	*High*	*KAF*	*Percent*
09110000	Taylor River At Almont	7,190	6,586	8,002	13,310	37,429	50,496	27,908	20,864	14,302	12,627	11,727	7,368	186,500	261,400	11,913	5%
09112500	East River At Almont	2,996	2,771	4,332	19,161	81,236	74,245	21,039	7,426	3,280	4,325	3,997	3,318	198,400	262,900	1,677	1%
09114500	Gunnison River Near Gunnison	12,546	11,262	15,652	40,313	126,276	131,667	48,888	26,888	14,429	17,318	18,346	13,130	400,400	575,600	21,332	4%
09119000	Tomichi Creek At Gunnison	3,526	3,522	7,381	13,702	29,209	29,225	12,444	2,595	1,404	2,708	4,861	3,868	75,100	169,100	17,529	13%
09126500	Cimarron River At Cimarron	977	1,126	2,432	4,622	17,704	14,734	5,200	4,562	3,435	1,675	343	936	37,700	82,600	10,545	15%
09128000	Gunnison River Below Gunnison Tunnel	23,343	20,038	24,753	45,531	178,803	148,953	56,484	38,580	42,676	55,504	58,555	52,255	492,400	1,060,000	118,826	14%
09136200	Gunnison River Near Lazear	31,690	27,527	35,641	104,235	326,434	222,417	67,993	42,268	46,387	61,770	69,561	61,240	763,500	1,484,800	117,094	10%
09149500	Uncompahgre River At Delta	9,207	8,646	8,893	12,847	30,219	29,342	14,666	13,904	13,872	10,917	11,956	10,288	117,000	246,800	42,298	19%
09152500	Gunnison River Near Grand Junction	53,849	49,918	66,711	141,353	404,128	287,919	101,884	73,453	79,528	88,669	96,670	85,008	1,078,400	2,030,900	176,467	10%

* Average for the five 2040 climate models
** Annual range for the five 2040 climate models
*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Table E3 - 2040 San Juan/Dolores River Basin Average Modeled Streamflow

2040 Climate Projections		Average Monthly Modeled Streamflow (AF)*												Range** in Average Annual Modeled Streamflow (AF)		Reduction*** in Avg Annual Modeled Streamflow	
USGS #	Location Name	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Low*	*High*	*AF*	*Percent*
09171100	Dolores River Near Bedrock	2,687	3,236	9,724	34,264	42,274	22,915	5,063	4,776	3,342	2,874	2,274	2,242	39,700	224,200	33,184	20%
09175500	San Miguel River At Naturita	4,828	5,356	9,310	41,013	49,483	32,083	12,064	5,734	5,139	4,389	5,050	4,845	109,900	246,200	34,259	16%
09346400	San Juan River Near Carracas	8,945	11,984	38,934	71,887	113,062	79,351	16,086	10,002	9,775	9,675	8,747	8,035	274,300	484,300	1,961	1%
09349800	Piedra River Near Arboles	3,961	5,607	21,266	59,933	80,380	45,663	8,768	6,546	6,932	5,851	4,849	3,870	177,600	329,200	15,381	6%
09354500	Los Pinos River At La Boca	5,073	9,860	18,661	25,263	18,332	31,047	8,378	6,656	5,715	10,032	5,351	4,907	87,000	200,200	14,854	9%
09363200	Florida River At Bondad	1,134	2,127	5,542	6,756	11,087	7,241	1,389	1,296	1,954	1,654	1,358	1,057	30,200	53,200	618	1%
09363500	Animas River Near Cedar Hill, Nm	13,640	15,391	33,211	75,699	173,308	130,360	39,795	21,771	19,704	16,917	14,574	13,392	411,600	732,300	72,837	11%
09365500	La Plata River At Hesperus	345	387	1,359	5,994	10,053	5,400	1,065	750	715	549	497	402	21,700	33,300	656	2%
09366500	La Plata River At Colorado-New Mexico State Line	736	1,028	3,006	7,475	3,884	1,832	738	502	352	503	823	749	14,000	27,600	-614	-3%
09371000	Mancos River Near Towaoc	854	1,488	3,486	5,008	5,000	2,191	1,330	1,006	850	668	819	690	11,700	32,600	994	4%
09372000	McElmo Creek near Colorado-Utah State Line	2,012	2,952	3,722	2,117	3,835	4,355	4,506	4,569	4,484	3,406	2,414	2,115	27,900	50,500	3,681	8%

* Average for the five 2040 climate models
** Annual range for the five 2040 climate models
*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Table E4 – 2040 Yampa River Basin Average Modeled Streamflow

2040 Climate Projections		Average Monthly Modeled Streamflow (AF)*												Range** in Average Annual Modeled Streamflow (AF)		Reduction*** in Avg Annual Modeled Streamflow	
USGS #	Location Name	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Low*	*High*	*AF*	*Percent*
09237500	Yampa River Below Stagecoach Reservoir	2,358	2,003	3,636	6,387	9,367	8,548	5,060	4,398	3,456	2,996	2,816	2,390	43,700	65,400	1,791	3%
09241000	Elk River At Clark	3,041	2,954	9,427	29,203	98,133	78,862	14,813	4,091	3,808	3,442	3,124	3,294	236,200	274,300	-24,252	-11%
09245000	Elkhead Creek Near Elkhead	379	442	1,494	10,737	24,690	4,780	516	255	203	364	423	391	37,400	52,500	-4,698	-12%
09249750	Williams Fork At Mouth, Near Hamilton	3,216	3,356	8,077	26,292	62,893	32,614	4,236	1,535	1,372	2,401	3,046	3,287	121,700	177,100	-1,778	-1%
09251000	Yampa River Near Maybell	14,594	20,402	64,139	216,626	427,080	298,587	31,282	7,957	5,390	14,230	16,414	14,312	925,000	1,321,500	-69,190	-7%
09260000	Little Snake River Near Lily	5,422	8,272	33,017	78,624	154,898	84,427	9,741	1,716	1,607	4,441	6,510	5,802	300,100	473,400	-7,997	-2%
09260050	Yampa River At Deerlodge Park	18,676	27,206	87,659	287,269	539,577	388,062	43,927	10,561	6,858	19,141	23,338	19,835	1,161,600	1,732,700	-52,770	-4%

* Average for the five 2040 climate models
** Annual range for the five 2040 climate models
*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Table E5 – 2040 White River Basin Average Modeled Streamflow

2040 Climate Projections		Average Monthly Modeled Streamflow (AF)*												Range** in Average Annual Modeled Streamflow (AF)		Reduction*** in Avg Annual Modeled Streamflow	
USGS #	Location Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Low	High	KAF	Percent
09303000	North Fork White River At Buford, Co	7,342	7,103	11,490	26,340	63,998	47,320	14,280	8,856	7,520	7,555	7,235	7,221	190,000	245,300	7,098	3%
09304000	South Fork White River At Buford	4,349	4,343	6,159	13,823	53,282	55,499	11,959	5,706	4,364	4,451	4,242	4,284	144,300	200,800	10,388	6%
09304800	White River Below Meeker	15,189	16,920	26,539	47,212	117,739	106,368	24,708	12,201	13,293	16,746	15,822	14,281	328,800	526,000	45,082	10%
09306222	Piceance Creek At White River	1,211	1,444	2,662	3,102	2,950	1,233	700	620	538	1,104	1,380	1,256	11,500	26,700	4,459	20%
09306395	White River Near Colorado-Utah State Line	18,313	20,867	32,088	49,601	112,069	110,695	26,592	12,145	15,192	18,624	18,336	17,194	330,900	572,800	58,509	11%

* Average for the five 2040 climate models
** Annual range for the five 2040 climate models
*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Table E6 - 2070 Upper Colorado River Basin Average Modeled Streamflow

2070 Climate Projections		Average Monthly Water Available to Meet Future Demands (AF)*												Range** in Average Annual Water Available (AF)		Reduction*** in Avg Annual Water Available	
USGS #	Location Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Low	High	AF	Percent
09011000	Colorado River Near Grand Lake	937	914	1,289	6,111	30,283	14,095	602	694	569	1,110	1,150	949	53,900	66,900	-3,500	-6%
09041500	Muddy Creek At Kremmling	777	830	2,374	5,079	23,611	7,217	6,559	10,492	840	231	914	852	53,300	71,200	3,905	6%
09050700	Blue River Below Dillon	3,874	3,846	5,488	4,256	25,162	31,361	13,140	9,522	4,280	3,757	3,816	3,821	89,200	139,400	21,557	16%
09057500	Blue River Below Green Mountain Reservoir	12,555	12,511	16,049	5,607	20,011	44,835	44,185	28,278	18,681	13,439	12,562	12,352	202,800	289,900	41,415	15%
09070000	Eagle River Below Gypsum	9,964	10,009	15,166	31,078	96,944	81,744	27,431	13,551	10,715	10,737	10,488	9,829	297,600	379,300	68,832	17%
09070500	Colorado River At Dotsero	46,433	48,077	72,897	114,736	288,396	251,549	111,424	84,329	50,670	46,870	49,629	45,644	1,082,600	1,447,900	181,629	13%
09073400	Roaring Fork River Near Aspen	1,195	1,102	1,434	3,626	23,518	14,457	4,027	2,501	1,911	1,547	1,206	1,237	53,300	60,400	-2,766	-5%
09085000	Roaring Fork River At Glenwood	19,792	18,410	26,680	58,693	220,652	187,059	63,906	32,752	28,426	28,411	21,857	20,742	667,200	800,800	89,586	11%
09095500	Colorado River Near Cameo	79,092	82,297	119,863	188,102	580,902	505,011	176,506	117,321	85,655	87,926	84,998	79,455	1,981,900	2,550,300	367,702	14%
09105000	Plateau Creek Near Cameo	4,269	4,950	8,751	10,554	18,965	12,055	5,319	3,796	3,571	4,777	4,596	4,312	71,200	103,000	43,231	33%
09163500	Colorado River Near Colorado-Utah State Line	129,986	137,304	194,844	326,344	895,422	656,194	199,884	134,471	136,683	169,546	173,976	150,044	2,823,100	3,908,300	917,093	22%

* Average for the five 2040 climate models
** Annual range for the five 2040 climate models
*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Table E7 - 2070 Gunnison River Basin Average Modeled Streamflow

2070 Climate Projections		Average Monthly Water Available to Meet Future Demands (AF)*												Range** in Average Annual Water Available (KF)		Reduction*** in Avg Annual Water Available	
USGS #	Location Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Low	High	AF	Percent
09110000	Taylor River At Almont	6,936	6,395	8,098	15,116	42,028	41,509	21,840	20,527	14,351	11,927	11,207	7,121	193,700	223,000	22,666	10%
09112500	East River At Almont	2,896	2,752	4,733	24,267	97,116	60,302	12,217	5,752	2,431	3,232	3,815	3,171	204,400	234,100	7,118	3%
09114500	Gunnison River Near Gunnison	12,144	11,098	16,521	49,025	145,524	102,857	31,959	24,835	13,427	14,795	17,621	12,665	412,200	487,300	45,576	9%
09119000	Tomichi Creek At Gunnison	3,340	3,433	7,579	14,216	24,906	16,771	8,545	2,385	1,098	1,692	4,538	3,612	75,800	111,000	39,861	30%
09126500	Cimarron River At Cimarron	898	1,116	2,518	4,724	15,550	7,268	4,009	4,334	3,143	1,514	299	855	38,300	54,500	22,063	32%
09128000	Gunnison River Below Gunnison Tunnel	22,726	19,915	24,753	50,097	175,477	92,069	39,752	28,918	31,359	39,210	46,167	40,999	493,600	729,500	252,859	29%
09136200	Gunnison River Near Lazear	30,993	27,619	35,960	113,887	320,187	143,944	47,132	31,443	34,307	44,469	56,120	49,535	760,900	1,086,000	278,662	23%
09149500	Uncompahgre River At Delta	8,255	7,906	8,054	12,121	26,788	14,676	9,147	12,095	12,416	9,472	10,143	8,860	116,800	163,000	77,123	36%
09152500	Gunnison River Near Grand Junction	52,292	49,663	67,348	144,199	381,137	193,324	73,437	59,175	65,055	69,728	81,031	71,510	1,072,800	1,506,600	397,658	23%

* Average for the five 2040 climate models
** Annual range for the five 2040 climate models
*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Table E8 - 2070 San Juan/Dolores River Basin Average Modeled Streamflow

2070 Climate Projections		Average Monthly Water Available to Meet Future Demands (AF)*												Range** in Average Annual Water Available (AF)		Reduction*** in Avg Annual Water Available	
USGS #	Location Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Low	High	AF	Percent
09171100	Dolores River Near Bedrock	2,582	2,647	7,719	21,015	12,545	6,164	3,286	4,459	2,710	2,270	1,779	1,791	45,000	92,600	99,888	59%
09175500	San Miguel River At Naturita	4,993	5,746	9,505	39,233	37,725	15,079	4,955	3,921	3,251	3,168	4,549	4,550	113,400	160,300	76,878	36%
09346400	San Juan River Near Carracas	8,902	13,141	40,511	69,845	101,706	47,848	6,193	5,891	7,204	7,709	7,812	7,414	279,400	344,000	64,269	17%
09349800	Piedra River Near Arboles	3,597	5,736	20,024	56,650	72,212	27,268	3,253	4,182	5,131	4,564	4,270	3,379	180,800	227,600	58,740	22%
09354500	Los Pinos River At La Boca	4,263	8,156	14,668	16,090	19,876	18,519	6,275	5,644	5,028	3,657	3,802	3,657	89,600	119,900	54,493	33%
09363200	Florida River At Bondad	1,051	2,420	5,158	5,804	9,572	4,993	1,448	1,303	1,691	1,378	1,128	877	30,500	40,800	6,389	15%
09363500	Animas River Near Cedar Hill, Nm	13,745	16,860	35,238	80,270	168,156	79,664	19,302	14,070	14,267	12,942	13,396	12,686	426,800	527,800	160,002	25%
09365500	La Plata River At Hesperus	341	418	1,585	6,859	9,421	2,941	604	585	565	491	457	379	22,200	27,500	3,526	13%
09366500	La Plata River At Colorado-New Mexico State Line	665	1,003	2,688	6,375	2,181	981	666	529	345	469	712	654	14,700	20,800	3,748	18%
09371000	Mancos River Near Towaoc	771	1,358	2,666	3,372	2,608	1,526	1,025	824	717	596	730	619	12,700	20,200	7,570	31%
09372000	Mcelmo Creek Near Colorado-Utah State Line	2,000	2,775	2,820	1,460	3,272	3,662	3,985	4,142	3,755	3,143	2,361	2,082	29,500	40,900	8,711	20%

* Average for the five 2040 climate models
** Annual range for the five 2040 climate models
*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Table E9 – 2070 Yampa River Basin Average Modeled Streamflow

2070 Climate Projections		Average Monthly Water Available to Meet Future Demands (AF)*												Range** in Average Annual Water Available (AF)		Reduction*** in Avg Annual Water Available	
USGS #	Location Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Low	High	AF	Percent
09237500	Yampa River Below Stagecoach Reservoir	2,301	2,037	3,985	9,082	9,674	6,725	4,813	4,268	3,176	2,634	2,499	2,157	46,900	61,500	1,854	3%
09241000	Elk River At Clark	3,299	3,737	17,397	43,063	113,853	62,368	6,691	3,082	3,659	3,133	2,915	3,215	238,000	279,000	-36,473	-16%
09245000	Elkhead Creek Near Elkhead	505	780	2,646	12,947	21,519	2,547	387	257	201	347	423	434	38,700	47,900	-3,016	-8%
09249750	Williams Fork At Mouth, Near Hamilton	3,459	4,139	11,755	30,525	59,102	22,971	1,635	1,044	1,153	1,907	2,857	3,199	125,900	163,000	6,802	5%
09251000	Yampa River Near Maybell	16,189	26,356	91,334	256,555	419,436	217,515	8,112	6,586	3,818	10,971	15,415	14,209	980,100	1,240,500	-24,673	-2%
09260000	Little Snake River Near Lily	5,868	9,603	44,668	92,301	134,312	47,930	5,177	1,428	1,320	3,349	6,075	5,618	314,600	427,800	28,831	7%
09260050	Yampa River At Deerlodge Park	20,195	33,175	118,774	336,078	507,067	269,799	13,918	8,592	4,910	14,605	21,872	19,391	1,231,600	1,600,300	50,963	4%

* Average for the five 2040 climate models
** Annual range for the five 2040 climate models
*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Table E10 – 2070 White River Basin Average Modeled Streamflow

2070 Climate Projections		Average Monthly Water Available to Meet Future Demands (AF)*												Range** in Average Annual Water Available (AF)		Reduction*** in Avg Annual Water Available	
USGS #	Location Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Low	High	AF	Percent
09303000	North Fork White River At Buford, Co	6,743	7,342	16,102	35,360	73,657	38,630	8,620	6,103	5,818	6,175	6,115	6,207	196,200	232,600	6,485	3%
09304000	South Fork White River At Buford	3,623	3,921	6,932	18,145	62,200	44,835	7,365	3,675	3,023	3,265	3,261	3,393	151,800	179,100	19,209	11%
09304800	White River Below Meeker	13,919	17,225	33,401	56,043	122,298	81,841	11,578	6,592	8,719	12,881	13,436	12,282	343,100	450,300	81,885	17%
09306222	Piceance Creek At White River	1,135	1,424	2,781	2,773	1,541	489	277	331	323	756	1,265	1,141	11,300	18,200	8,424	37%
09306395	White River Near Colorado-Utah State Line	17,187	20,743	36,277	53,559	108,730	83,300	11,610	6,569	10,647	14,832	16,329	15,508	334,300	469,300	114,935	23%

* Average for the five 2040 climate models
** Annual range for the five 2040 climate models
*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Figure E1 –2040 Colorado River near Grand Lake Average Modeled Streamflow Comparison

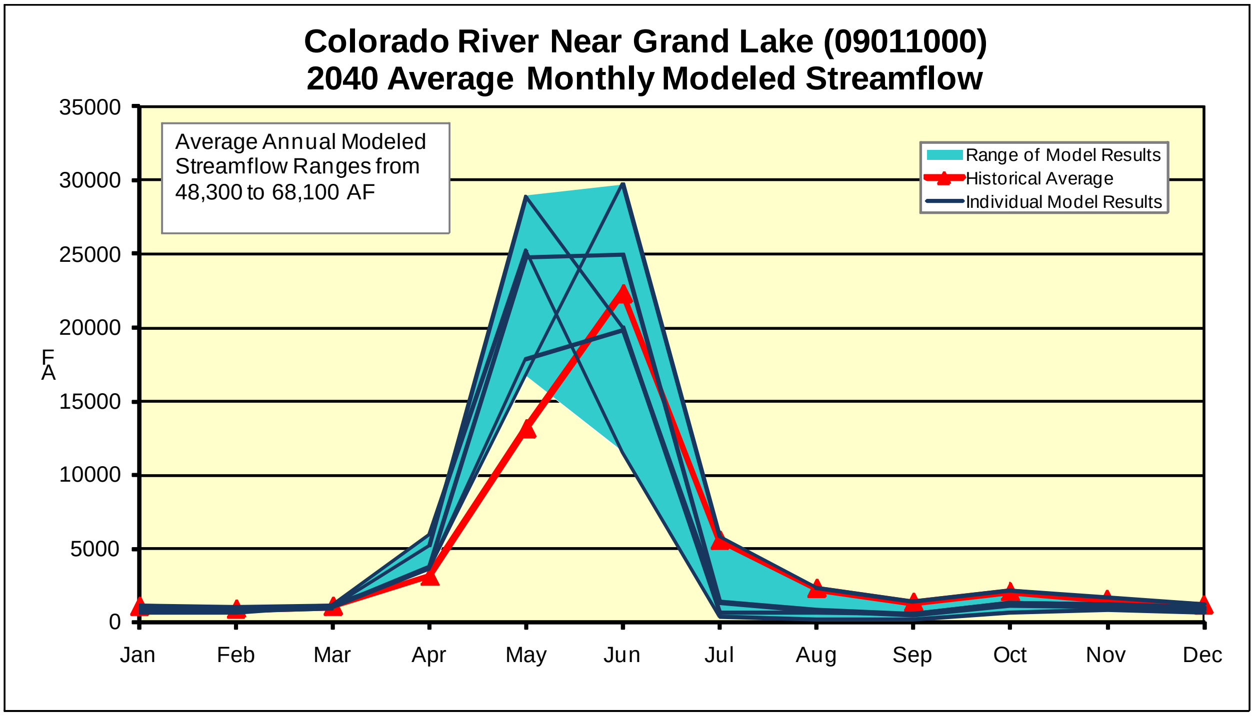


Figure E2 –2040 Muddy Creek at Kremmling Average Modeled Streamflow Comparison

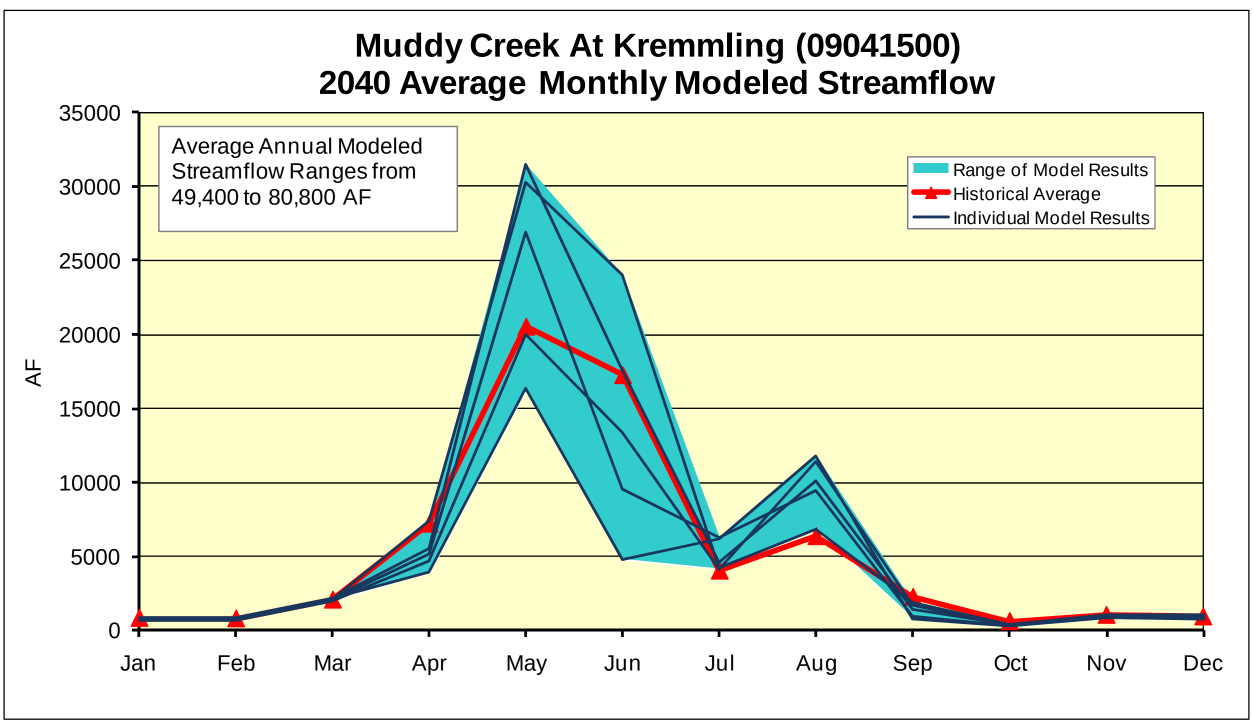


Figure E3 –2040 Blue River below Dillon Average Modeled Streamflow Comparison

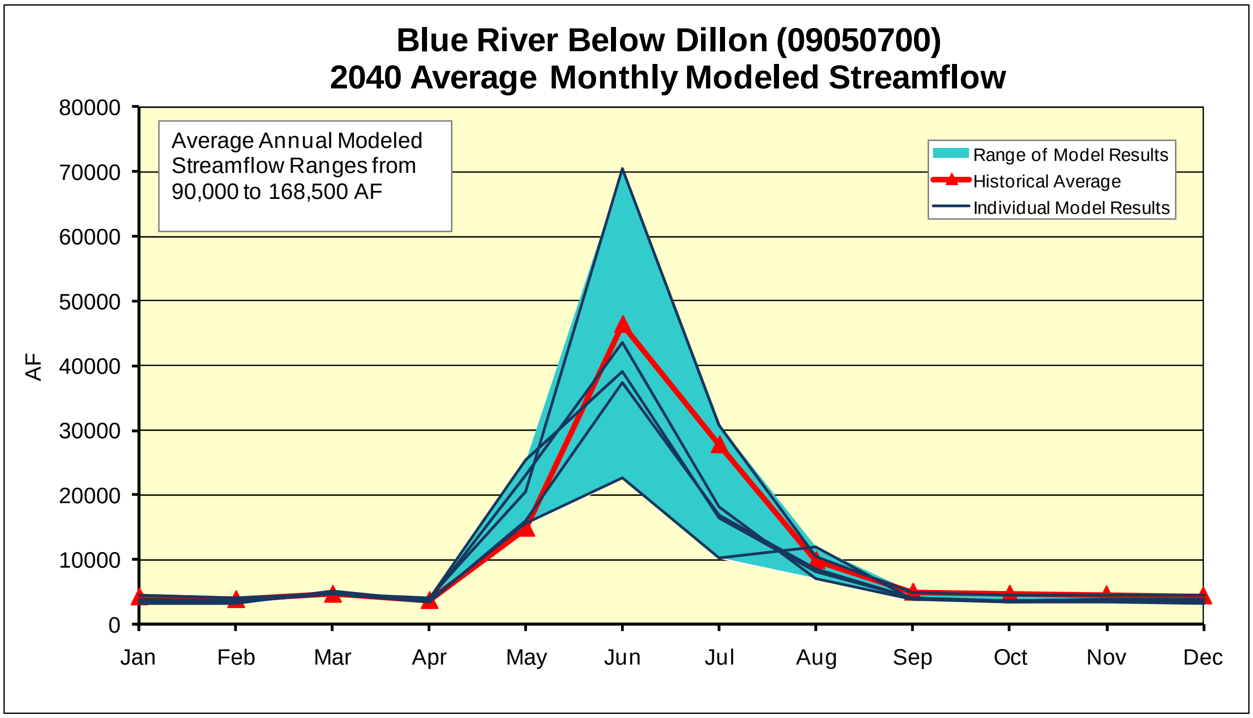


Figure E4 –2040 Blue River below Green Mountain Reservoir Average Modeled Streamflow Comparison

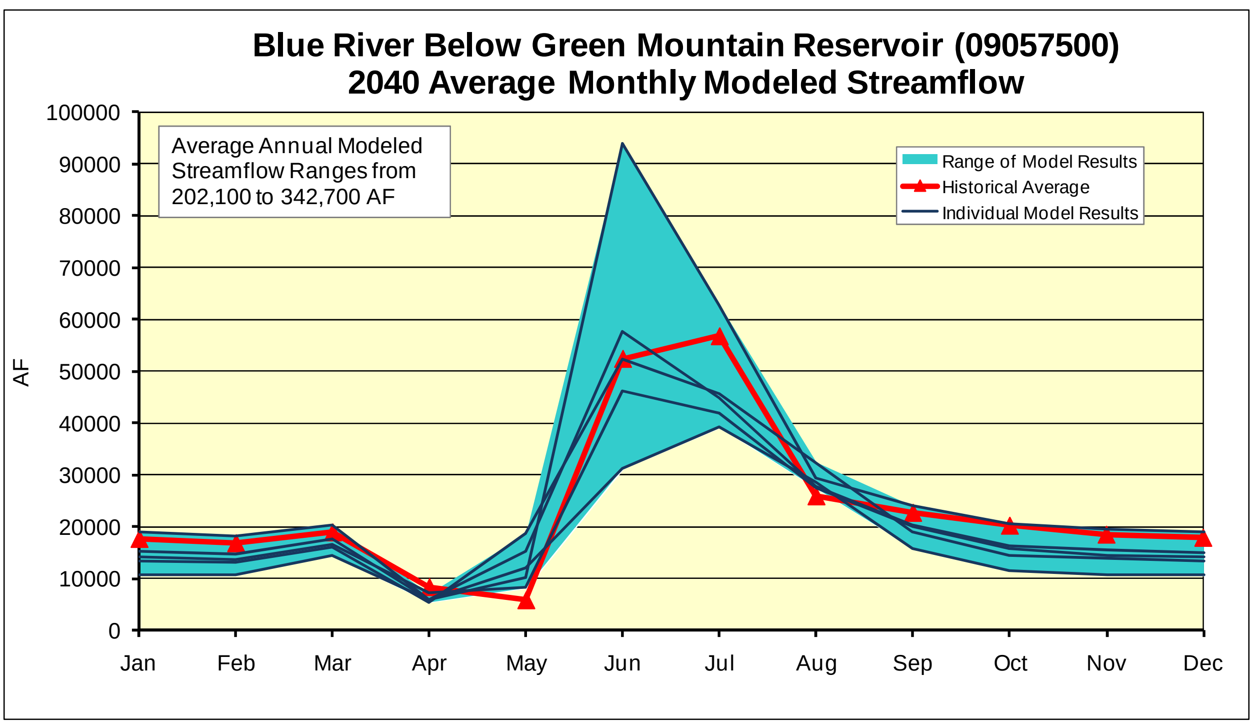


Figure E5 –2040 Eagle River below Gypsum Average Modeled Streamflow Comparison

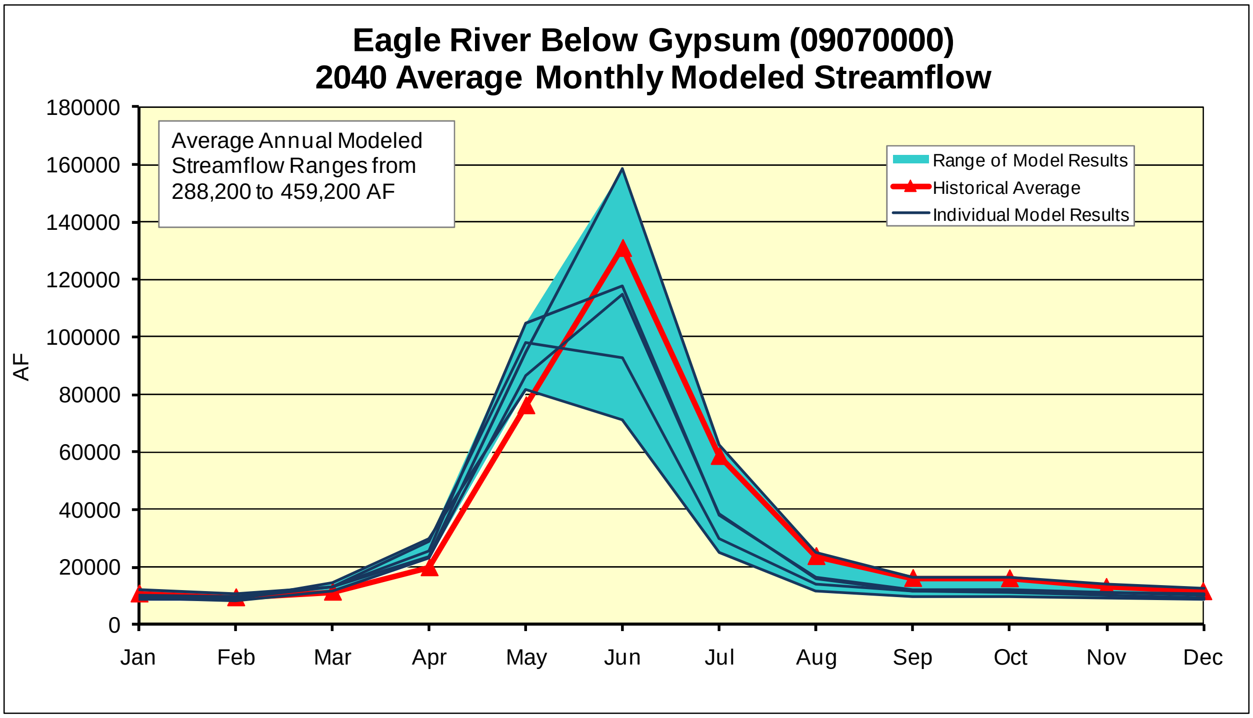


Figure E6 –2040 Colorado River at Dotsero Average Modeled Streamflow Comparison

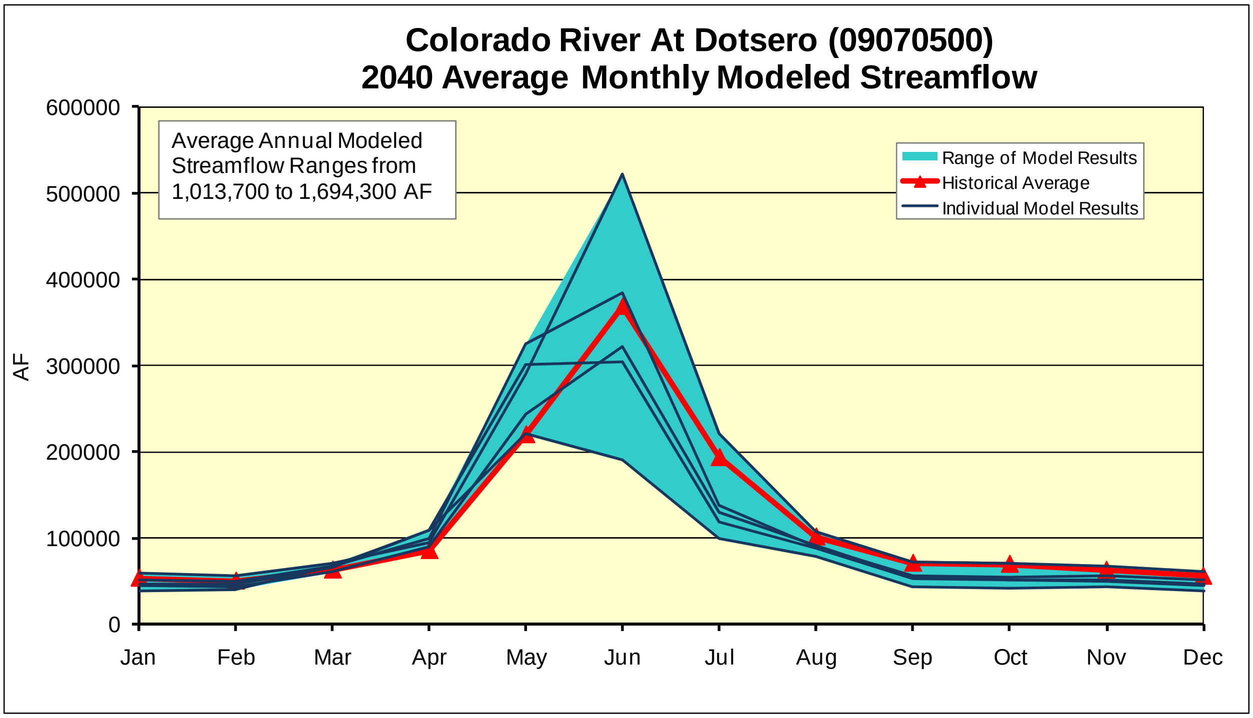


Figure E7 –2040 Roaring Fork River near Aspen Average Modeled Streamflow Comparison

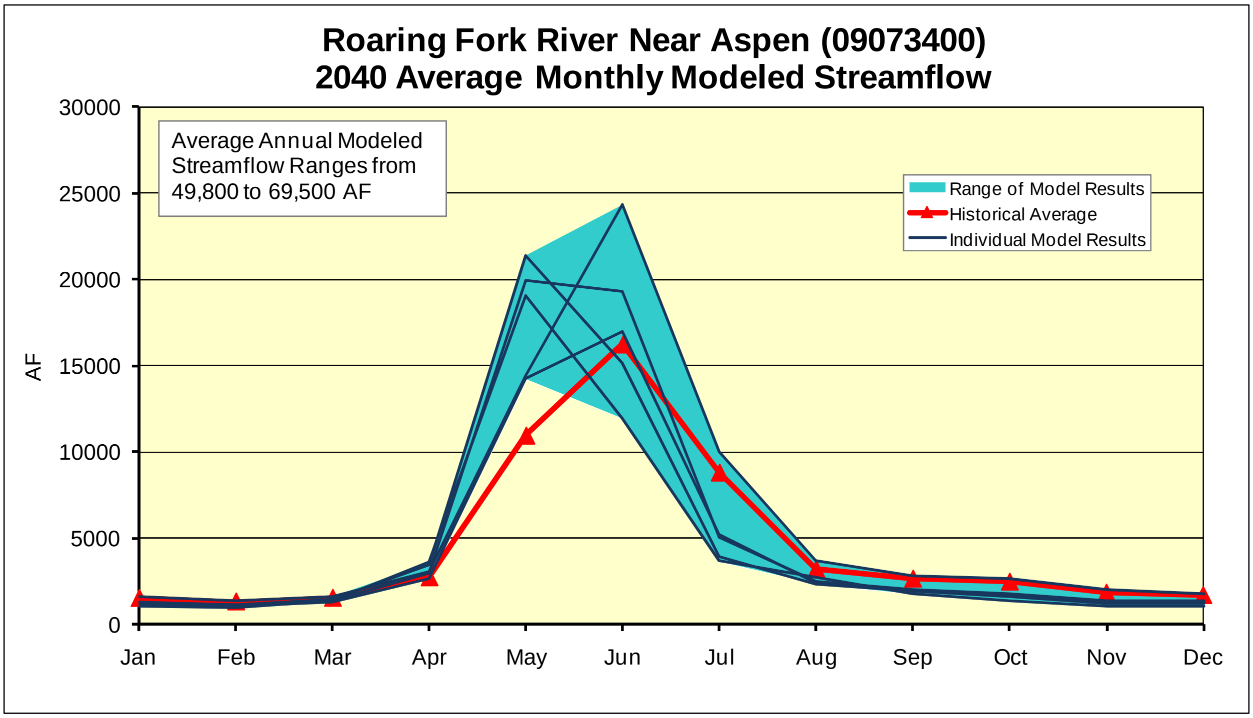


Figure E8 –2040 Roaring Fork River at Glenwood Average Modeled Streamflow Comparison

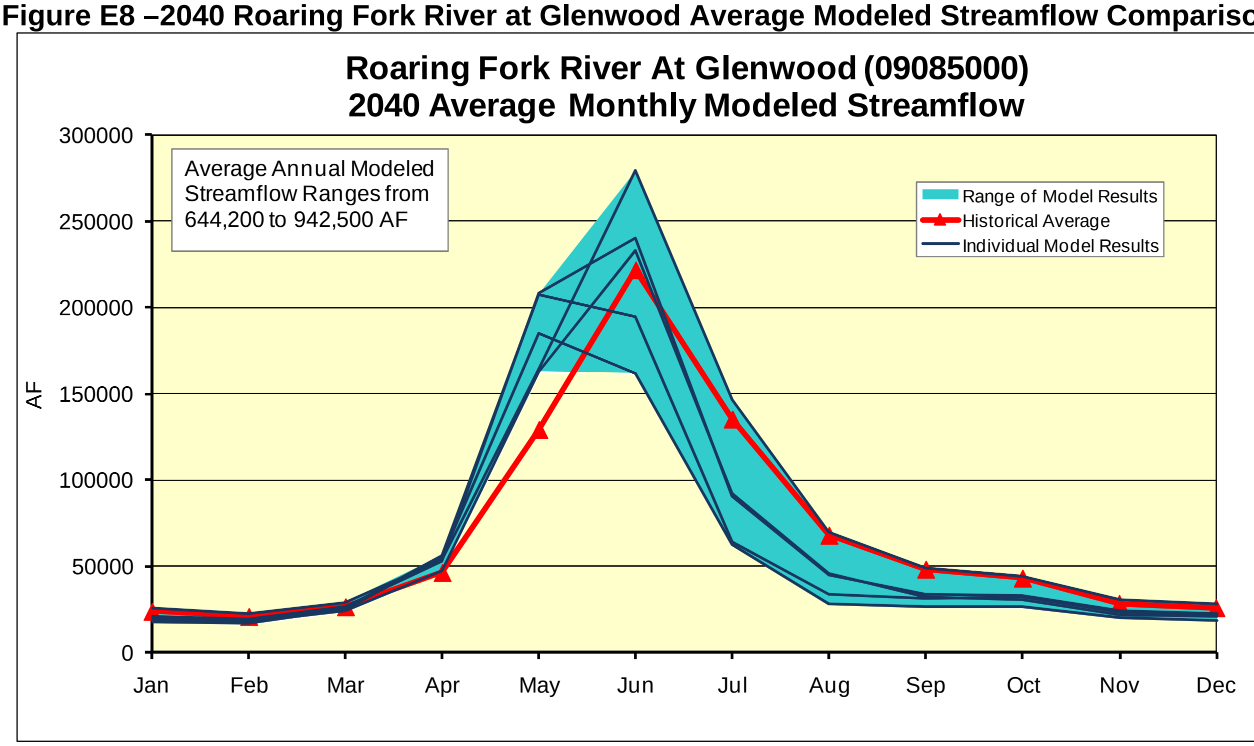


Figure E9 –2040 Colorado River near Cameo Average Modeled Streamflow Comparison

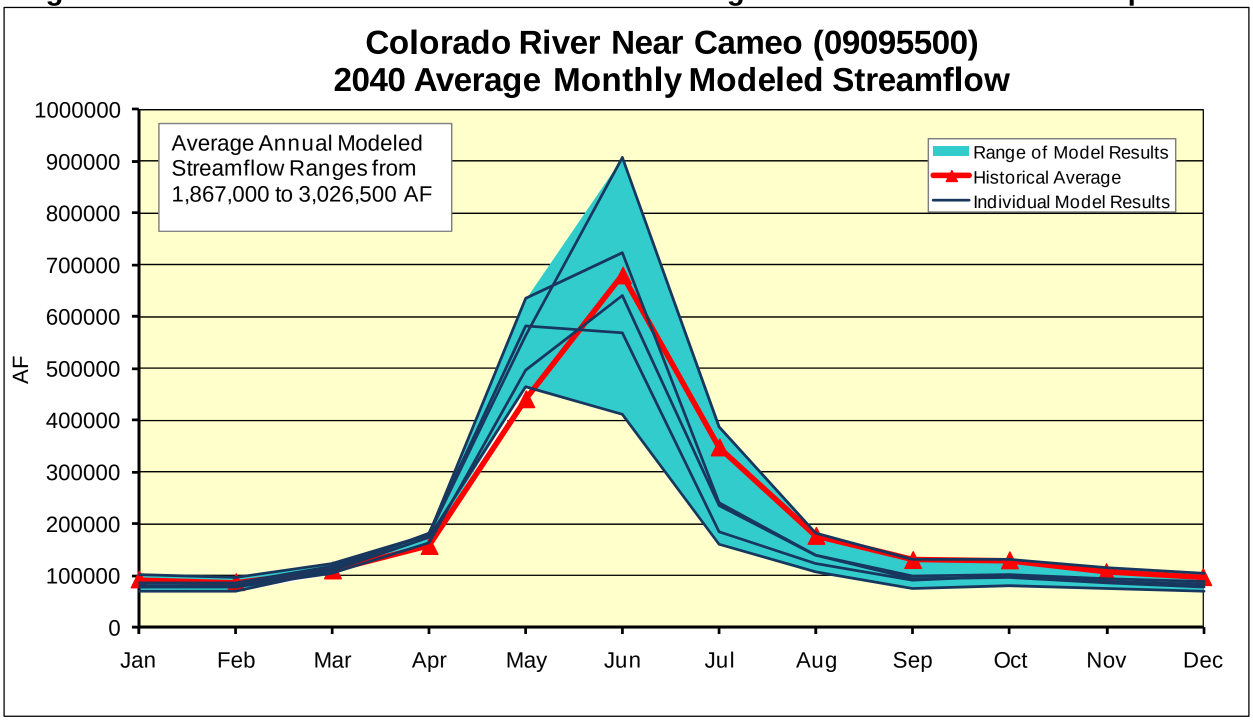


Figure E10 –2040 Plateau near Cameo Average Modeled Streamflow Comparison

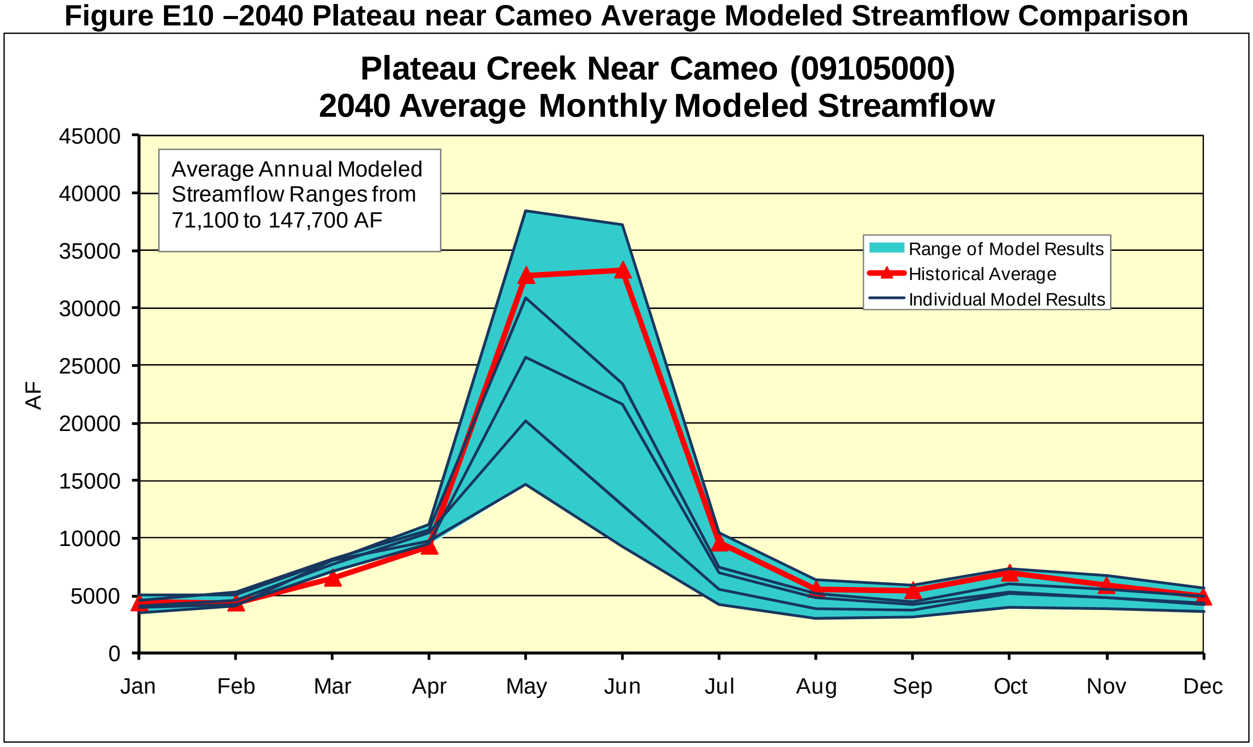


Figure E11 –2040 Colorado River near CO-UT State Line Average Modeled Streamflow Comparison

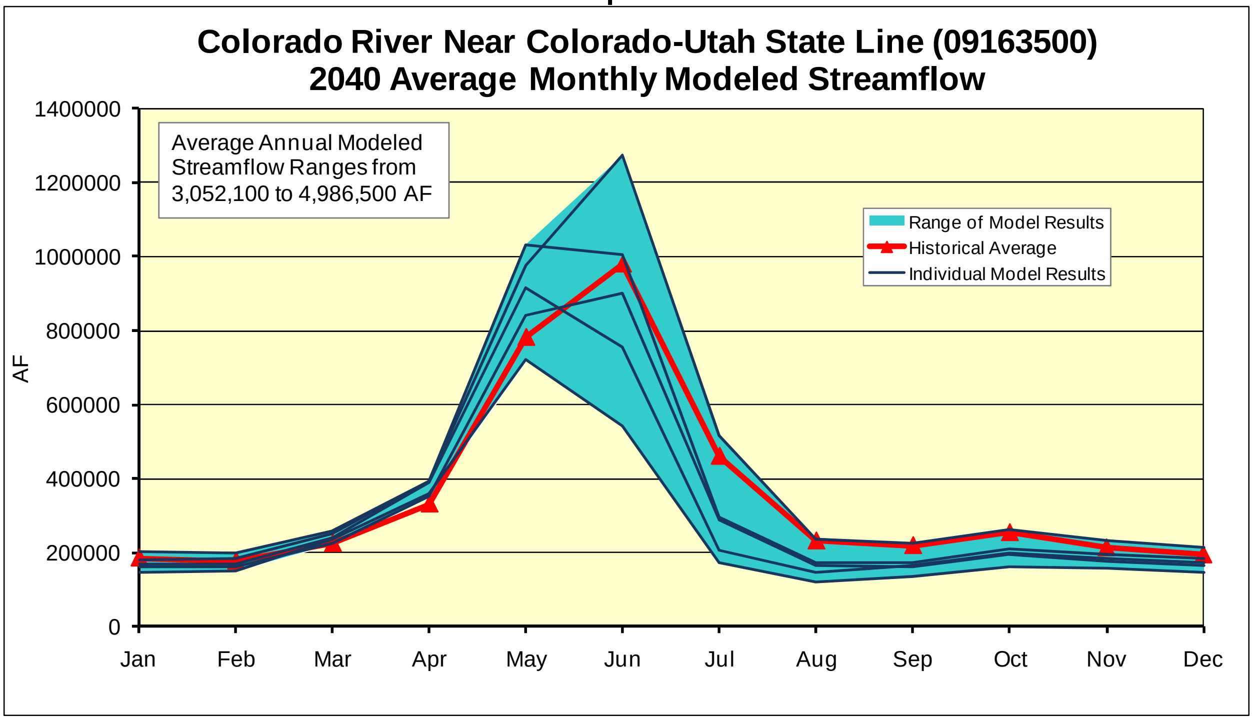


Figure E12 –2040 East River at Almont Average Modeled Streamflow Comparison

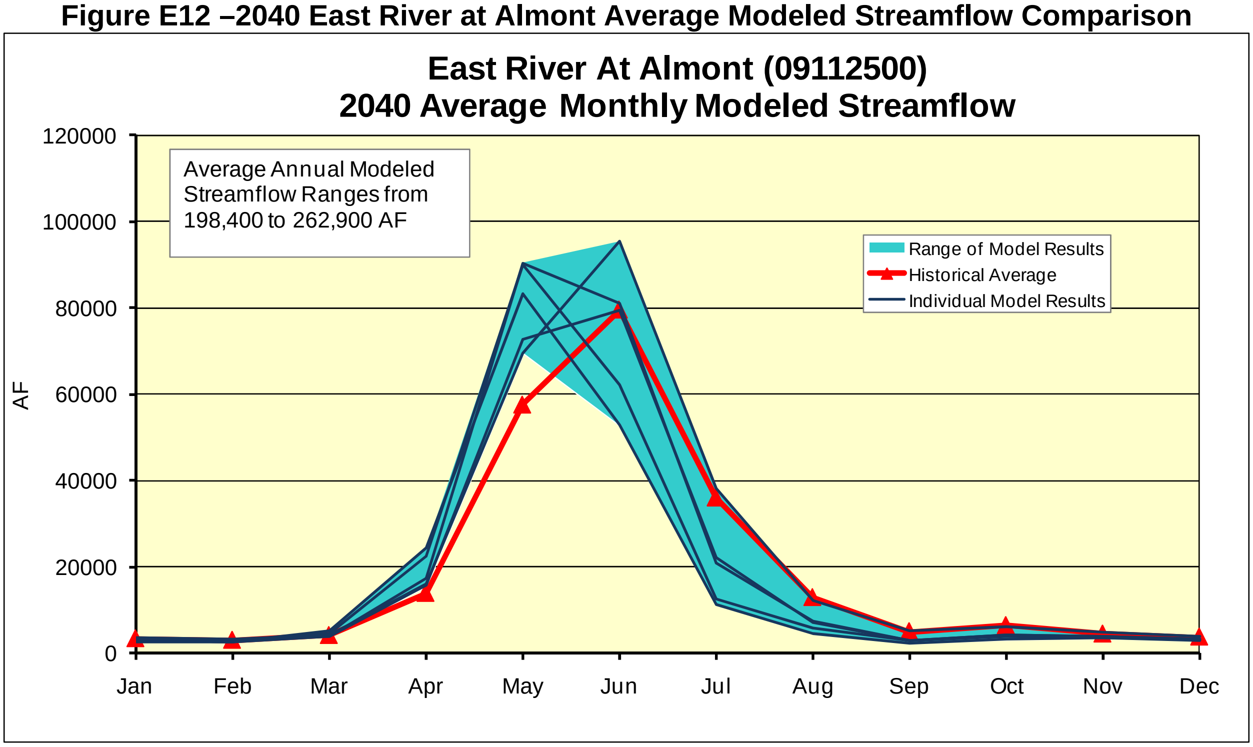


Figure E13 –2040 Taylor River at Almont Average Modeled Streamflow Comparison

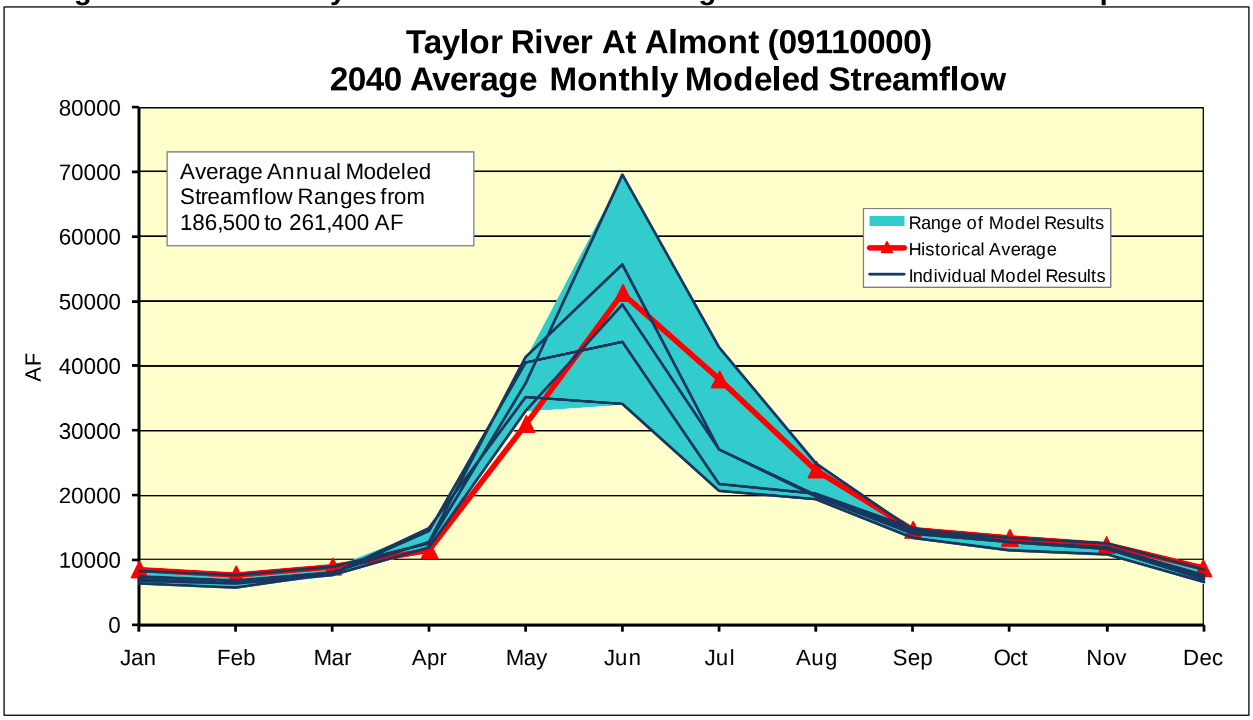


Figure E14 –2040 Tomichi Creek at Gunnison Average Modeled Streamflow Comparison

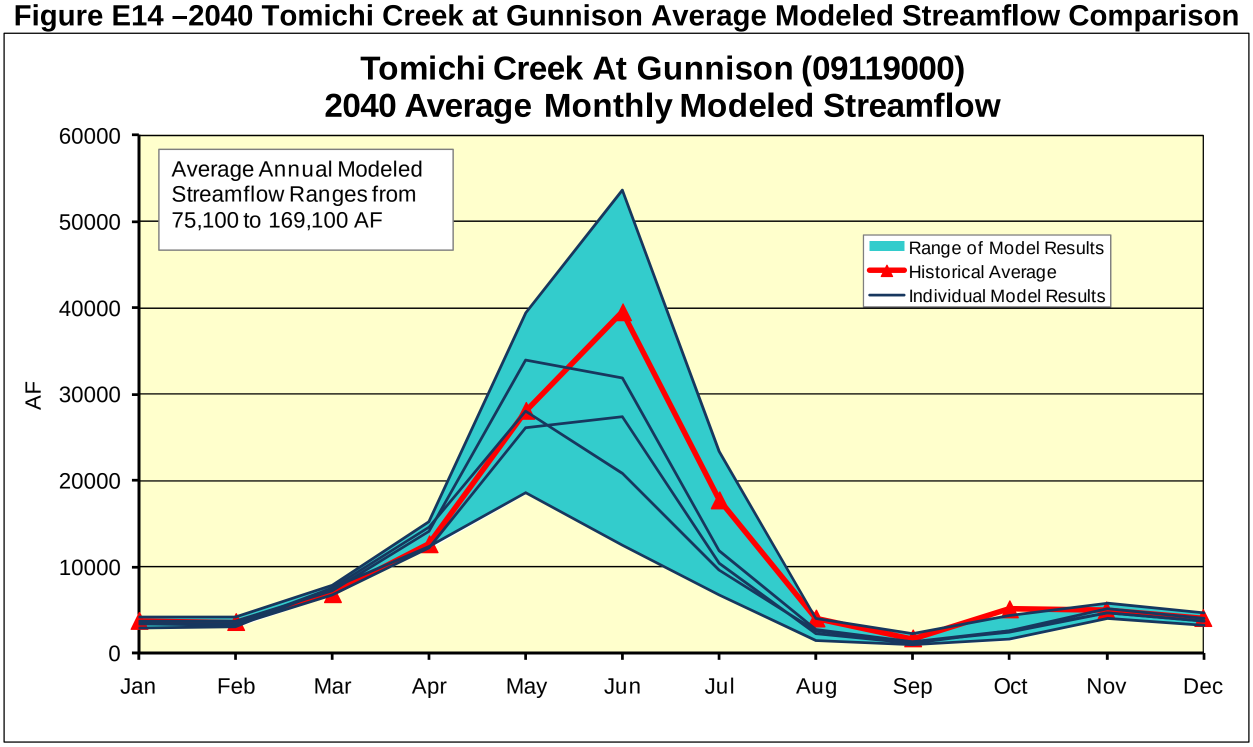


Figure E15 –2040 Gunnison River near Gunnison Average Modeled Streamflow Comparison

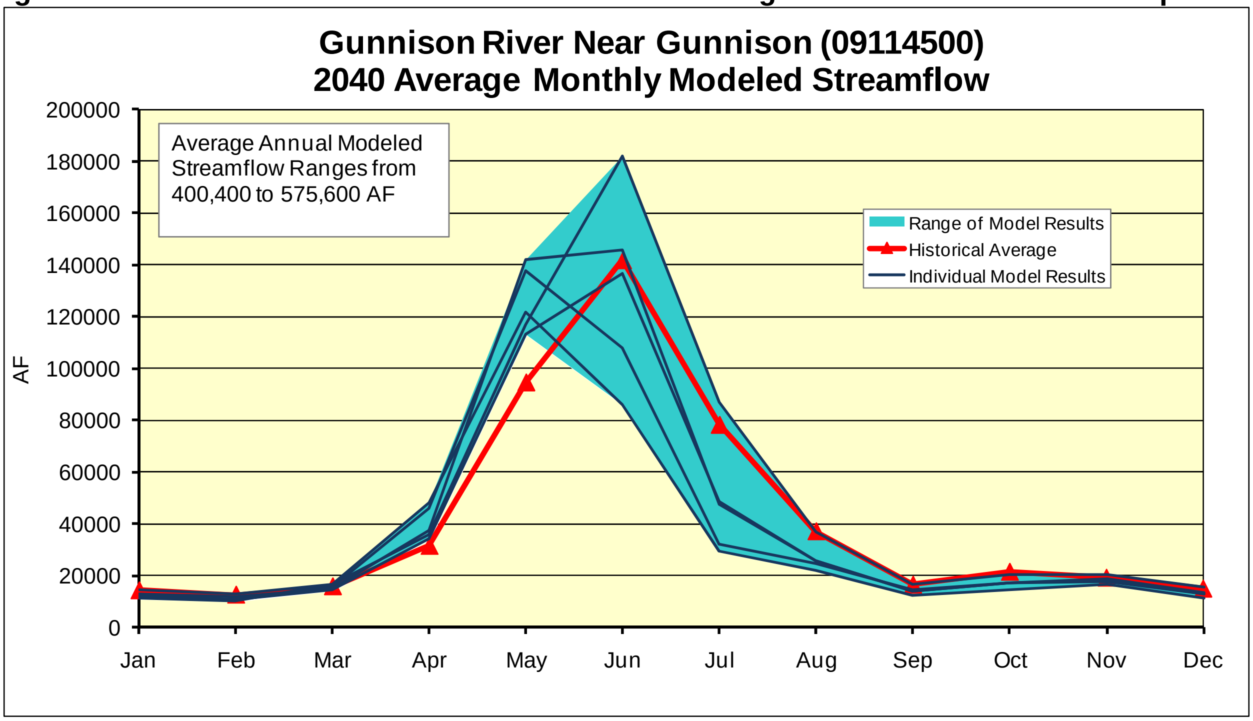


Figure E16 –2040 Cimarron River at Cimarron Average Modeled Streamflow Comparison

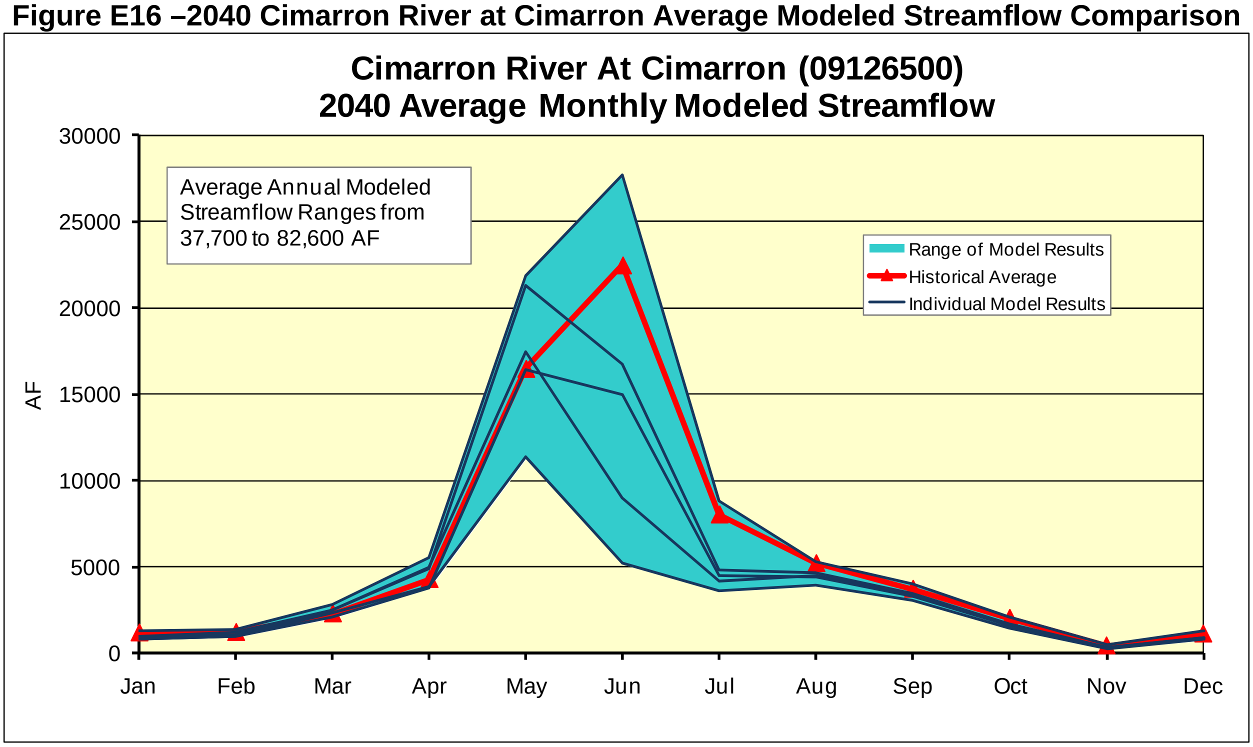


Figure E17 –2040 Gunnison River below Gunnison Tunnel Average Modeled Streamflow Comparison

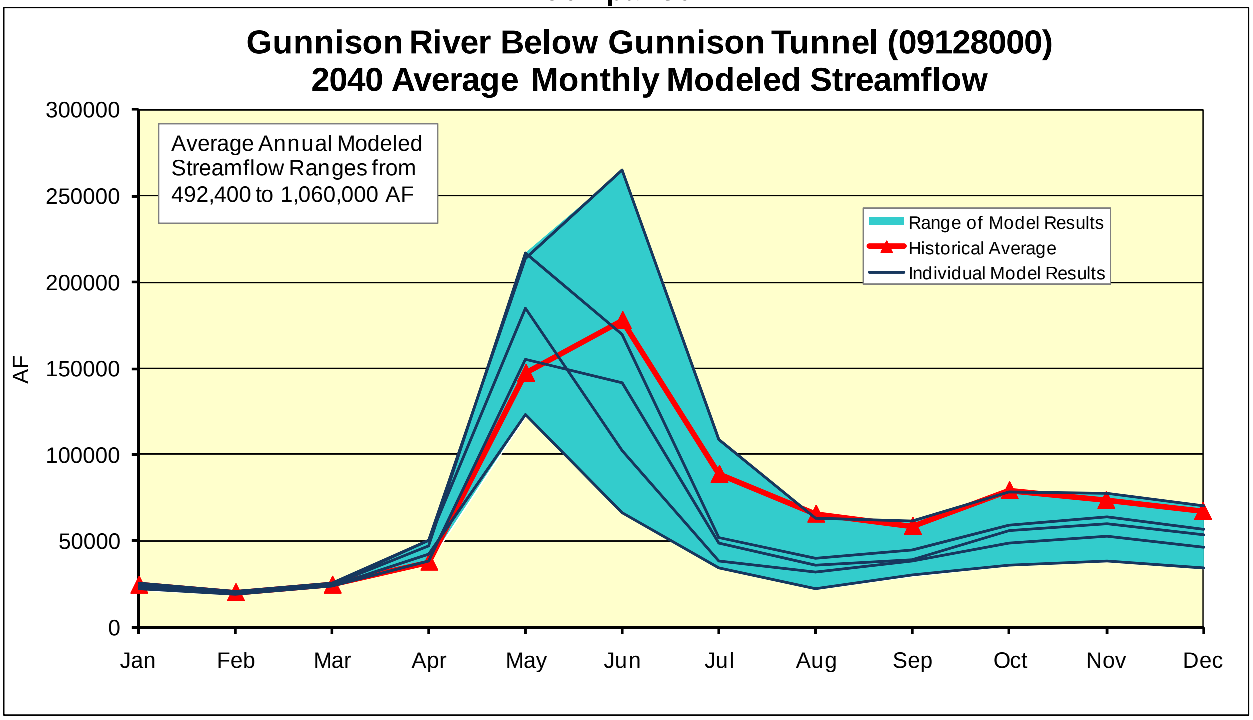


Figure E18 –2040 Gunnison River near Lazear Average Modeled Streamflow Comparison

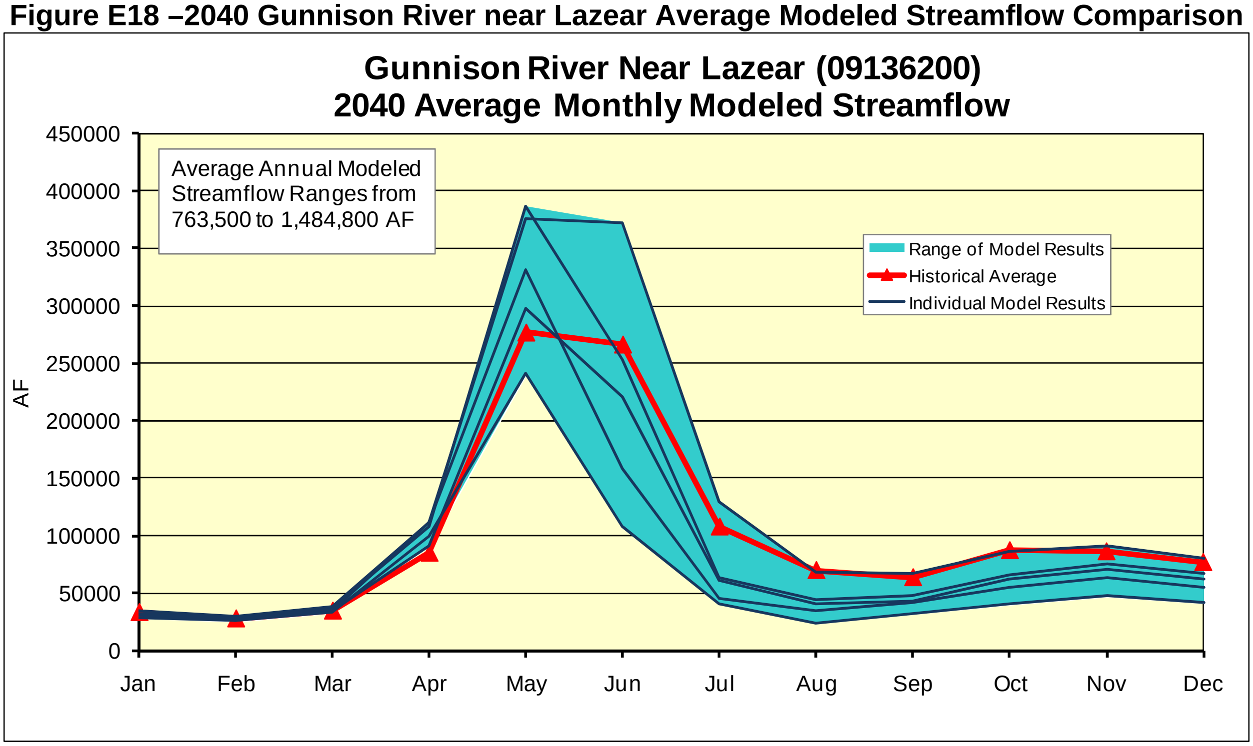


Figure E19 –2040 Uncompahgre River at Delta Average Modeled Streamflow Comparison

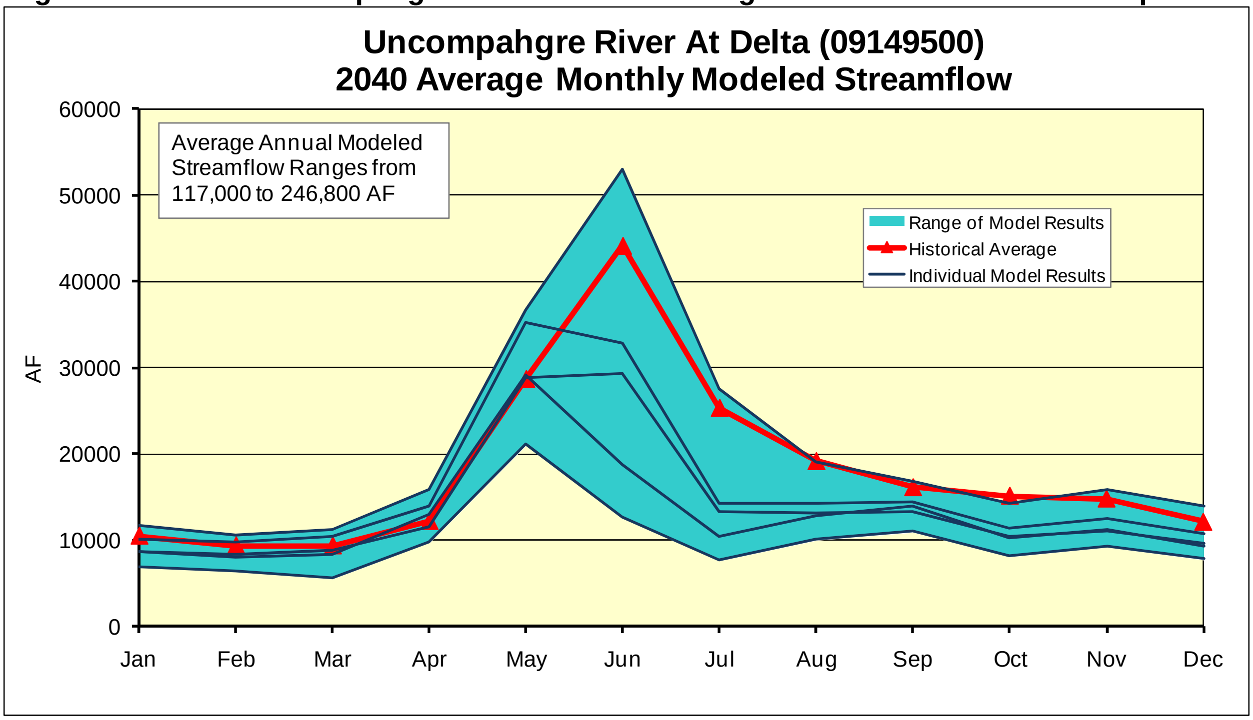


Figure E20 –2040 Gunnison River near Grand Junction Average Modeled Streamflow Comparison

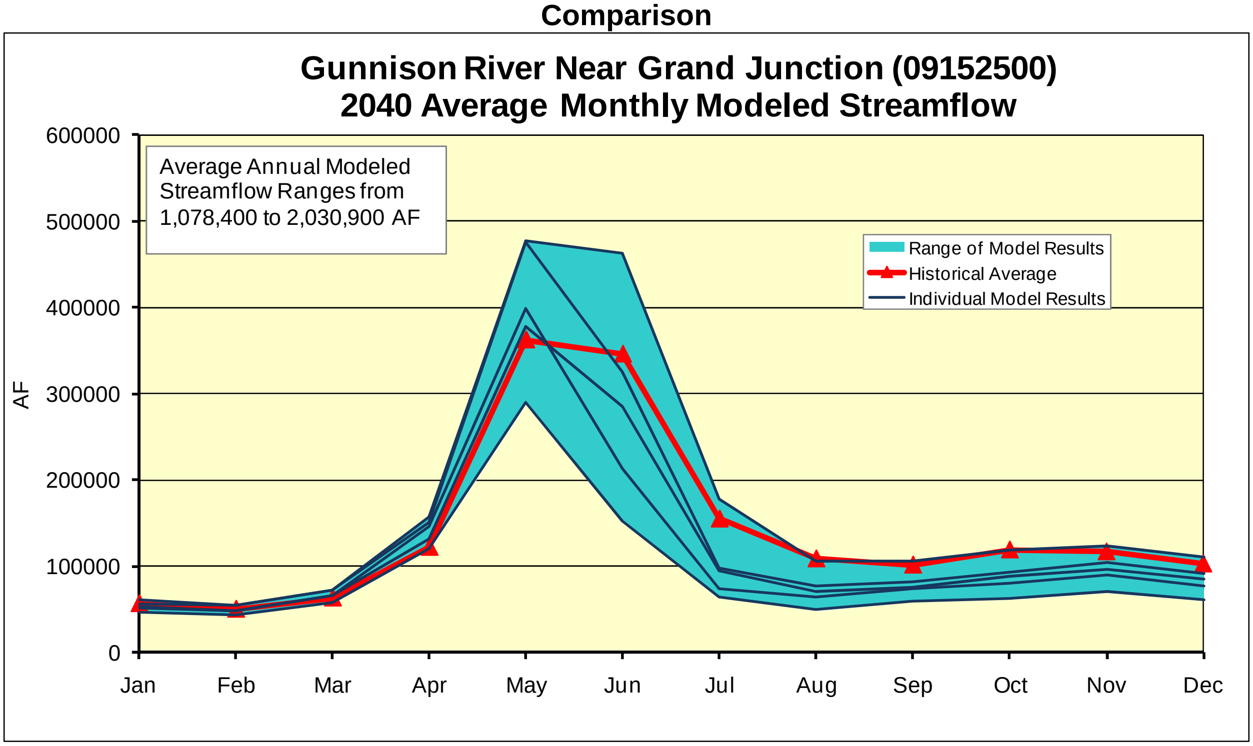


Figure E21 –2040 San Juan River near Carracas Average Modeled Streamflow Comparison

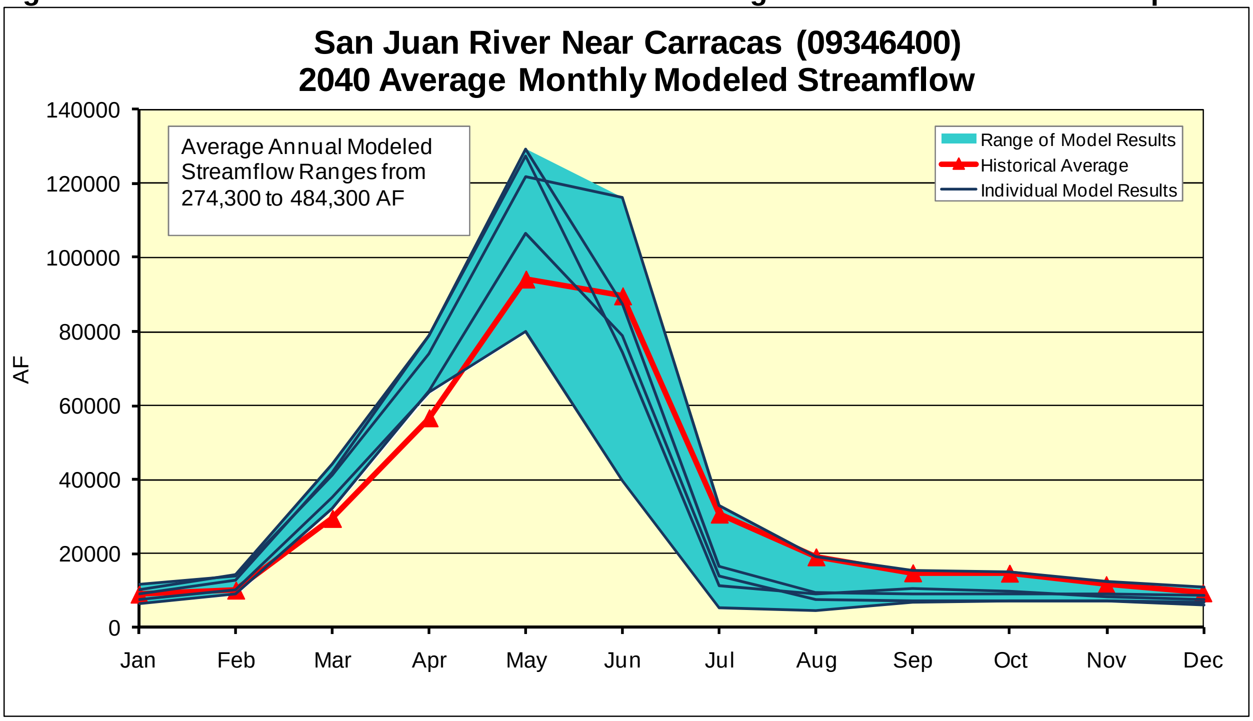


Figure E22 –2040 Piedra River near Arboles Average Modeled Streamflow Comparison

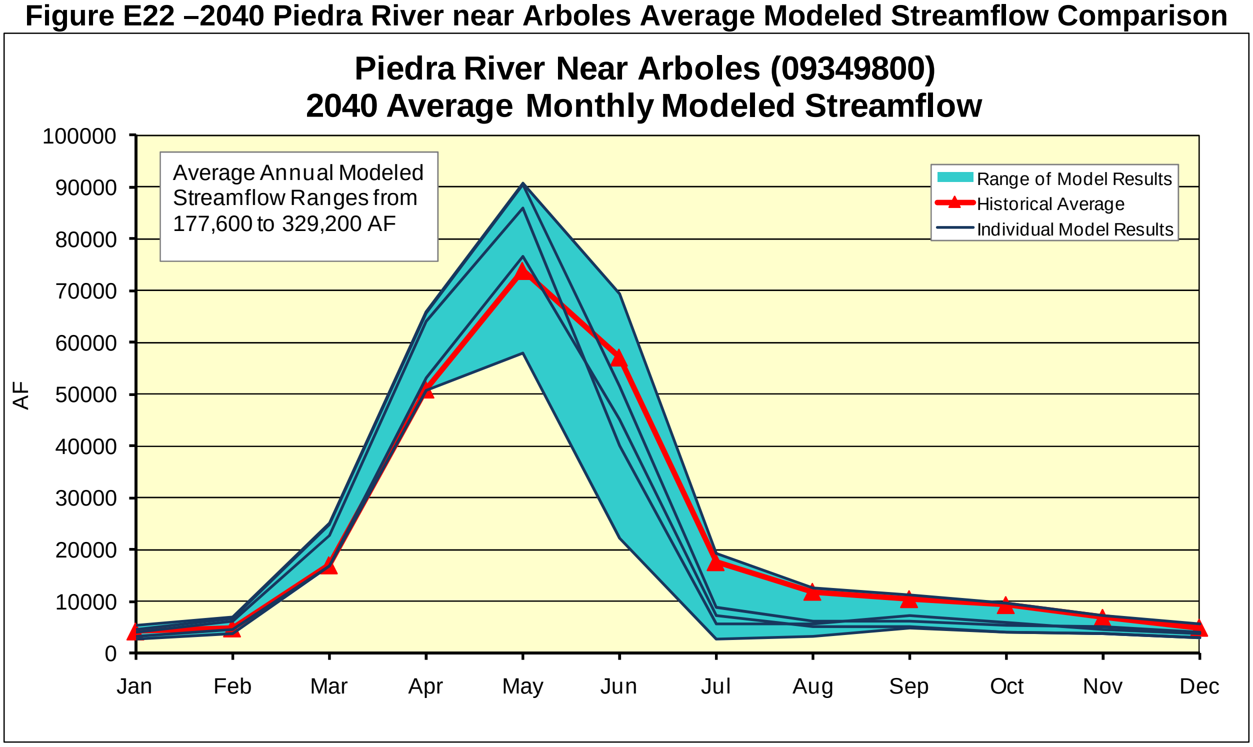


Figure E23 –2040 Los Pinos River at La Boca Average Modeled Streamflow Comparison

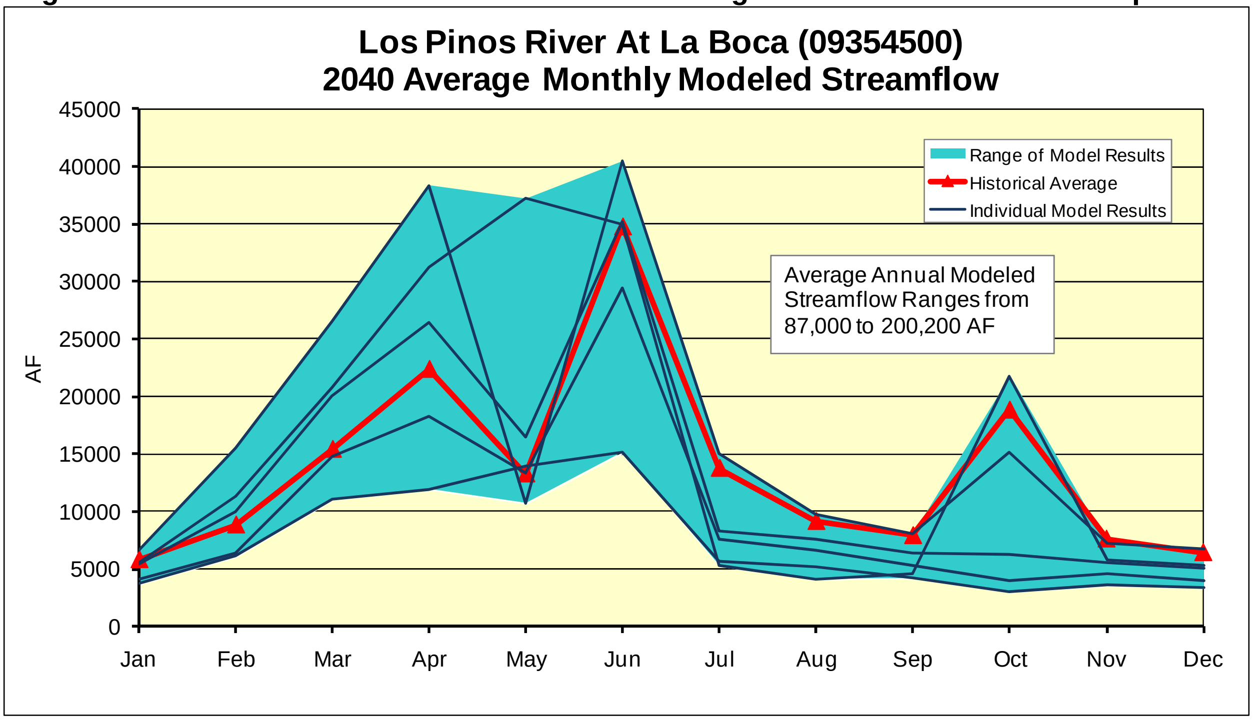


Figure E24 –2040 Florida River at Bondad Average Modeled Streamflow Comparison

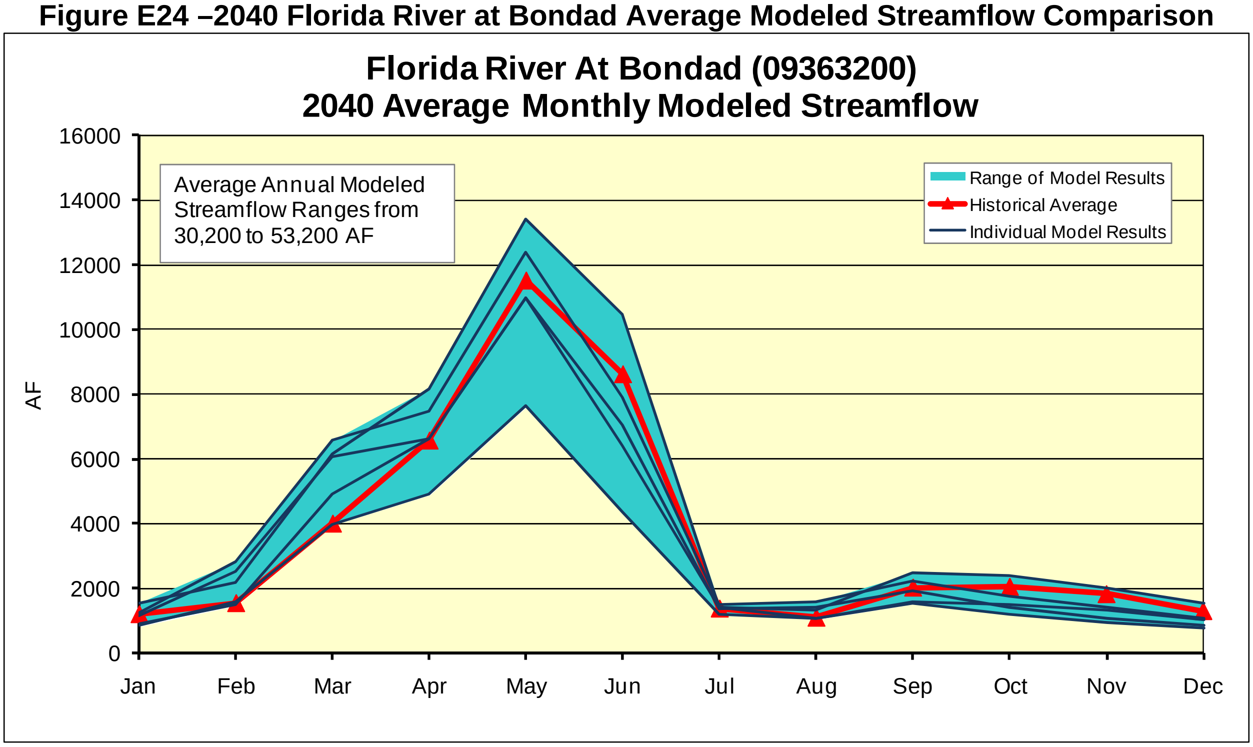


Figure E25 –2040 Animas River near Cedar Hill, NM Average Modeled Streamflow Comparison

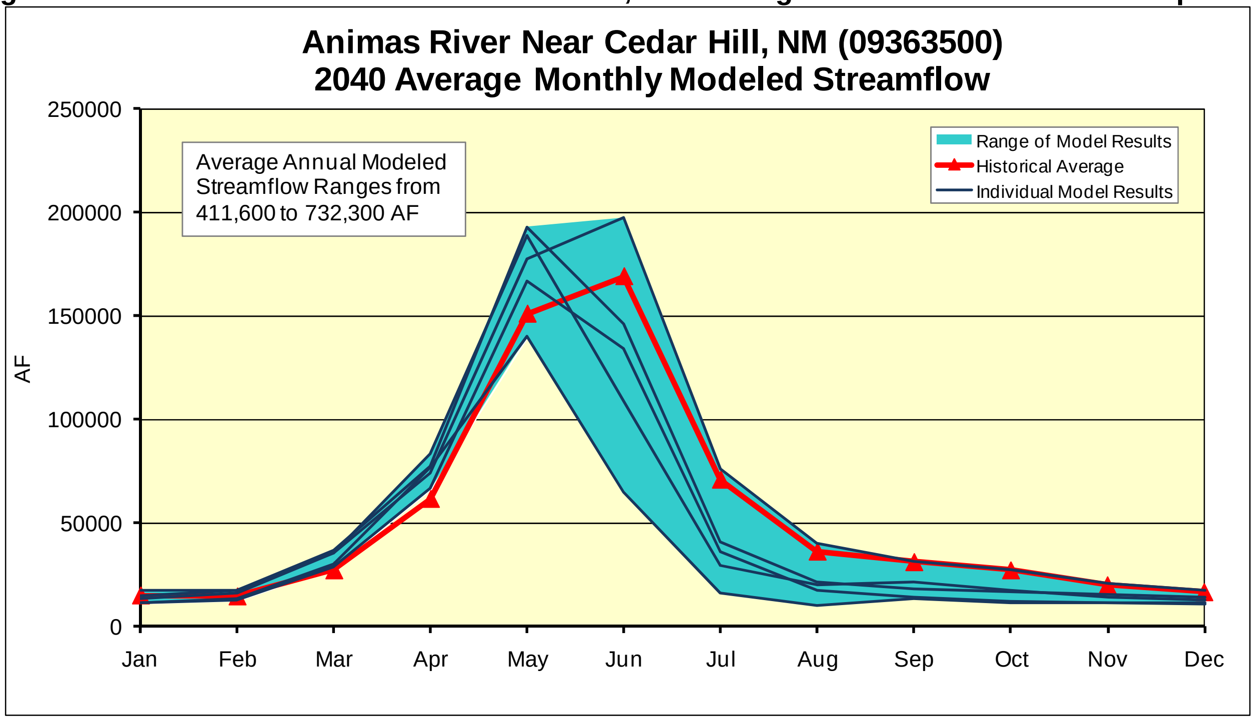


Figure E26 –2040 La Plata River at Hesperus Average Modeled Streamflow Comparison

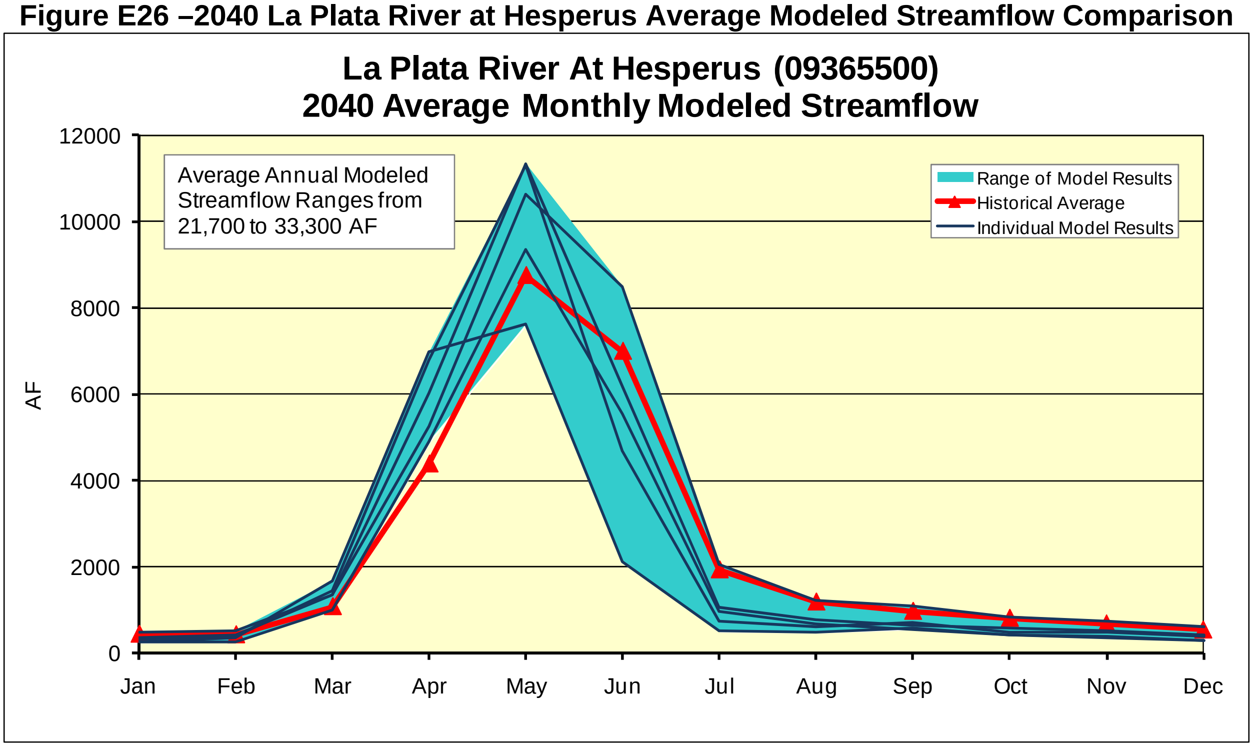


Figure E27 –2040 La Plata River at CO-NM State Line Average Modeled Streamflow Comparison

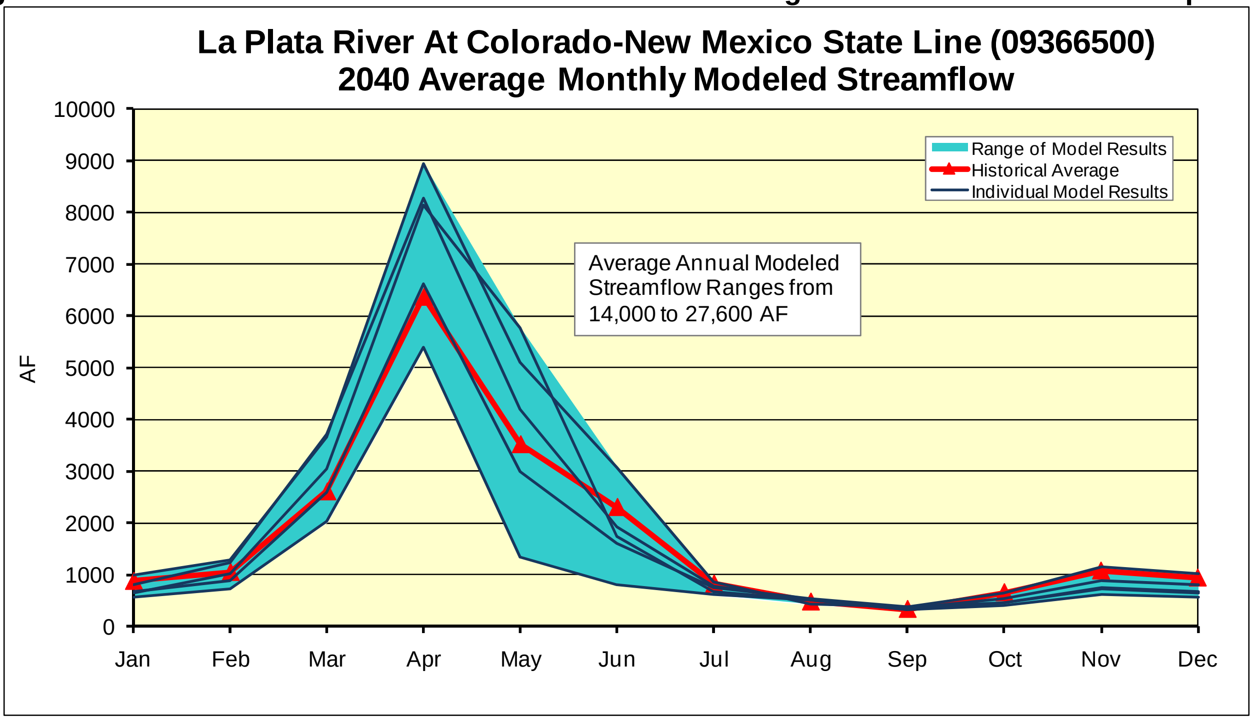


Figure E28 –2040 Mancos River near Towaoc Average Modeled Streamflow Comparison

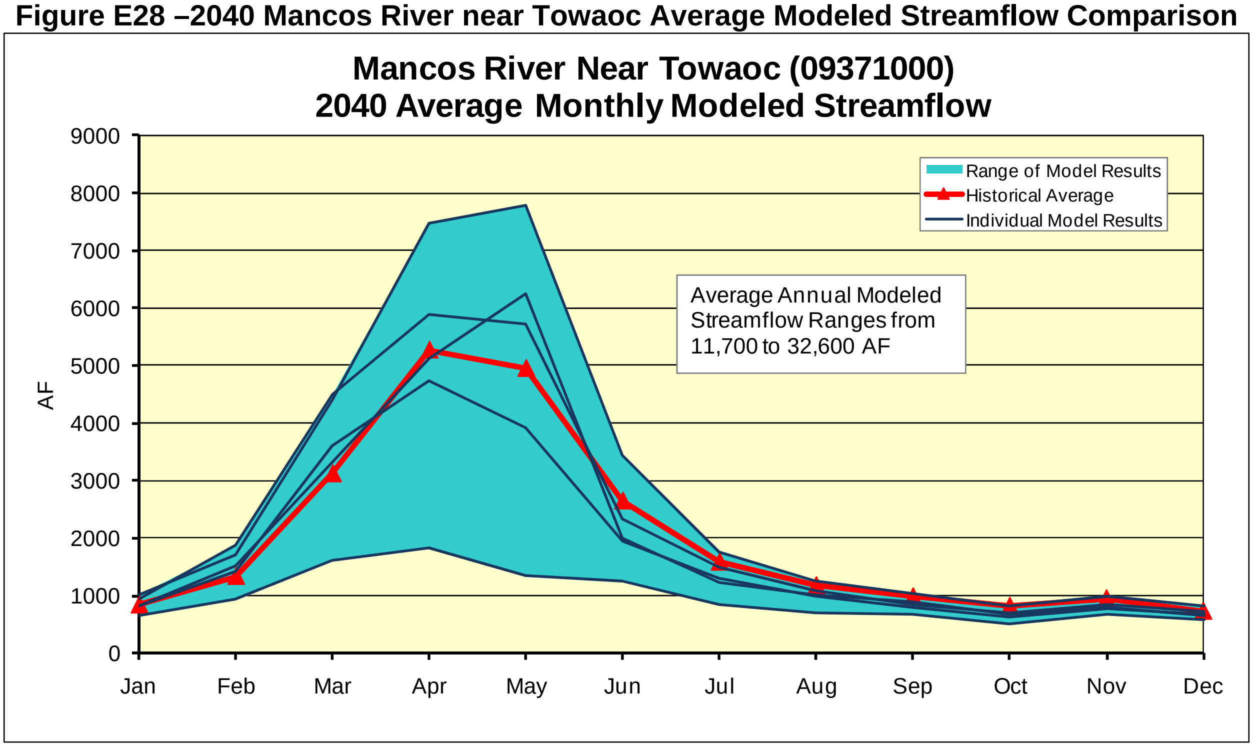


Figure E29 –2040 McElmo Creek near CO-UT State Line Average Modeled Streamflow Comparison

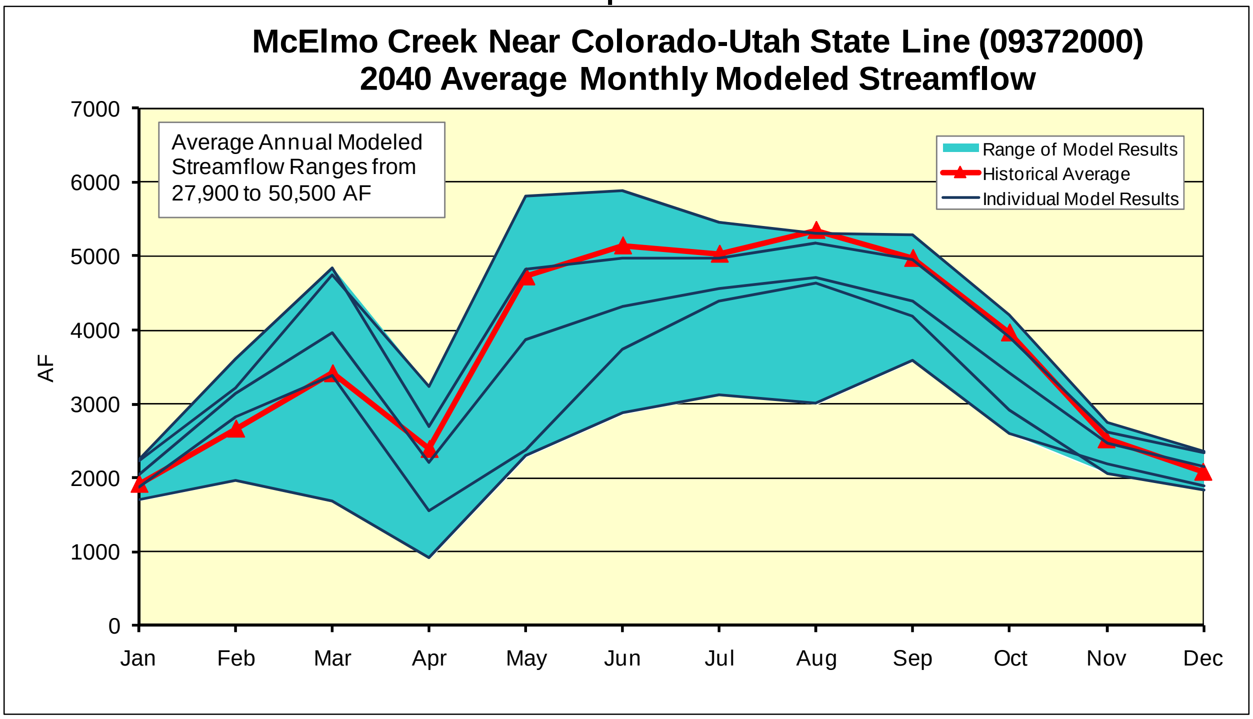


Figure E30 –2040 Dolores River near Bedrock Average Modeled Streamflow Comparison

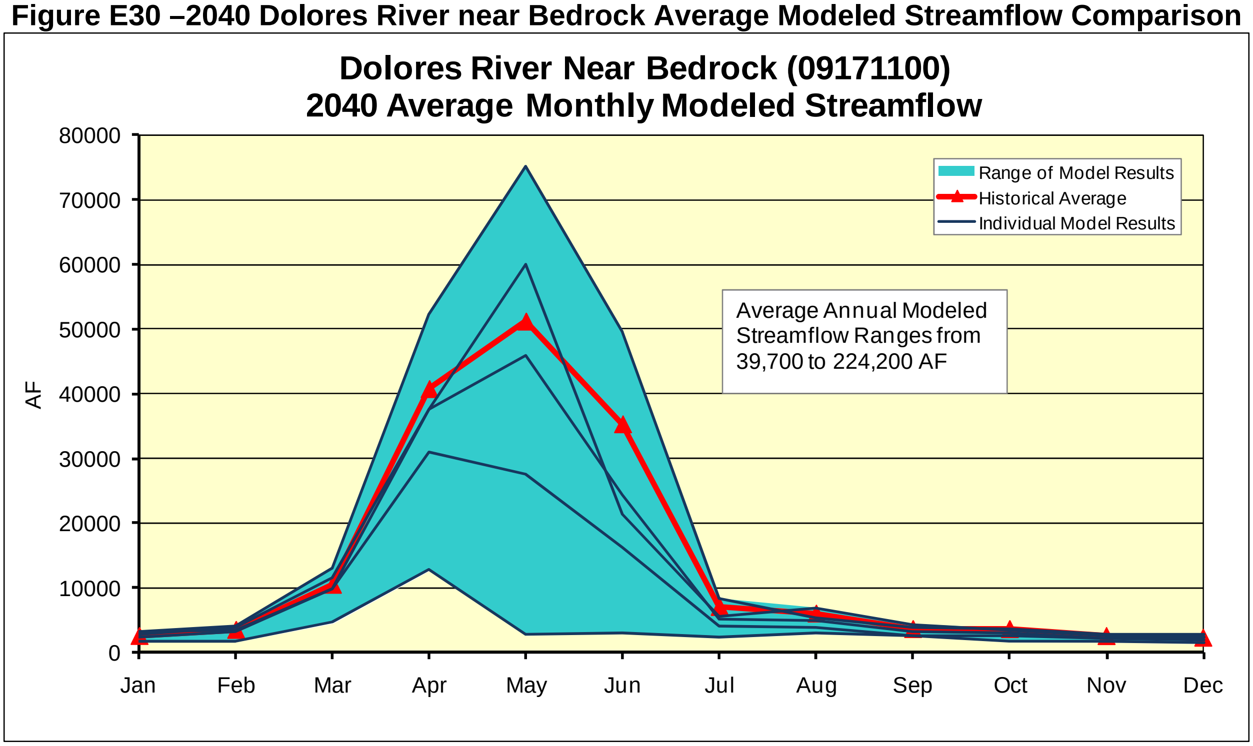


Figure E31 –2040 San Miguel River at Naturita Average Modeled Streamflow Comparison

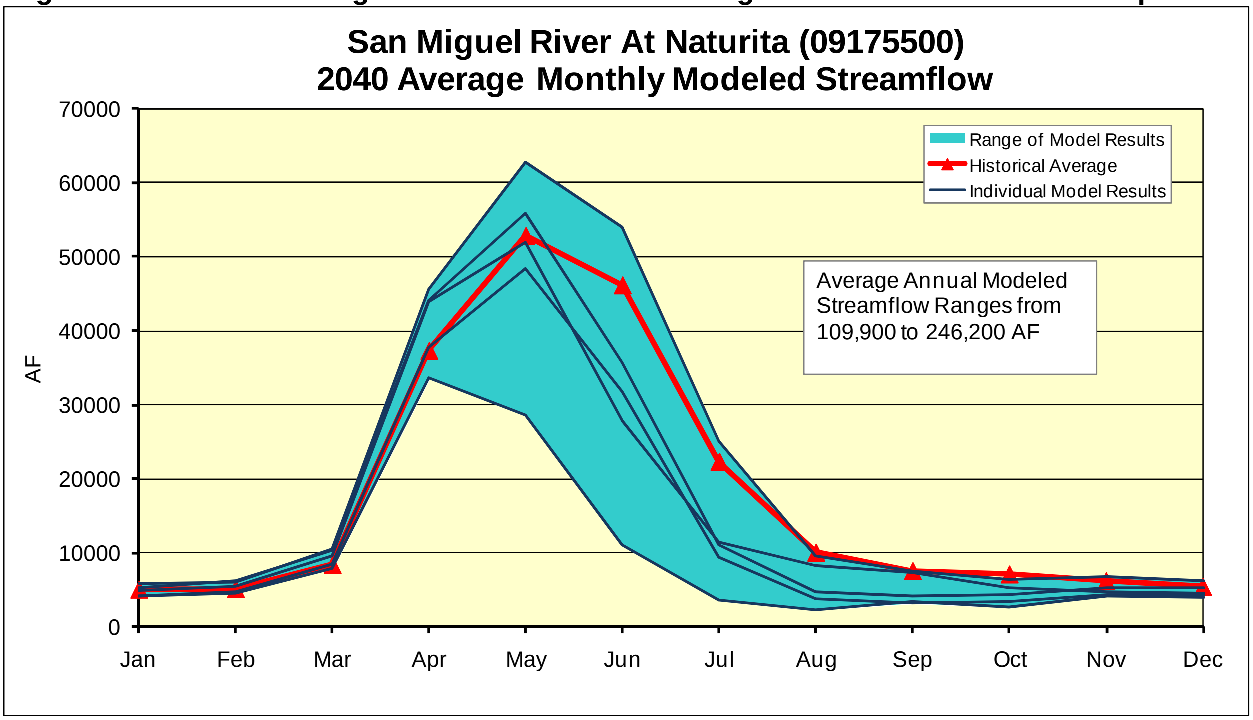


Figure E32 –2040 Yampa River below Stagecoach Reservoir Average Modeled Streamflow Comparison

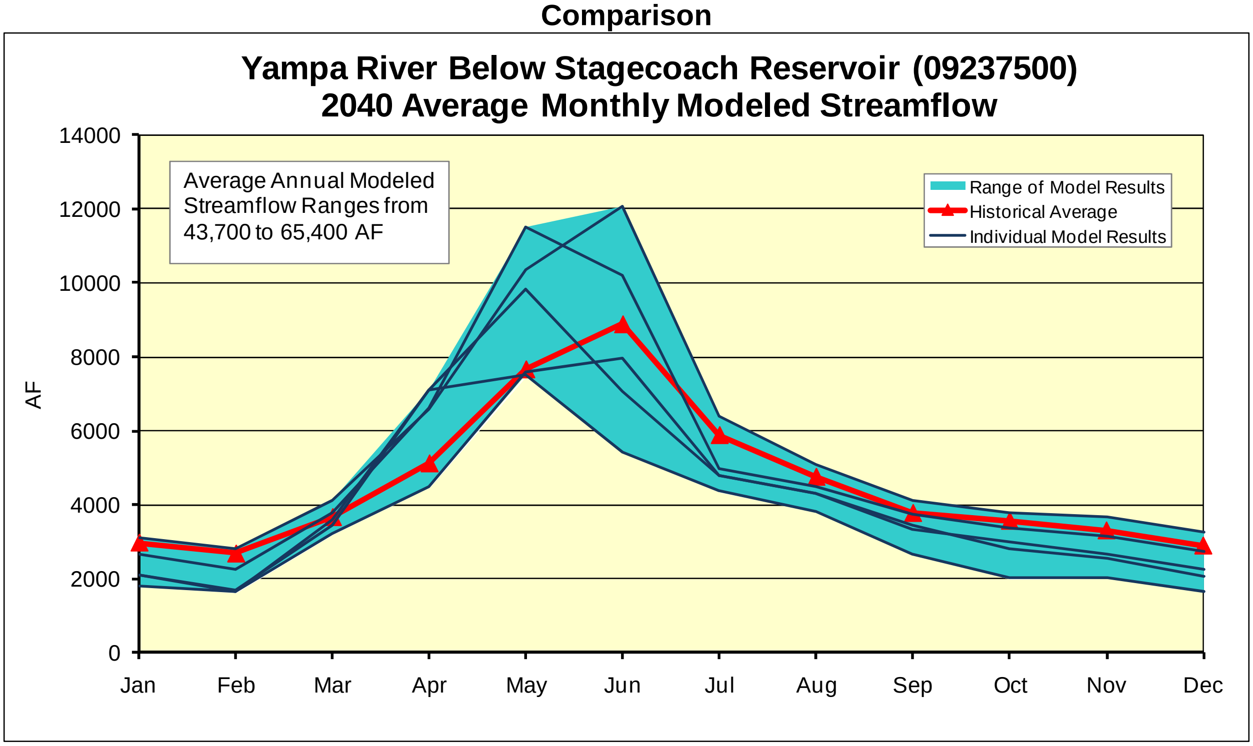


Figure E33 –2040 Elk River at Clark Average Modeled Streamflow Comparison

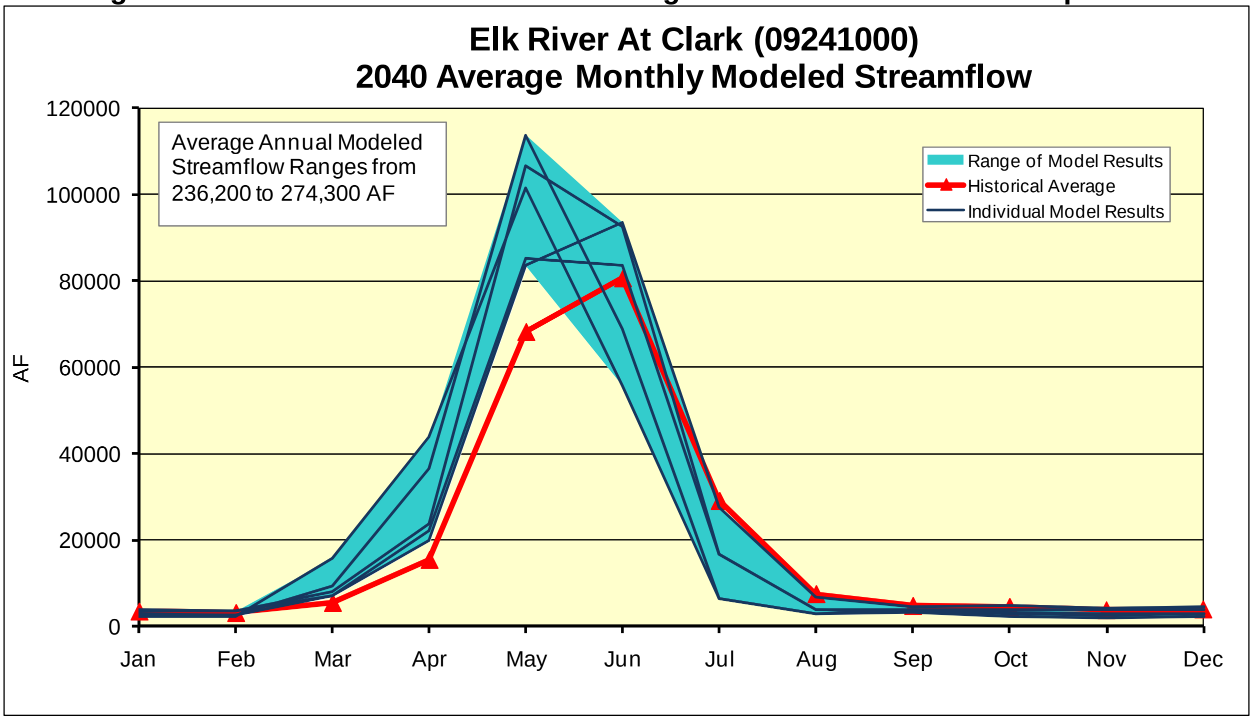


Figure E34 –2040 Elkhead Creek near Elkhead Average Modeled Streamflow Comparison

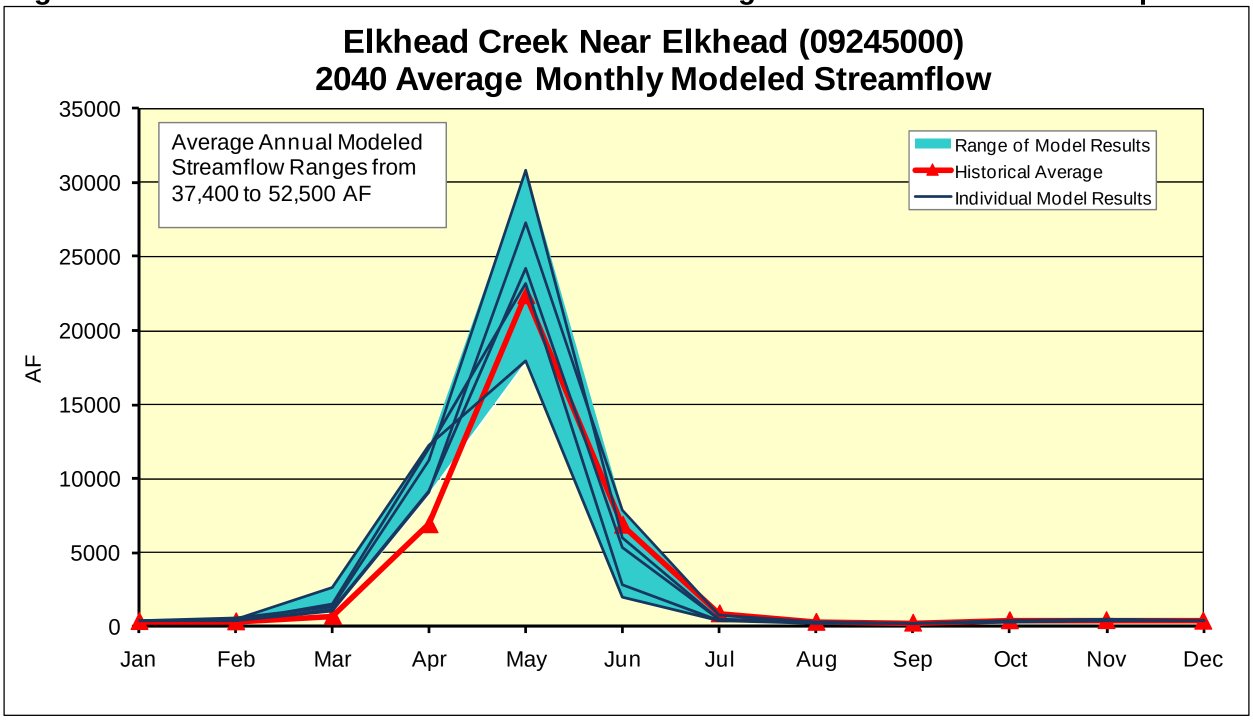


Figure E35 –2040 Williams Fork at Mouth, near Hamilton Average Modeled Streamflow Comparison

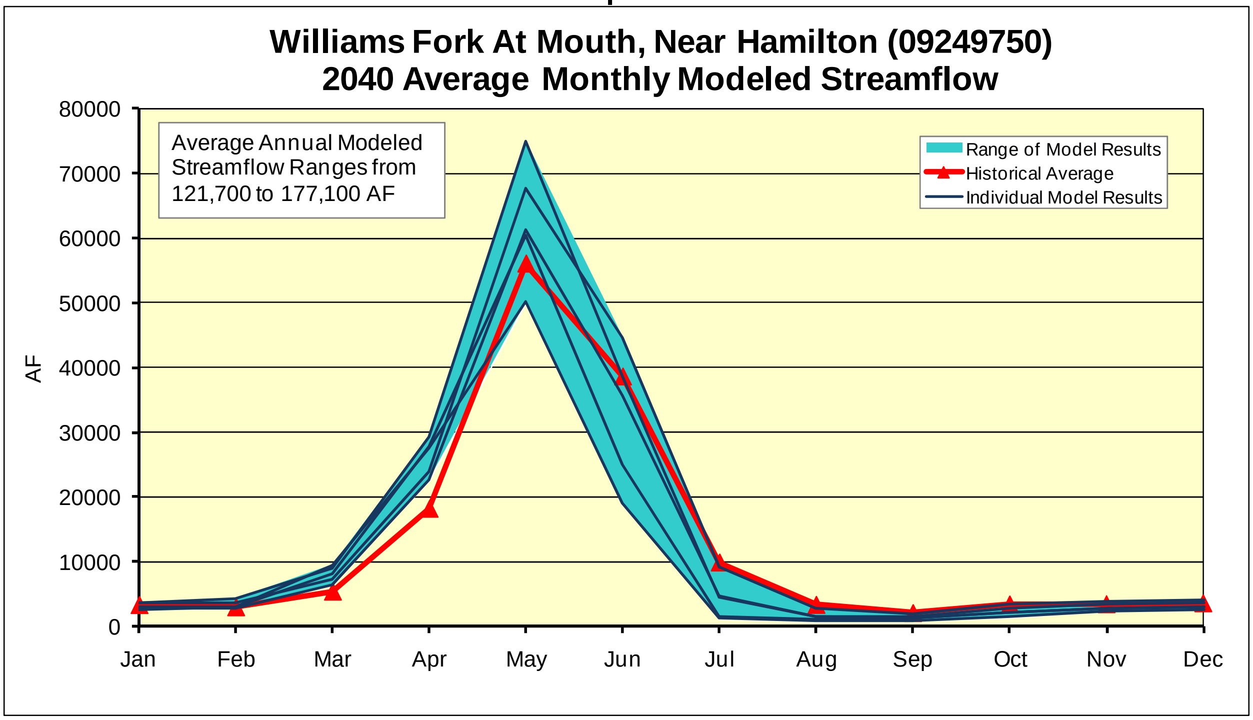


Figure E36 –2040 Yampa River near Maybell Average Modeled Streamflow Comparison

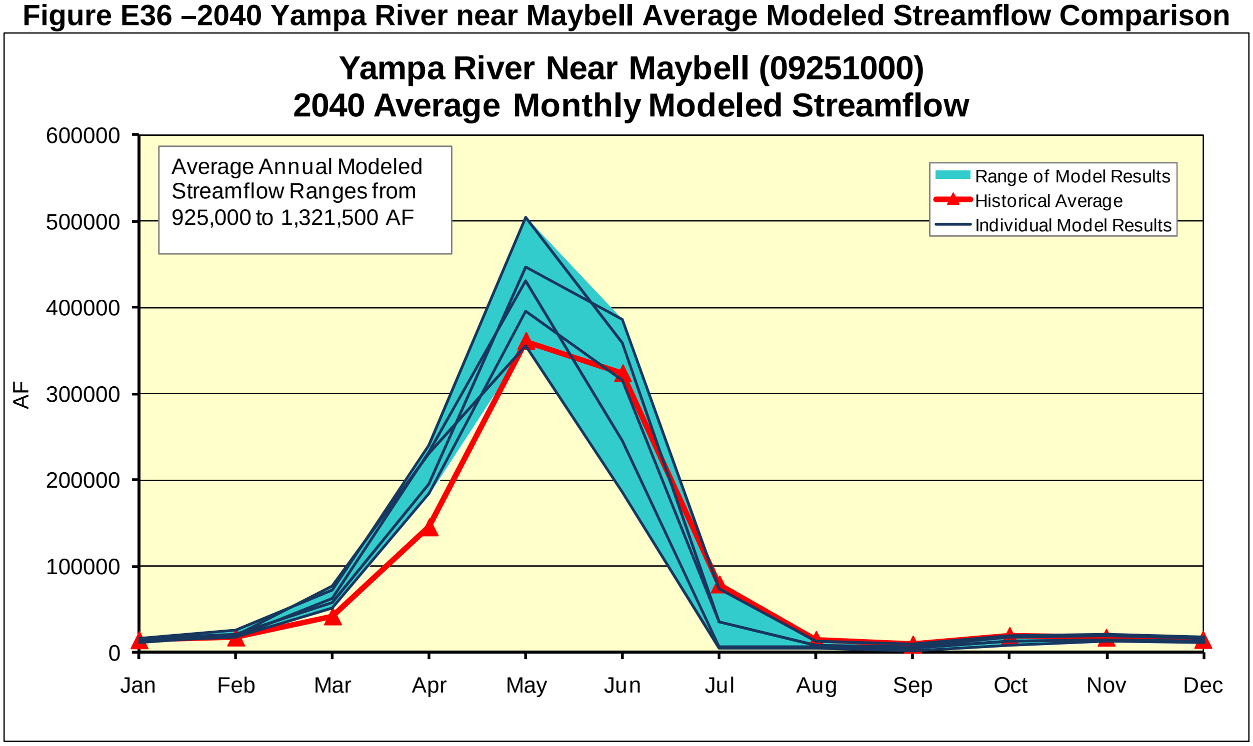


Figure E37 –2040 Little Snake River near Lily Average Modeled Streamflow Comparison

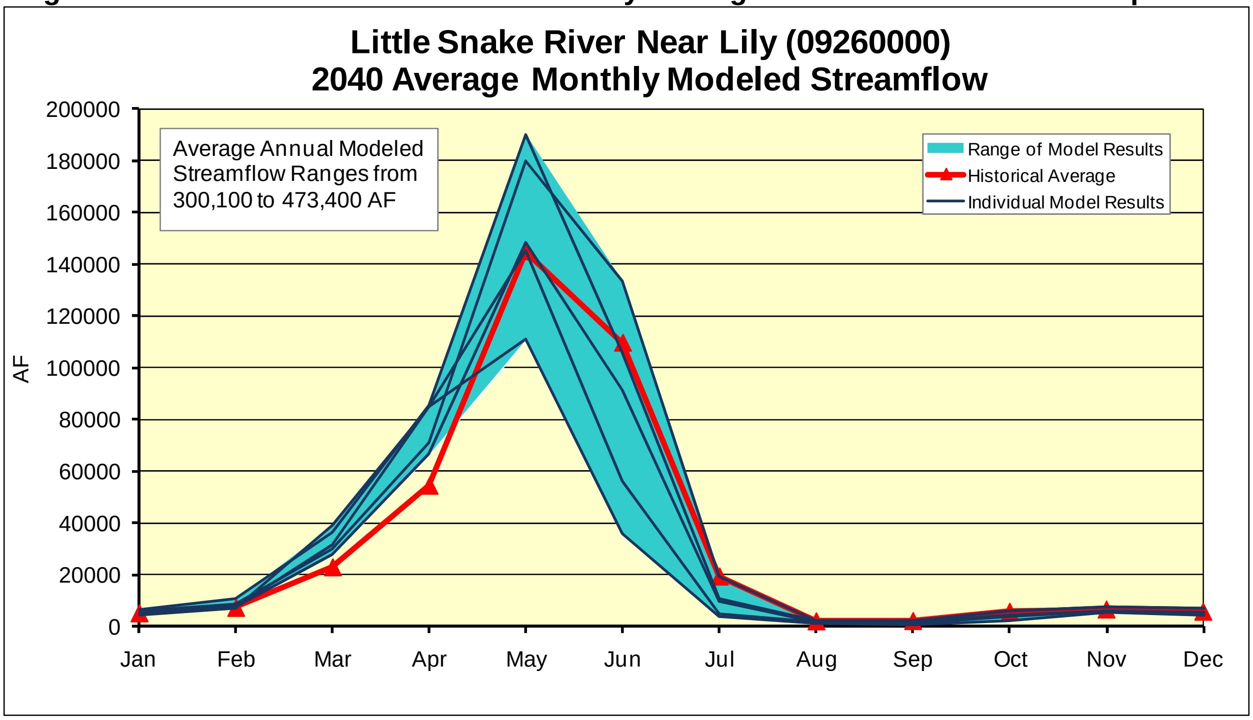


Figure E38 –2040 Yampa River at Deerlodge Park Average Modeled Streamflow Comparison

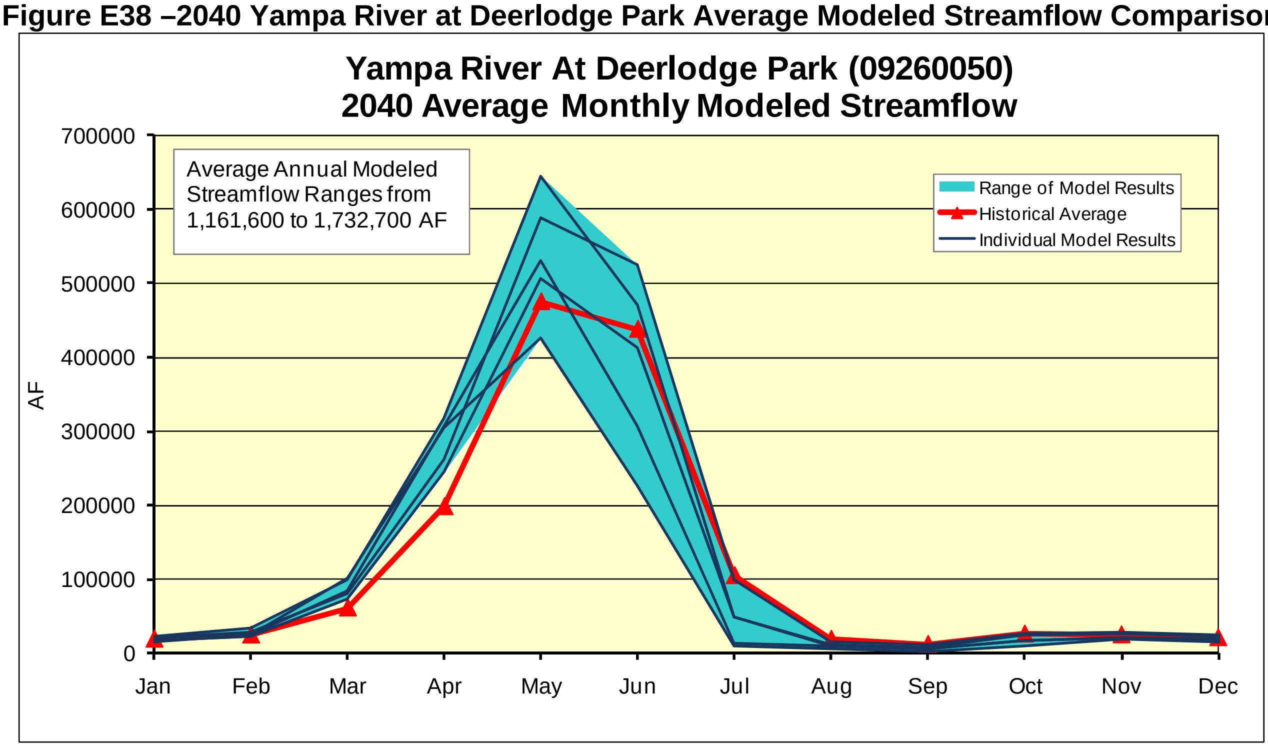


Figure E39 –2040 North Fork White River at Buford Average Modeled Streamflow Comparison

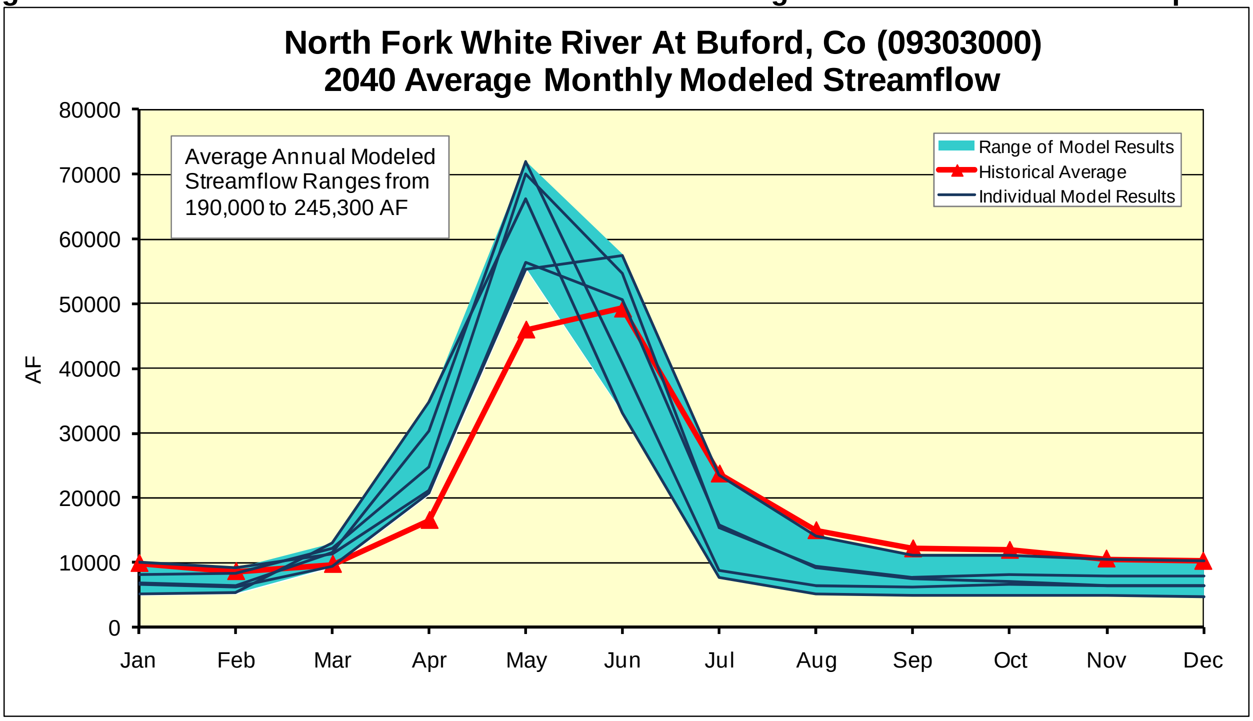


Figure E40 –2040 South Fork White River at Buford Average Modeled Streamflow Comparison

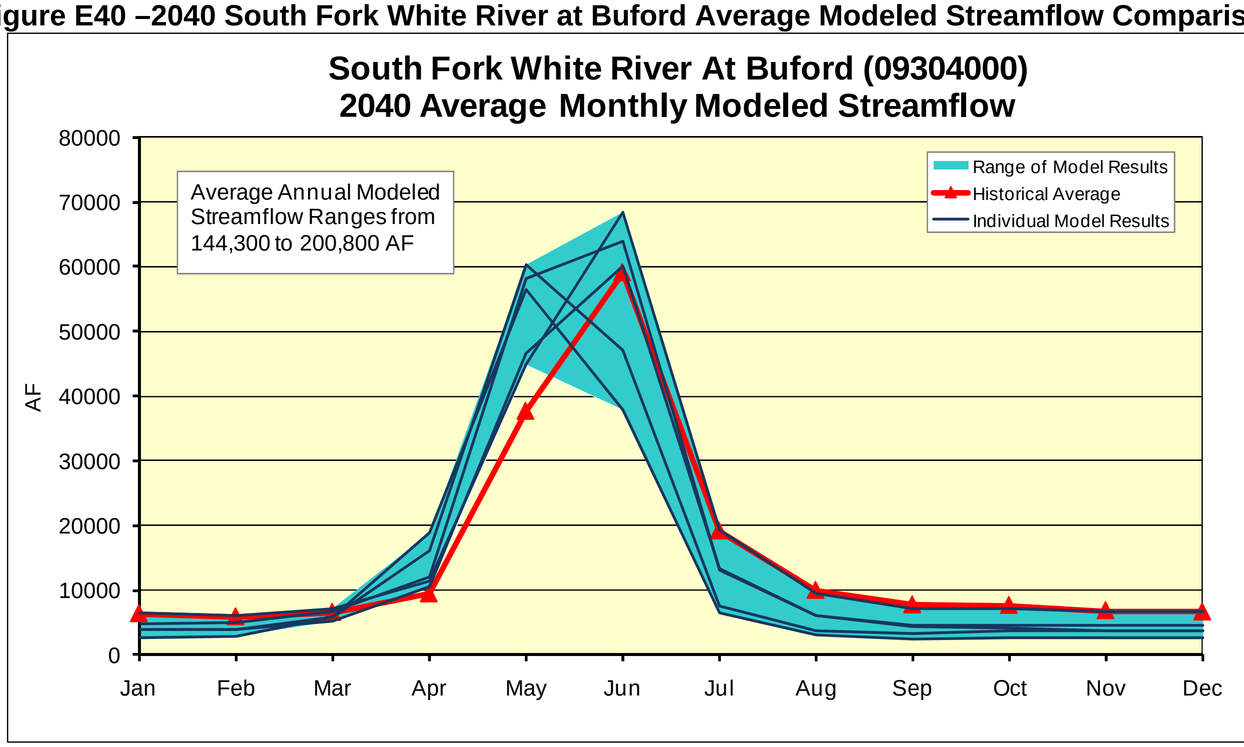


Figure E41 –2040 White River below Meeker Average Modeled Streamflow Comparison

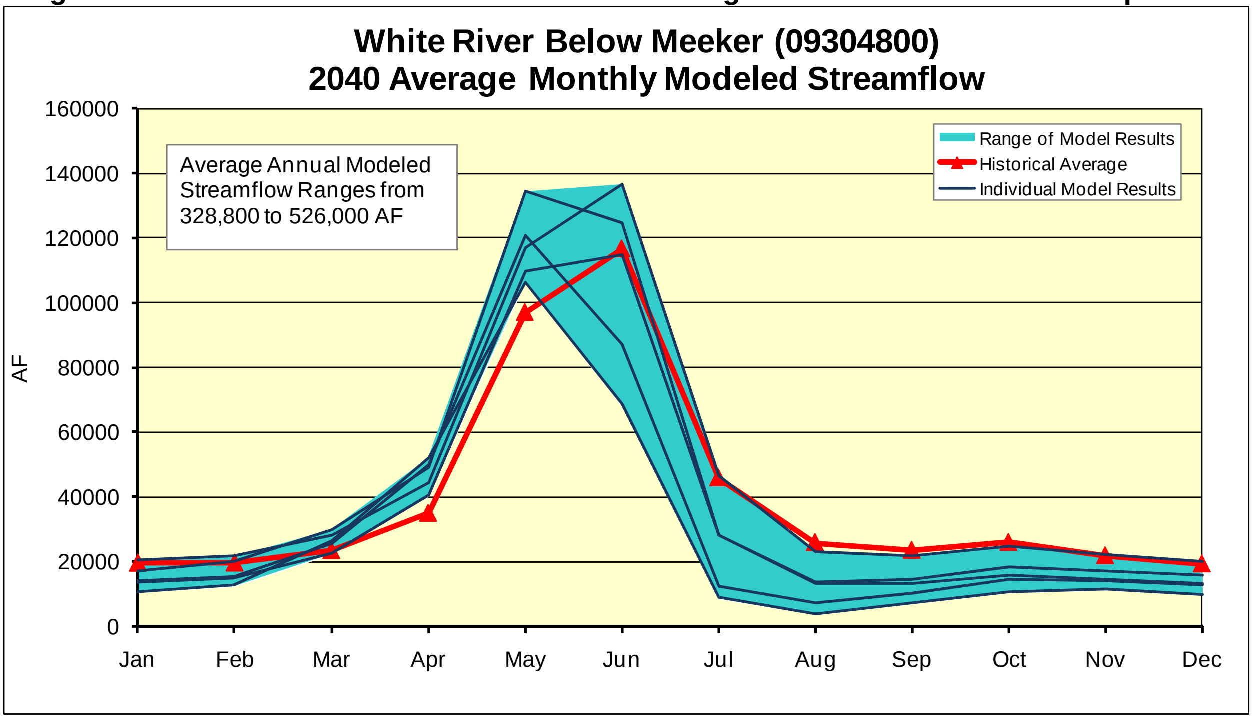


Figure E42 –2040 Piceance Creek at White River Average Modeled Streamflow Comparison

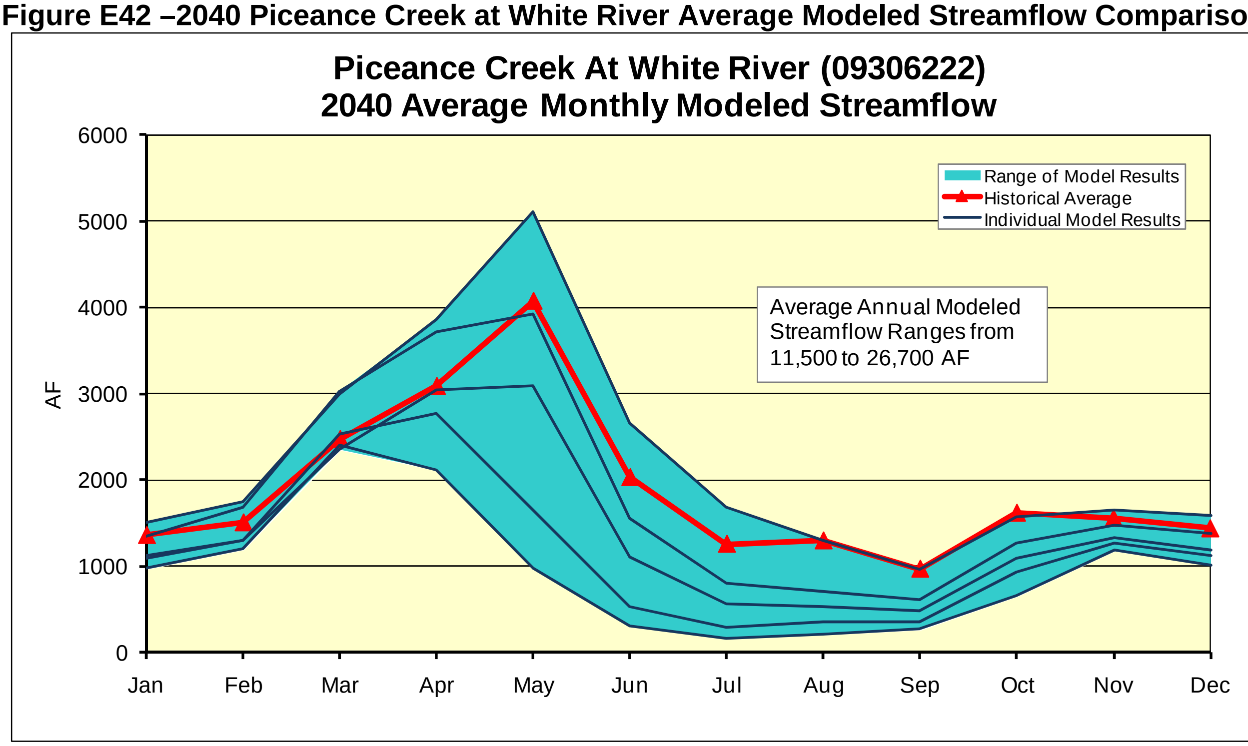


Figure E43 –2040 White River near CO-UT State Line Average Modeled Streamflow Comparison

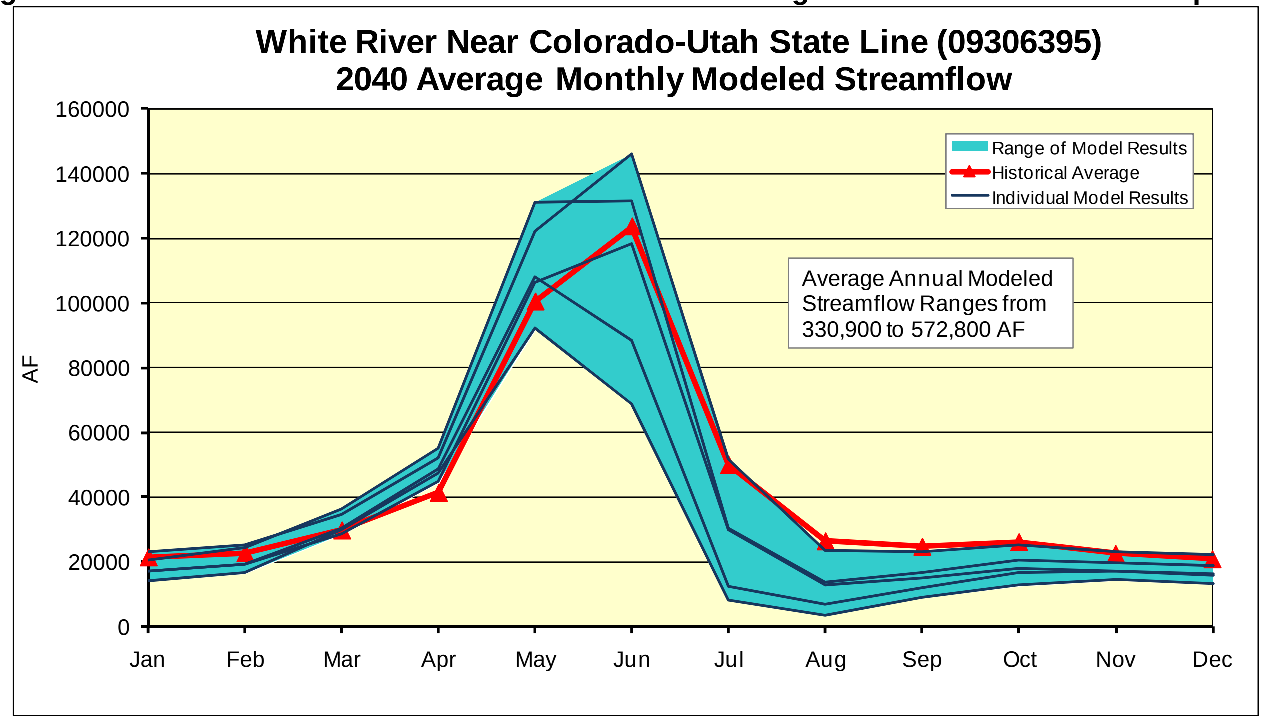


Figure E44 –2070 Colorado River near Grand Lake Average Modeled Streamflow Comparison

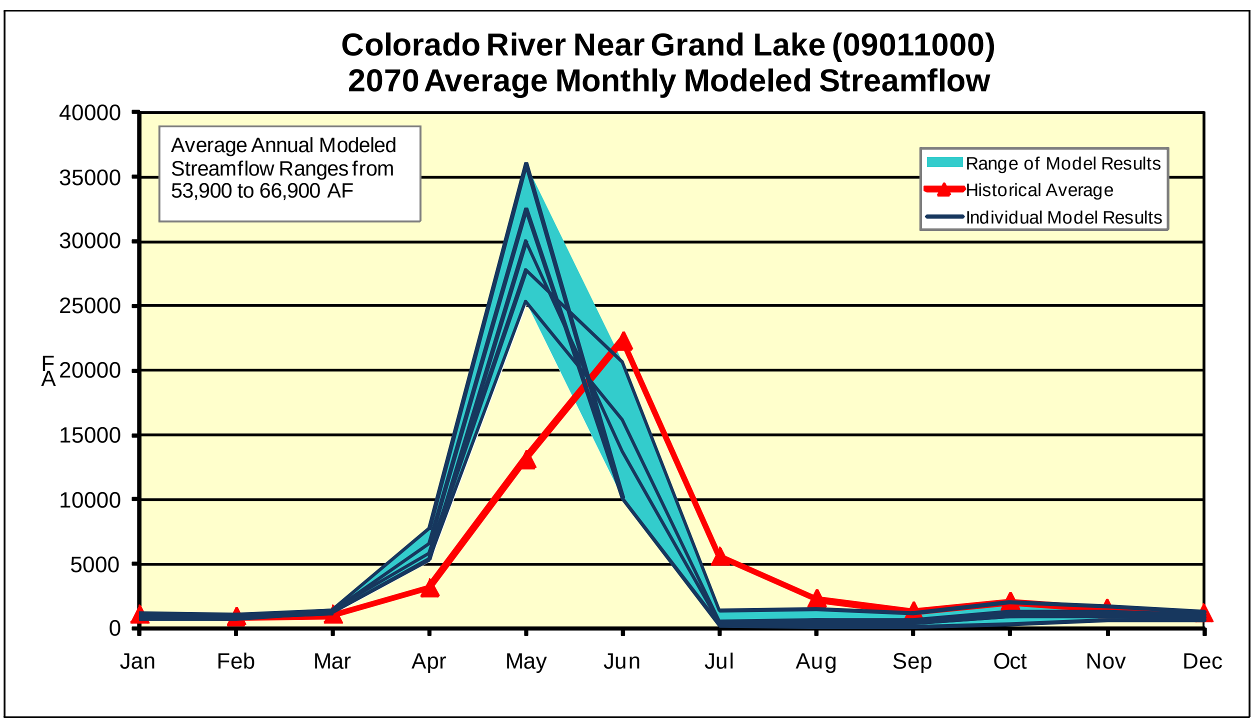


Figure E45 –2070 Muddy Creek at Kremmling Average Modeled Streamflow Comparison

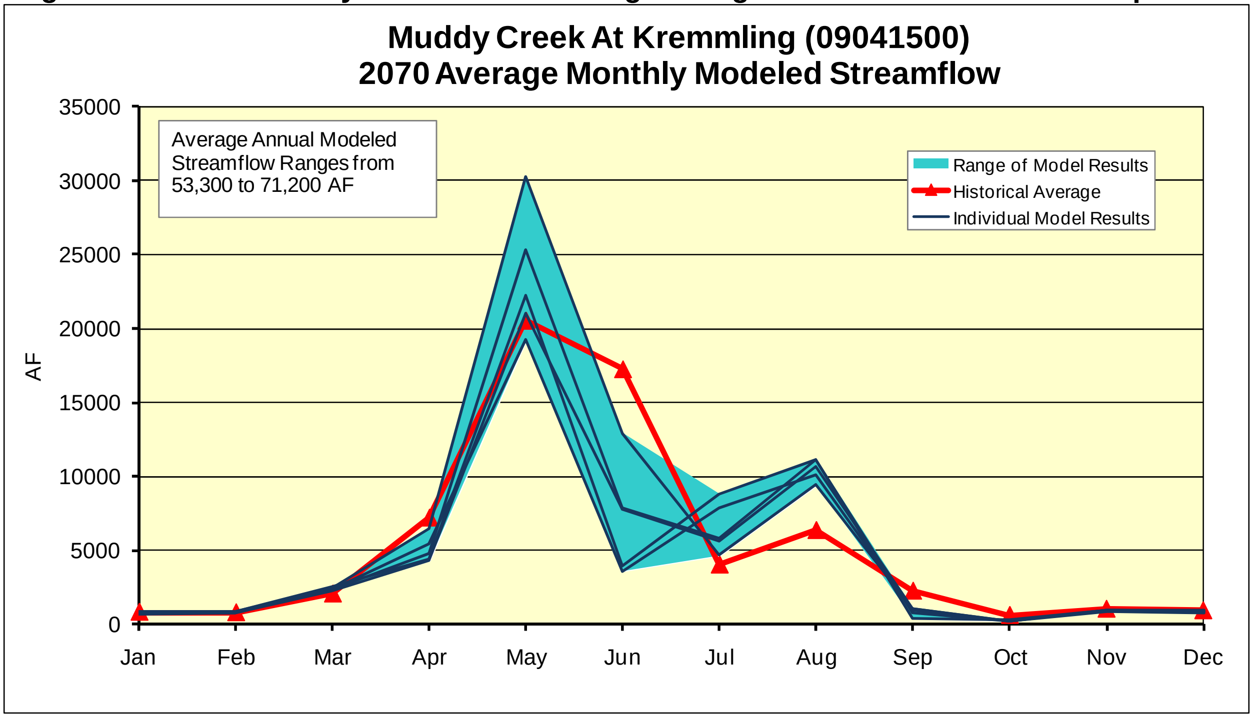


Figure E46 –2070 Blue River below Dillon Average Modeled Streamflow Comparison

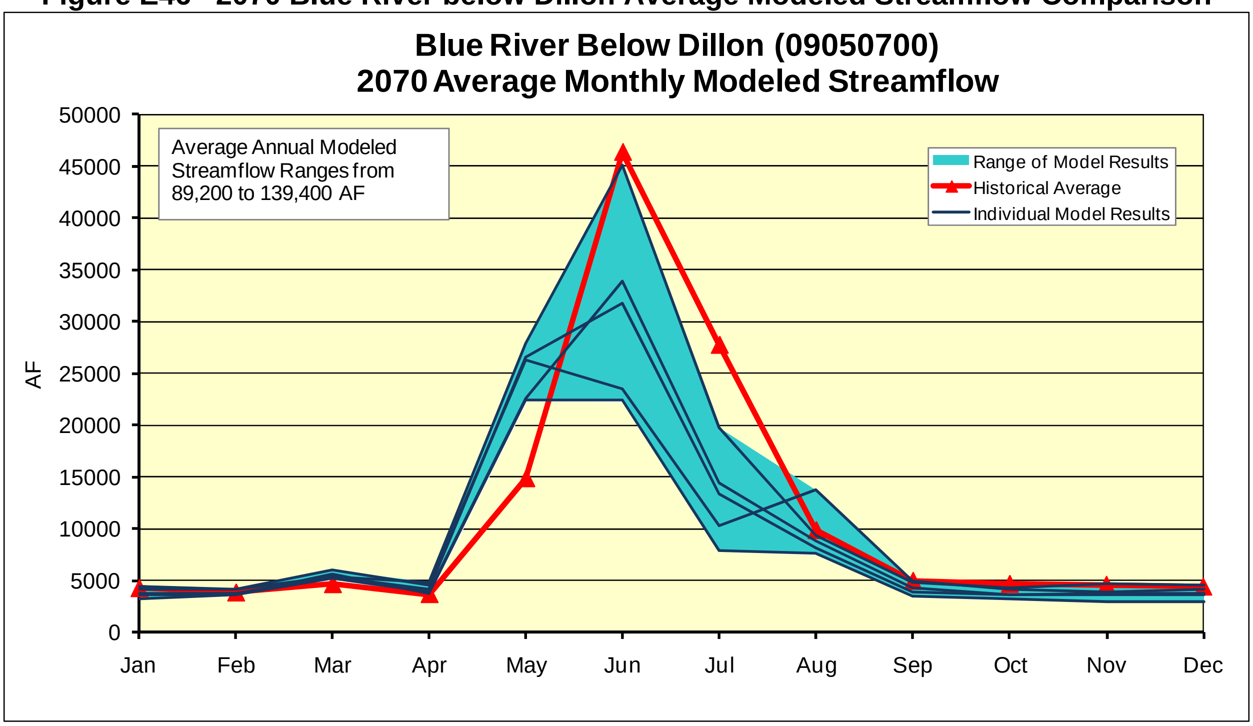


Figure E47 –2070 Blue River below Green Mountain Reservoir Average Modeled Streamflow Comparison

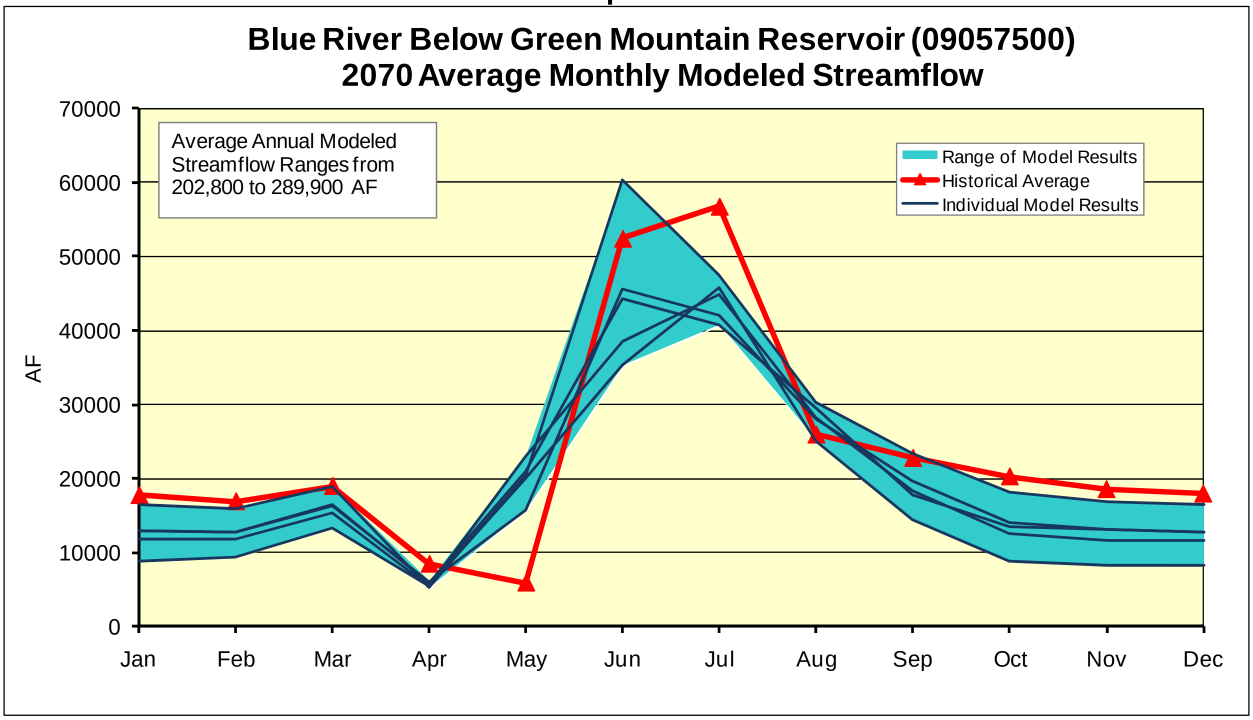


Figure E48 –2070 Eagle River below Gypsum Average Modeled Streamflow Comparison

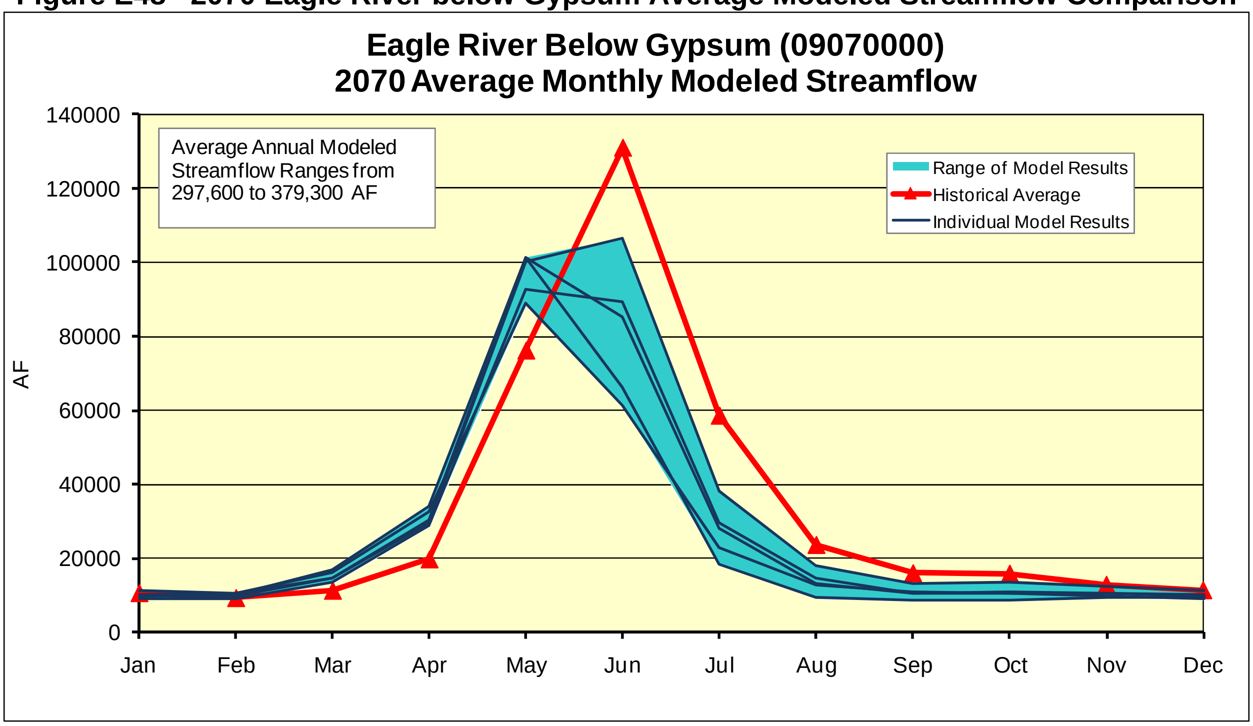


Figure E49 –2070 Colorado River at Dotsero Average Modeled Streamflow Comparison

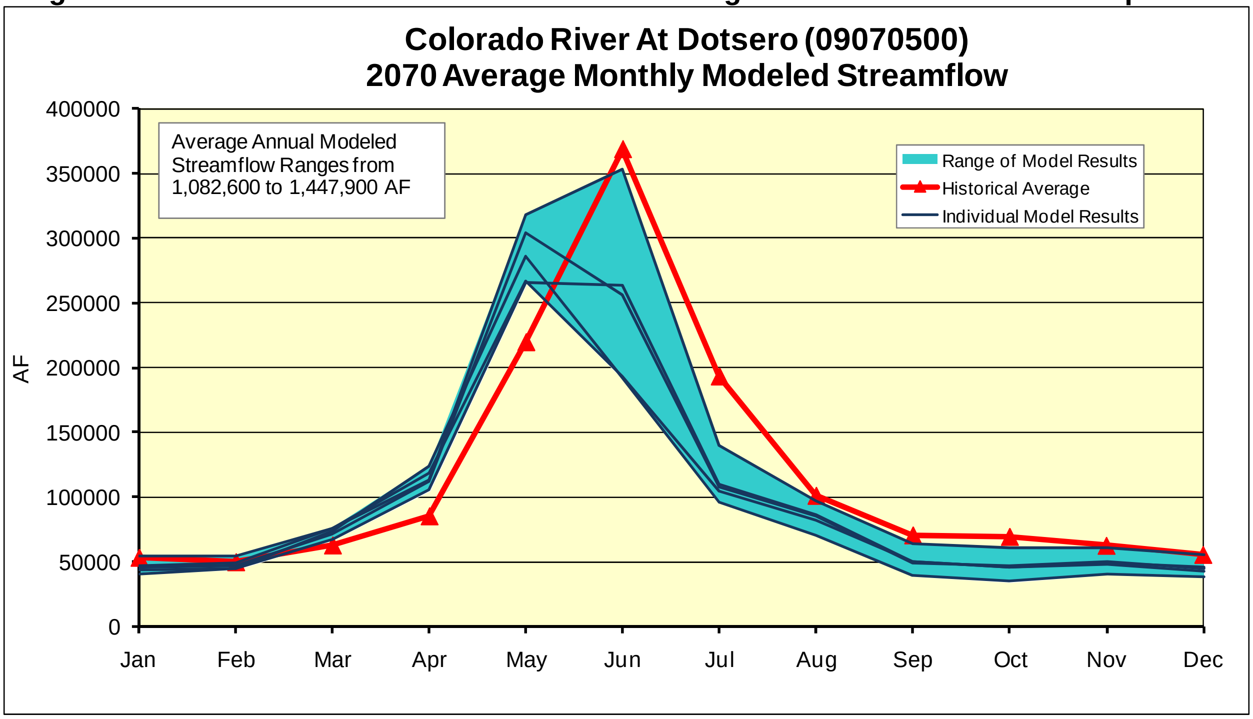


Figure E50 –2070 Roaring Fork River near Aspen Average Modeled Streamflow Comparison

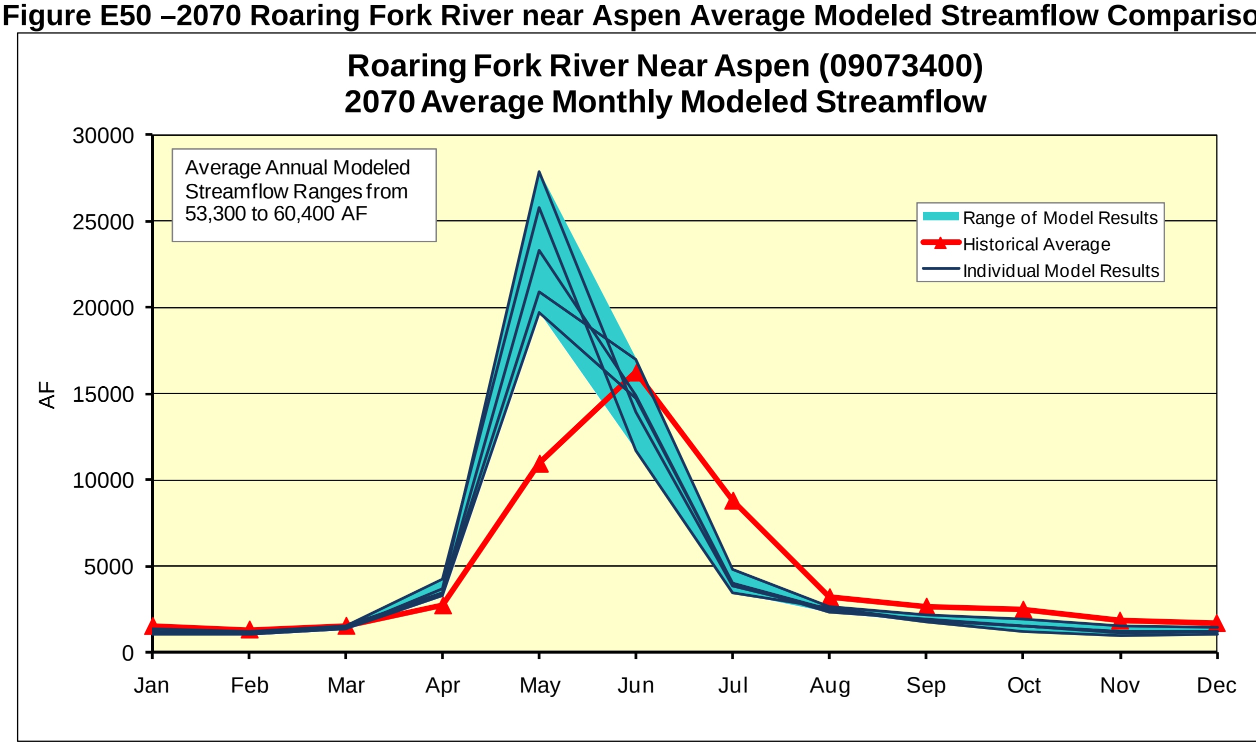


Figure E51 –2070 Roaring Fork River at Glenwood Average Modeled Streamflow Comparison

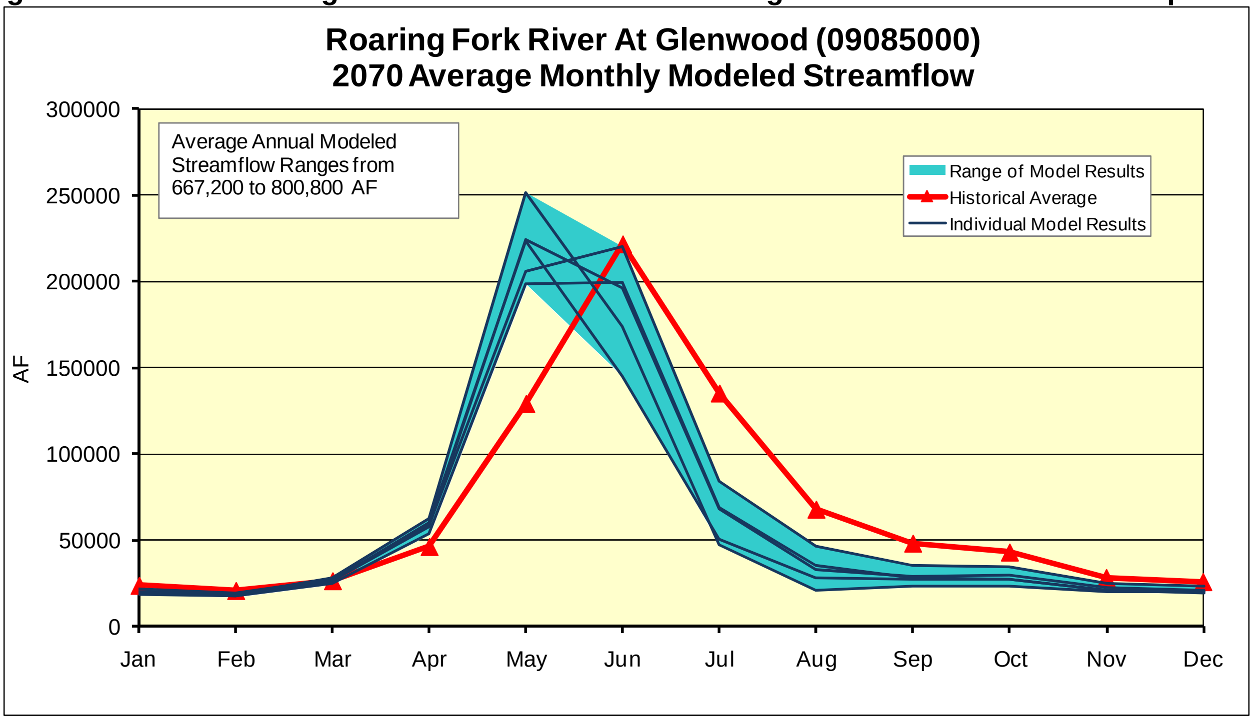


Figure E52 –2070 Colorado River near Cameo Average Modeled Streamflow Comparison

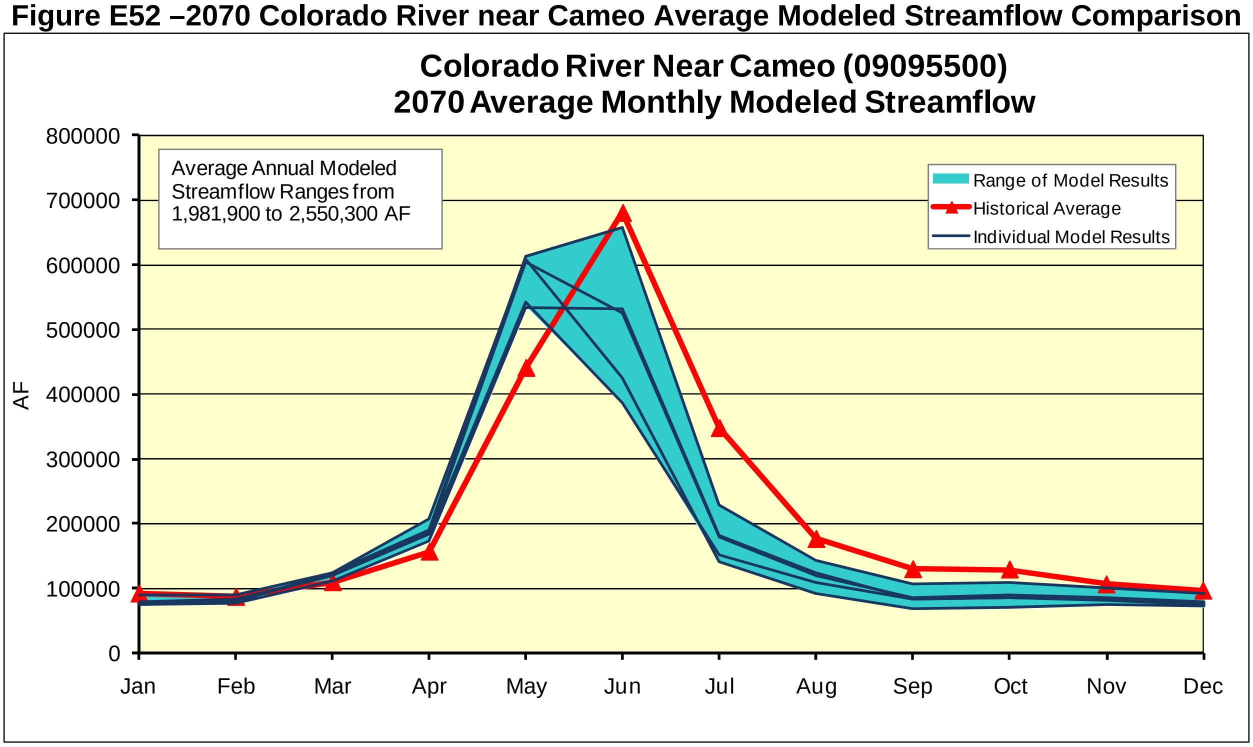


Figure E53 –2070 Plateau near Cameo Average Modeled Streamflow Comparison

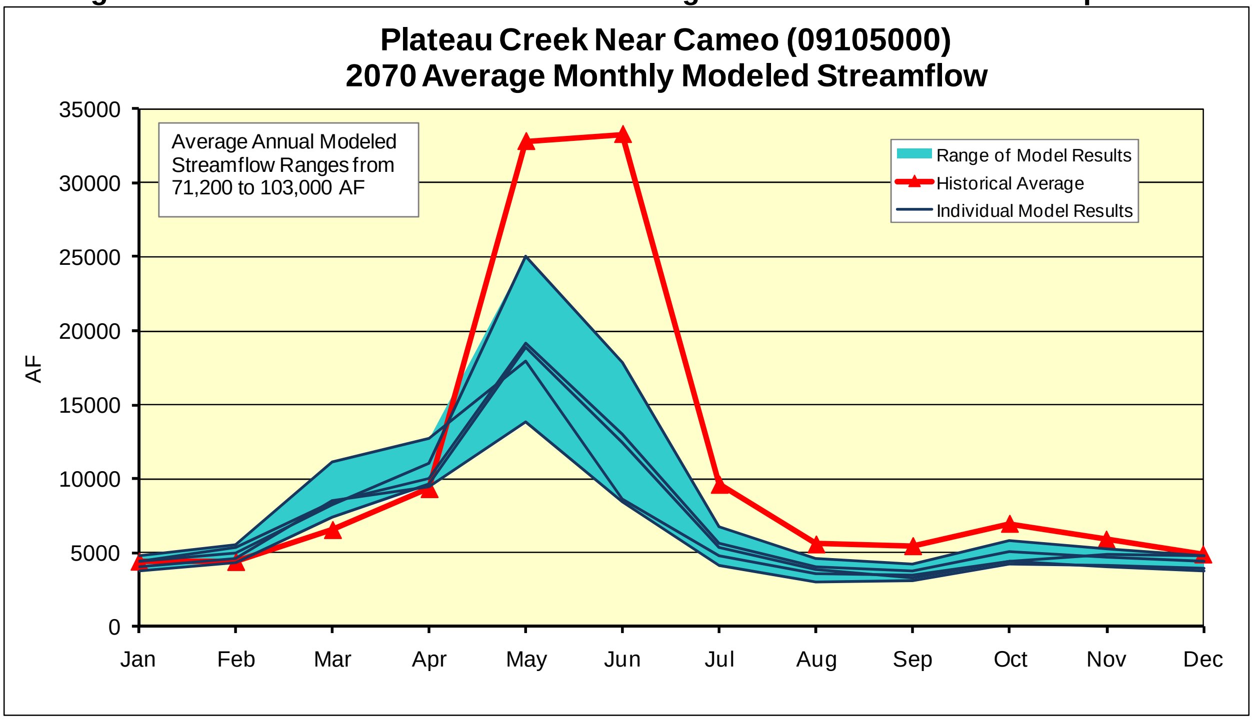


Figure E54 –2070 Colorado River near CO-UT State Line Average Modeled Streamflow Comparison

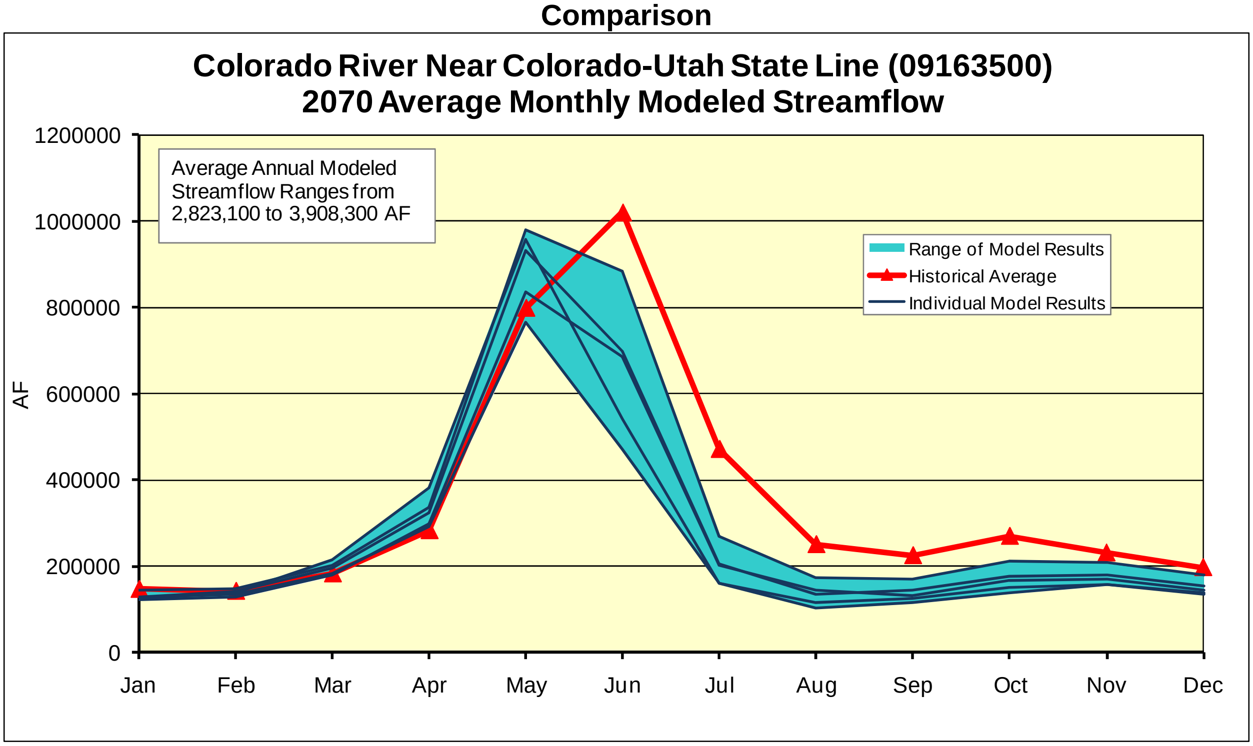


Figure E55 –2070 East River at Almont Average Modeled Streamflow Comparison

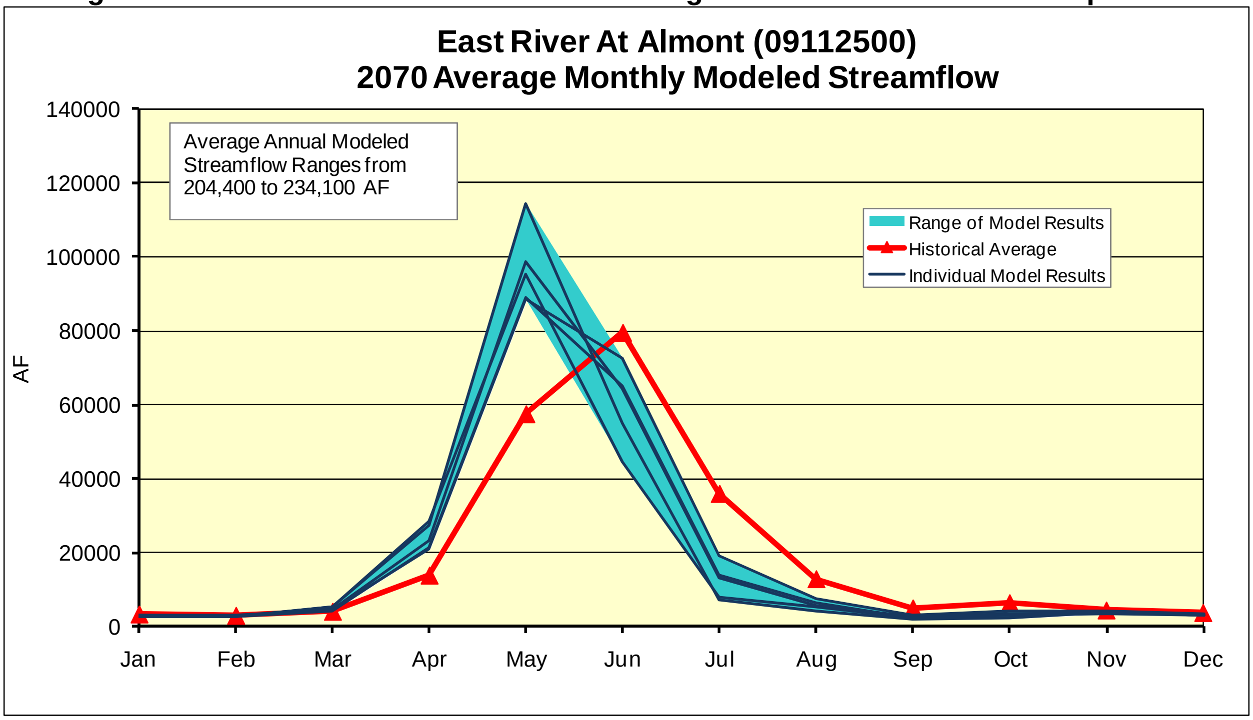


Figure E56 –2070 Taylor River at Almont Average Modeled Streamflow Comparison

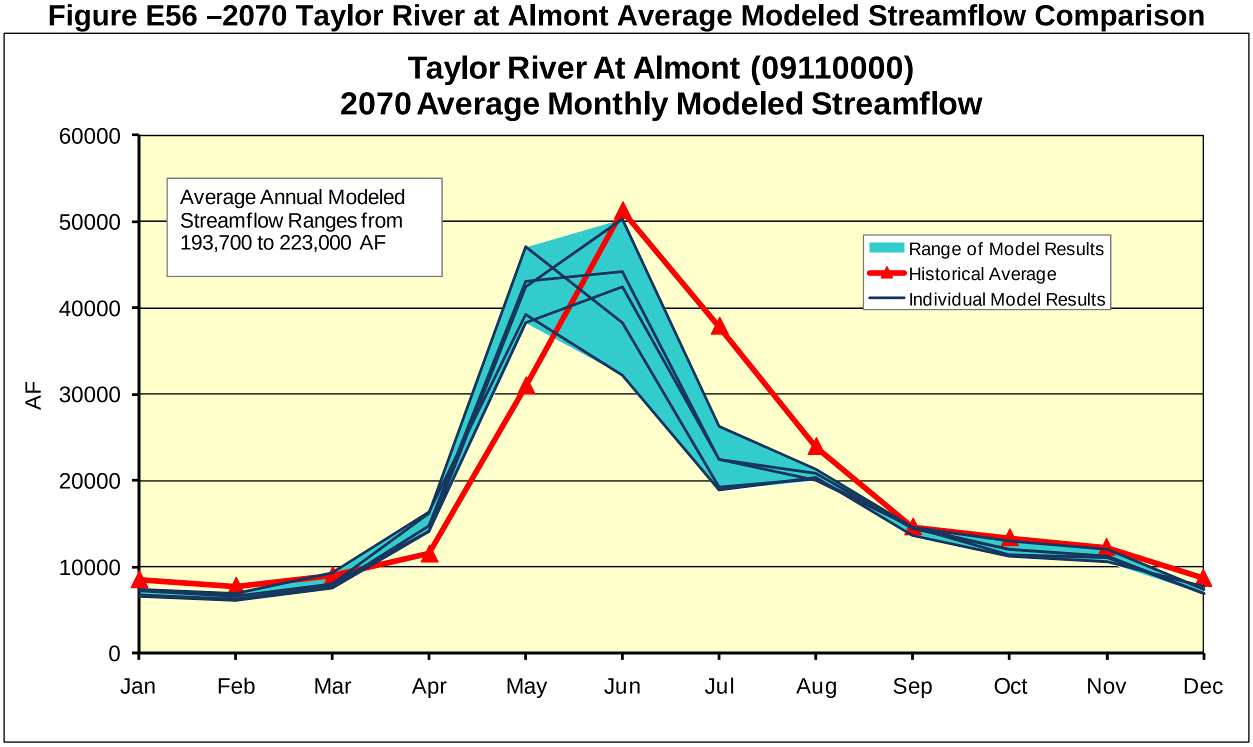


Figure E57 –2070 Tomichi Creek at Gunnison Average Modeled Streamflow Comparison

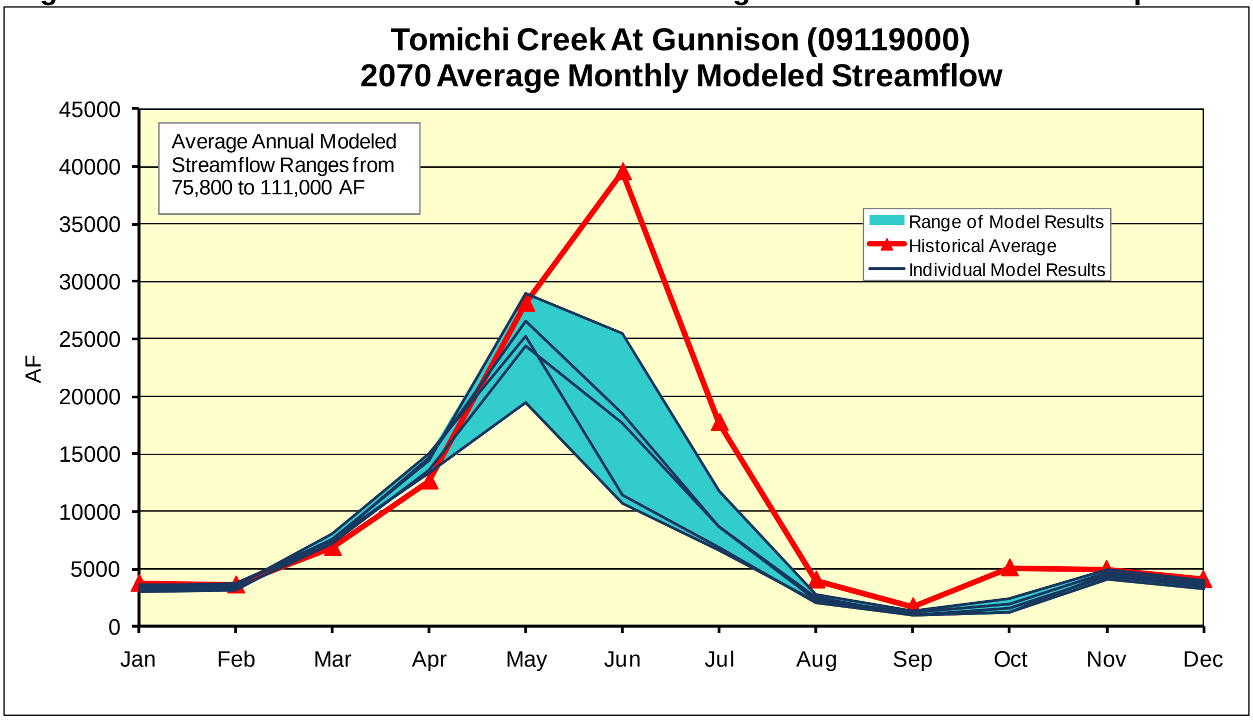
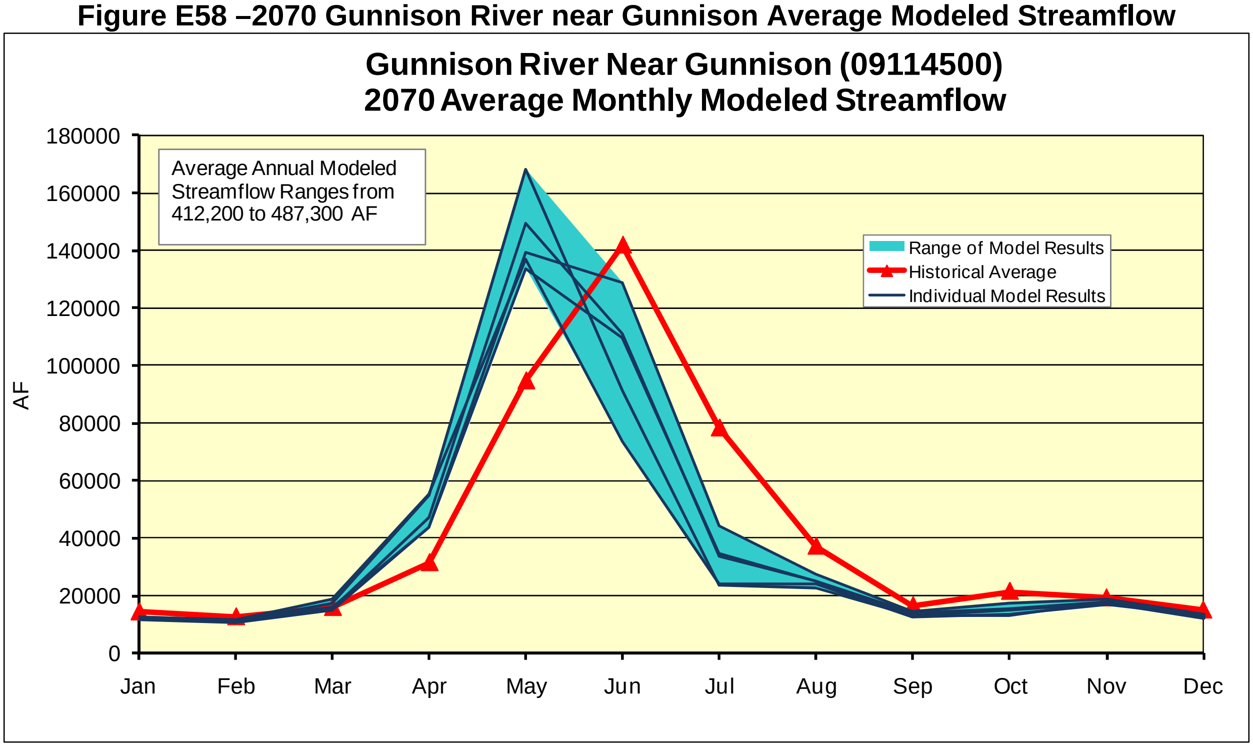


Figure E58 –2070 Gunnison River near Gunnison Average Modeled Streamflow



Comparison

Figure E59 –2070 Cimarron River at Cimarron Average Modeled Streamflow Comparison

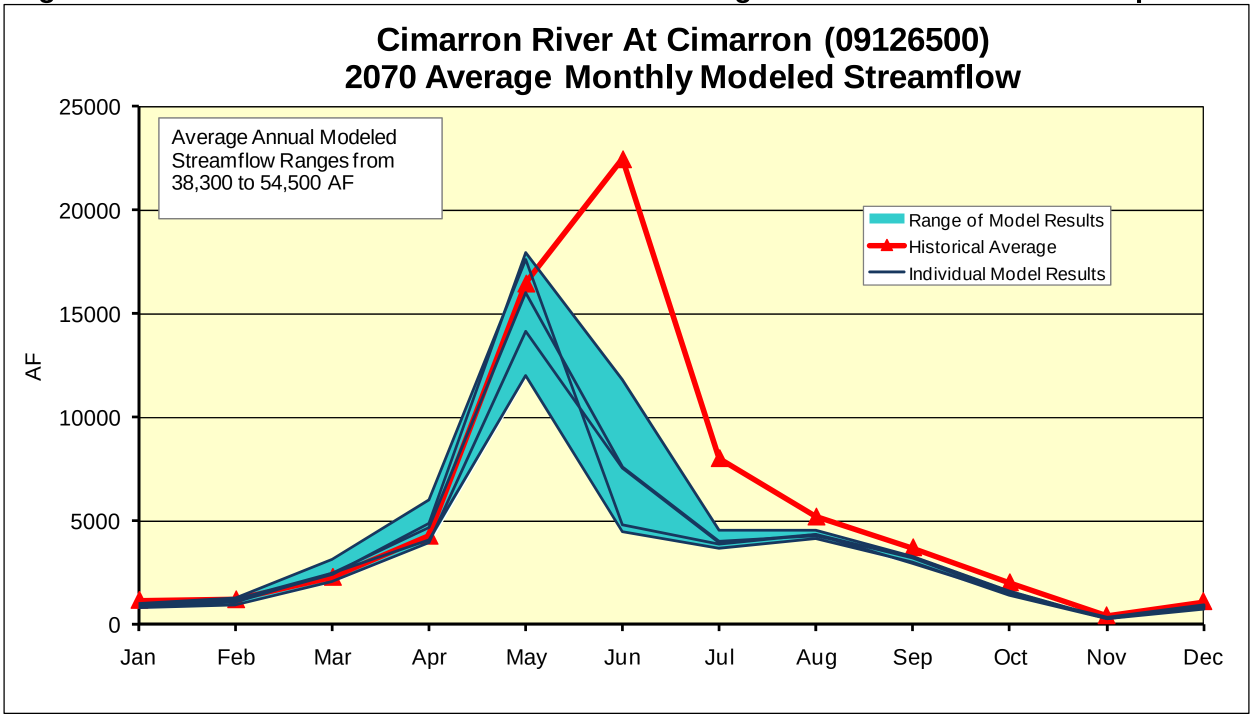


Figure E60 –2070 Gunnison River below Gunnison Tunnel Average Modeled Streamflow Comparison

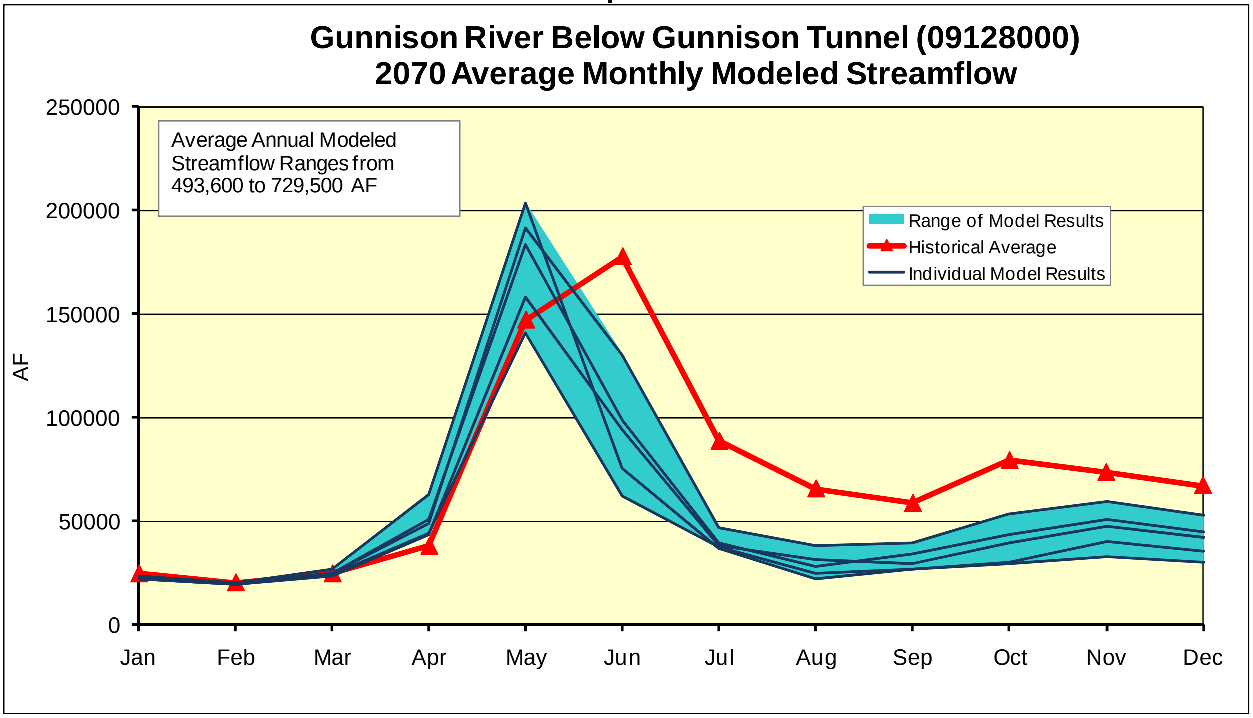


Figure E61 –2070 Gunnison River near Lazear Average Modeled Streamflow Comparison

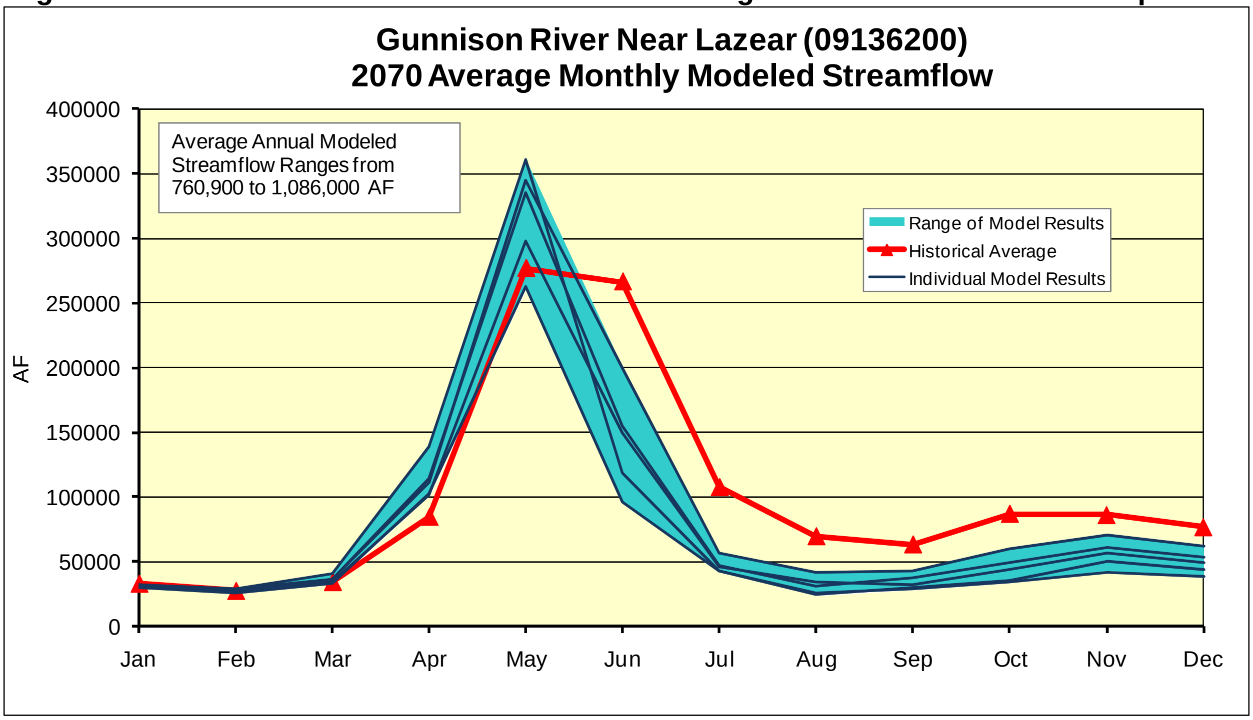


Figure E62 –2070 Uncompahgre River at Delta Average Modeled Streamflow Comparison

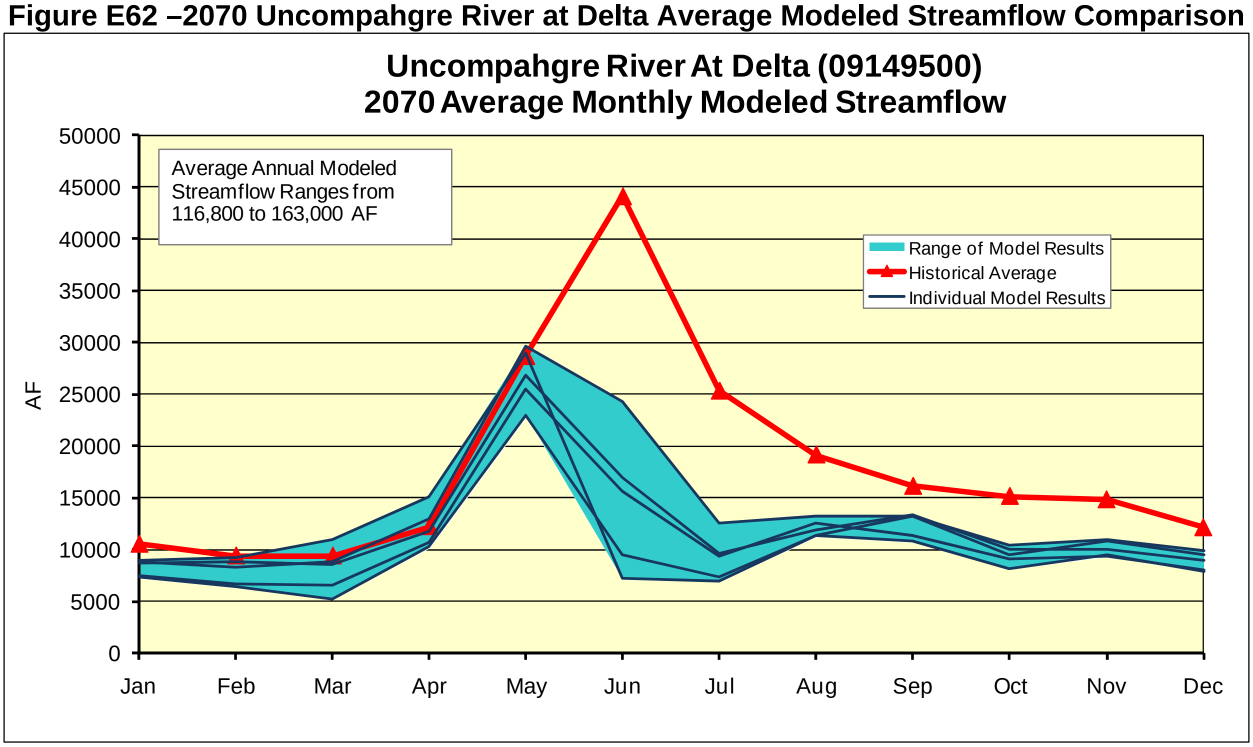


Figure E63 –2070 Gunnison River near Grand Junction Average Modeled Streamflow Comparison

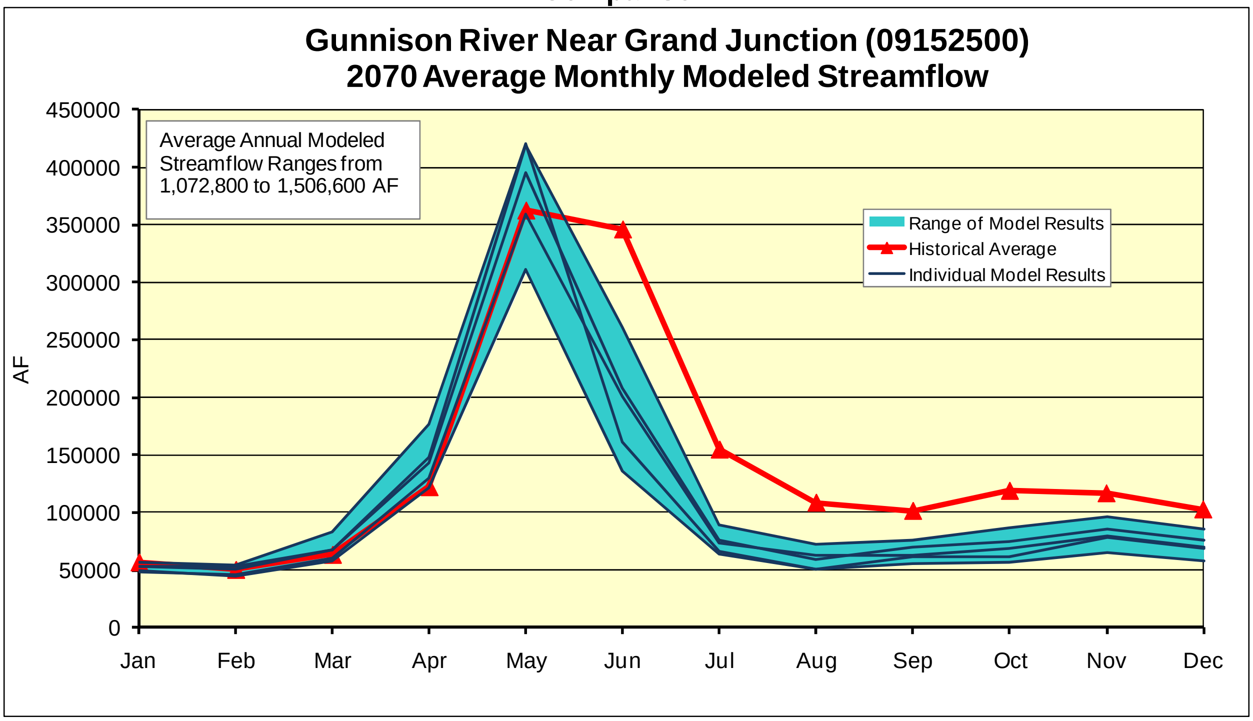


Figure E64 –2070 San Juan River near Carracas Average Modeled Streamflow Comparison

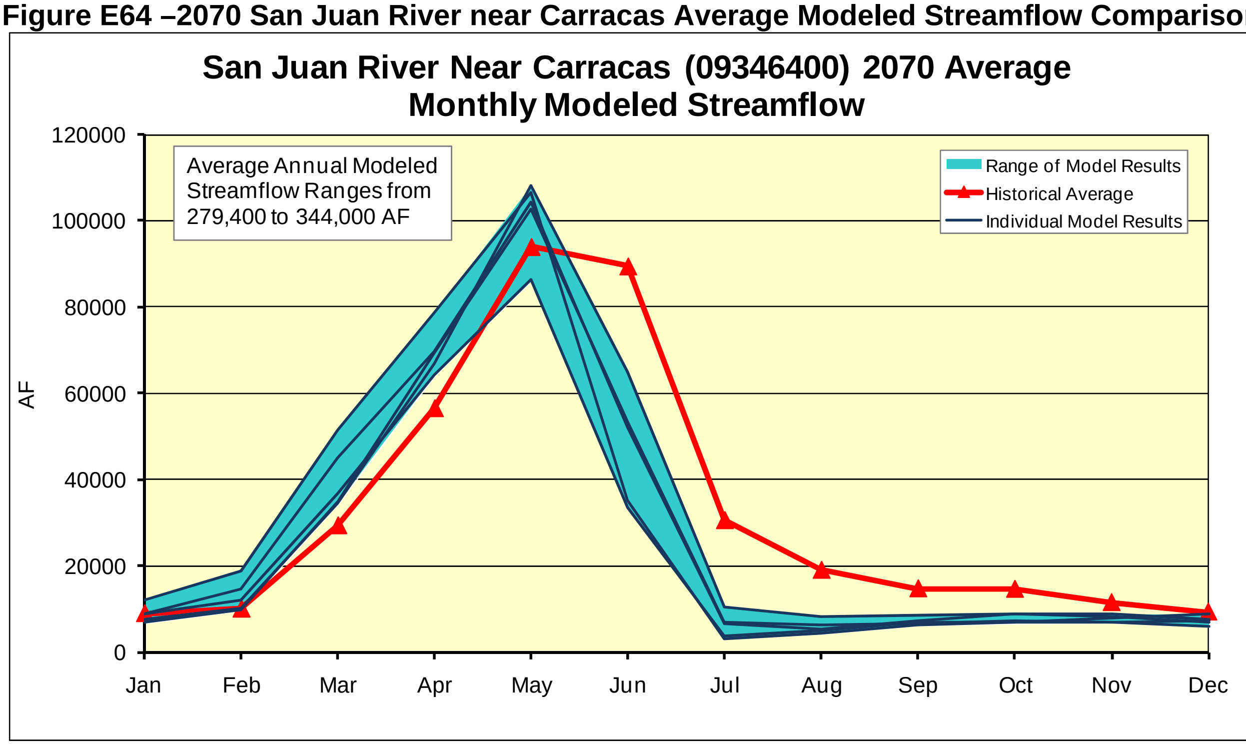


Figure E65 –2070 Piedra River near Arboles Average Modeled Streamflow Comparison

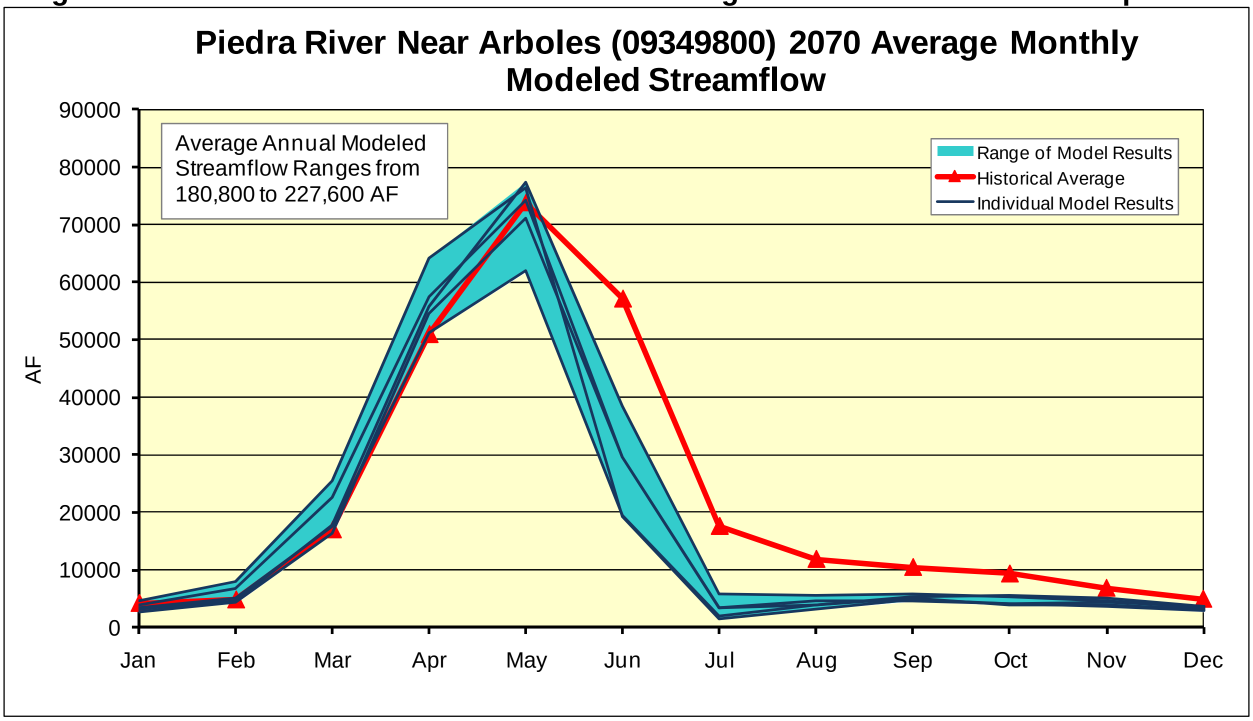


Figure E66 –2070 Los Pinos River at La Boca Average Modeled Streamflow Comparison

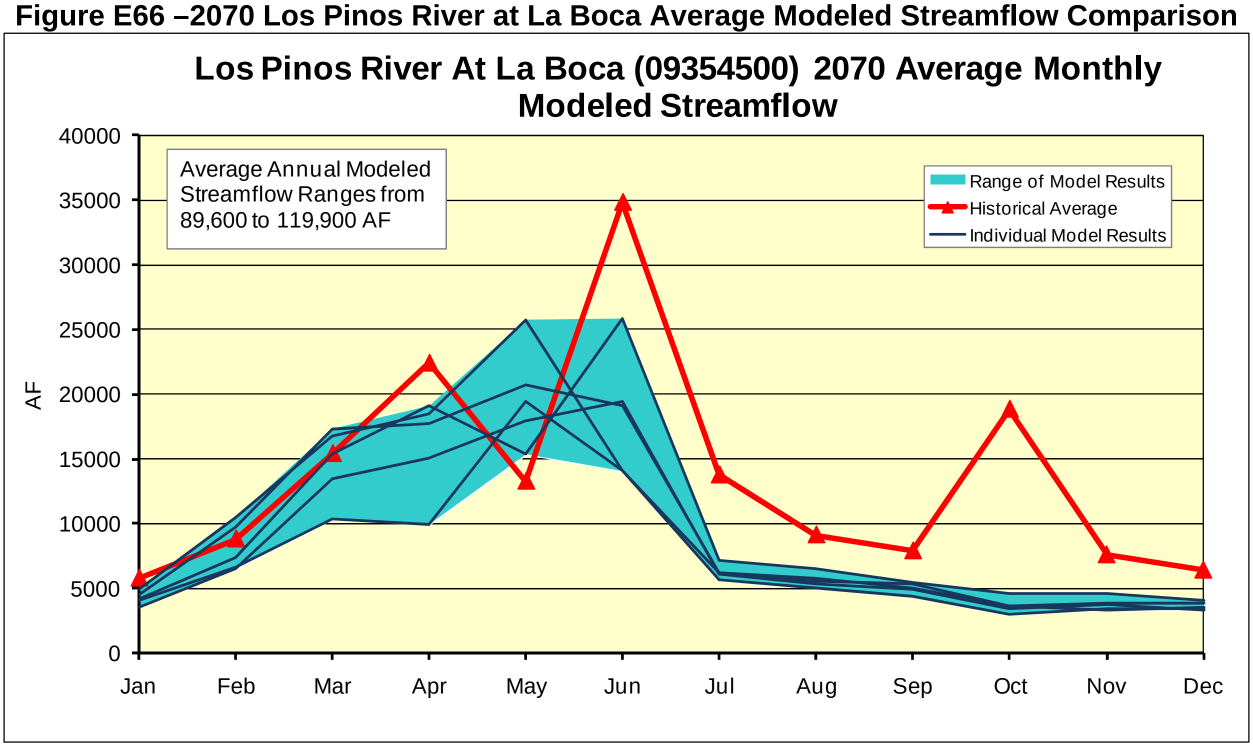


Figure E67 –2070 Florida River at Bondad Average Modeled Streamflow Comparison

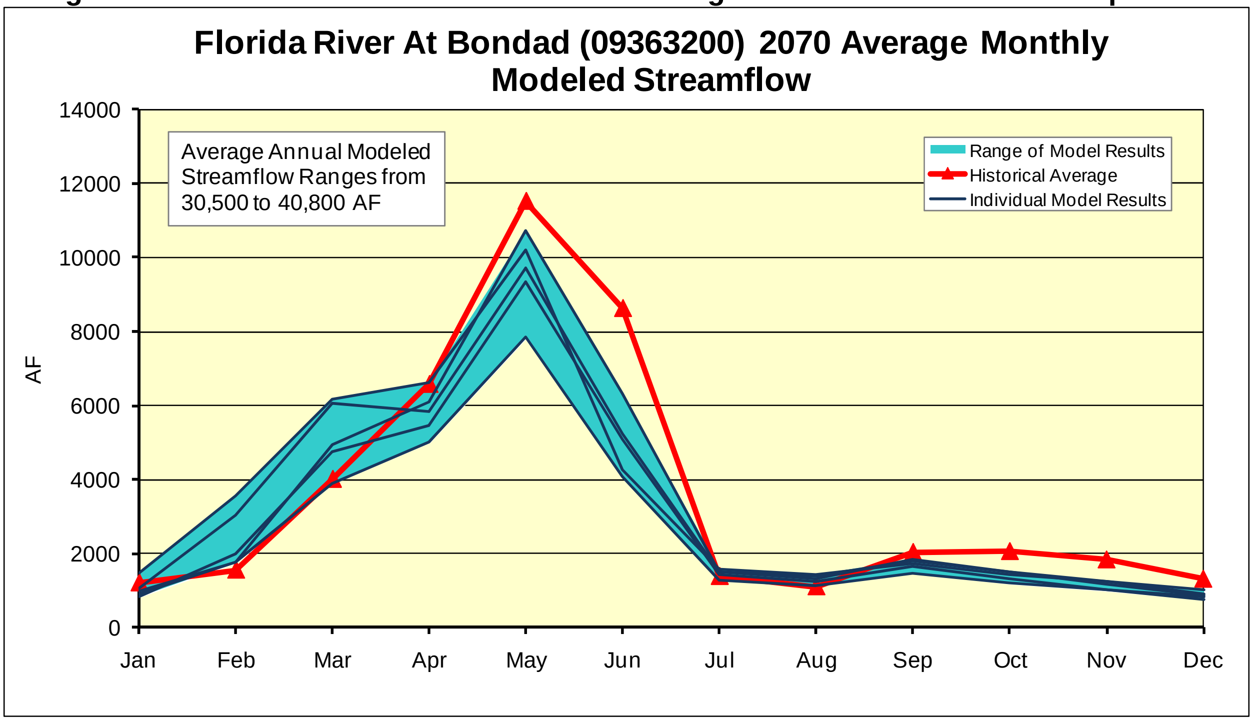


Figure E68 –2070 Animas River near Cedar Hill, NM Average Modeled Streamflow Comparison

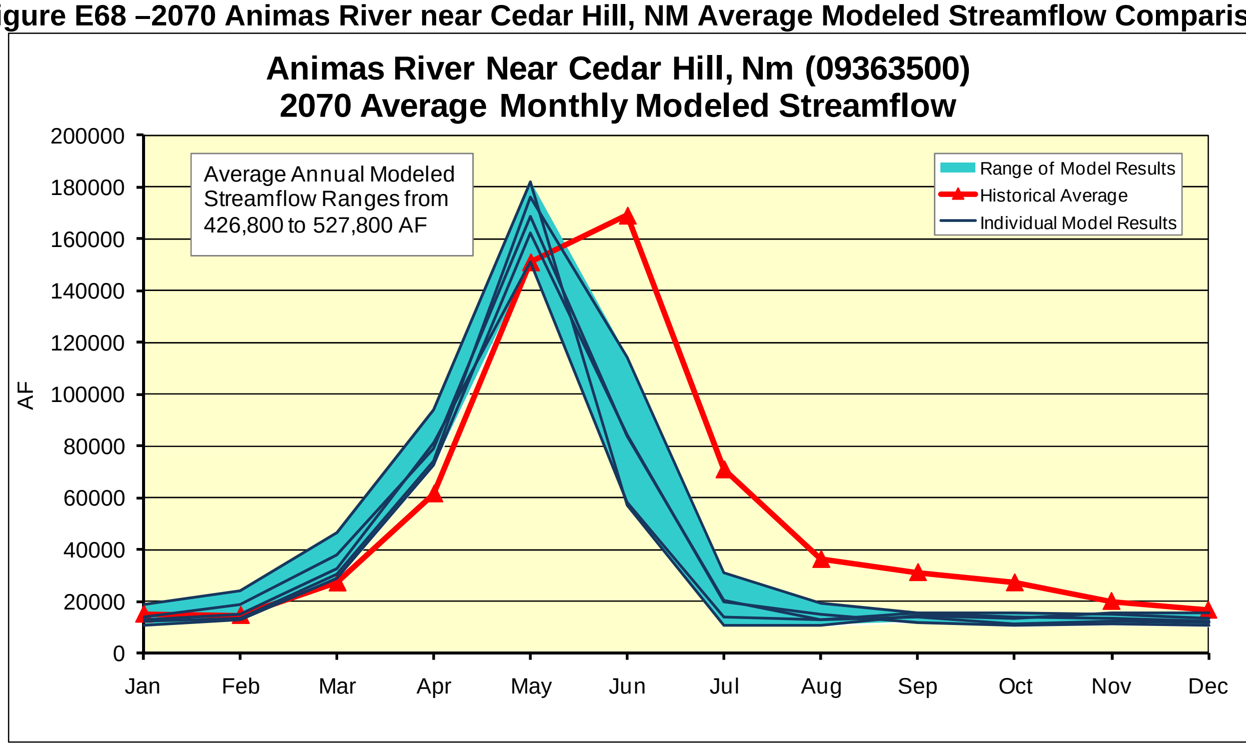


Figure E69 –2070 La Plata River at Hesperus Average Modeled Streamflow Comparison

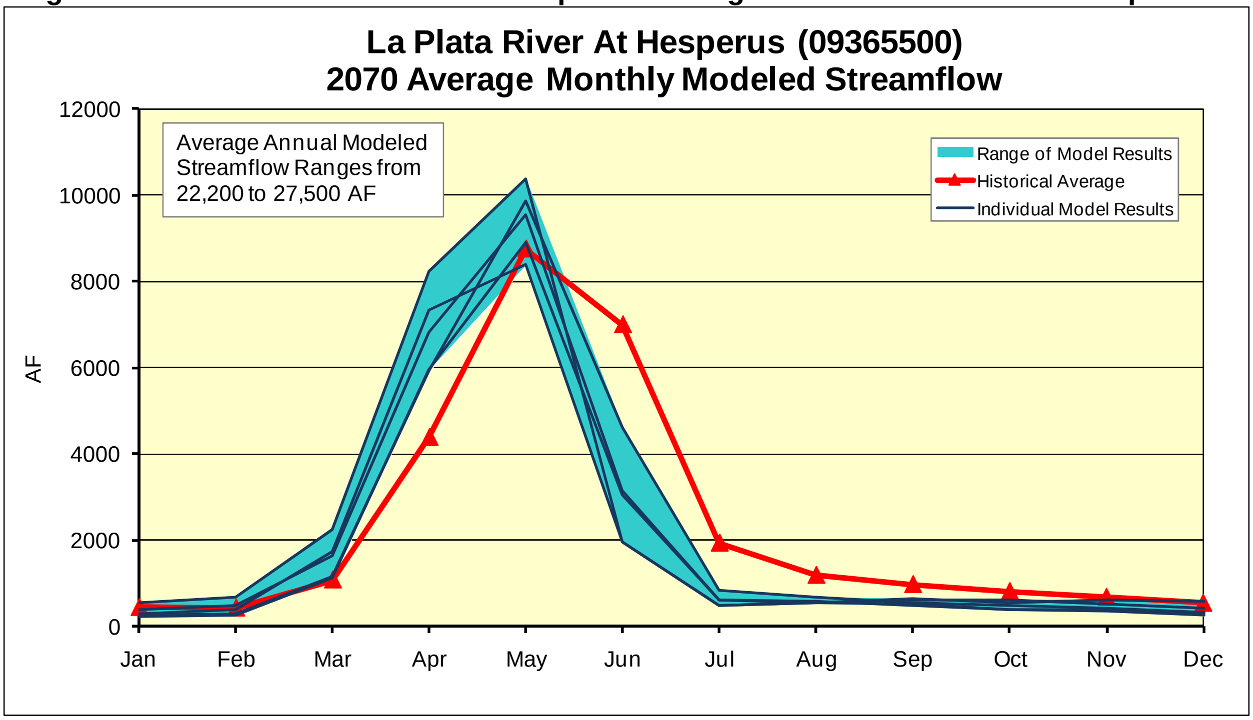


Figure E70 –2070 La Plata River at CO-NM State Line Average Modeled Streamflow Comparison

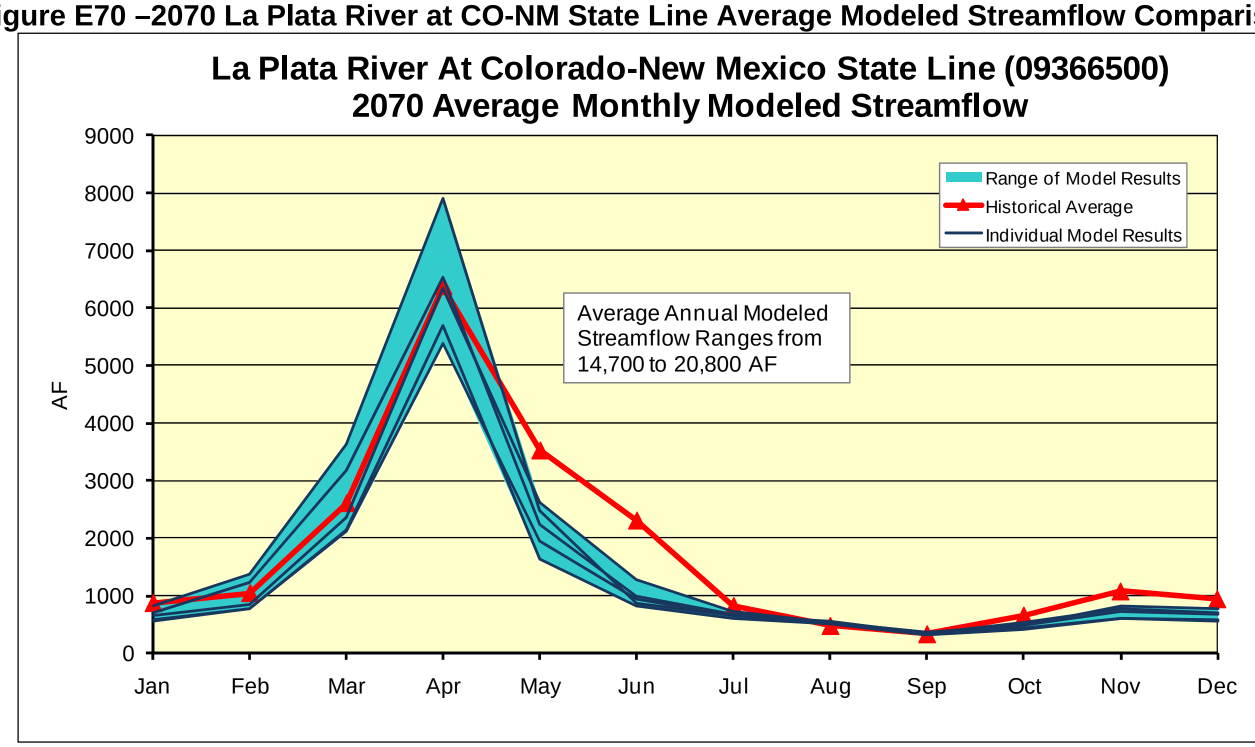


Figure E71 –2070 Mancos River near Towaoc Average Modeled Streamflow Comparison

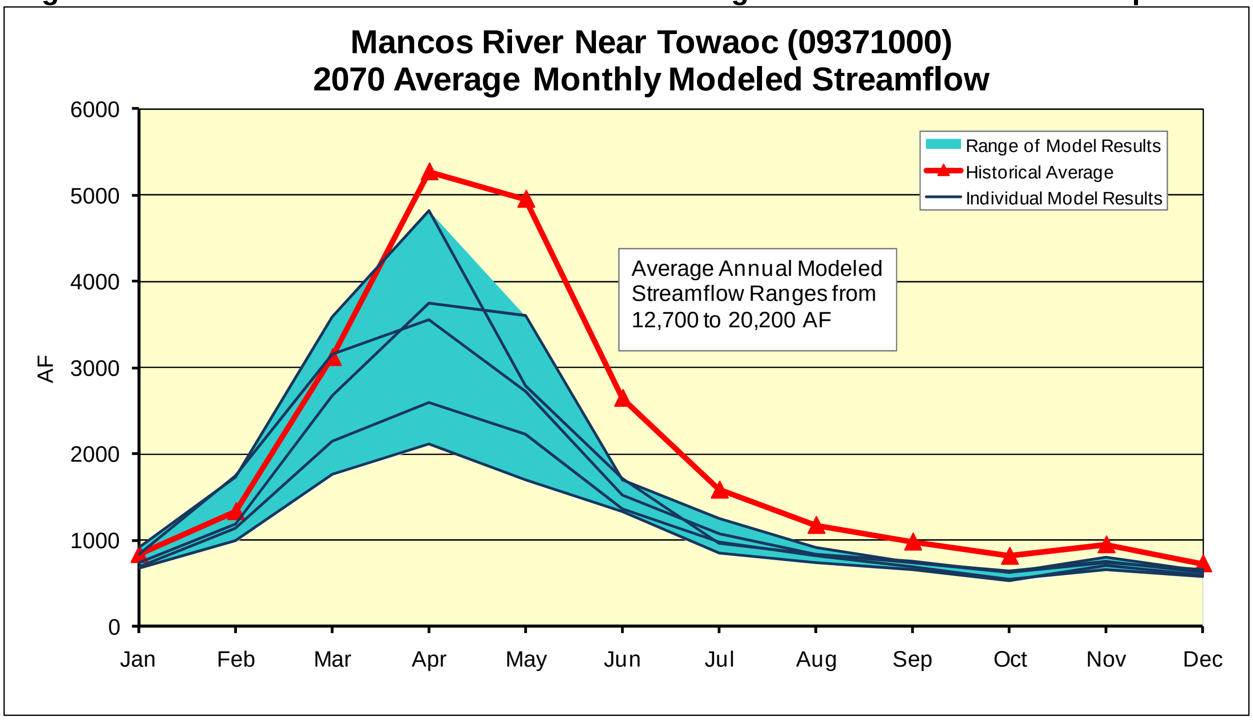


Figure E72 –2070 McElmo Creek near CO-UT State Line Average Modeled Streamflow Comparison

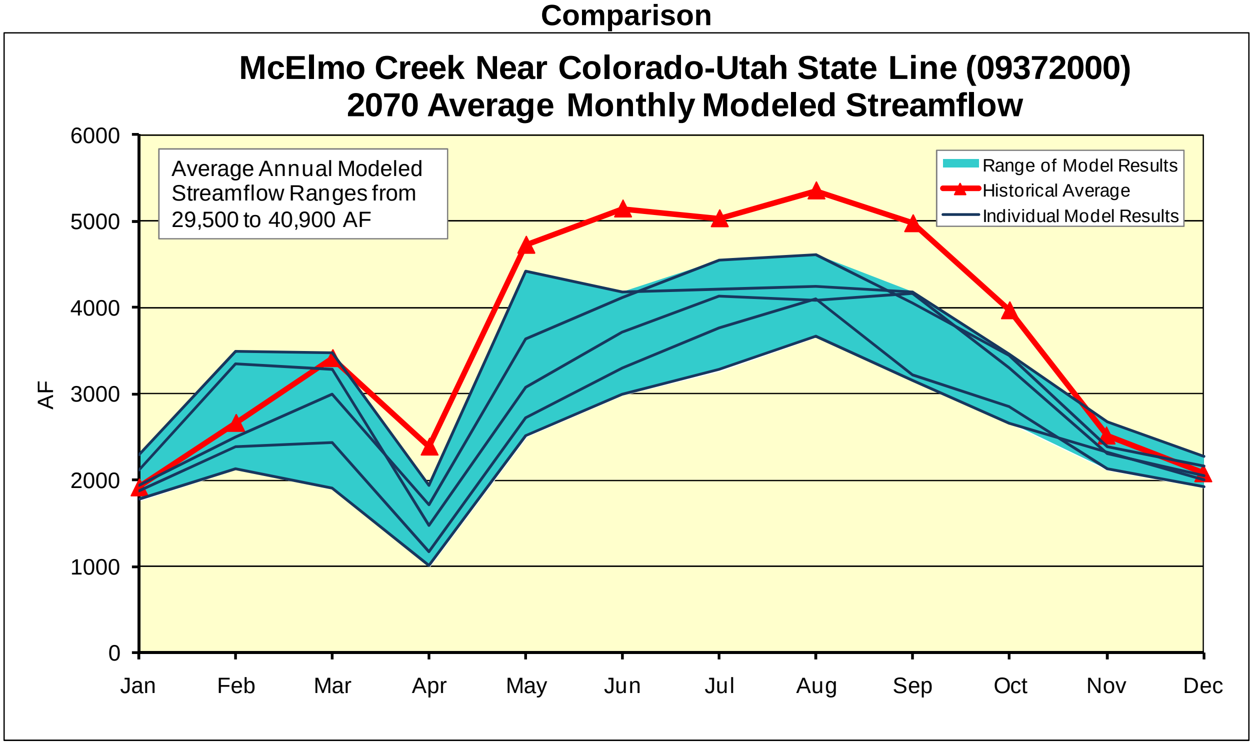


Figure E73 –2070 Dolores River near Bedrock Average Modeled Streamflow Comparison

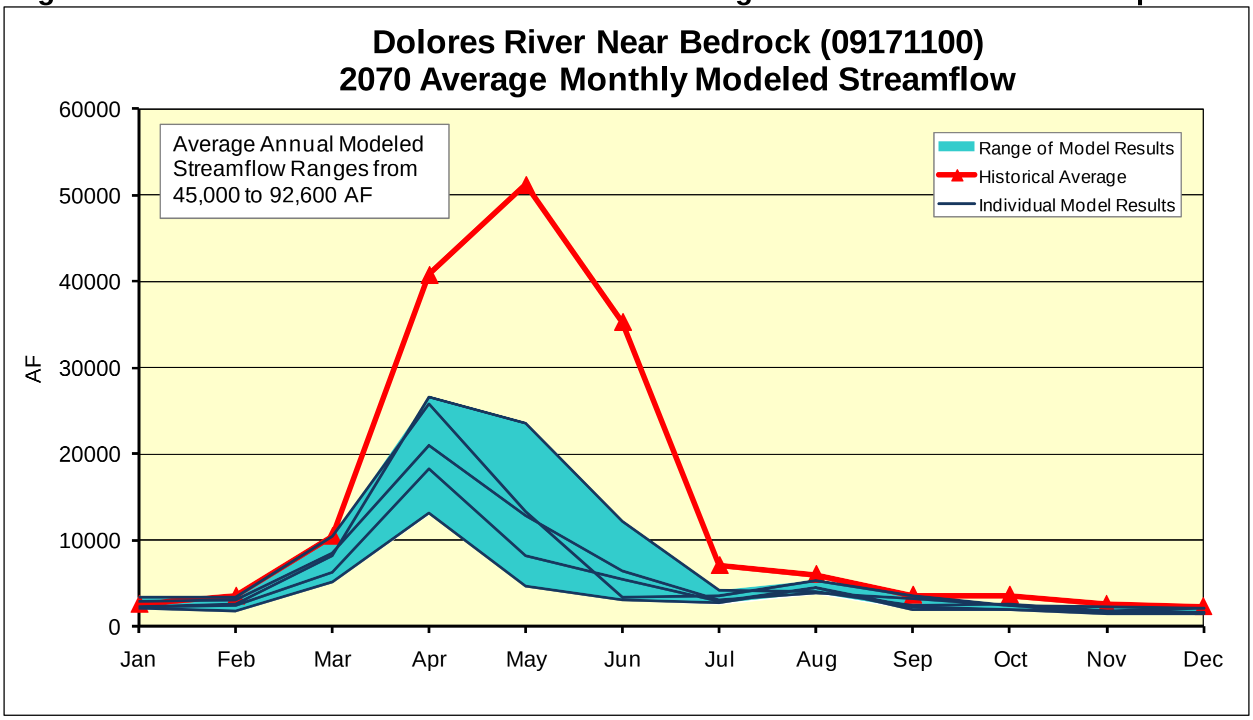


Figure E74 –2070 San Miguel River at Naturita Average Modeled Streamflow Comparison

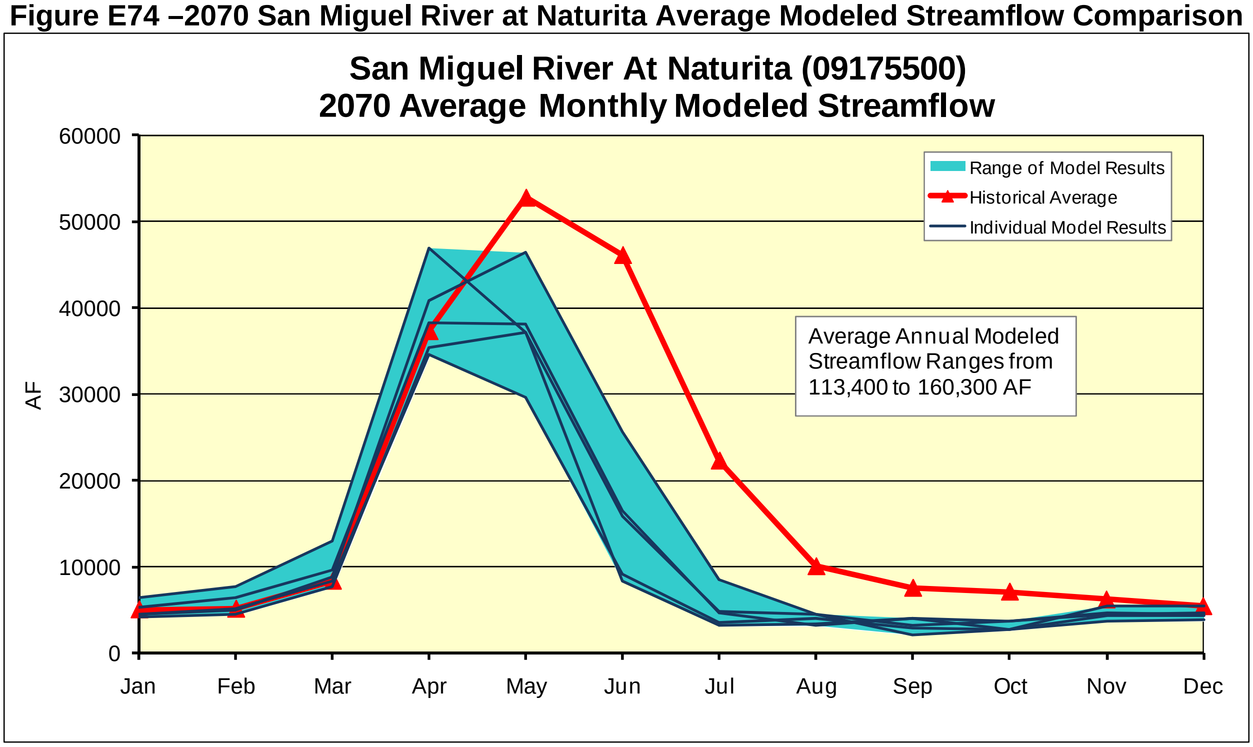


Figure E75 –2070 Yampa River below Stagecoach Reservoir Average Modeled Streamflow Comparison

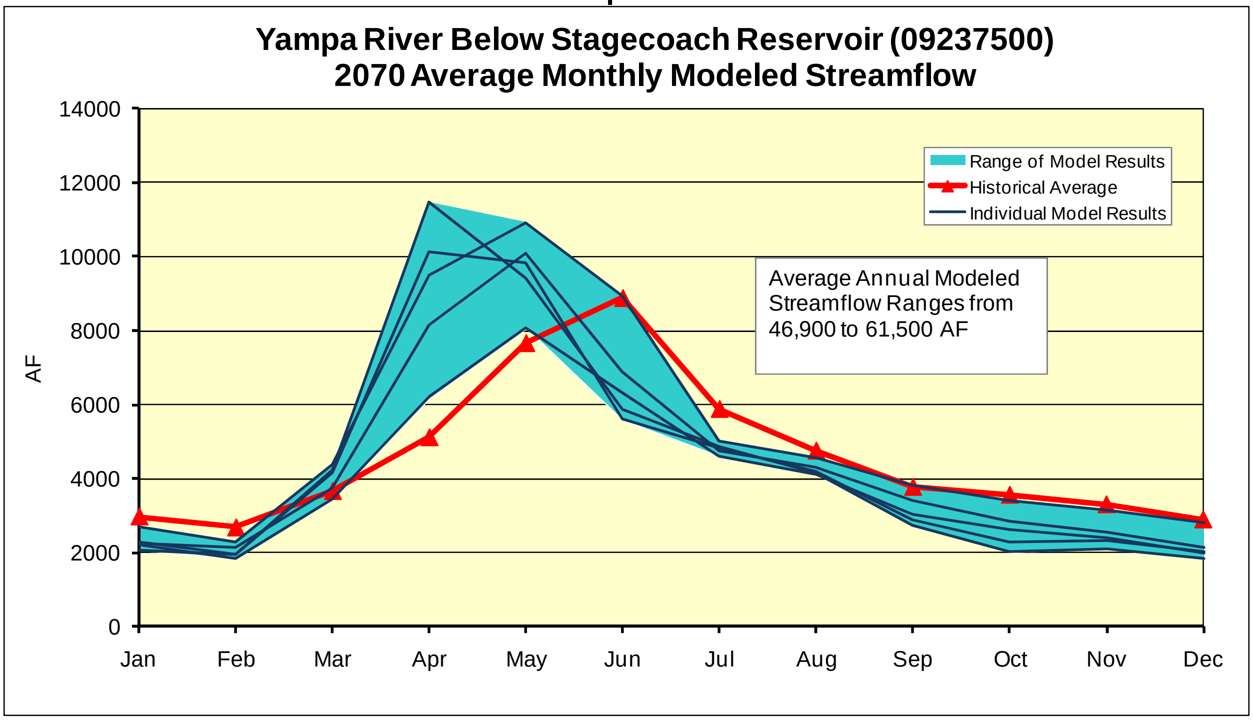


Figure E76 –2070 Elk River at Clark Average Modeled Streamflow Comparison

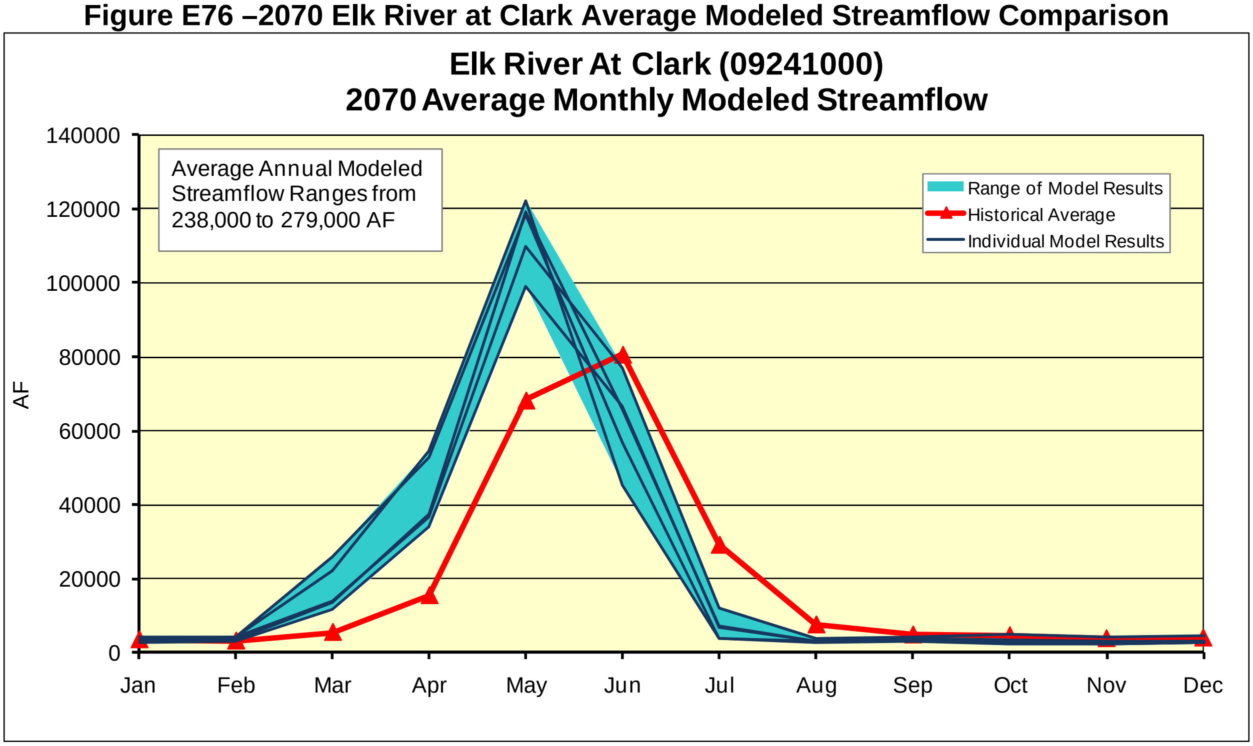


Figure E77 –2070 Elkhead Creek near Elkhead Average Modeled Streamflow Comparison

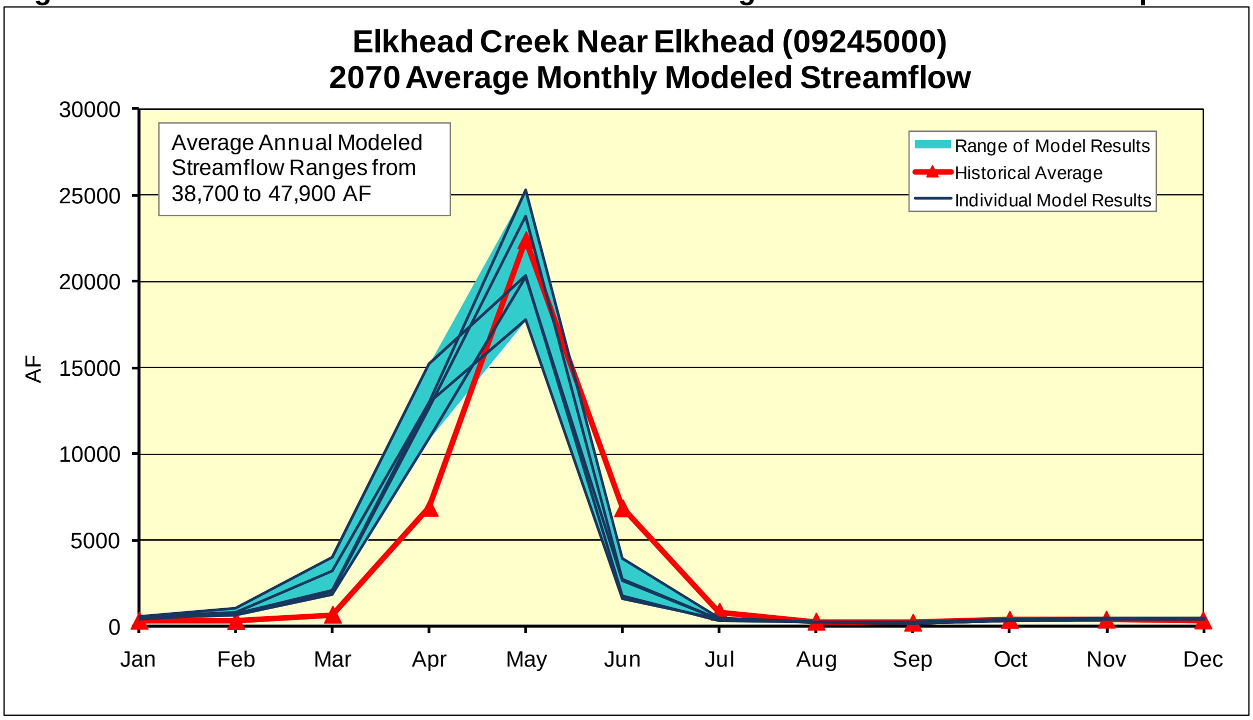


Figure E78 –2070 Williams Fork at Mouth, near Hamilton Average Modeled Streamflow Comparison

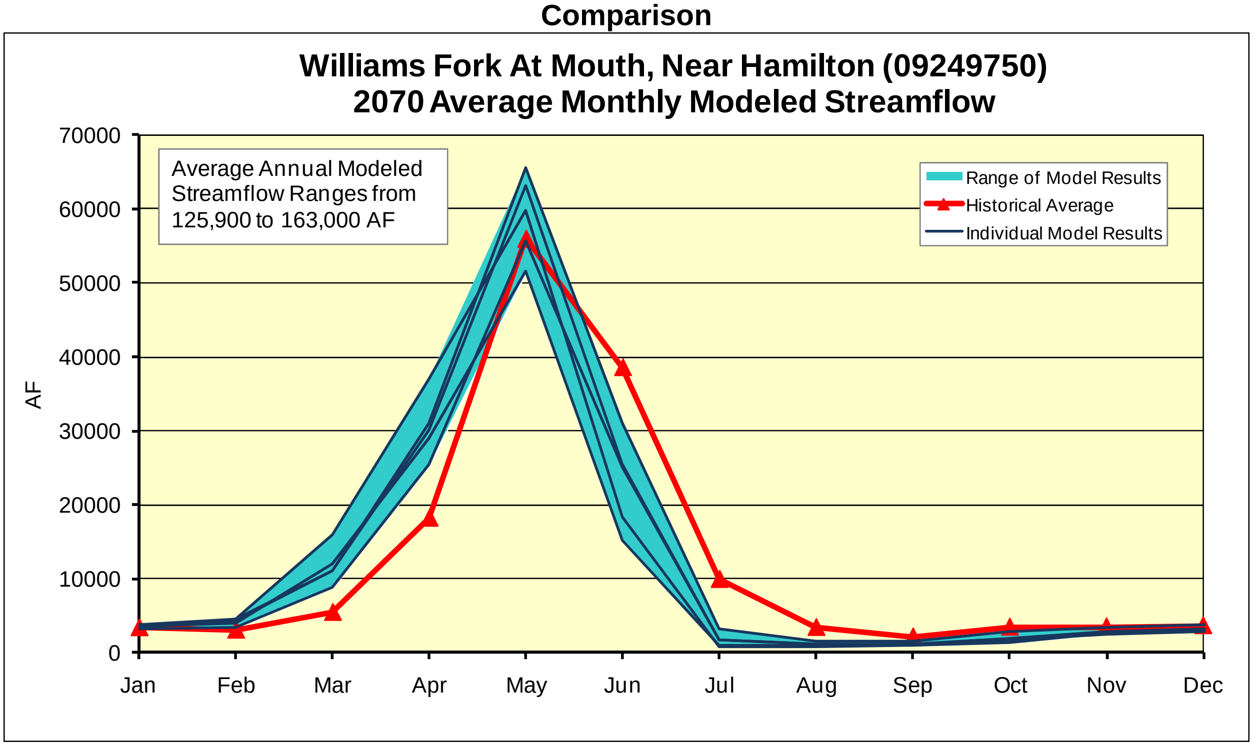


Figure E79 –2070 Yampa River near Maybell Average Modeled Streamflow Comparison

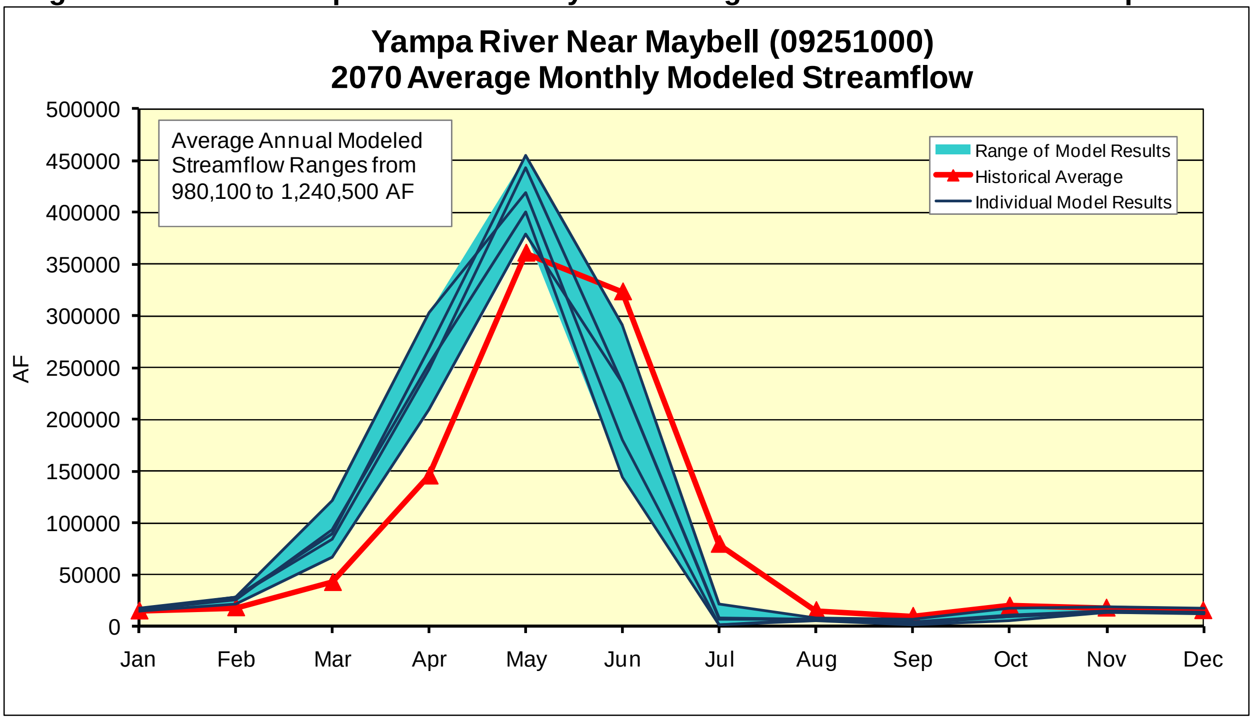


Figure E80 –2070 Little Snake River near Lily Average Modeled Streamflow Comparison

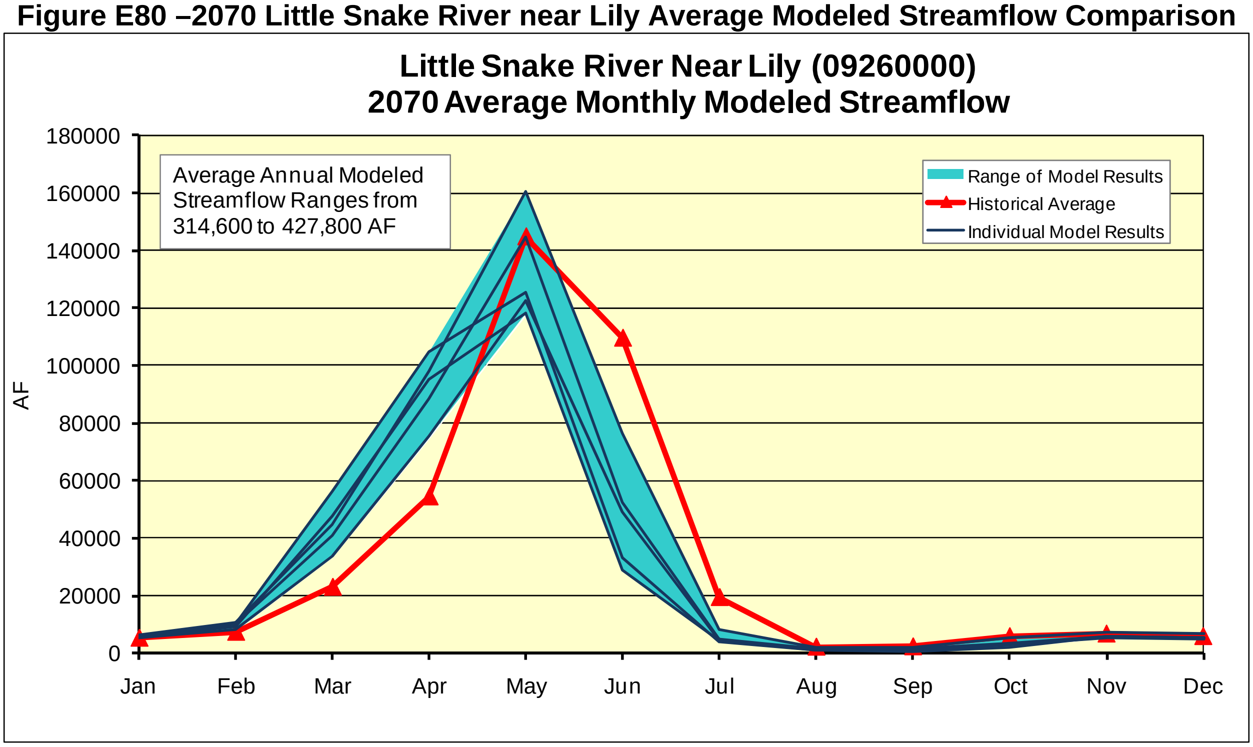


Figure E81 –2070 Yampa River at Deerlodge Park Average Modeled Streamflow Comparison

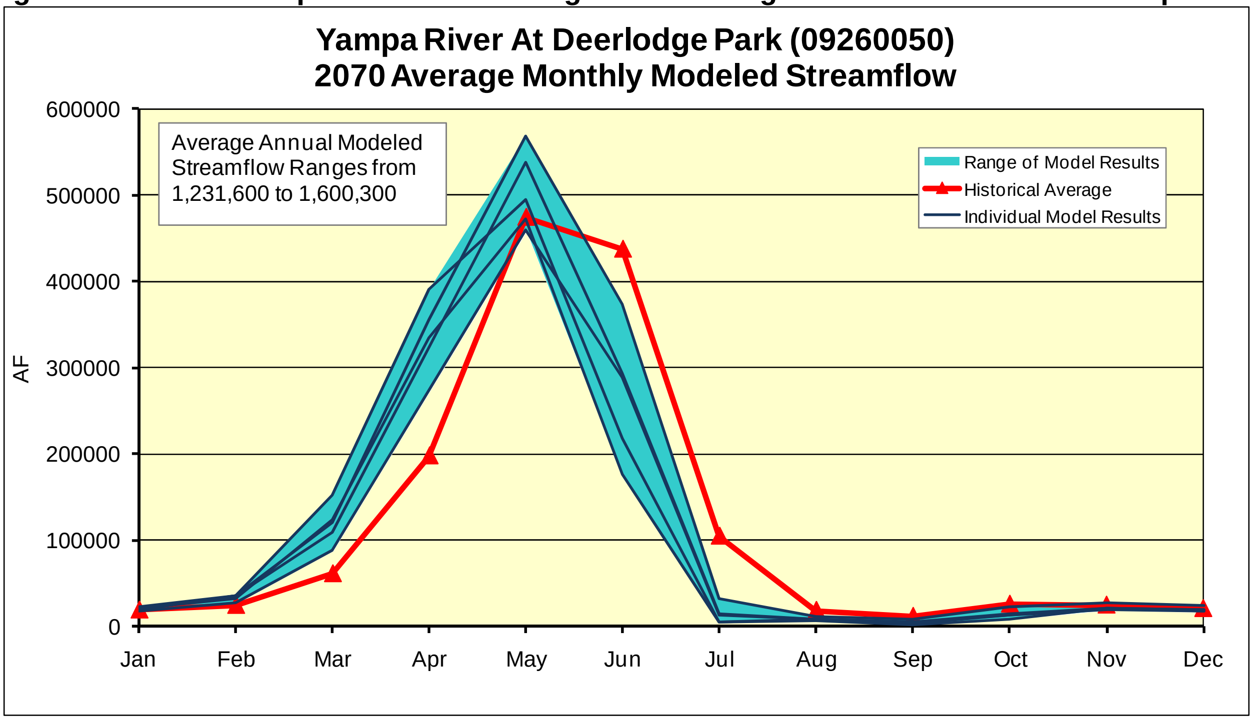


Figure E82 –2070 North Fork White River at Buford Average Modeled Streamflow Comparison

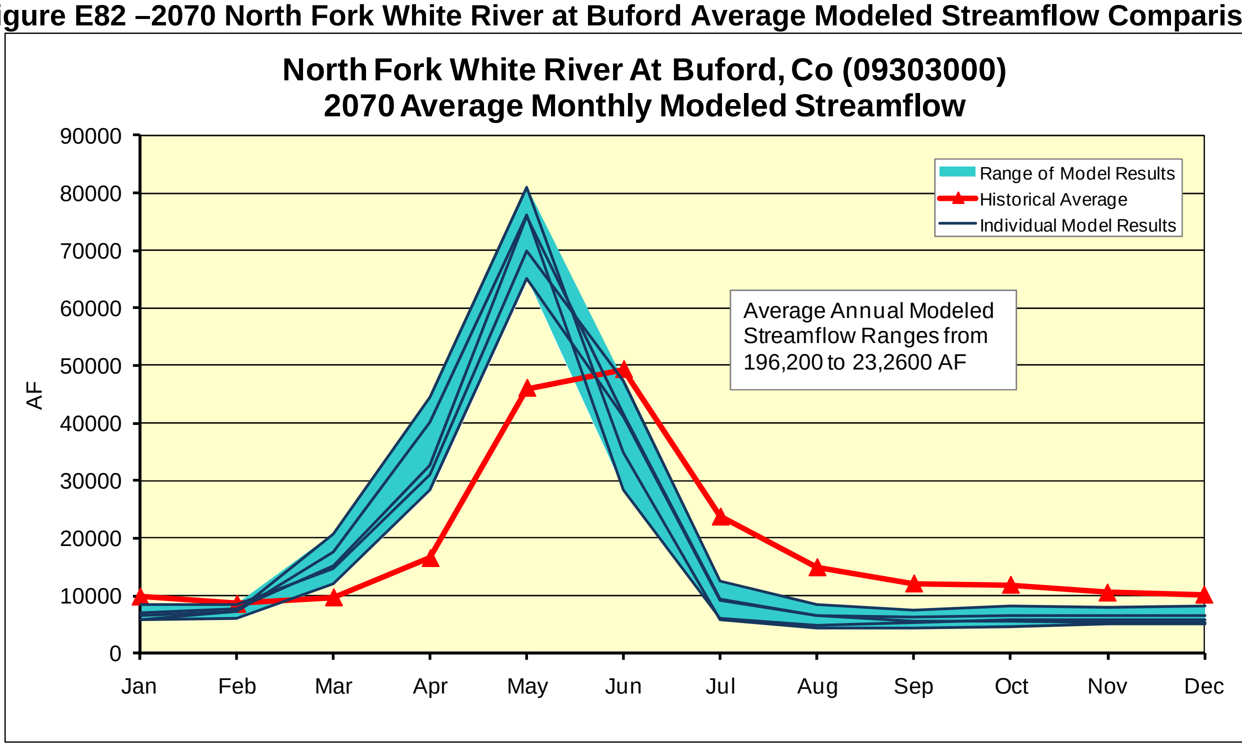


Figure E83 –2070 South Fork White River at Buford Average Modeled Streamflow Comparison

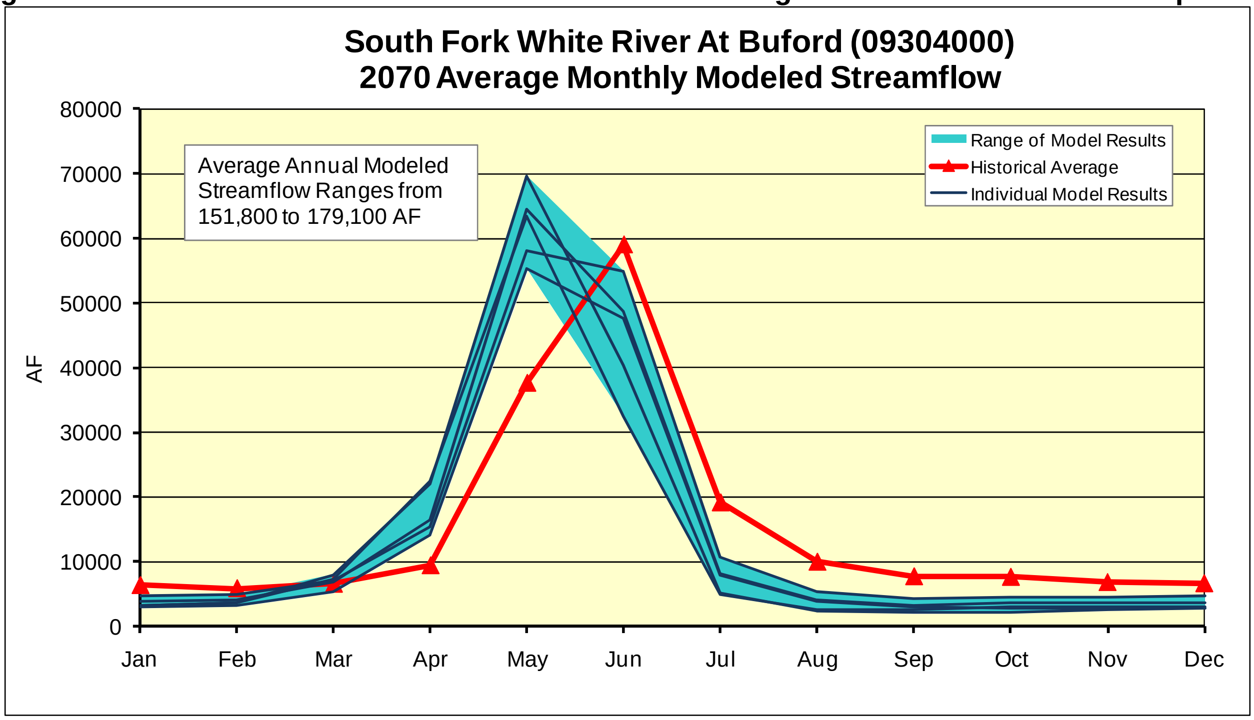


Figure E84 –2070 White River below Meeker Average Modeled Streamflow Comparison

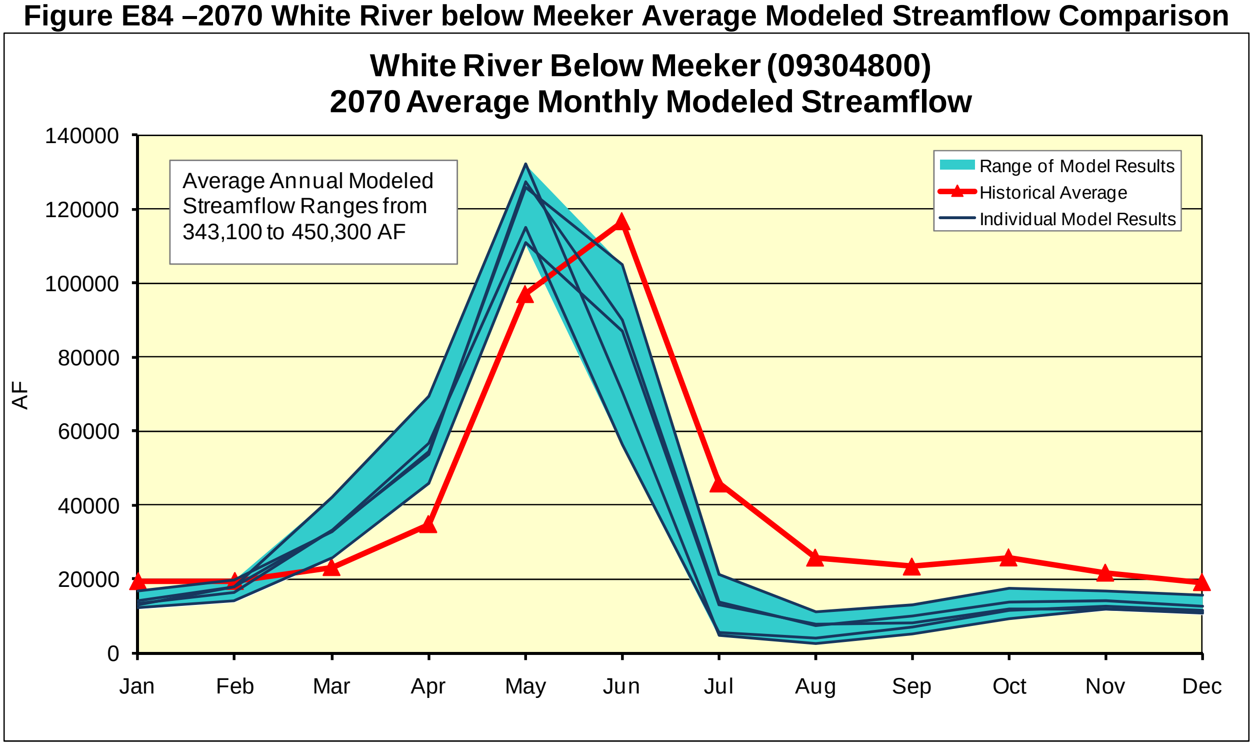


Figure E85 –2070 Piceance Creek at White River Average Modeled Streamflow Comparison

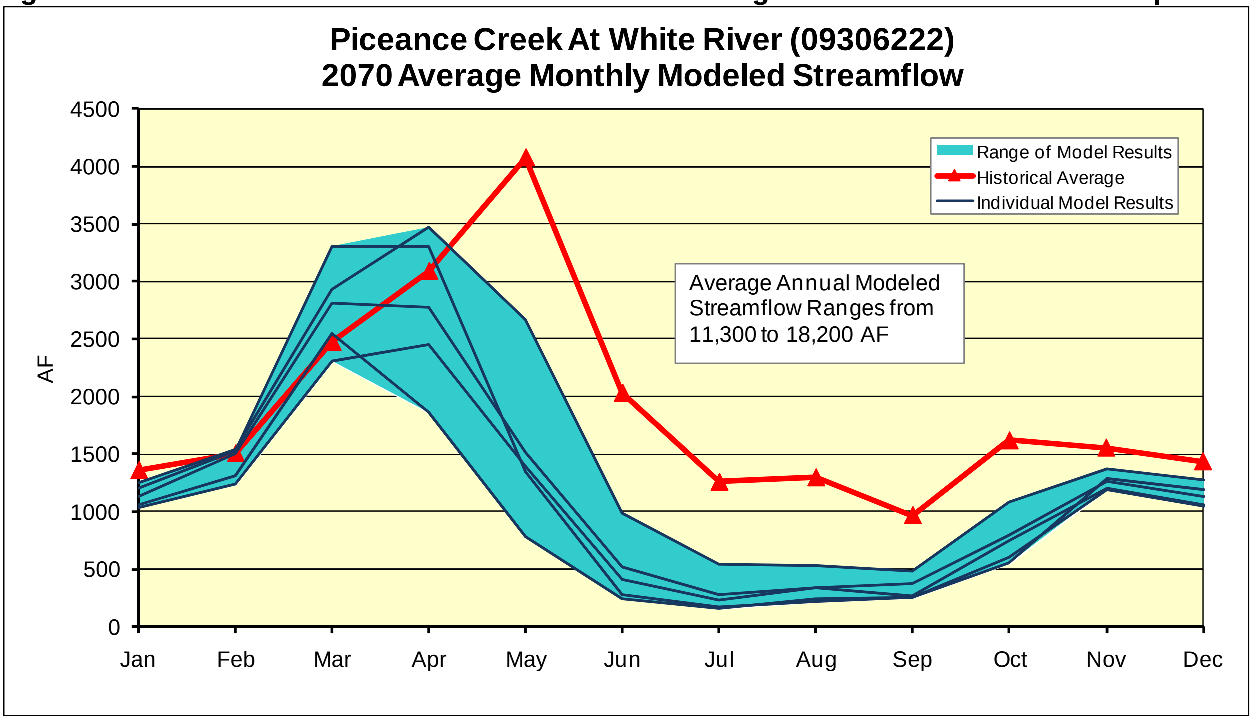


Figure E86 –2070 White River near CO-UT State Line Average Modeled Streamflow Comparison

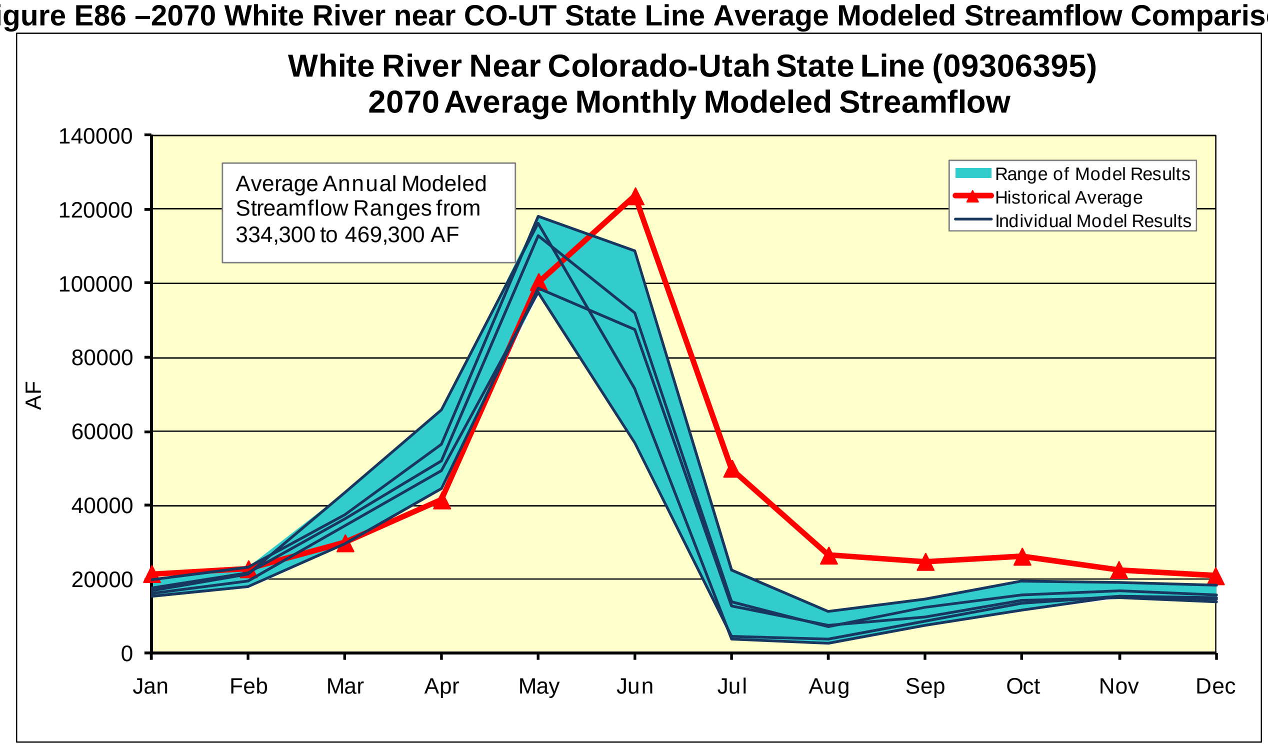


Figure E87 –2040 Colorado River near Grand Lake Modeled Streamflow Low-flow Comparison

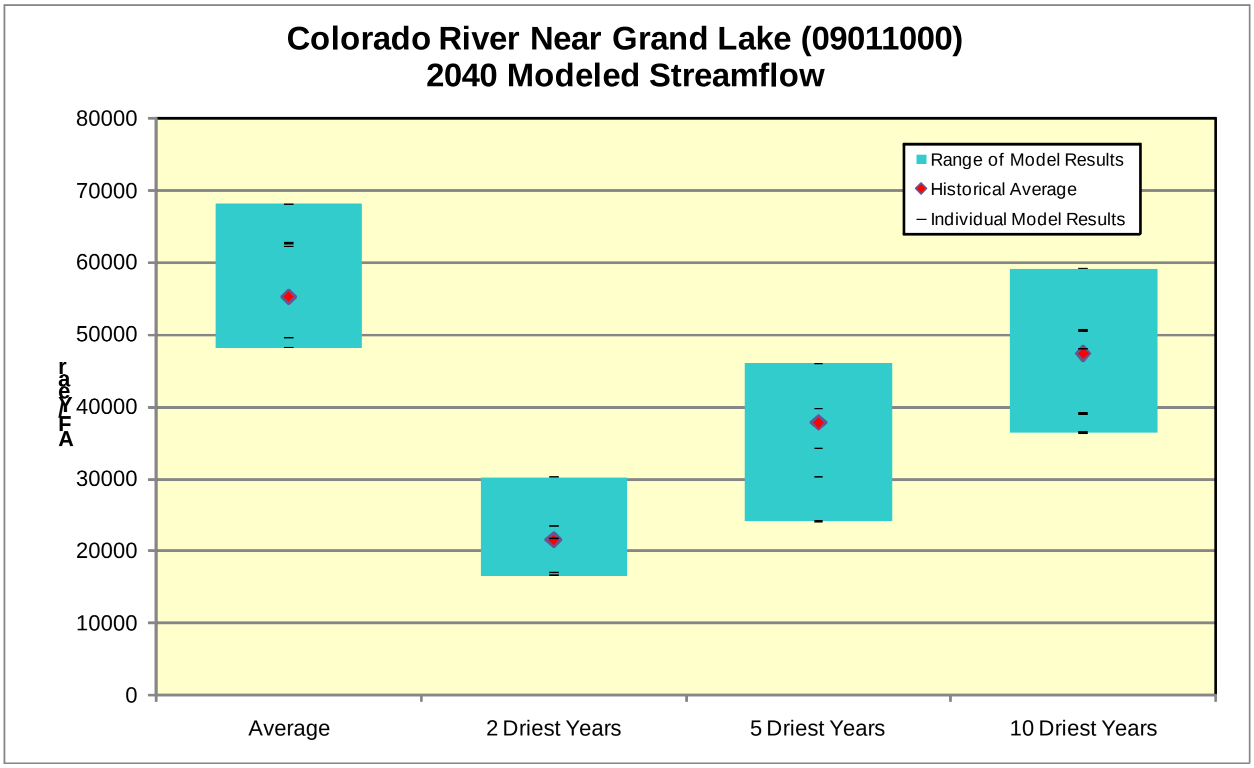


Figure E88 –2040 Muddy Creek at Kremmling Modeled Streamflow Low-flow Comparison

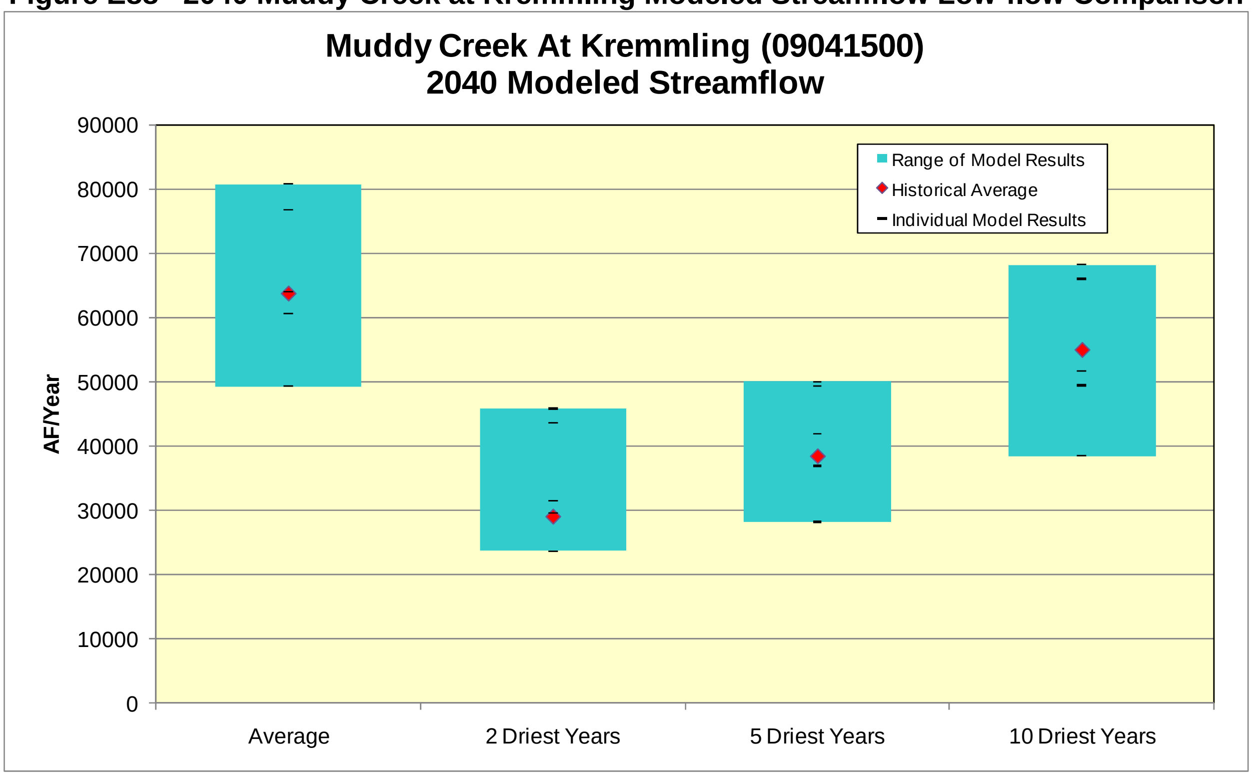


Figure E89 –2040 Blue River below Dillon Modeled Streamflow Low-flow Comparison

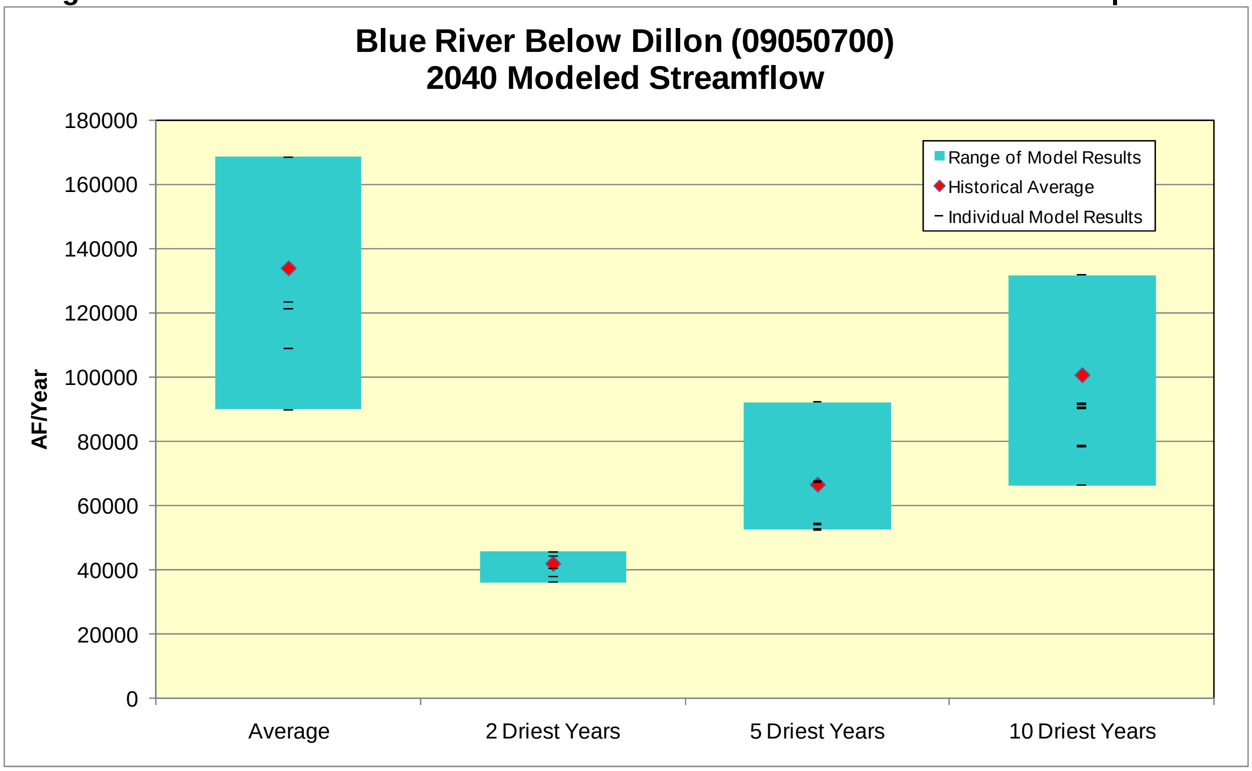


Figure E90 –2040 Blue River below Green Mountain Reservoir Modeled Streamflow Low-flow Comparison

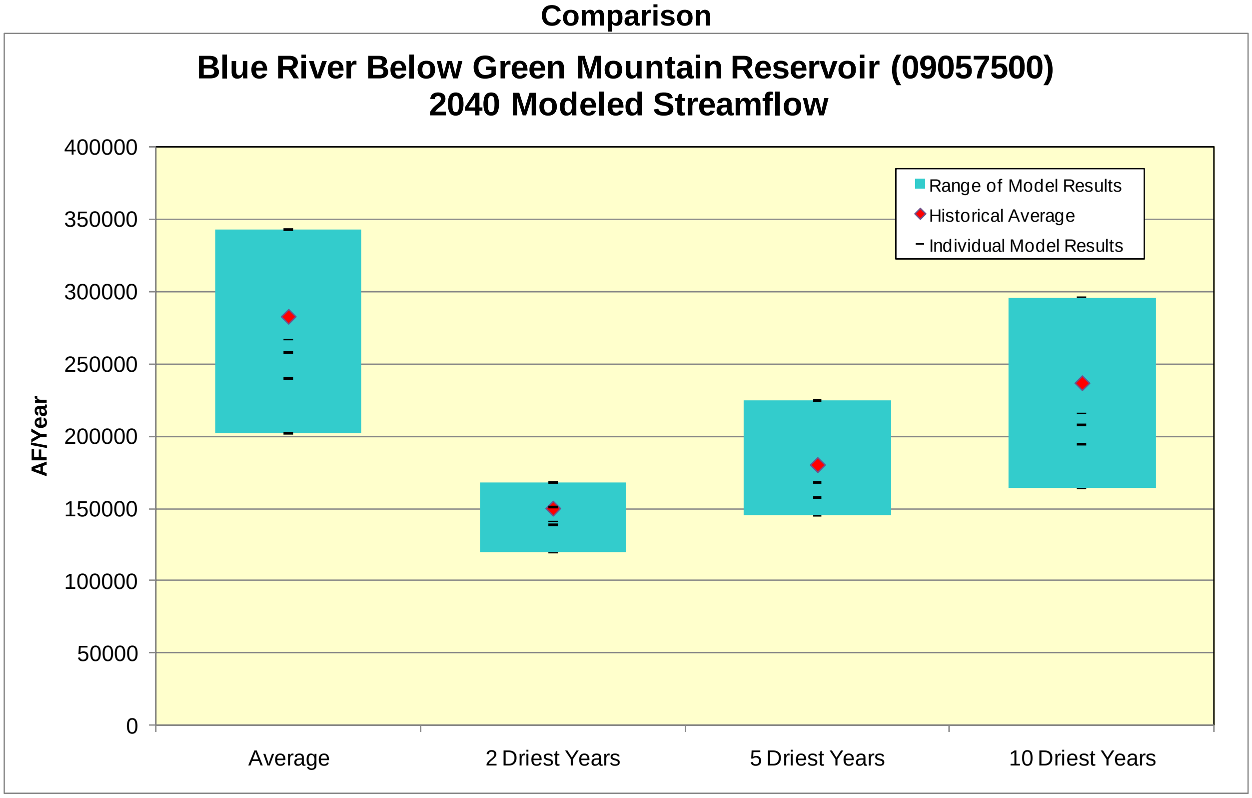


Figure E91 –2040 Eagle River below Gypsum Modeled Streamflow Low-flow Comparison

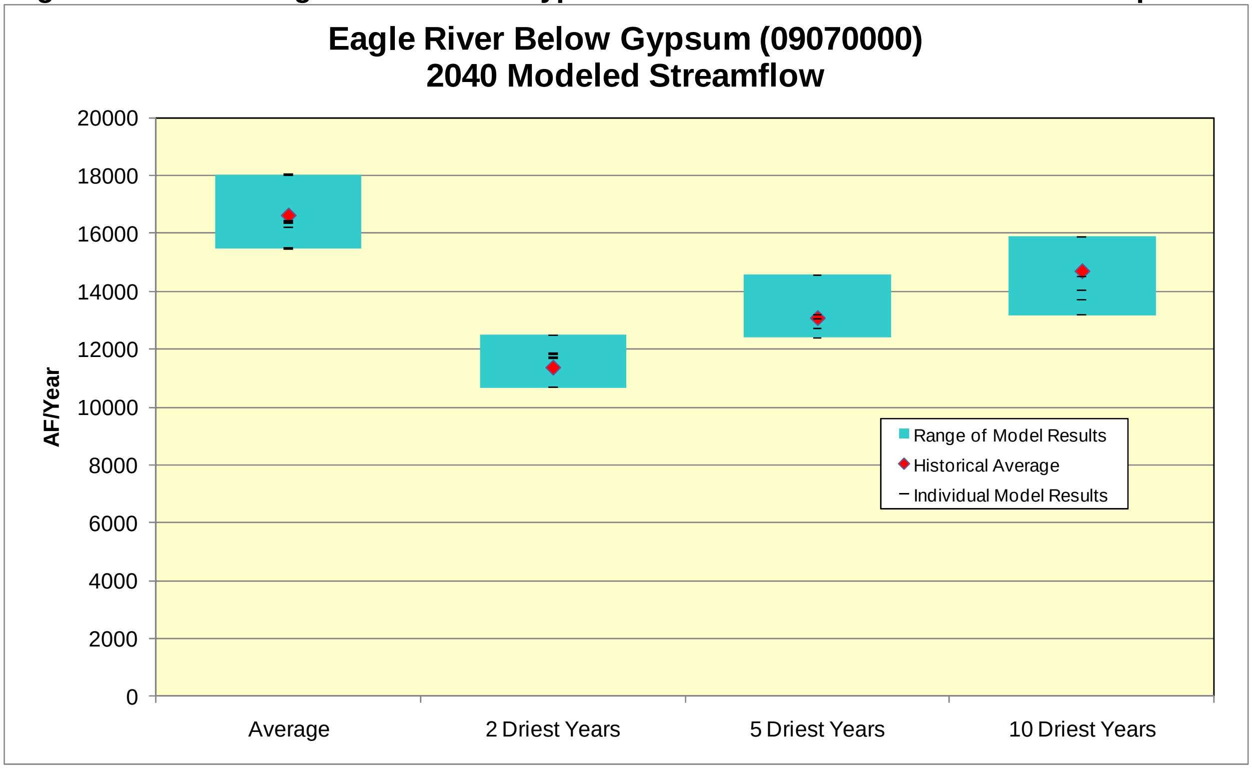


Figure E92 –2040 Colorado River at Dotsero Modeled Streamflow Low-flow Comparison

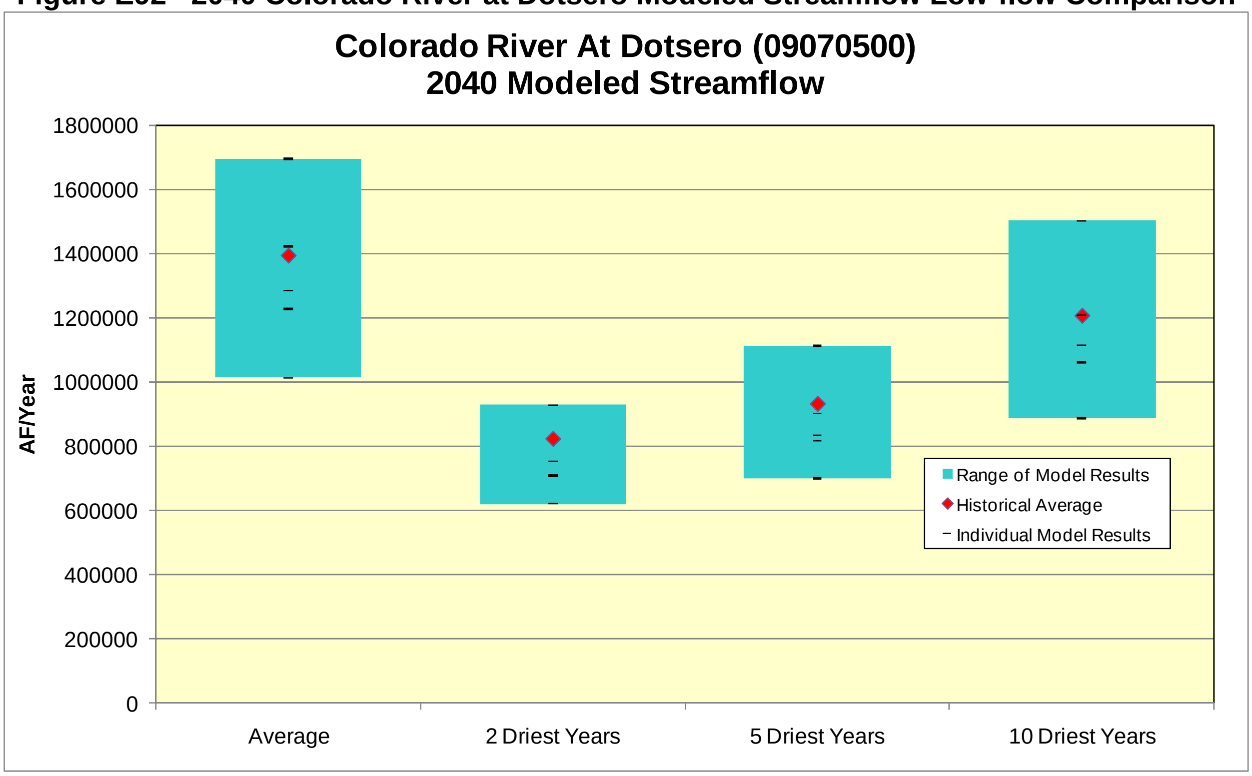


Figure E93 –2040 Roaring Fork River near Aspen Modeled Streamflow Low-flow Comparison

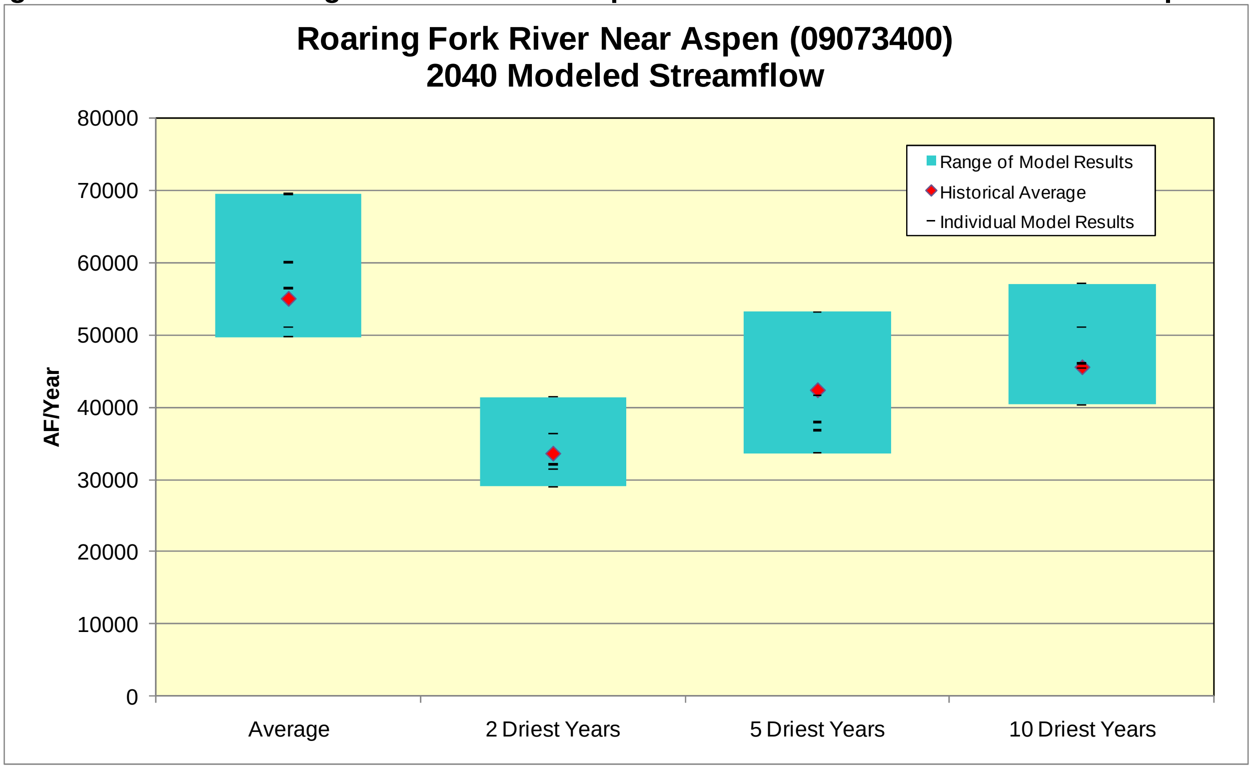


Figure E94 –2040 Roaring Fork River at Glenwood Modeled Streamflow Low-flow Comparison

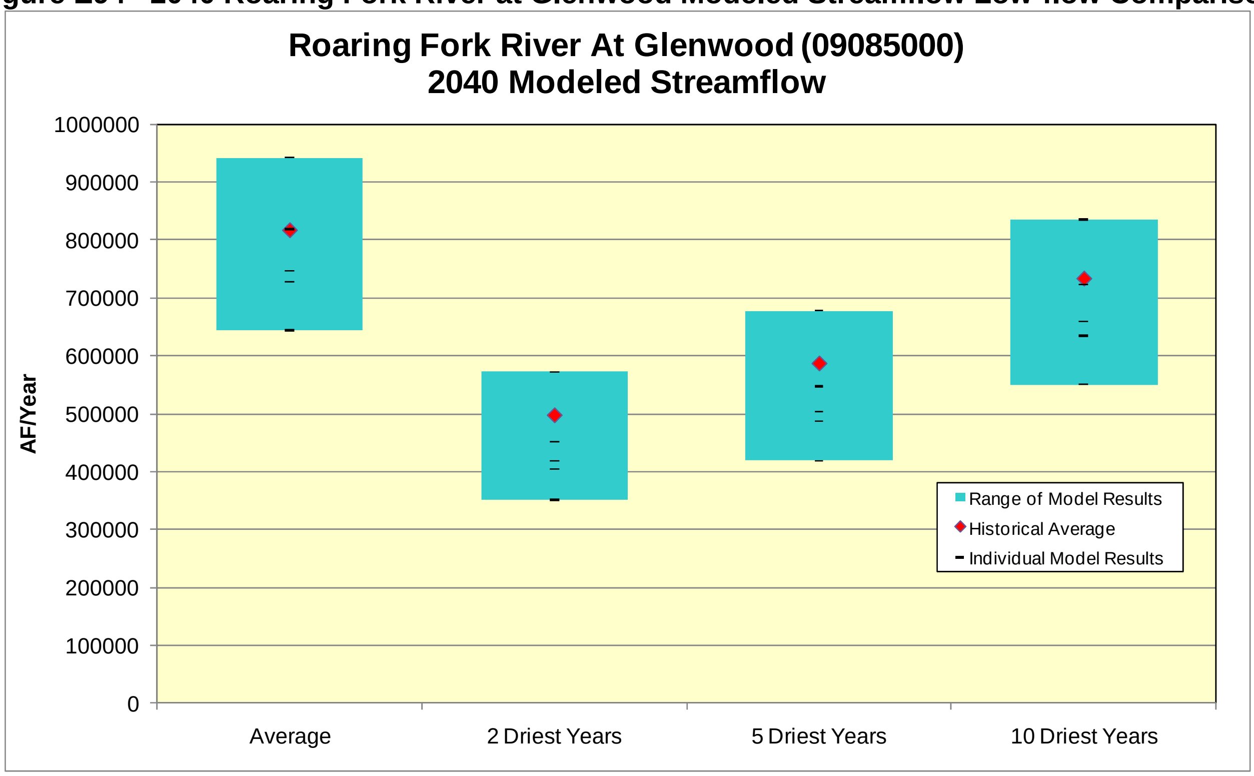


Figure E95 –2040 Colorado River near Cameo Modeled Streamflow Low-flow Comparison

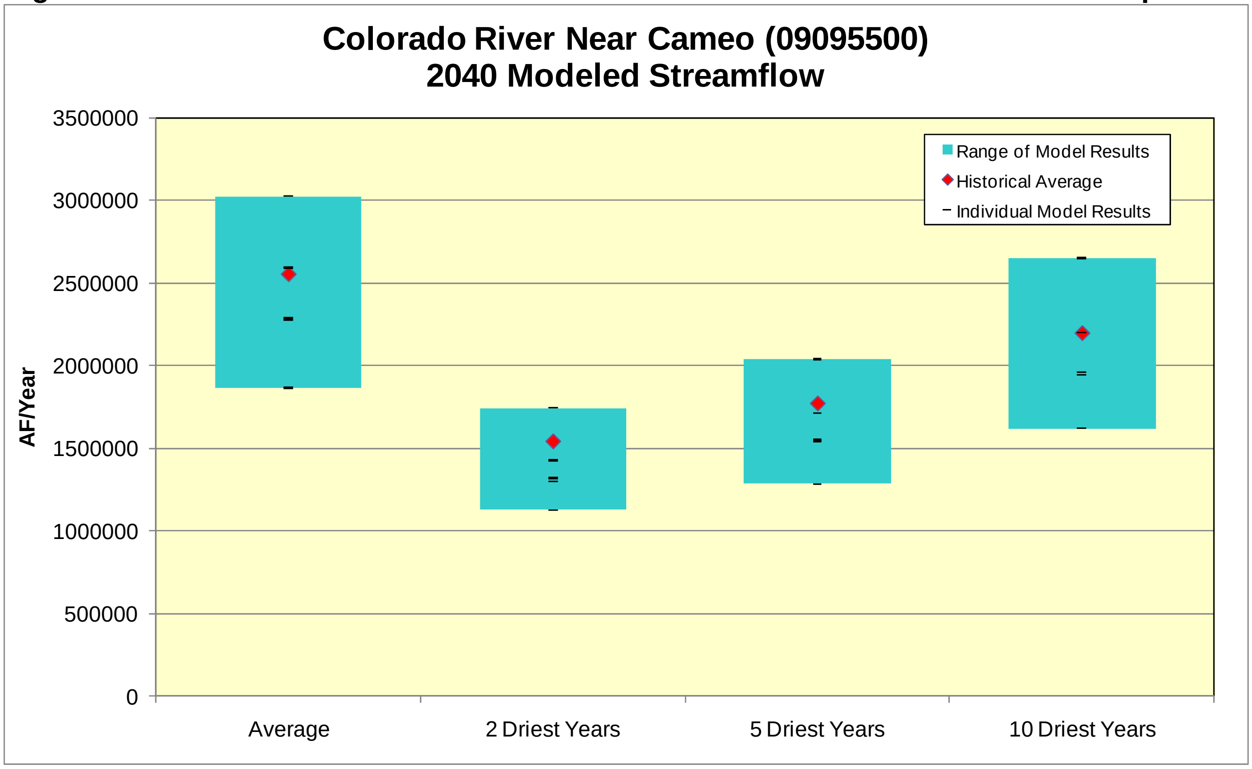


Figure E96 –2040 Plateau near Cameo Modeled Streamflow Low-flow Comparison

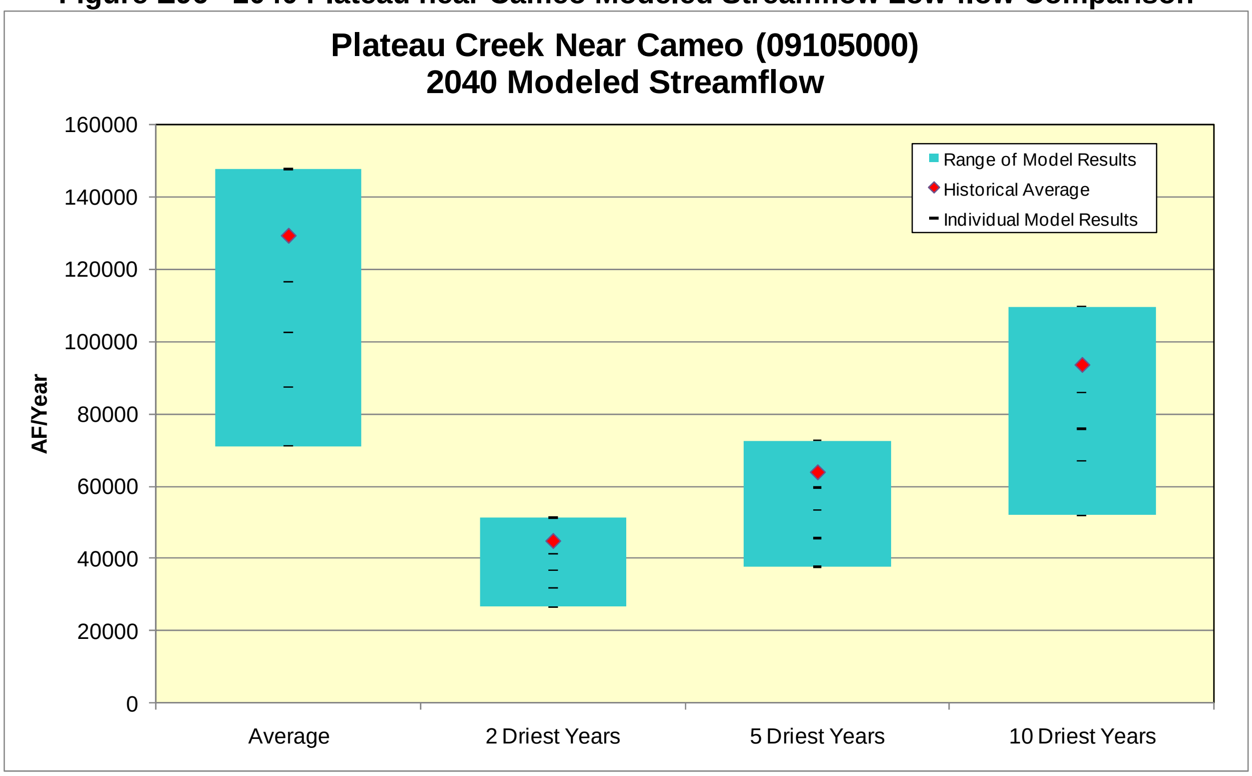


Figure E97 –2040 Colorado River near CO-UT State Line Modeled Streamflow Low-flow Comparison

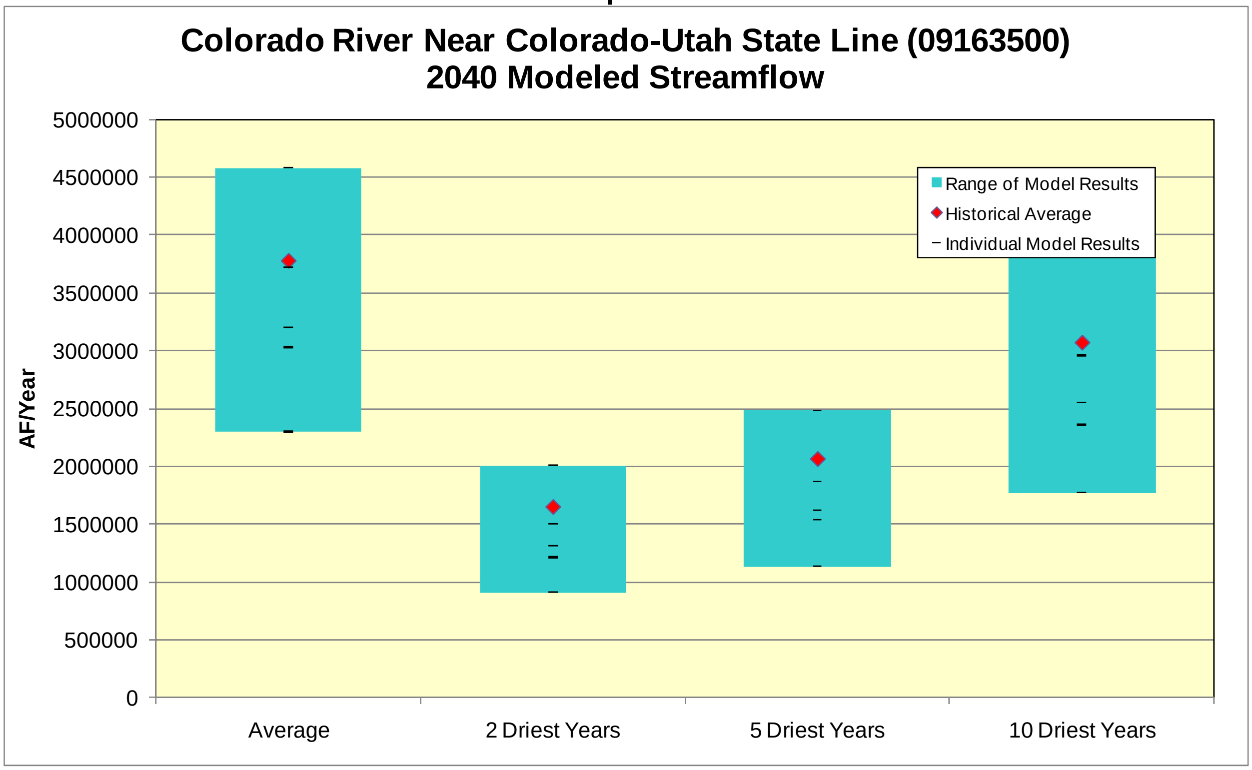


Figure E98 –2040 East River at Almont Modeled Streamflow Low-flow Comparison

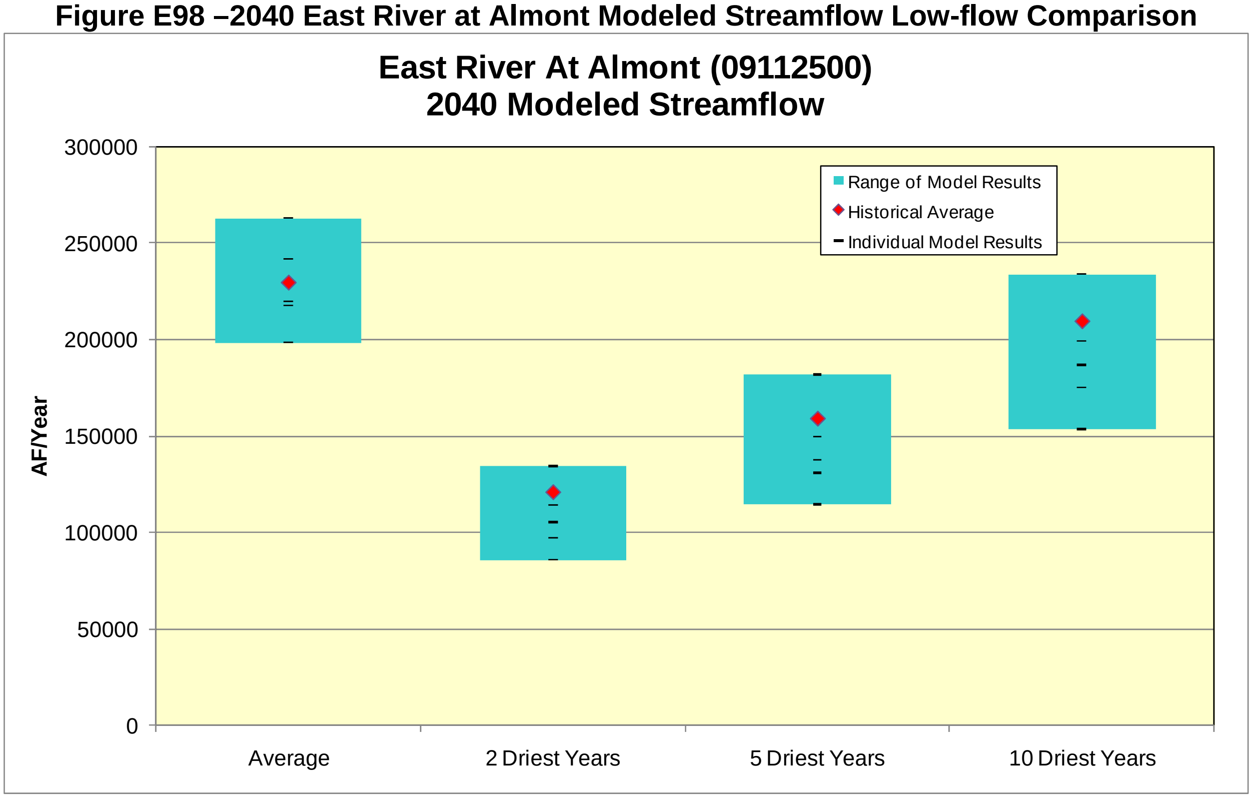


Figure E99 –2040 Taylor River at Almont Modeled Streamflow Low-flow Comparison

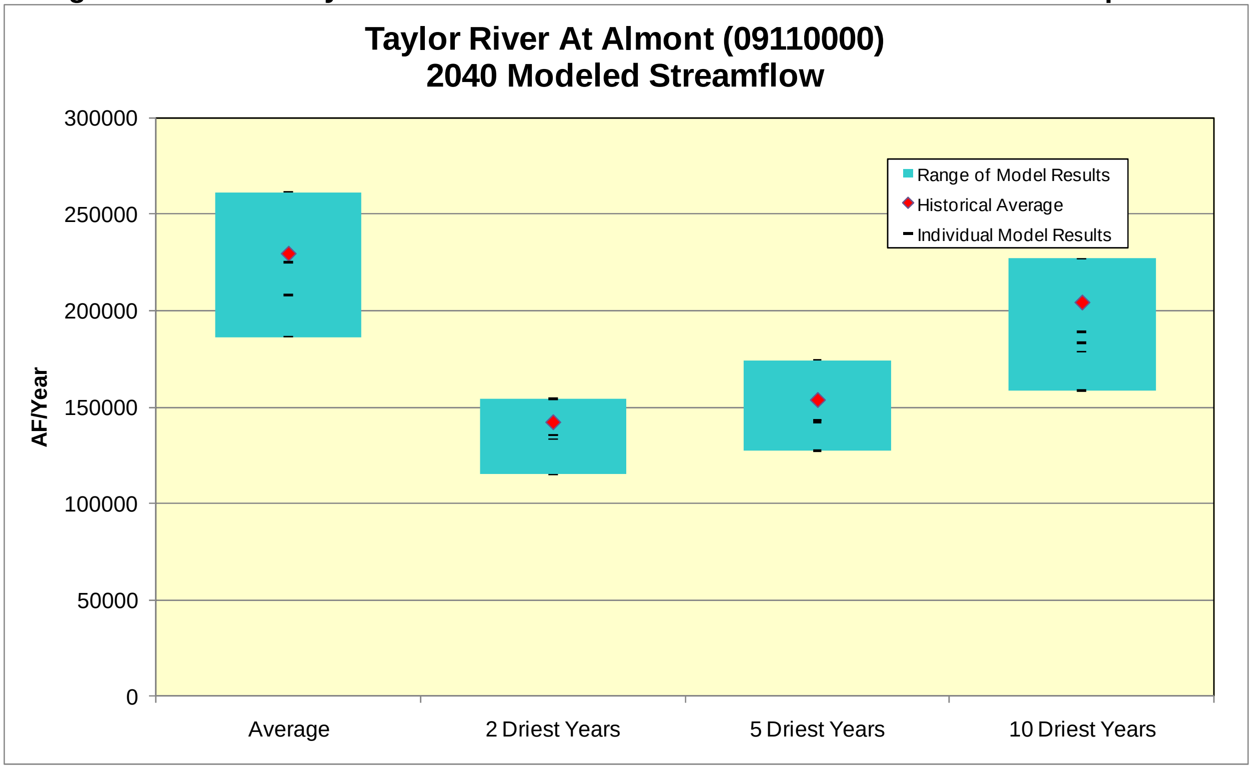


Figure E100 –2040 Tomichi Creek at Gunnison Modeled Streamflow Low-flow Comparison

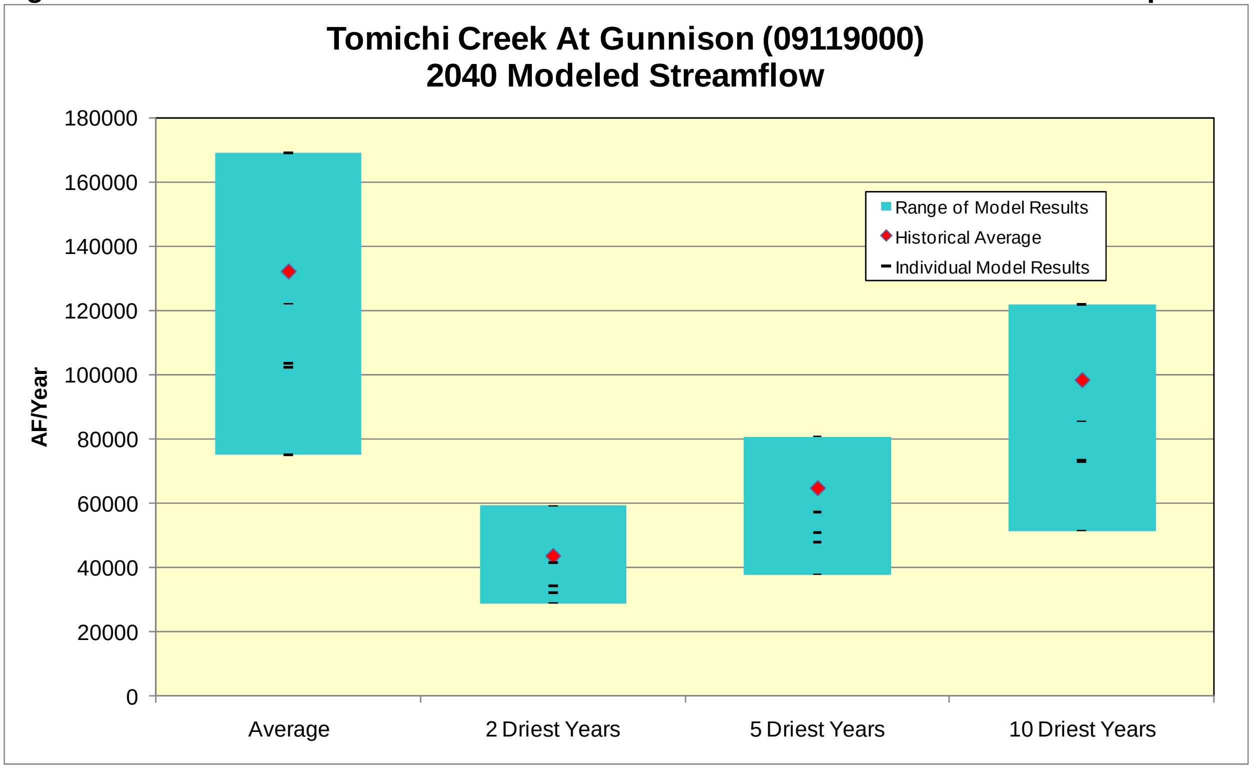


Figure E101 –2040 Gunnison River near Gunnison Modeled Streamflow Low-flow Comparison

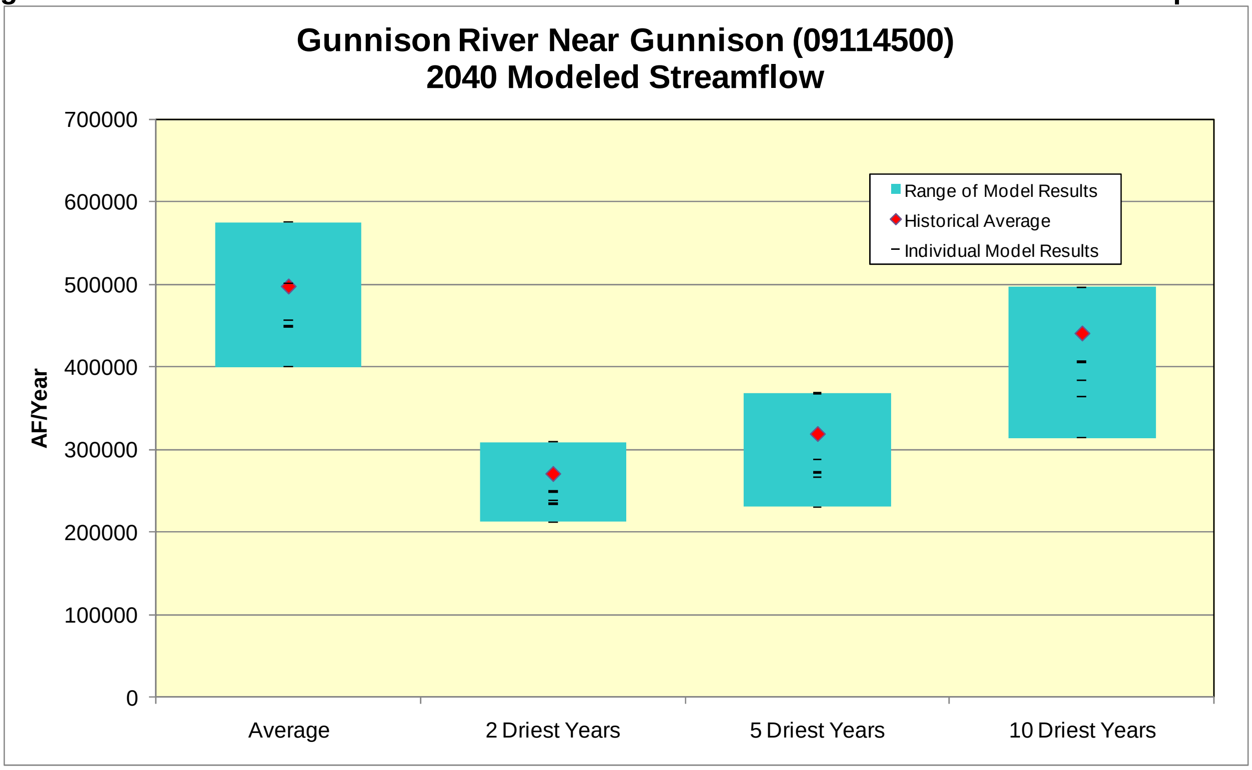


Figure E102 –2040 Cimarron River at Cimarron Modeled Streamflow Low-flow Comparison

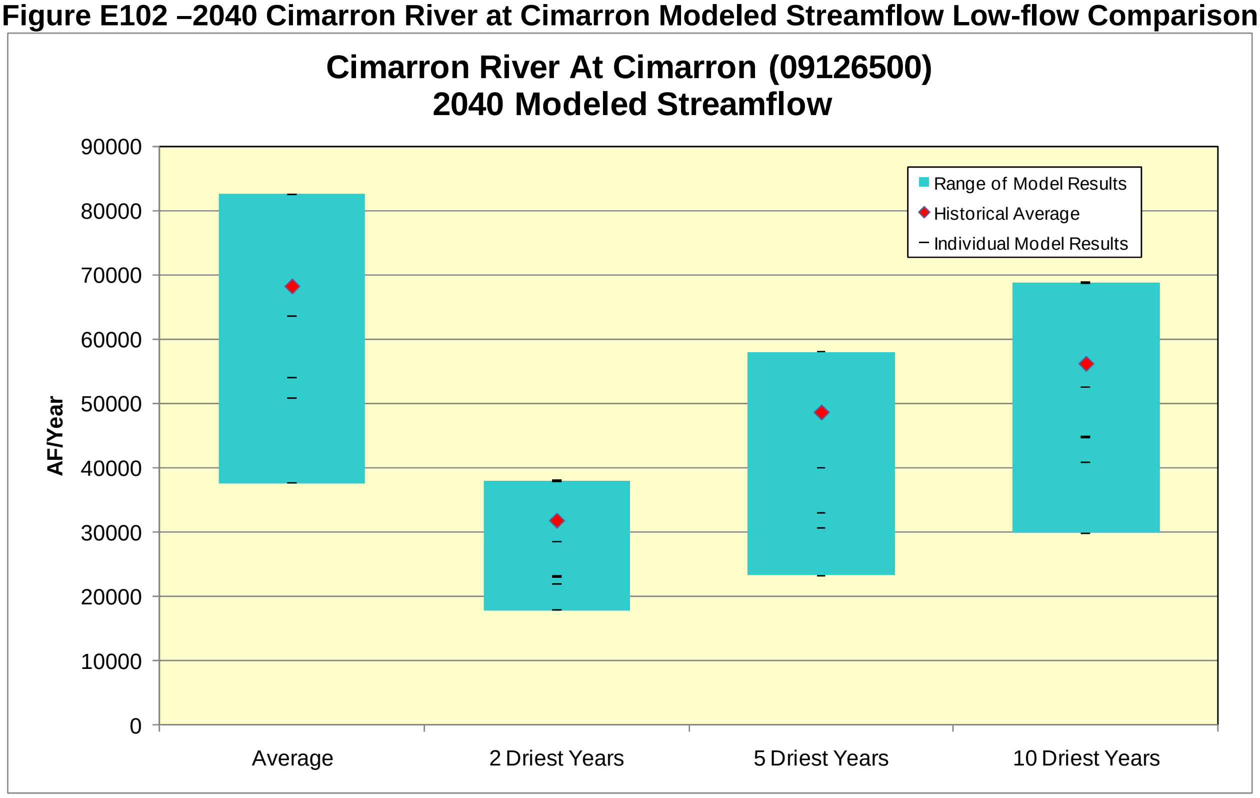


Figure E103 –2040 Gunnison River below Gunnison Tunnel Modeled Streamflow Low-flow Comparison

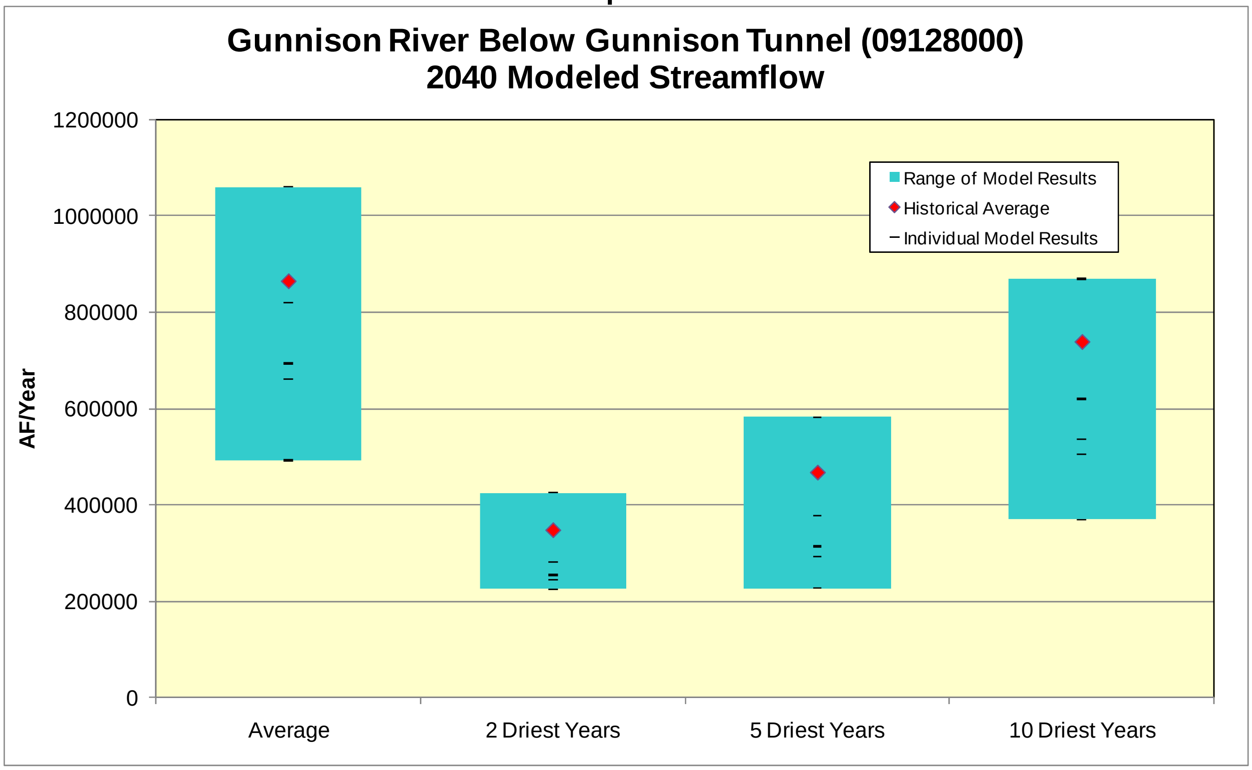


Figure E104 –2040 Gunnison River near Lazear Modeled Streamflow Low-flow Comparison

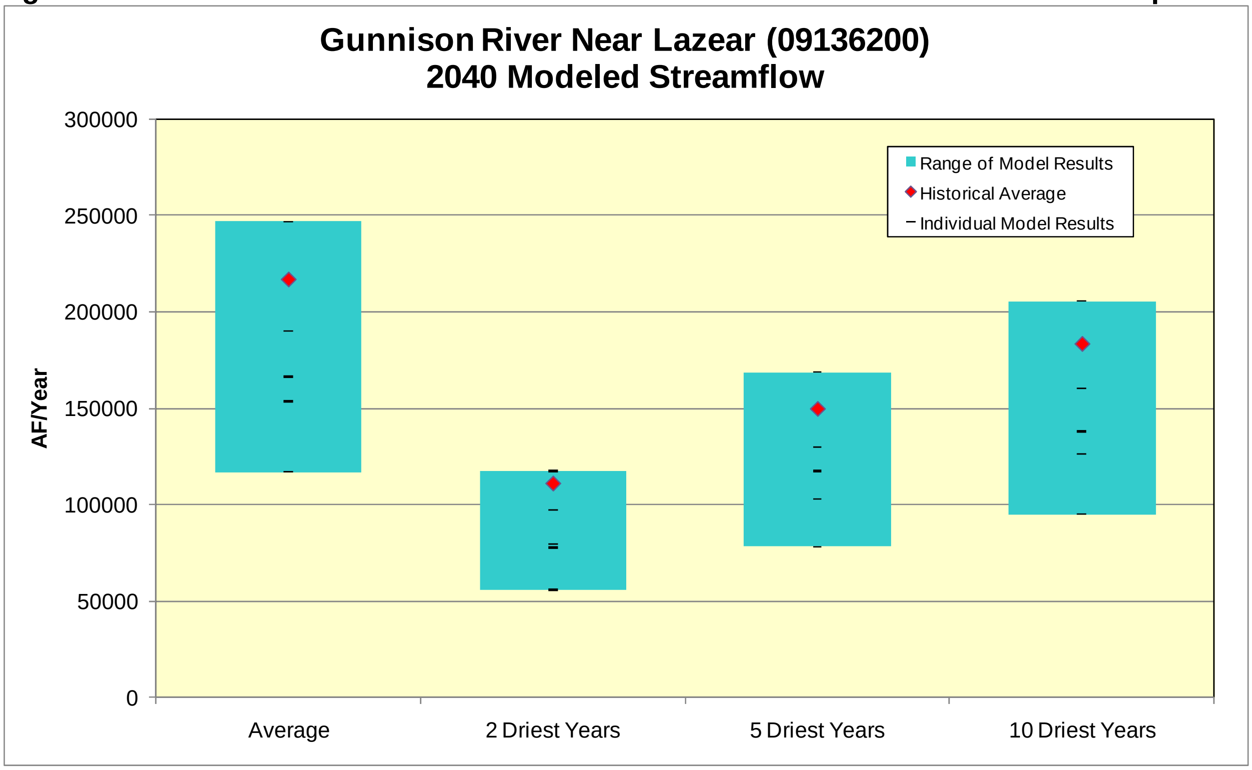


Figure E105 –2040 Uncompahgre River at Delta Modeled Streamflow Low-flow Comparison

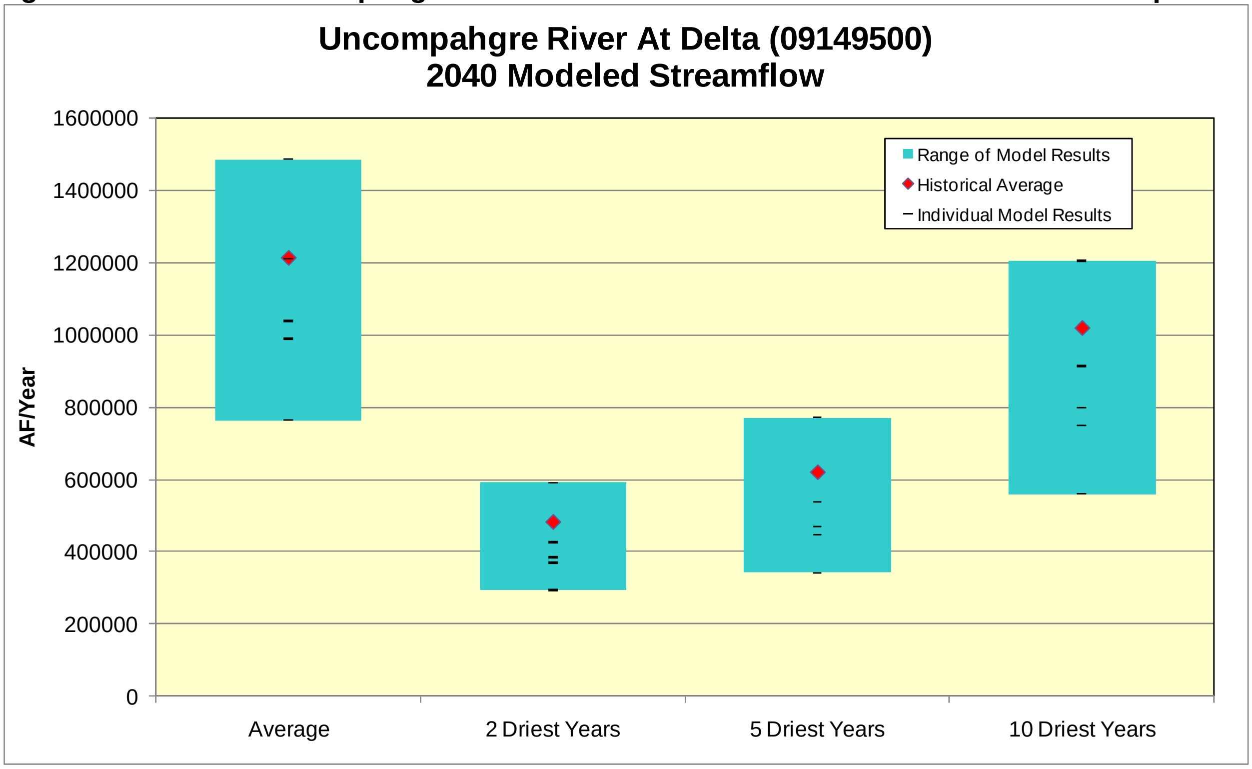


Figure E106 –2040 Gunnison River near Grand Junction Modeled Streamflow Low-flow Comparison

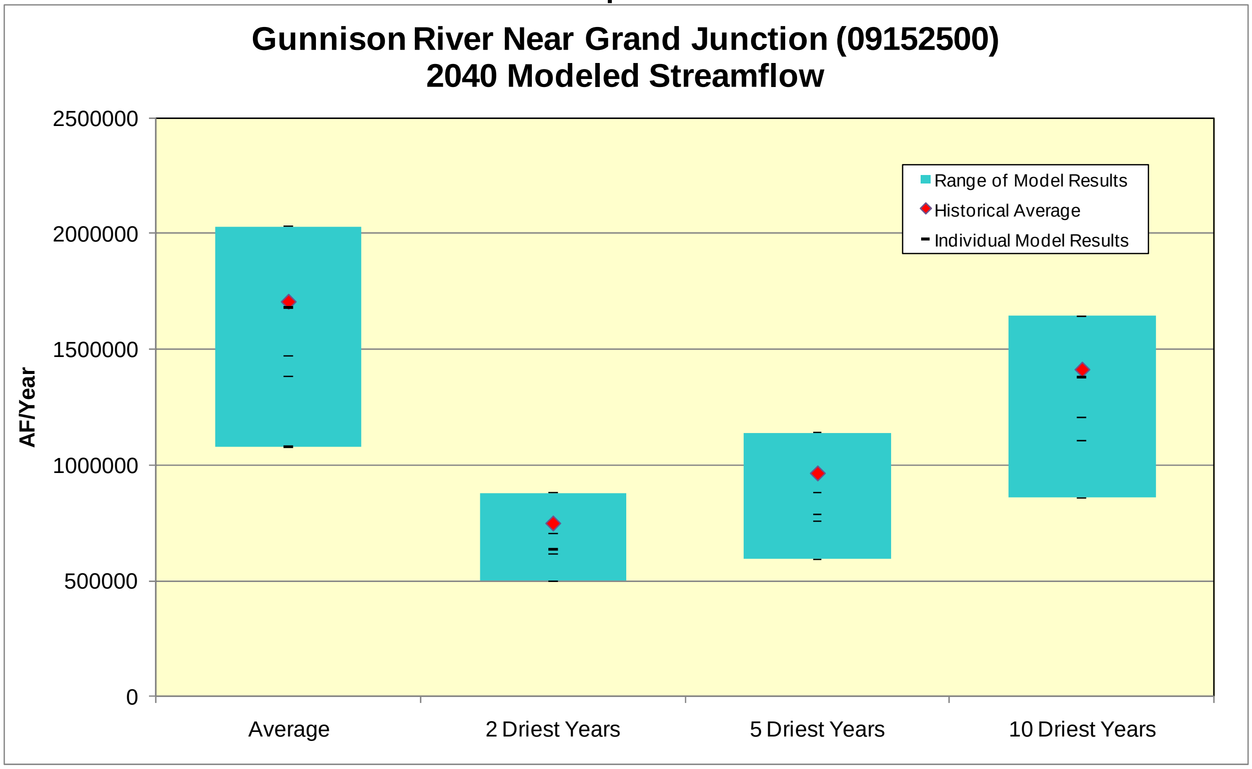


Figure E107 –2040 San Juan River near Carracas Modeled Streamflow Low-flow Comparison

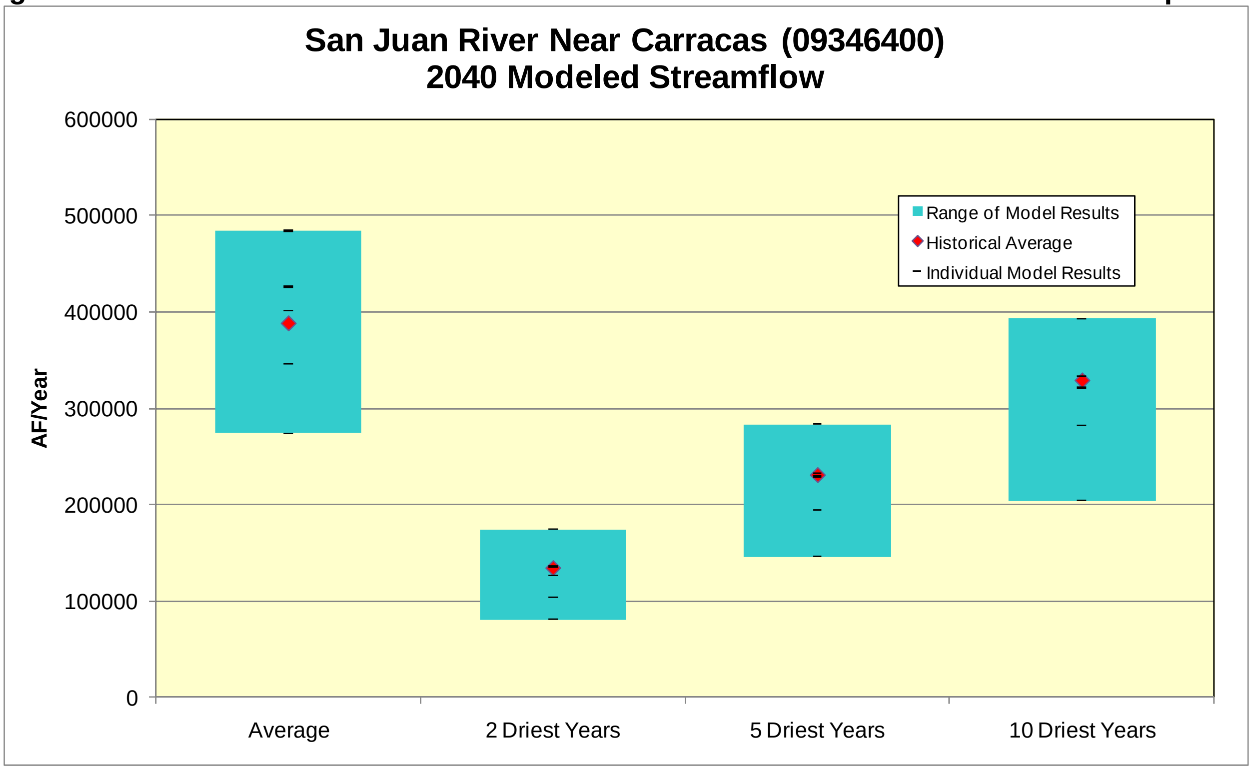


Figure E108 –2040 Piedra River near Arboles Modeled Streamflow Low-flow Comparison

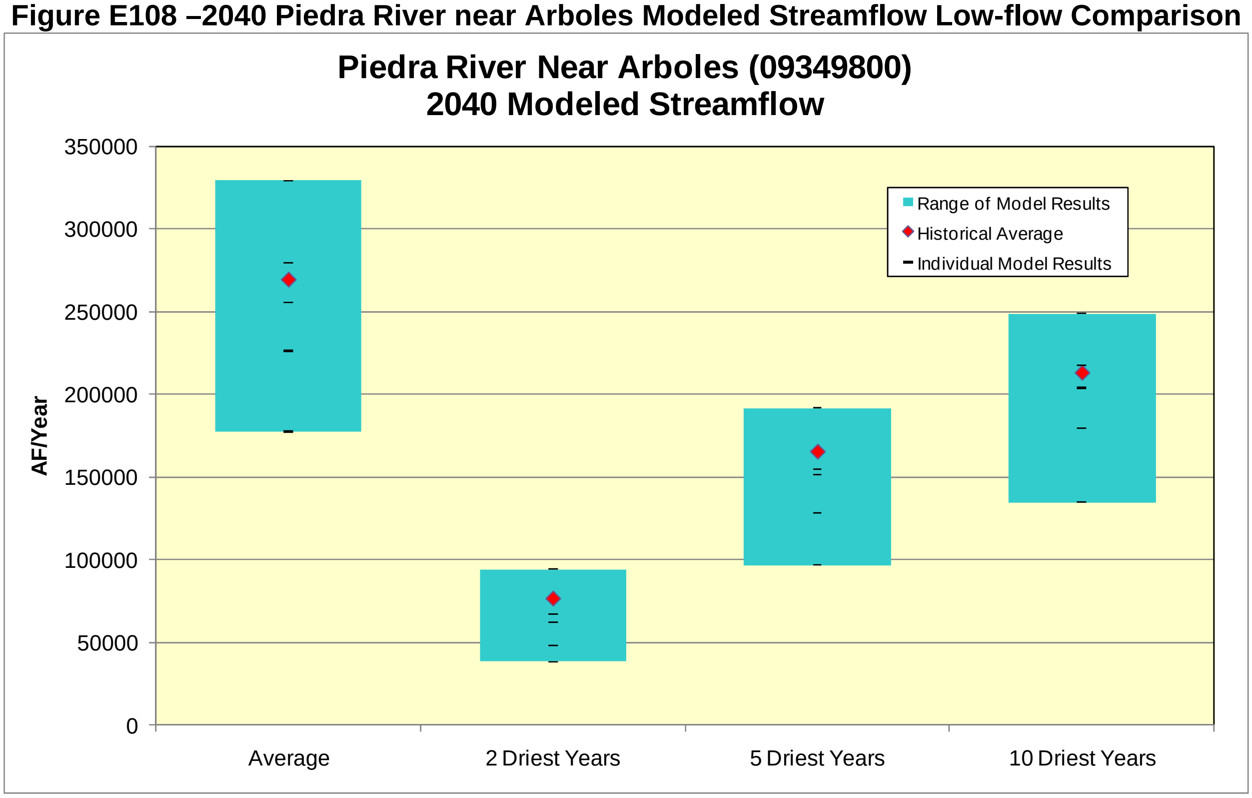


Figure E109 –2040 Los Pinos River at La Boca Modeled Streamflow Low-flow Comparison

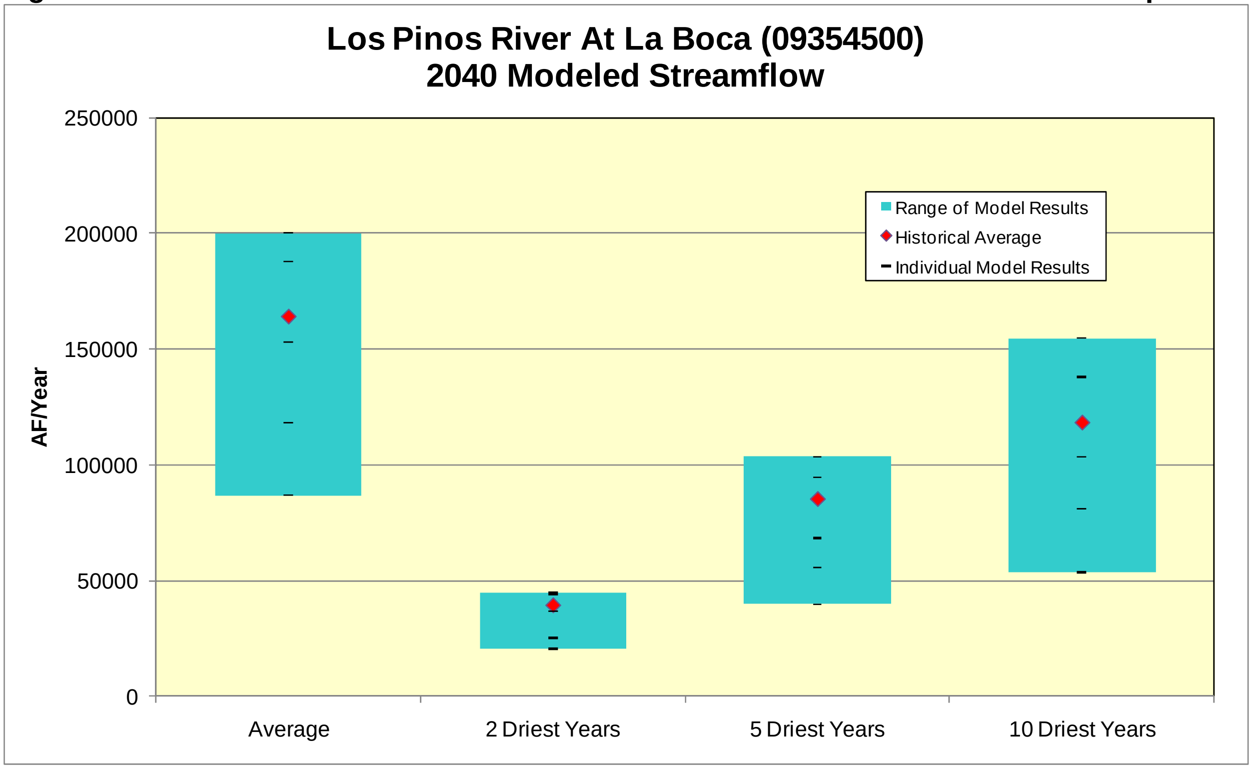


Figure E110 –2040 Florida River at Bondad Modeled Streamflow Low-flow Comparison

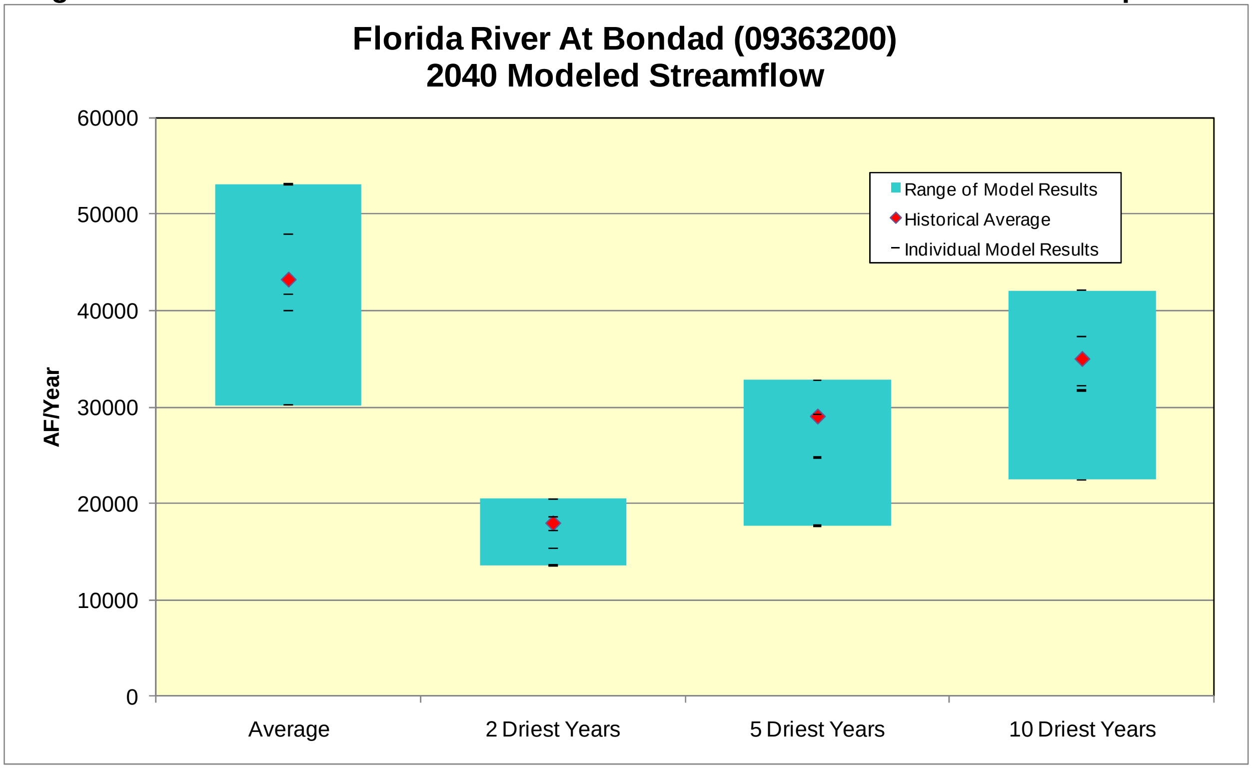


Figure E111 –2040 Animas River near Cedar Hill, NM Modeled Streamflow Low-flow Comparison

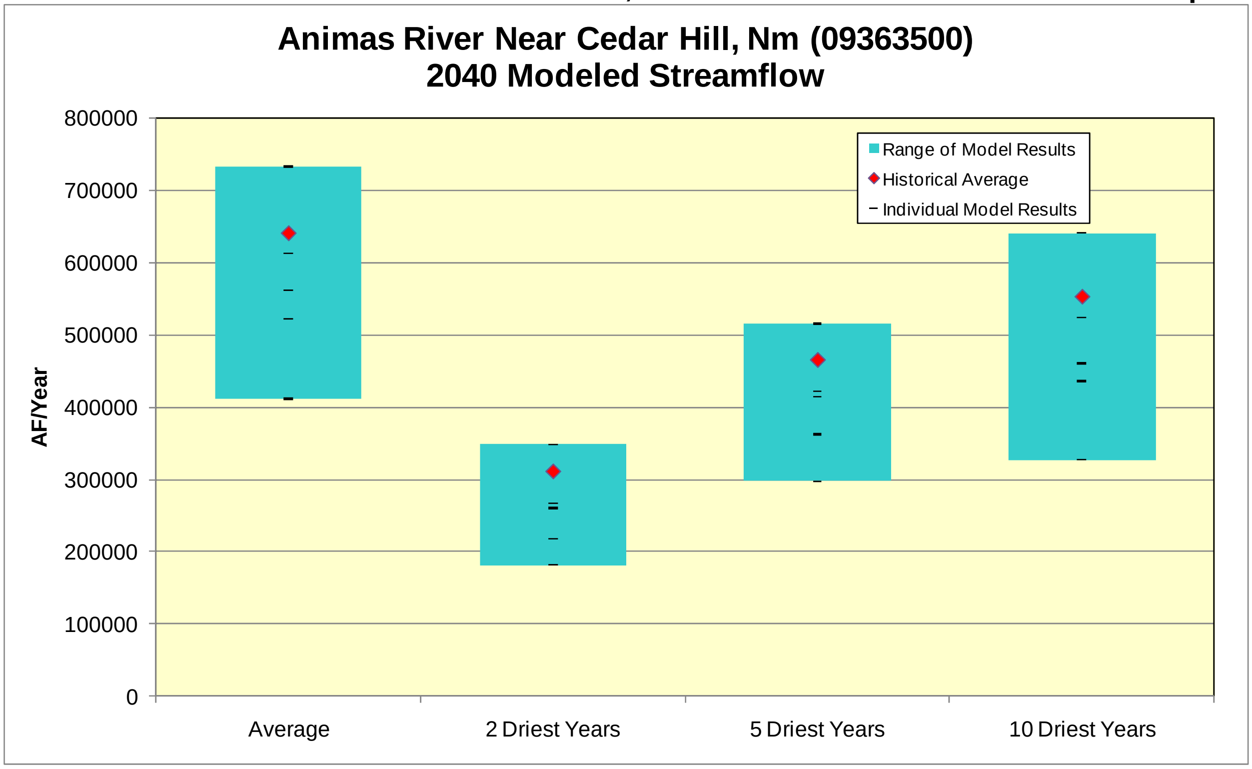


Figure E112 –2040 La Plata River at Hesperus Modeled Streamflow Low-flow Comparison

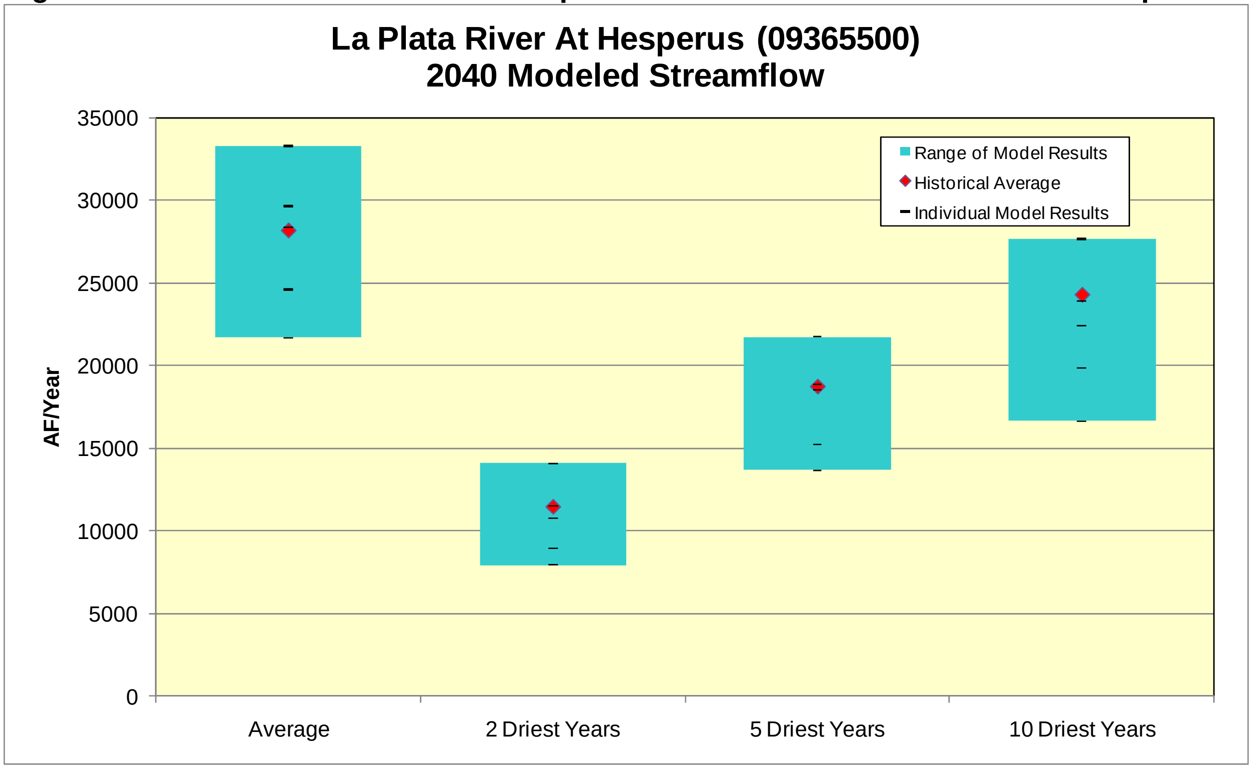


Figure E113 –2040 La Plata River at CO-NM State Line Modeled Streamflow Low-flow Comparison

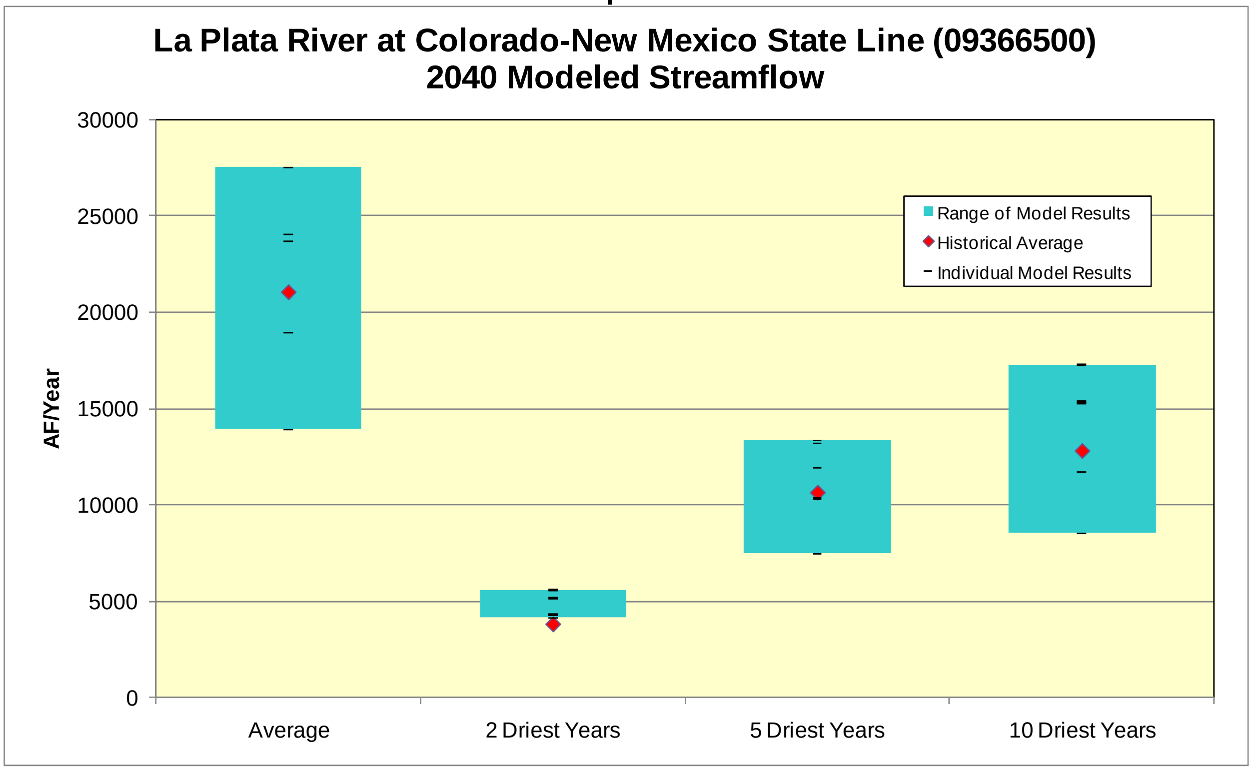


Figure E114 –2040 Mancos River near Towaoc Modeled Streamflow Low-flow Comparison

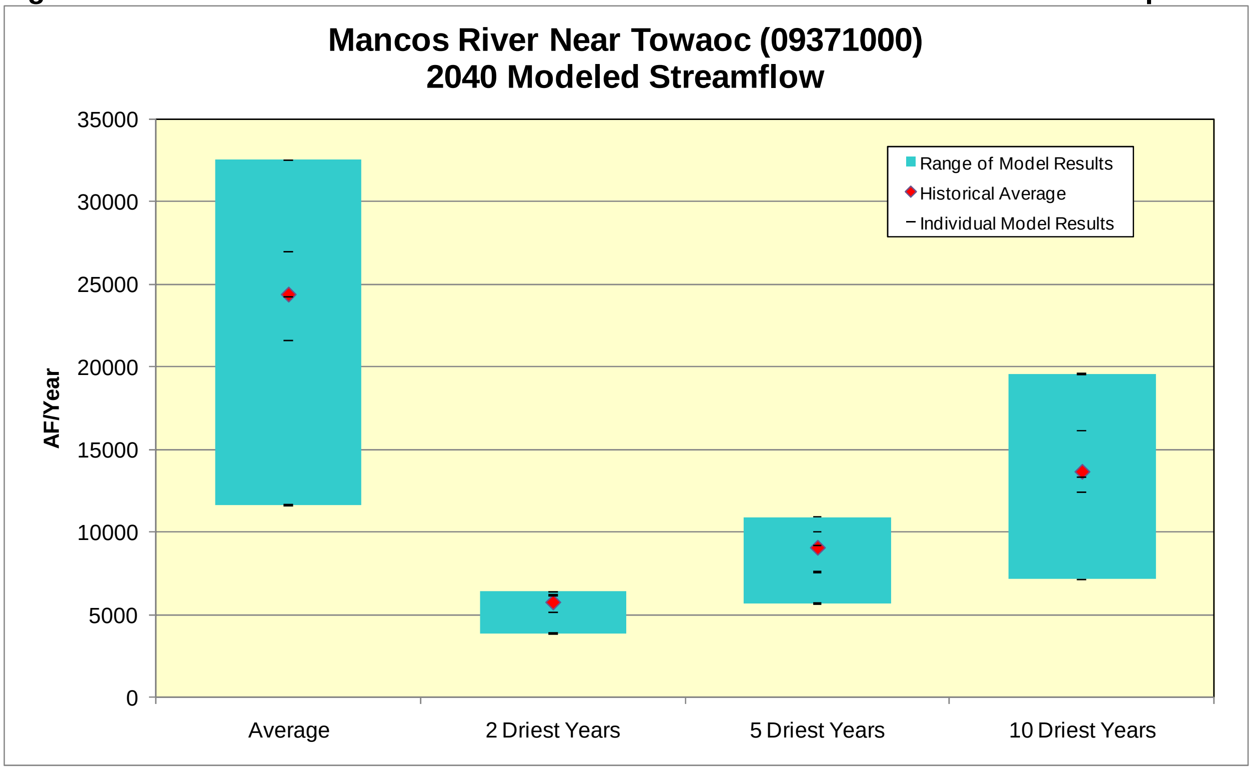


Figure E115 –2040 McElmo Creek near CO-UT State Line Modeled Streamflow Low-flow Comparison

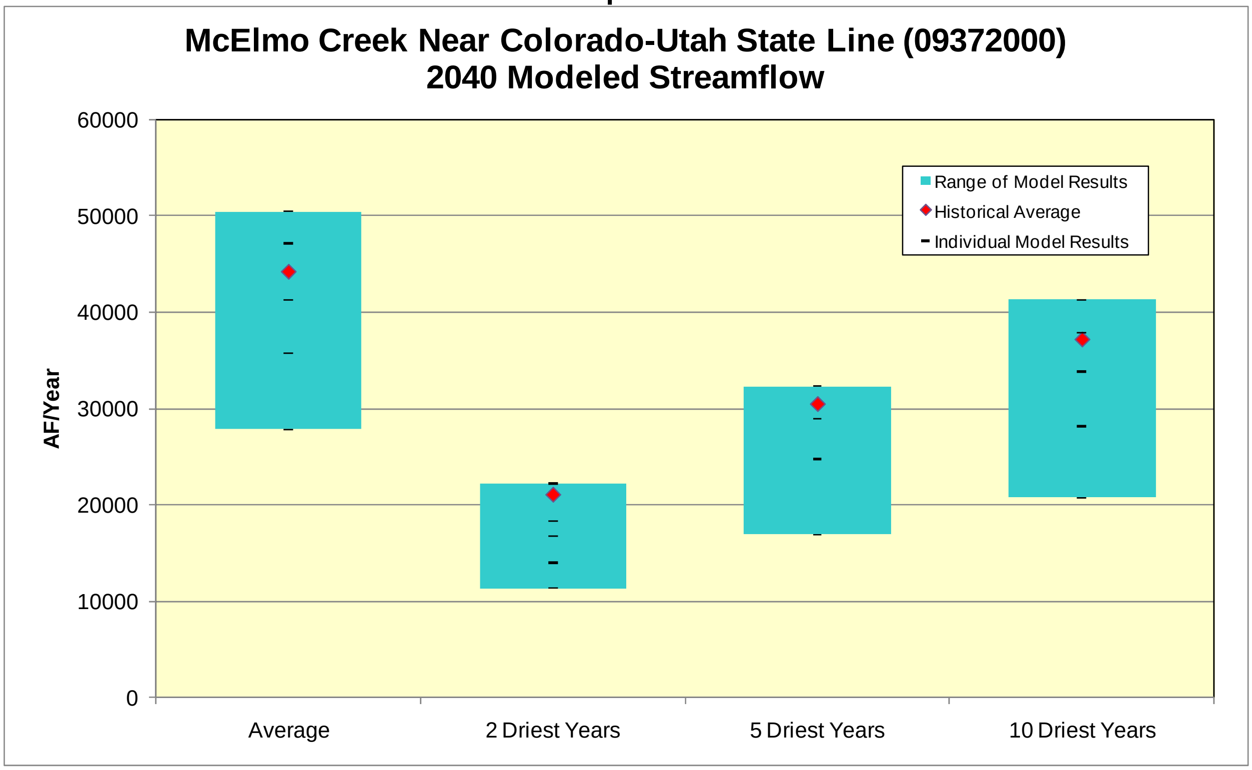


Figure E116 –2040 Dolores River near Bedrock Modeled Streamflow Low-flow Comparison

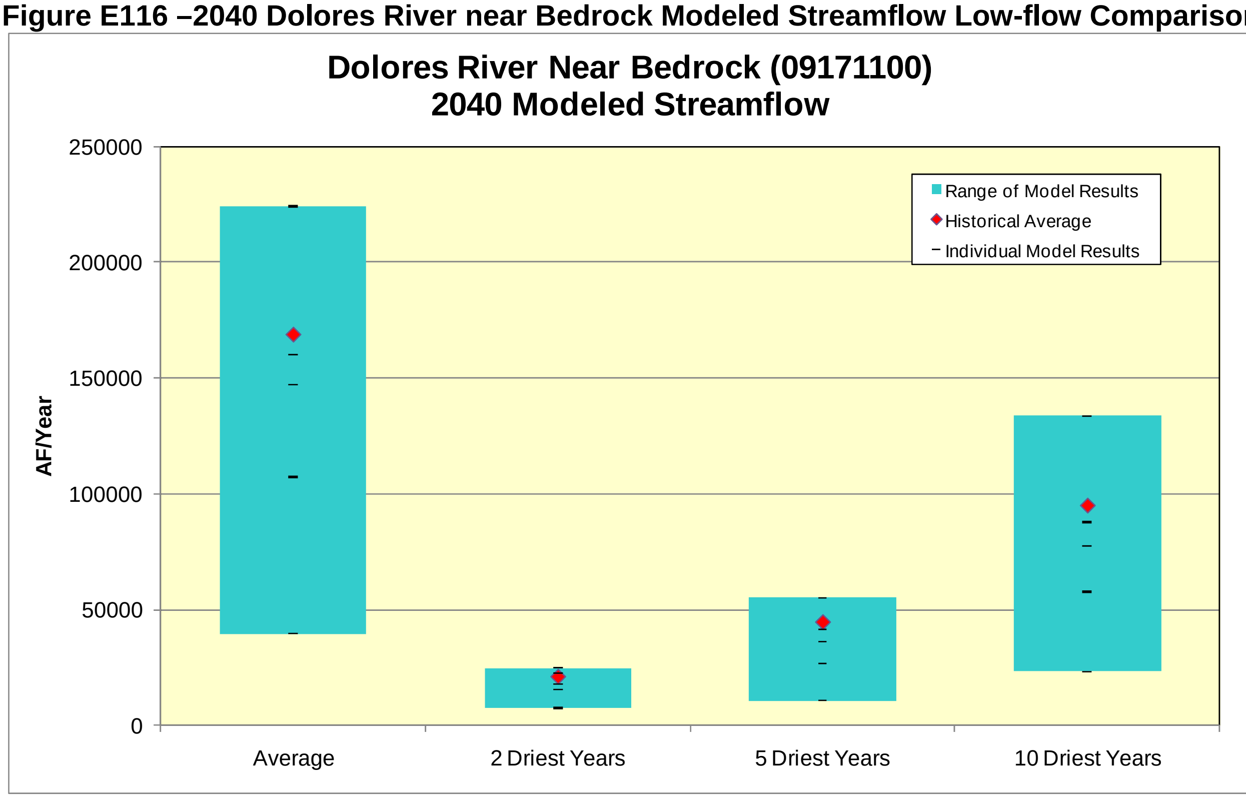


Figure E117 –2040 San Miguel River at Naturita Modeled Streamflow Low-flow Comparison

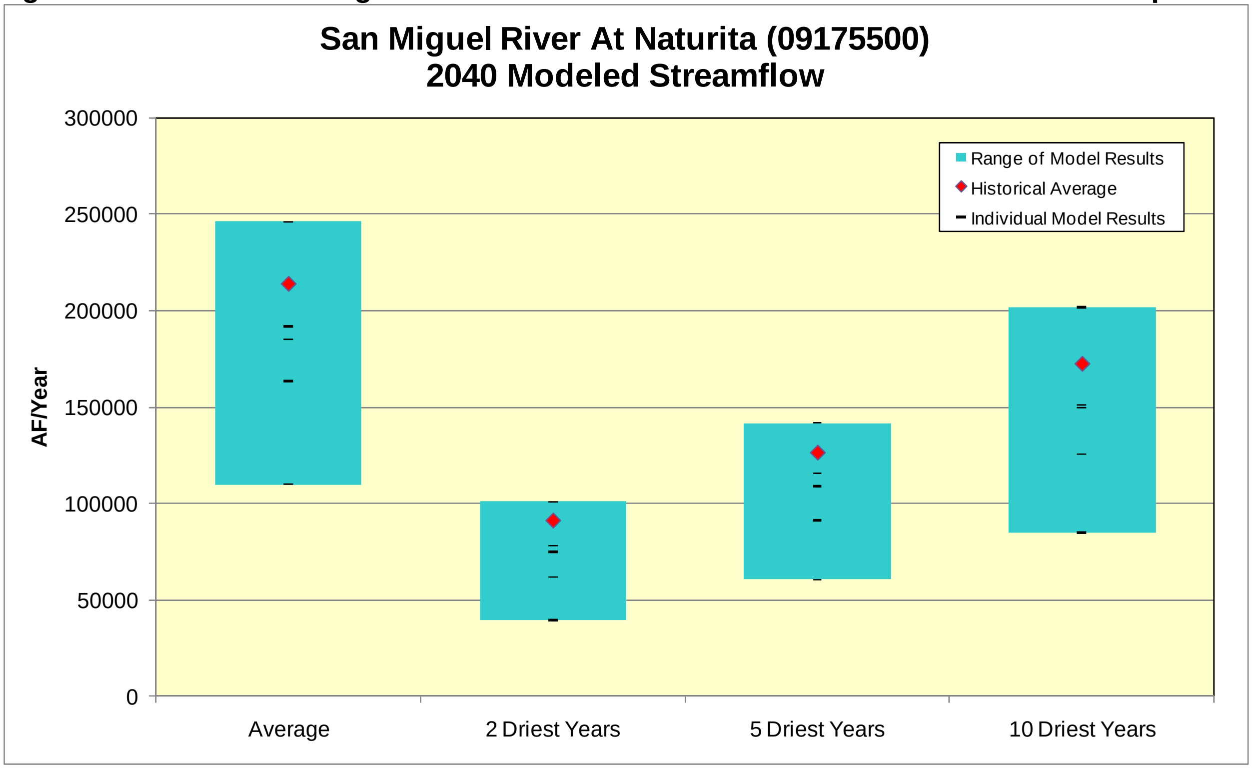


Figure E118 –2040 Yampa River below Stagecoach Reservoir Modeled Streamflow Low-flow Comparison

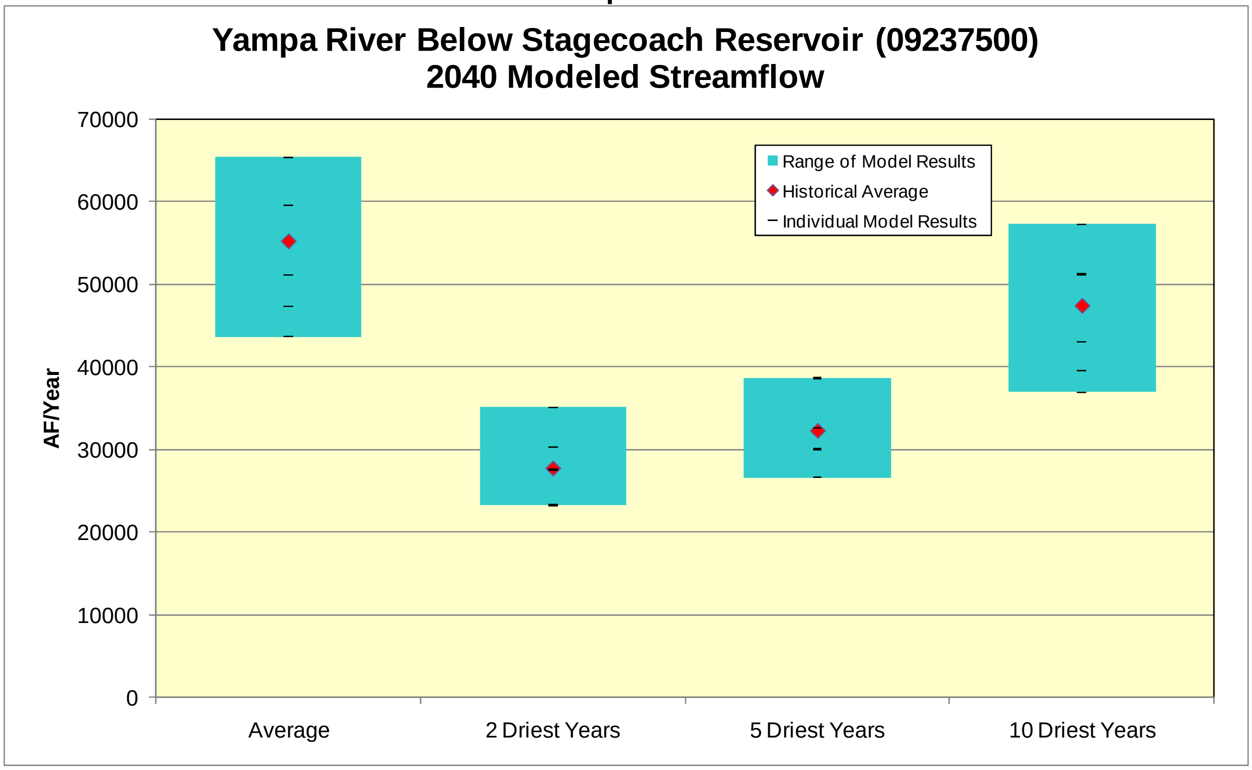
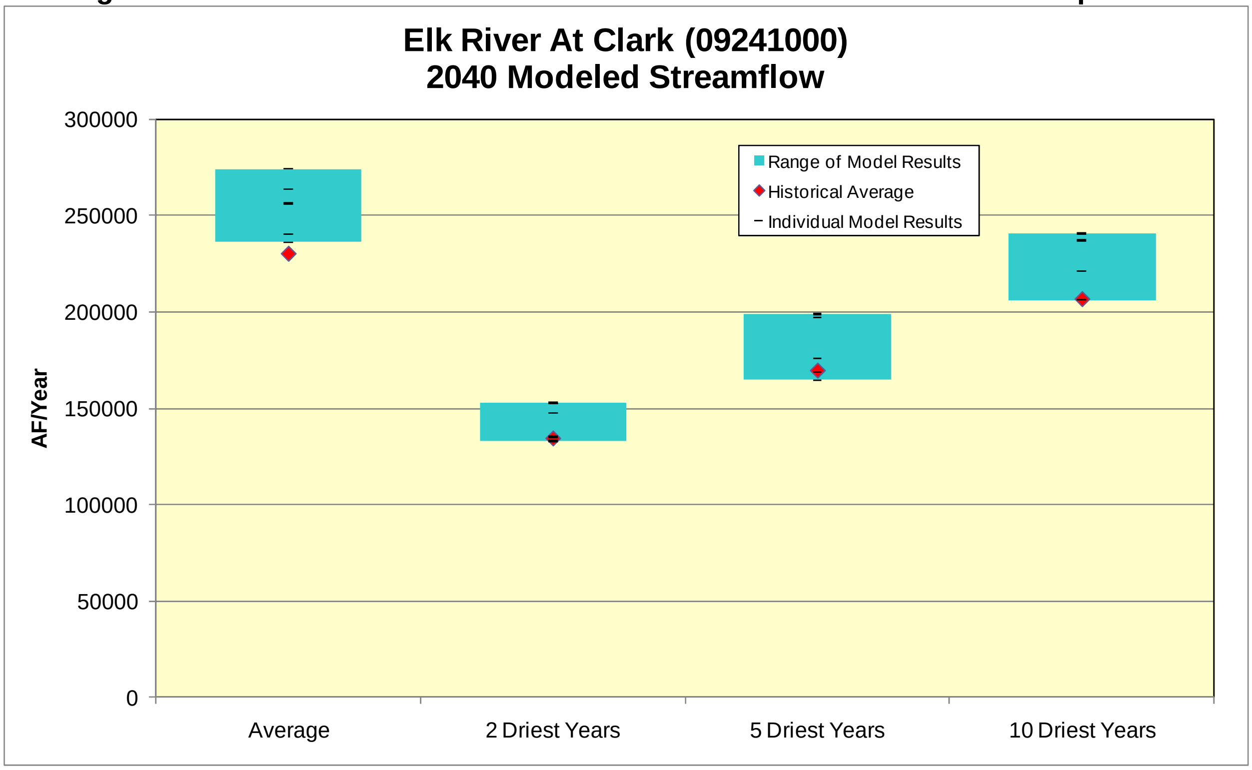


Figure E119 –2040 Elk River at Clark Modeled Streamflow Low-flow Comparison



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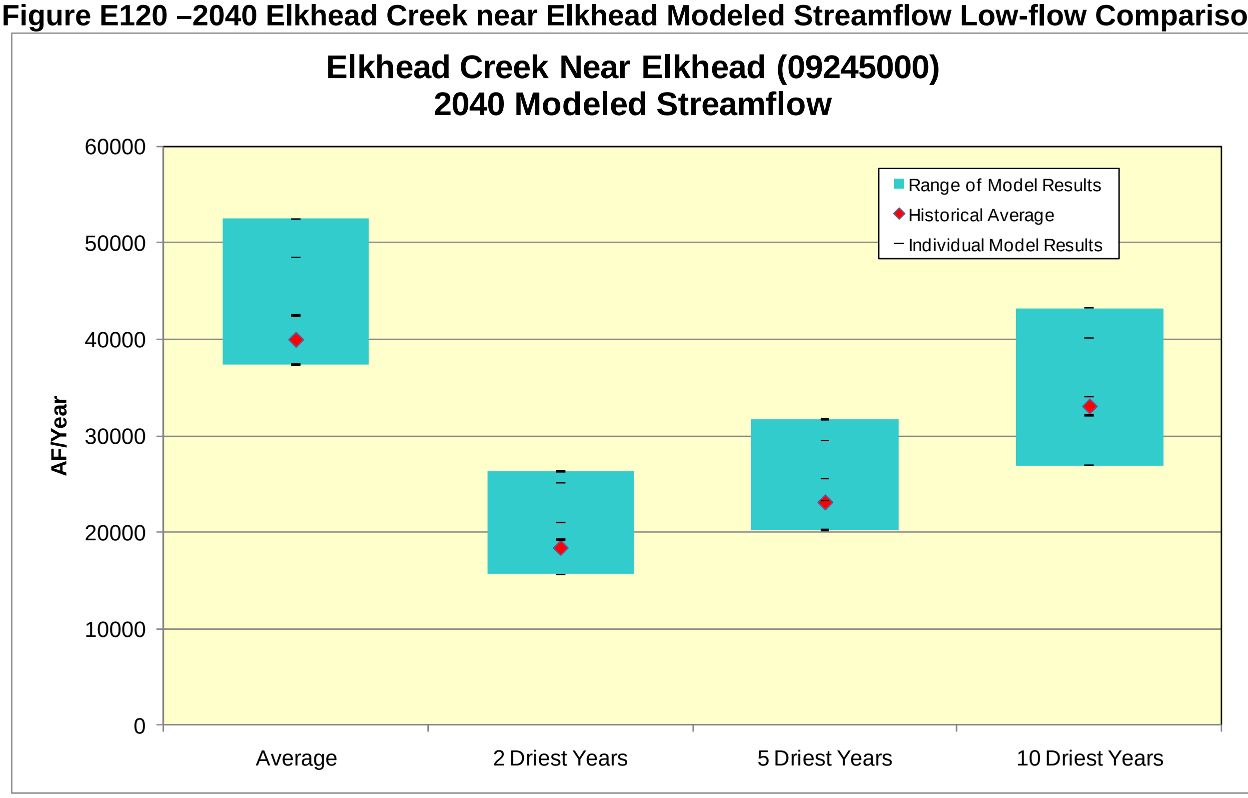


Figure E121 –2040 Williams Fork at Mouth, near Hamilton Modeled Streamflow Low-flow Comparison

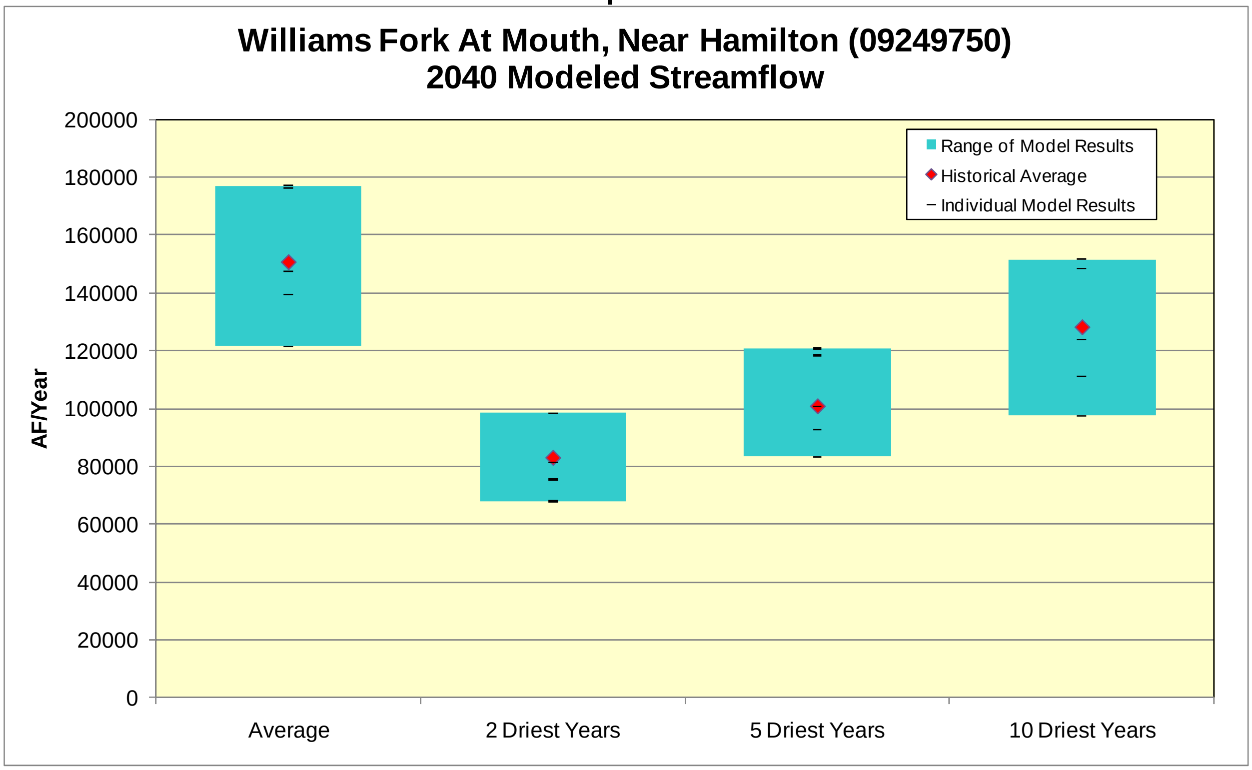
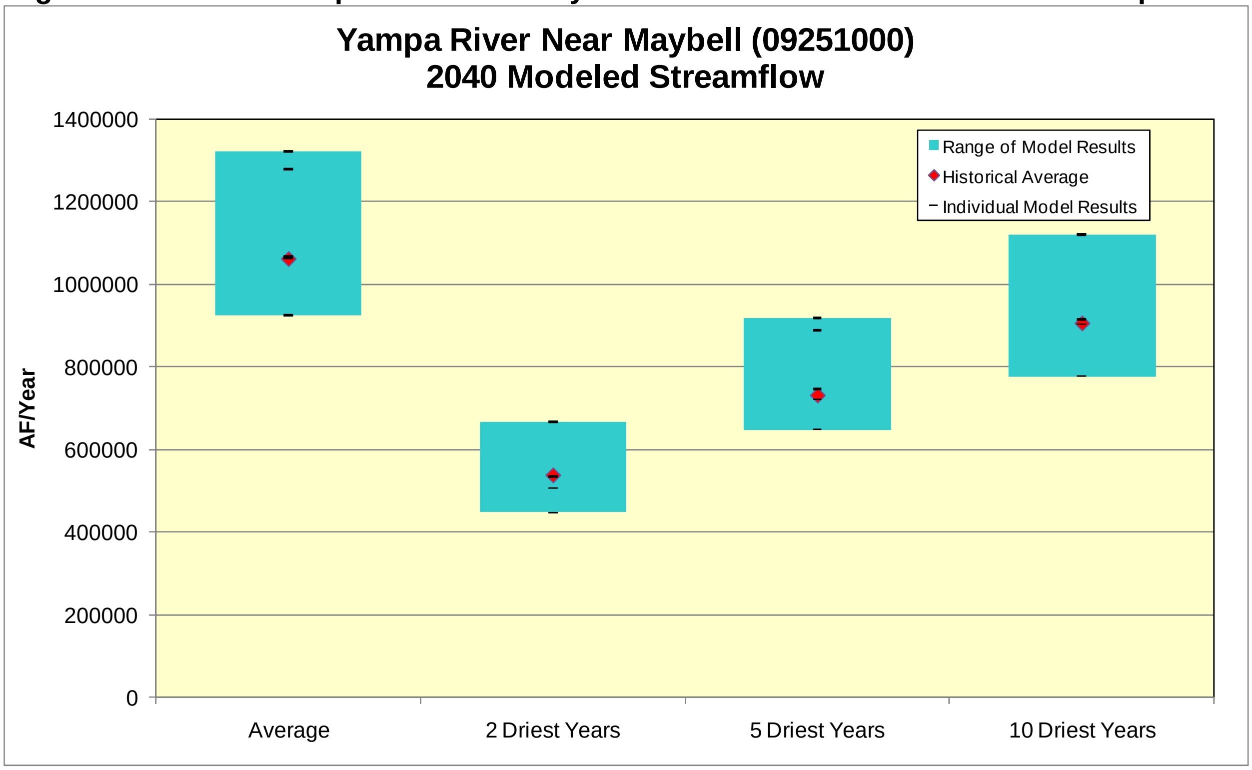


Figure E122 –2040 Yampa River near Maybell Modeled Streamflow Low-flow Comparison



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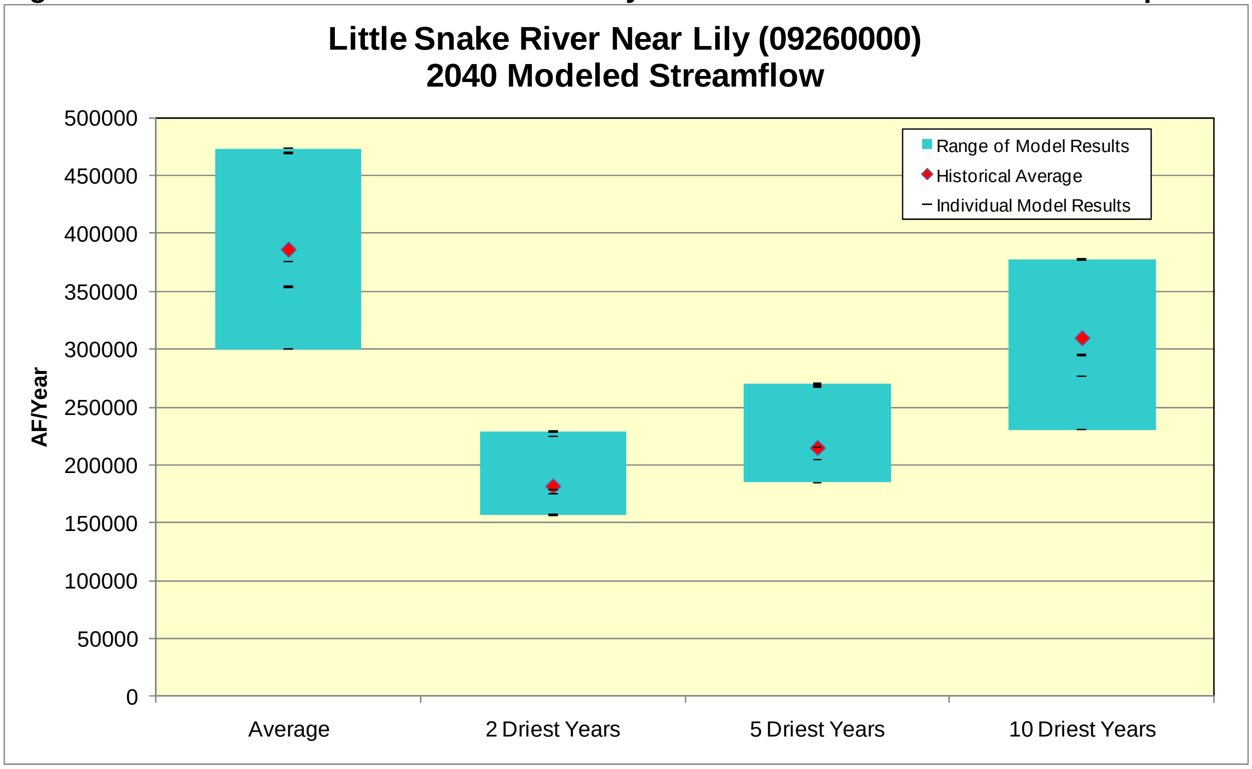

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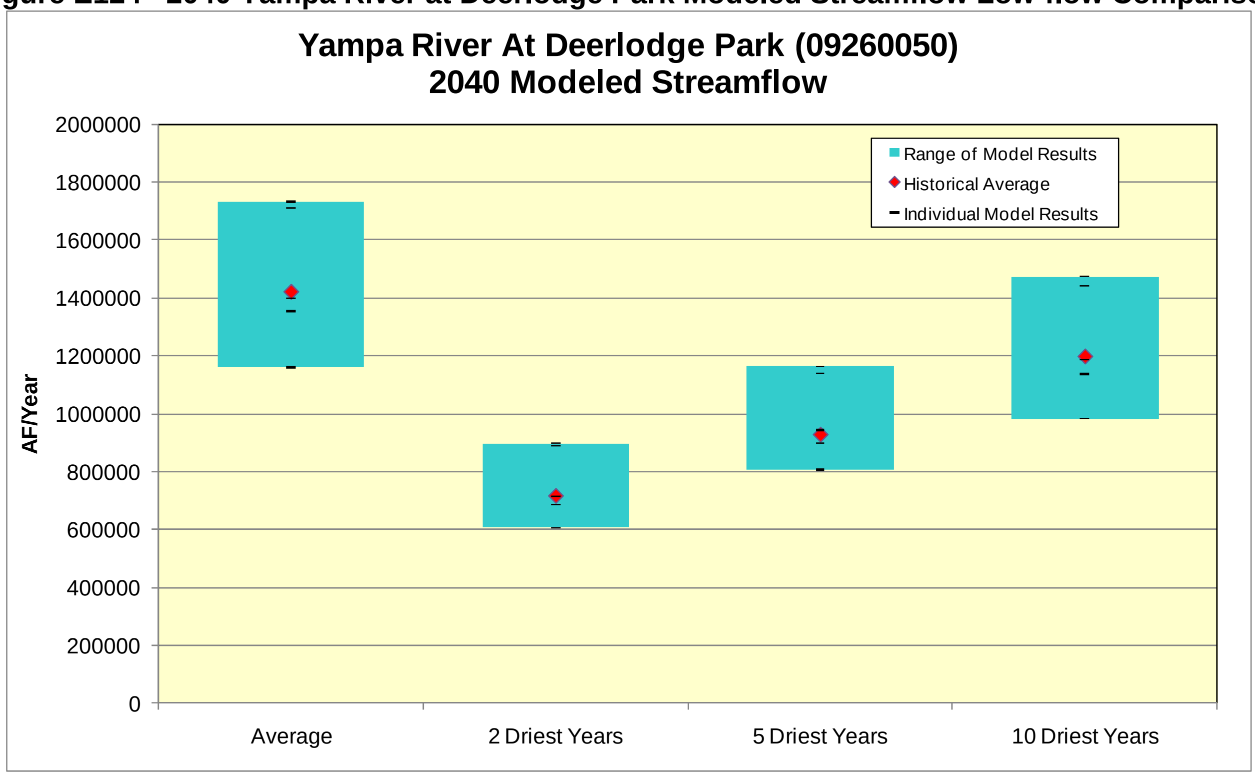
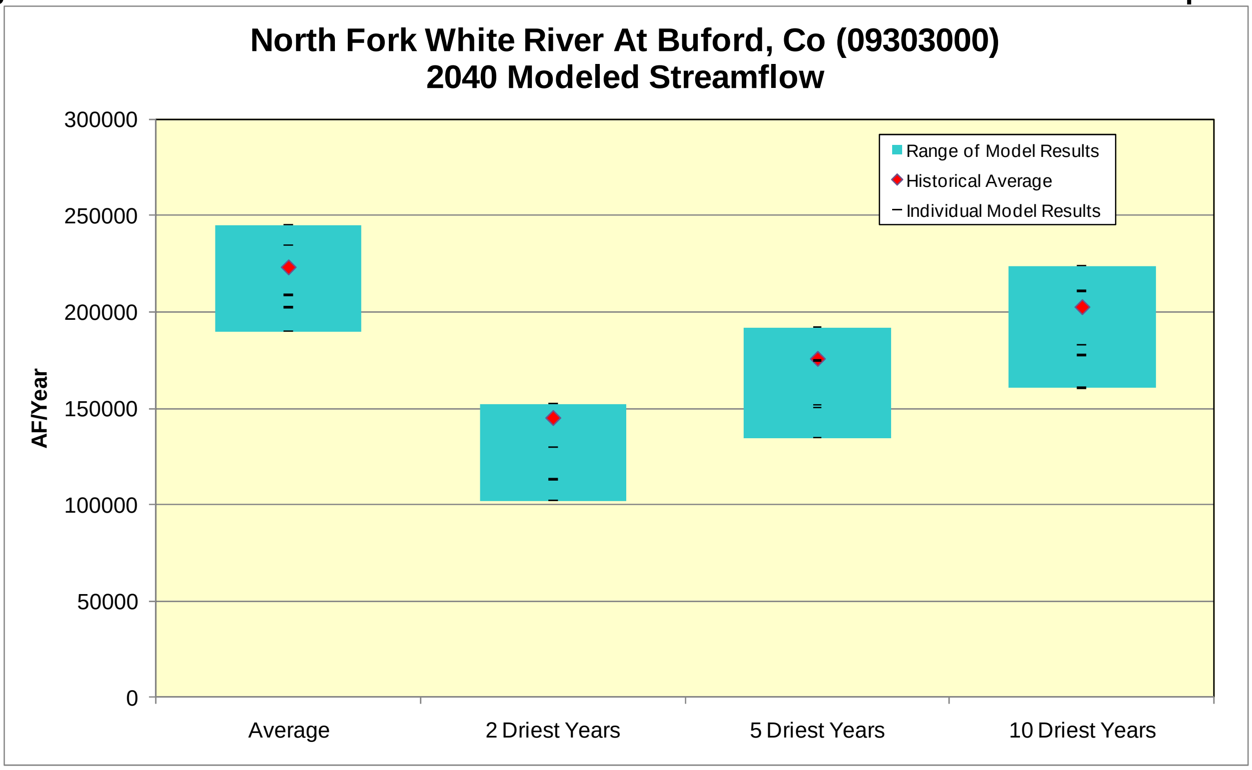


Figure E125 –2040 North Fork White River at Buford Modeled Streamflow Low-flow Comparison



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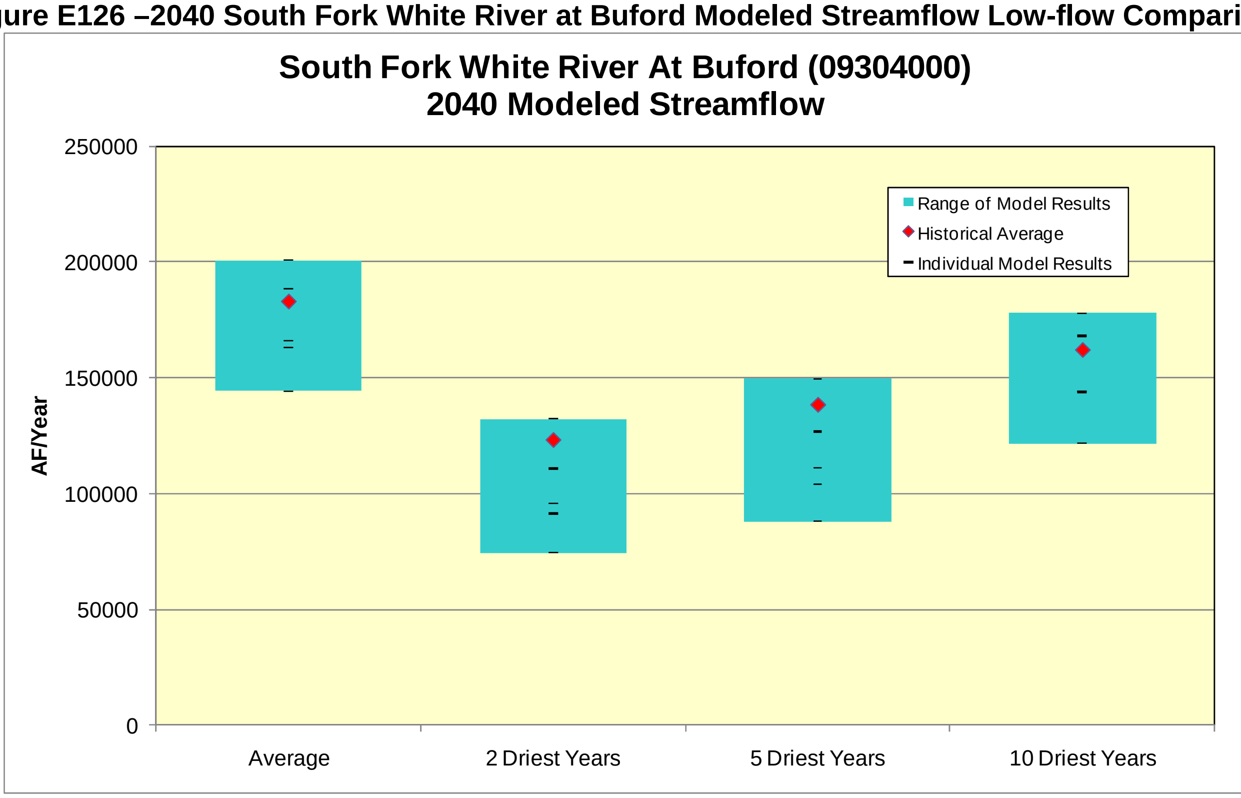

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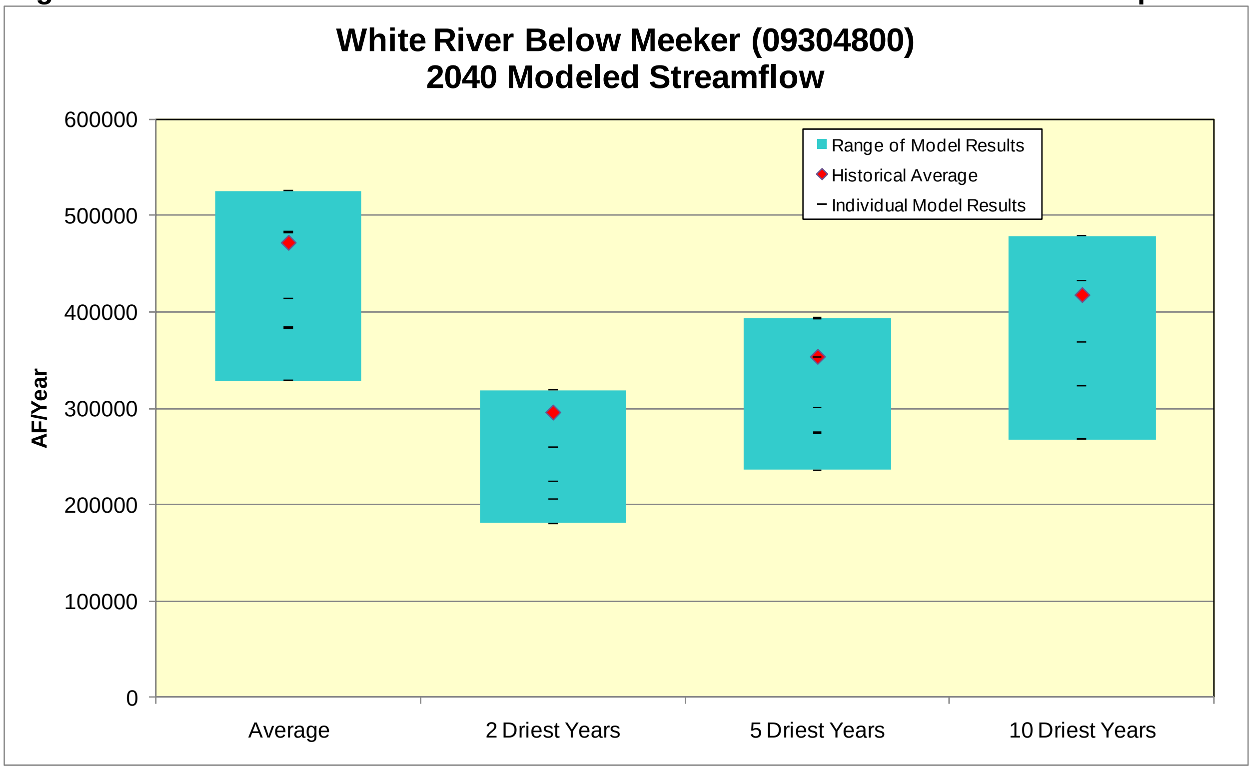

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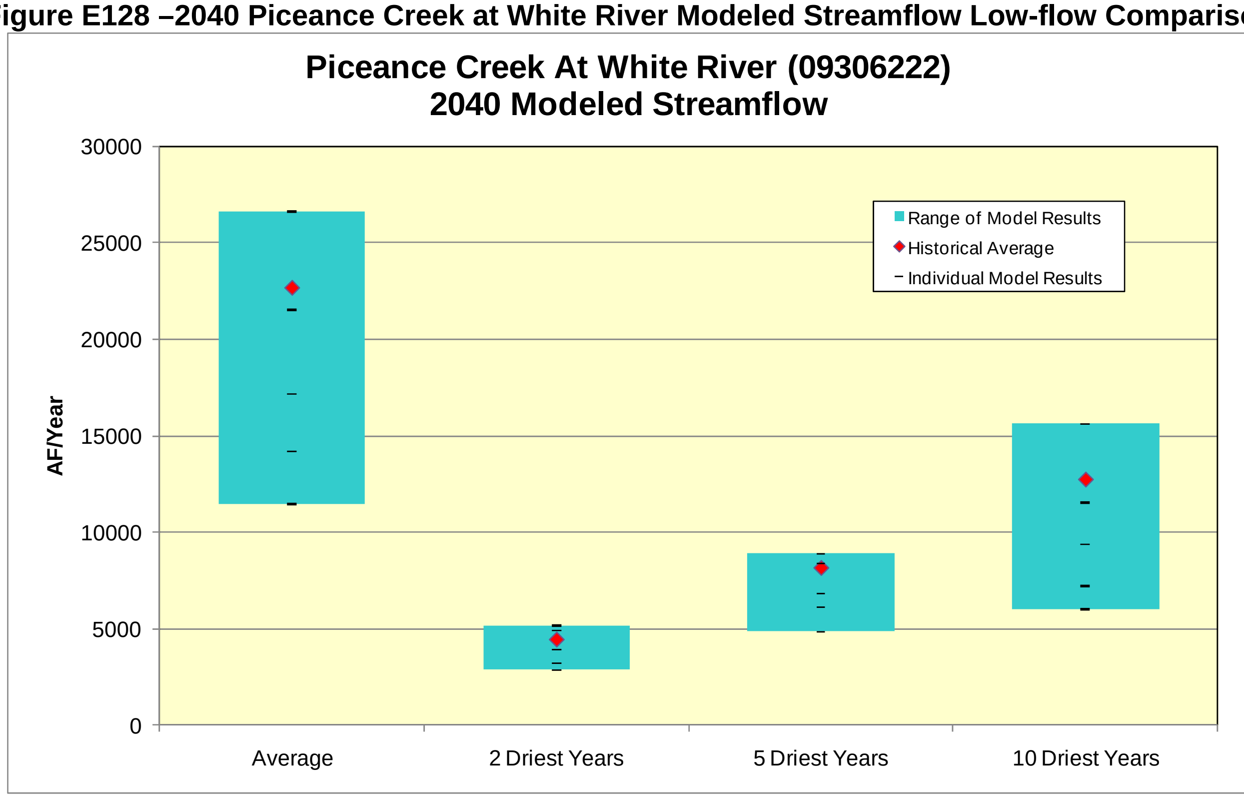

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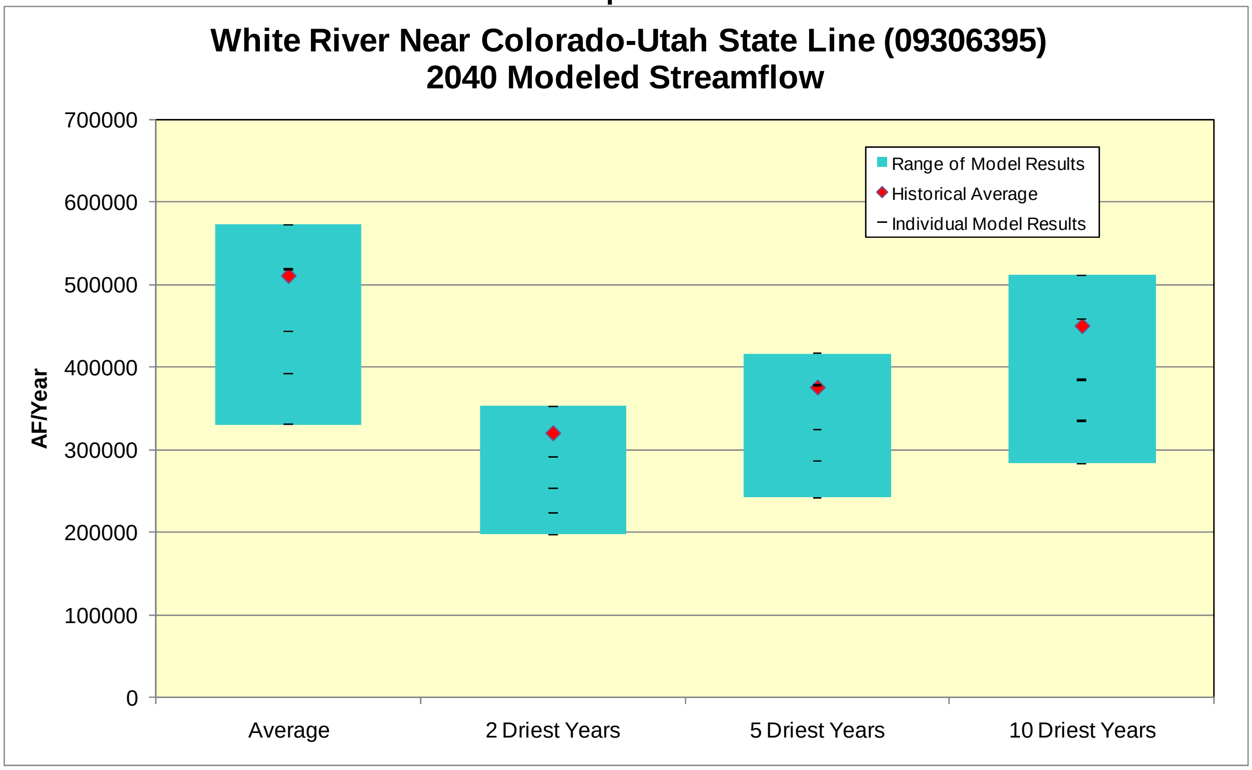

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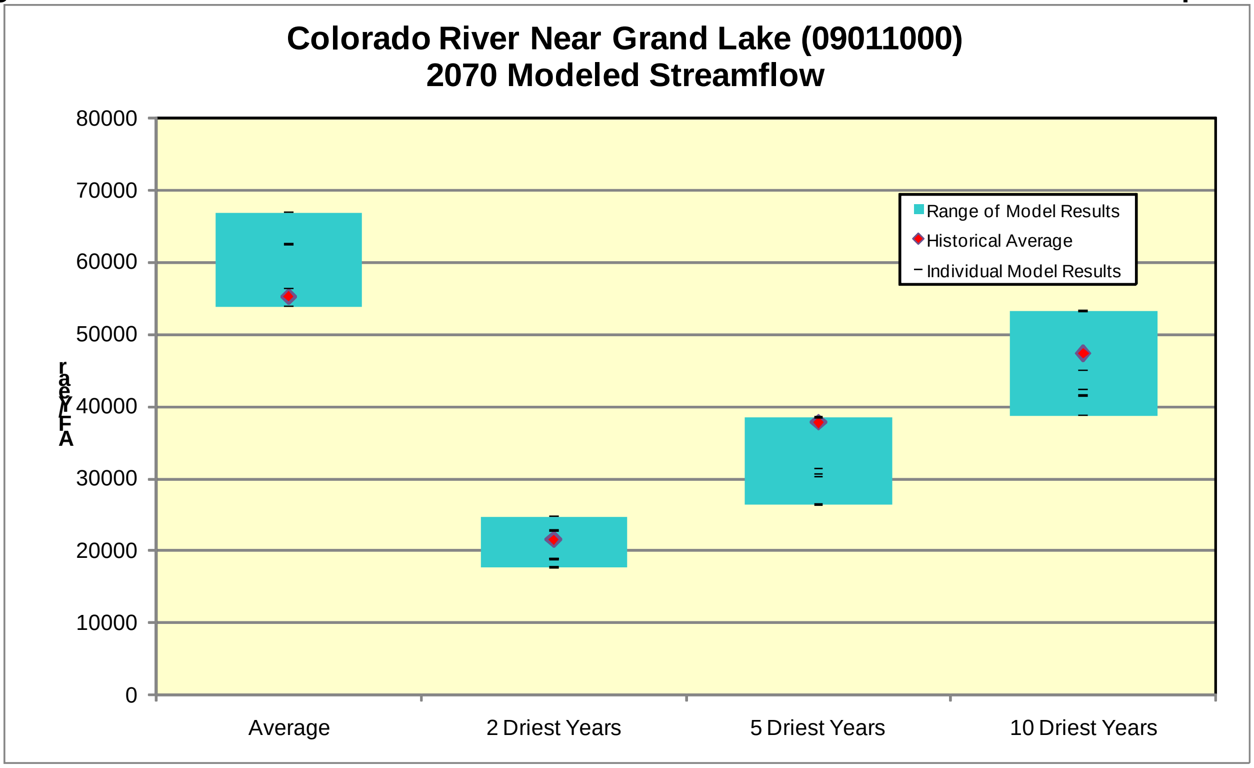

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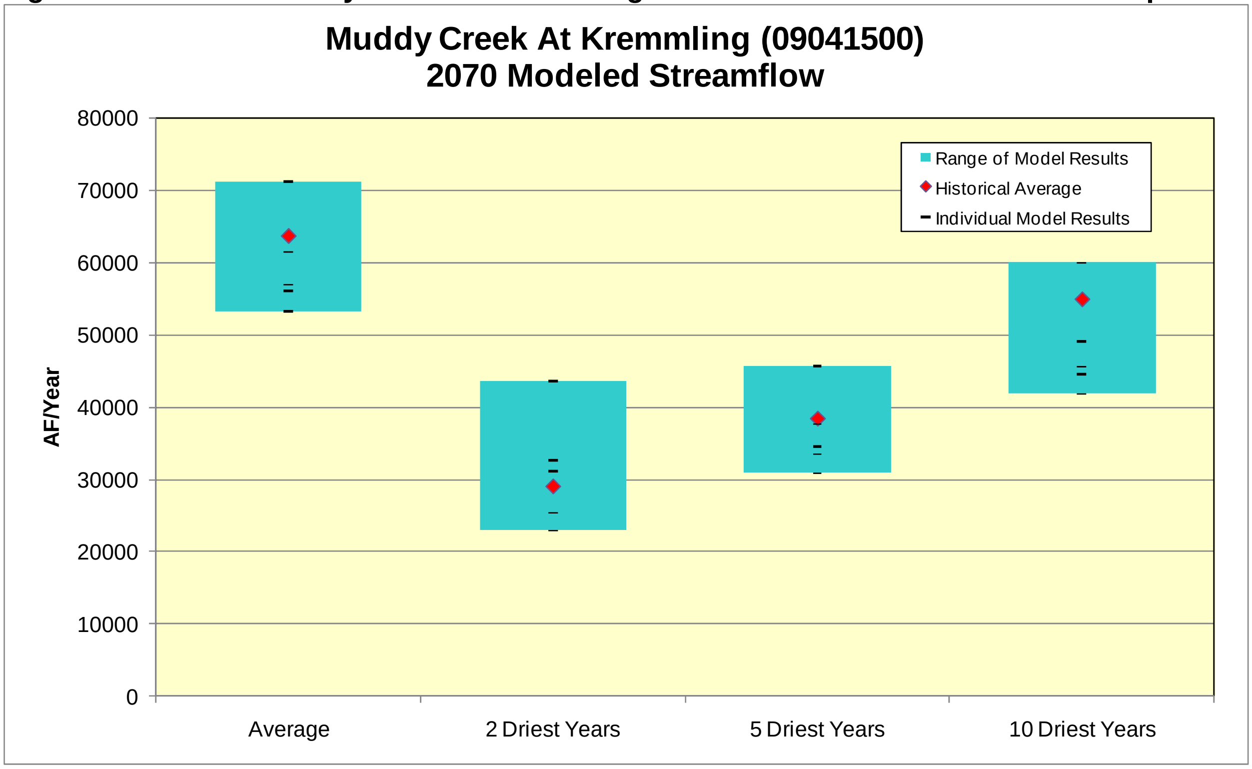

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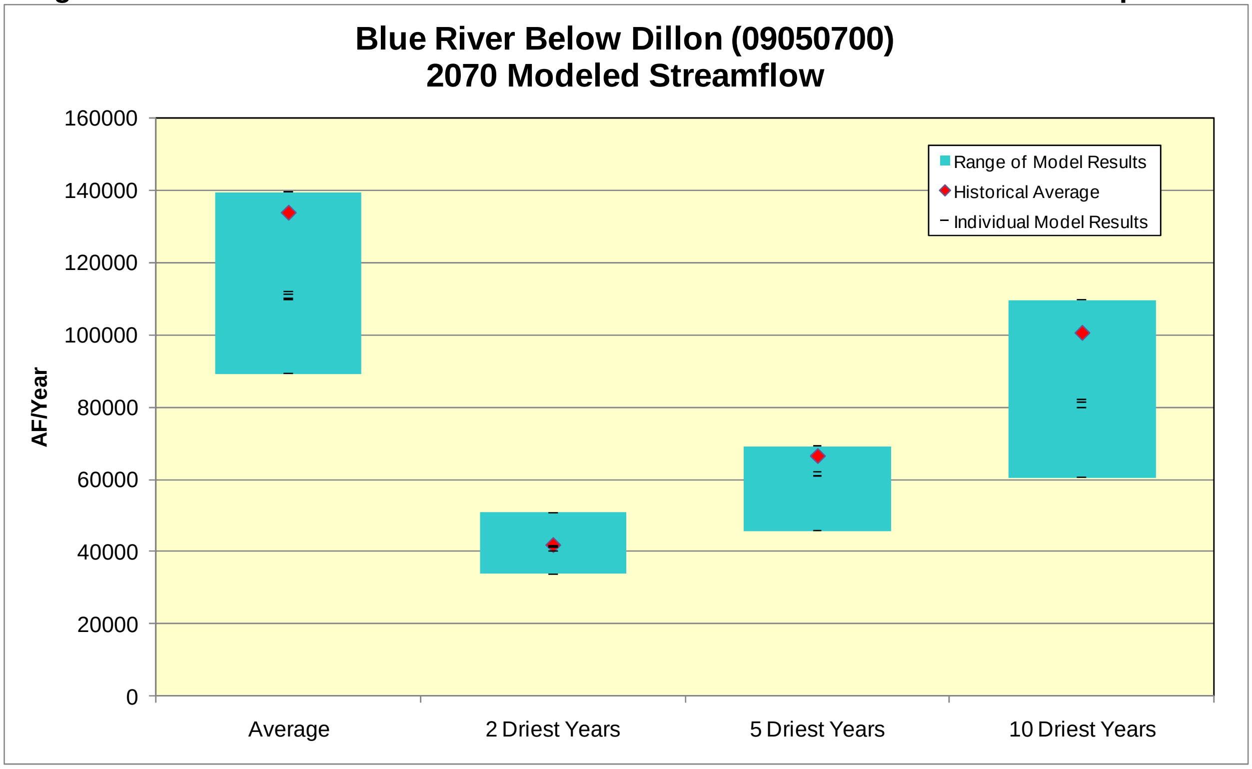

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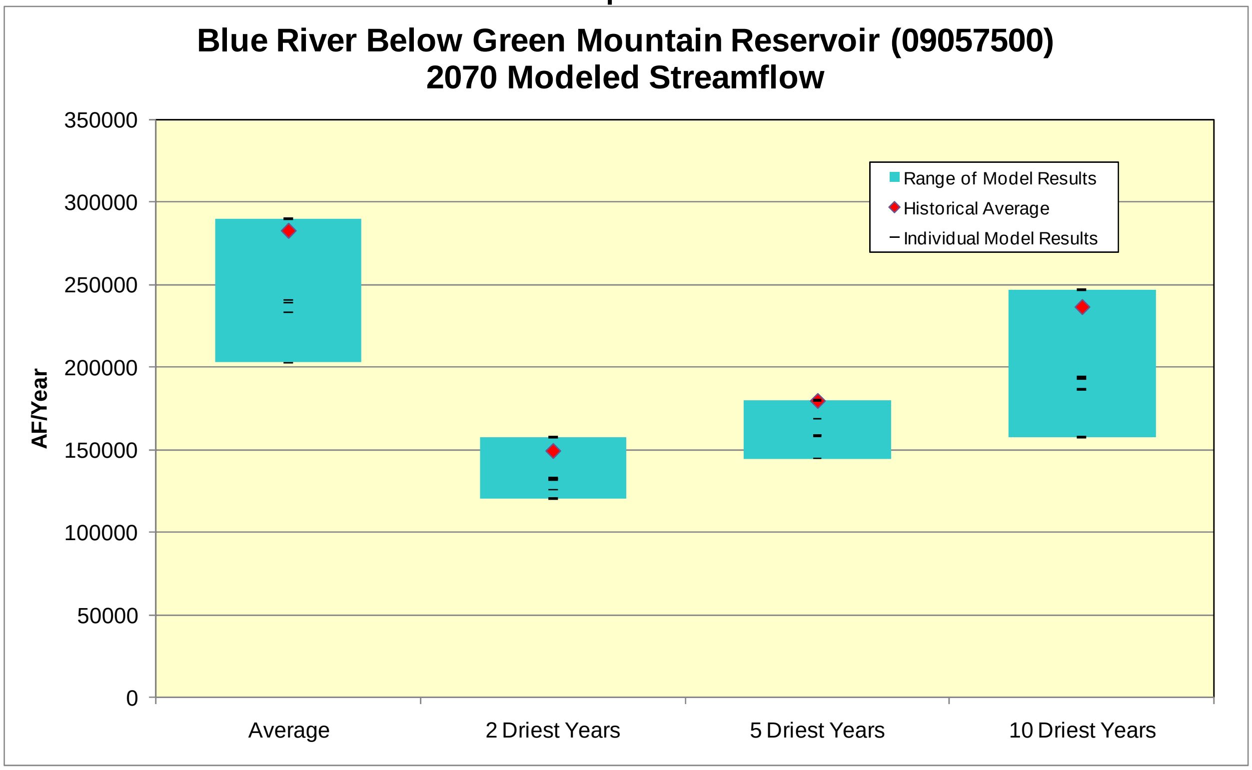
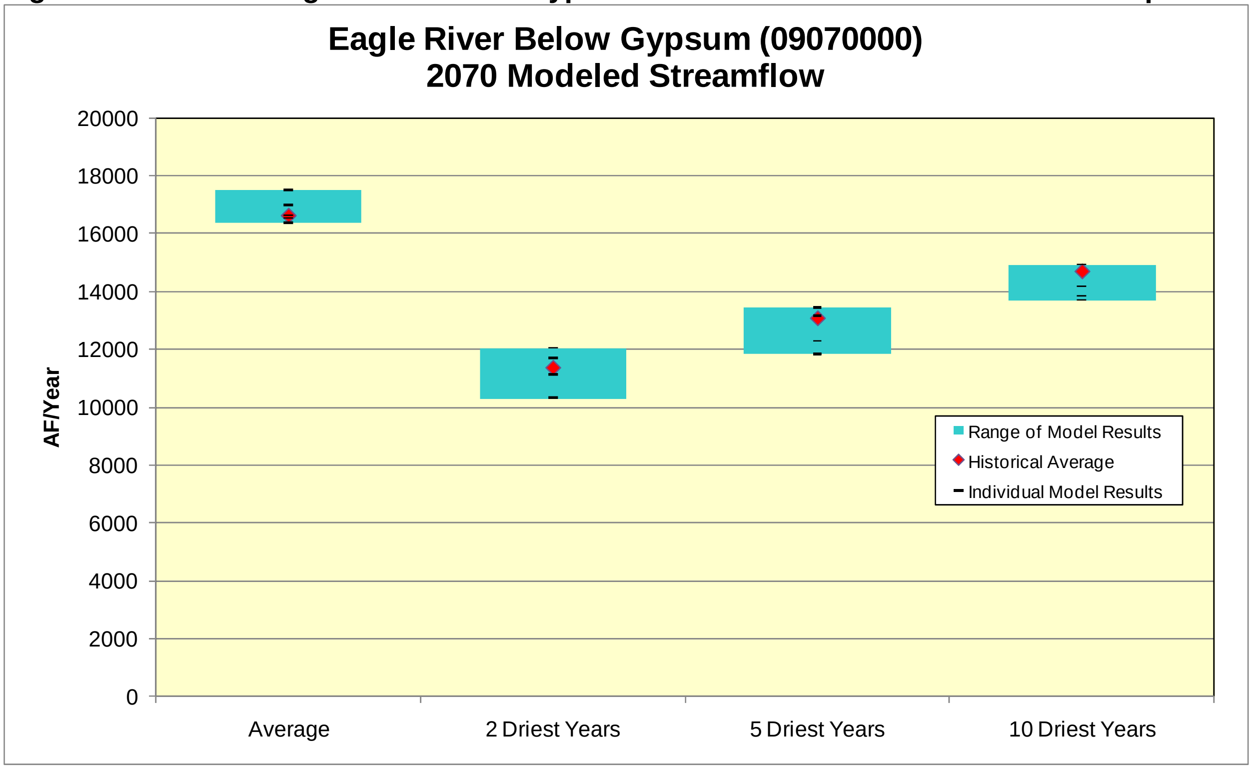


Figure E134 –2070 Eagle River below Gypsum Modeled Streamflow Low-flow Comparison



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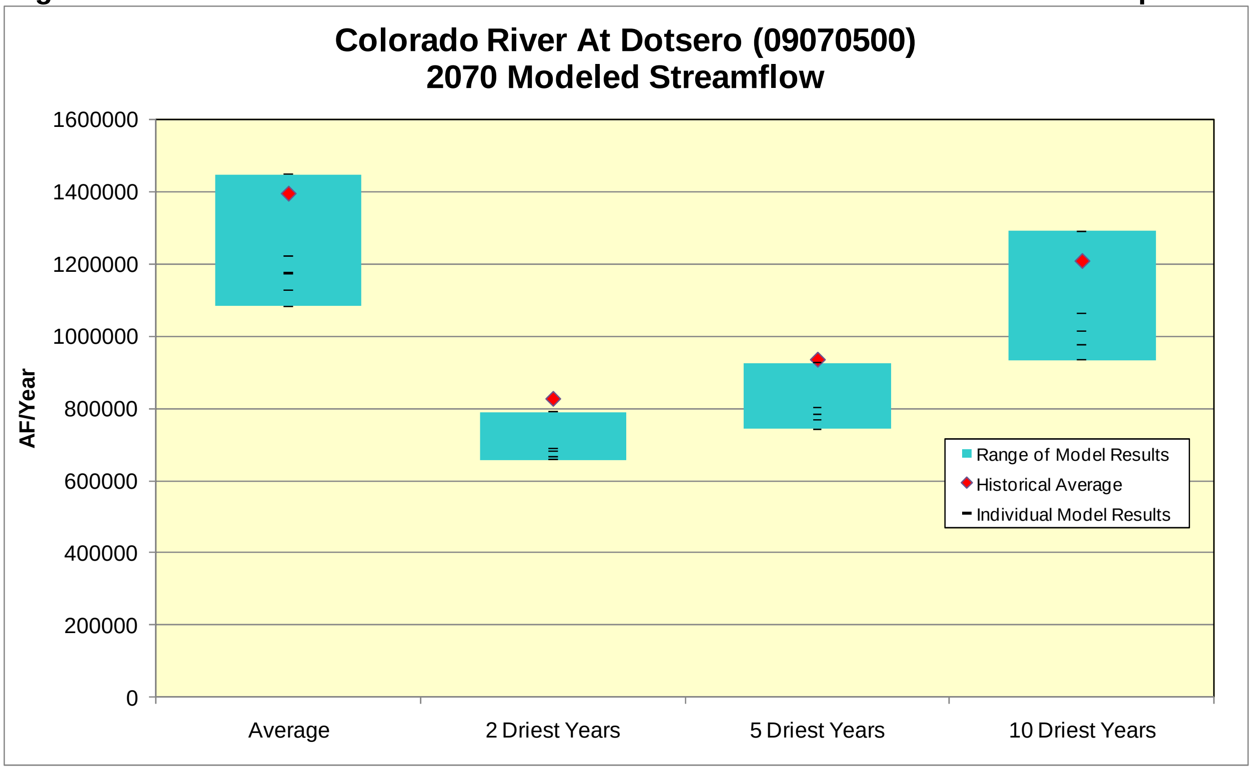
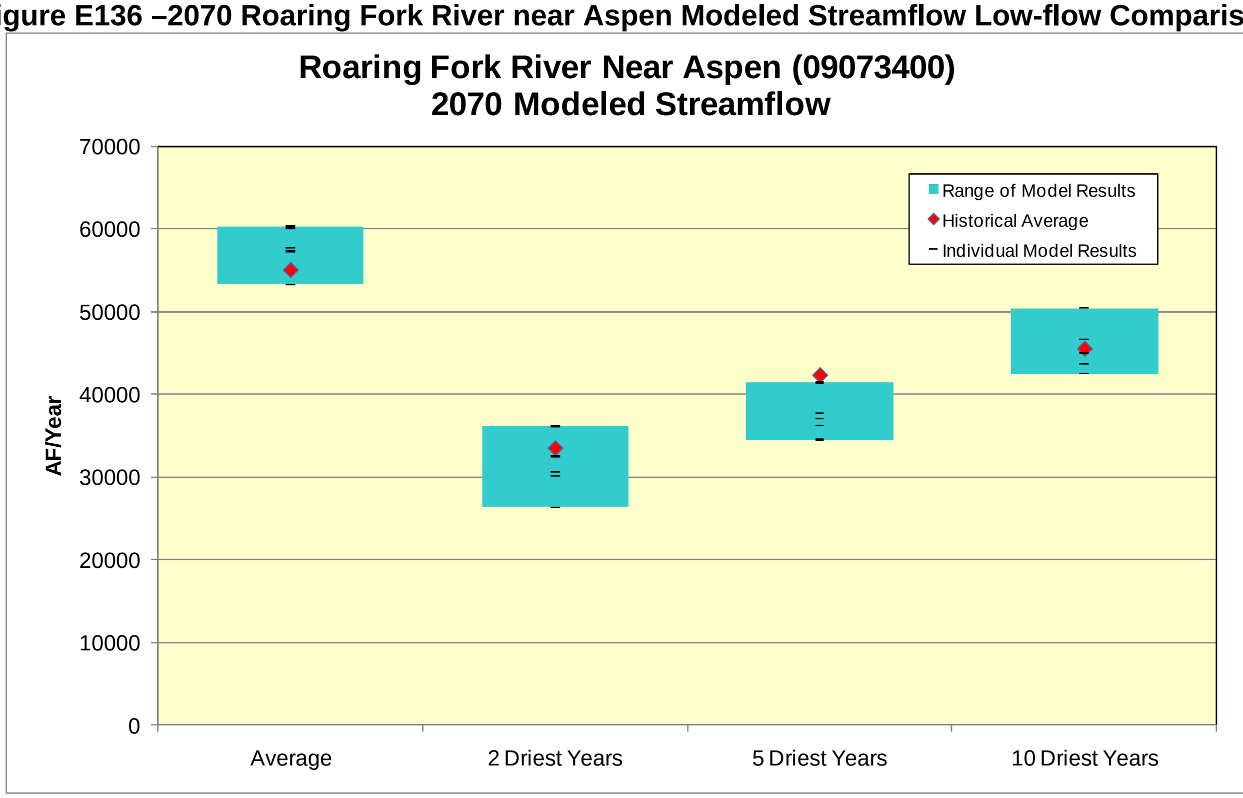


Figure E136 –2070 Roaring Fork River near Aspen Modeled Streamflow Low-flow Comparison



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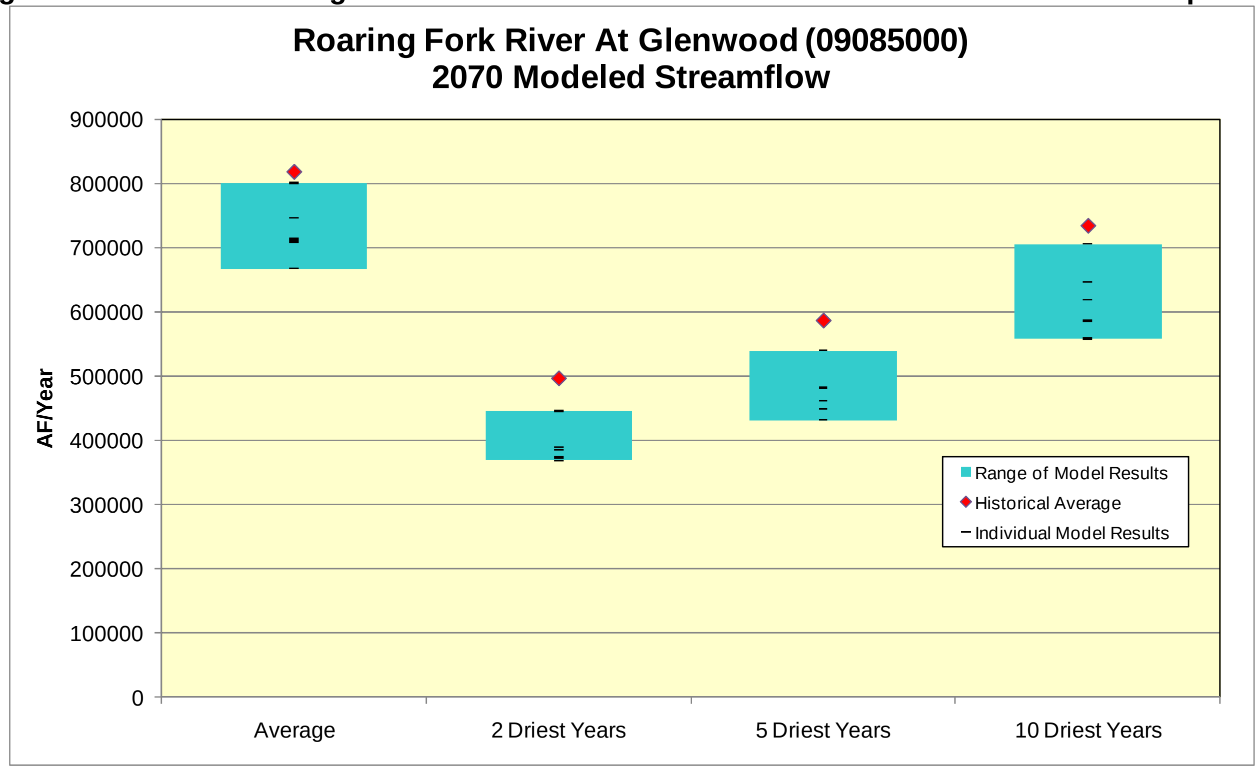

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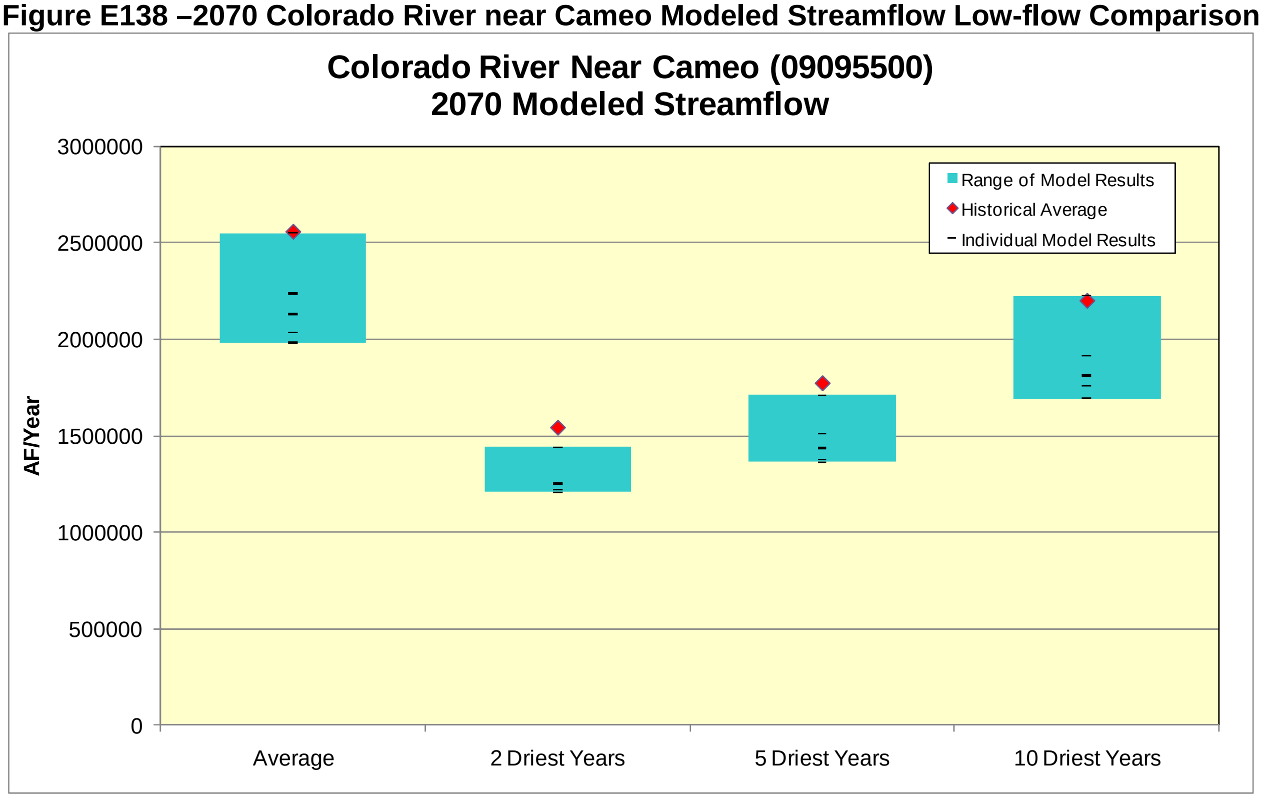

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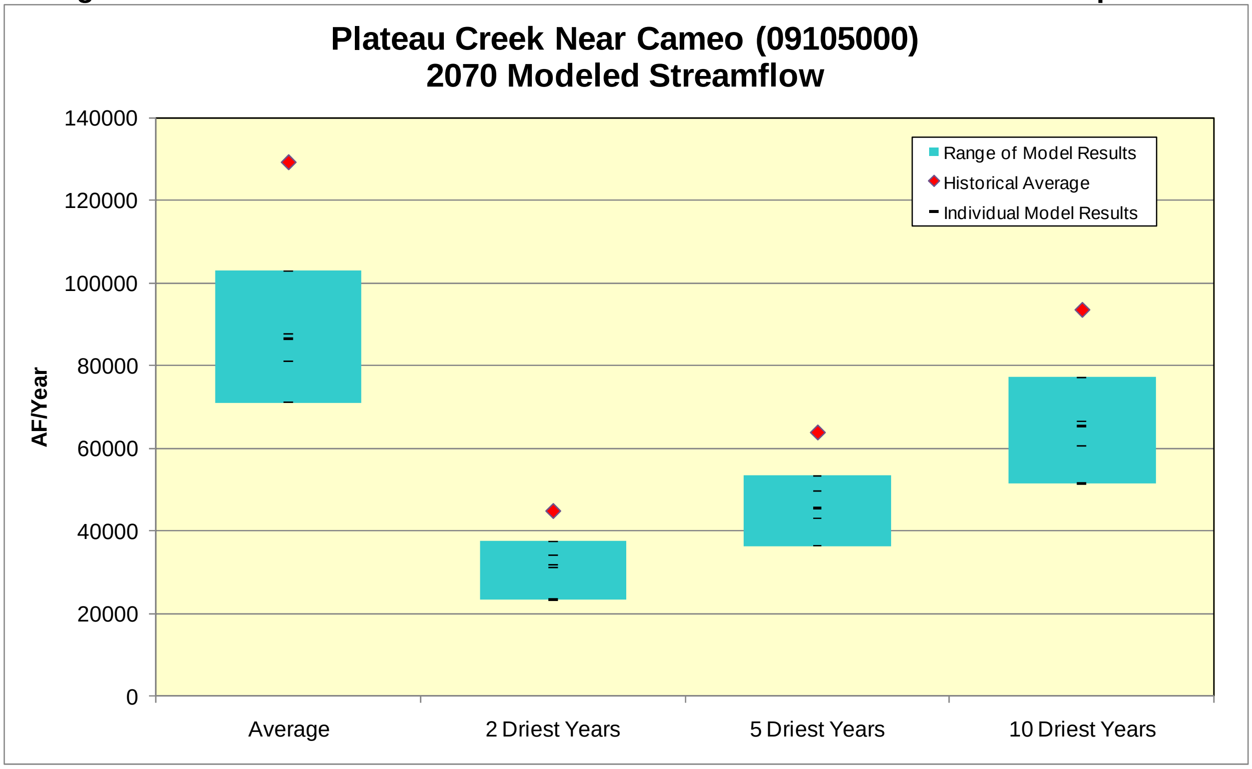

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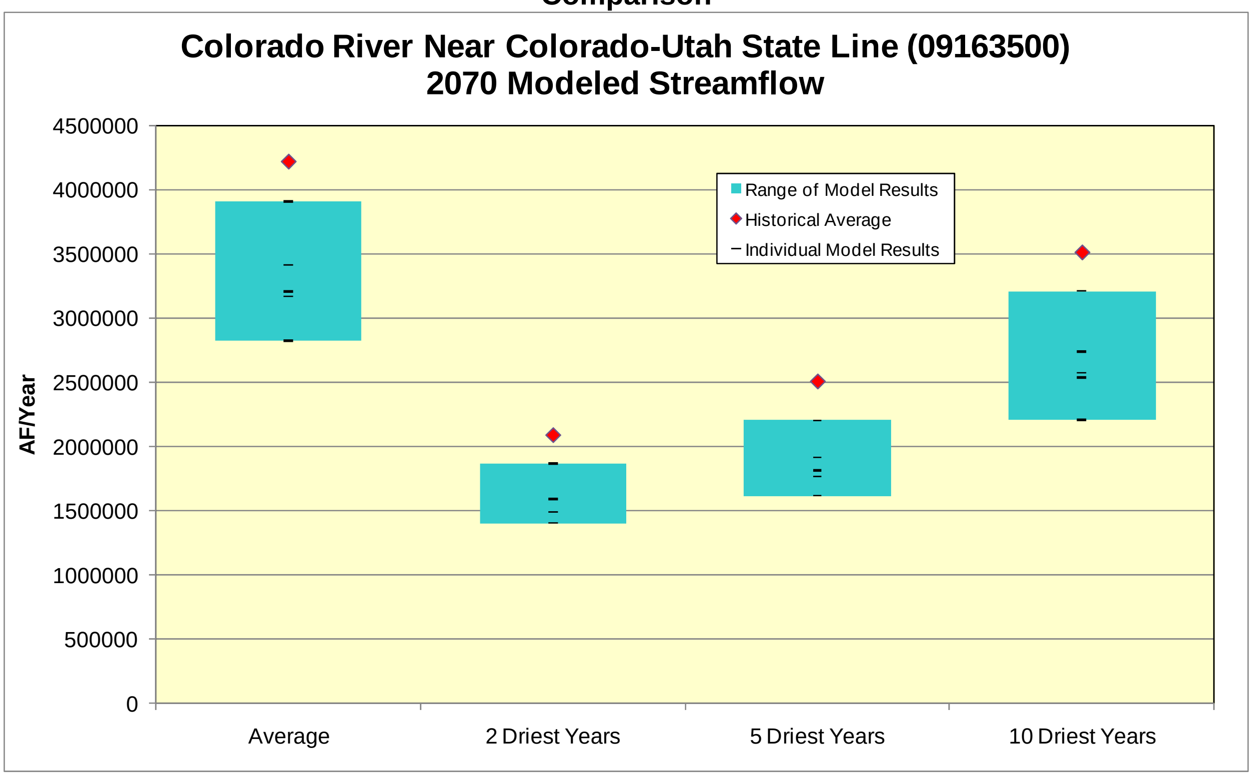


Figure E141 –2070 East River at Almont Modeled Streamflow Low-flow Comparison

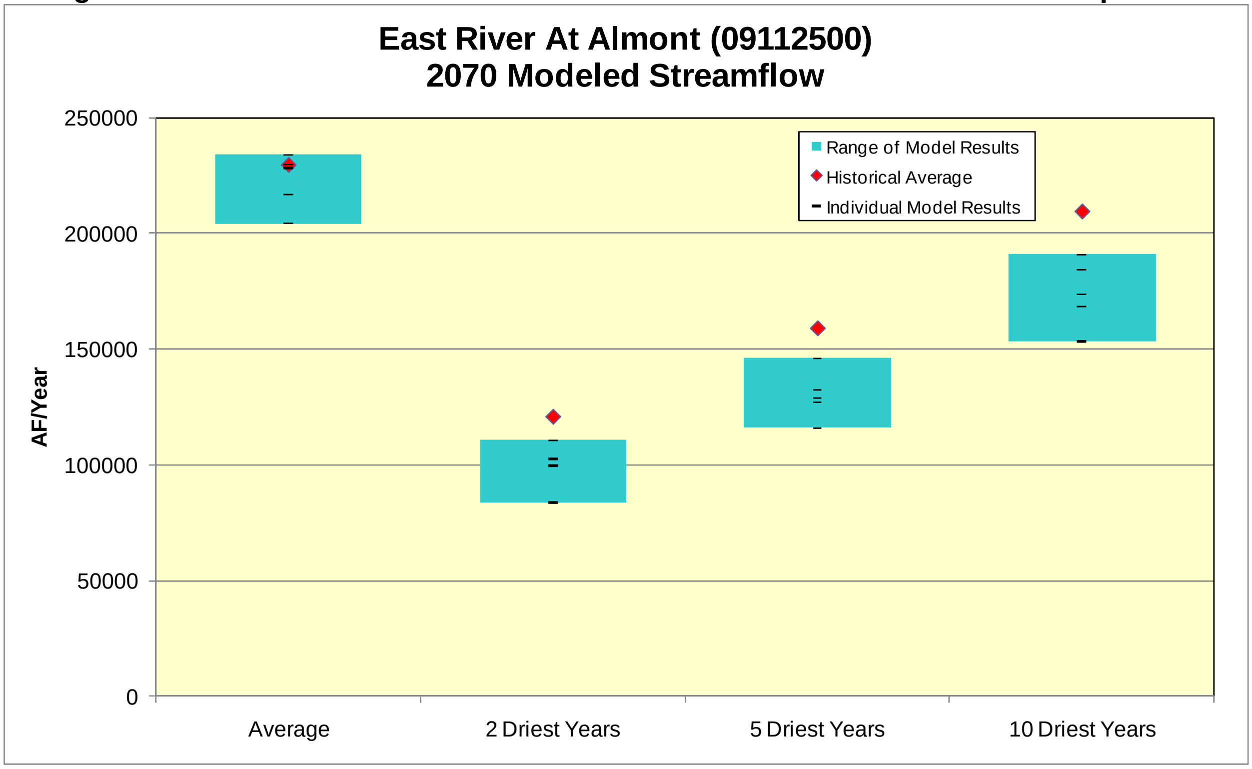
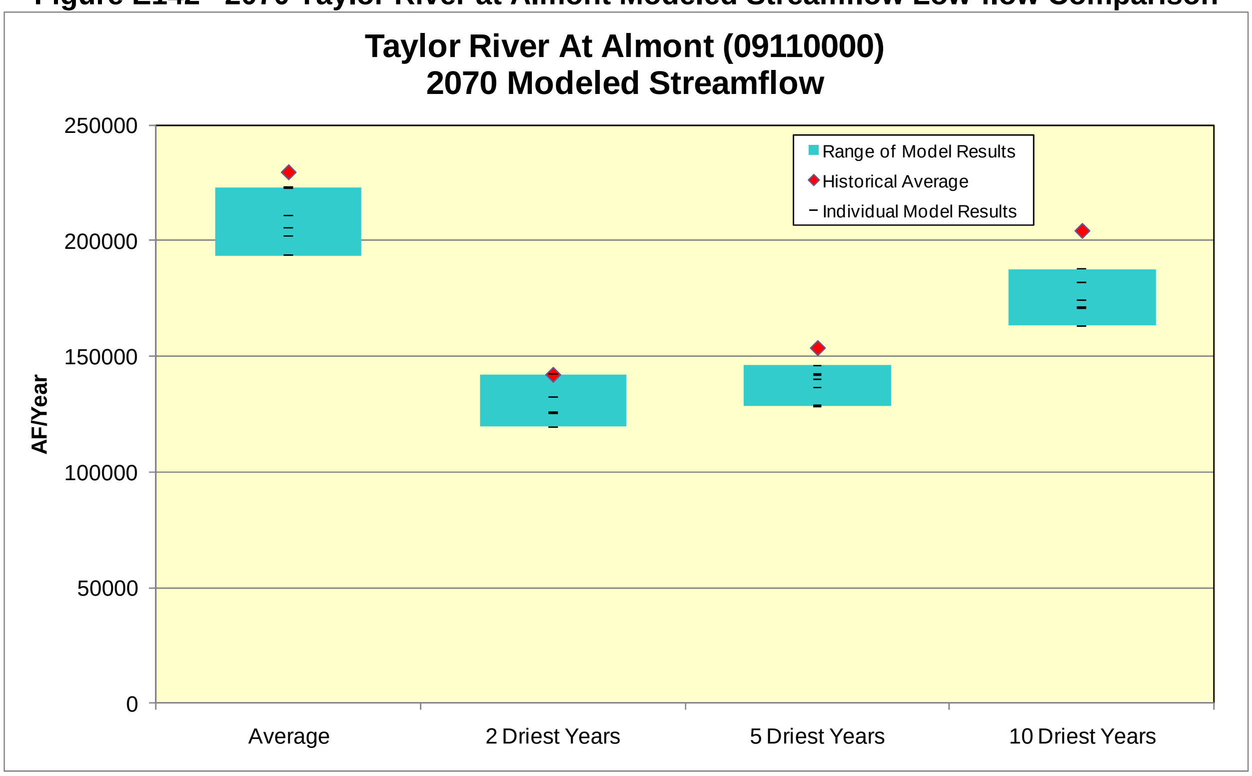


Figure E142 –2070 Taylor River at Almont Modeled Streamflow Low-flow Comparison



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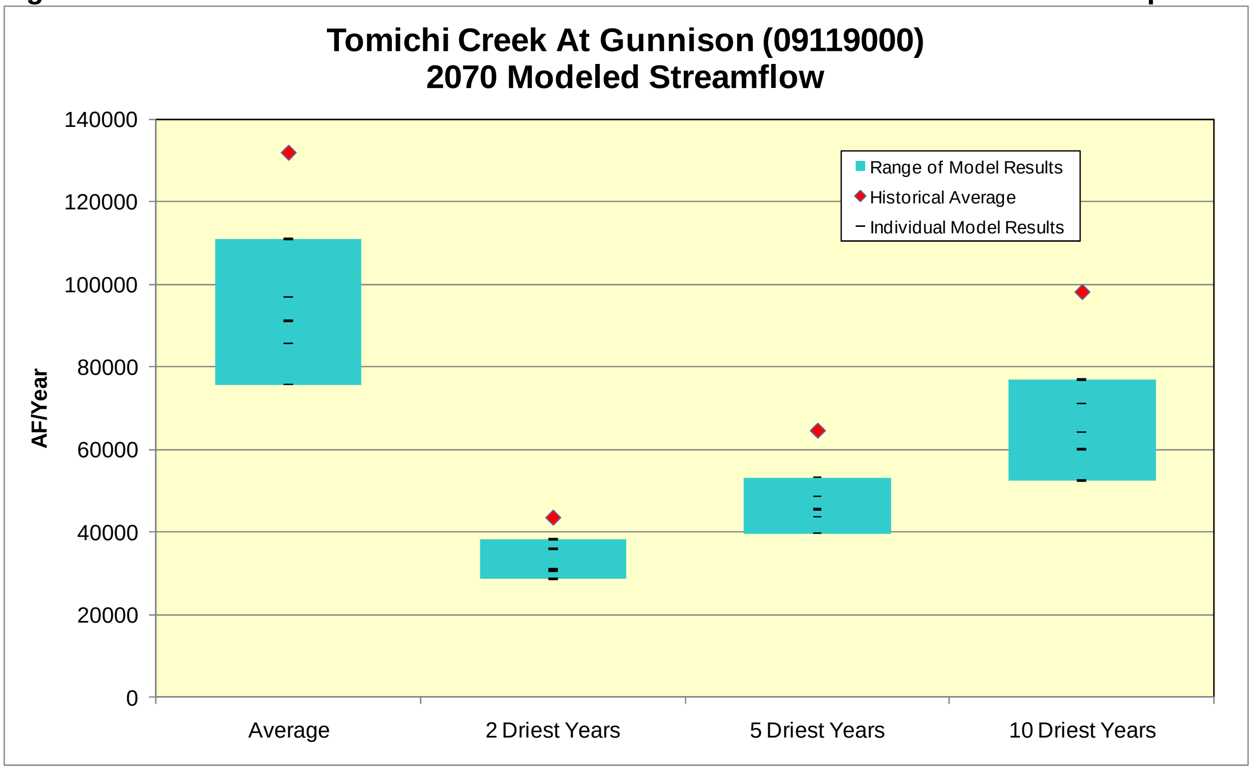

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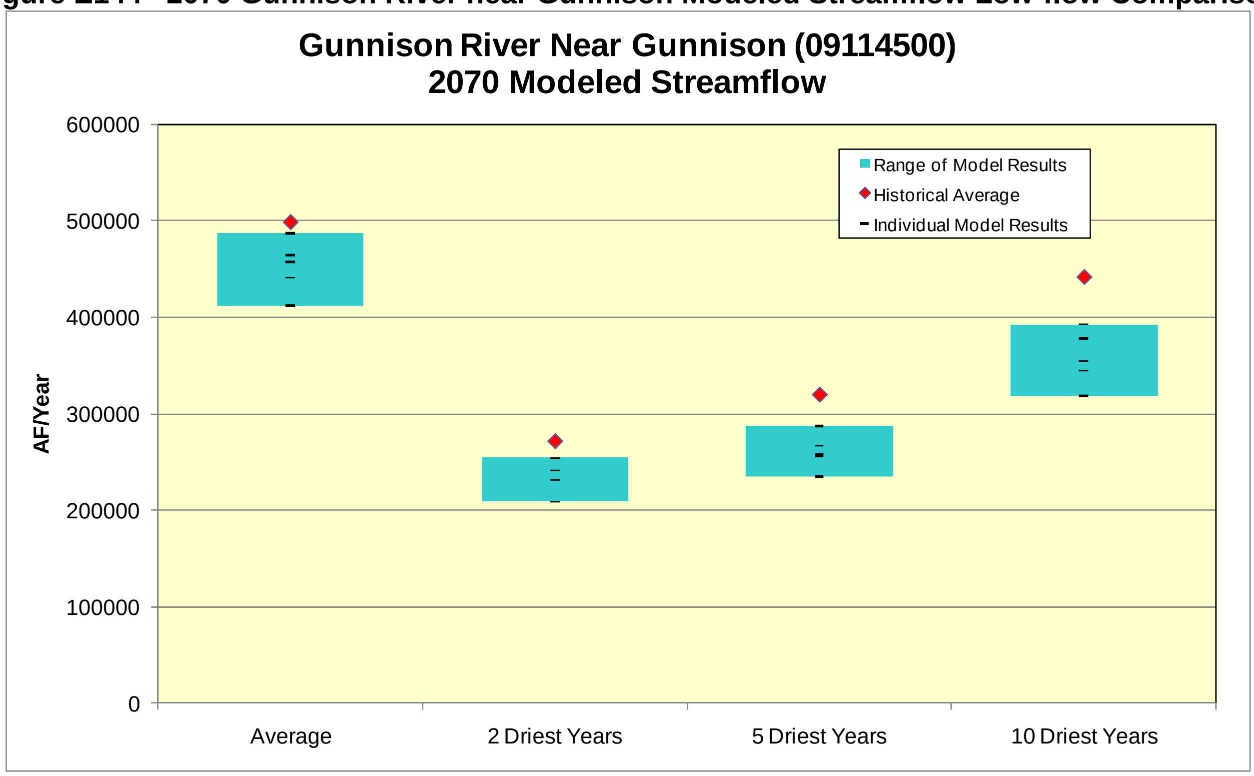

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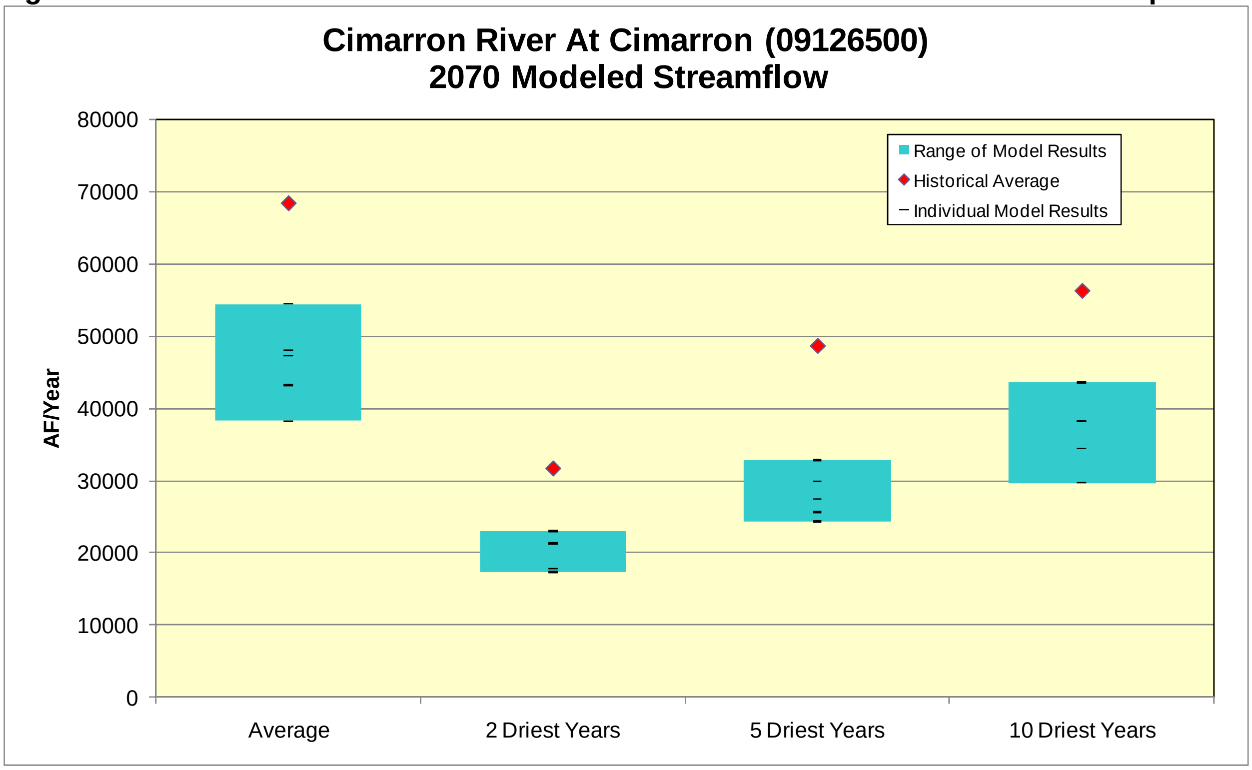

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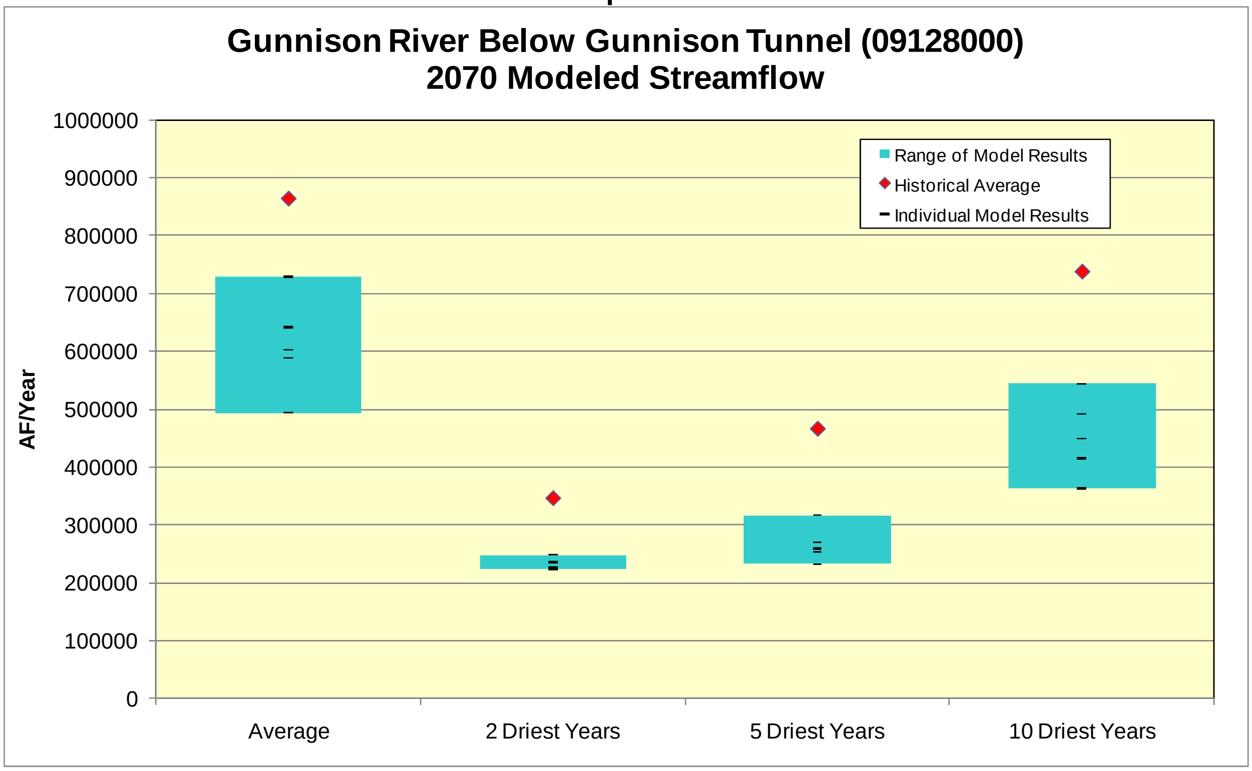

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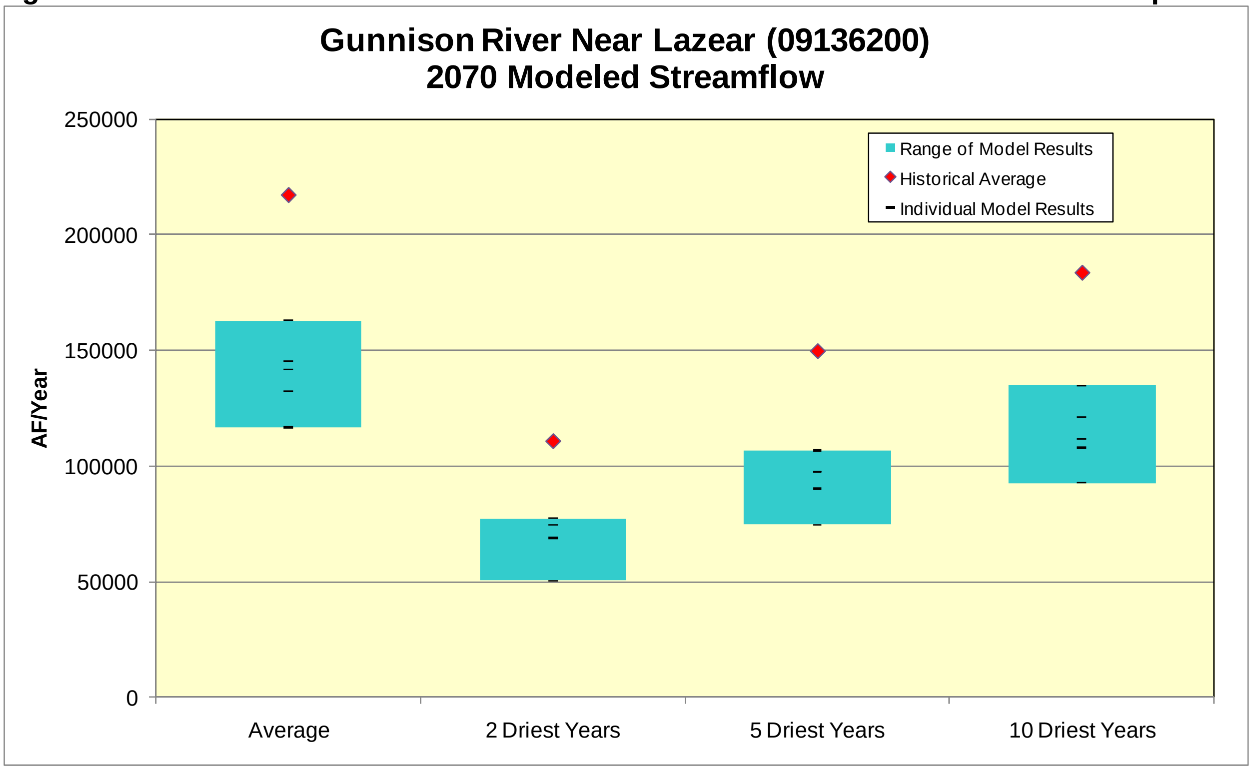

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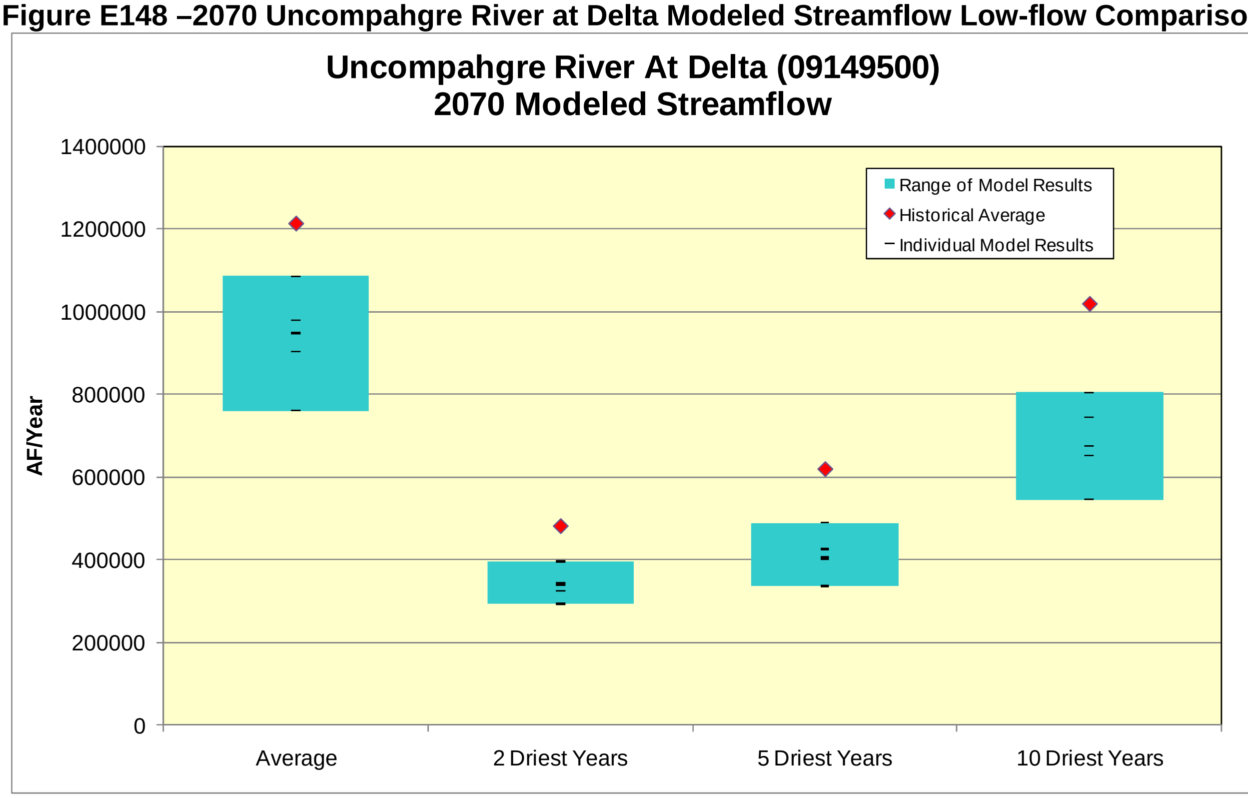

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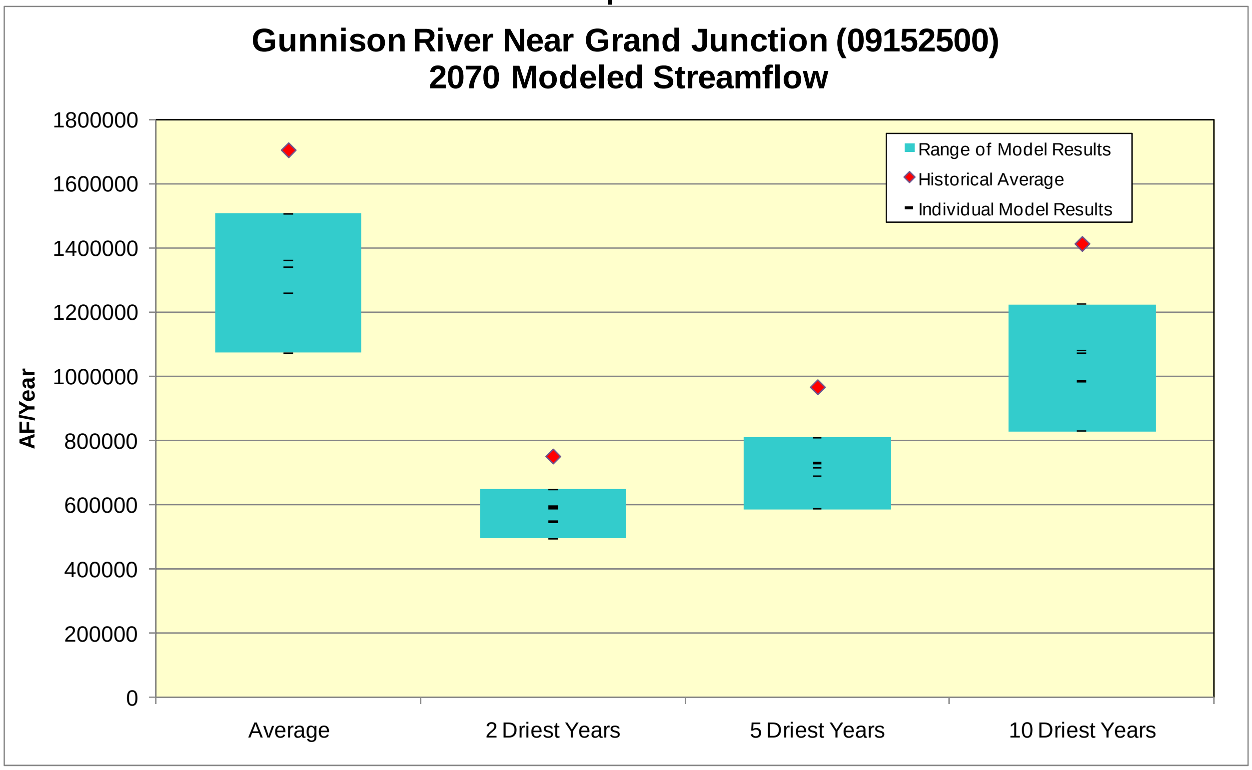

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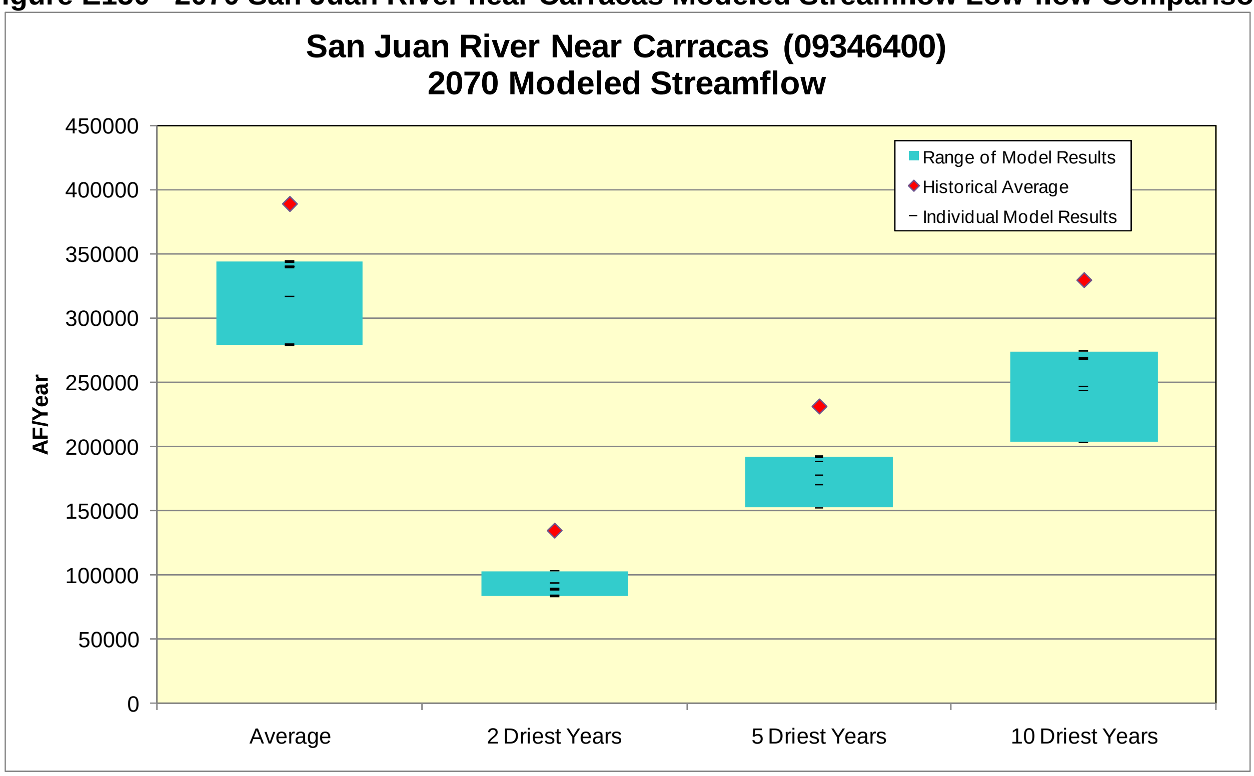

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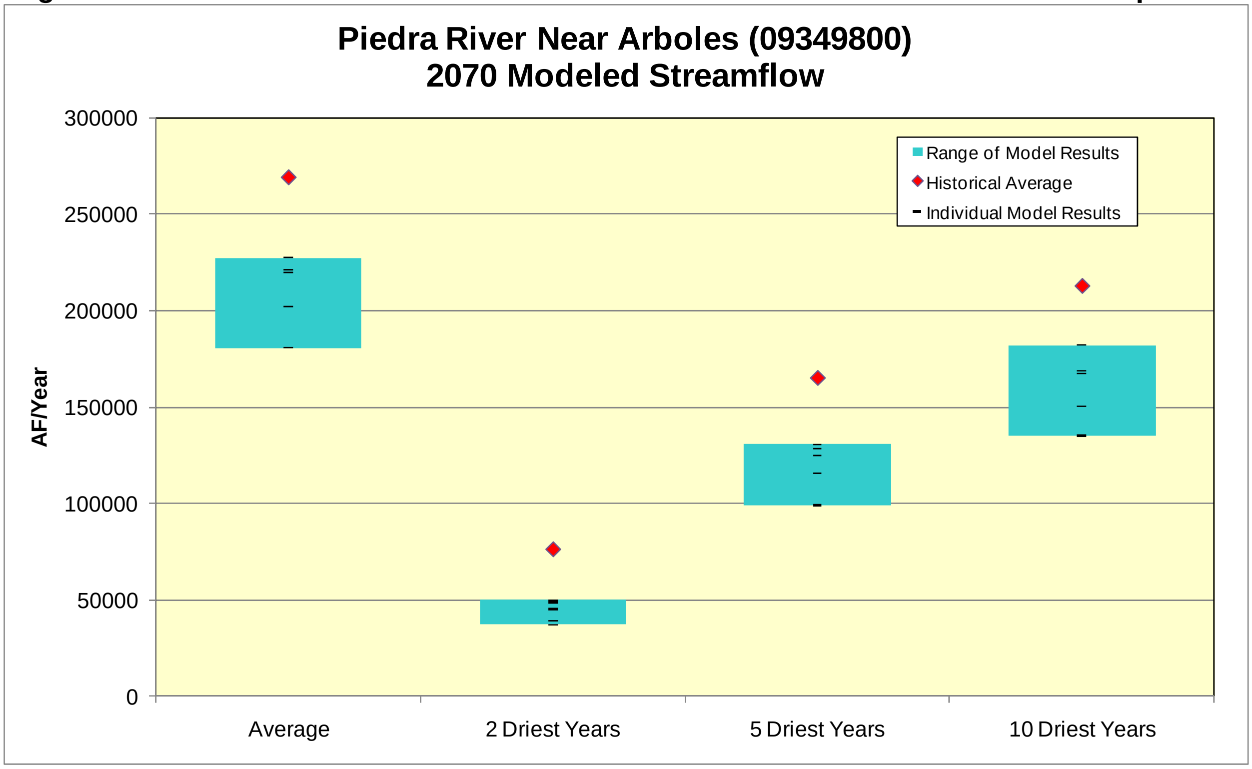


Figure E152 –2070 Los Pinos River at La Boca Modeled Streamflow Low-flow Comparison

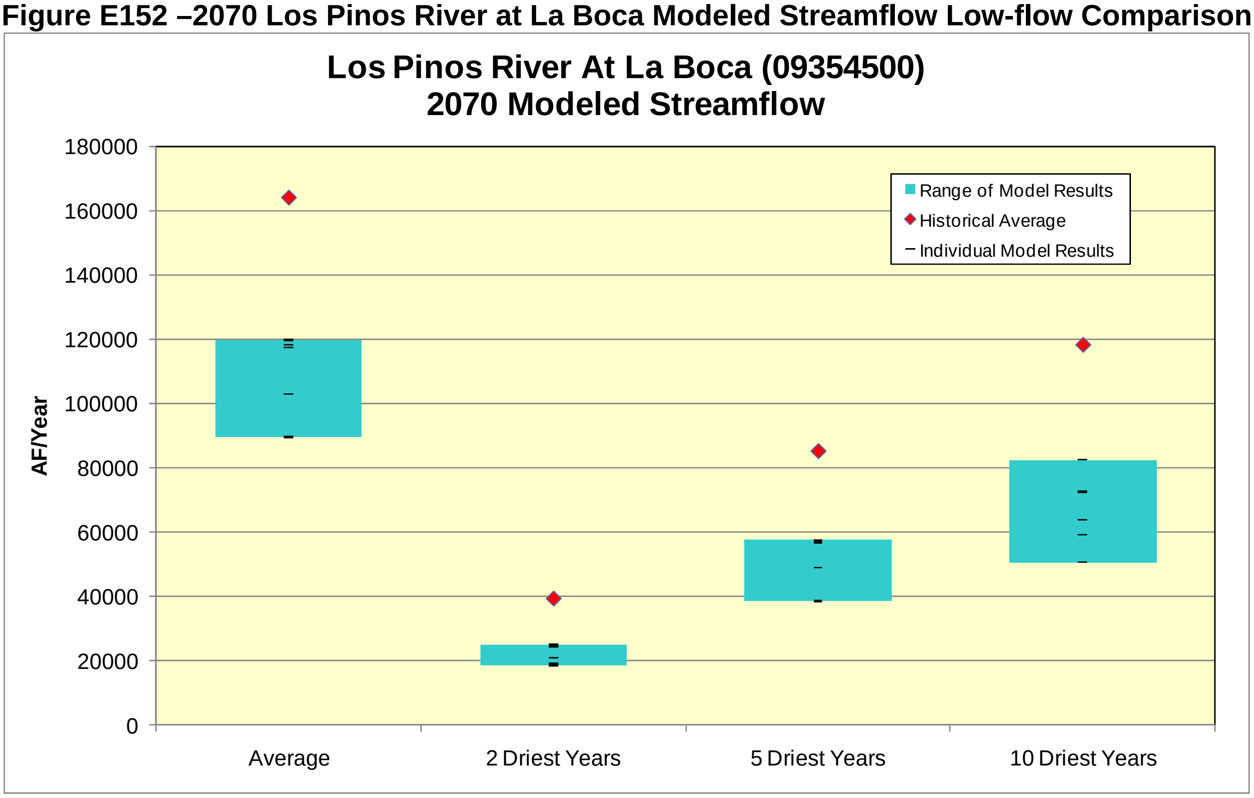
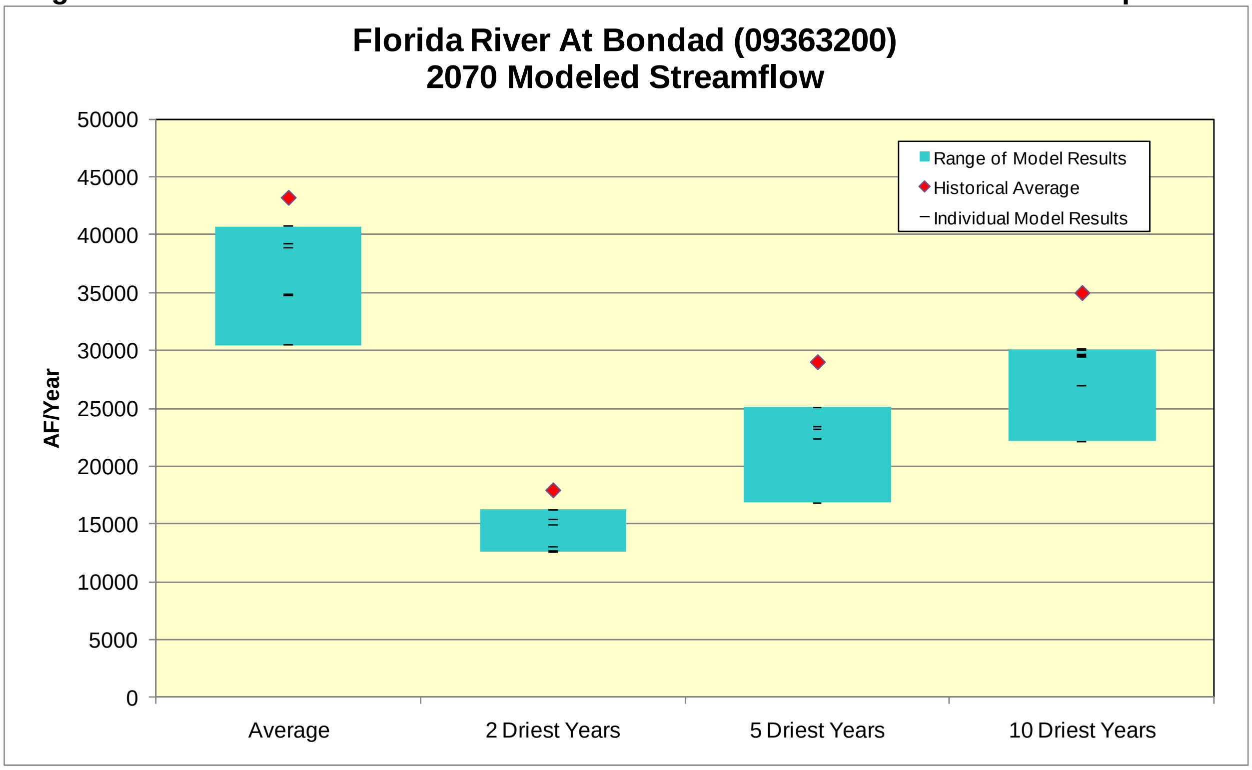


Figure E153 –2070 Florida River at Bondad Modeled Streamflow Low-flow Comparison



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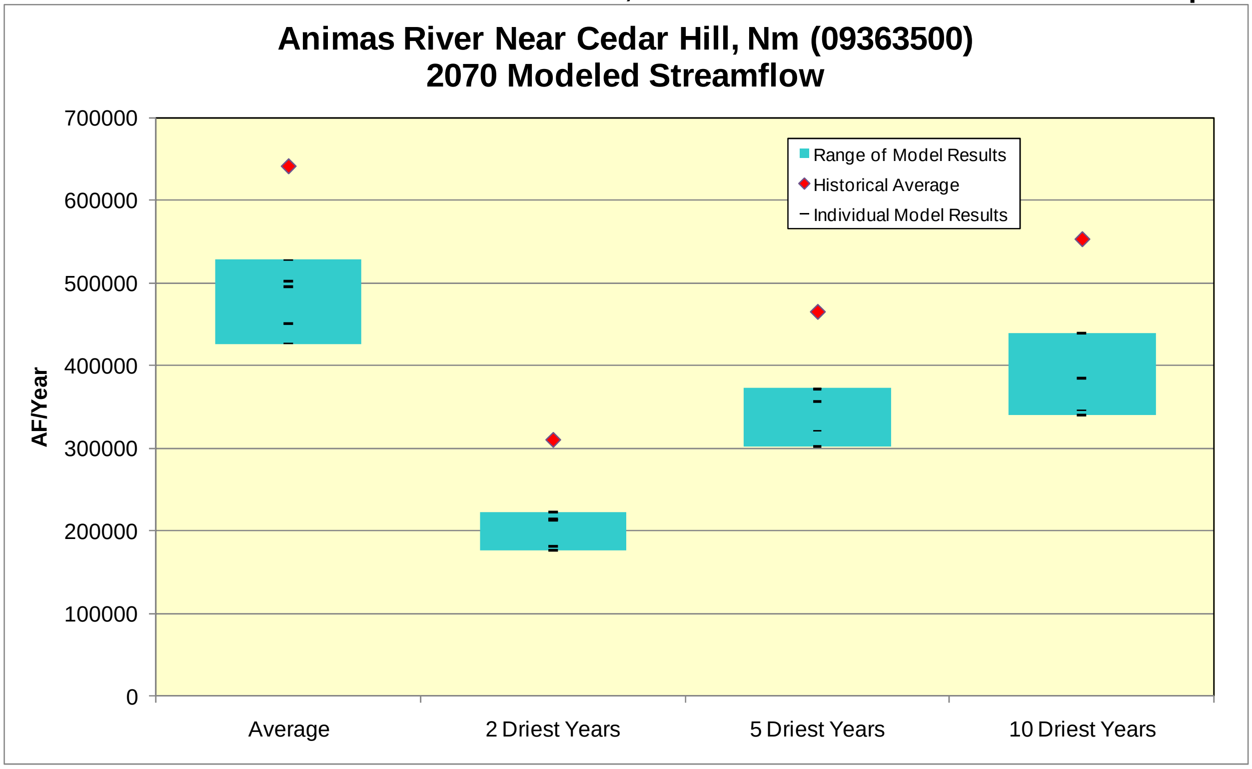


Figure E155 –2070 La Plata River at Hesperus Modeled Streamflow Low-flow Comparison

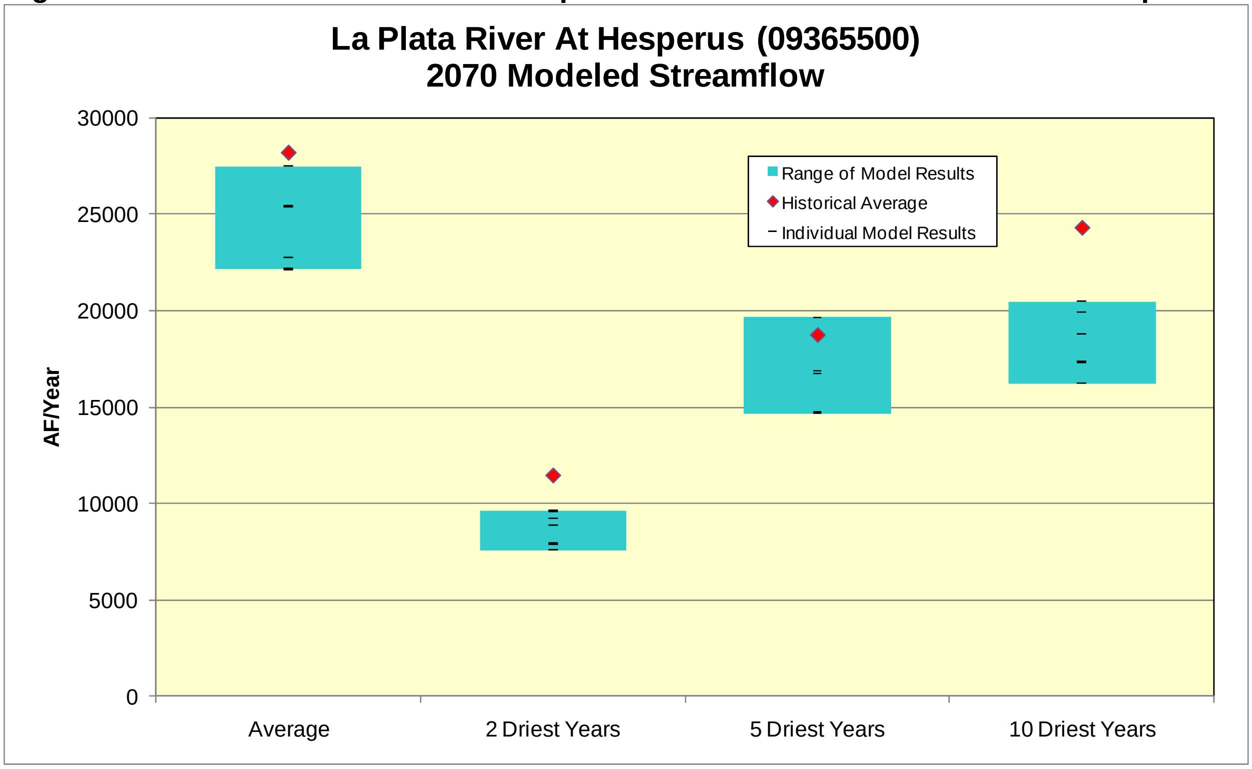


Figure E156 –2070 La Plata River at CO-NM State Line Modeled Streamflow Low-flow Comparison

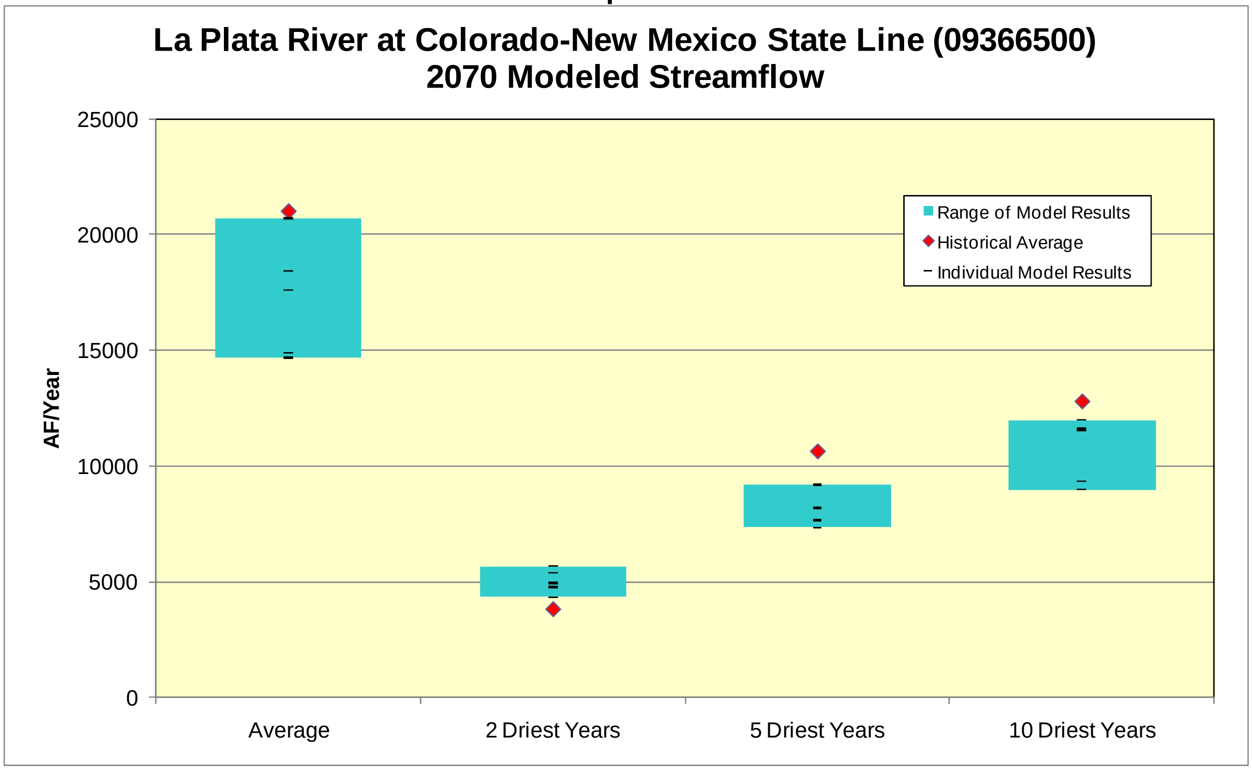


Figure E157 –2070 Mancos River near Towaoc Modeled Streamflow Low-flow Comparison

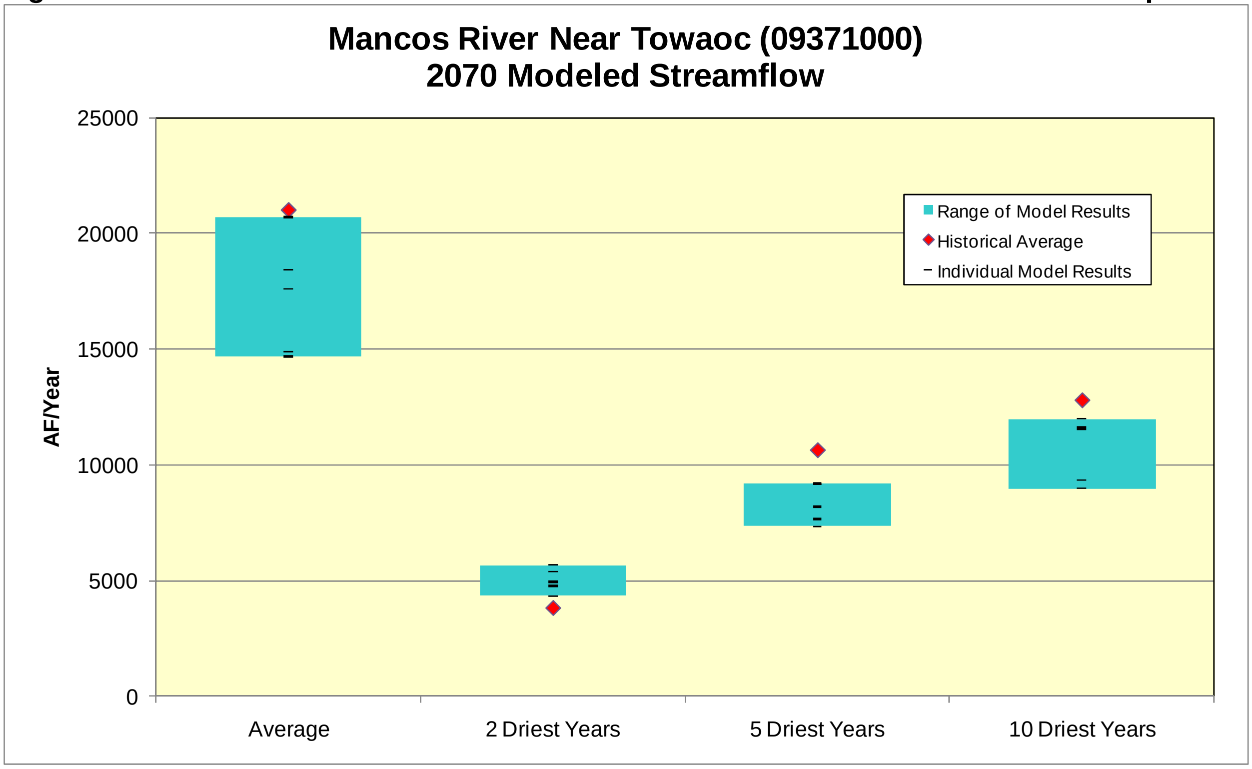
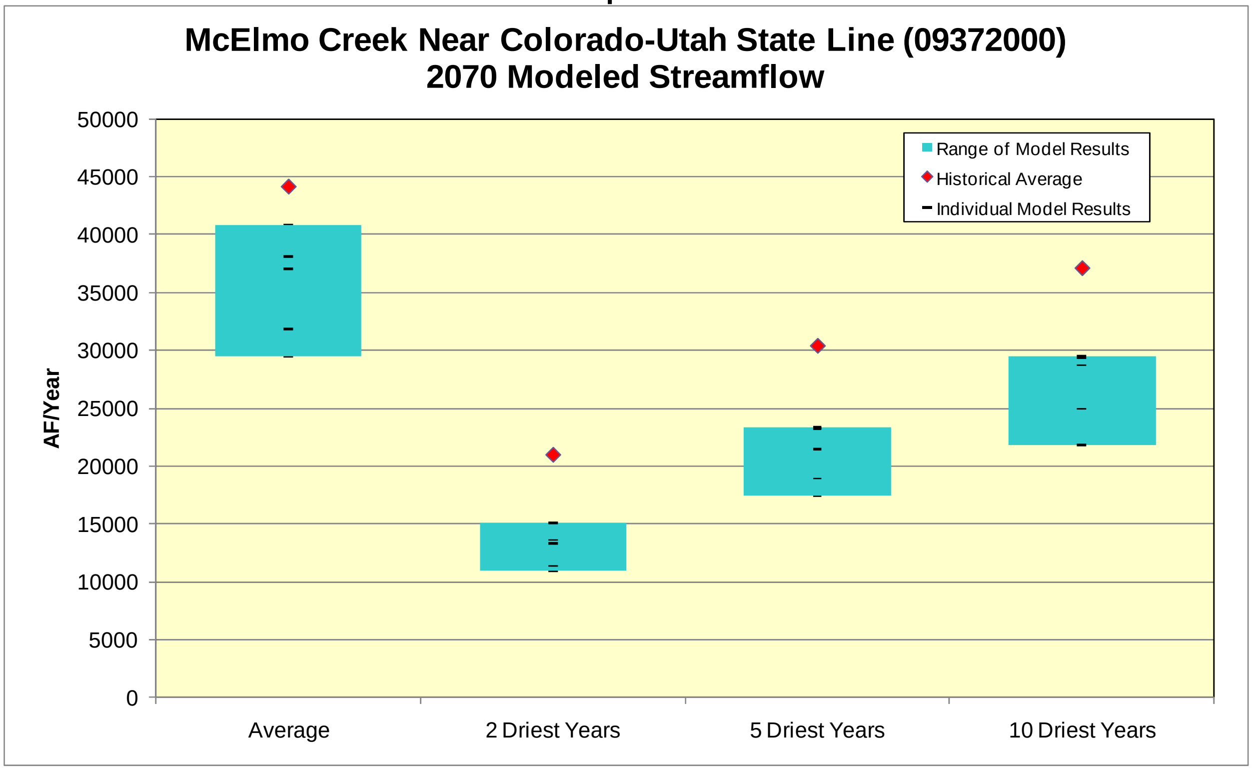


Figure E158 –2070 McElmo Creek near CO-UT State Line Modeled Streamflow Low-flow Comparison



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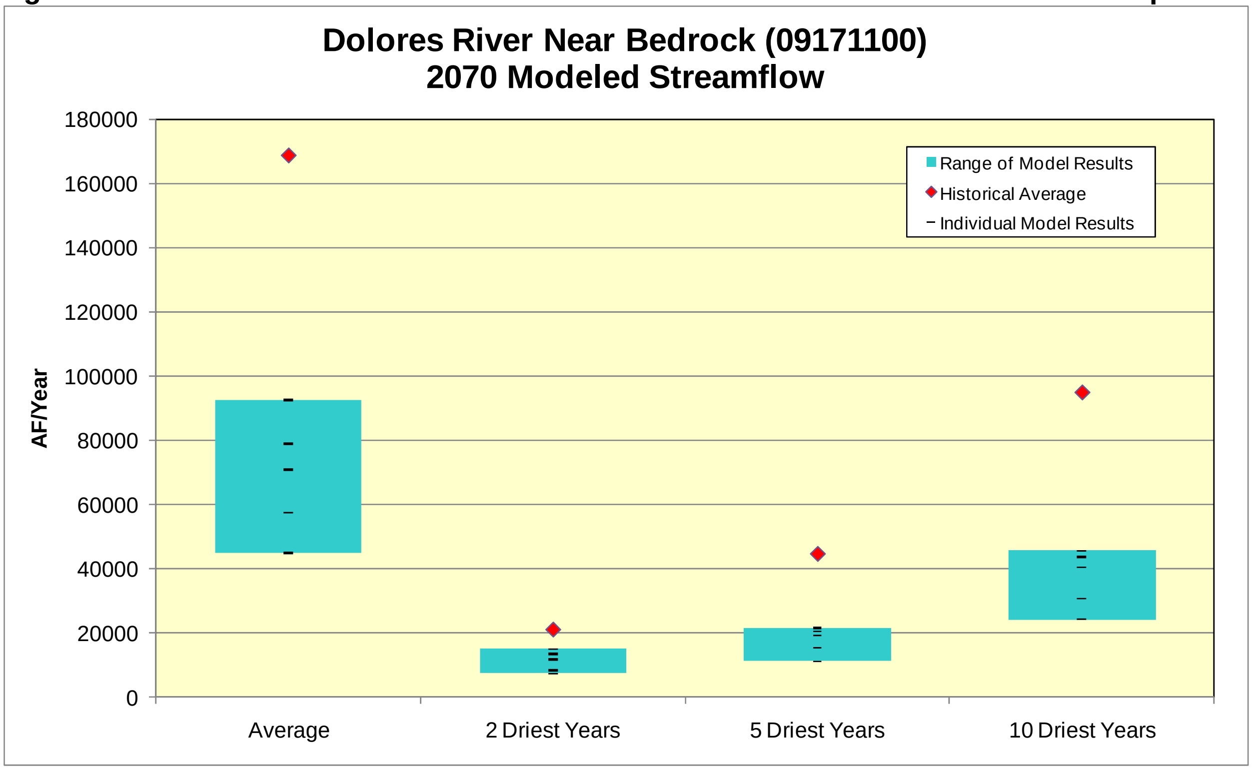


Figure E160 –2070 San Miguel River at Naturita Modeled Streamflow Low-flow Comparison

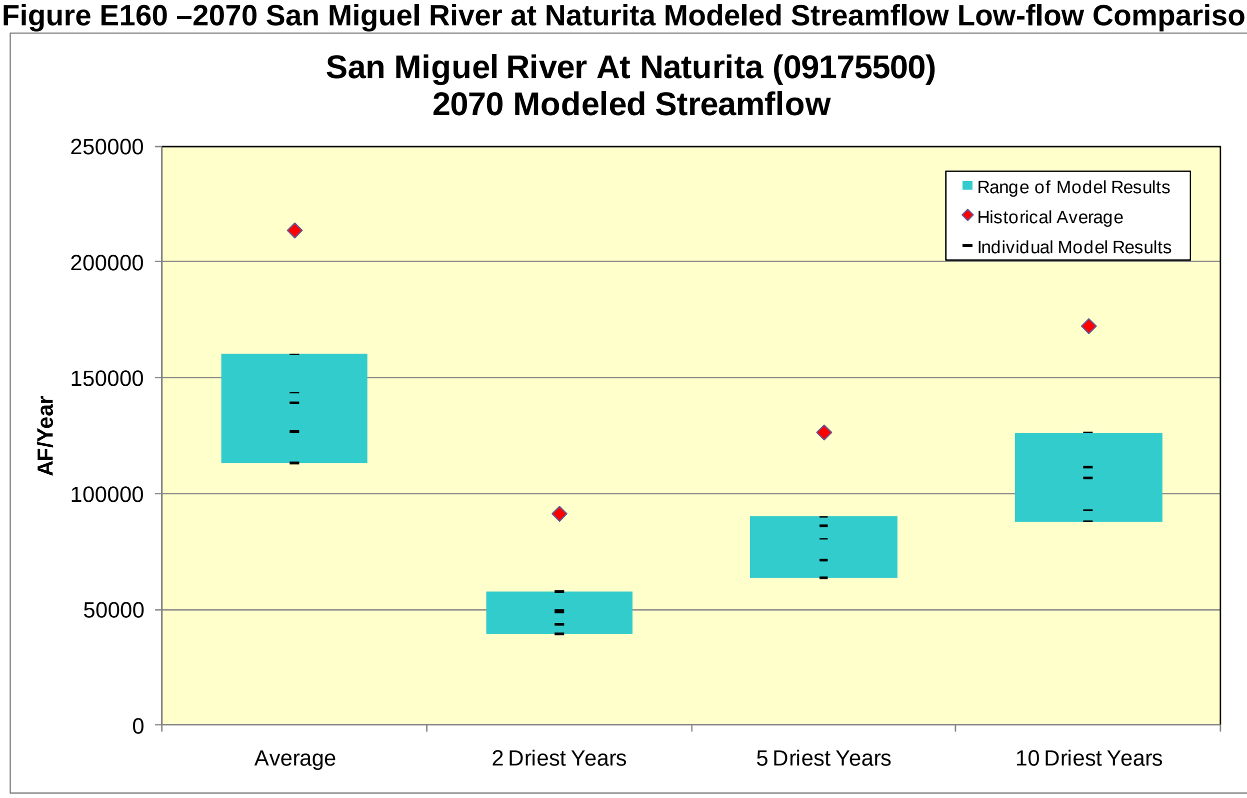


Figure E161 –2070 Yampa River below Stagecoach Reservoir Modeled Streamflow Low-flow Comparison

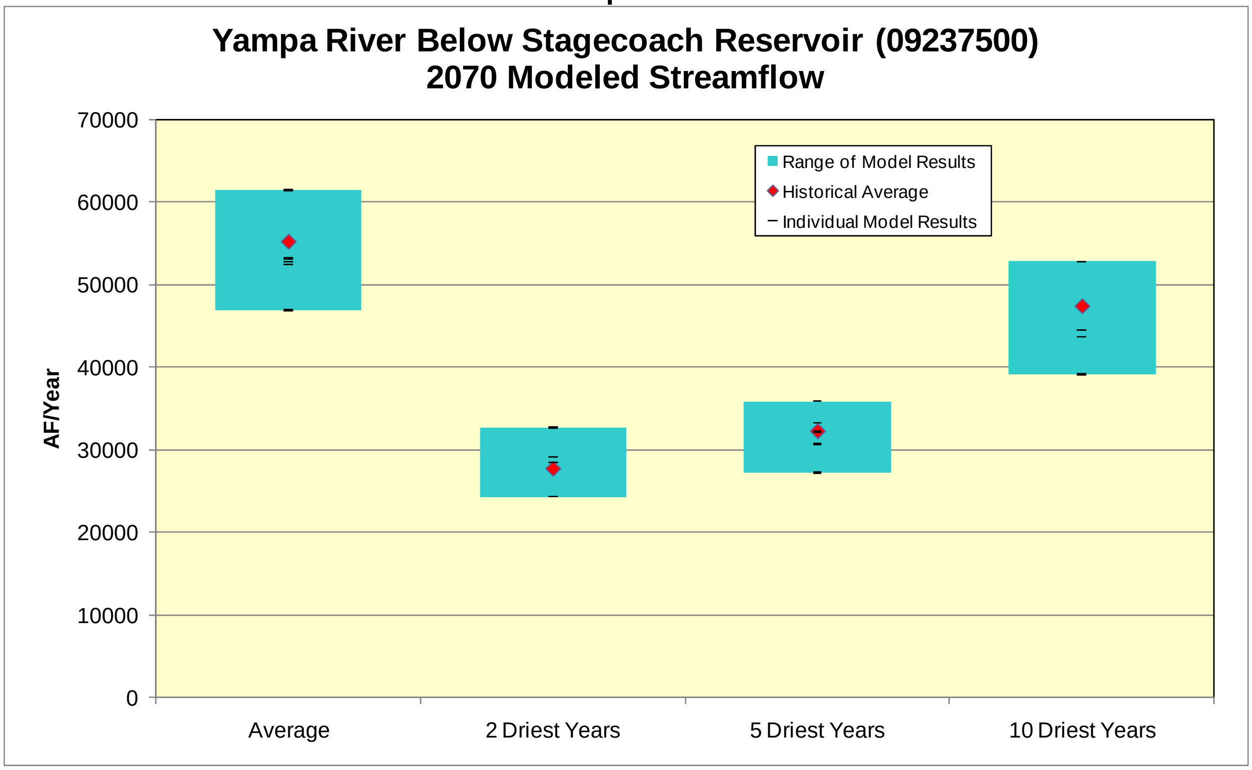
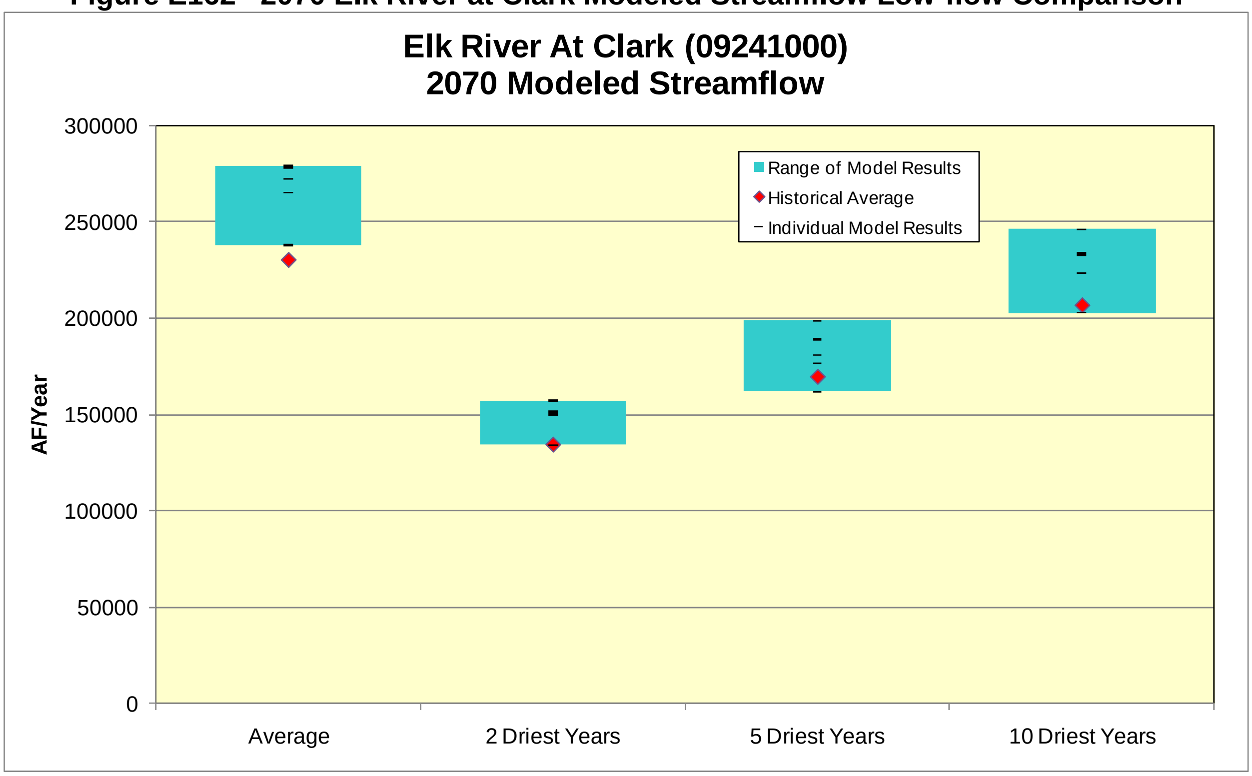


Figure E162 –2070 Elk River at Clark Modeled Streamflow Low-flow Comparison



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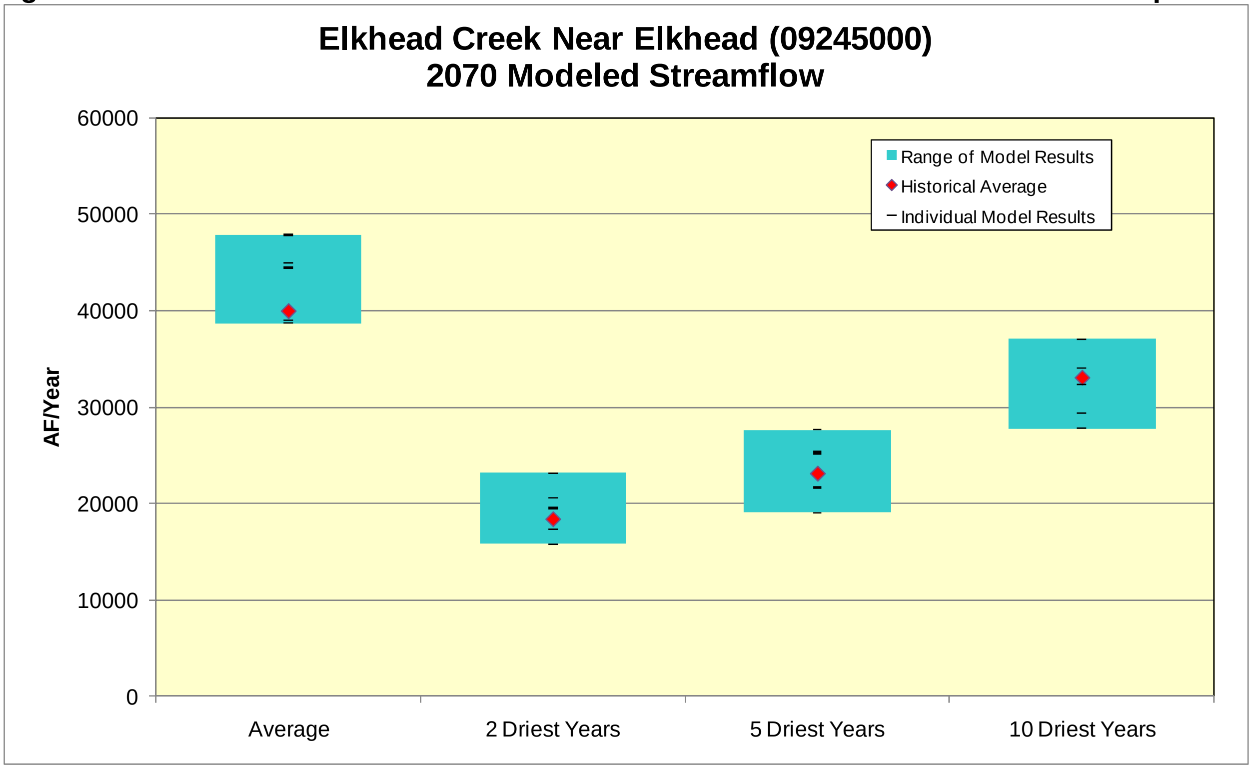

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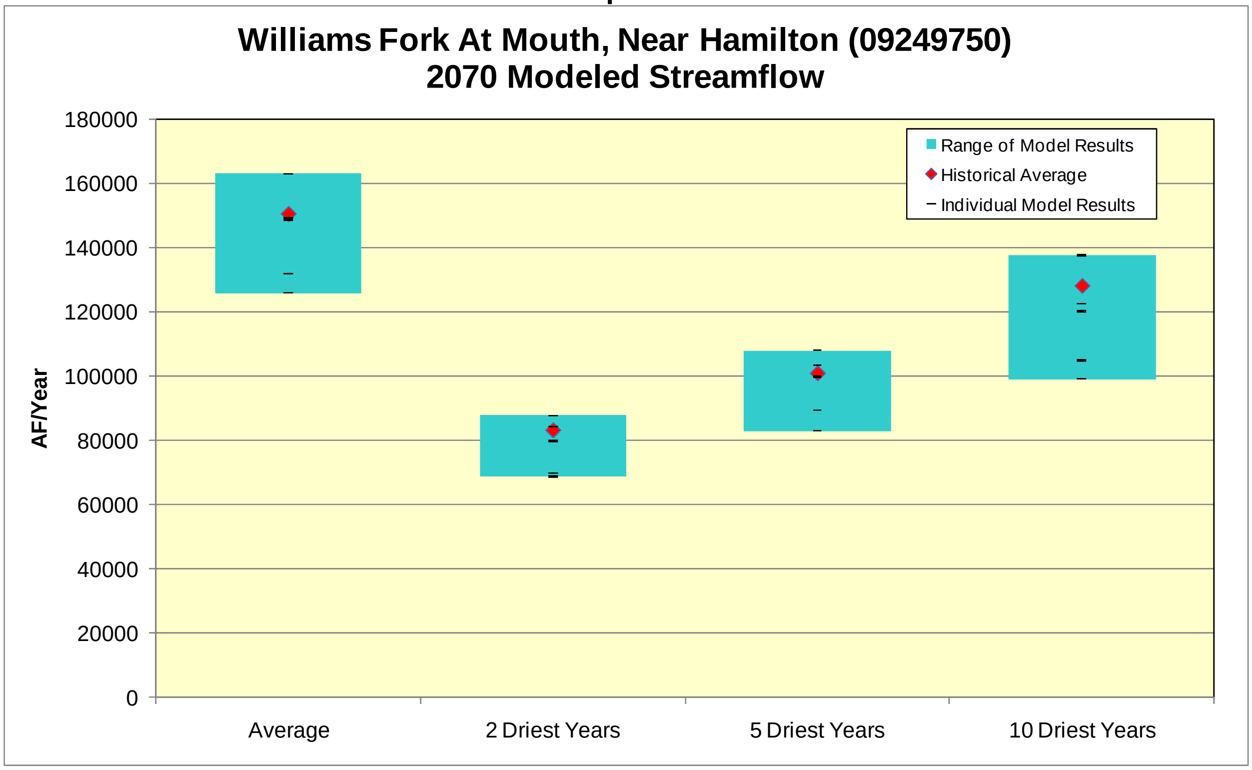

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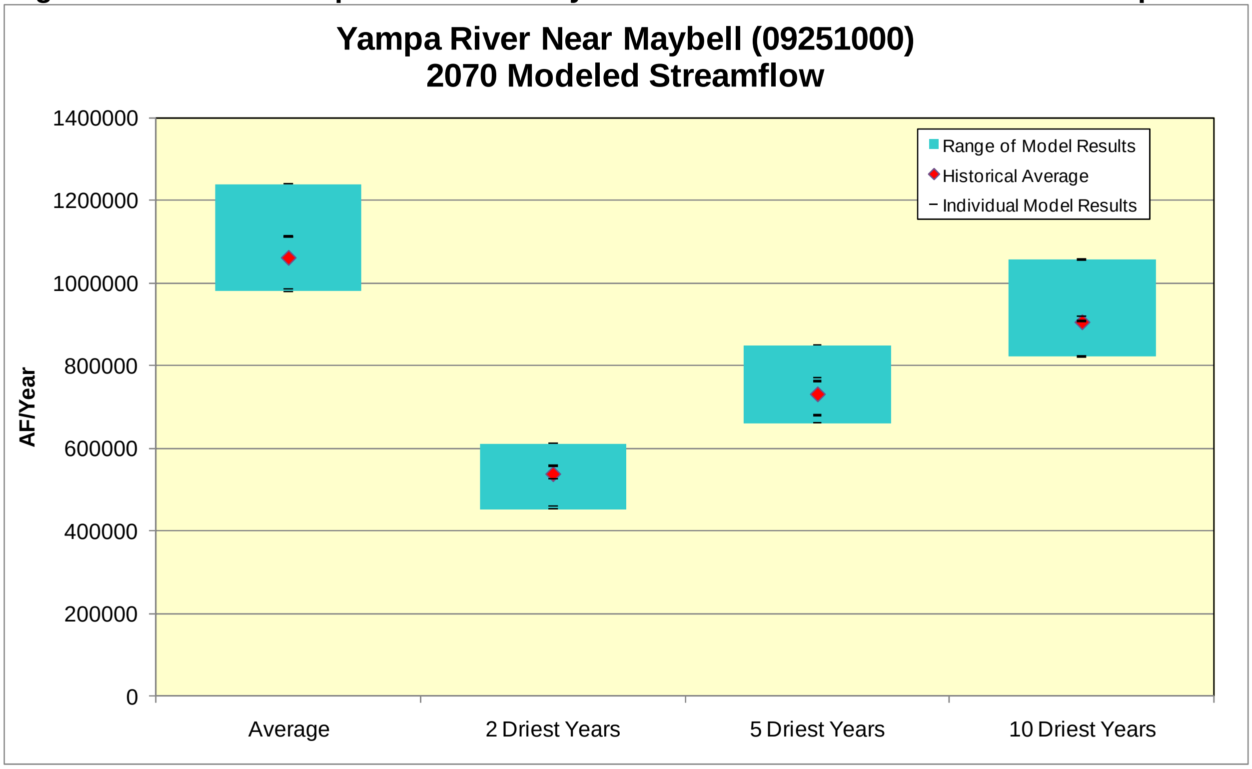

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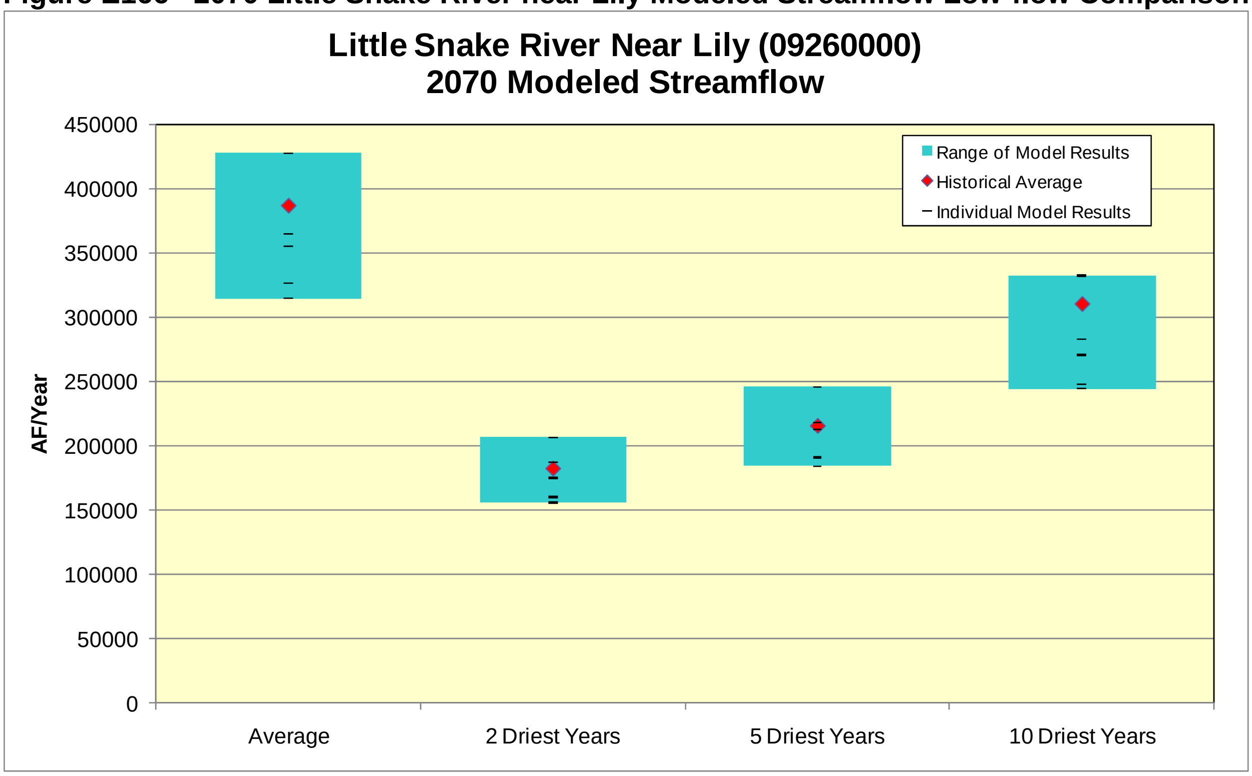

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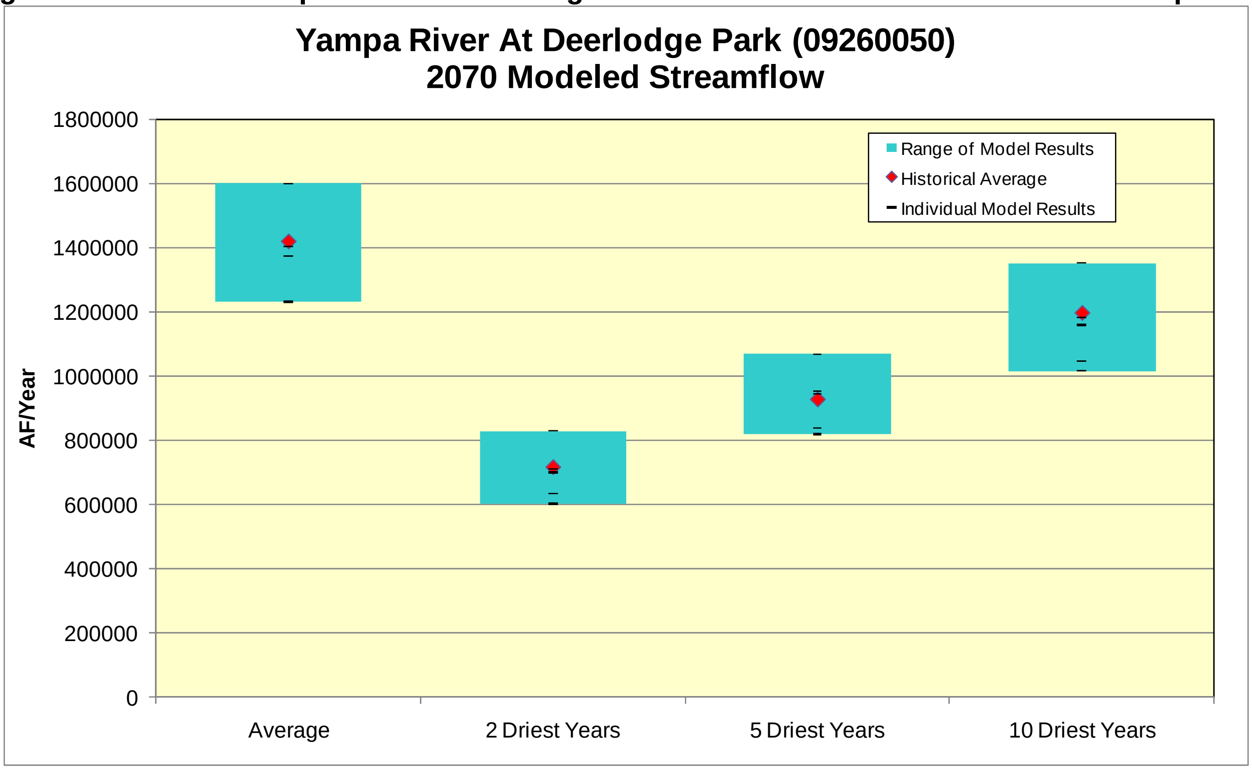

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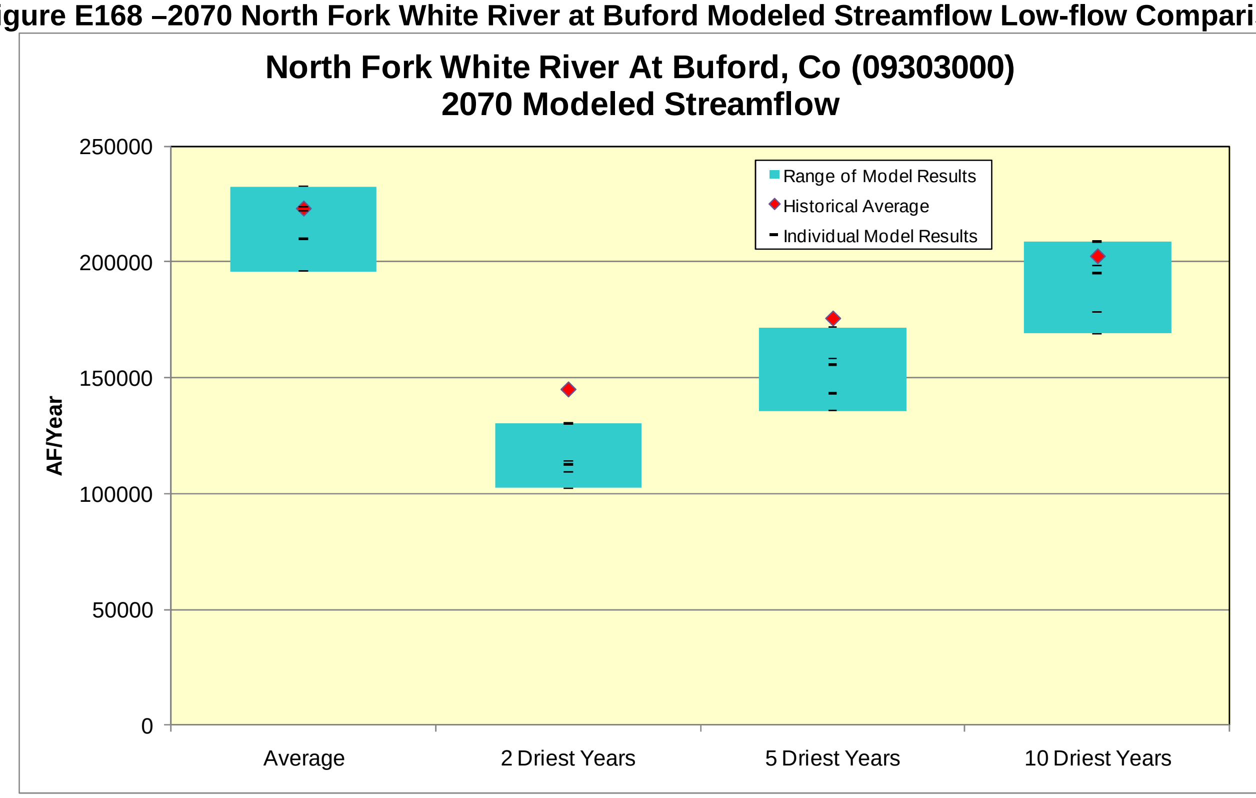

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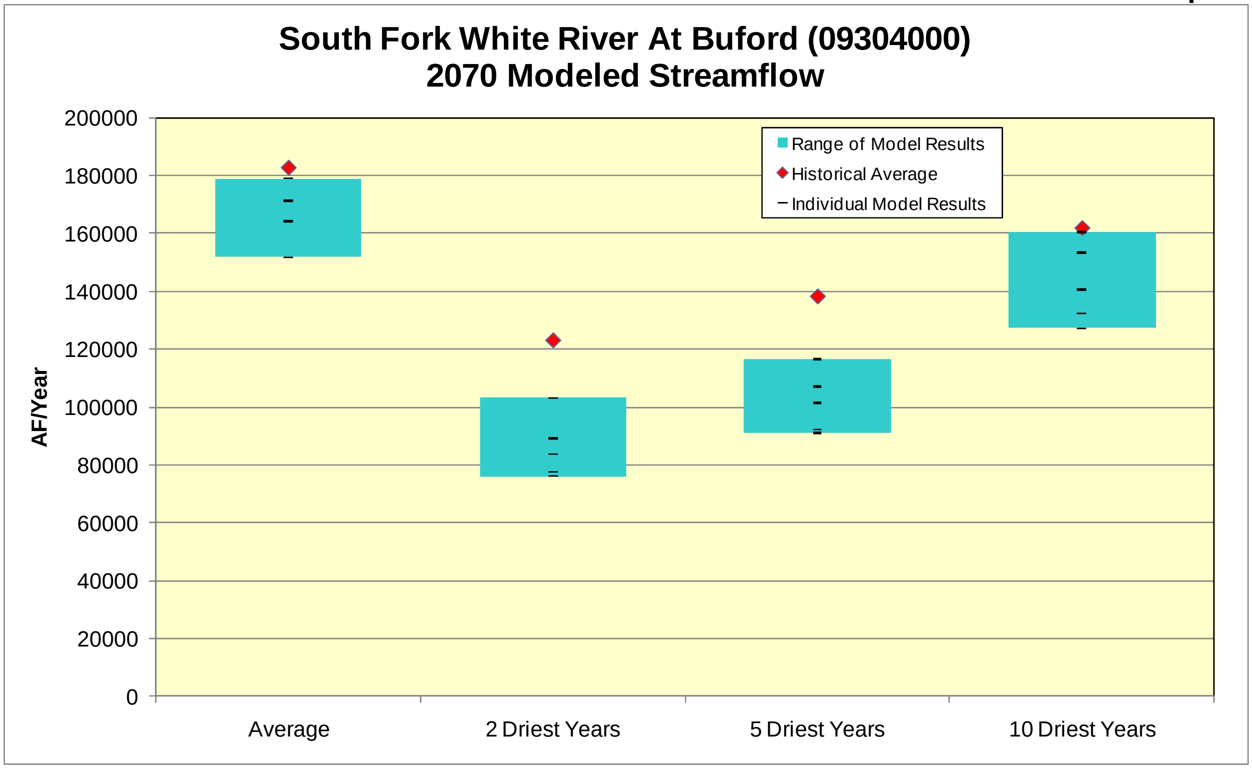

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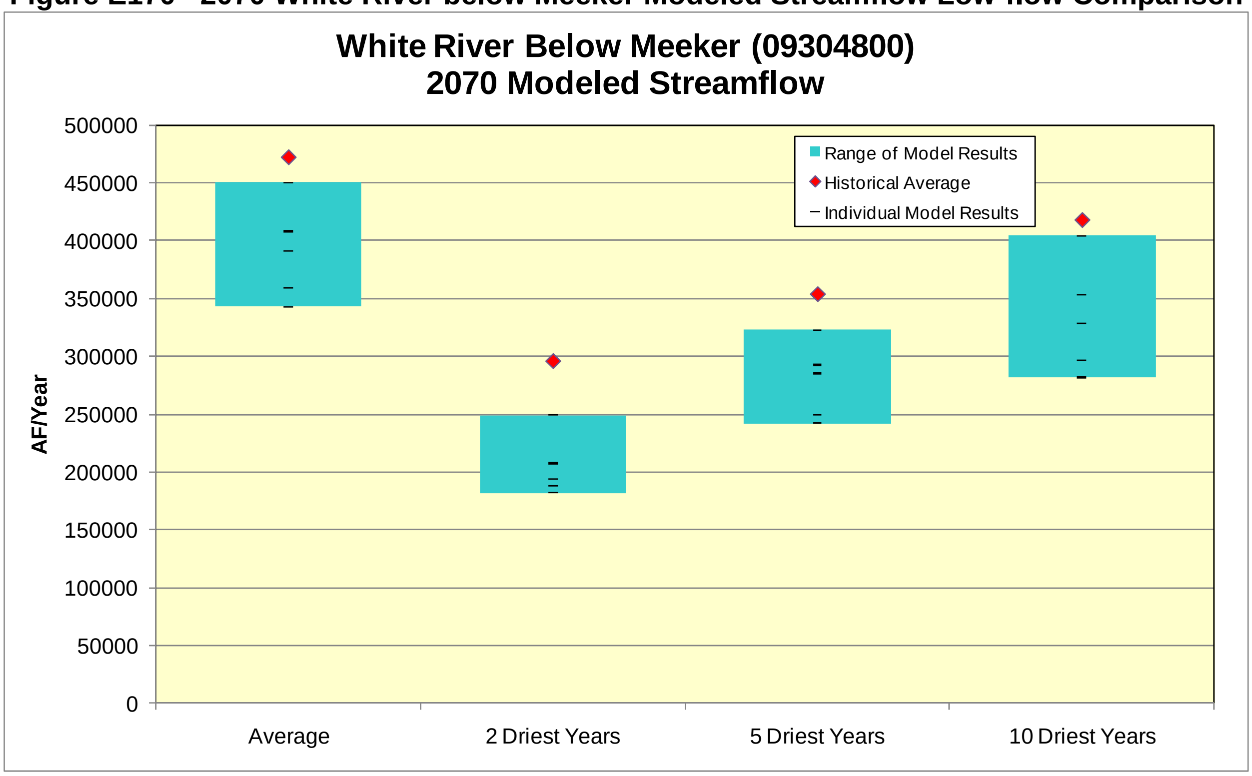

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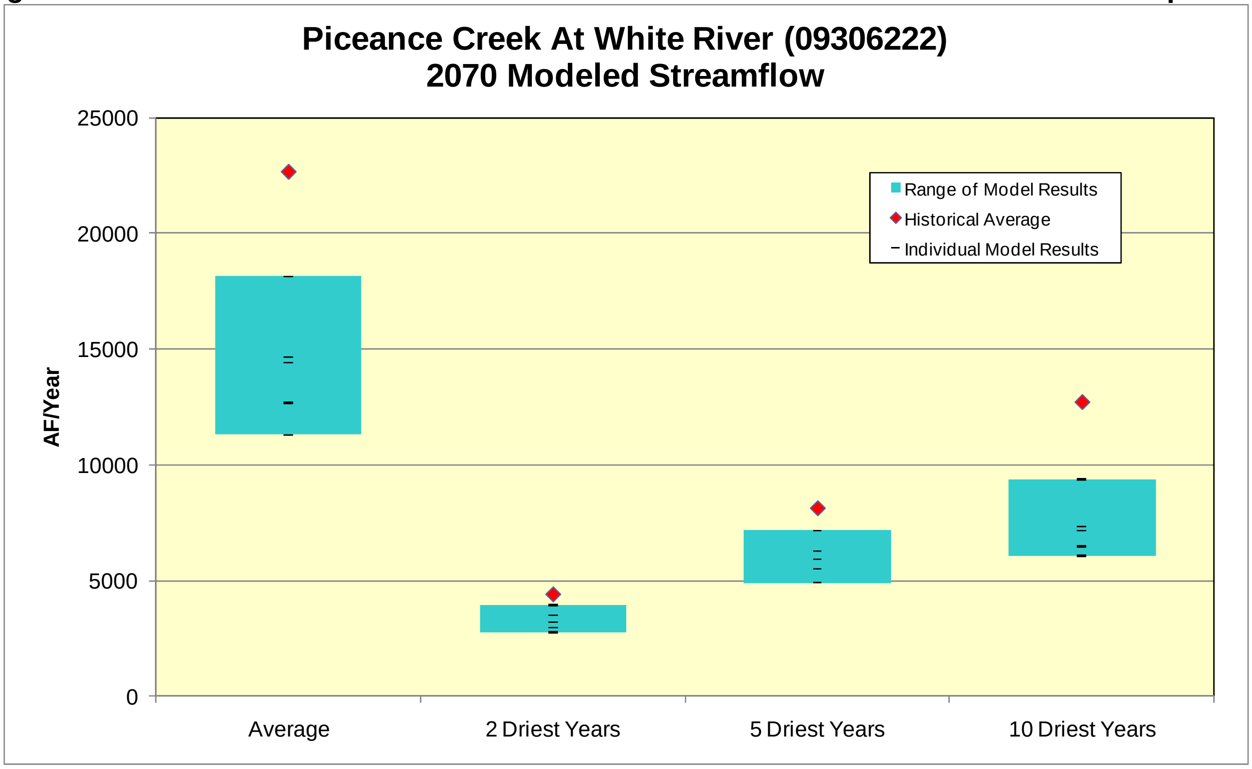

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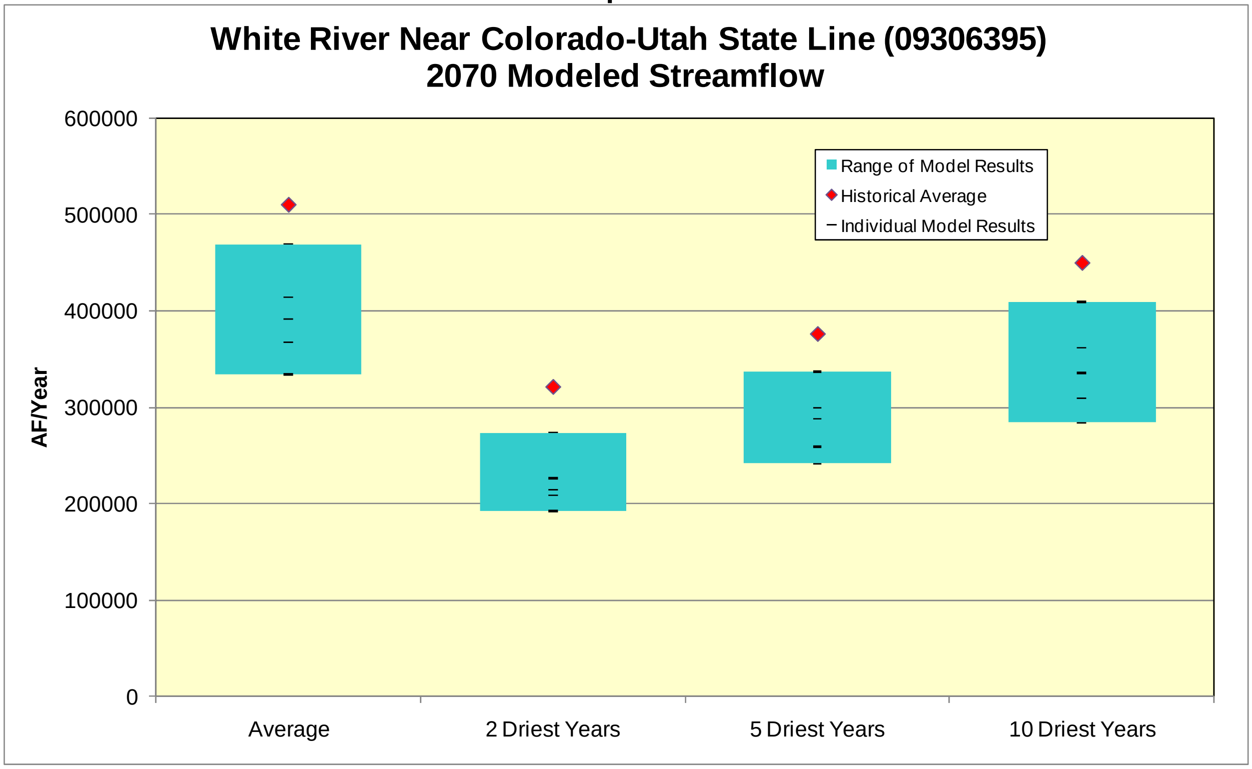

F. Water Available to Meet Future Demands

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2040 Climate Projections		Average Monthly Water Available to Meet Future Demands (AF)*												Range** in Average Annual Water Available (AF)		Reduction*** in Avg Annual Water Available	
USGS #	Location Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Low	High	AF	Percent
09011000	Colorado River Near Grand Lake	0	0	0	0	2,741	9,326	1,106	128	43	32	0	0	3,500	23,200	-2,880	-27%
09041500	Muddy Creek At Kremmling	3	14	148	2,646	24,402	13,511	944	41	18	19	19	8	21,900	61,800	1,170	3%
09050700	Blue River Below Dillon	2	6	13	0	7,521	34,549	10,668	1,420	305	169	51	3	23,700	101,200	10,484	16%
09057500	Blue River Below Green Mountain Reservoir	3	50	699	711	7,761	50,856	21,772	2,820	835	773	250	27	34,700	165,700	22,447	21%
09070000	Eagle River Below Gypsum	3	50	711	12,336	81,822	96,914	20,540	2,210	702	737	210	27	141,200	305,600	28,799	12%
09070500	Colorado River At Dotsero	3	50	872	19,663	190,121	261,277	48,539	4,469	1,195	978	312	27	278,900	817,700	25,428	5%
09073400	Roaring Fork River Near Aspen	13	7	36	1,335	15,843	5,718	381	323	347	312	97	43	18,700	28,000	-7,623	-45%
09085000	Roaring Fork River At Glenwood	19,441	18,417	25,915	53,150	185,240	217,408	51,119	4,734	6,099	19,133	23,397	20,925	502,300	818,100	65,442	9%
09095500	Colorado River Near Cameo	33,704	37,689	61,491	127,721	456,459	539,076	80,959	6,125	7,507	24,664	43,751	35,709	947,600	2,033,900	145,668	9%
09105000	Plateau Creek Near Cameo	3,271	3,767	6,823	9,355	25,027	19,909	4,504	943	1,327	3,622	4,223	3,588	52,600	129,900	28,096	25%
09163500	Colorado River Near Colorado-Utah State Li	171,706	172,690	241,525	376,727	898,039	895,048	296,197	169,024	172,019	205,698	189,074	175,785	3,052,100	4,986,500	286,233	7%

* Average for the five 2040 climate models
** Annual range for the five 2040 climate models
*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Table F2 - 2040 Gunnison River Basin Average Water Available to Meet Future Demands

2040 Climate Projections		Average Monthly Water Available to Meet Future Demands (AF)*												Range** in Average Annual Water Available (AF)		Reduction*** in Avg Annual Water Available	
USGS #	Location Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Low	High	KAF	Percent
09110000	Taylor River At Almont	0	0	0	0	12,066	25,026	4,509	606	0	0	0	0	20,700	72,600	4,184	9%
09112500	East River At Almont	40	0	13	7,313	60,041	52,374	8,523	3,547	1,078	2,414	2,081	1,438	82,200	202,900	20,107	13%
09114500	Gunnison River Near Gunnison	262	0	15	13,968	93,095	89,395	15,391	13,225	9,069	13,459	14,914	10,427	145,600	423,600	55,922	17%
09119000	Tomichi Creek At Gunnison	76	0	15	6,388	26,935	24,681	5,091	1,797	1,034	2,421	4,098	3,186	34,100	136,100	23,943	24%
09126500	Cimarron River At Cimarron	841	960	2,112	3,771	16,711	12,348	1,782	2,359	2,188	1,355	276	807	20,500	76,900	16,335	26%
09136200	Gunnison River Near Lazear	19,150	17,006	25,637	90,218	318,569	213,685	51,960	28,016	35,486	48,219	63,092	50,029	586,800	1,378,200	139,511	13%
09128000	Gunnison River Below Gunnison Tunnel	4,887	3,201	6,106	27,287	141,037	112,425	18,075	19,058	24,218	36,032	40,704	33,794	226,100	760,400	122,737	21%
09149500	Uncompahgre River At Delta	8,742	8,203	8,807	12,510	30,083	28,941	12,812	10,874	12,250	10,230	11,886	9,892	100,500	242,400	46,280	22%
09152500	Gunnison River Near Grand Junction	19,743	18,065	31,753	105,655	364,631	246,591	59,851	33,101	39,976	49,906	64,772	50,432	637,200	1,586,000	179,193	14%

* Average for the five 2040 climate models
** Annual range for the five 2040 climate models
*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Table F3 - 2040 San Juan/Dolores River Basin Average Water Available to Meet Future Demands

2040 Climate Projections		Average Monthly Water Available to Meet Future Demands (AF)*												Range** in Average Annual Water Available (AF)		Reduction*** in Avg Annual Water Available	
USGS #	Location Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Low	High	AF	Percent
09171100	Dolores River Near Bedrock	412	473	4,597	29,391	38,640	19,204	1,314	1,277	380	197	97	211	13,400	177,600	29,325	23%
09175500	San Miguel River At Naturita	4,745	5,283	8,409	38,976	48,109	31,368	11,654	5,336	4,267	4,226	4,767	4,407	100,600	237,100	34,187	17%
09346400	San Juan River Near Carracas	0	286	6,056	20,487	50,113	48,254	4,016	500	550	1,276	1,191	954	18,000	271,600	19,277	13%
09349800	Piedra River Near Arboles	0	227	4,038	17,892	38,474	29,140	2,435	399	473	743	588	432	14,500	188,600	15,879	14%
09354500	Los Pinos River At La Boca	0	337	4,173	11,206	9,125	23,126	1,889	285	289	2,097	816	664	6,500	105,300	11,270	17%
09363200	Florida River At Bondad	101	894	3,536	4,901	9,871	6,128	676	336	309	470	375	171	14,200	39,100	2,542	8%
09363500	Animas River Near Cedar Hill, Nm	1,032	3,032	13,816	38,610	126,074	95,025	11,421	2,844	2,552	4,195	2,968	1,991	146,300	456,900	53,447	15%
09365500	La Plata River At Hesperus	11	30	576	3,178	1,052	116	0	5	25	99	92	42	3,500	7,300	-1,542	-42%
09366500	La Plata River At Colorado-New Mexico State Line	183	542	2,063	5,142	1,193	120	11	7	42	230	335	241	4,300	15,300	-273	-3%
09371000	Mancos River Near Towaoc	440	1,211	3,230	4,880	4,903	2,093	940	707	539	380	500	310	7,700	30,500	2,027	9%
09372000	Mcelmo Creek Near Colorado-Utah State Line	1,488	2,630	3,503	2,091	3,787	4,242	3,401	3,744	3,362	2,368	1,744	1,358	18,600	46,700	6,426	16%

* Average for the five 2040 climate models
** Annual range for the five 2040 climate models
*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Table F4 – 2040 Yampa River Basin Average Water Available to Meet Future Demands

2040 Climate Projections		Average Monthly Water Available to Meet Future Demands (AF)*												Range** in Average Annual Water Available (AF)		Reduction*** in Avg Annual Water Available	
USGS #	Location Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Low	High	AF	Percent
09237500	Yampa River Below Stagecoach Reservoir	306	236	1,282	4,649	8,623	6,766	741	228	102	553	503	343	16,700	34,200	220	1%
09241000	Elk River At Clark	195	157	4,964	25,193	87,558	68,514	7,717	150	75	217	356	277	180,700	214,500	-24,162	-14%
09245000	Elkhead Creek Near Elkhead	216	322	1,325	10,379	24,683	4,534	135	12	16	88	123	125	33,900	50,100	-3,982	-10%
09249750	Williams Fork At Mouth, Near Hamilton	3,207	3,356	7,731	26,292	62,893	32,612	3,884	457	228	1,702	3,046	3,188	118,000	173,300	-1,384	-1%
09251000	Yampa River Near Maybell	14,594	20,402	64,139	216,626	427,080	298,587	31,282	7,957	5,390	14,230	16,414	14,312	925,000	1,321,500	-69,190	-7%
09260000	Little Snake River Near Lily	5,422	8,272	31,459	78,624	154,898	84,424	9,595	1,716	1,505	4,441	6,510	5,799	297,800	472,100	-7,238	-2%
09260050	Yampa River At Deerlodge Park	18,676	27,206	87,658	287,247	539,495	387,935	43,816	10,455	6,784	19,118	23,338	19,835	1,161,000	1,732,100	-52,654	-4%

* Average for the five 2040 climate models
** Annual range for the five 2040 climate models
*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Table F5 – 2040 White River Basin Average Water Available to Meet Future Demands

2040 Climate Projections		Average Monthly Water Available to Meet Future Demands (AF)*												Range** in Average Annual Water Available (AF)		Reduction*** in Avg Annual Water Available	
USGS #	Location Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Low	High	AF	Percent
09303000	North Fork White River At Buford, Co	863	1,046	4,159	18,814	56,263	40,095	6,629	1,559	1,031	1,130	1,041	742	116,500	156,200	1,633	1%
09304000	South Fork White River At Buford	516	646	1,555	9,061	48,117	50,314	6,458	1,133	570	720	608	454	99,800	141,800	3,856	3%
09304800	White River Below Meeker	3,428	5,851	13,883	32,661	96,762	92,531	14,189	3,042	3,024	4,671	4,167	2,925	189,000	371,800	41,667	13%
09306222	Piceance Creek At White River	1,125	1,427	2,662	3,102	2,950	1,231	657	495	451	1,030	1,310	1,124	9,800	26,700	5,077	22%
09306395	White River Near Colorado-Utah State Line	18,313	20,867	32,088	49,601	112,069	110,695	26,592	12,145	15,192	18,624	18,336	17,194	330,900	572,800	58,509	11%

* Average for the five 2040 climate models

** Annual range for the five 2040 climate models

*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Table F6 - 2070 Upper Colorado River Basin Average Water Available to Meet Future Demands

2070 Climate Projections		Average Monthly Water Available to Meet Future Demands (AF)*												Range** in Average Annual Water Available (AF)		Reduction*** in Avg Annual Water Available	
USGS #	Location Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Low	High	AF	Percent
09011000	Colorado River Near Grand Lake	0	0	0	0	6,204	6,013	278	72	52	25	0	0	7,000	20,500	-2,148	-20%
09041500	Muddy Creek At Kremmling	0	12	293	3,204	22,814	6,782	238	14	16	12	7	0	25,300	48,400	9,549	22%
09050700	Blue River Below Dillon	0	2	28	0	12,246	23,458	4,521	689	221	111	29	0	28,000	63,500	23,888	37%
09057500	Blue River Below Green Mountain Reservoir	0	105	1,644	839	13,343	36,922	8,611	1,167	488	421	110	0	41,300	102,700	45,354	42%
09070000	Eagle River Below Gypsum	0	105	1,859	19,235	84,162	65,018	8,012	930	387	376	99	0	145,000	228,600	64,876	26%
09070500	Colorado River At Dotsero	0	105	2,432	32,606	202,158	168,302	15,503	1,525	759	504	110	0	337,900	589,600	128,929	23%
09073400	Roaring Fork River Near Aspen	8	5	56	1,803	21,546	4,636	6	103	180	151	43	23	24,300	32,900	-11,727	-70%
09085000	Roaring Fork River At Glenwood	18,007	17,933	26,588	58,625	219,964	179,112	17,231	1,313	3,095	11,656	21,175	18,982	536,500	670,200	116,739	16%
09095500	Colorado River Near Cameo	29,909	37,781	67,170	136,740	478,470	385,969	23,789	1,690	3,949	14,548	36,357	30,265	1,045,700	1,571,600	353,886	22%
09105000	Plateau Creek Near Cameo	3,286	4,062	7,767	9,617	18,001	11,003	1,989	475	653	2,373	3,661	3,334	53,100	84,500	48,234	42%
09163500	Colorado River Near Colorado-Utah State Li	129,986	137,304	194,844	326,344	895,422	656,194	199,884	134,471	136,683	169,546	173,976	150,044	2,823,100	3,908,300	917,093	22%

* Average for the five 2040 climate models

** Annual range for the five 2040 climate models

*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Table F7 - 2070 Gunnison River Basin Average Water Available to Meet Future Demands

2070 Climate Projections		Average Monthly Water Available to Meet Future Demands (AF)*												Range** in Average Annual Water Available (AF)		Reduction*** in Avg Annual Water Available	
USGS #	Location Name	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Low*	*High*	*AF*	*Percent*
09110000	Taylor River At Almont	0	0	0	60	16,582	16,095	840	94	0	0	0	0	24,300	43,300	12,721	27%
09112500	East River At Almont	38	0	69	10,036	66,492	31,702	1,864	1,677	496	1,319	1,733	1,137	89,400	140,700	42,408	27%
09114500	Gunnison River Near Gunnison	254	0	93	18,718	100,912	50,860	2,655	7,064	5,532	8,474	12,395	8,236	150,300	272,400	113,951	35%
09119000	Tomichi Creek At Gunnison	69	0	91	7,711	22,222	10,608	821	1,219	517	1,236	3,423	2,555	33,600	69,800	49,192	49%
09126500	Cimarron River At Cimarron	706	909	2,060	3,688	14,310	4,212	225	1,464	1,276	906	194	673	20,500	41,700	31,222	50%
09128000	Gunnison River Below Gunnison Tunnel	4,267	3,052	6,078	31,908	139,088	56,874	2,680	9,297	12,856	19,806	28,316	22,543	217,000	453,000	252,795	43%
09136200	Gunnison River Near Lazear	17,627	16,478	25,158	96,779	310,383	133,251	29,008	16,540	22,446	29,981	48,162	36,828	582,400	950,800	317,936	29%
09149500	Uncompahgre River At Delta	7,753	7,456	7,942	11,731	26,665	14,068	6,944	7,981	9,853	8,212	10,056	8,330	99,100	154,300	84,520	40%
09152500	Gunnison River Near Grand Junction	18,186	17,780	32,292	108,307	341,193	151,670	31,712	19,416	25,627	30,896	49,063	36,931	630,500	1,060,600	400,598	32%

* Average for the five 2040 climate models
** Annual range for the five 2040 climate models
*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Table F8 - 2070 San Juan/Dolores River Basin Average Water Available to Meet Future Demands

2070 Climate Projections		Average Monthly Water Available to Meet Future Demands (AF)*												Range** in Average Annual Water Available (AF)		Reduction*** in Avg Annual Water Available	
USGS #	Location Name	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Low*	*High*	*AF*	*Percent*
09171100	Dolores River Near Bedrock	593	429	3,039	16,636	9,746	3,255	368	1,268	300	131	81	203	16,900	56,800	89,470	71%
09175500	San Miguel River At Naturita	4,894	5,580	8,214	36,361	35,557	14,479	4,740	3,759	2,704	3,059	4,251	4,054	103,000	153,600	78,081	38%
09346400	San Juan River Near Carracas	0	0	986	9,590	24,295	17,990	84	0	0	0	233	146	23,500	70,700	99,636	65%
09349800	Piedra River Near Arboles	0	0	746	8,195	19,072	11,257	84	0	0	0	127	55	19,200	50,700	71,186	64%
09354500	Los Pinos River At La Boca	0	0	828	4,017	6,829	8,836	36	0	0	0	161	89	9,800	26,900	44,480	68%
09363200	Florida River At Bondad	136	1,201	2,942	3,983	8,277	3,742	207	103	125	256	198	51	15,000	24,500	9,090	30%
09363500	Animas River Near Cedar Hill, Nm	1,226	2,987	10,324	35,168	110,726	45,723	1,045	609	627	1,814	1,933	862	160,900	253,400	143,963	40%
09365500	La Plata River At Hesperus	25	61	689	3,279	220	0	0	1	6	92	84	46	3,300	6,700	-821	-22%
09366500	La Plata River At Colorado-New Mexico State Line	128	513	1,553	3,815	220	0	2	1	16	199	239	162	4,700	10,200	2,987	30%
09371000	Mancos River Near Towaoc	310	1,012	2,332	3,249	2,508	1,385	584	470	380	309	378	239	8,700	16,700	9,002	41%
09372000	Mcelmo Creek Near Colorado-Utah State Line	1,305	2,376	2,554	1,435	3,226	3,480	2,363	3,247	2,643	1,909	1,505	1,085	20,300	33,200	13,014	32%

* Average for the five 2040 climate models
** Annual range for the five 2040 climate models
*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Table F9 – 2070 Yampa River Basin Average Water Available to Meet Future Demands

2070 Climate Projections		Average Monthly Water Available to Meet Future Demands (AF)*												Range** in Average Annual Water Available (AF)		Reduction*** in Avg Annual Water Available	
USGS #	Location Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Low	High	AF	Percent
09237500	Yampa River Below Stagecoach Reservoir	256	238	1,847	7,743	8,633	4,238	121	46	70	384	305	223	18,600	30,900	450	2%
09241000	Elk River At Clark	359	739	11,433	38,854	98,435	51,307	1,426	0	52	128	318	284	180,700	214,900	-32,123	-19%
09245000	Elkhead Creek Near Elkhead	286	632	2,377	12,186	21,439	2,232	21	3	12	72	109	122	34,500	45,100	-1,516	-4%
09249750	Williams Fork At Mouth, Near Hamilton	3,445	4,139	11,158	30,525	59,102	22,954	1,092	65	157	1,134	2,857	3,099	121,700	159,000	7,483	5%
09251000	Yampa River Near Maybell	14,108	23,119	73,284	238,978	376,678	213,677	7,095	87	629	4,533	14,826	13,187	879,500	1,131,100	2,619	0%
09260000	Little Snake River Near Lily	5,868	9,603	42,524	92,301	134,312	47,913	4,859	1,428	1,198	3,347	6,075	5,618	312,200	425,300	30,381	8%
09260050	Yampa River At Deerlodge Park	20,195	33,175	118,773	336,047	506,972	269,657	13,798	8,486	4,831	14,573	21,872	19,391	1,231,000	1,599,700	51,139	4%

* Average for the five 2040 climate models
** Annual range for the five 2040 climate models
*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Table F10 – 2070 White River Basin Average Water Available to Meet Future Demands

2070 Climate Projections		Average Monthly Water Available to Meet Future Demands (AF)*												Range** in Average Annual Water Available (AF)		Reduction*** in Avg Annual Water Available	
USGS #	Location Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Low	High	AF	Percent
09303000	North Fork White River At Buford, Co	536	1,277	8,717	27,204	65,285	31,348	1,750	178	190	502	449	303	119,600	151,800	-2,734	-2%
09304000	South Fork White River At Buford	288	514	2,344	13,358	56,617	39,148	2,135	123	83	306	230	182	104,900	124,700	8,680	7%
09304800	White River Below Meeker	2,464	6,039	19,495	38,822	95,696	68,116	4,058	436	755	1,931	2,229	1,505	196,100	294,200	77,255	24%
09306222	Piceance Creek At White River	990	1,407	2,781	2,773	1,541	485	190	144	179	588	1,149	898	9,900	17,900	9,518	42%
09306395	White River Near Colorado-Utah State Line	17,187	20,743	36,277	53,559	108,730	83,300	11,610	6,569	10,647	14,832	16,329	15,508	334,300	469,300	114,935	23%

* Average for the five 2040 climate models
** Annual range for the five 2040 climate models
*** Reduction in Average Annual from Historical = Historical Average - Average of five 2040 models. Positive values indicates modeled streamflow for climate projections decreases from historical (reduction), negative values indicates modeled streamflow for climate projections increases from historical

Figure F1 –2040 Colorado River near Grand Lake Average Water Available to Meet Future Demands Comparison

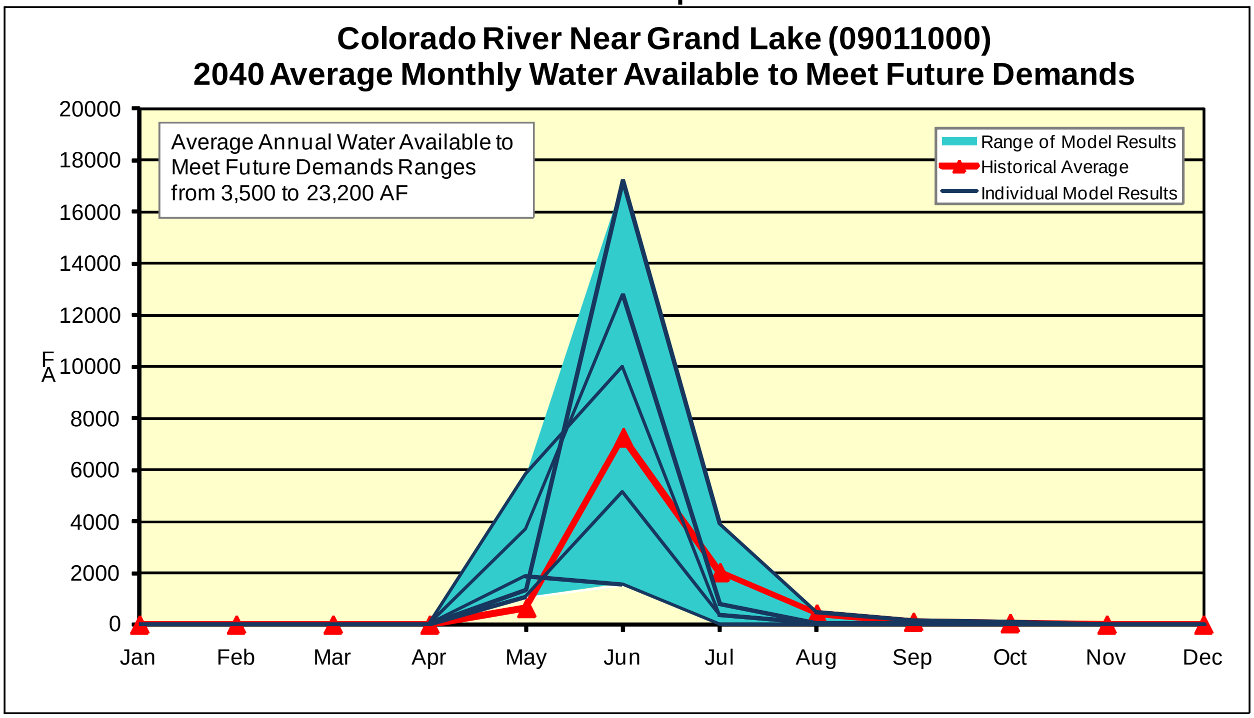


Figure F2 –2040 Muddy Creek at Kremmling Average Water Available to Meet Future Demands Comparison

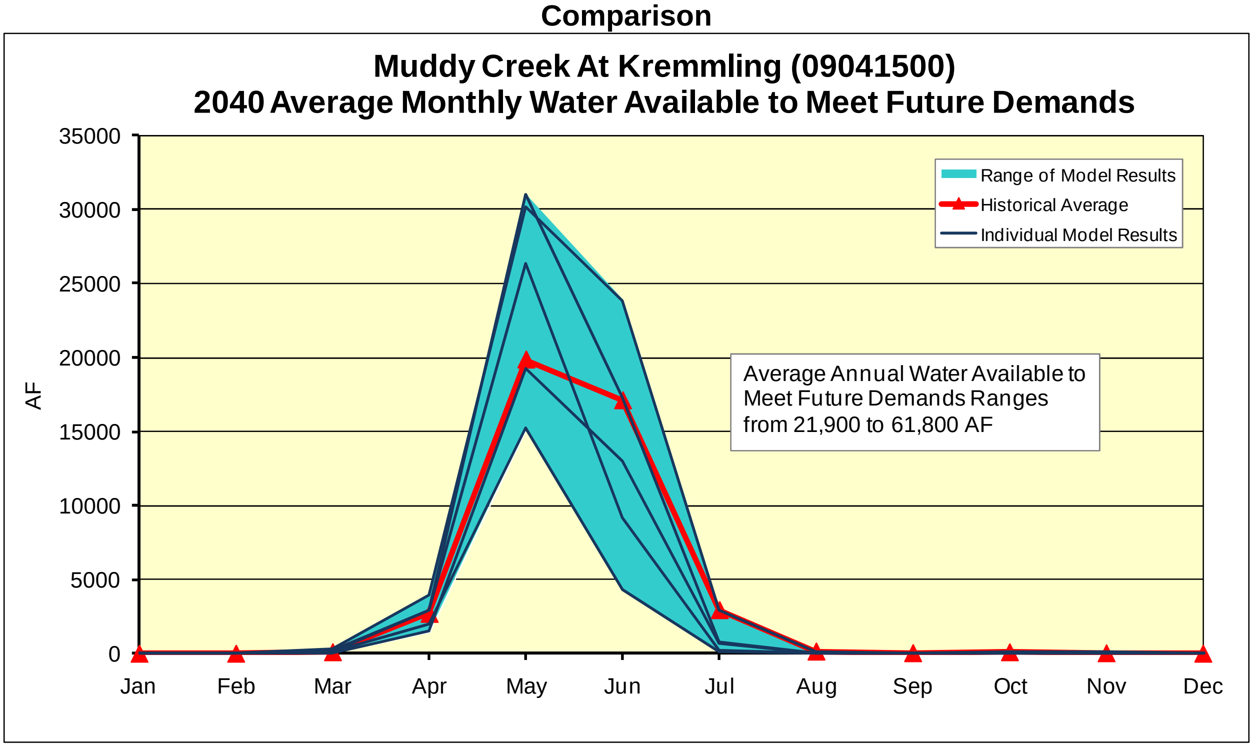


Figure F3 –2040 Blue River below Dillon Average Water Available to Meet Future Demands Comparison

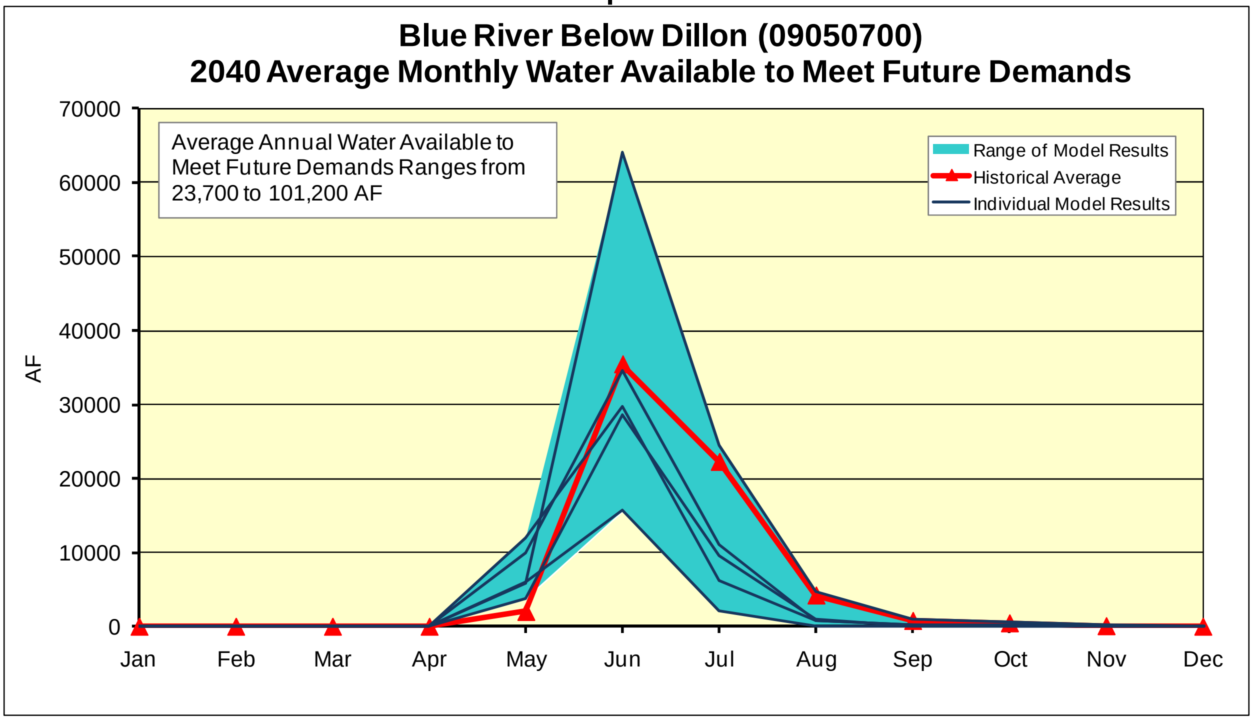


Figure F4 –2040 Blue River below Green Mountain Reservoir Average Water Available to Meet Future Demands Comparison

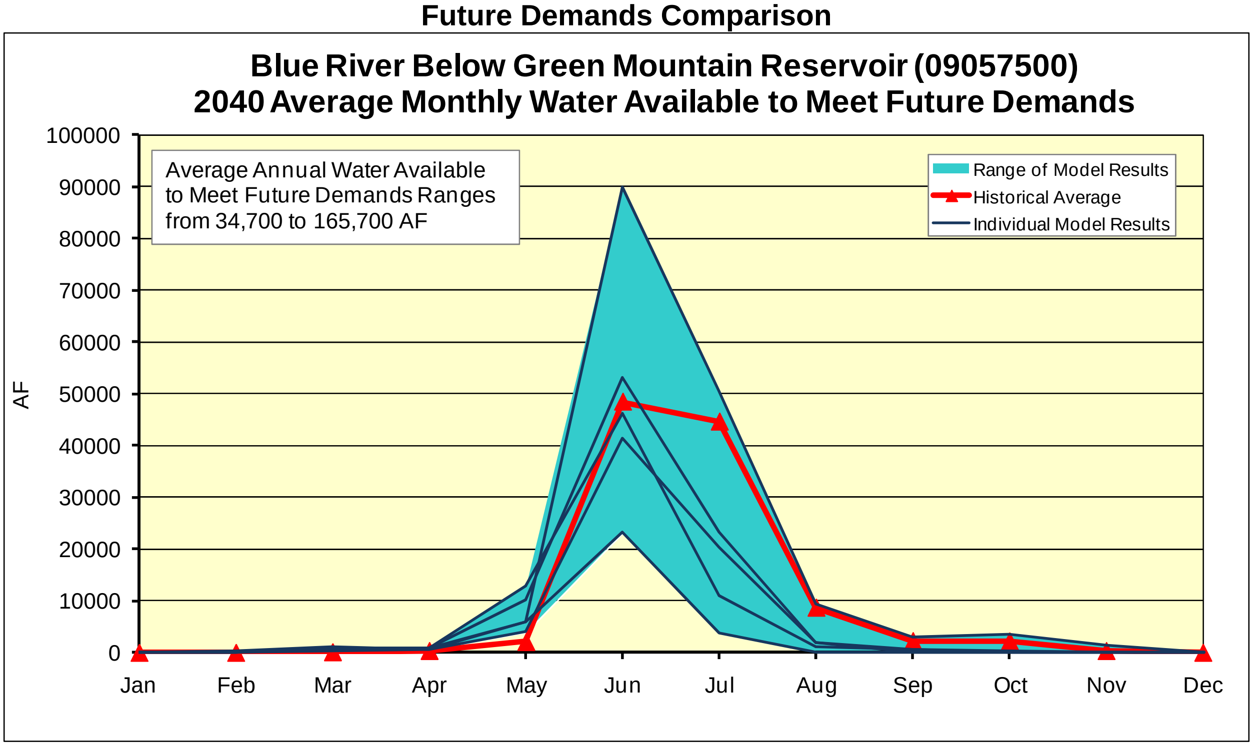


Figure F5 –2040 Eagle River below Gypsum Average Water Available to Meet Future Demands Comparison

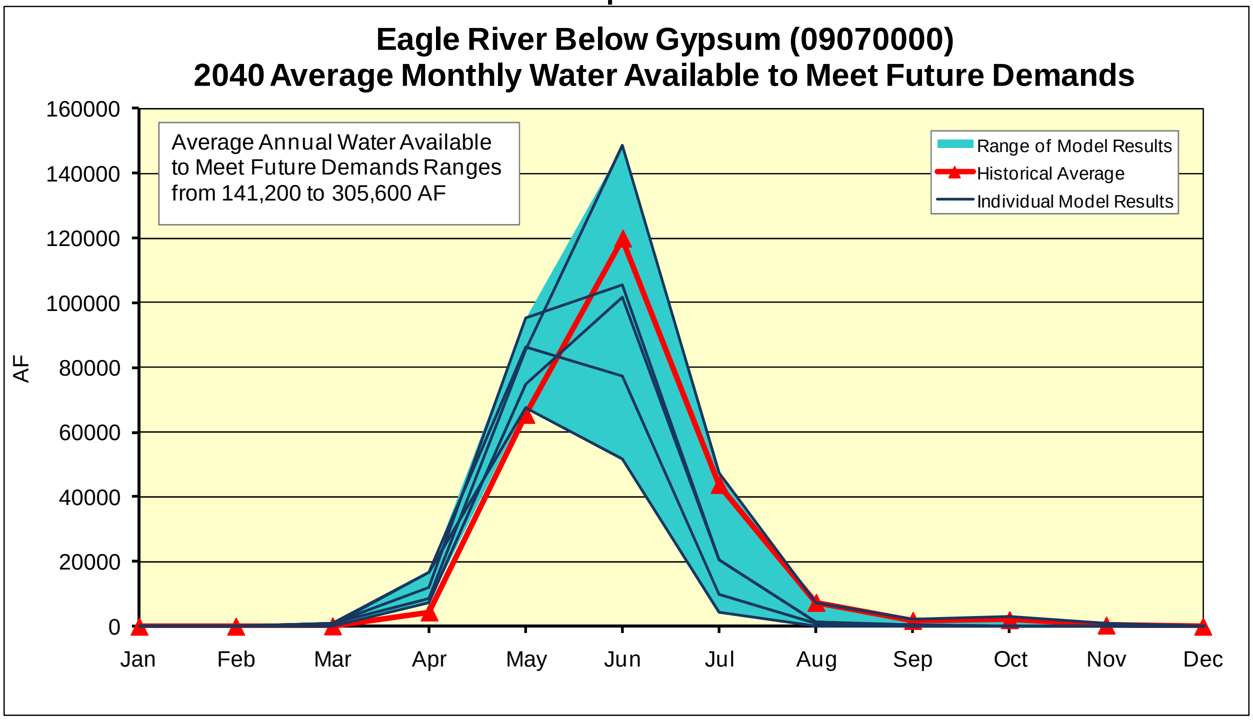


Figure F6 –2040 Colorado River at Dotsero Average Water Available to Meet Future Demands Comparison

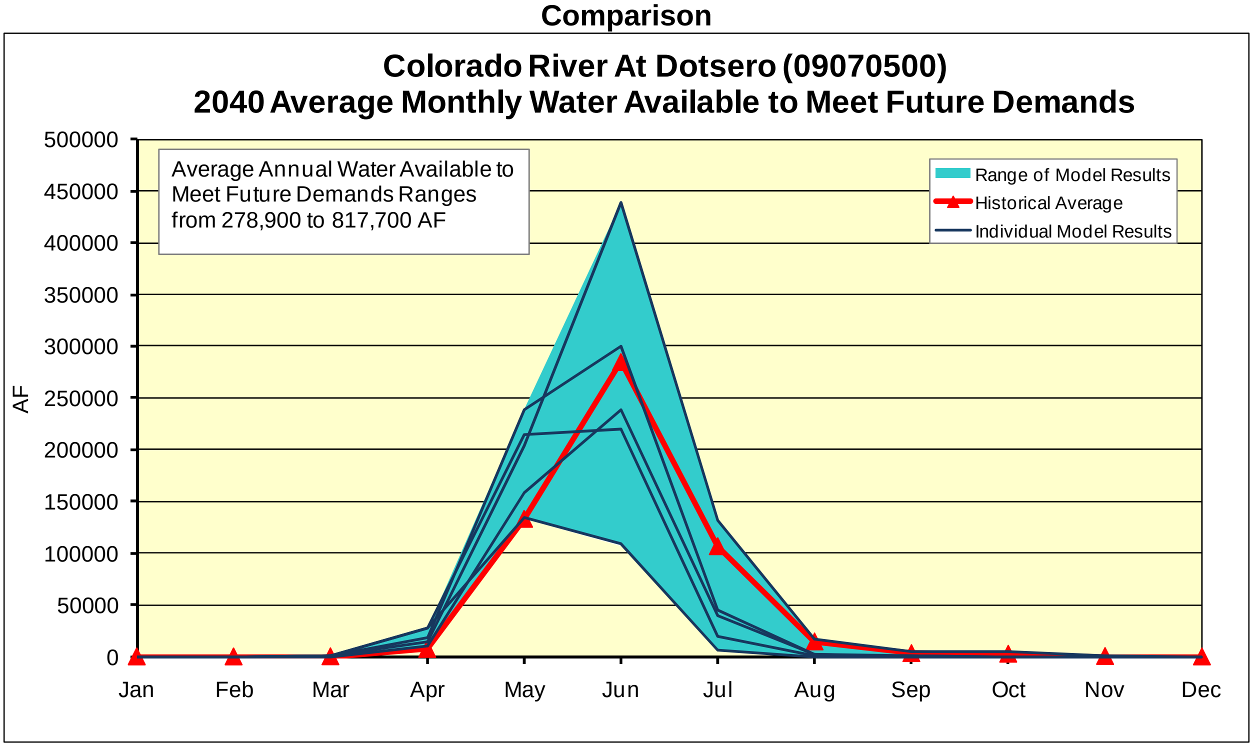


Figure F7 –2040 Roaring Fork River near Aspen Average Water Available to Meet Future Demands Comparison

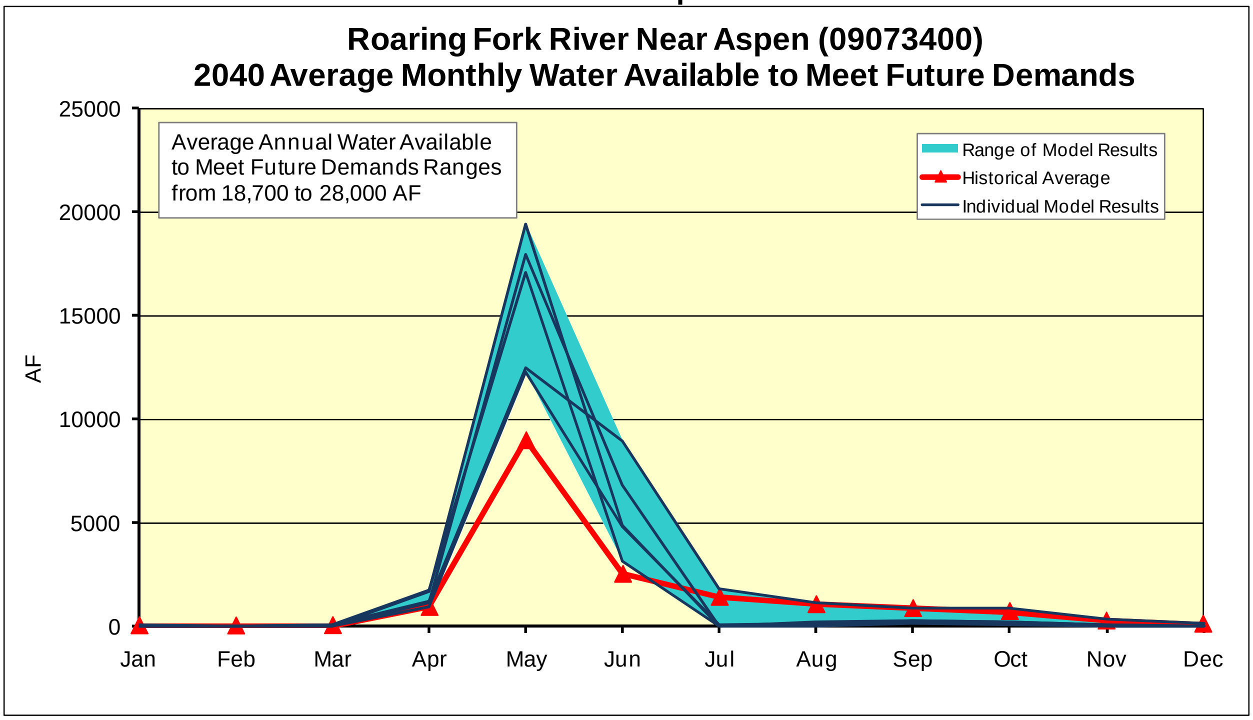


Figure F8 –2040 Roaring Fork River at Glenwood Average Water Available to Meet Future Demands Comparison

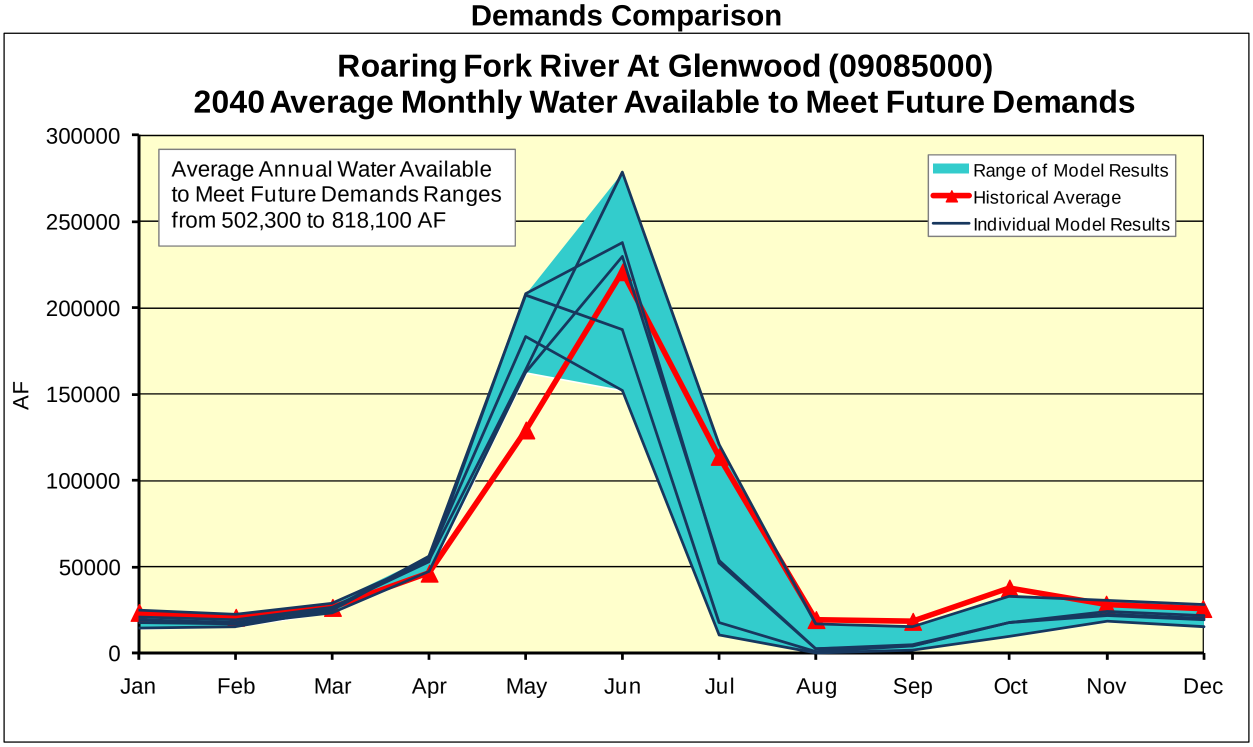


Figure F9 –2040 Colorado River near Cameo Average Water Available to Meet Future Demands Comparison

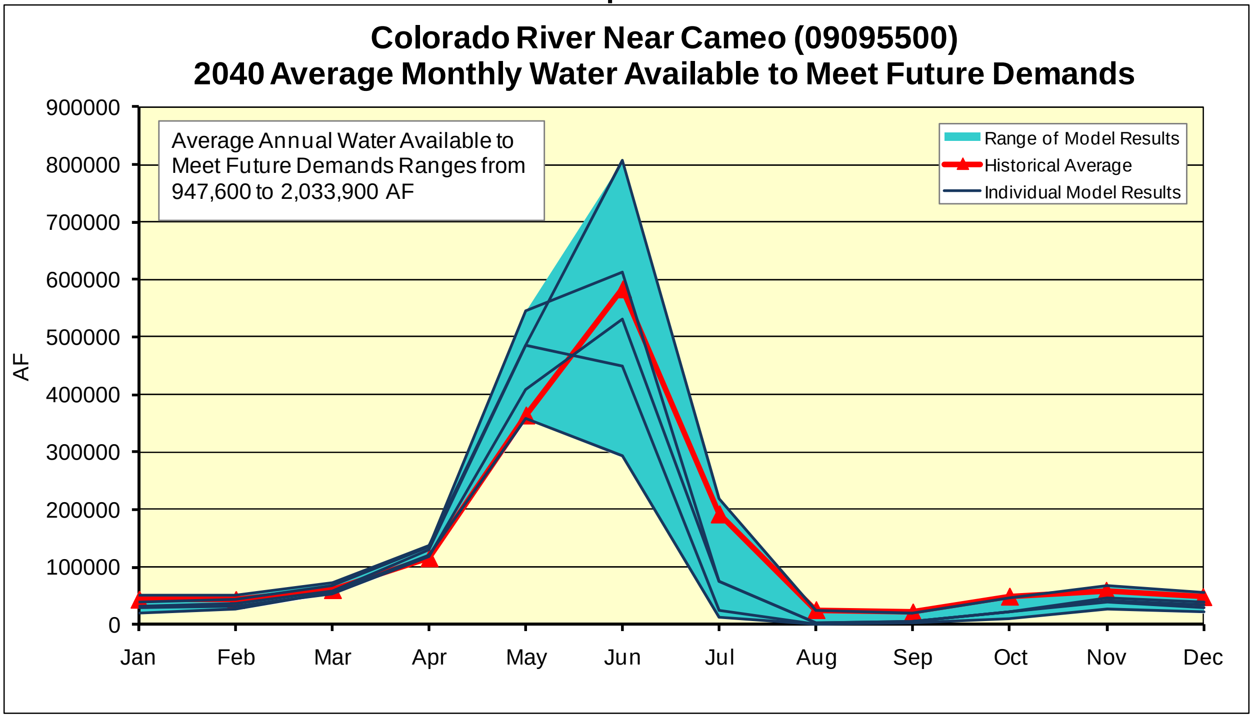


Figure F10 –2040 Plateau near Cameo Average Water Available to Meet Future Demands Comparison

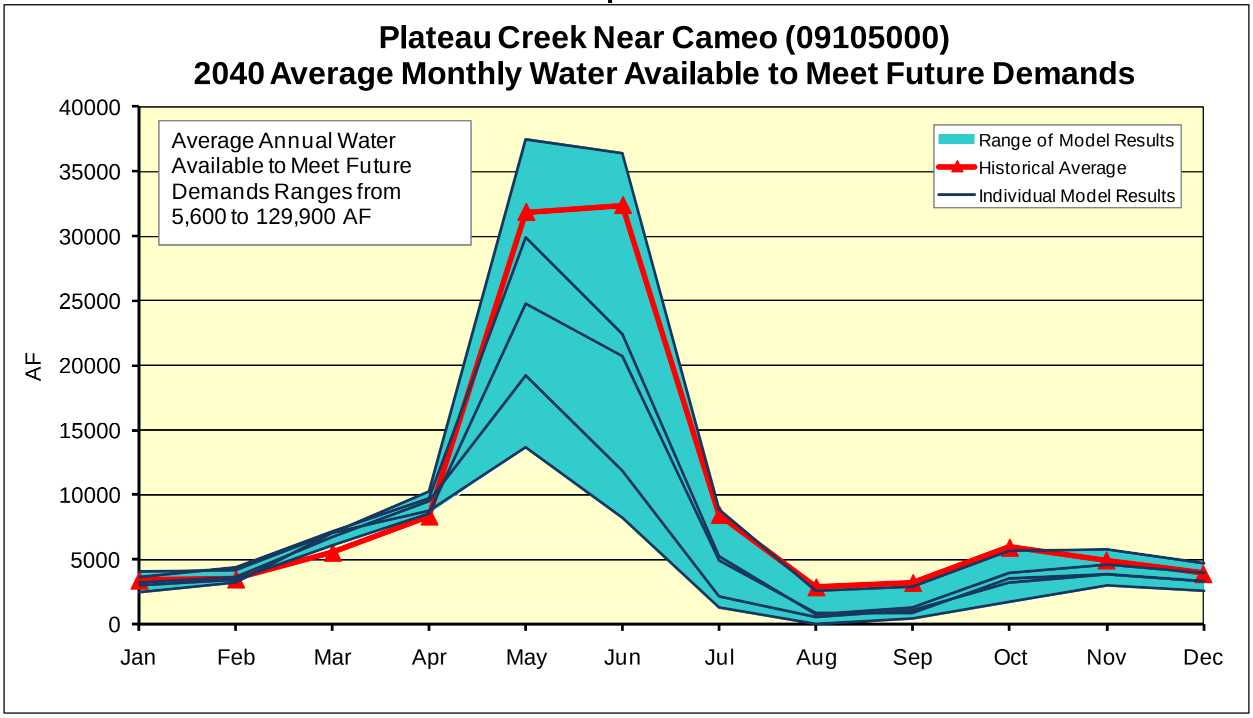


Figure F11 –2040 Colorado River near CO-UT State Line Average Water Available to Meet Future Demands Comparison

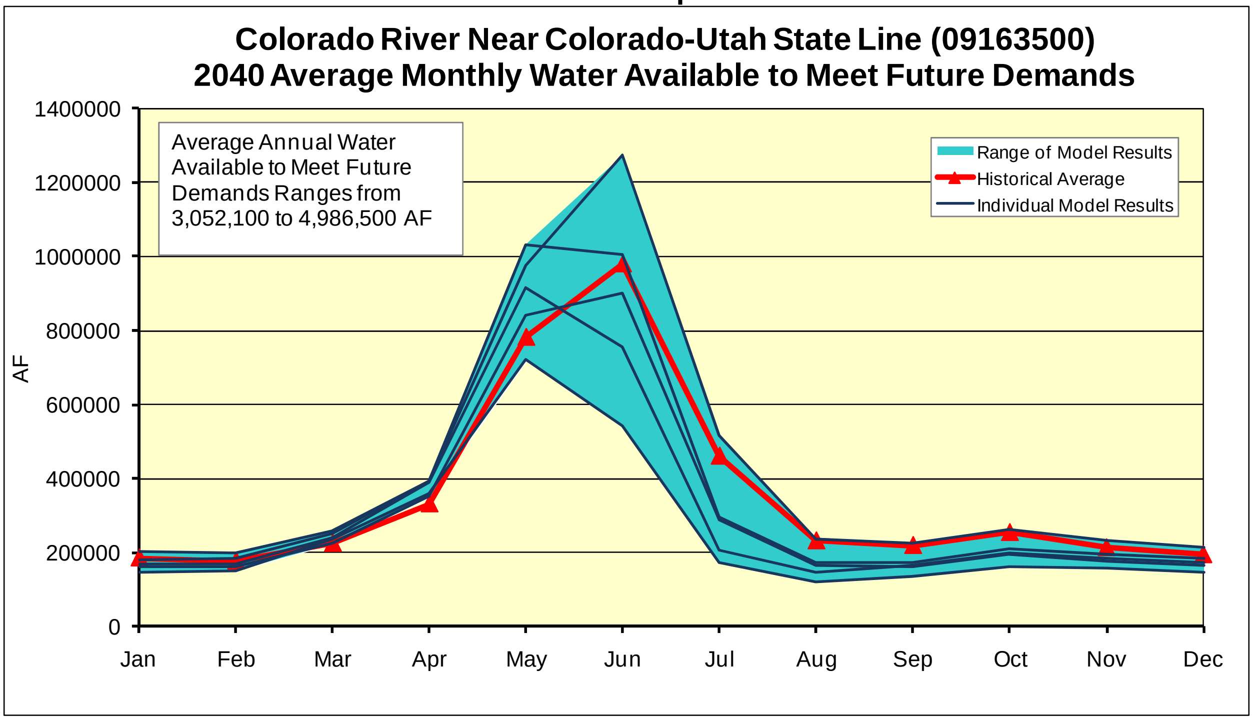


Figure F12 –2040 East River at Almont Average Water Available to Meet Future Demands Comparison

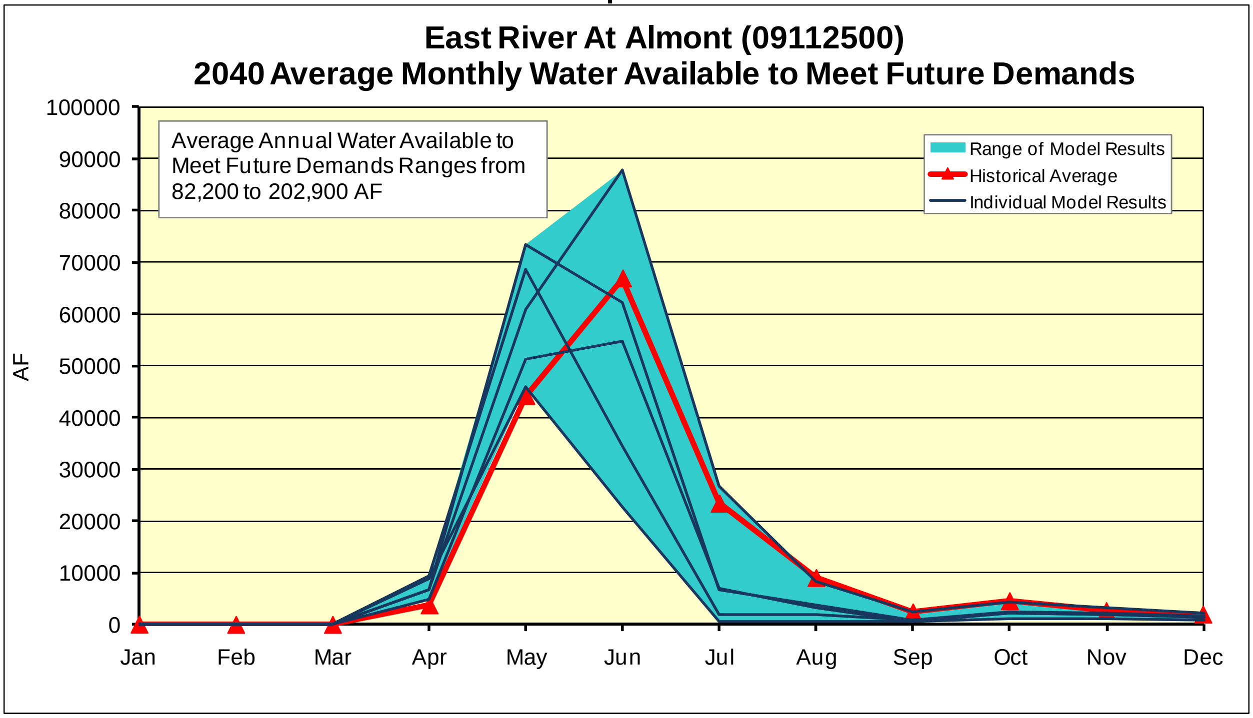


Figure F13 –2040 Taylor River at Almont Average Water Available to Meet Future Demands Comparison

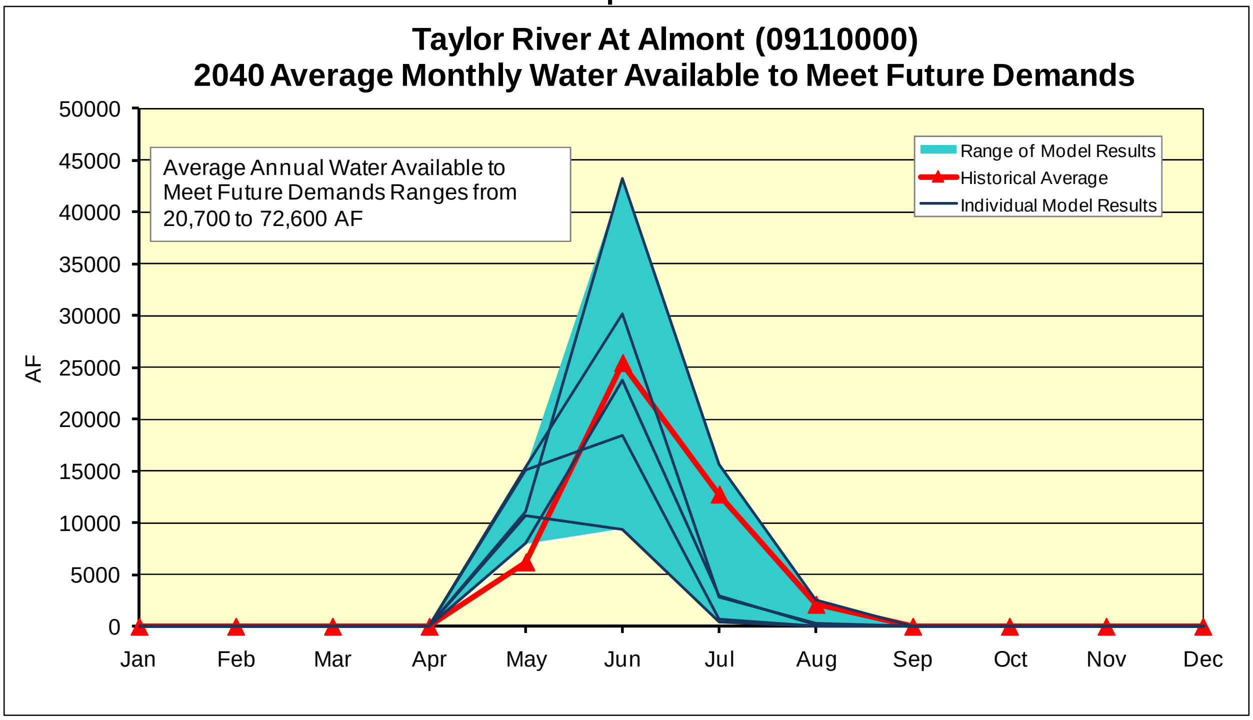


Figure F14 –2040 Tomichi Creek at Gunnison Average Water Available to Meet Future Demands Comparison

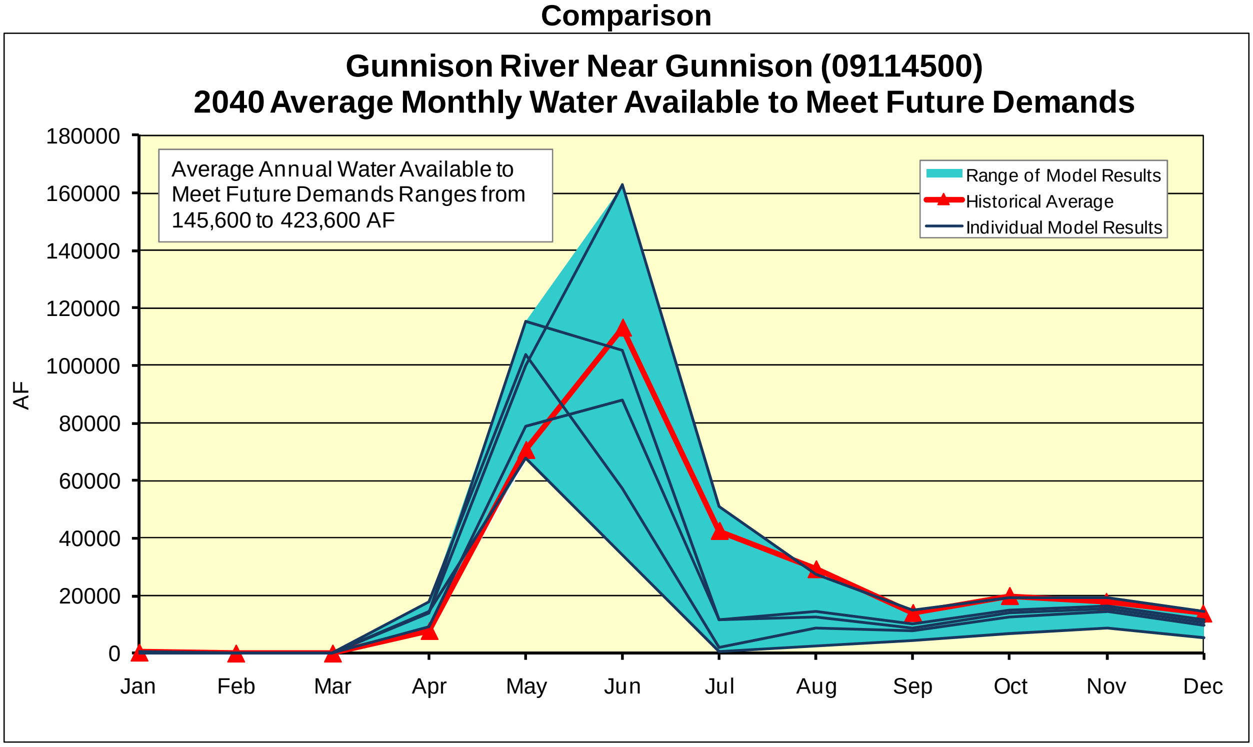


Figure F15 –2040 Gunnison River near Gunnison Average Water Available to Meet Future Demands Comparison

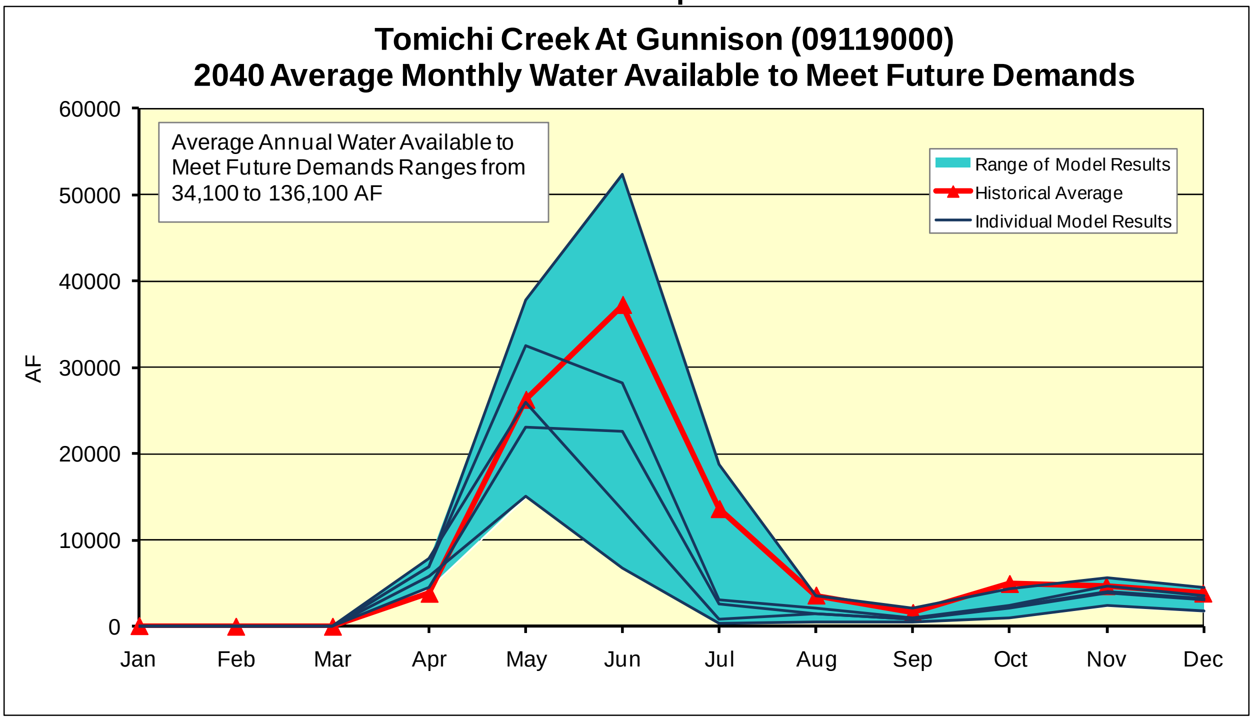


Figure F16 –2040 Cimarron River at Cimarron Average Water Available to Meet Future Demands Comparison

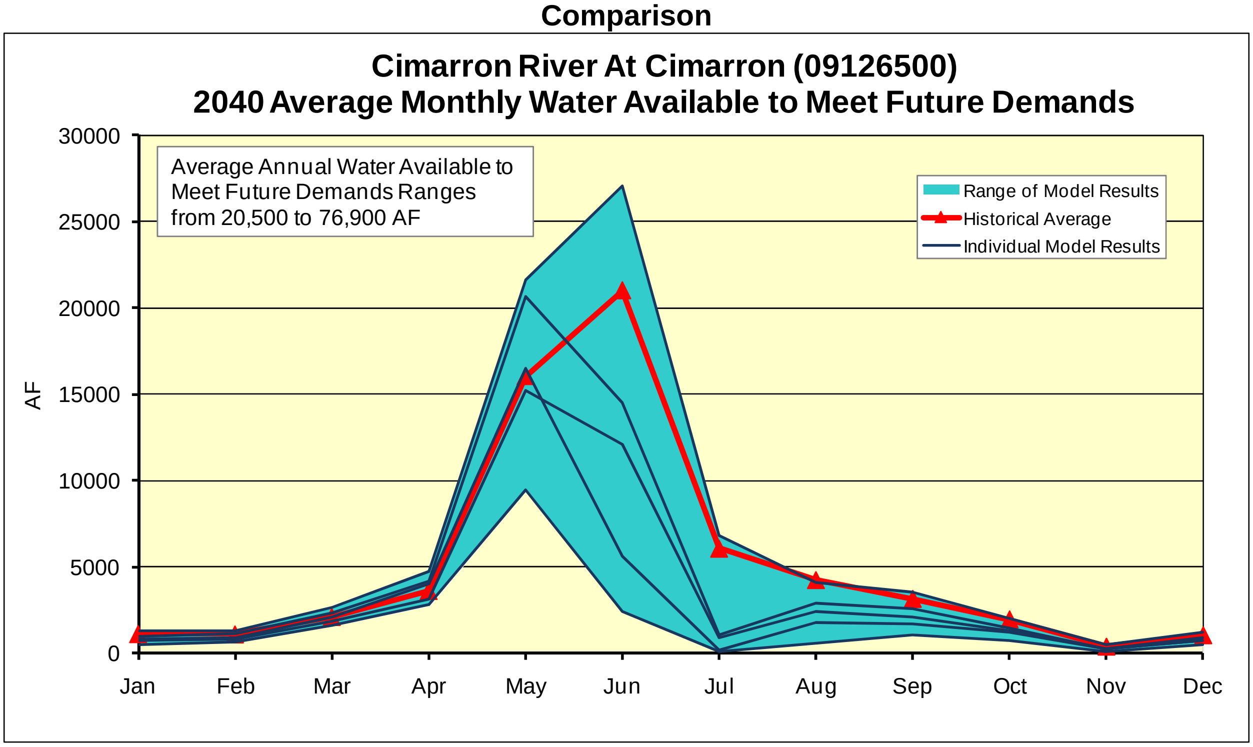


Figure F17 –2040 Gunnison River below Gunnison Tunnel Average Water Available to Meet Future Demands Comparison

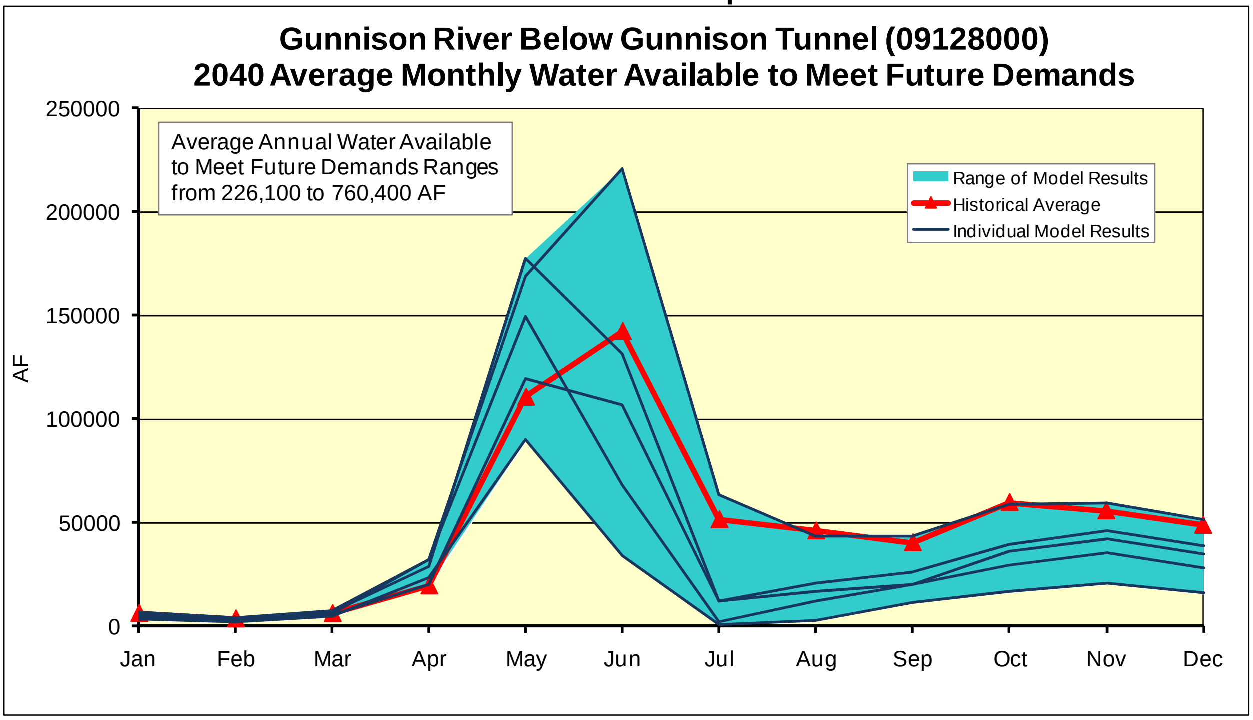


Figure F18 –2040 Gunnison River near Lazear Average Water Available to Meet Future Demands Comparison

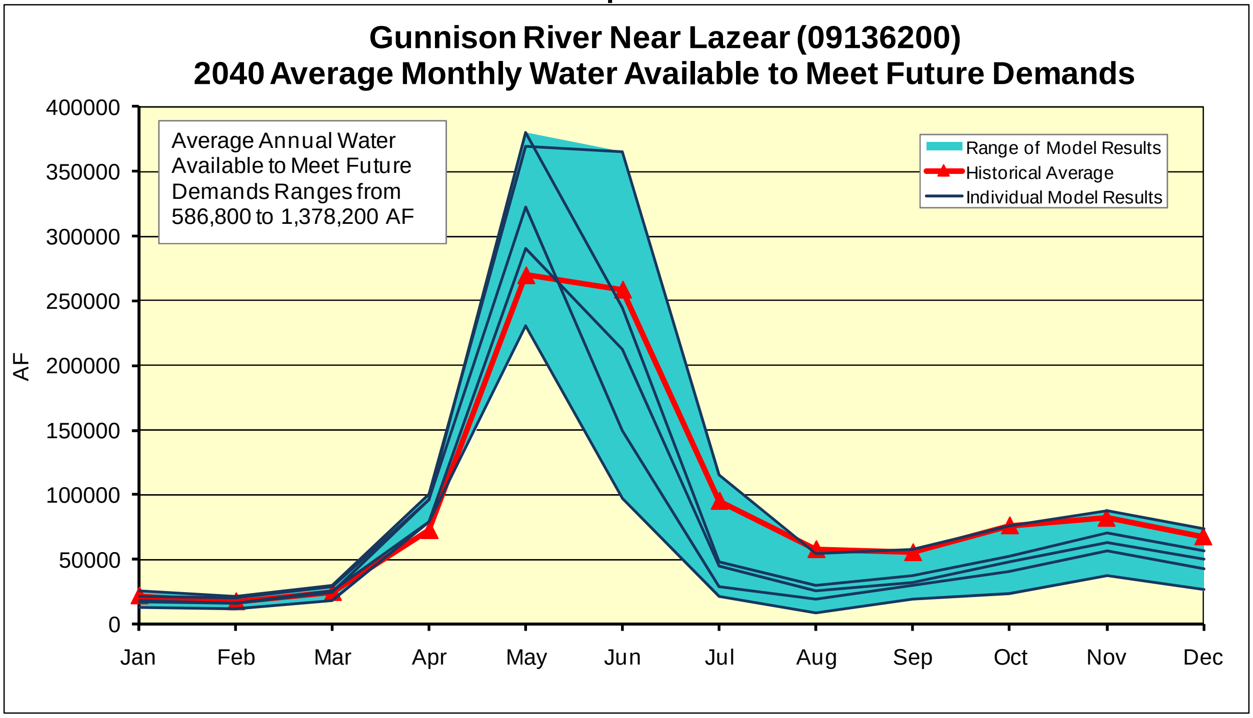


Figure F19 –2040 Uncompahgre River at Delta Average Water Available to Meet Future Demands Comparison

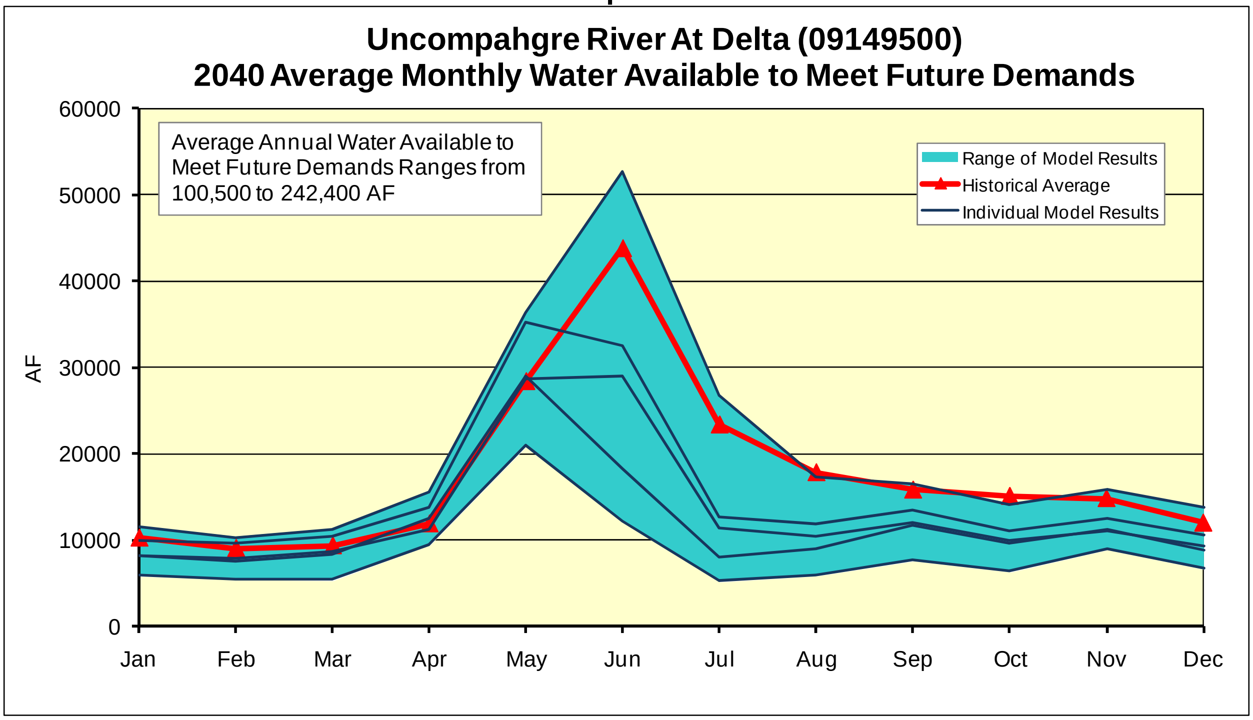


Figure F20 –2040 Gunnison River near Grand Junction Average Water Available to Meet Future Demands Comparison

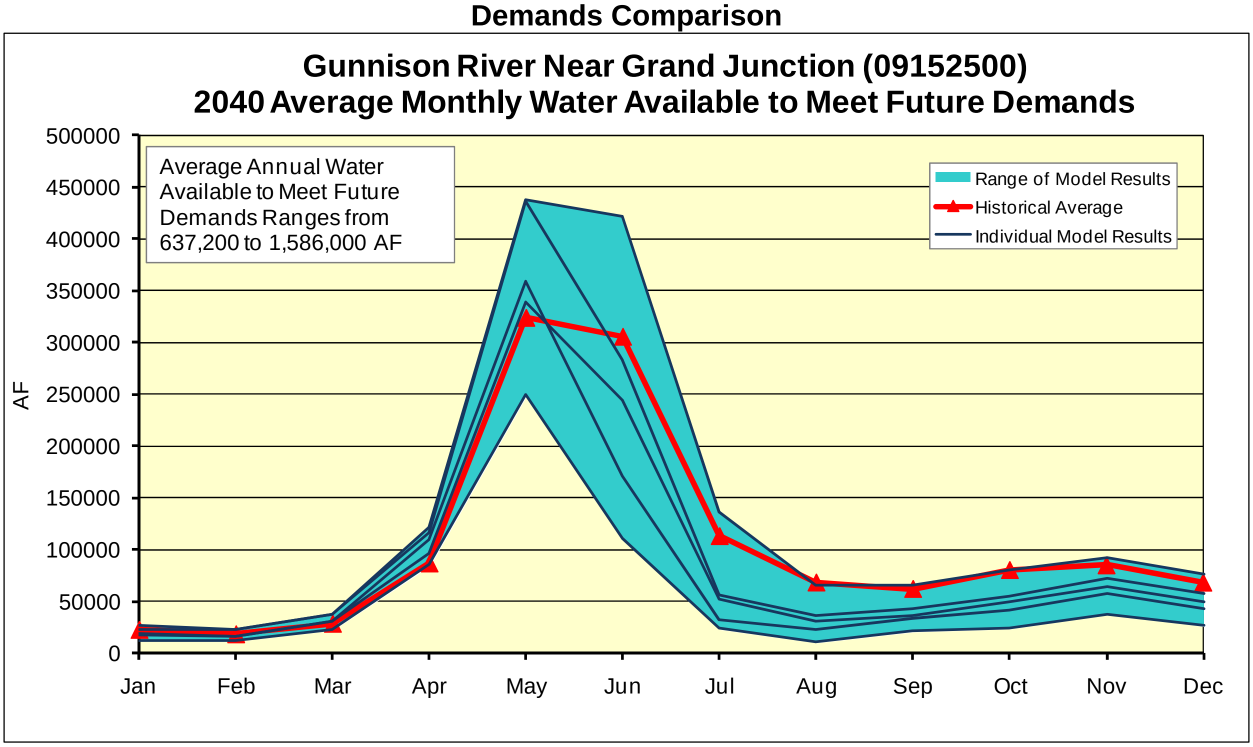


Figure F21 –2040 San Juan River near Carracas Average Water Available to Meet Future Demands Comparison

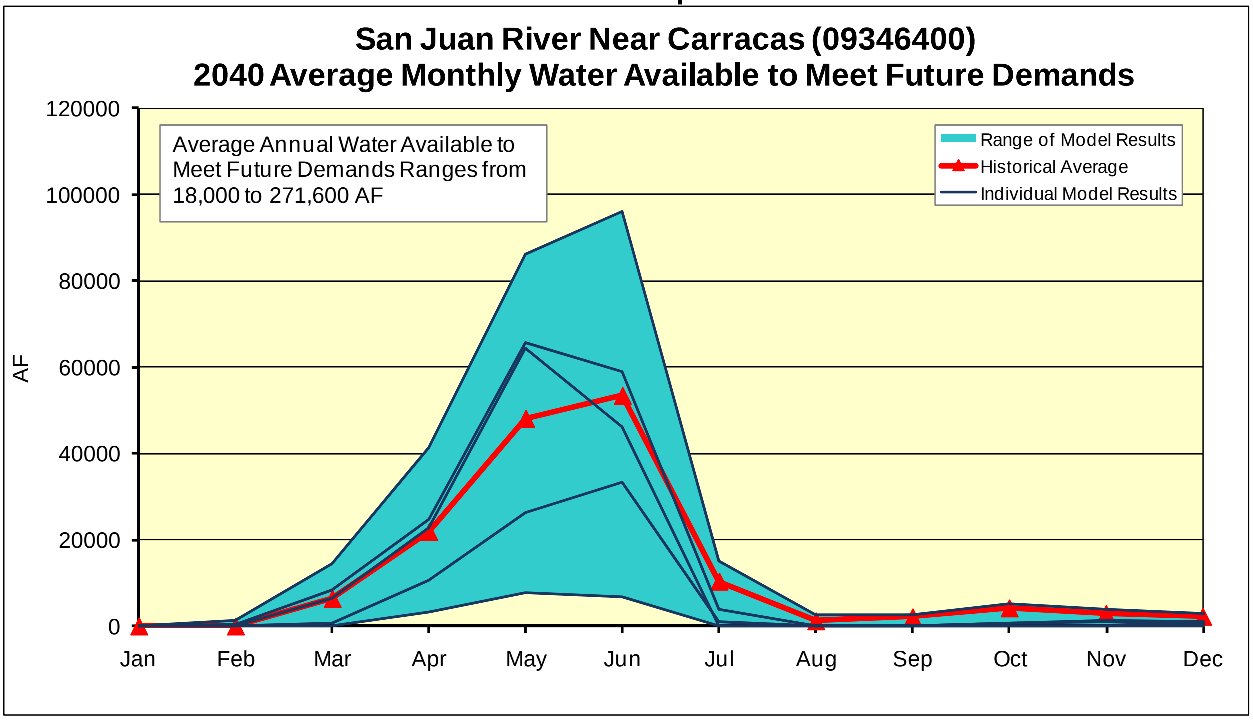


Figure F22 –2040 Piedra River near Arboles Average Water Available to Meet Future Demands Comparison

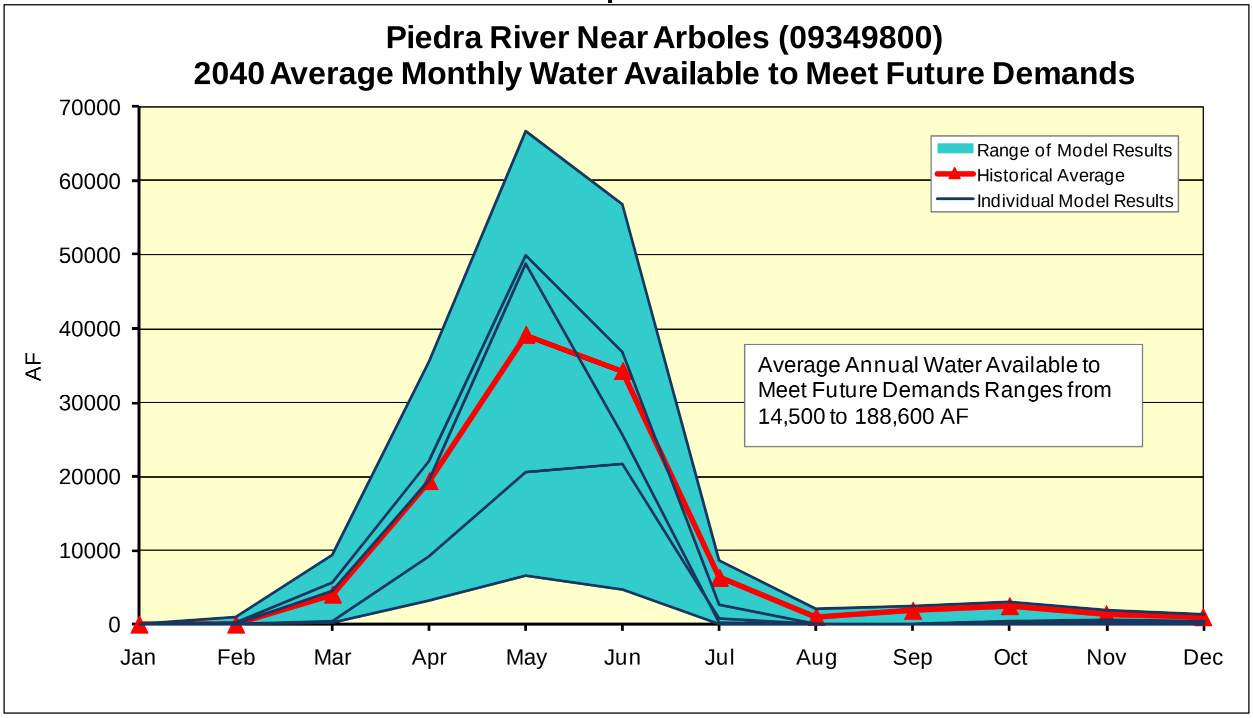


Figure F23 –2040 Los Pinos River at La Boca Average Water Available to Meet Future Demands Comparison

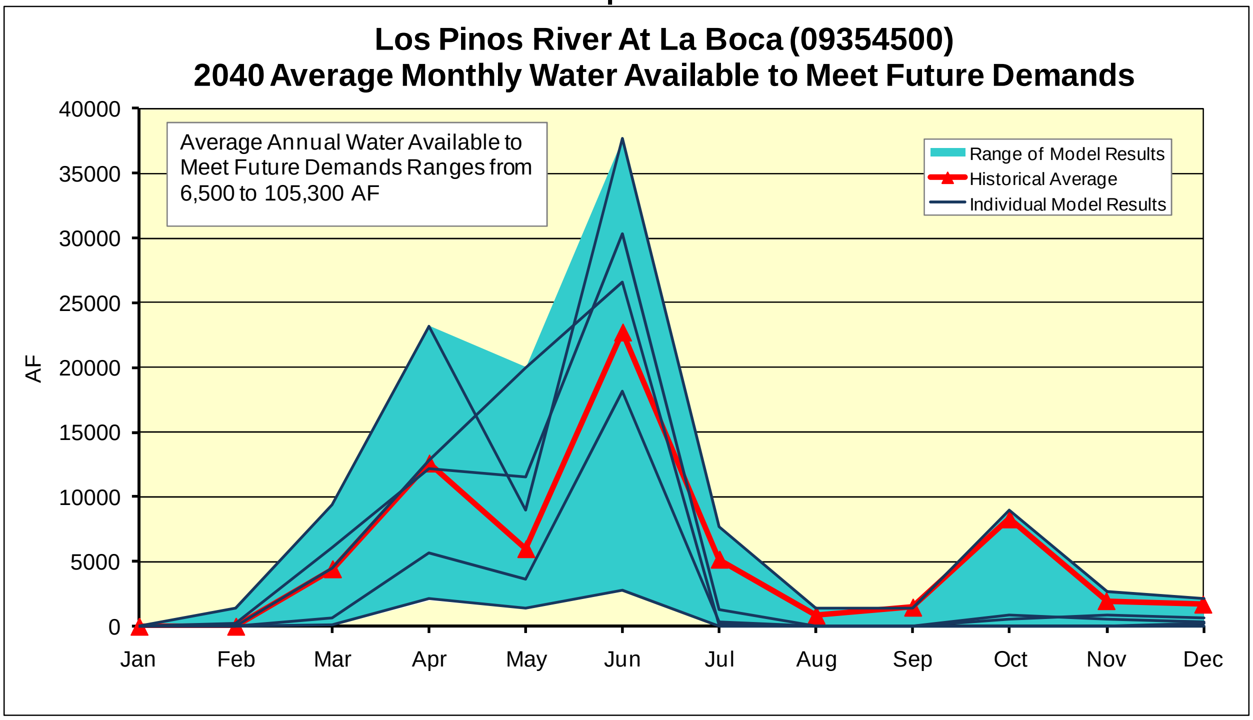


Figure F24 –2040 Florida River at Bondad Average Water Available to Meet Future Demands Comparison

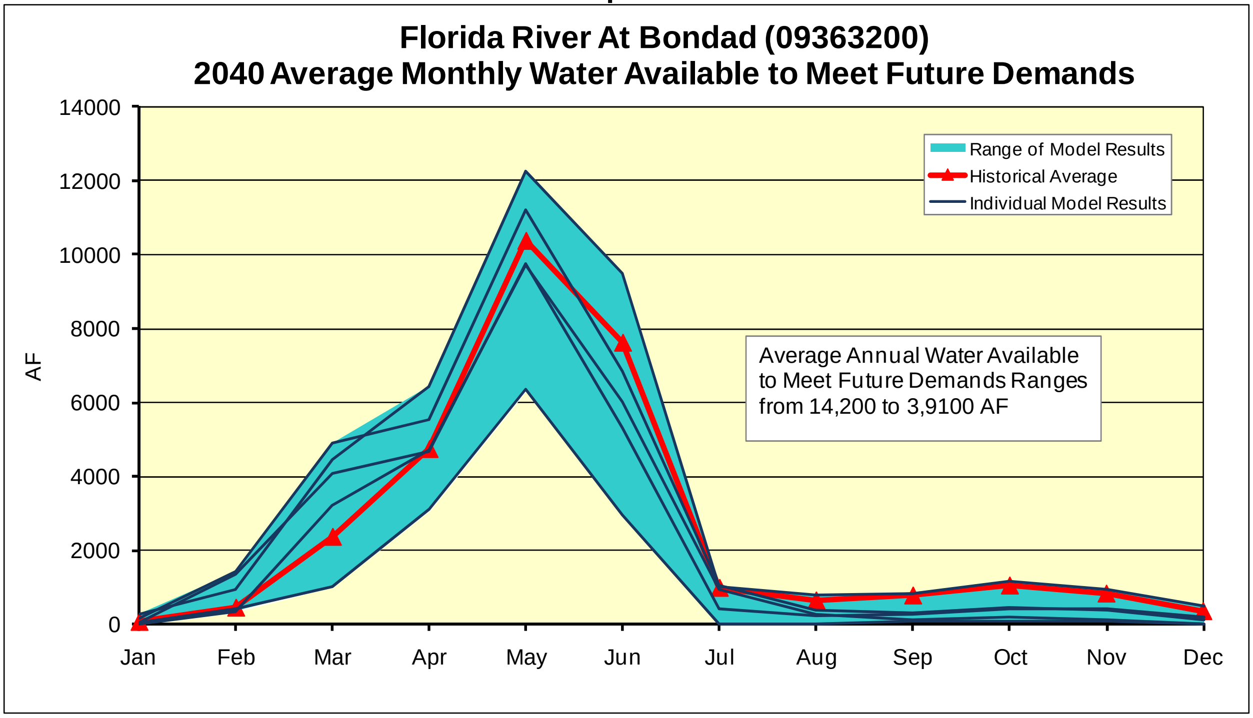


Figure F25 –2040 Animas River near Cedar Hill, NM Average Water Available to Meet Future Demands Comparison

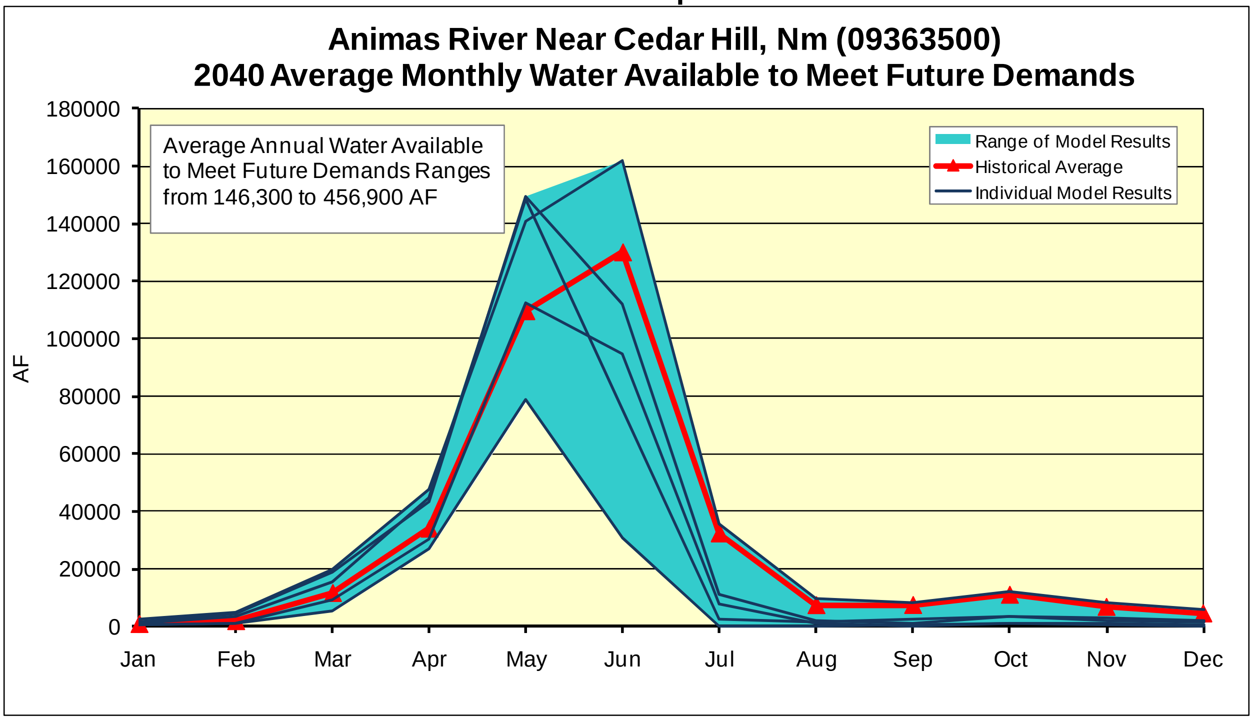


Figure F26 –2040 La Plata River at Hesperus Average Water Available to Meet Future Demands Comparison

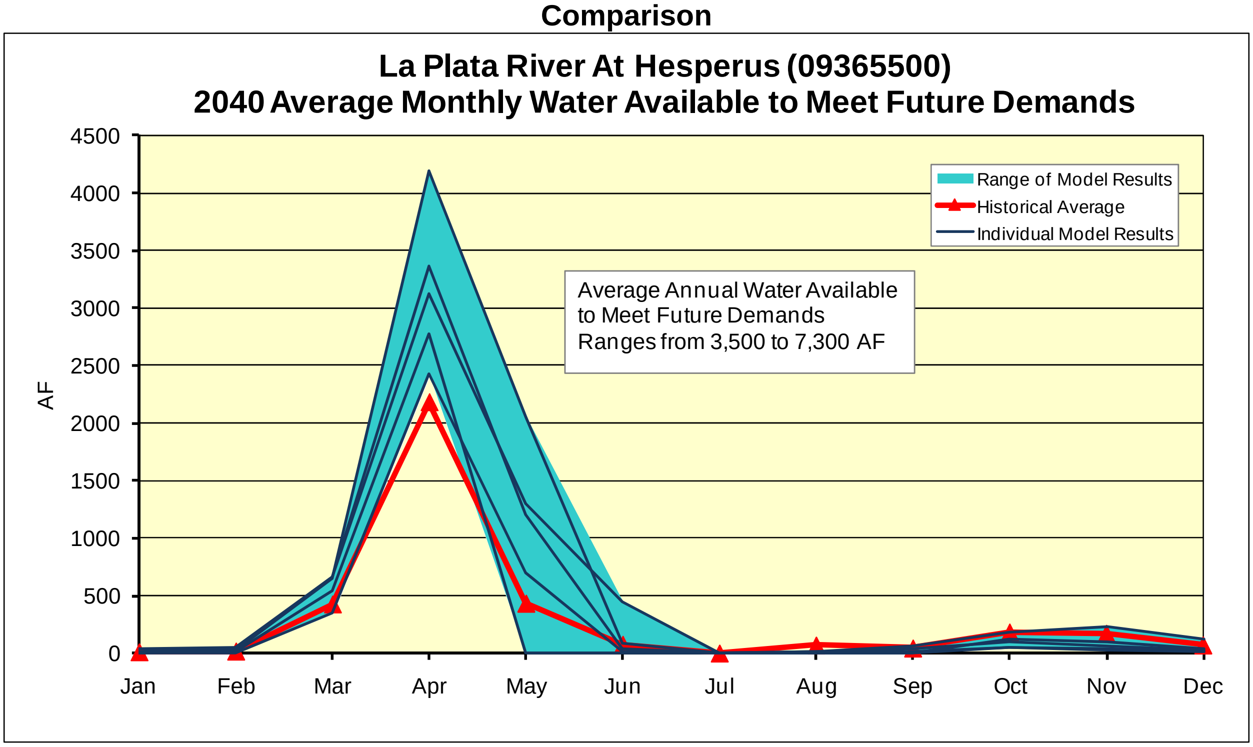


Figure F27 –2040 La Plata River at CO-NM State Line Average Water Available to Meet Future Demands Comparison

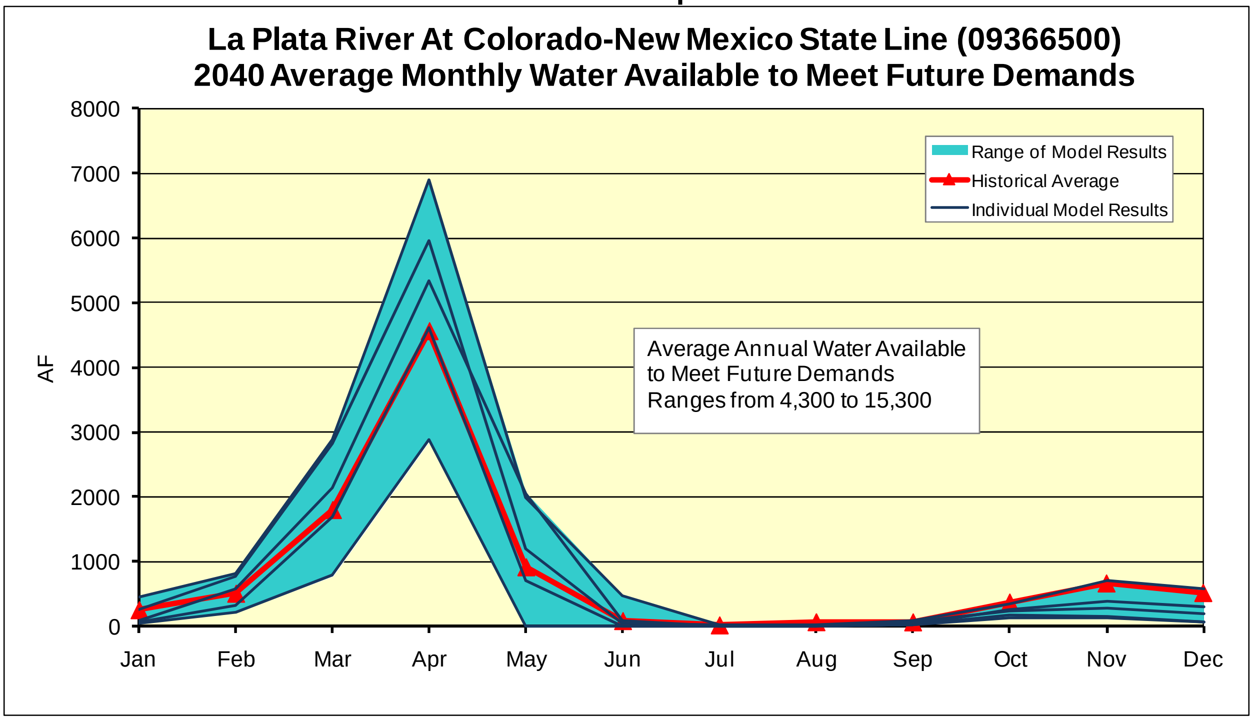


Figure F28 –2040 Mancos River near Towaoc Average Water Available to Meet Future Demands Comparison

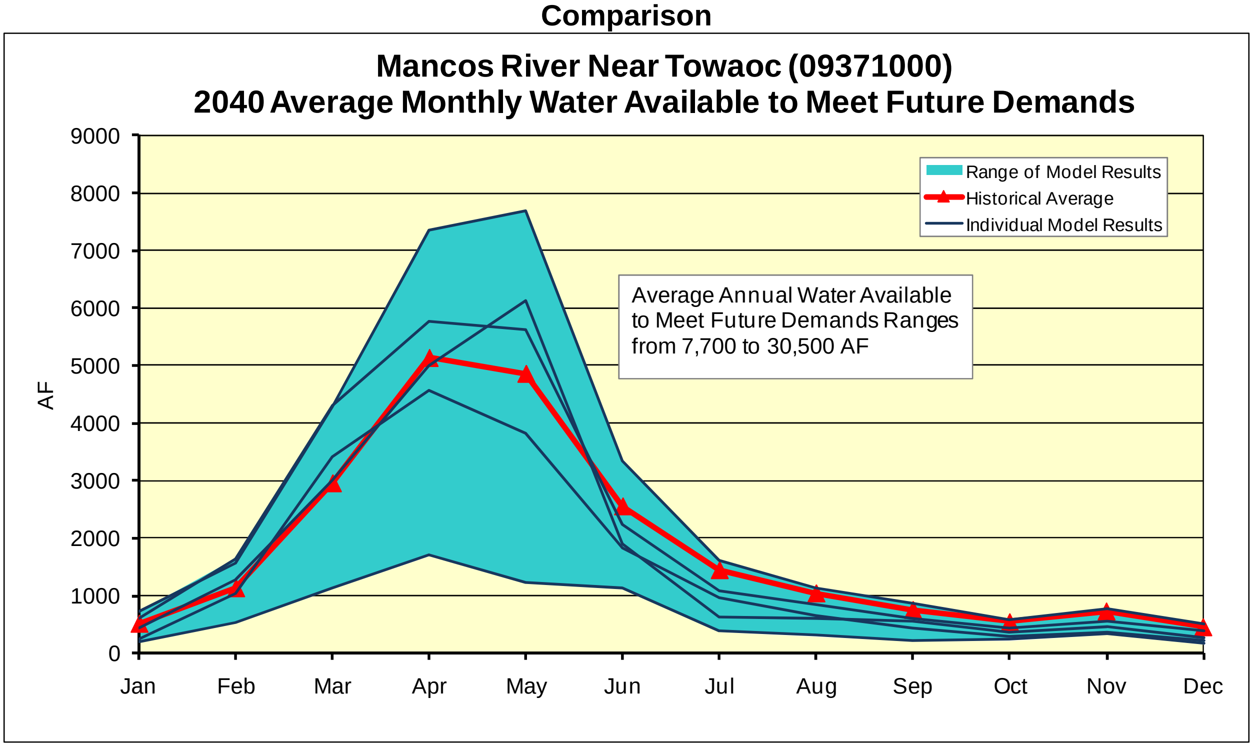


Figure F29 –2040 McElmo Creek near CO-UT State Line Average Water Available to Meet Future Demands Comparison

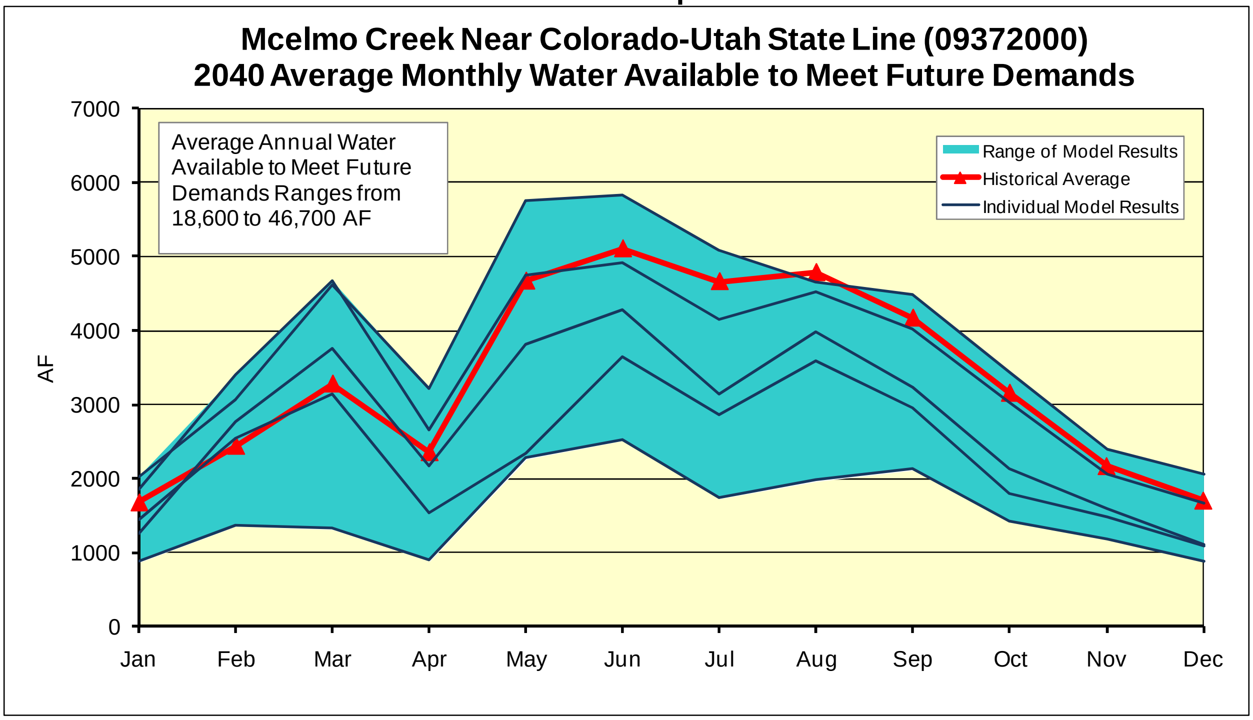


Figure F30 –2040 Dolores River near Bedrock Average Water Available to Meet Future Demands Comparison

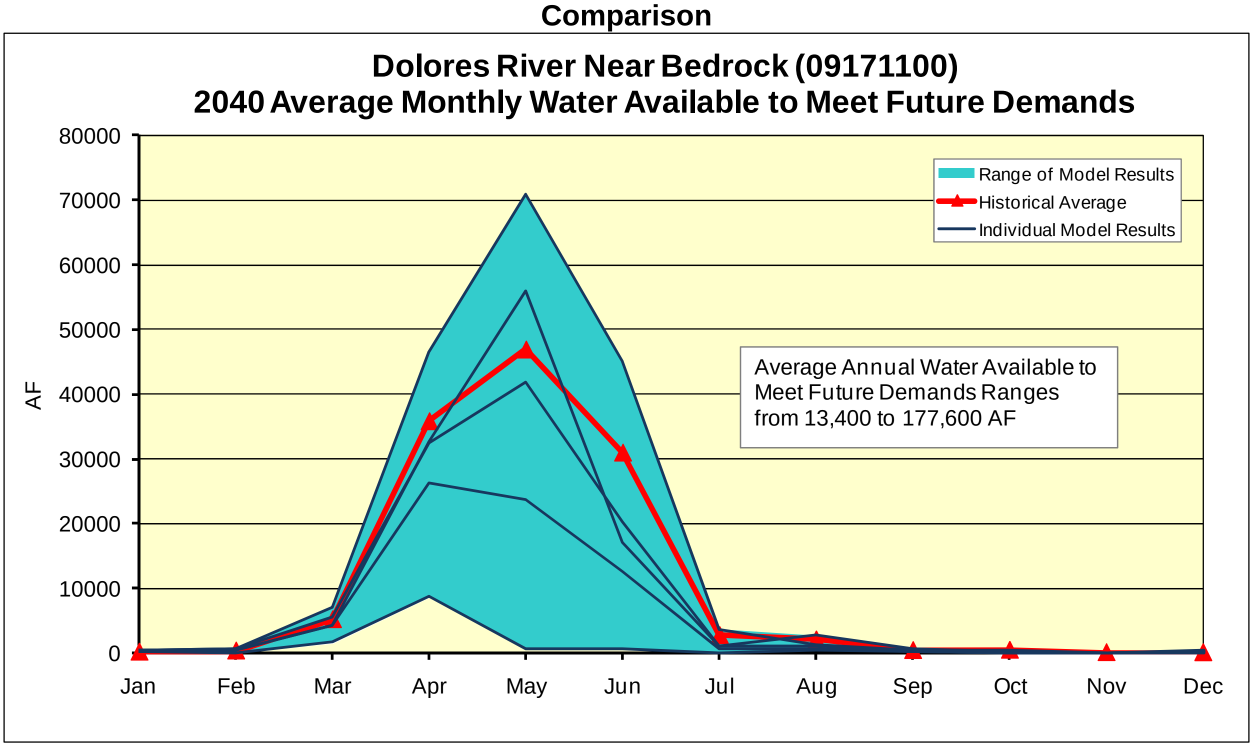


Figure F31 –2040 San Miguel River at Naturita Average Water Available to Meet Future Demands Comparison

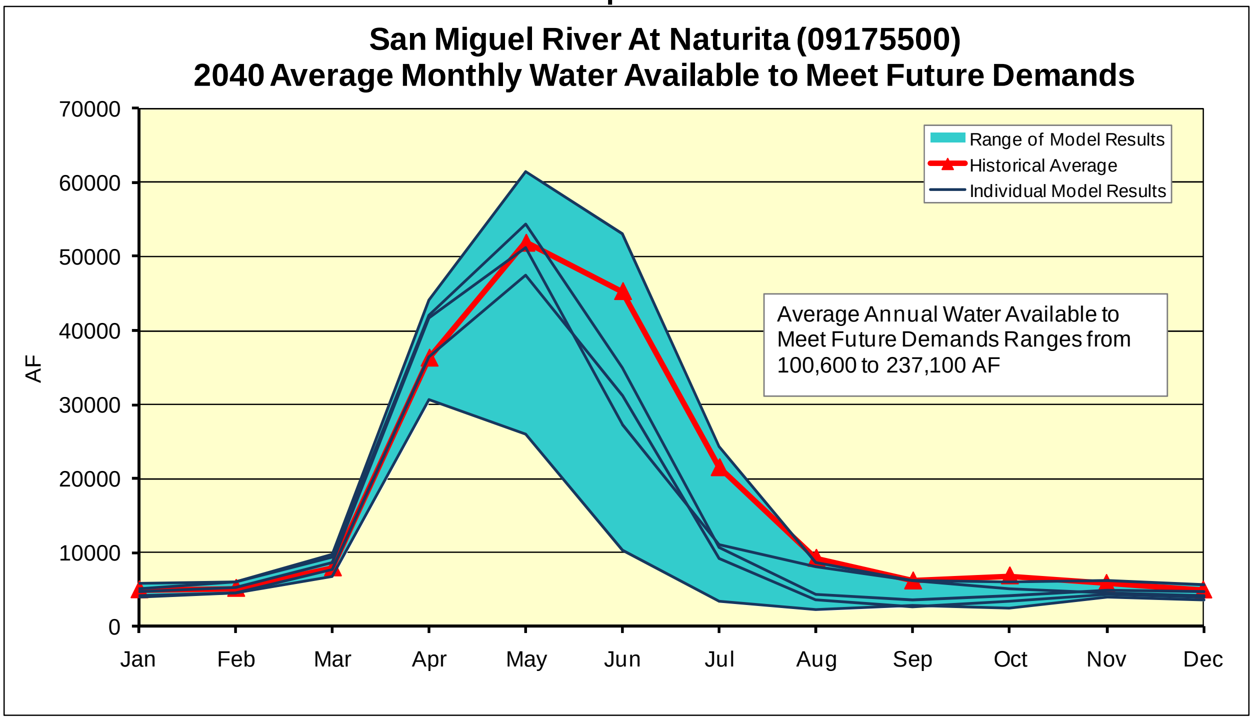


Figure F32 –2040 Yampa River below Stagecoach Reservoir Average Water Available to Meet Future Demands Comparison

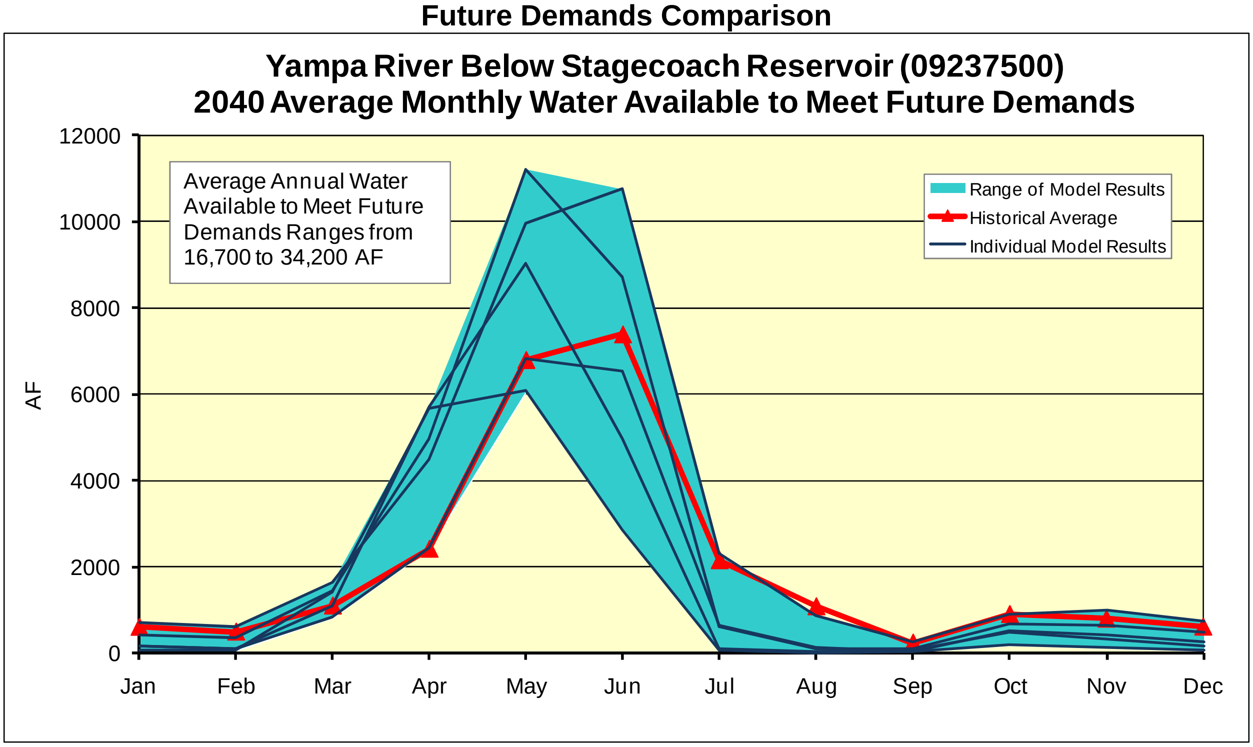


Figure F33 –2040 Elk River at Clark Average Water Available to Meet Future Demands Comparison

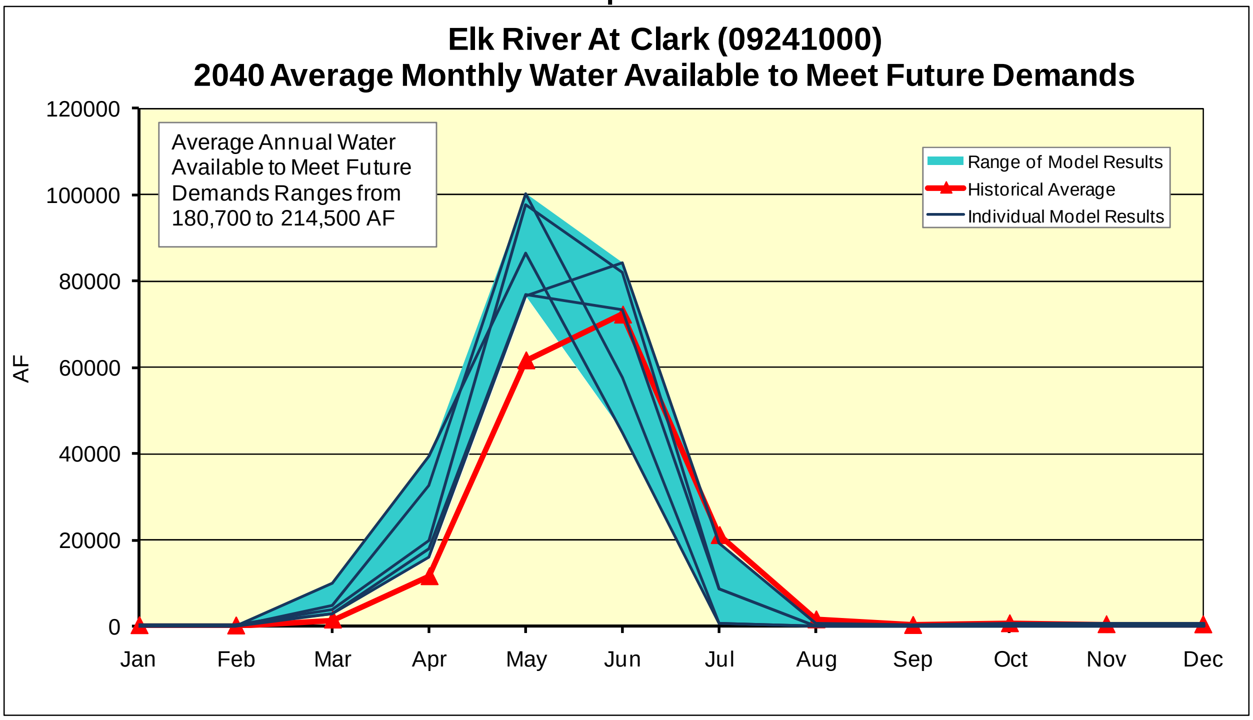


Figure F34 –2040 Elkhead Creek near Elkhead Average Water Available to Meet Future Demands Comparison

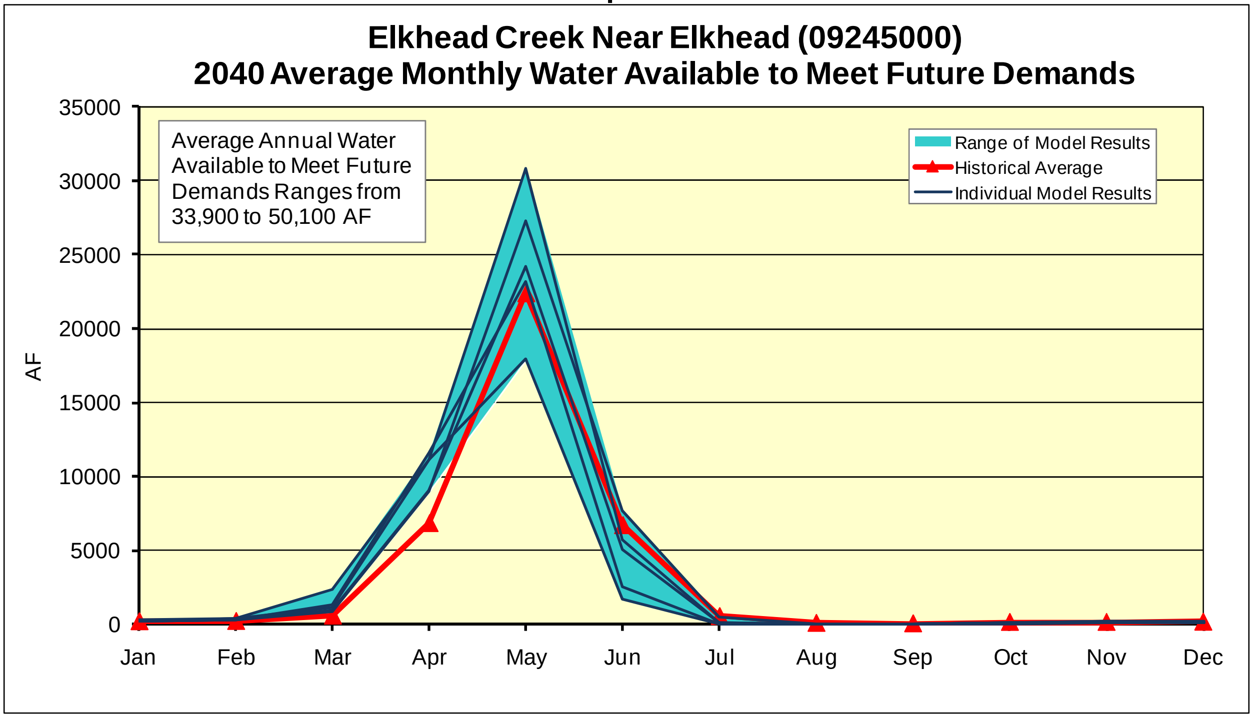


Figure F35 –2040 Williams Fork at Mouth, near Hamilton Average Water Available to Meet Future Demands Comparison

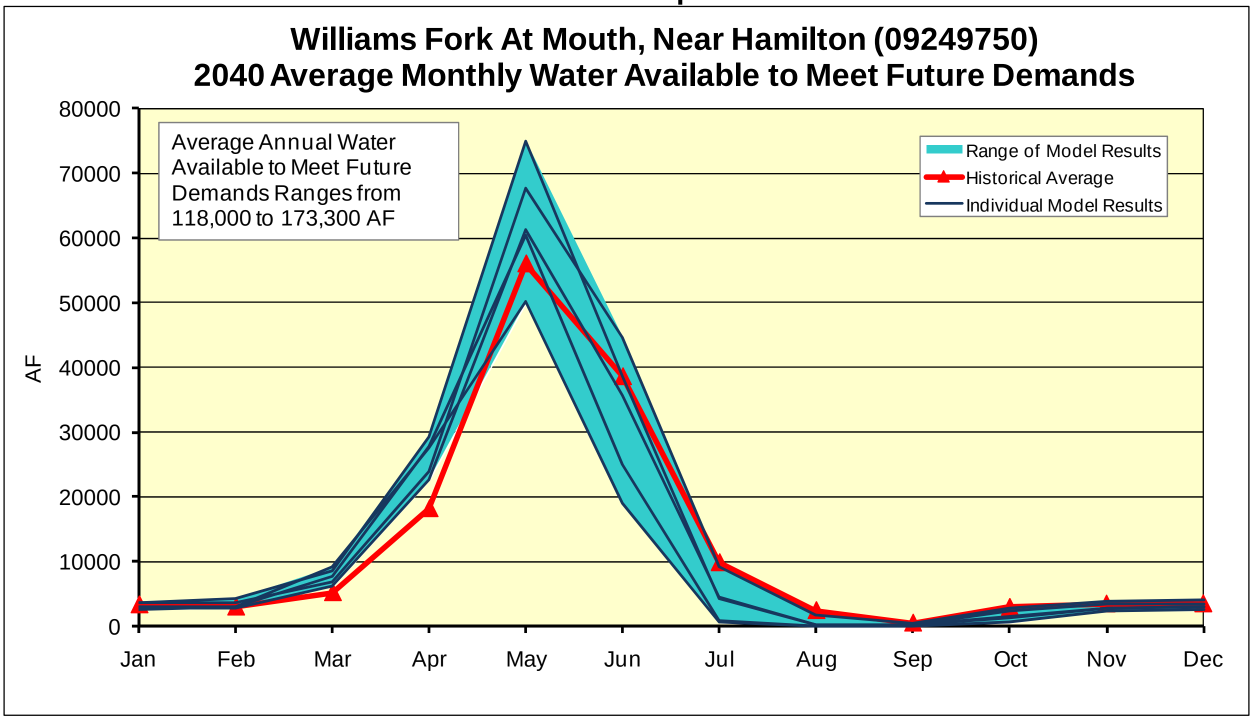


Figure F36 –2040 Yampa River near Maybell Average Water Available to Meet Future Demands Comparison

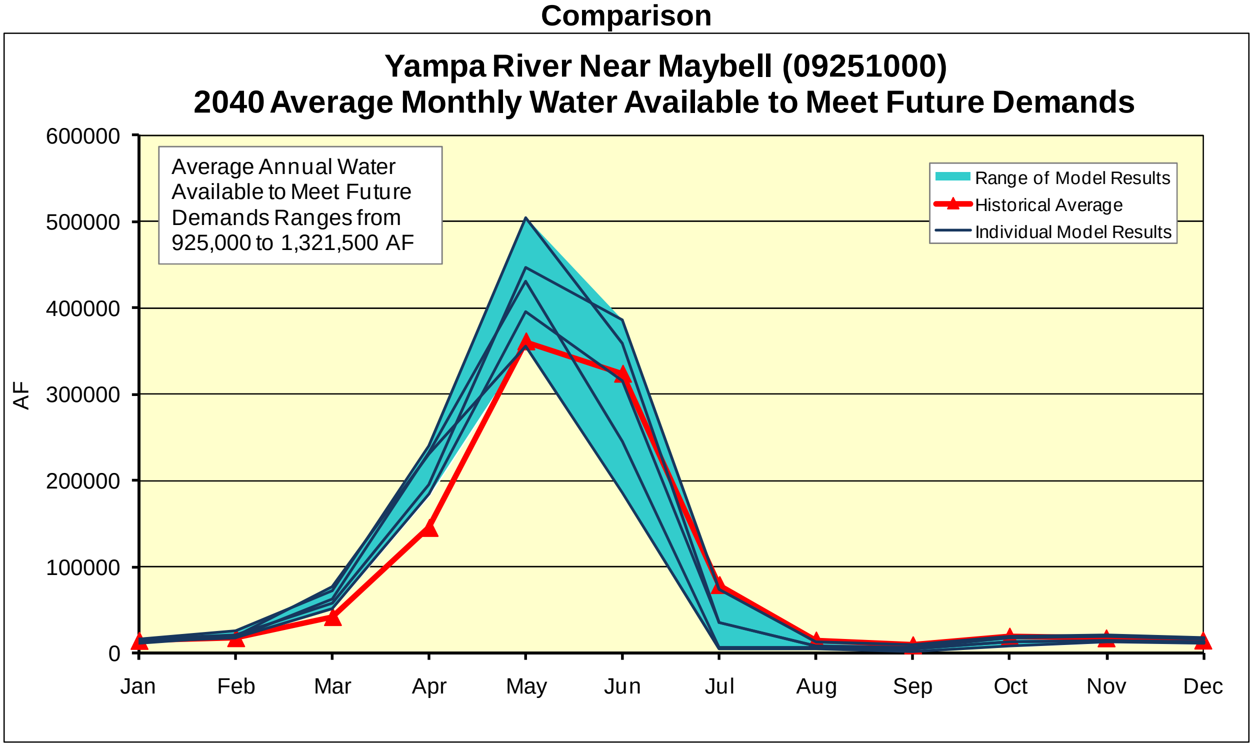


Figure F37 –2040 Little Snake River near Lily Average Water Available to Meet Future Demands Comparison

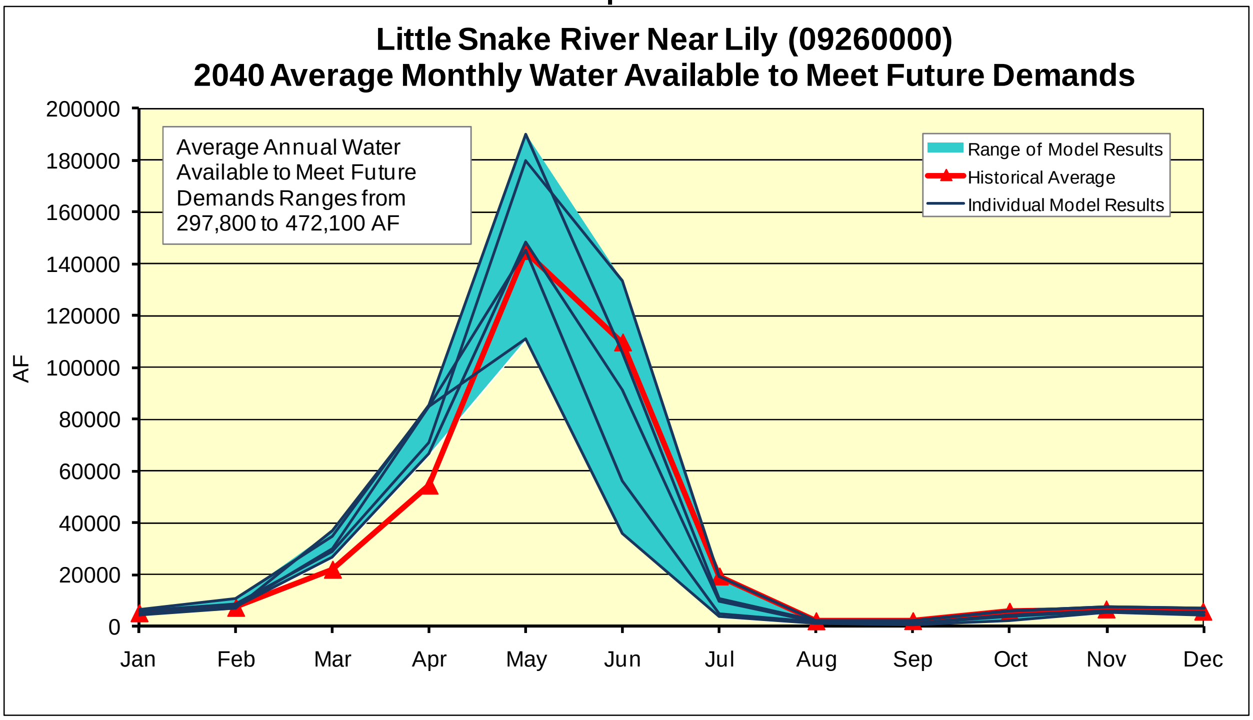


Figure F38 –2040 Yampa River at Deerlodge Park Average Water Available to Meet Future Demands Comparison

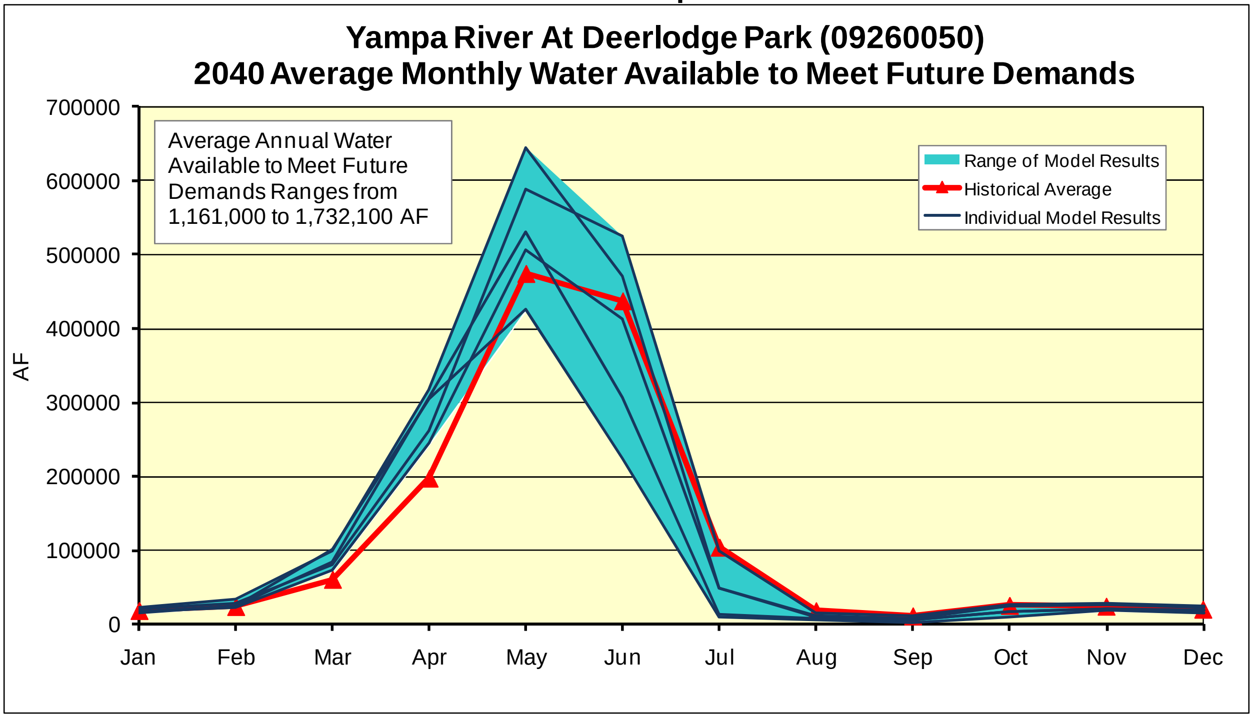


Figure F39 –2040 North Fork White River at Buford Average Water Available to Meet Future Demands Comparison

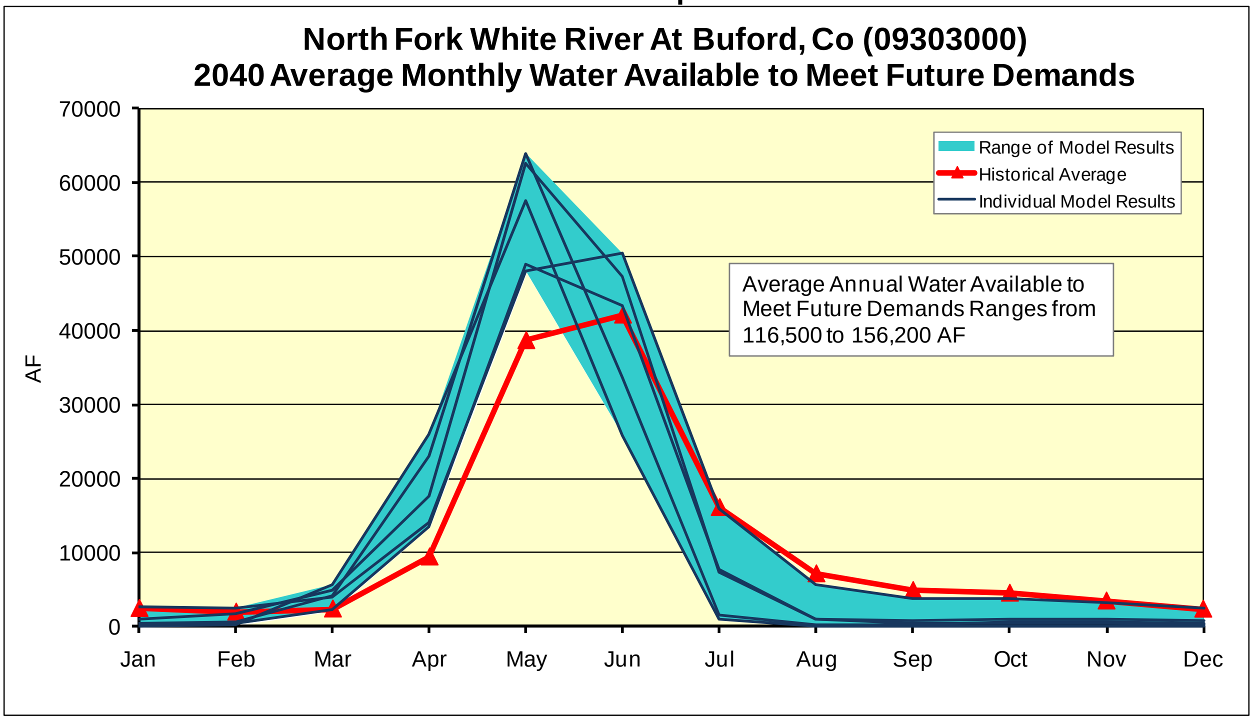


Figure F40 –2040 South Fork White River at Buford Average Water Available to Meet Future Demands Comparison

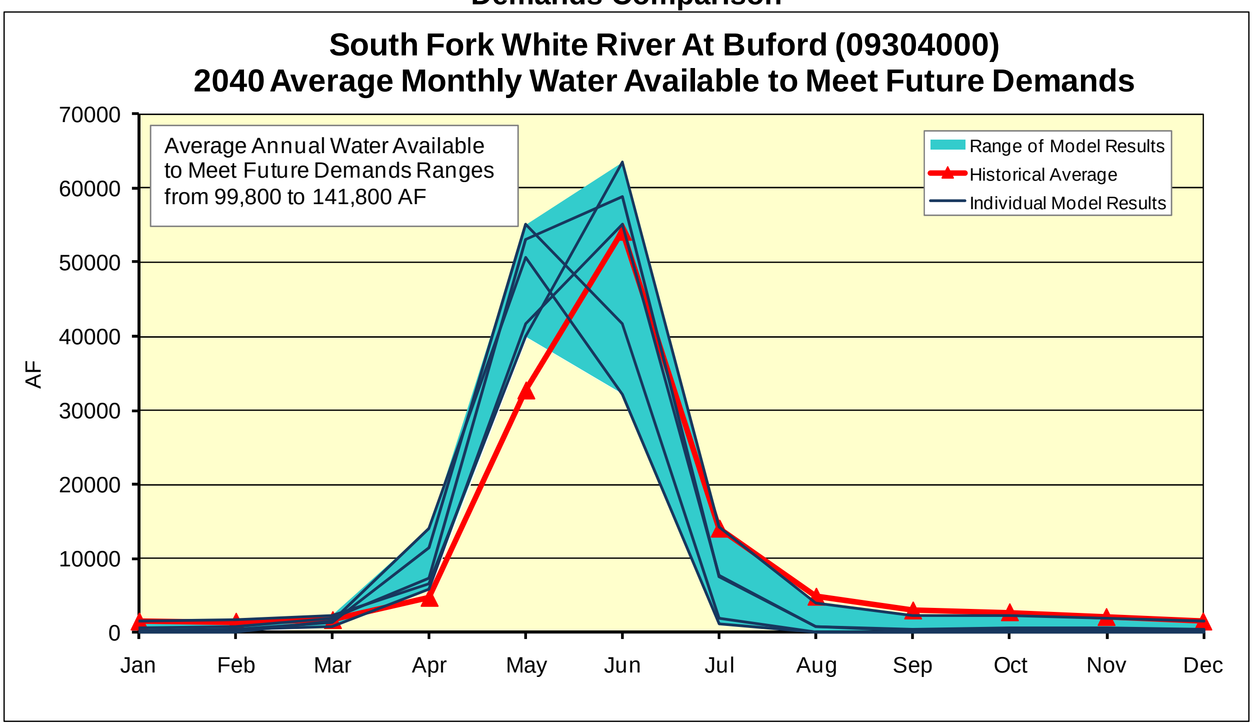


Figure F41 –2040 White River below Meeker Average Water Available to Meet Future Demands Comparison

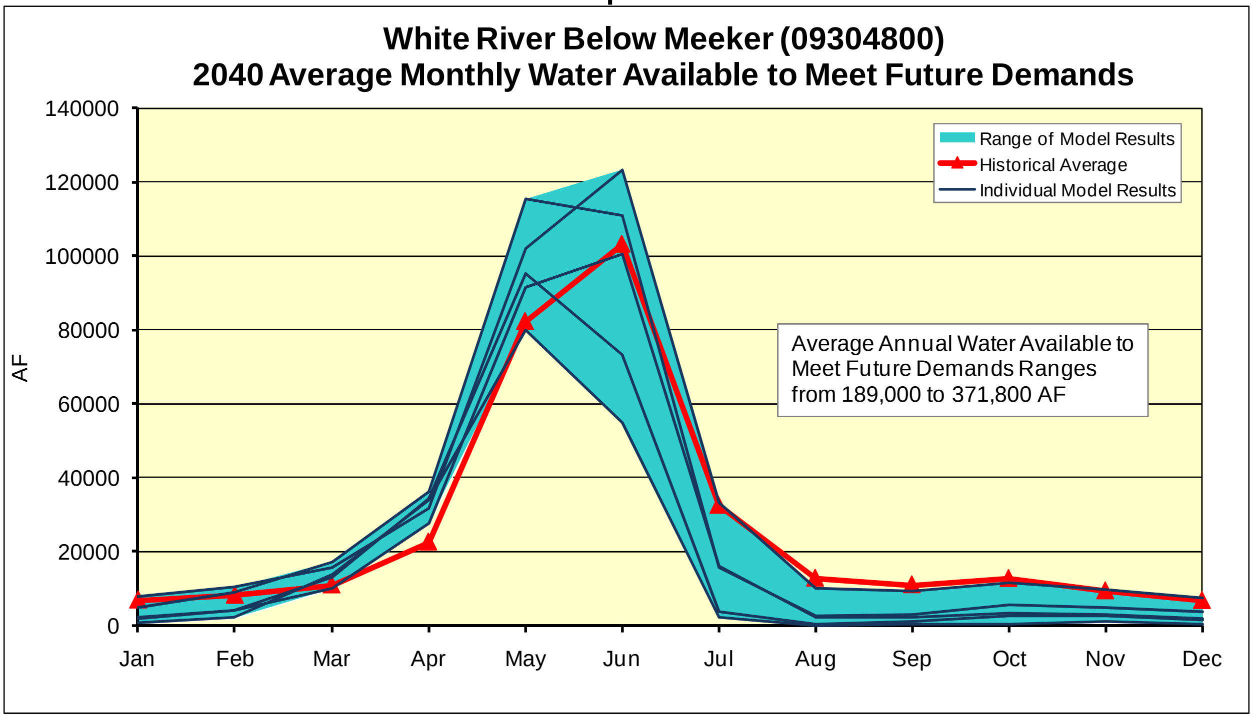


Figure F42 –2040 Piceance Creek at White River Average Water Available to Meet Future Demands Comparison

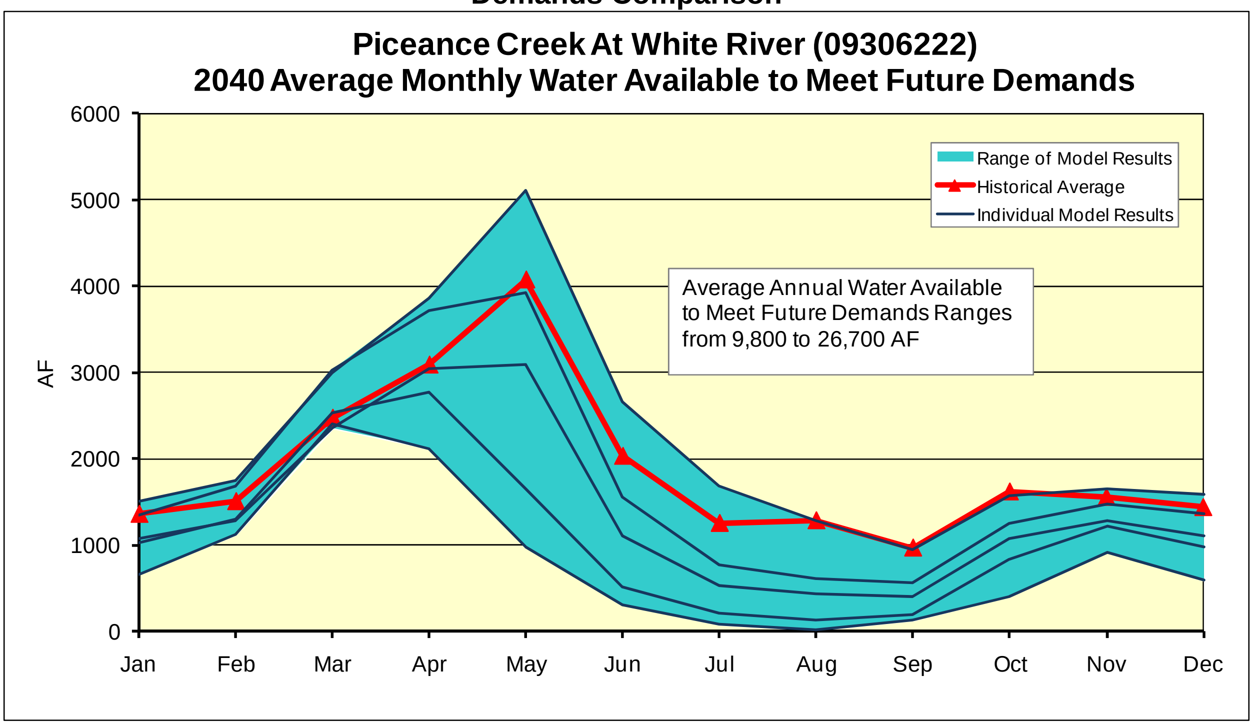


Figure F43 –2040 White River near CO-UT State Line Average Water Available to Meet Future Demands Comparison

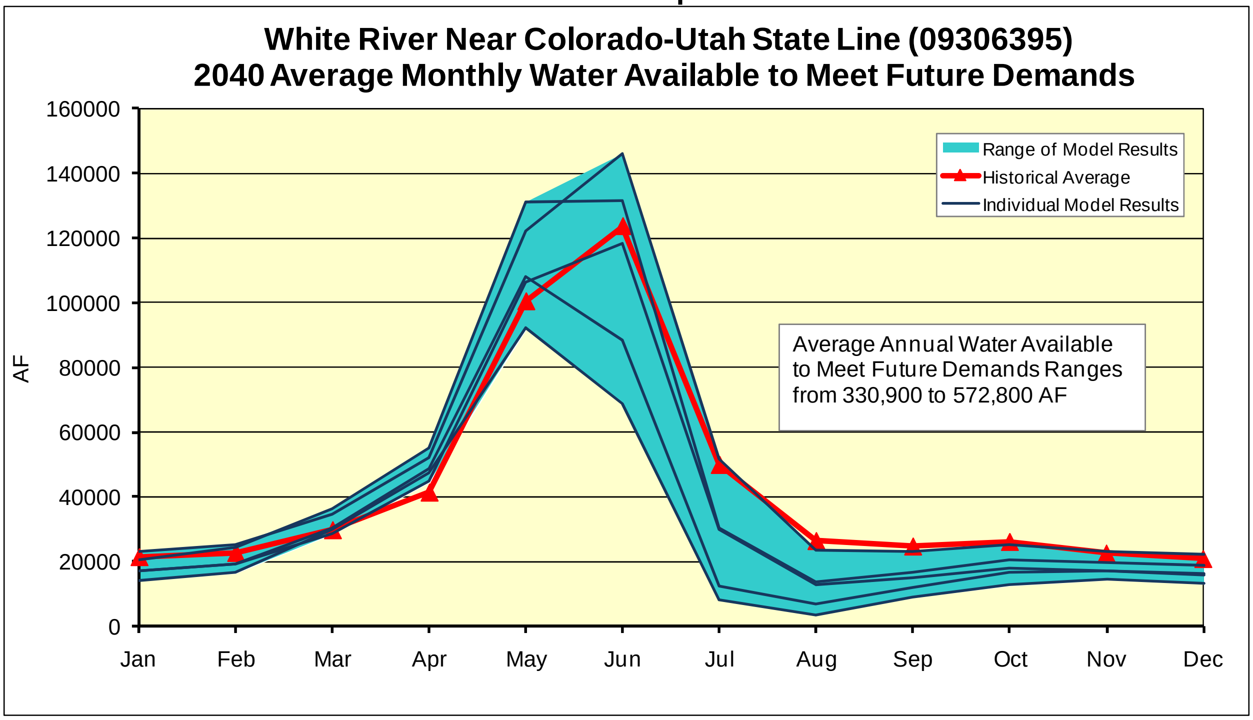


Figure F44 –2070 Colorado River near Grand Lake Average Water Available to Meet Future Demands Comparison

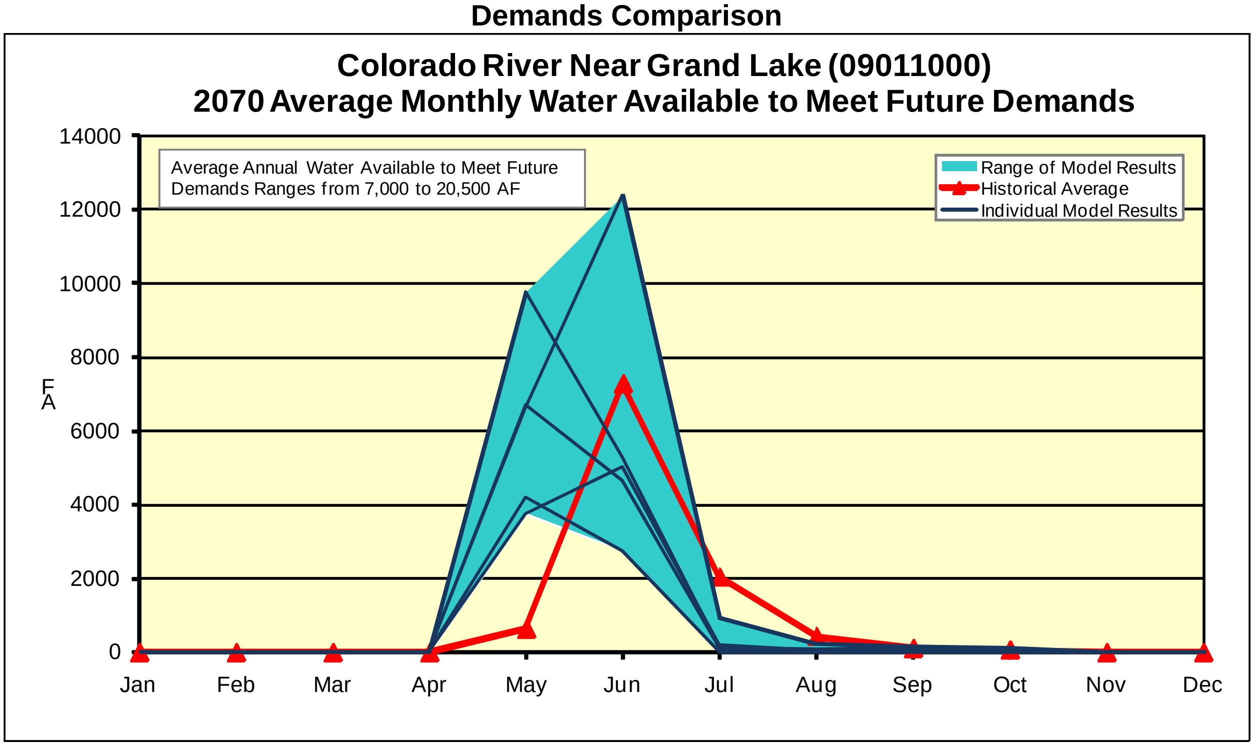


Figure F45 –2070 Muddy Creek at Kremmling Average Water Available to Meet Future Demands Comparison

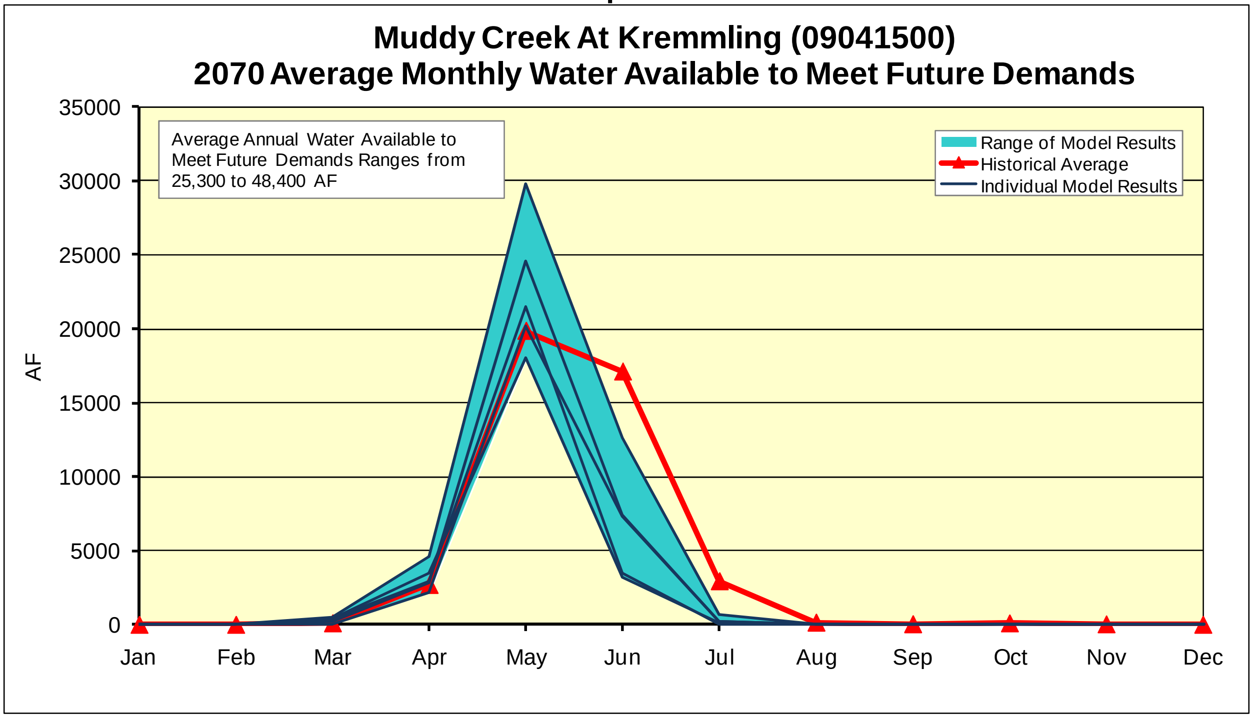


Figure F46 –2070 Blue River below Dillon Average Water Available to Meet Future Demands Comparison

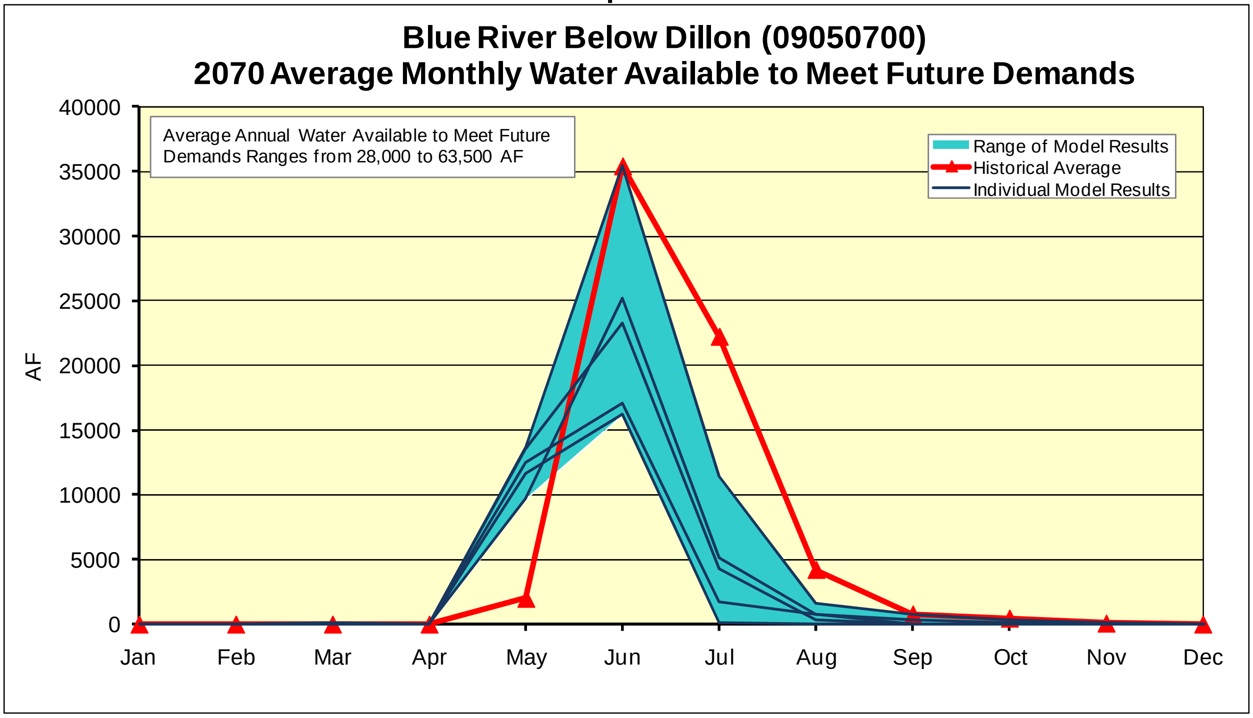


Figure F47 –2070 Blue River below Green Mountain Reservoir Average Water Available to Meet Future Demands Comparison

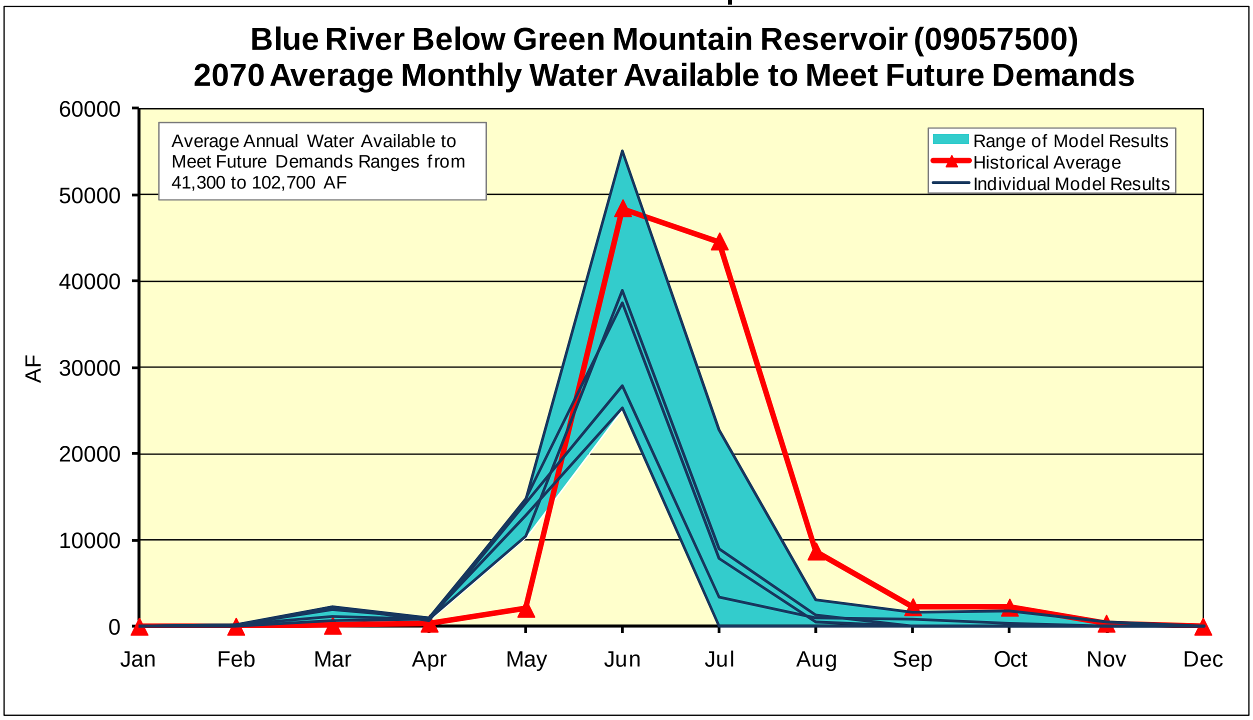


Figure F48 –2070 Eagle River below Gypsum Average Water Available to Meet Future Demands Comparison

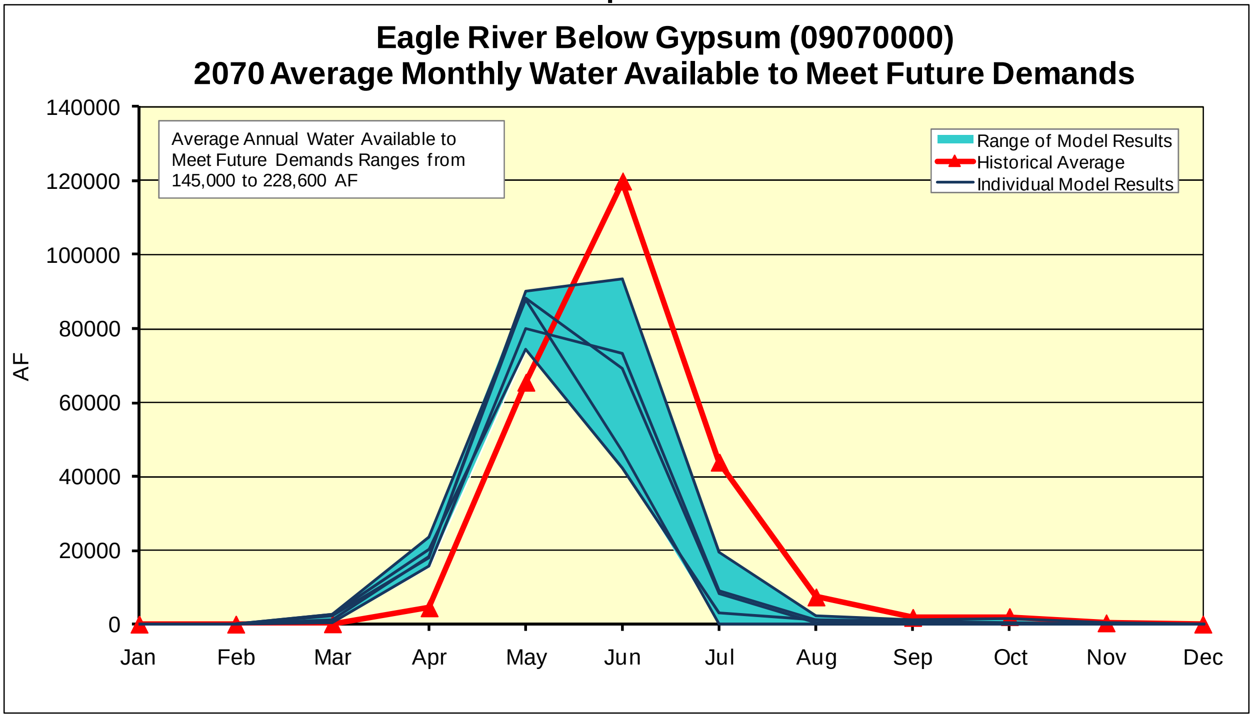


Figure F49 –2070 Colorado River at Dotsero Average Water Available to Meet Future Demands Comparison

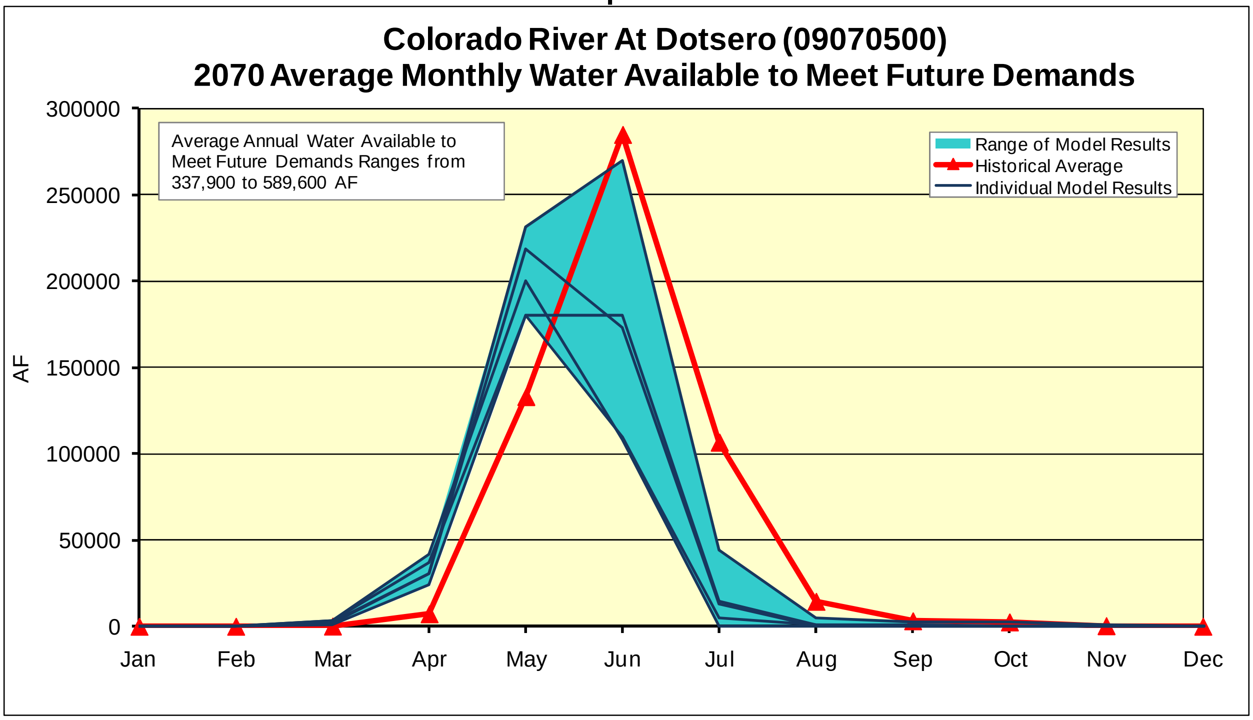


Figure F50 –2070 Roaring Fork River near Aspen Average Water Available to Meet Future Demands Comparison

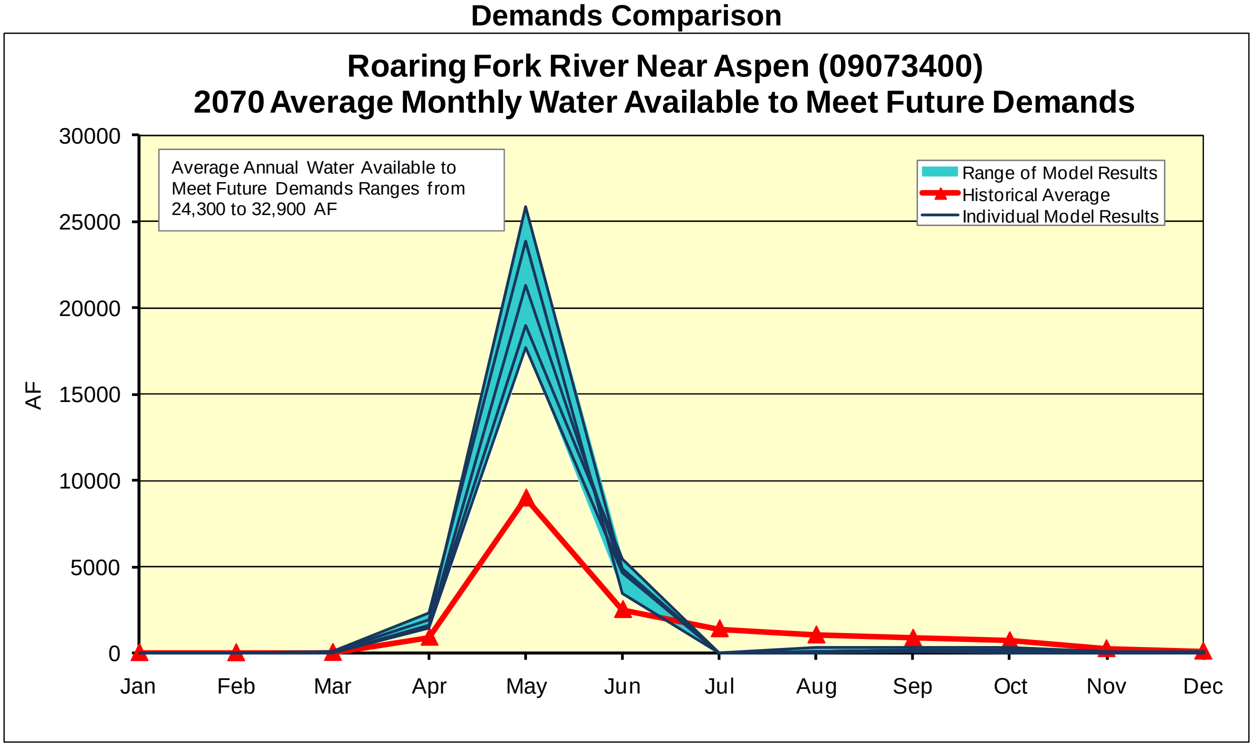


Figure F51 –2070 Roaring Fork River at Glenwood Average Water Available to Meet Future Demands Comparison

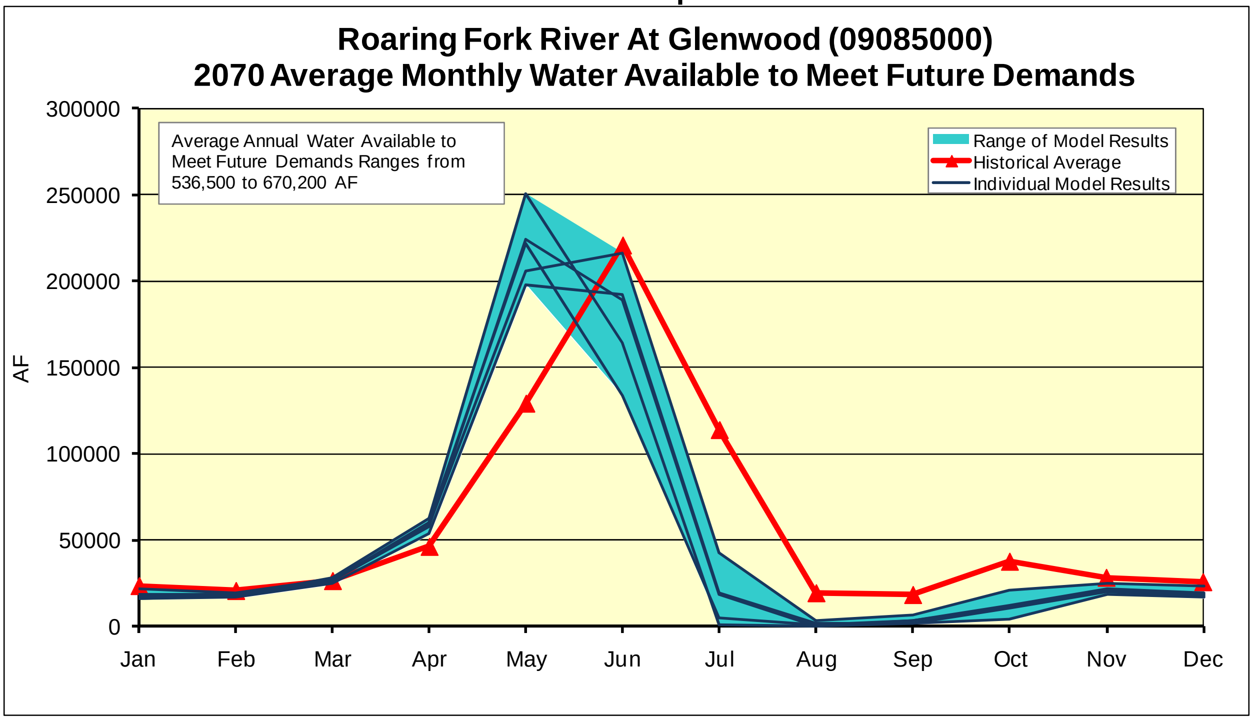


Figure F52 –2070 Colorado River near Cameo Average Water Available to Meet Future Demands Comparison

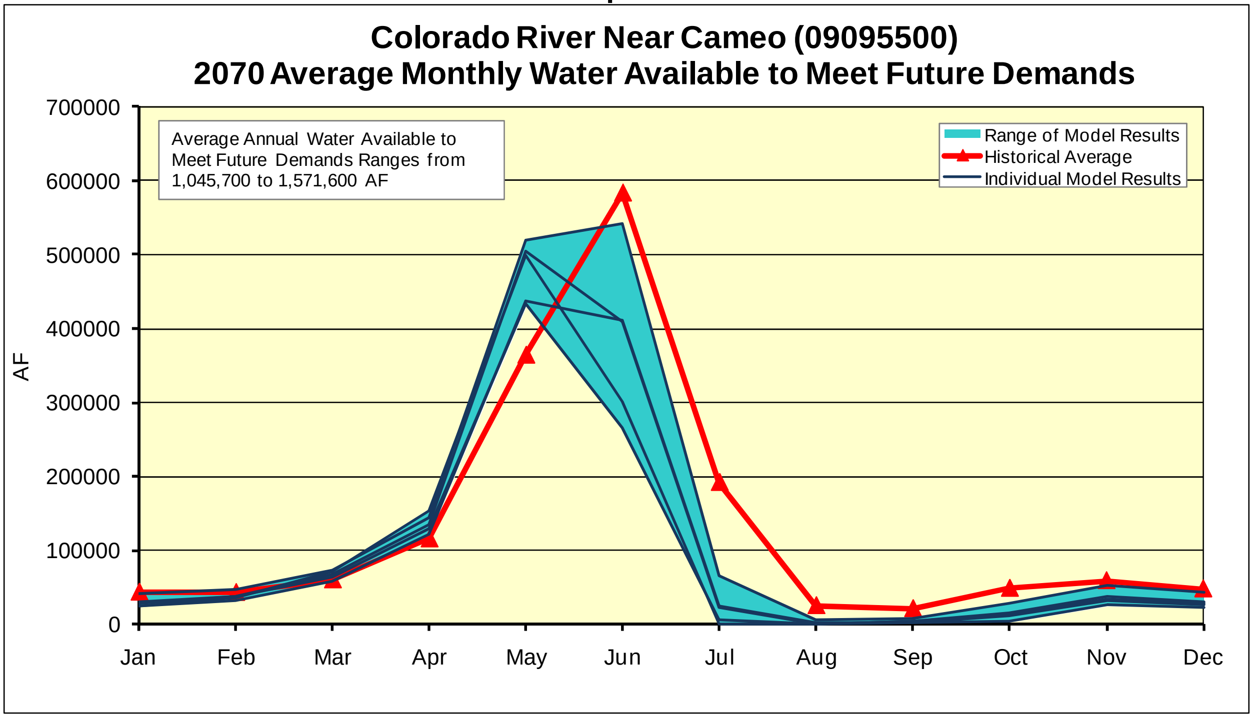


Figure F53 –2070 Plateau near Cameo Average Water Available to Meet Future Demands Comparison

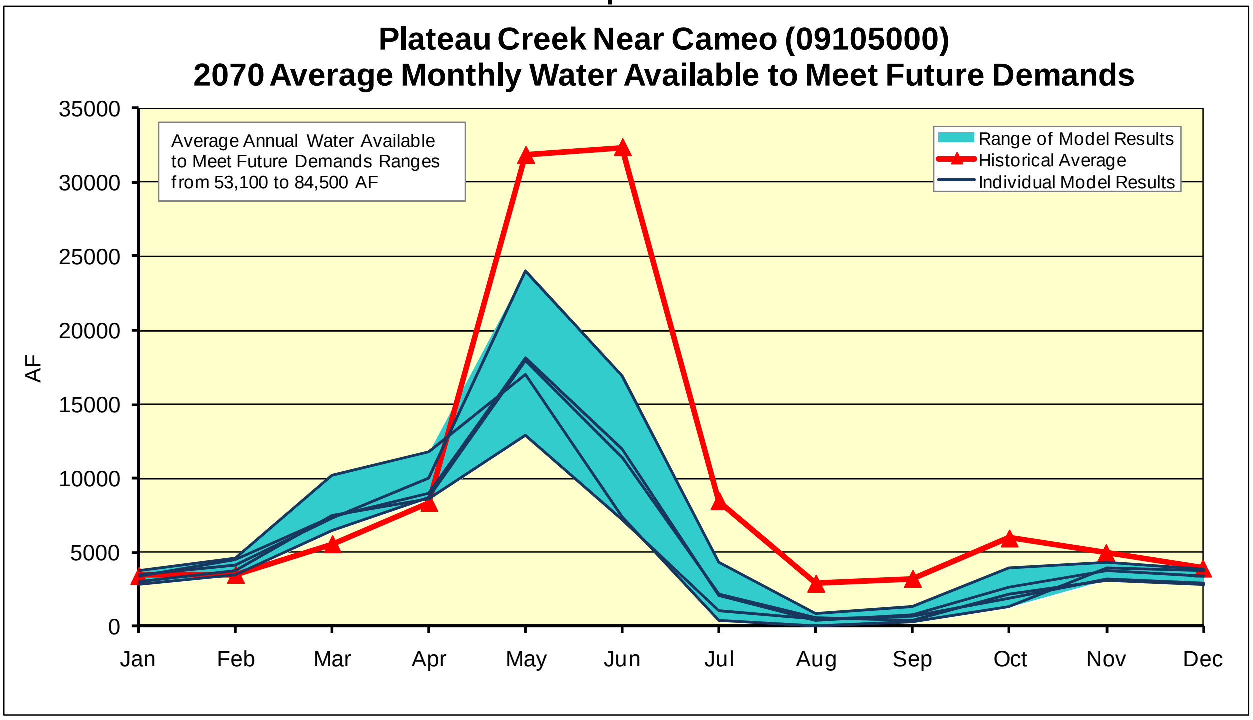


Figure F54 –2070 Colorado River near CO-UT State Line Average Water Available to Meet Future Demands Comparison

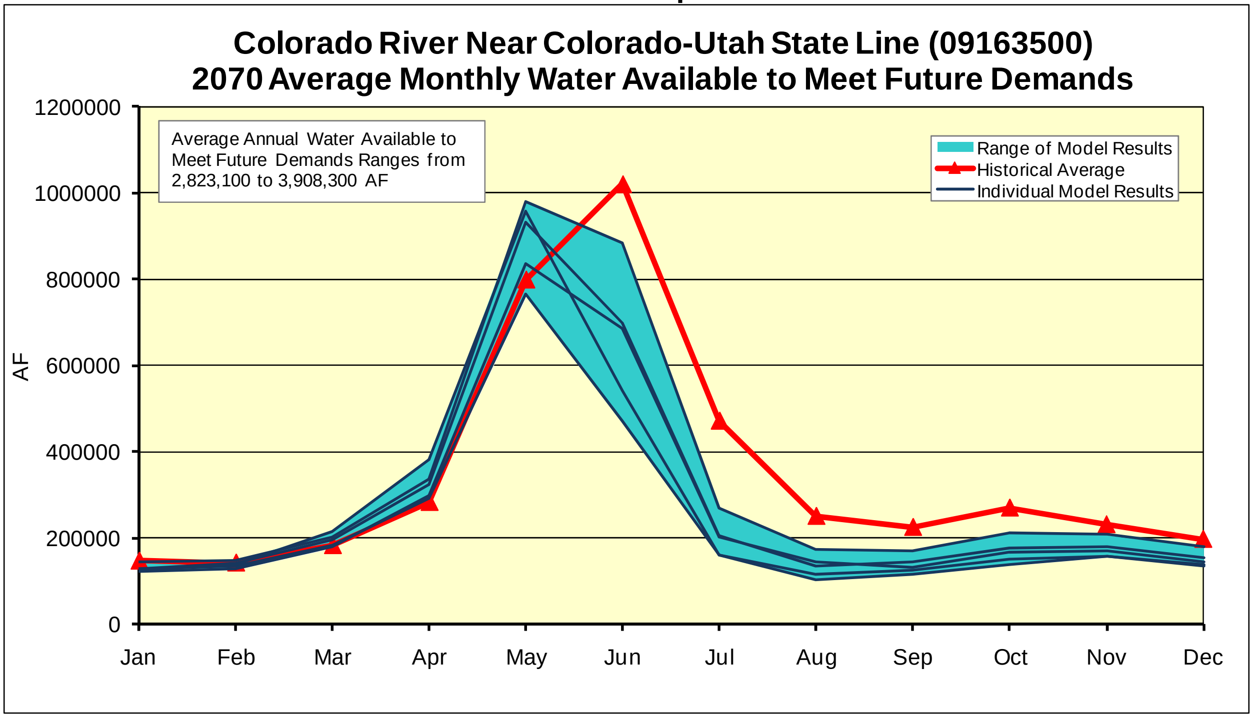


Figure F55 –2070 East River at Almont Average Water Available to Meet Future Demands Comparison

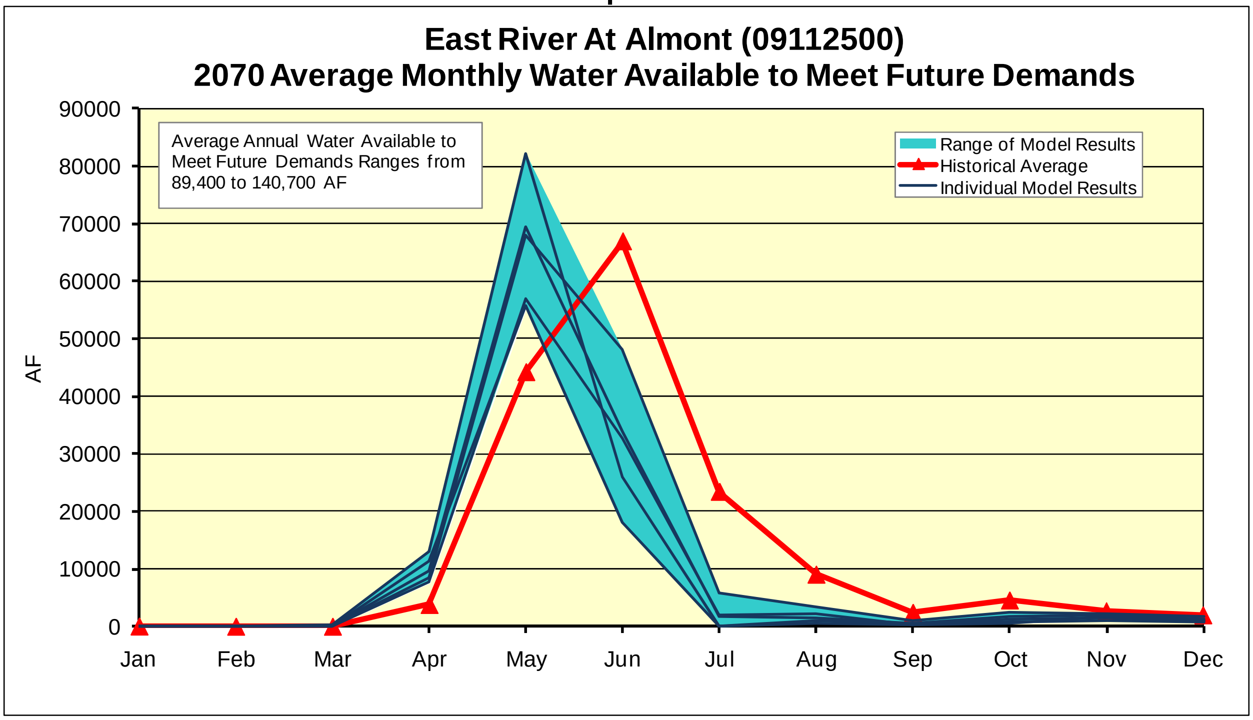


Figure F56 –2070 Taylor River at Almont Average Water Available to Meet Future Demands Comparison

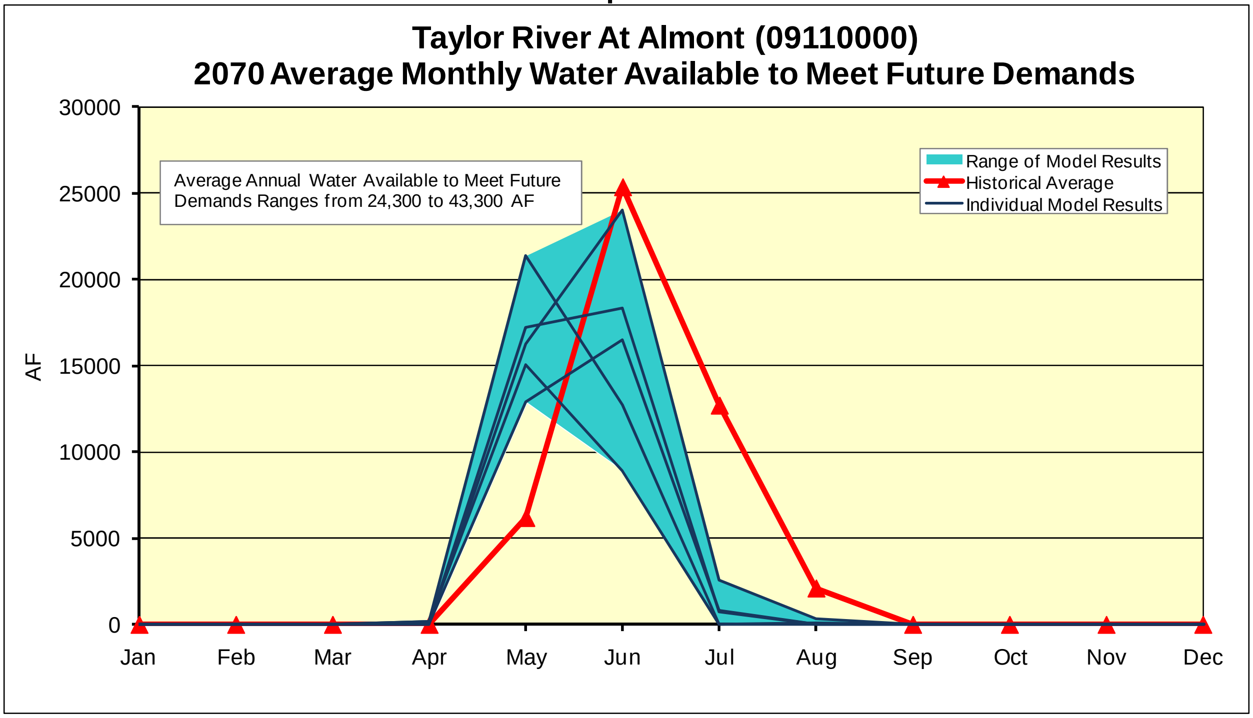


Figure F57 –2070 Tomichi Creek at Gunnison Average Water Available to Meet Future Demands Comparison

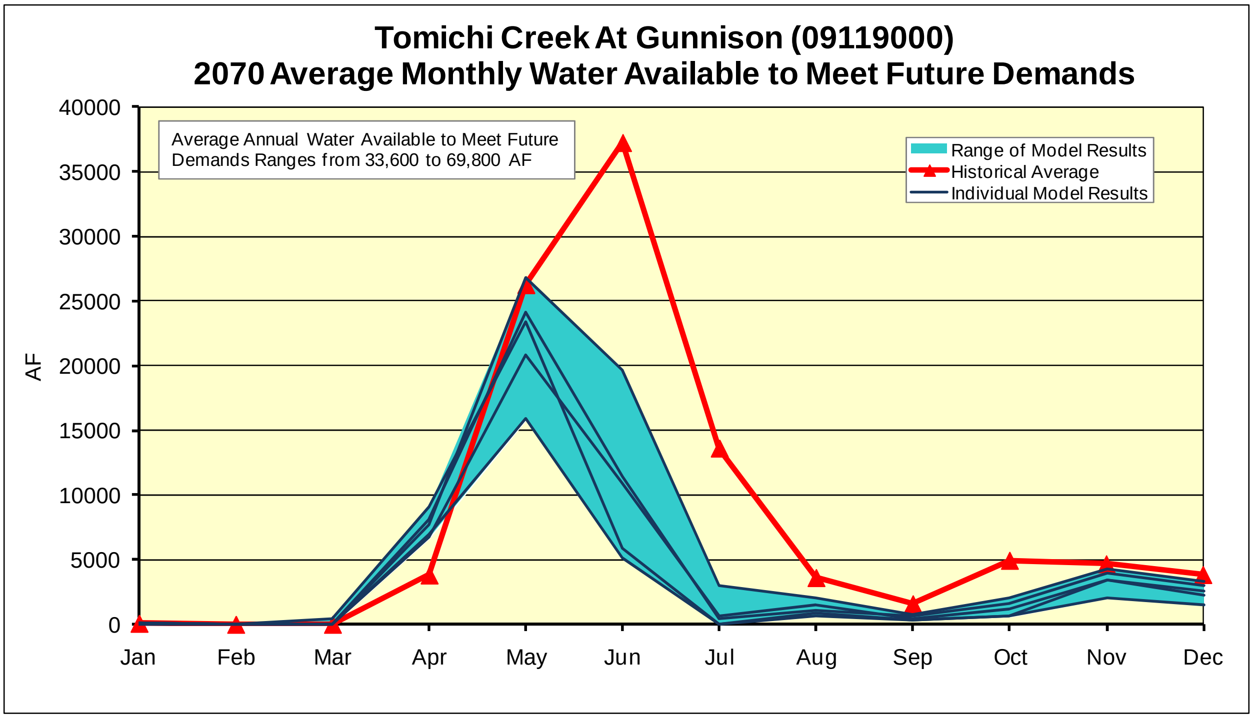


Figure F58 –2070 Gunnison River near Gunnison Average Water Available to Meet Future Demands Comparison

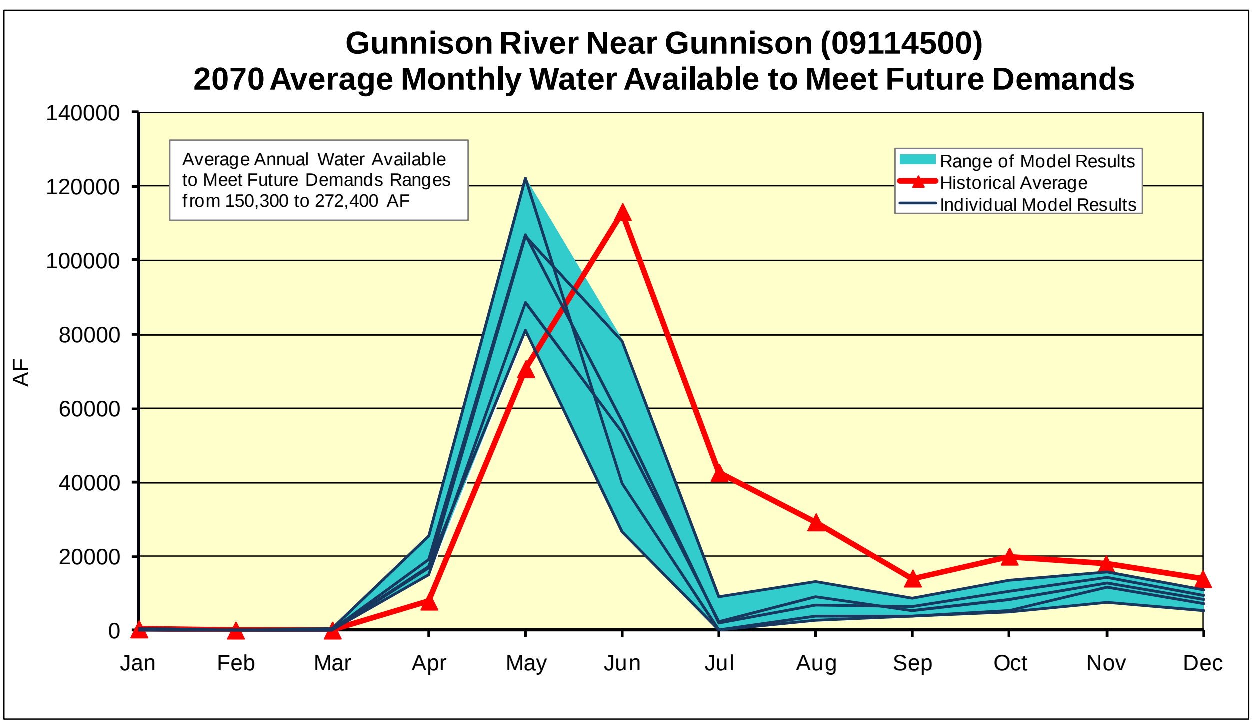


Figure F59 –2070 Cimarron River at Cimarron Average Water Available to Meet Future Demands Comparison

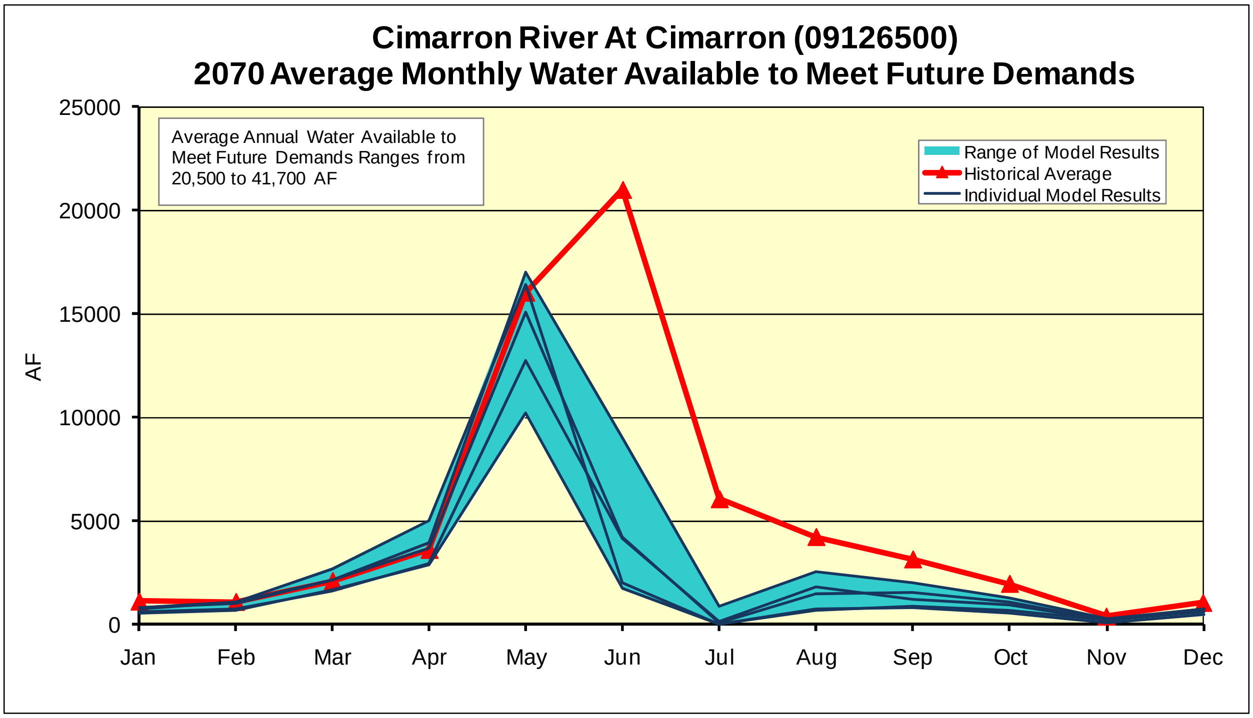


Figure F60 –2070 Gunnison River below Gunnison Tunnel Average Water Available to Meet Future Demands Comparison

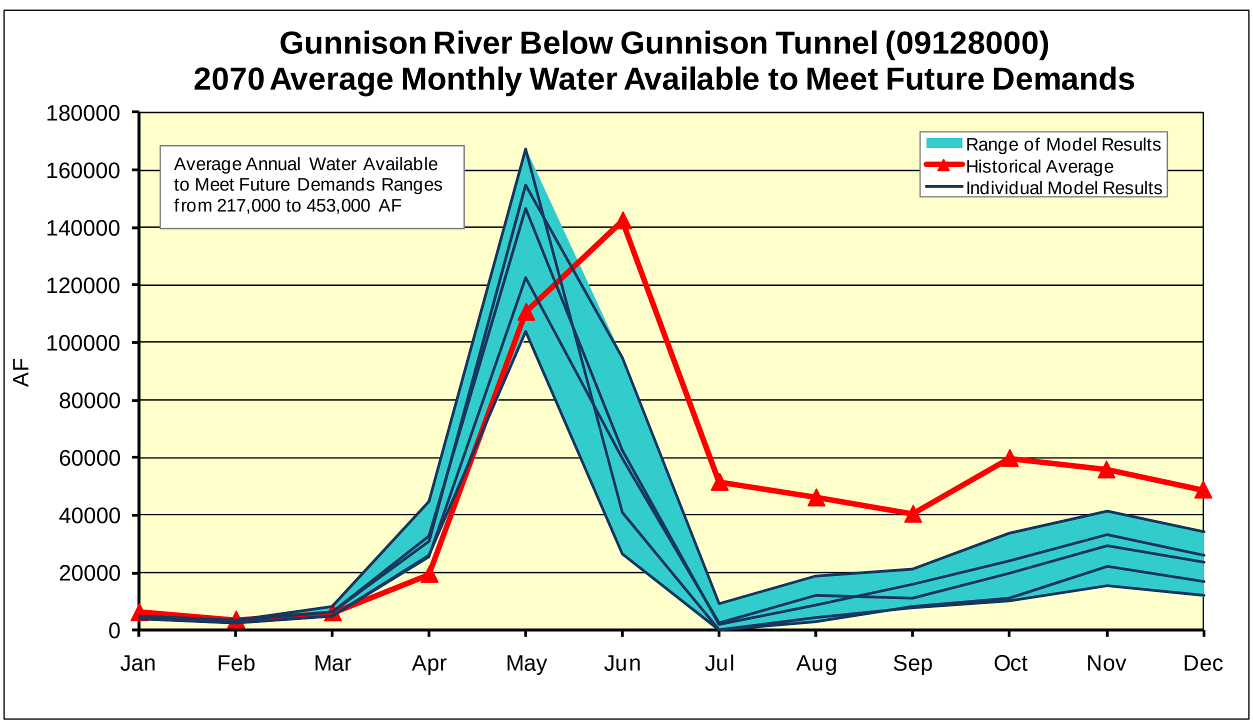


Figure F61 –2070 Gunnison River near Lazear Average Water Available to Meet Future Demands Comparison

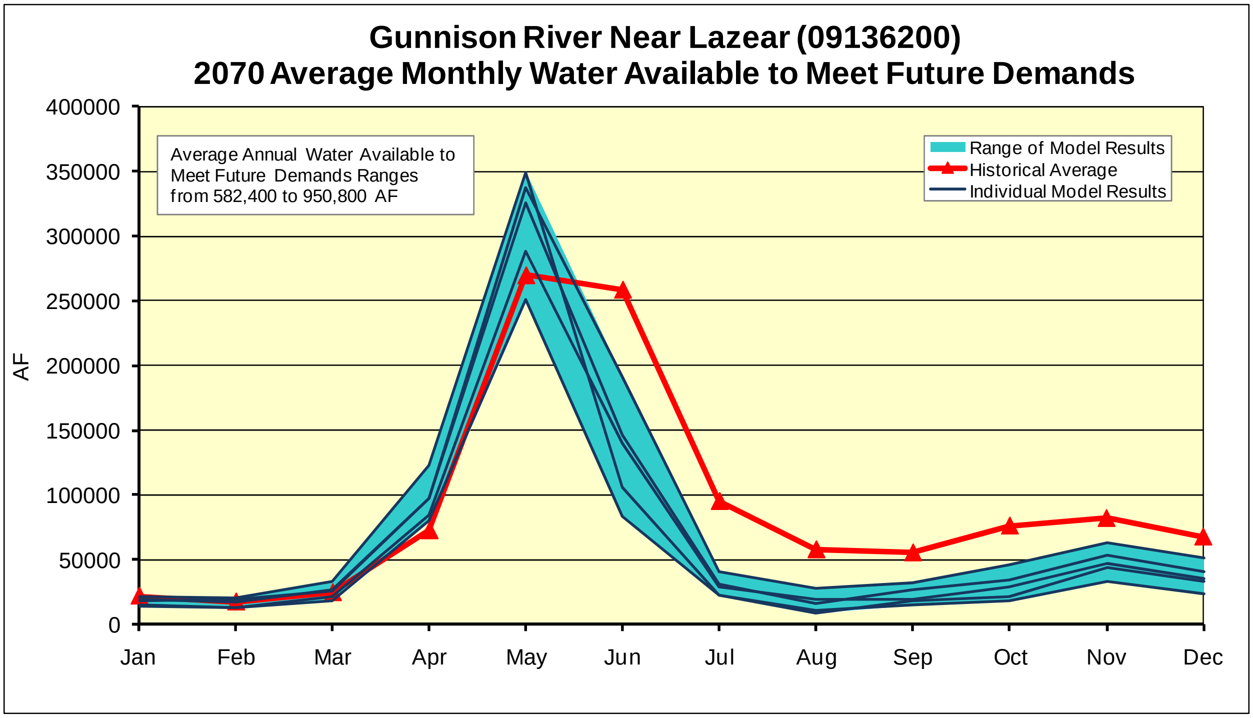


Figure F62 –2070 Uncompahgre River at Delta Average Water Available to Meet Future Demands Comparison

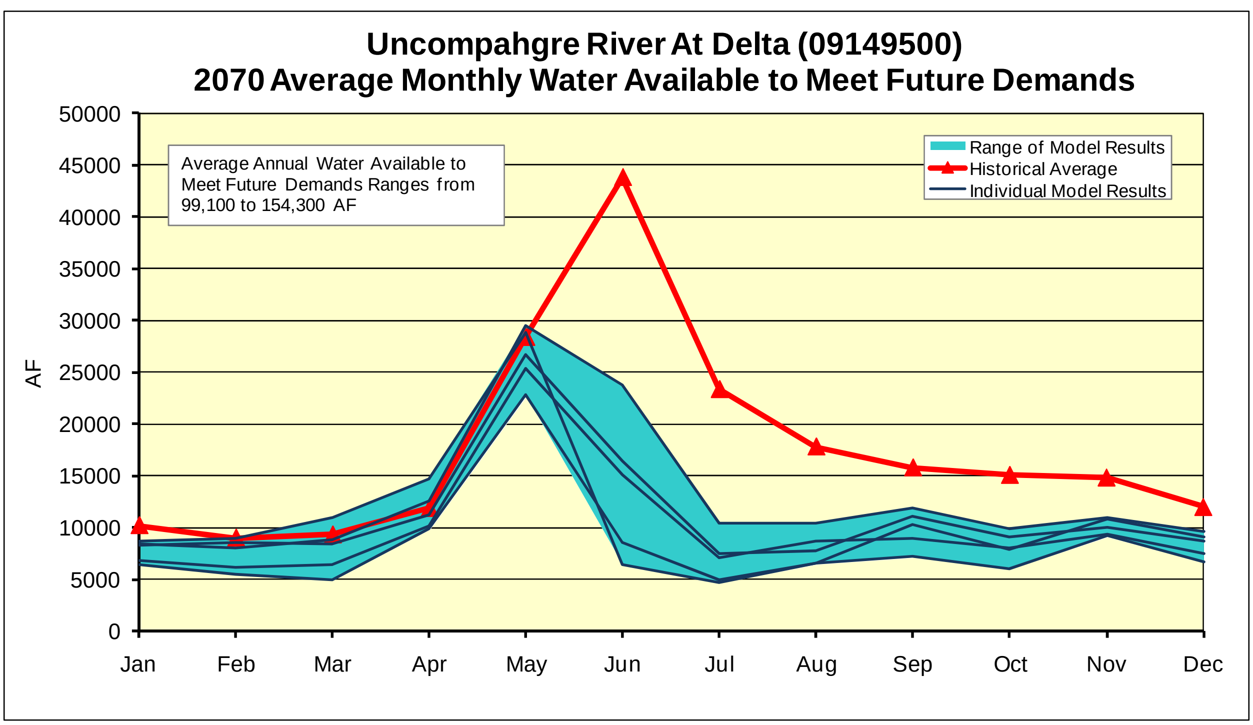


Figure F63 –2070 Gunnison River near Grand Junction Average Water Available to Meet Future Demands Comparison

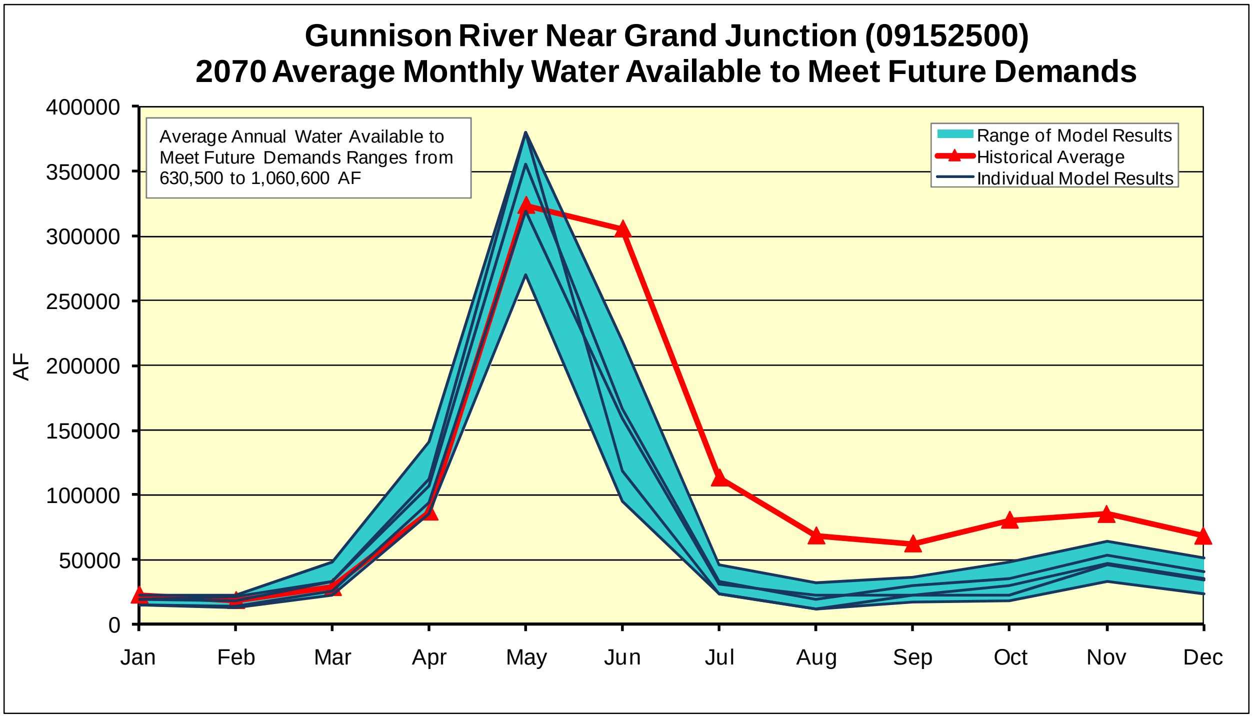


Figure F64 –2070 San Juan River near Carracas Average Water Available to Meet Future Demands Comparison

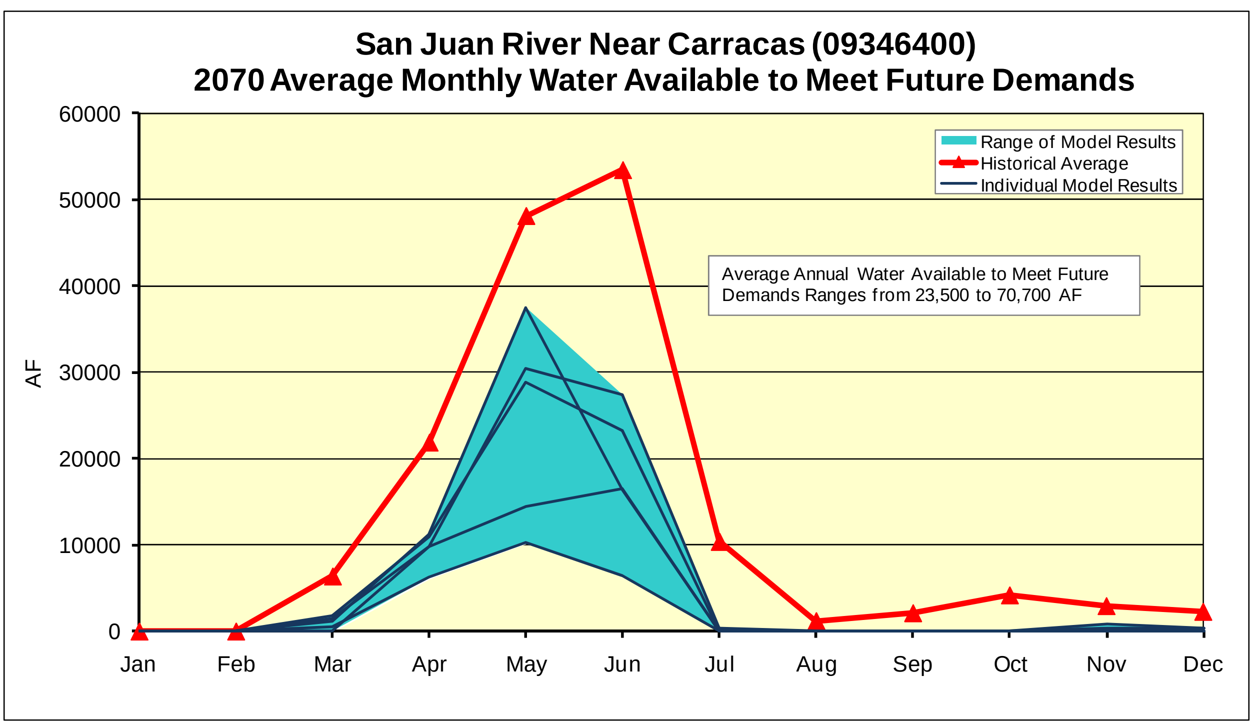


Figure F65 –2070 Piedra River near Arboles Average Water Available to Meet Future Demands Comparison

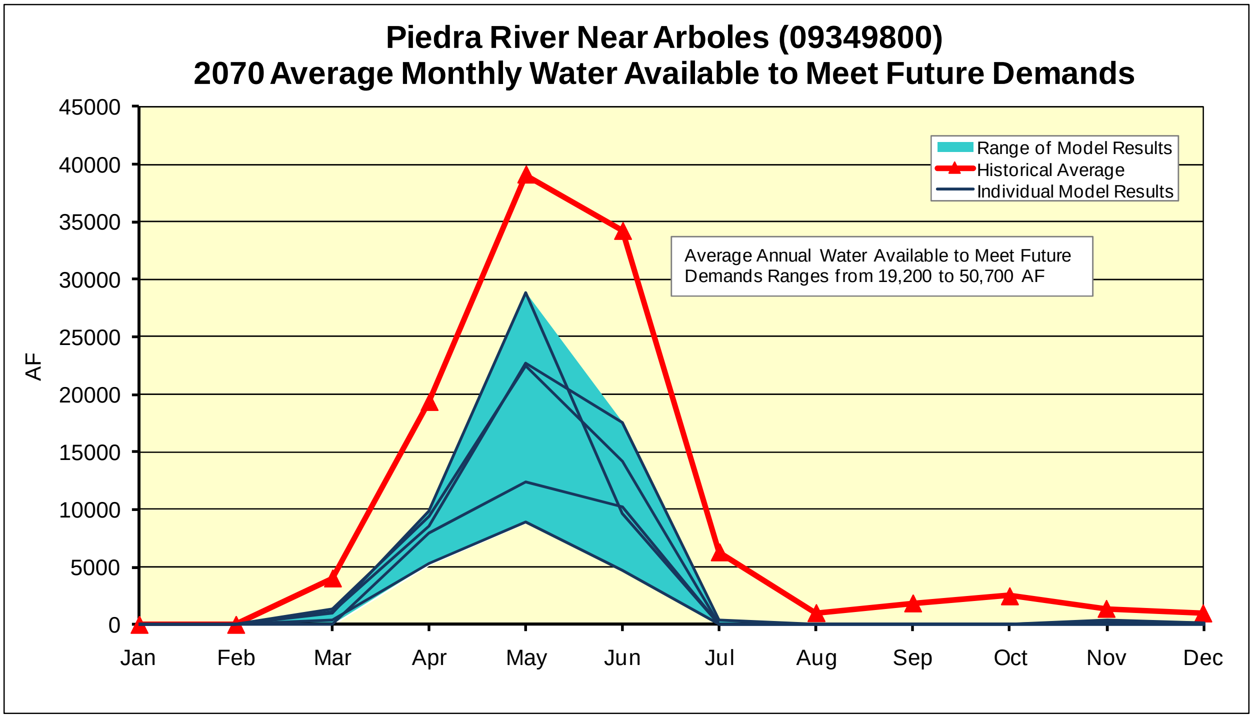


Figure F66 –2070 Los Pinos River at La Boca Average Water Available to Meet Future Demands Comparison

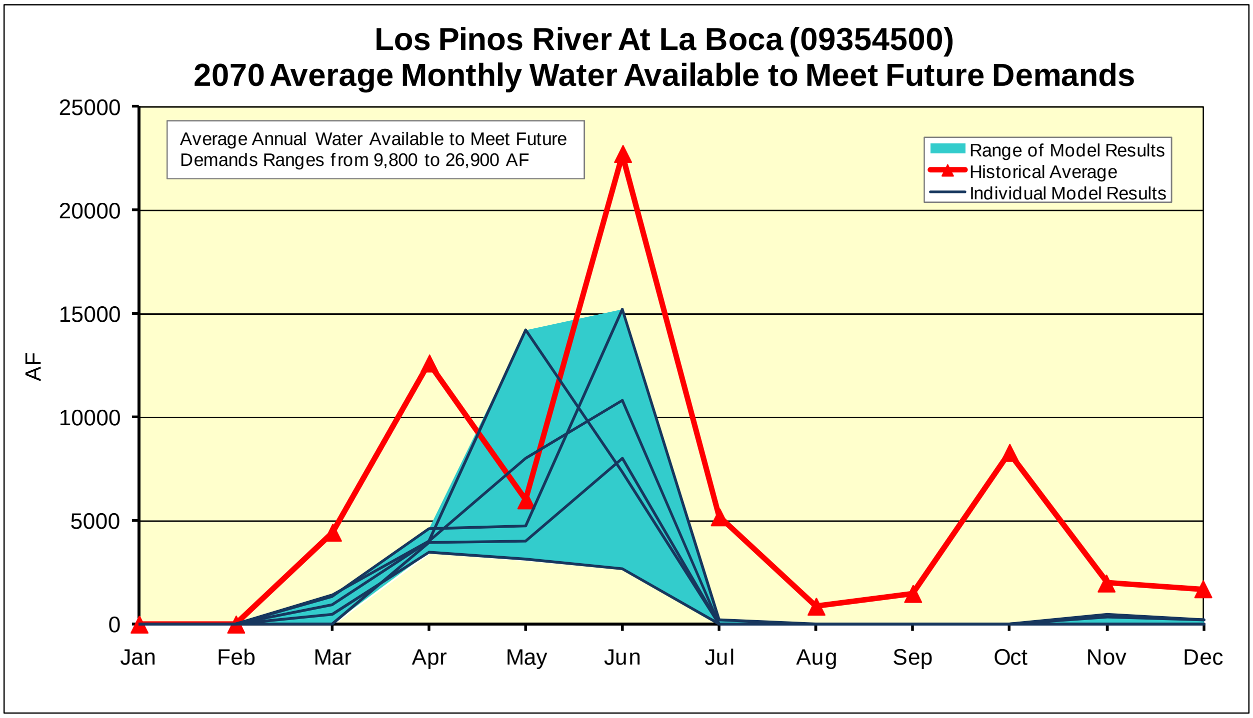


Figure F67 –2070 Florida River at Bondad Average Water Available to Meet Future Demands Comparison

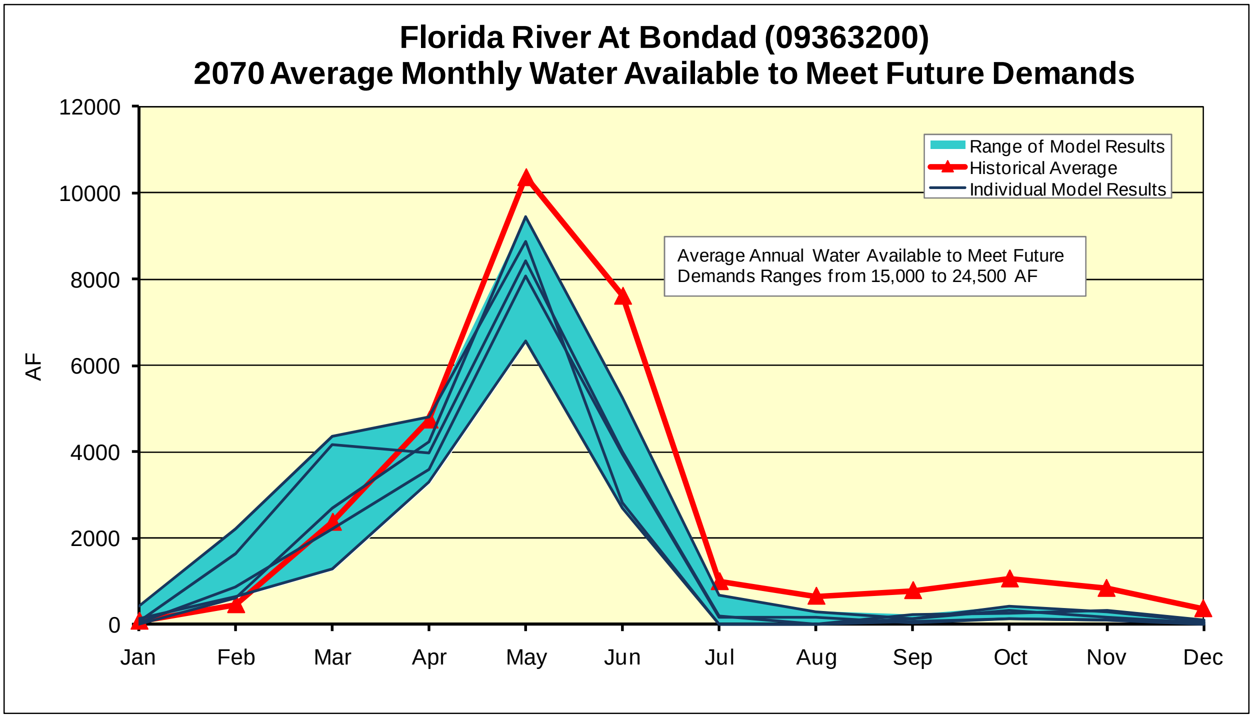


Figure F68 –2070 Animas River near Cedar Hill, NM Average Water Available to Meet Future Demands Comparison

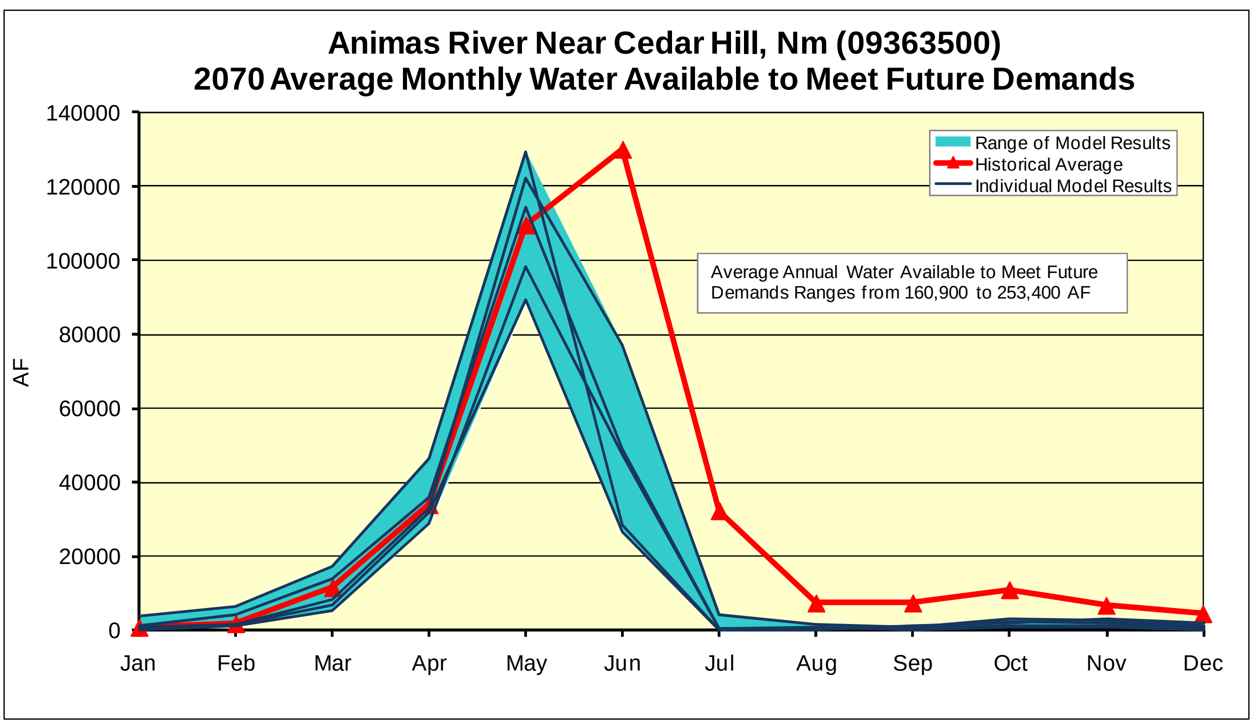


Figure F69 –2070 La Plata River at Hesperus Average Water Available to Meet Future Demands Comparison

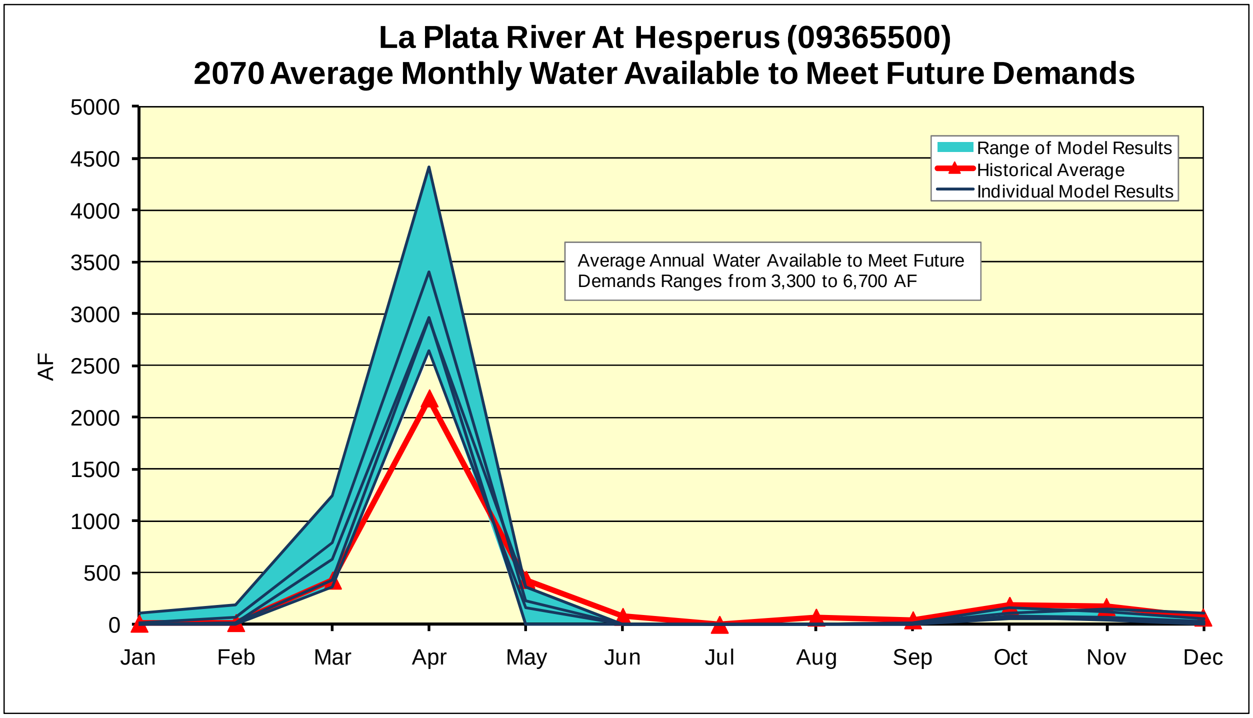


Figure F70 –2070 La Plata River at CO-NM State Line Average Water Available to Meet Future Demands Comparison

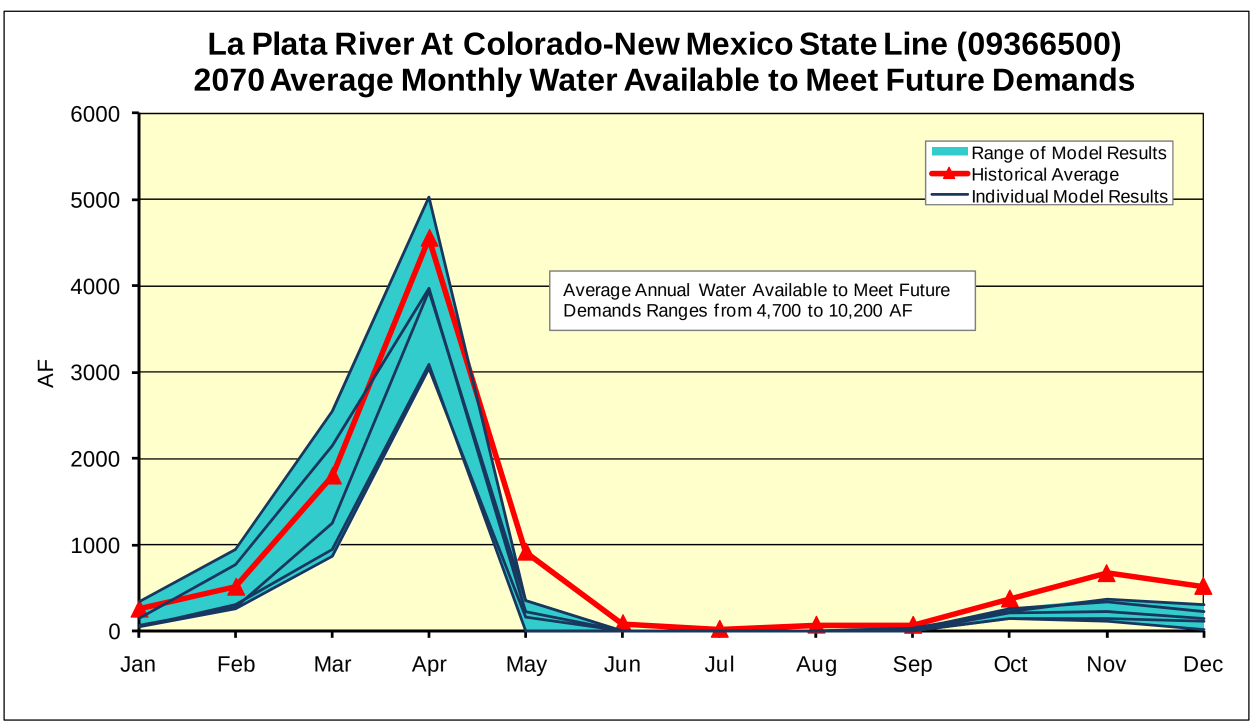


Figure F71 –2070 Mancos River near Towaoc Average Water Available to Meet Future Demands Comparison

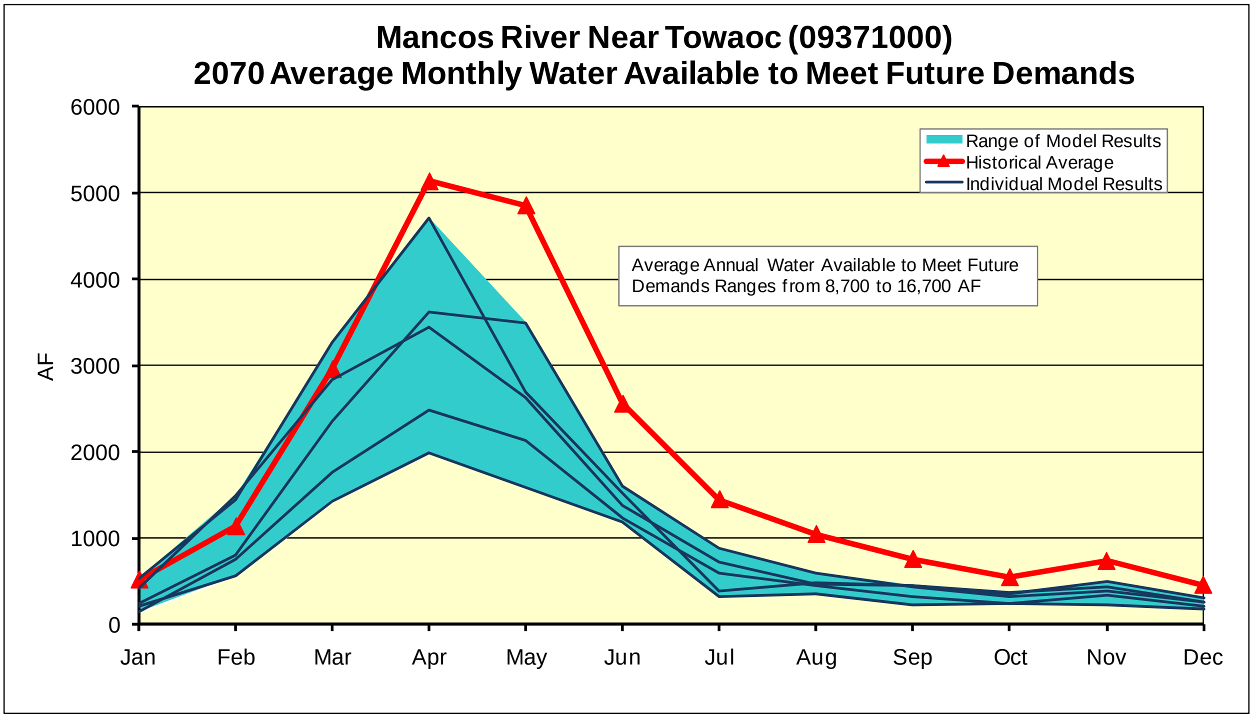


Figure F72 –2070 McElmo Creek near CO-UT State Line Average Water Available to Meet Future Demands Comparison

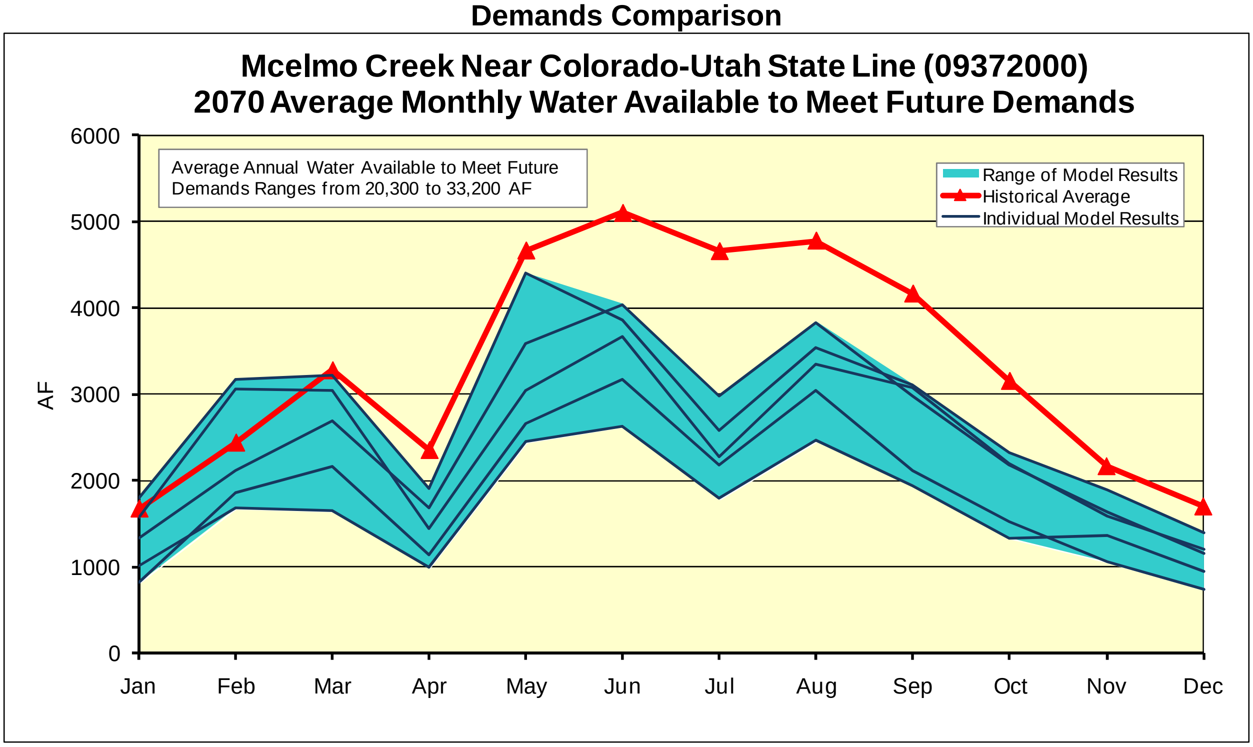


Figure F73 –2070 Dolores River near Bedrock Average Water Available to Meet Future Demands Comparison

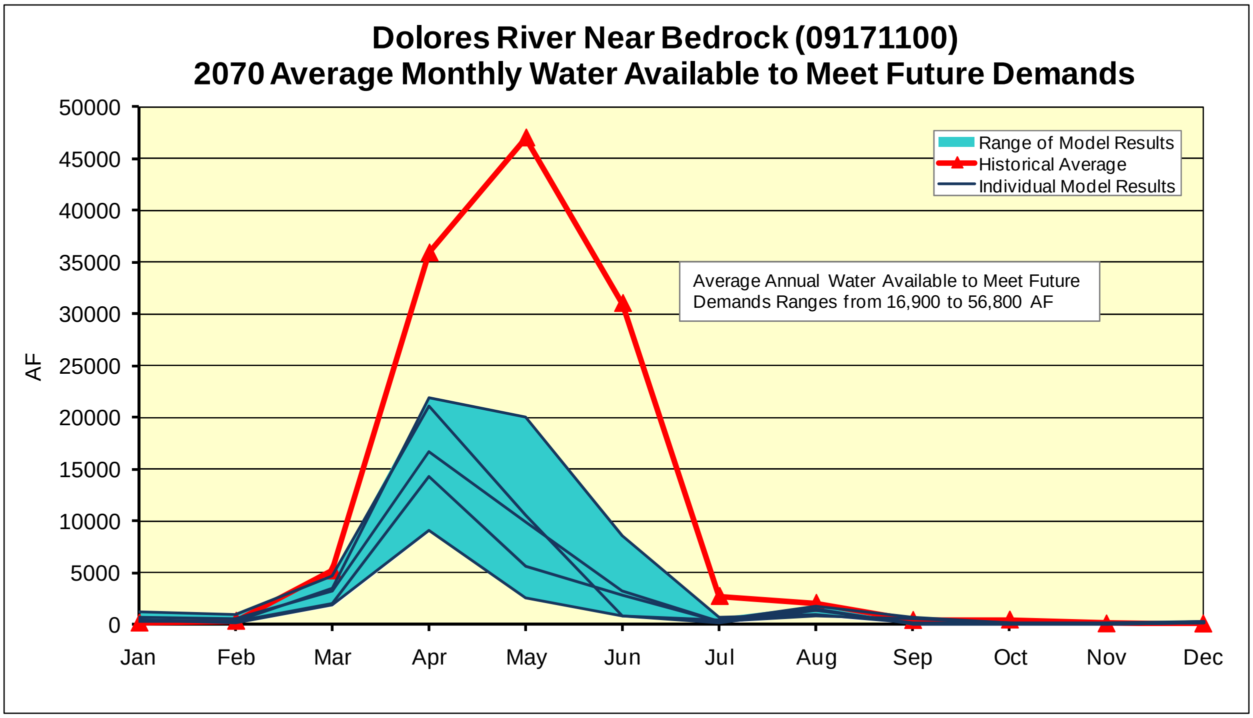


Figure F74 –2070 San Miguel River at Naturita Average Water Available to Meet Future Demands Comparison

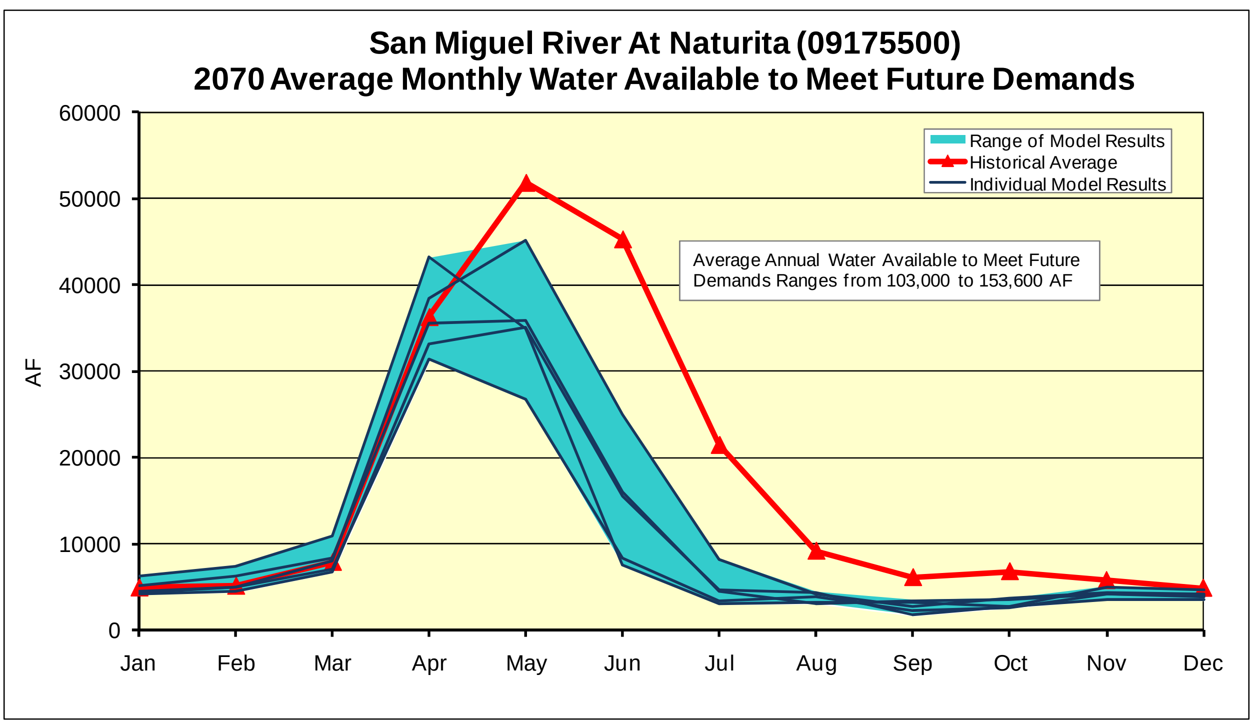


Figure F75 –2070 Yampa River below Stagecoach Reservoir Average Water Available to Meet Future Demands Comparison

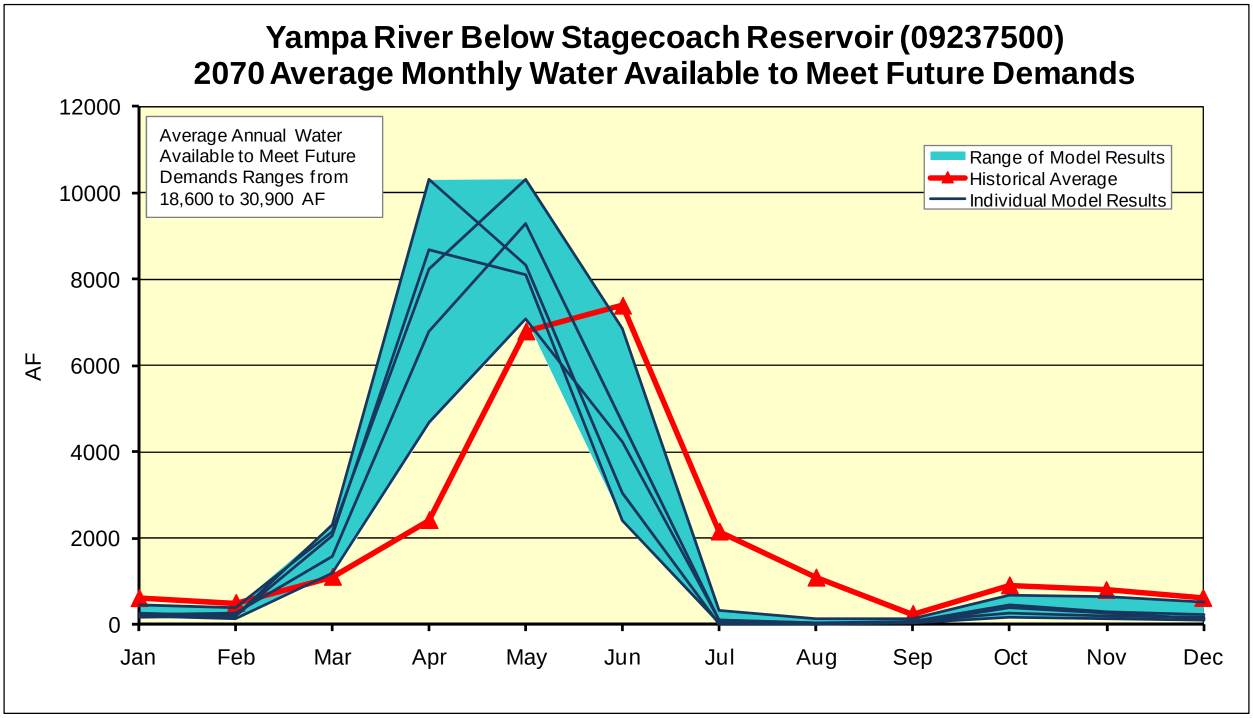


Figure F76 –2070 Elk River at Clark Average Water Available to Meet Future Demands Comparison

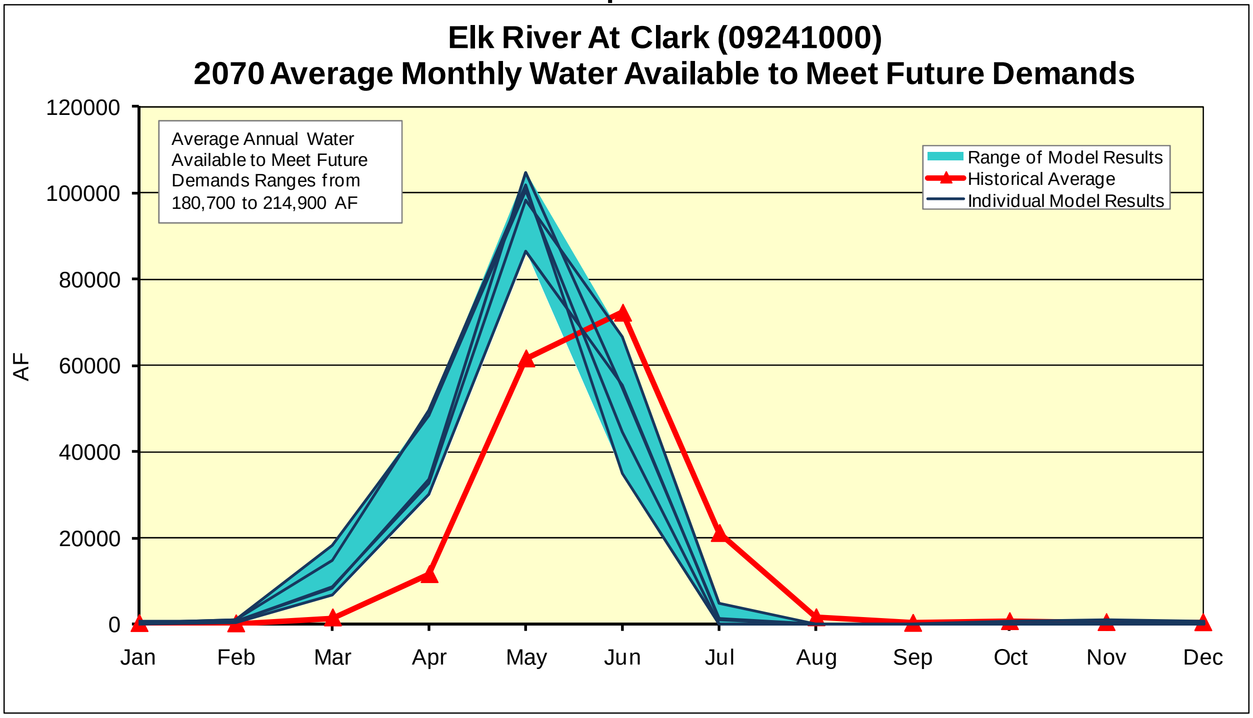


Figure F77 –2070 Elkhead Creek near Elkhead Average Water Available to Meet Future Demands Comparison

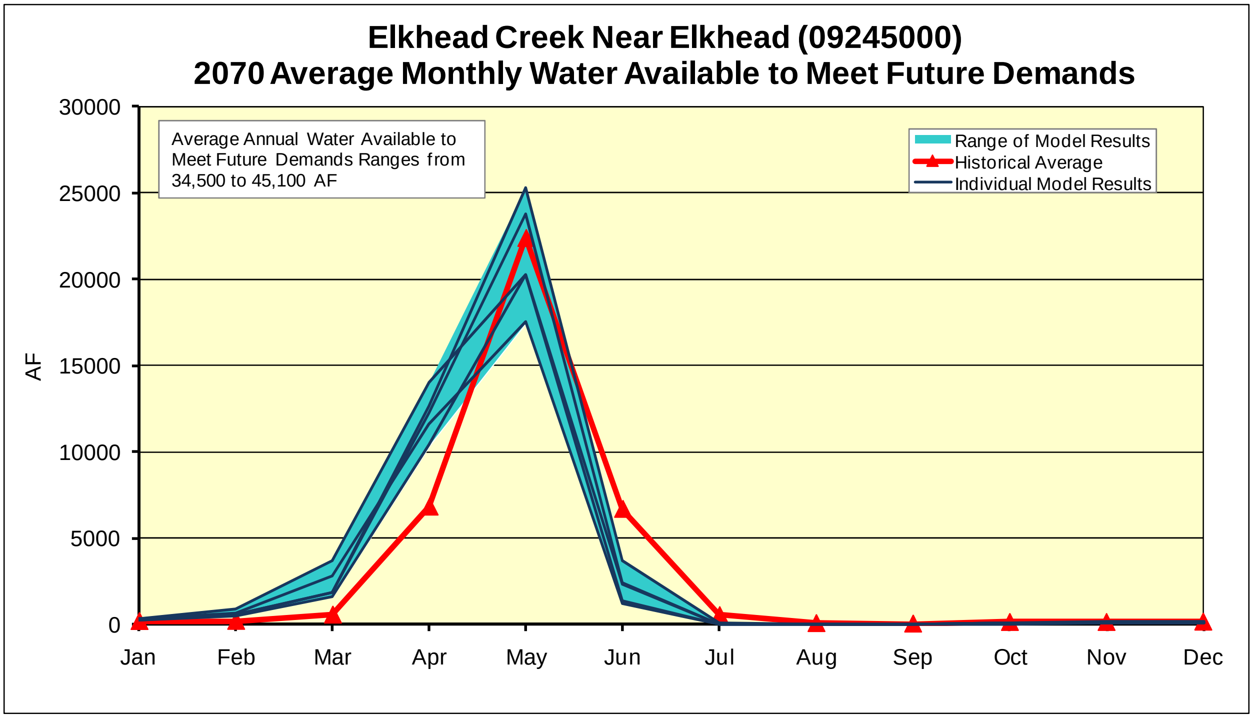


Figure F78 –2070 Williams Fork at Mouth, near Hamilton Average Water Available to Meet Future Demands Comparison

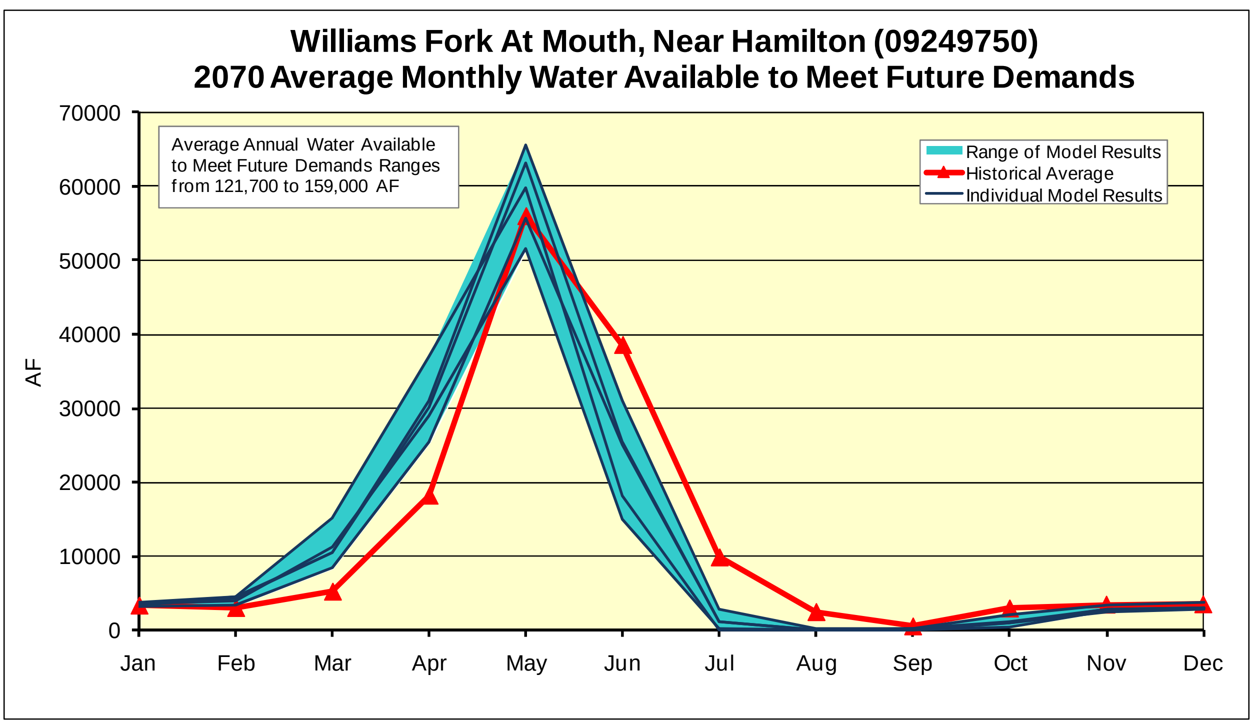


Figure F79 –2070 Yampa River near Maybell Average Water Available to Meet Future Demands Comparison

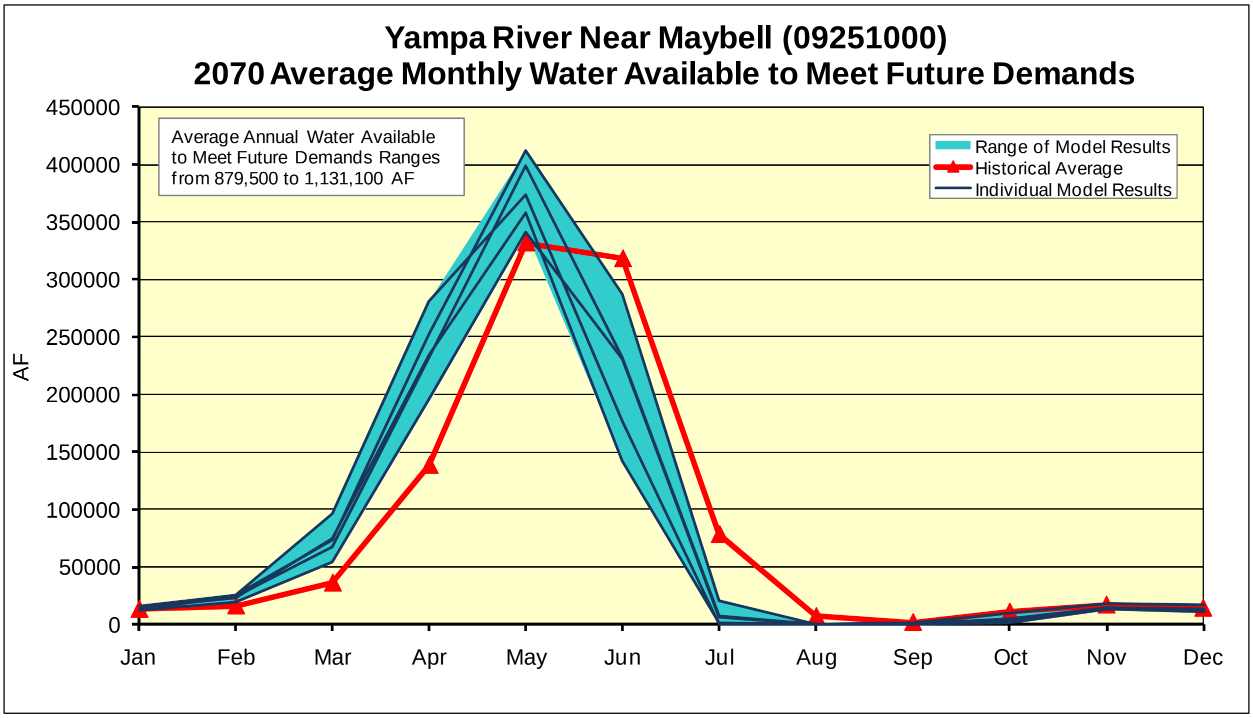


Figure F80 –2070 Little Snake River near Lily Average Water Available to Meet Future Demands Comparison

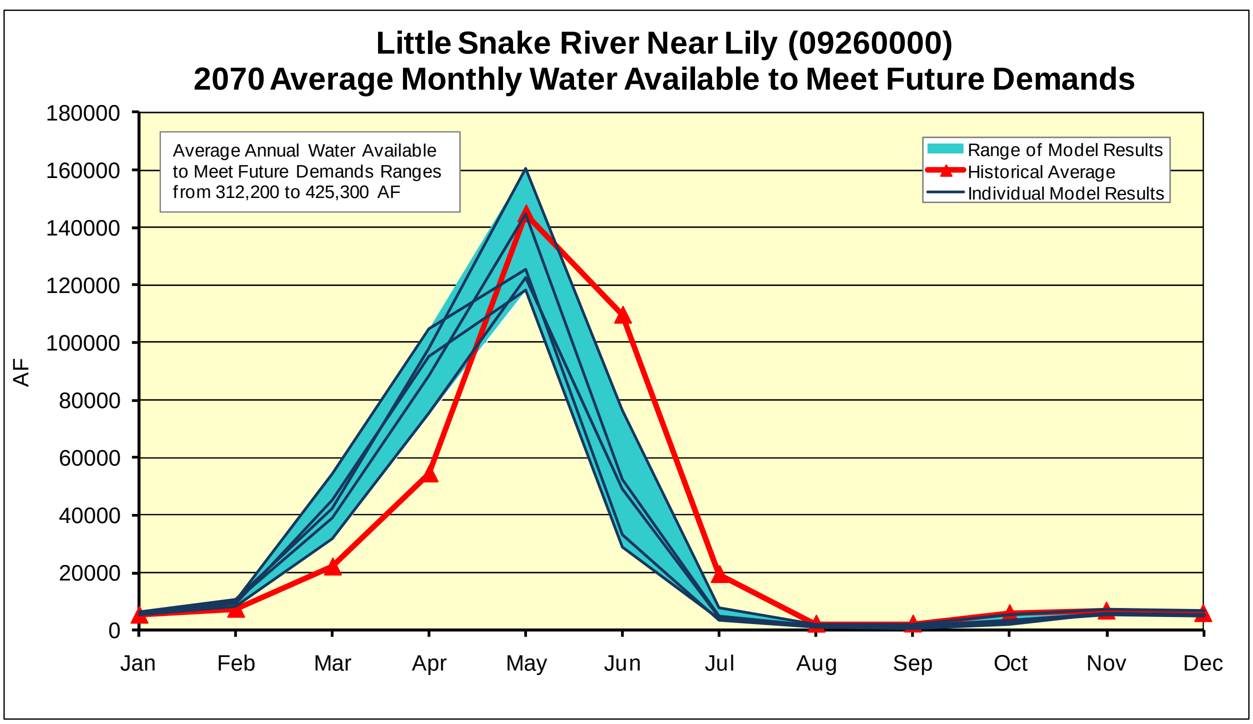


Figure F81 –2070 Yampa River at Deerlodge Park Average Water Available to Meet Future Demands Comparison

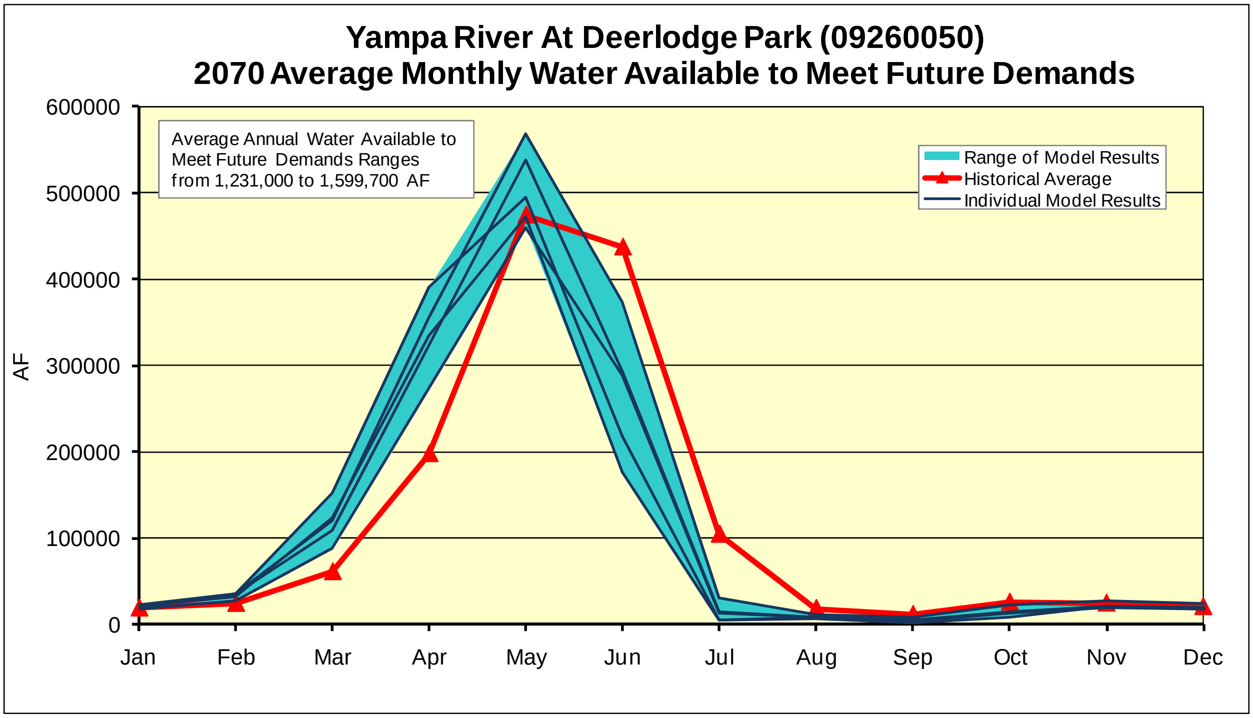


Figure F82 –2070 North Fork White River at Buford Average Water Available to Meet Future Demands Comparison

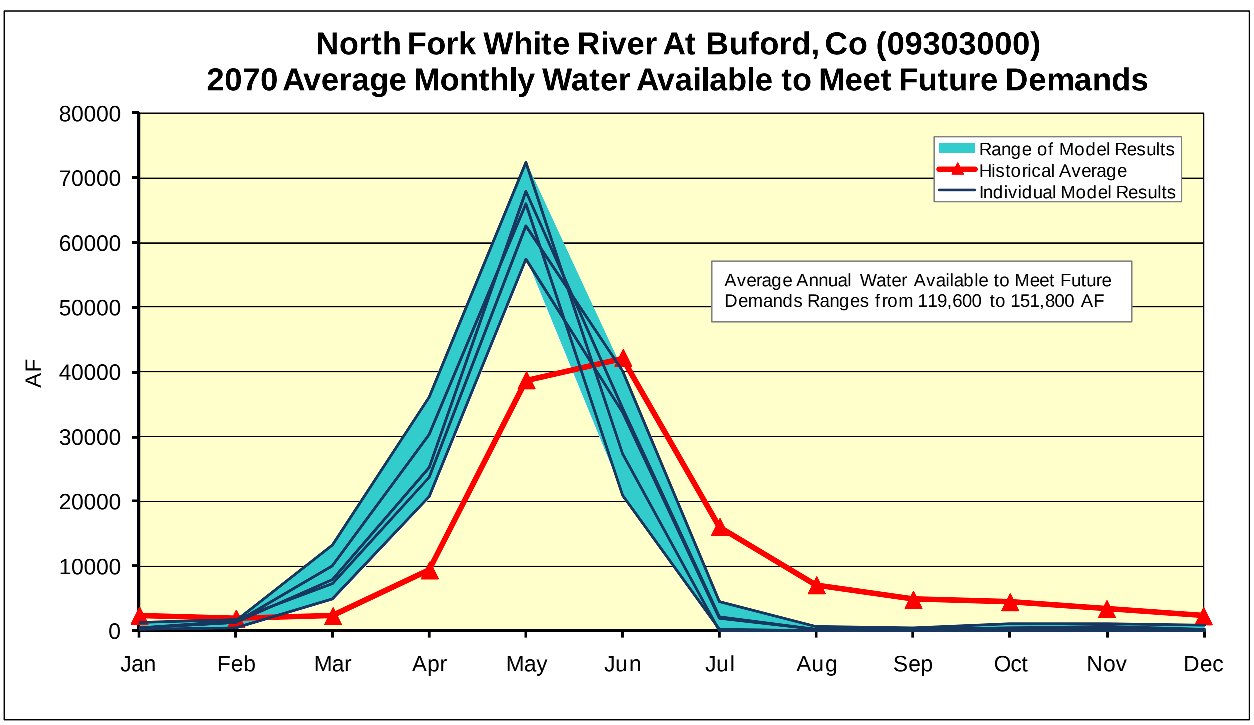


Figure F83 –2070 South Fork White River at Buford Average Water Available to Meet Future Demands Comparison

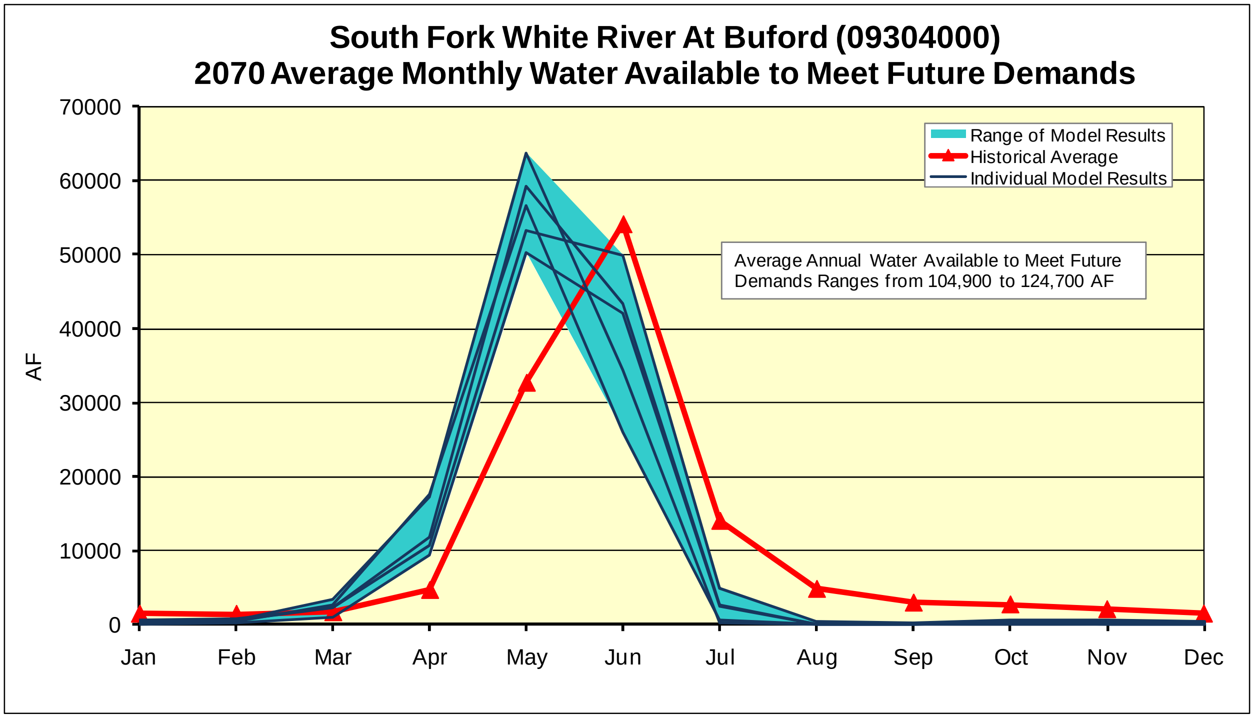


Figure F84 –2070 White River below Meeker Average Water Available to Meet Future Demands Comparison

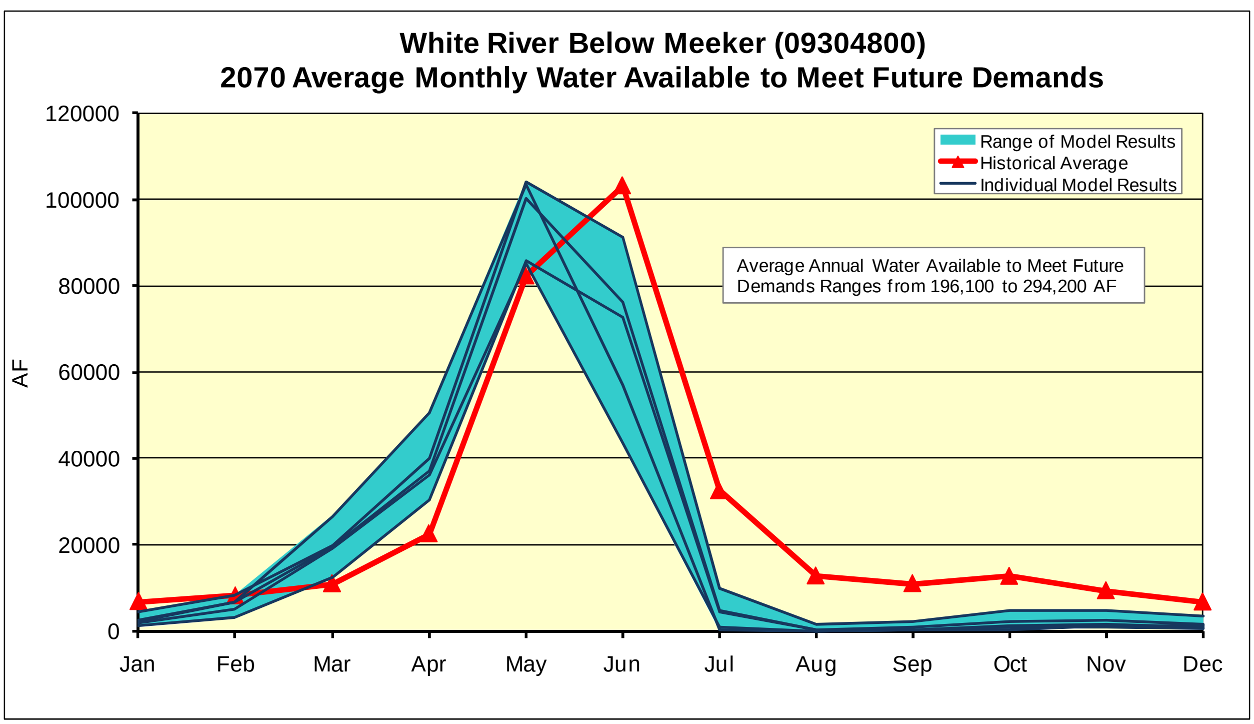


Figure F85 –2070 Piceance Creek at White River Average Water Available to Meet Future Demands Comparison

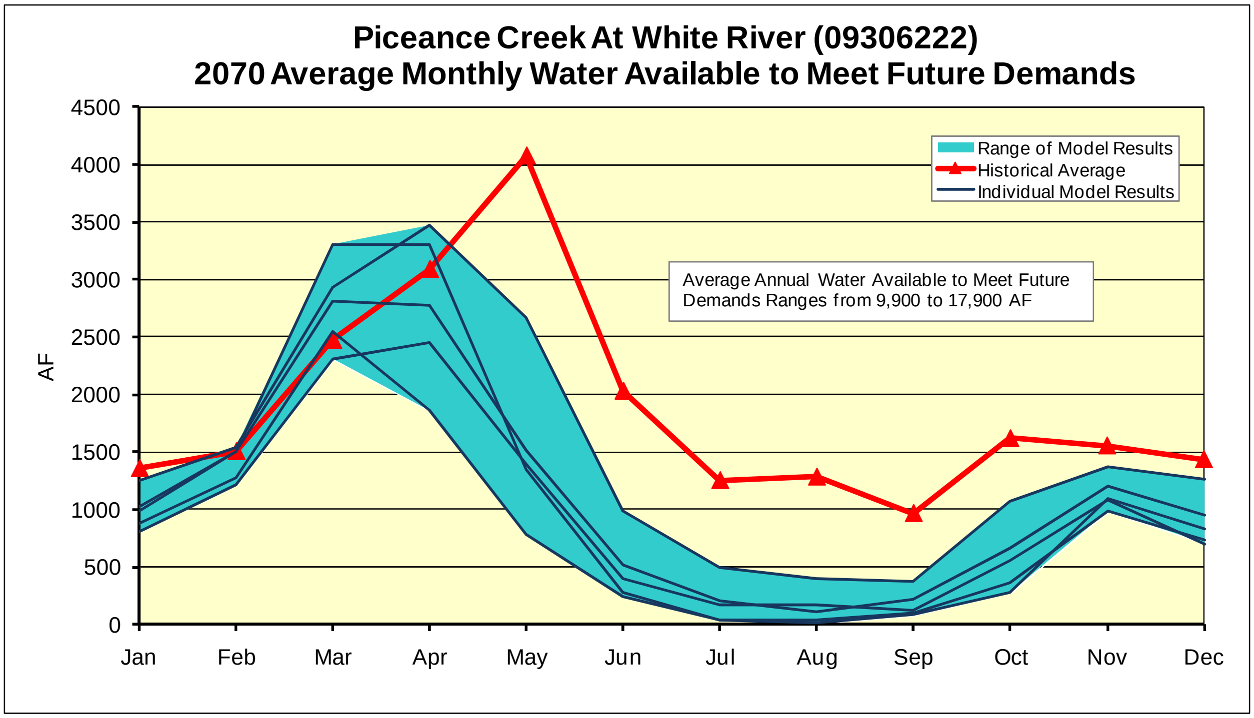


Figure F86 –2070 White River near CO-UT State Line Average Water Available to Meet Future Demands Comparison

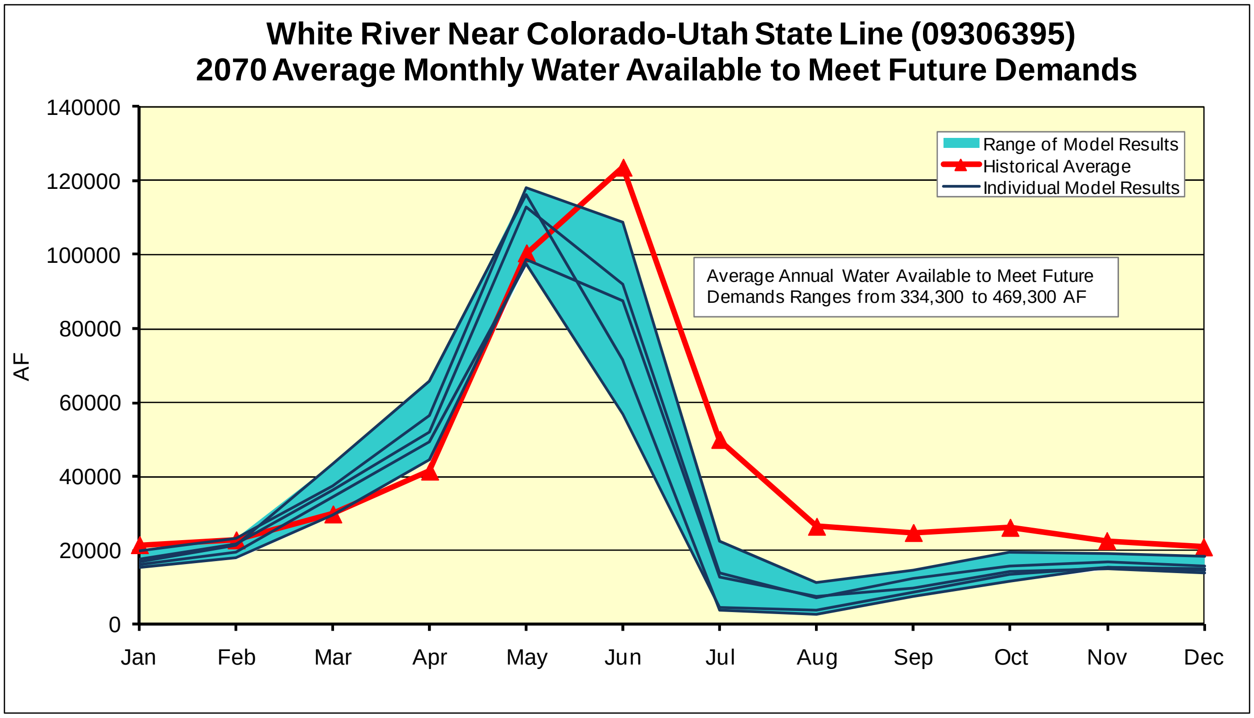


Figure F87 –2040 Colorado River near Grand Lake Average Water Available to Meet Future Demands Comparison

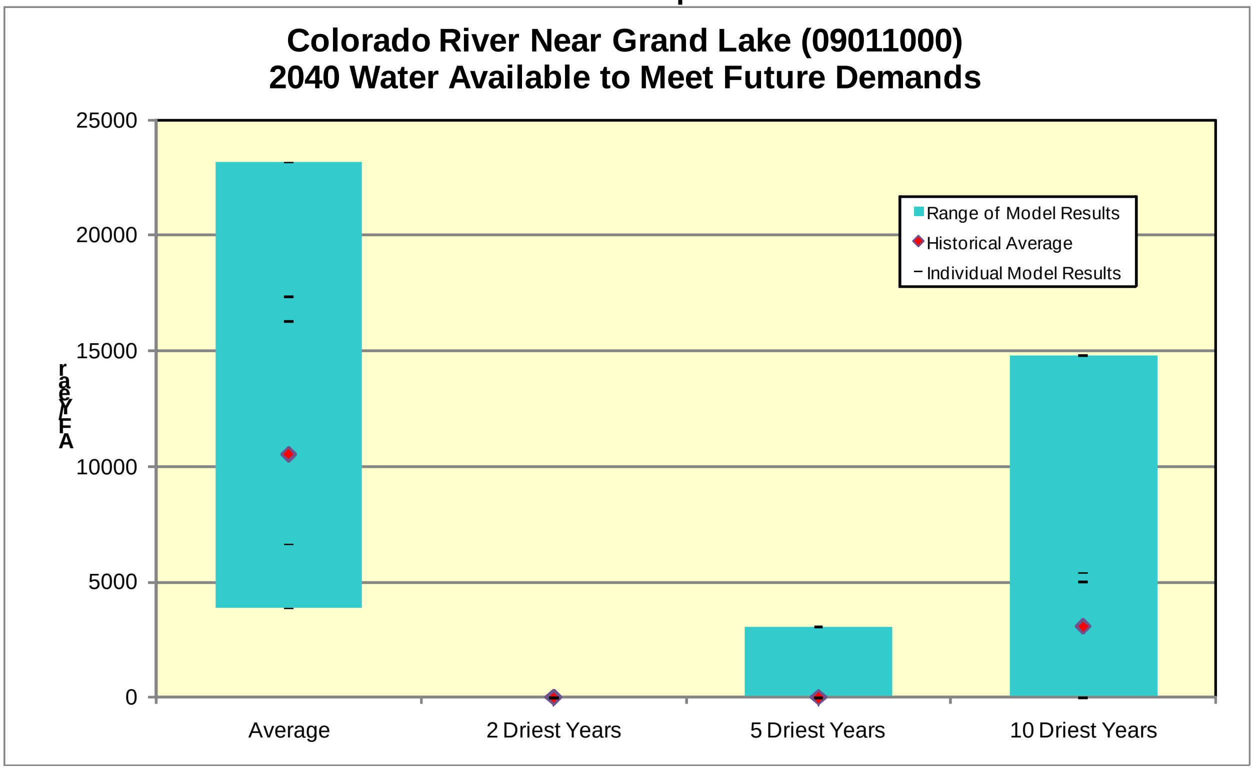


Figure F88 –2040 Muddy Creek at Kremmling Water Available to Meet Future Demands Low-flow Comparison

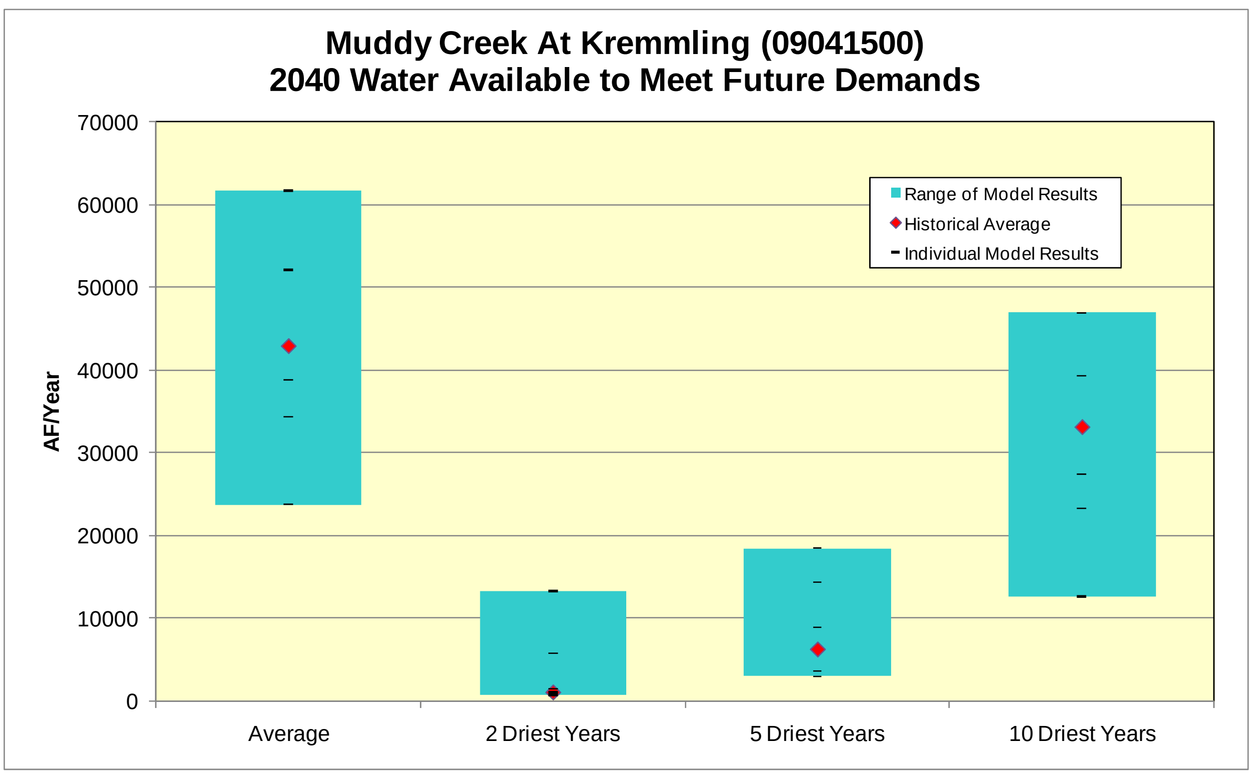


Figure F89 –2040 Blue River below Dillon Water Available to Meet Future Demands Low-flow Comparison

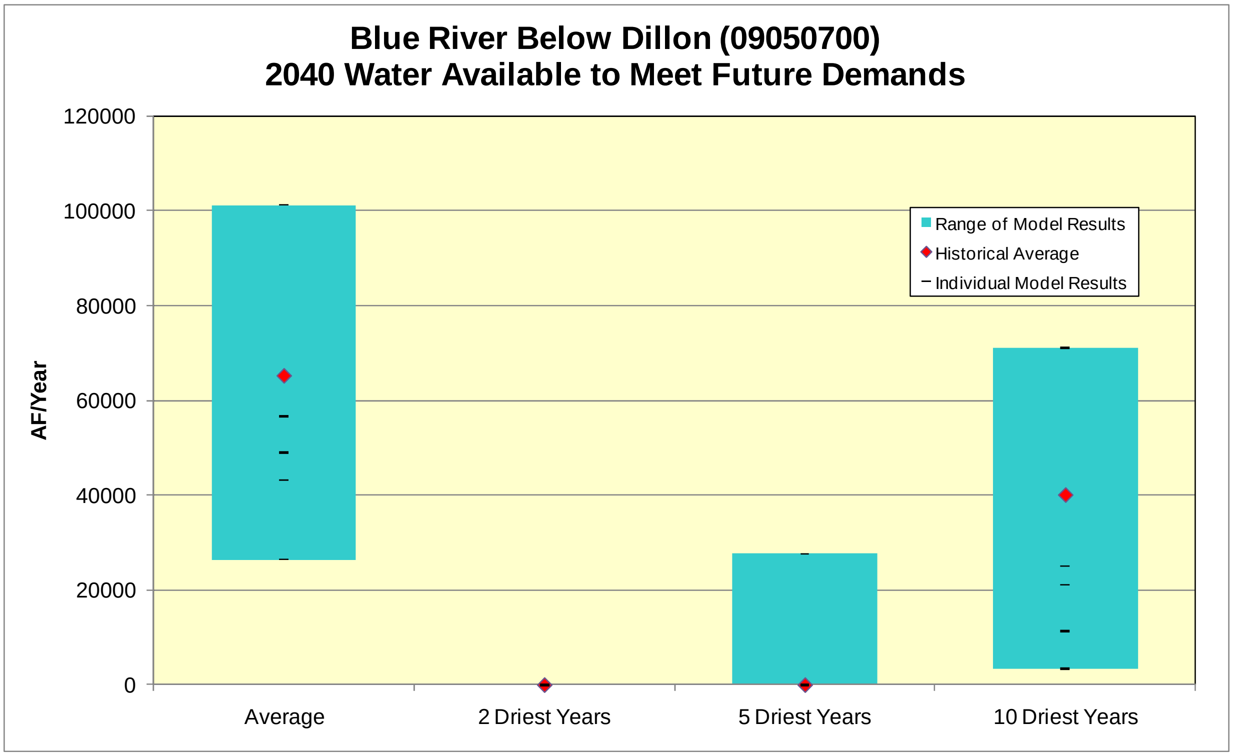


Figure F90 –2040 Blue River below Green Mountain Reservoir Water Available to Meet Future Demands Low-flow Comparison

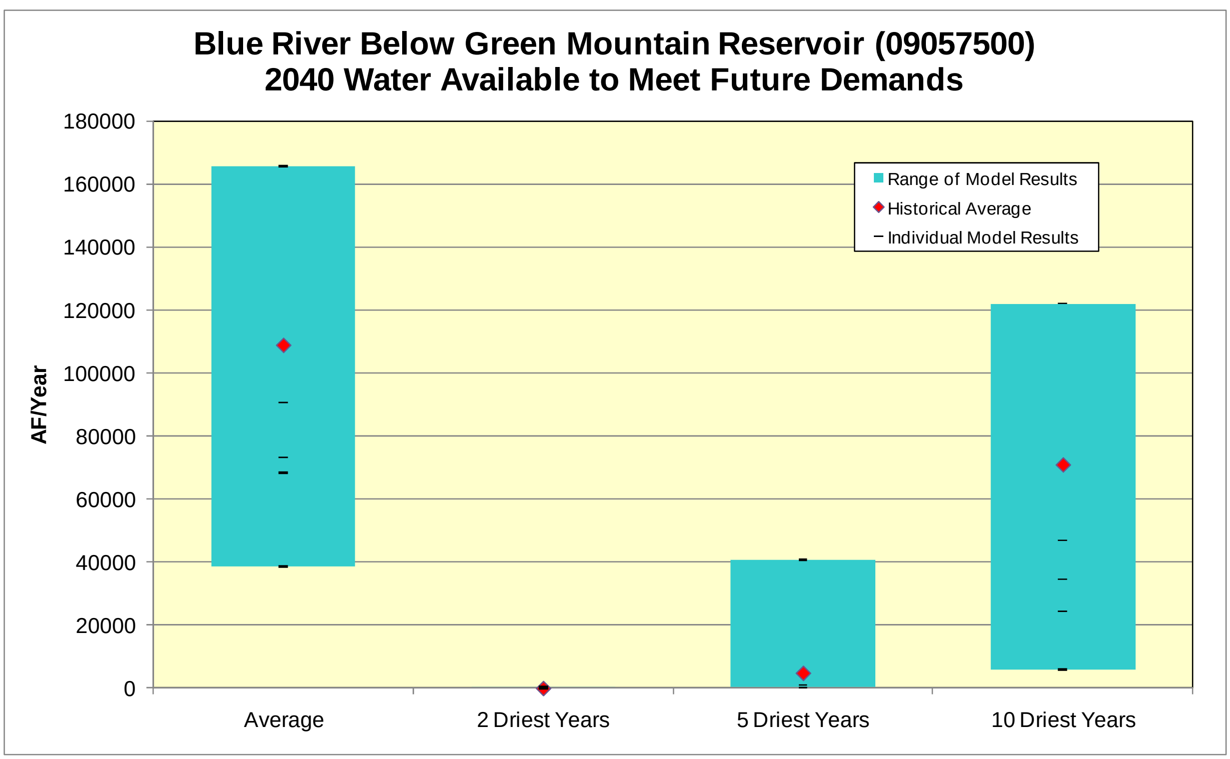


Figure F91 –2040 Eagle River below Gypsum Water Available to Meet Future Demands Low-flow Comparison

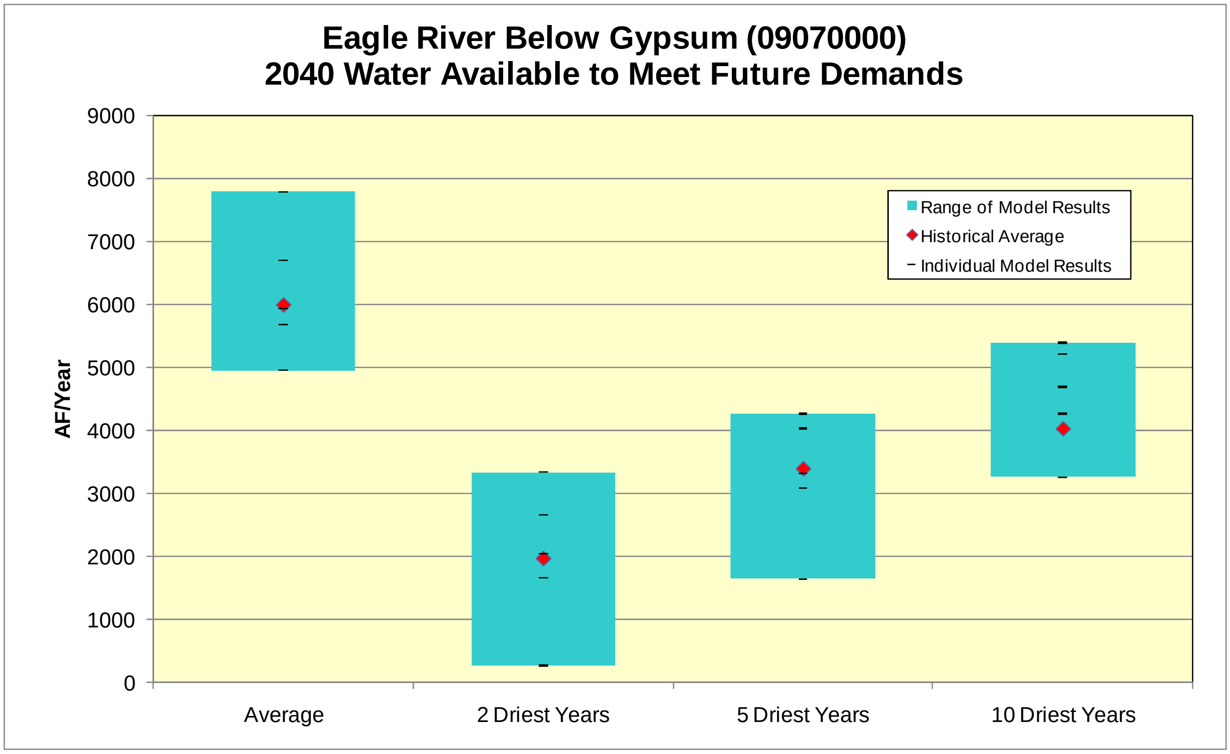


Figure F92 –2040 Colorado River at Dotsero Water Available to Meet Future Demands Low-flow Comparison

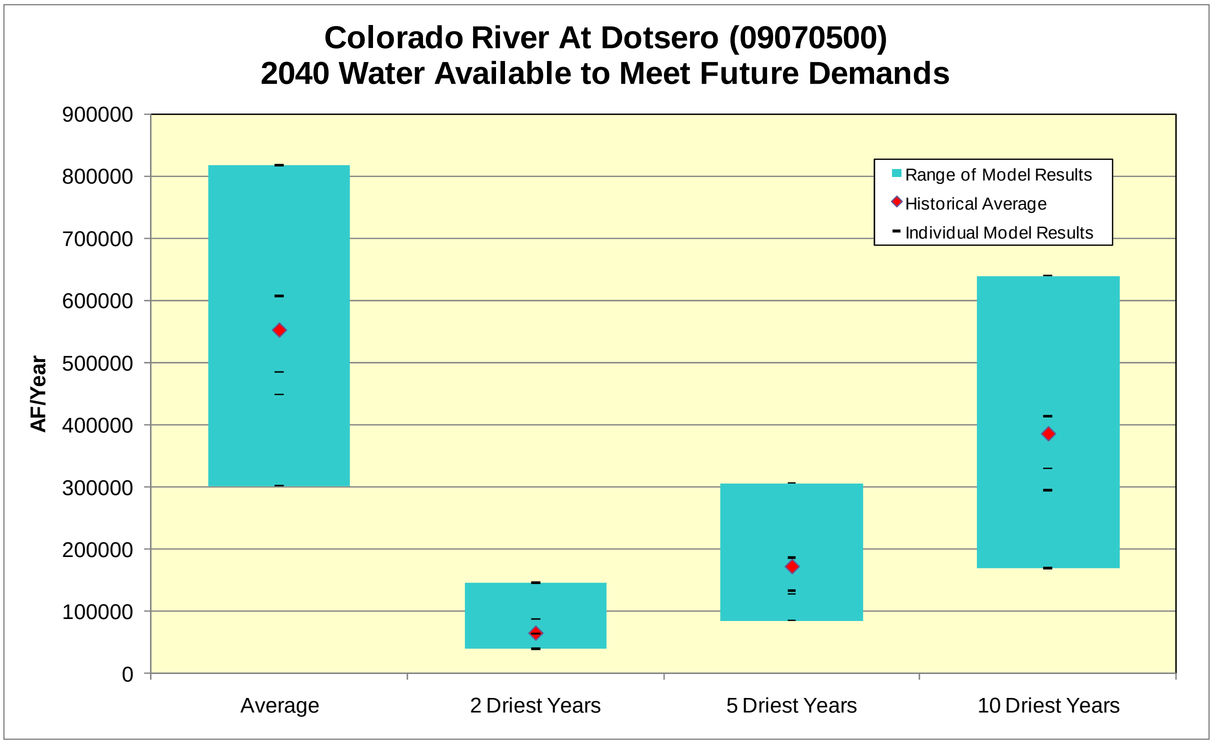


Figure F93 –2040 Roaring Fork River near Aspen Water Available to Meet Future Demands Low-flow Comparison

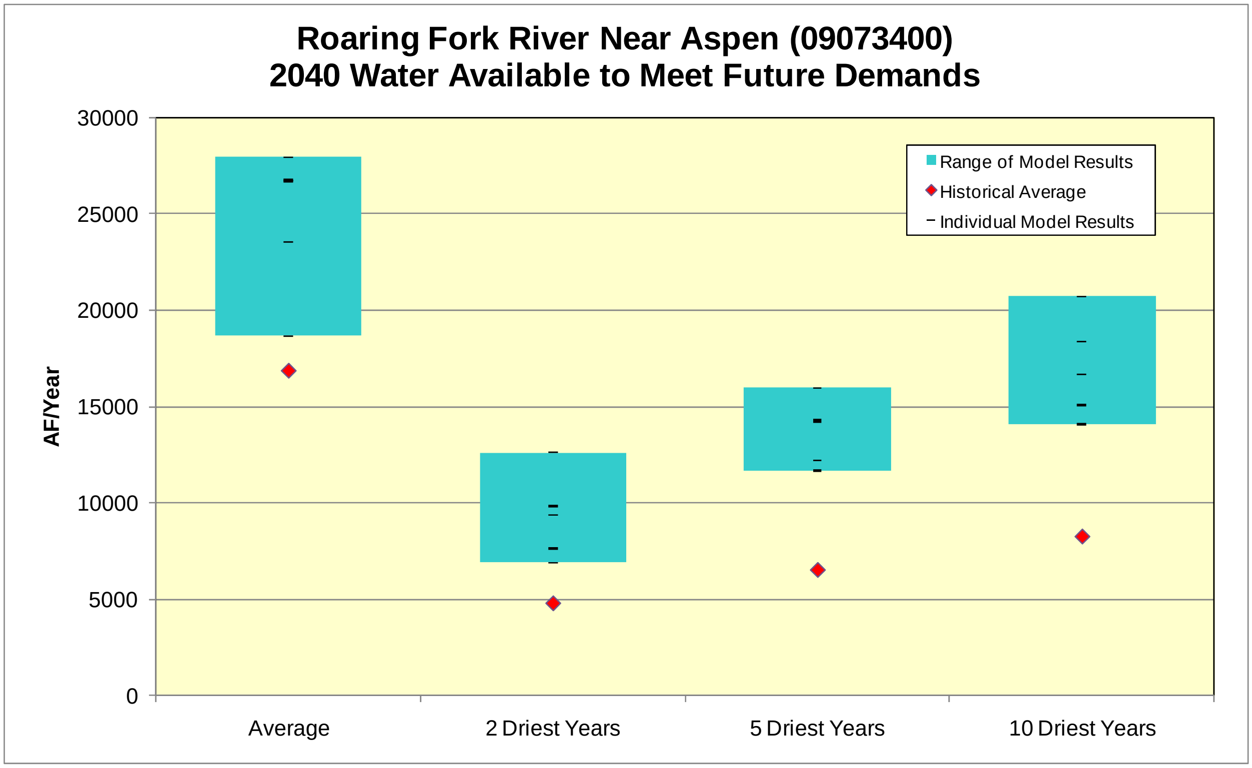


Figure F94 –2040 Roaring Fork River at Glenwood Water Available to Meet Future Demands Low-flow Comparison

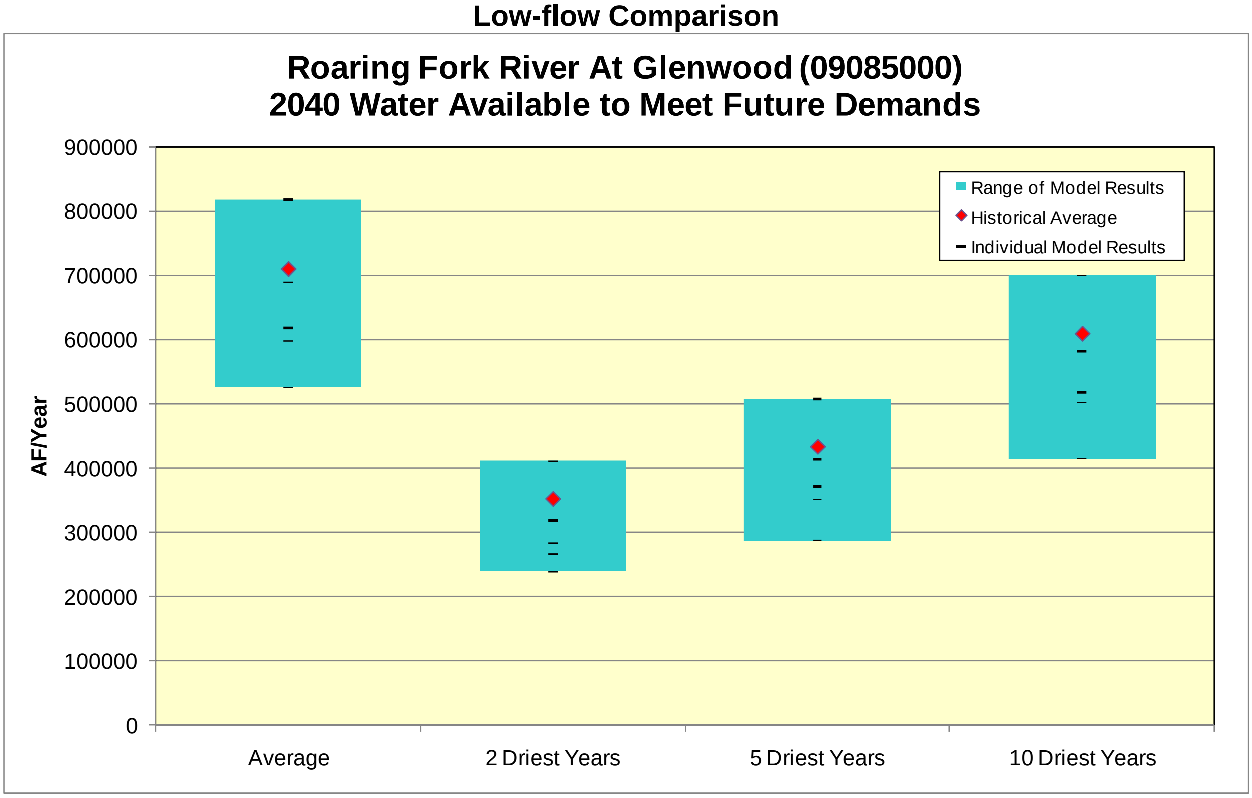


Figure F95 –2040 Colorado River near Cameo Water Available to Meet Future Demands Low-flow Comparison

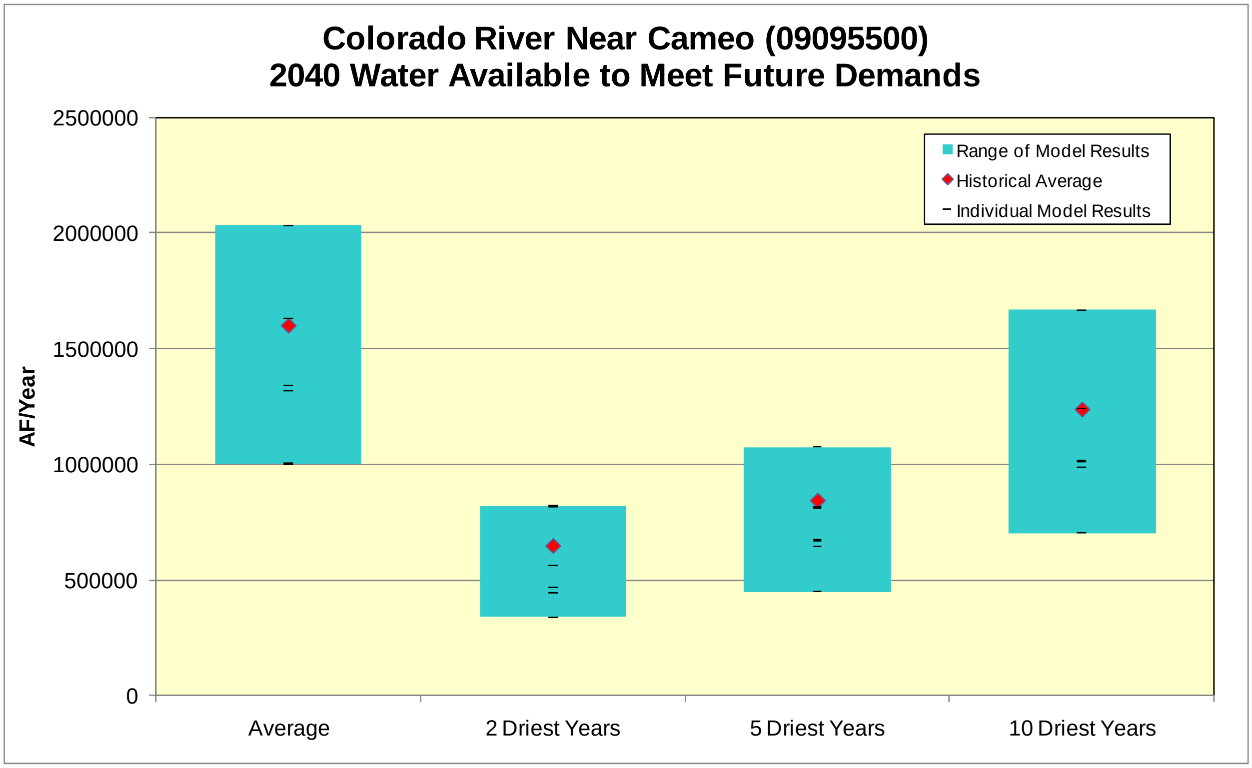


Figure F96 –2040 Plateau near Cameo Water Available to Meet Future Demands Low-flow Comparison

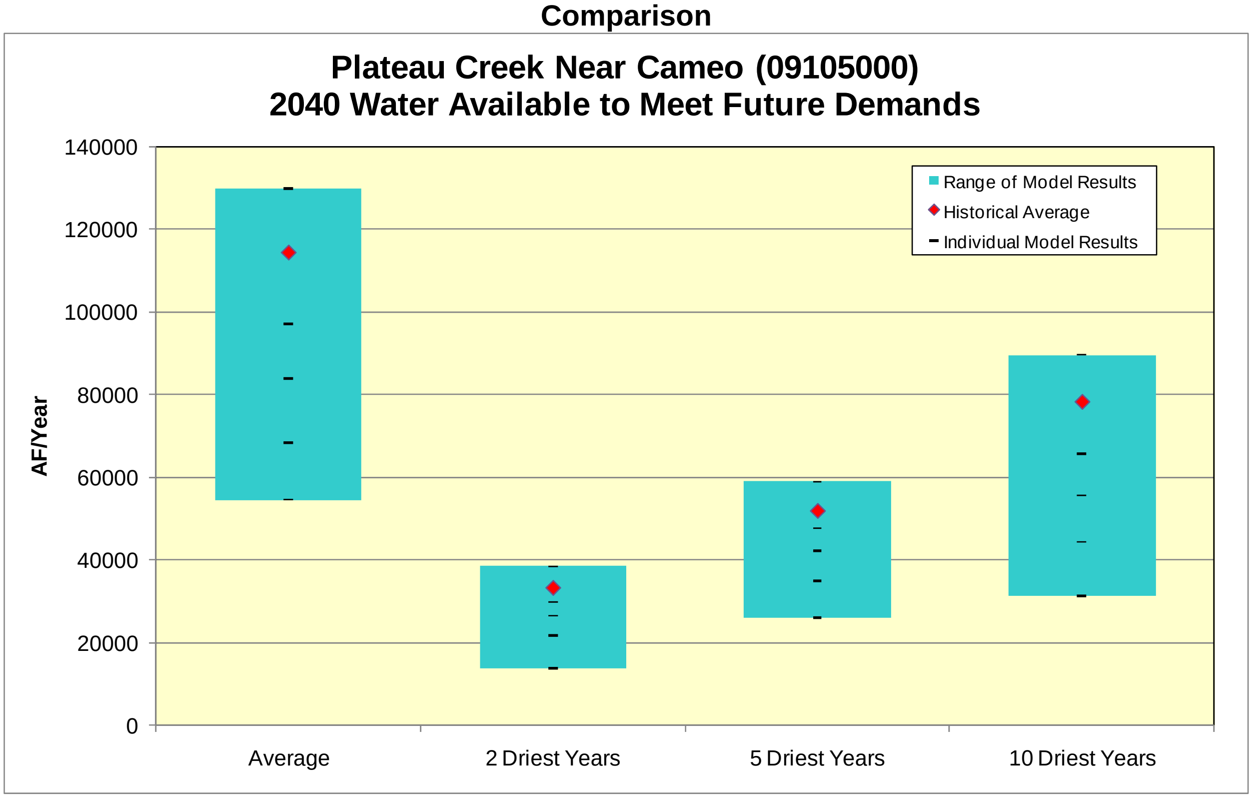


Figure F97 –2040 Colorado River near CO-UT State Line Water Available to Meet Future Demands Low-flow Comparison

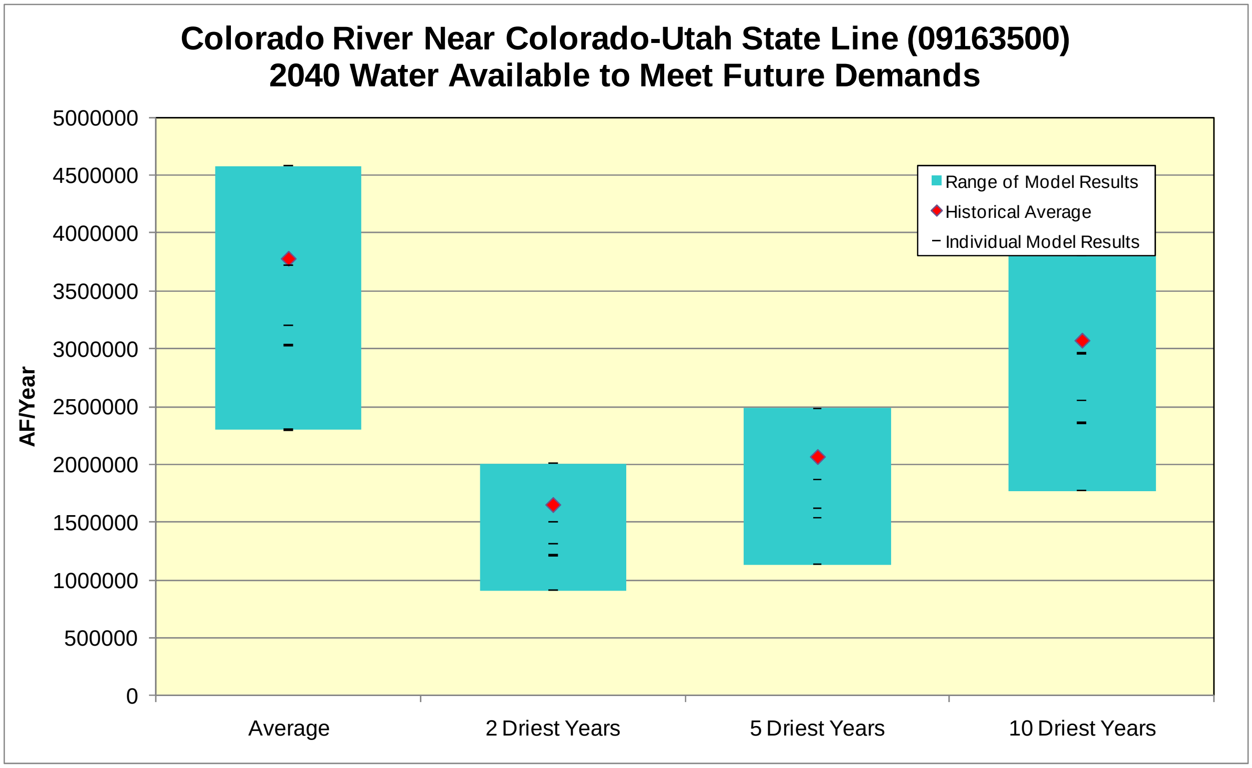


Figure F98 –2040 East River at Almont Water Available to Meet Future Demands Low-flow Comparison

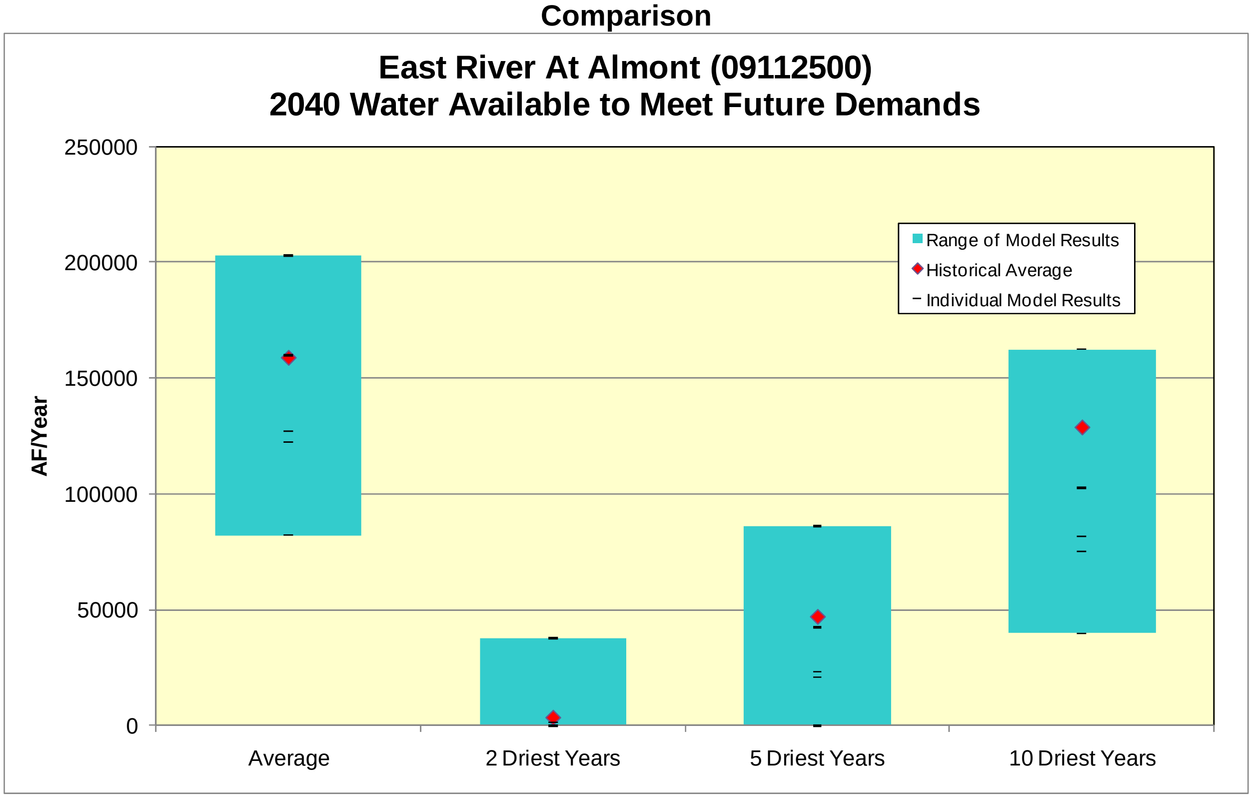


Figure F99 –2040 Taylor River at Almont Water Available to Meet Future Demands Low-flow Comparison

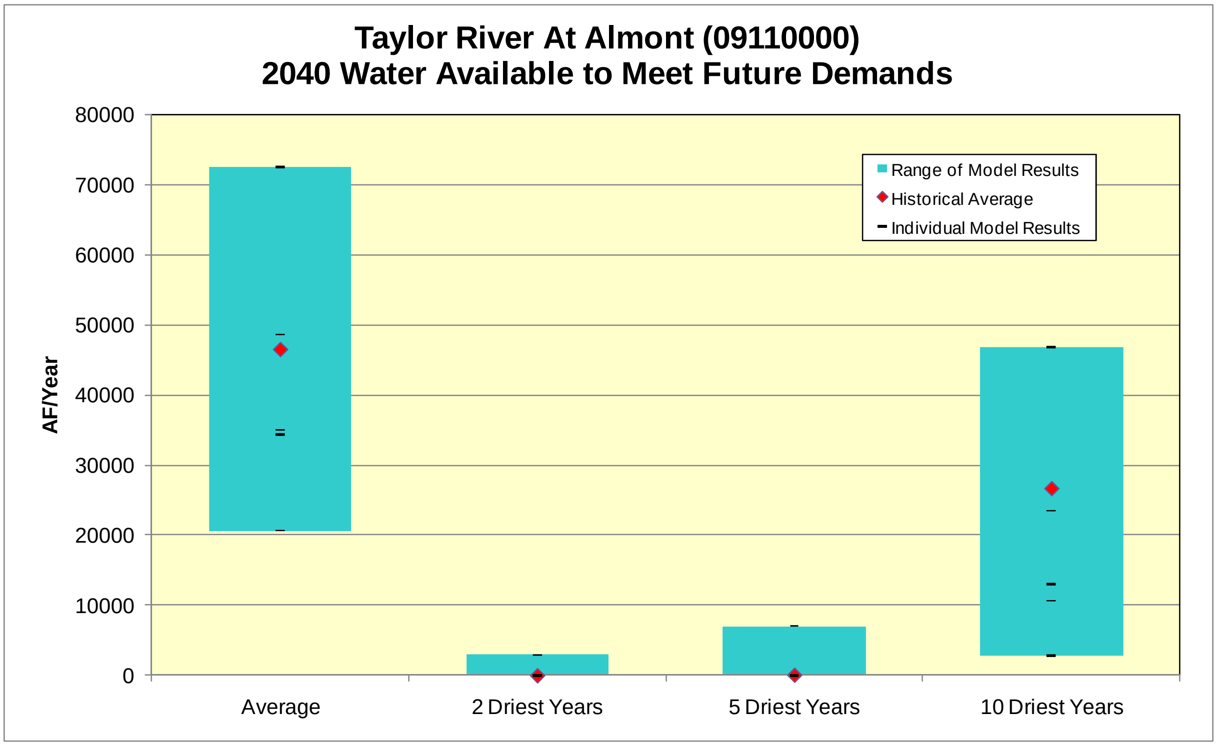


Figure F100 –2040 Tomichi Creek at Gunnison Water Available to Meet Future Demands Low-flow Comparison

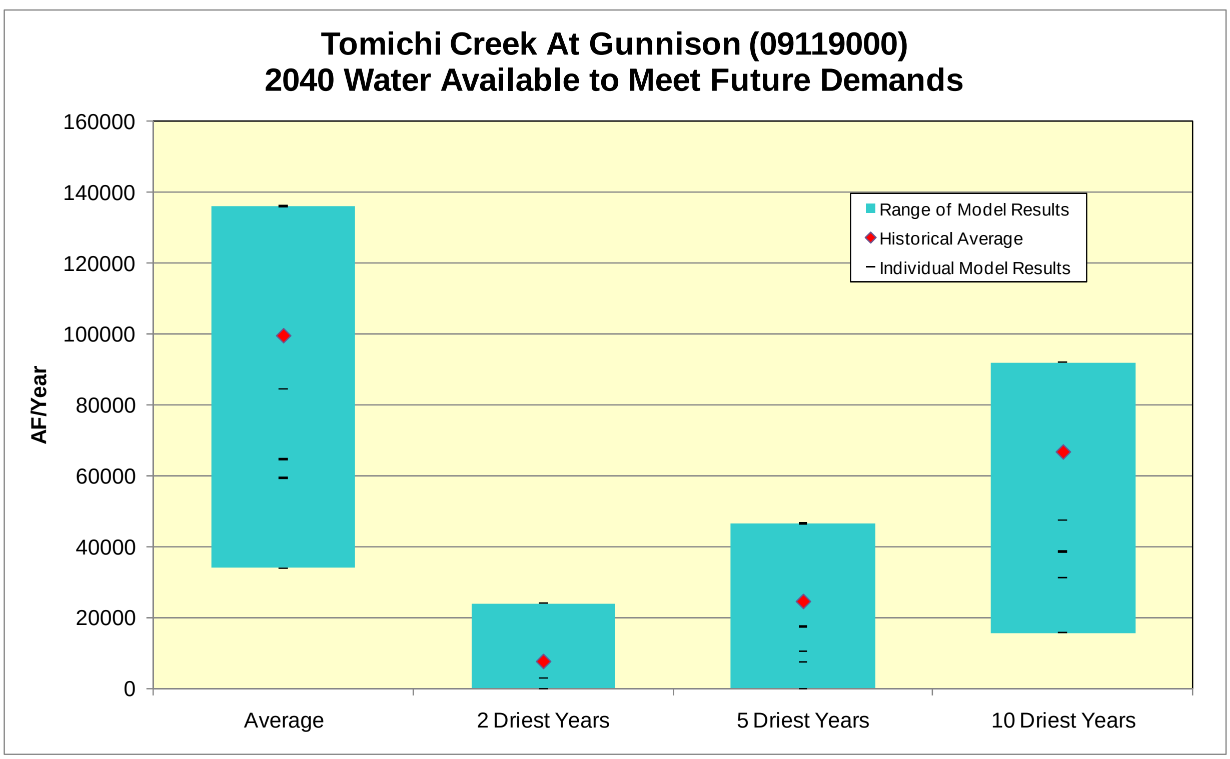


Figure F101 –2040 Gunnison River near Gunnison Water Available to Meet Future Demands Low-flow Comparison

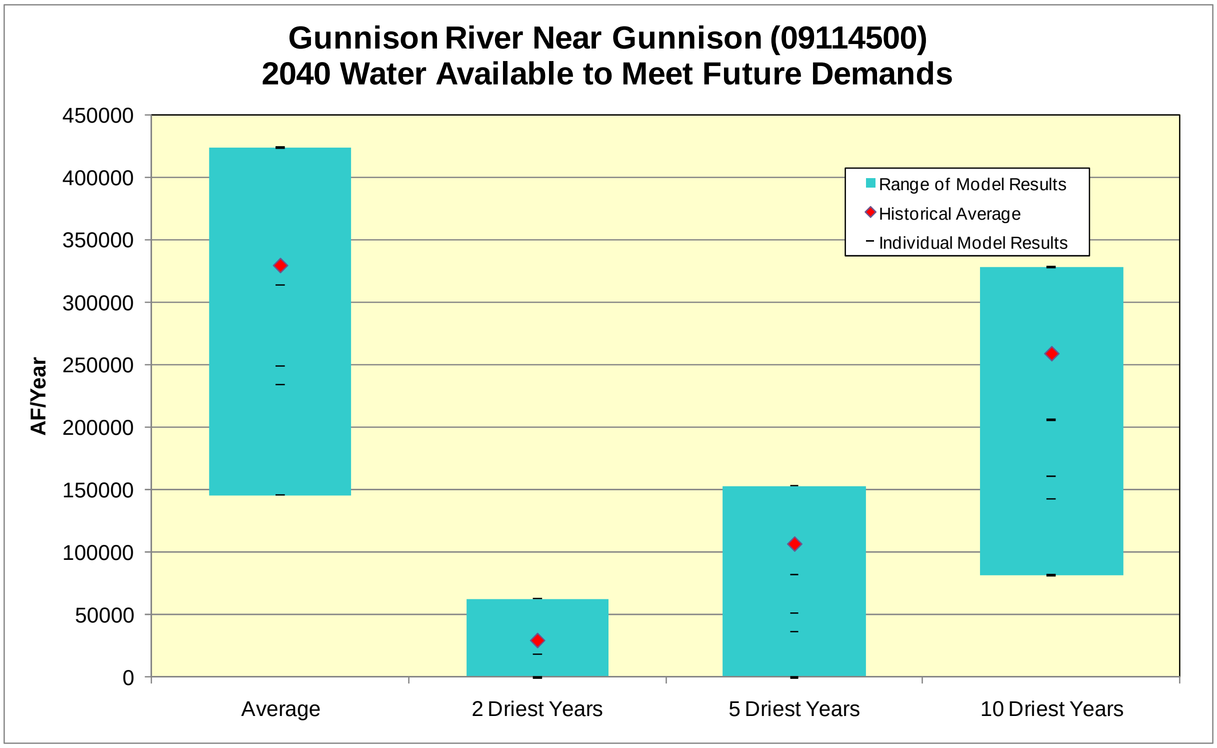


Figure F102 –2040 Cimarron River at Cimarron Water Available to Meet Future Demands Low-flow Comparison

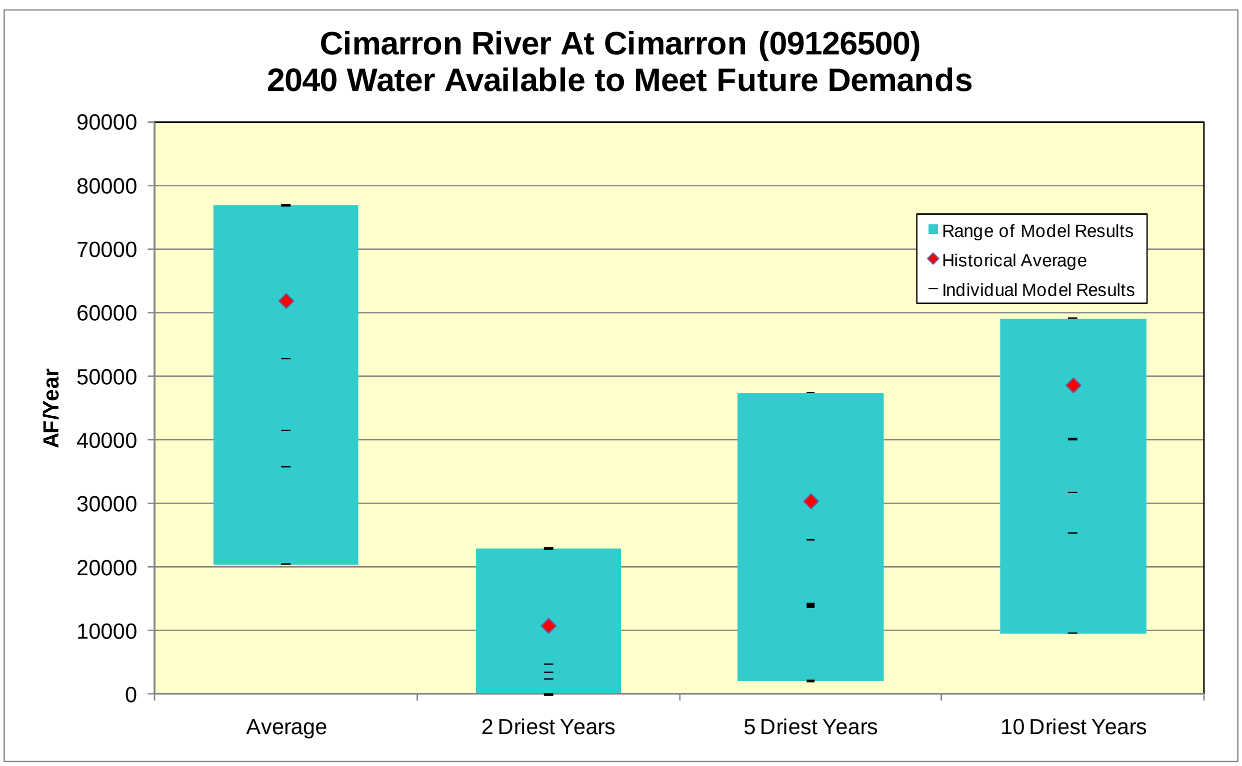


Figure F103 –2040 Gunnison River below Gunnison Tunnel Water Available to Meet Future Demands Low-flow Comparison

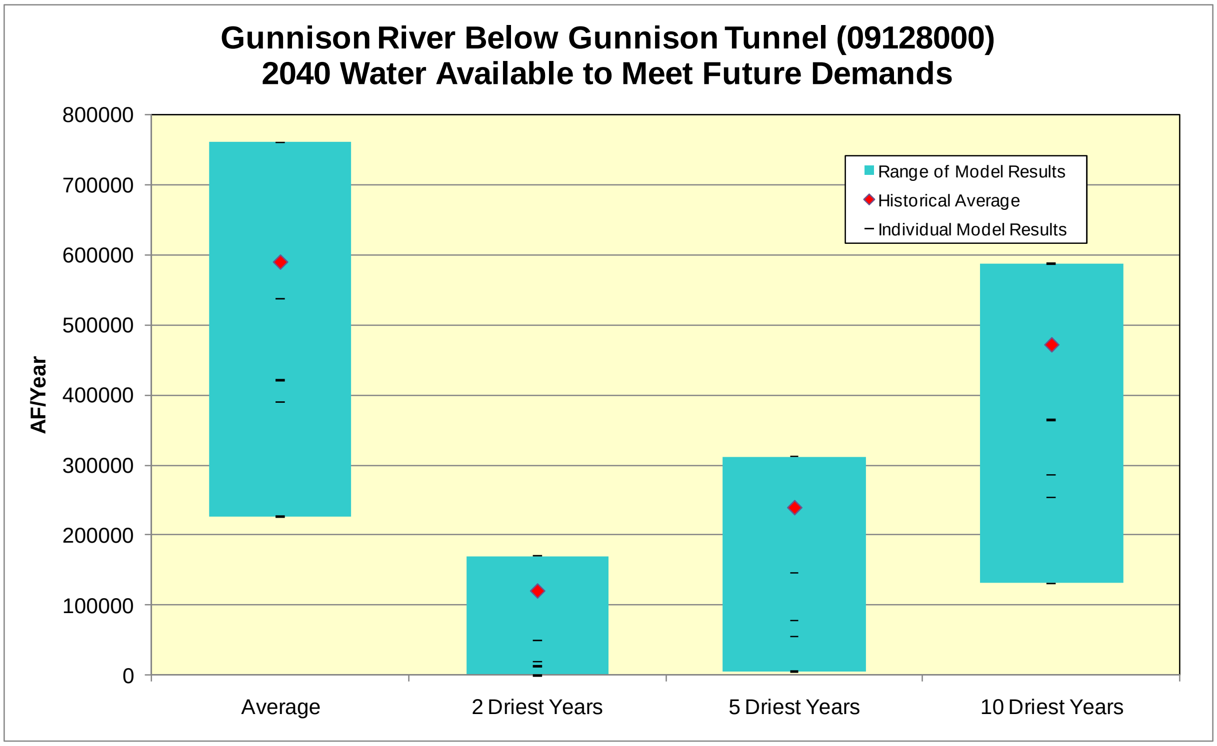


Figure F104 –2040 Gunnison River near Lazear Water Available to Meet Future Demands Low-flow Comparison

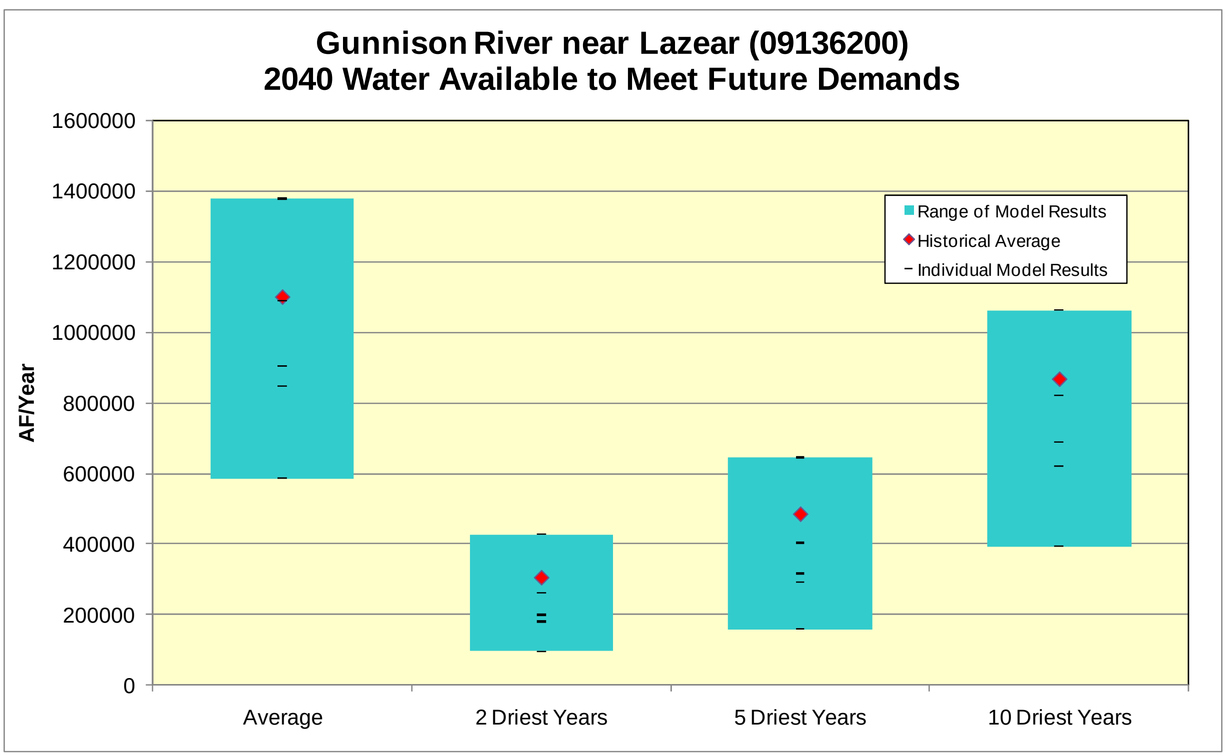


Figure F105 –2040 Uncompahgre River at Delta Water Available to Meet Future Demands Low-flow Comparison

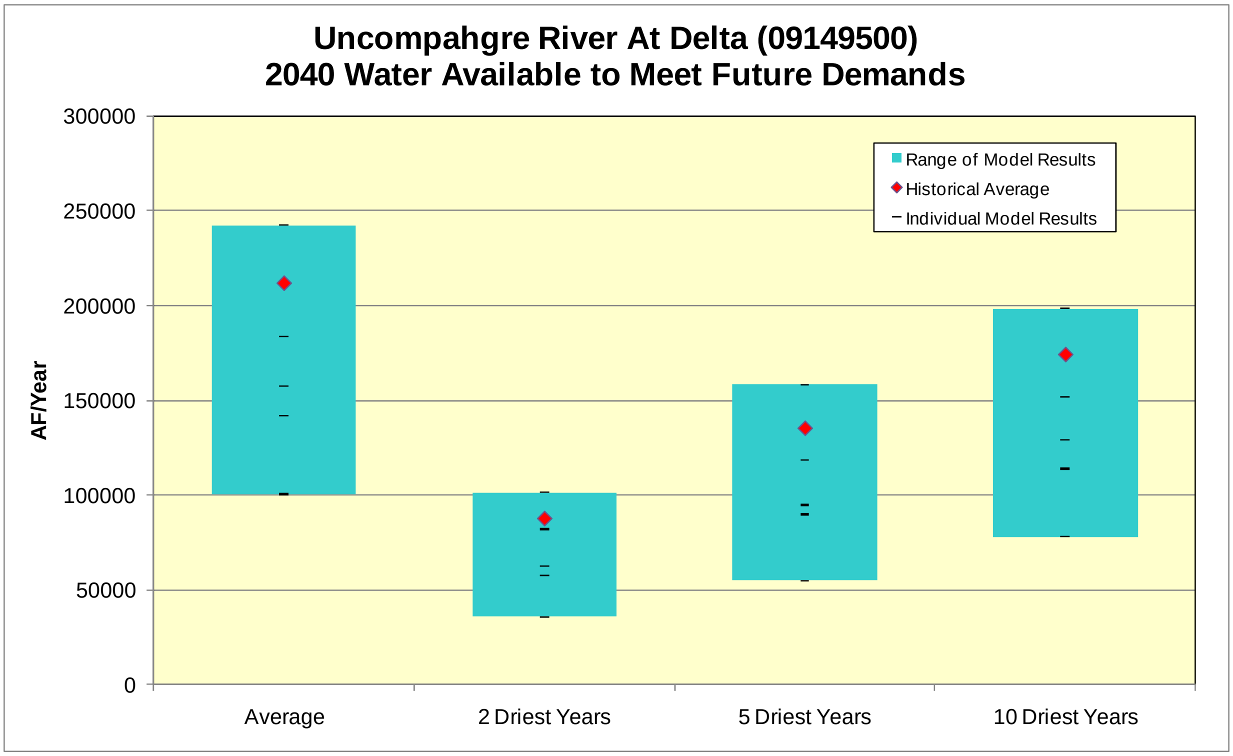


Figure F106 –2040 Gunnison River near Grand Junction Water Available to Meet Future Demands Low-flow Comparison

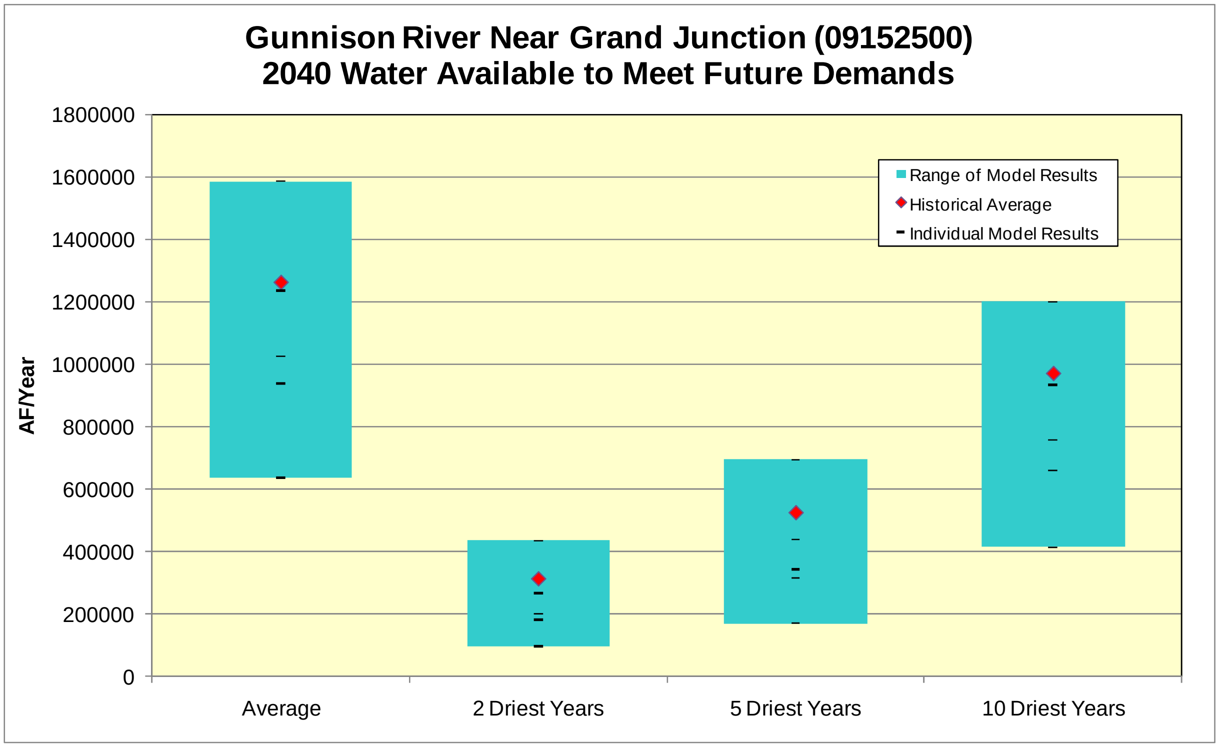


Figure F107 –2040 San Juan River near Carracas Water Available to Meet Future Demands Low-flow Comparison

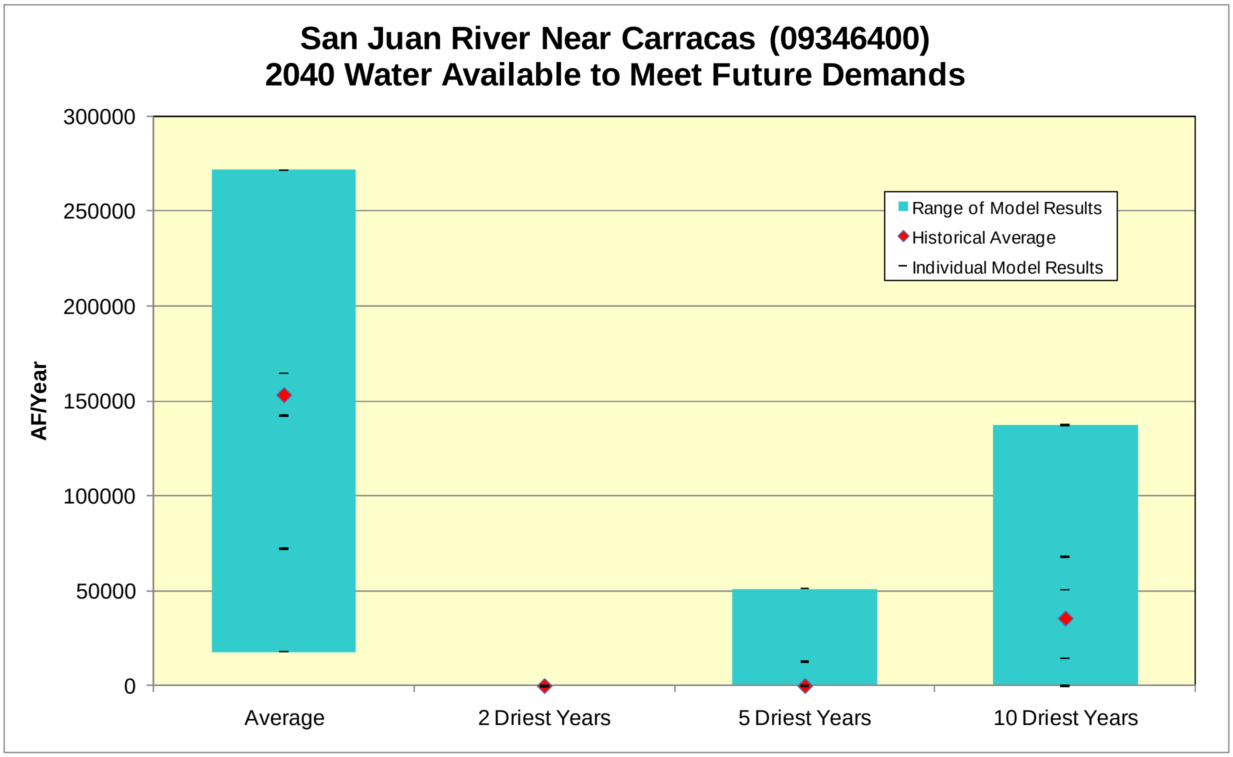


Figure F108 –2040 Piedra River near Arboles Water Available to Meet Future Demands Low-flow Comparison

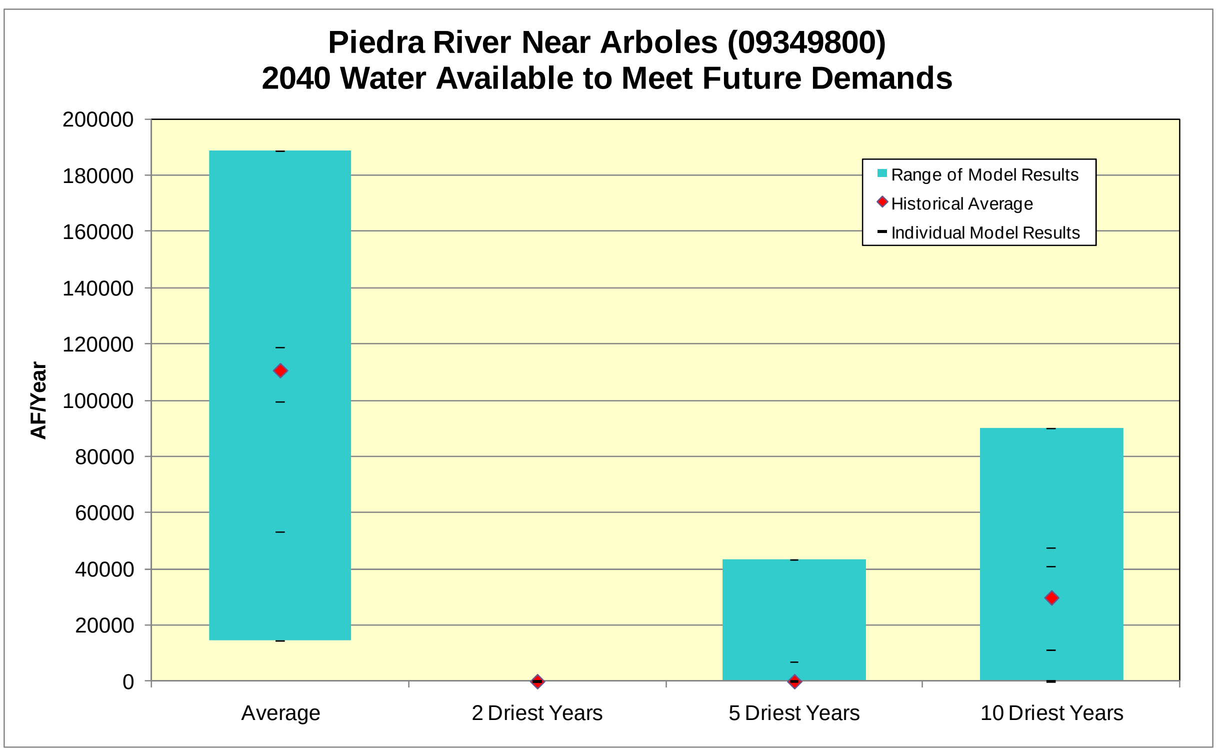


Figure F109 –2040 Los Pinos River at La Boca Water Available to Meet Future Demands Low-flow Comparison

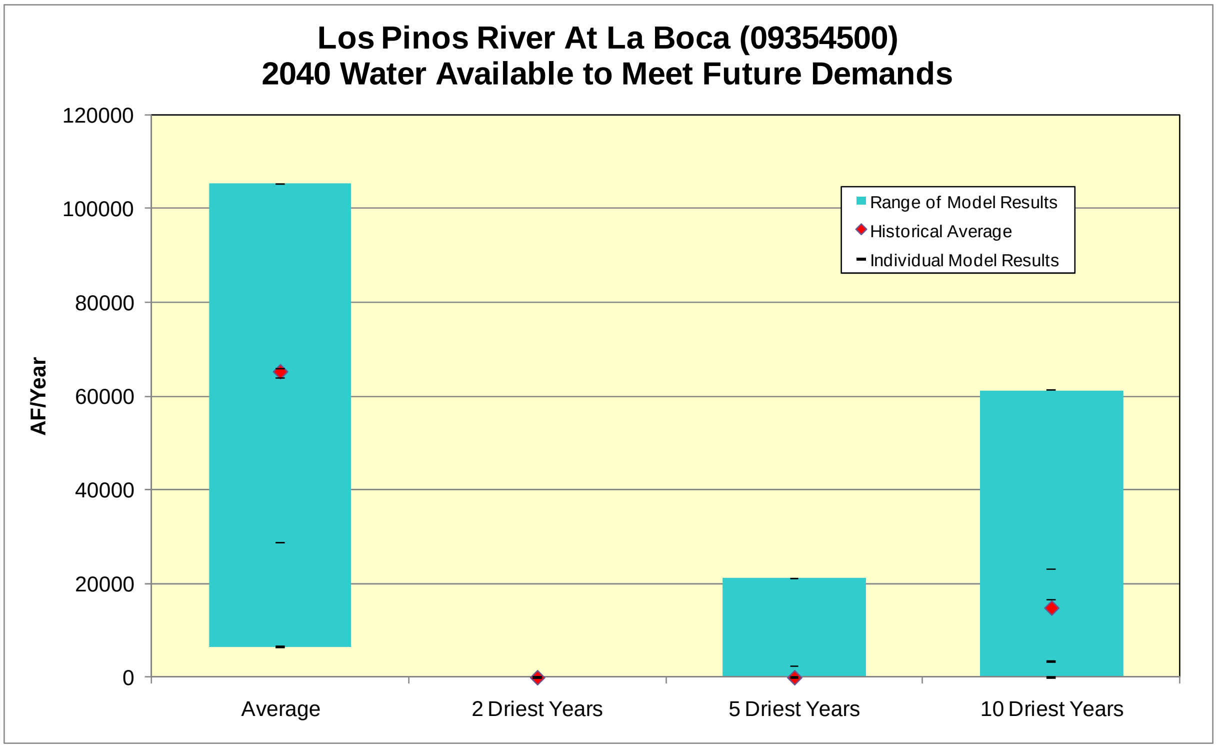


Figure F110 –2040 Florida River at Bondad Water Available to Meet Future Demands Low-flow Comparison

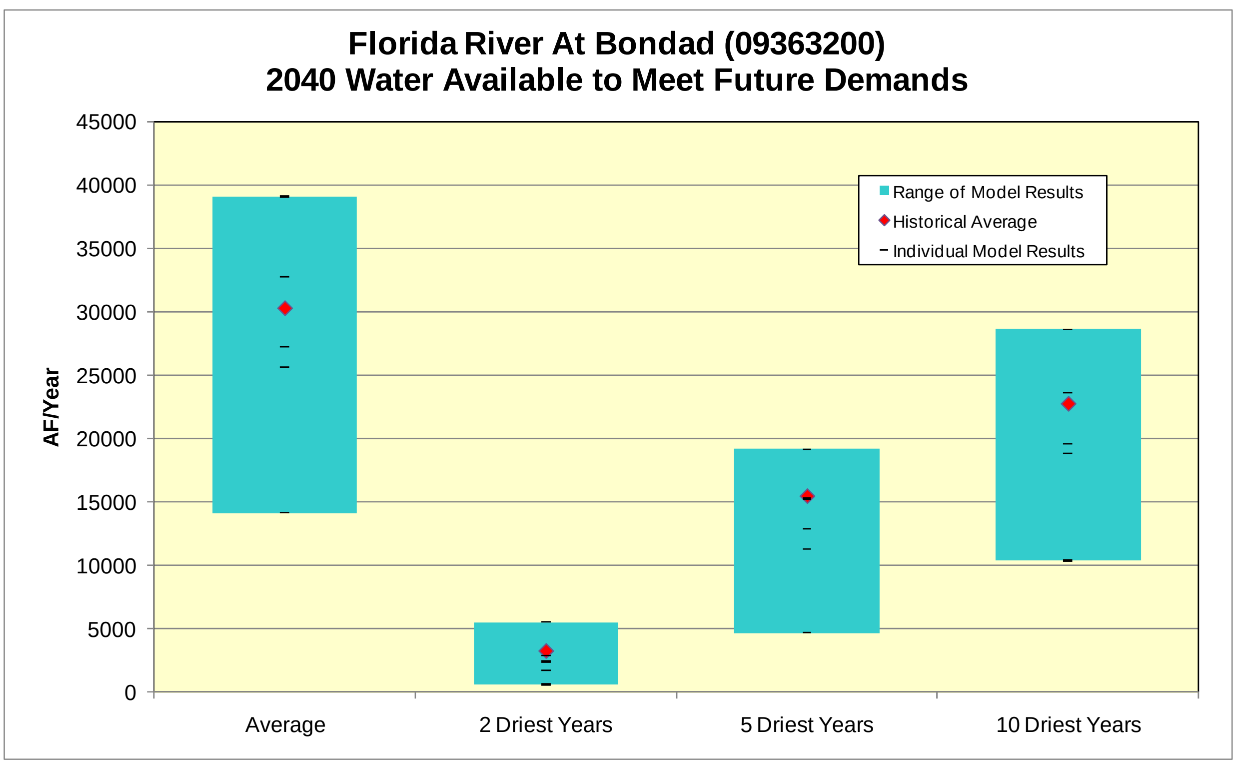


Figure F111 –2040 Animas River near Cedar Hill, NM Water Available to Meet Future Demands Low-flow Comparison

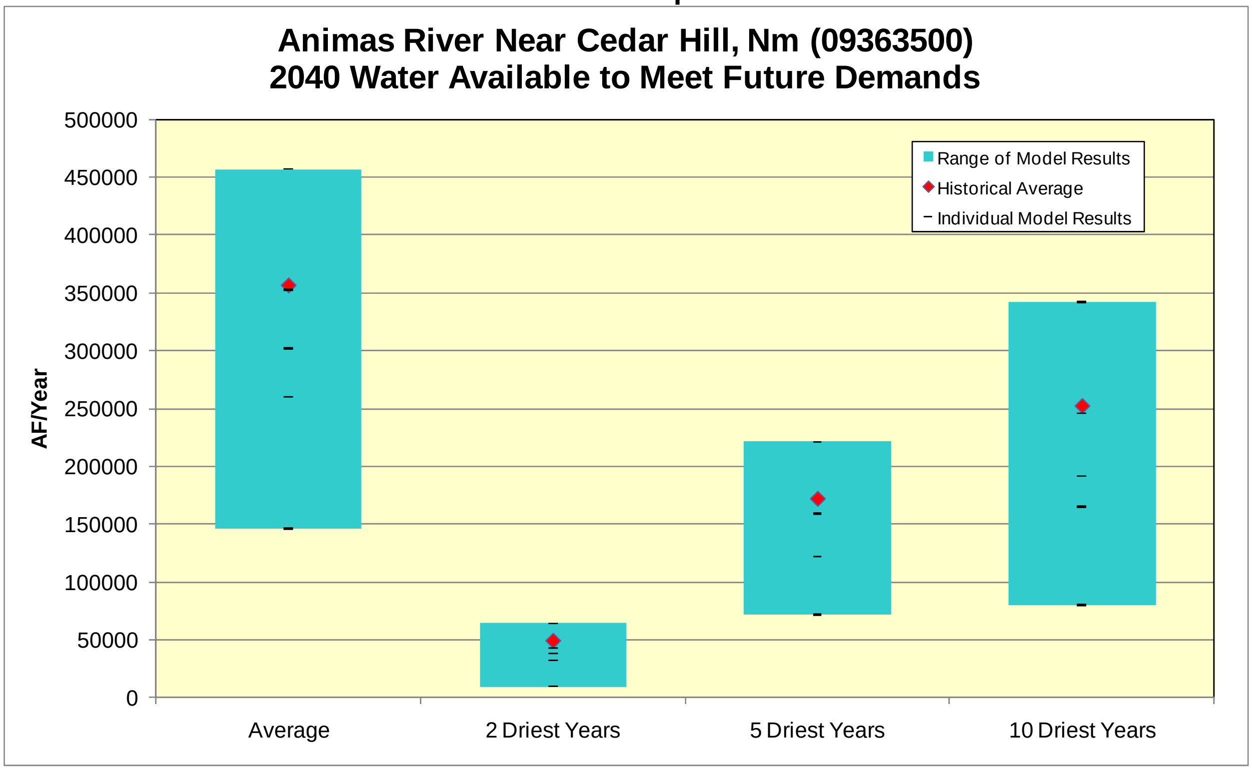


Figure F112 –2040 La Plata River at Hesperus Water Available to Meet Future Demands Low-flow Comparison

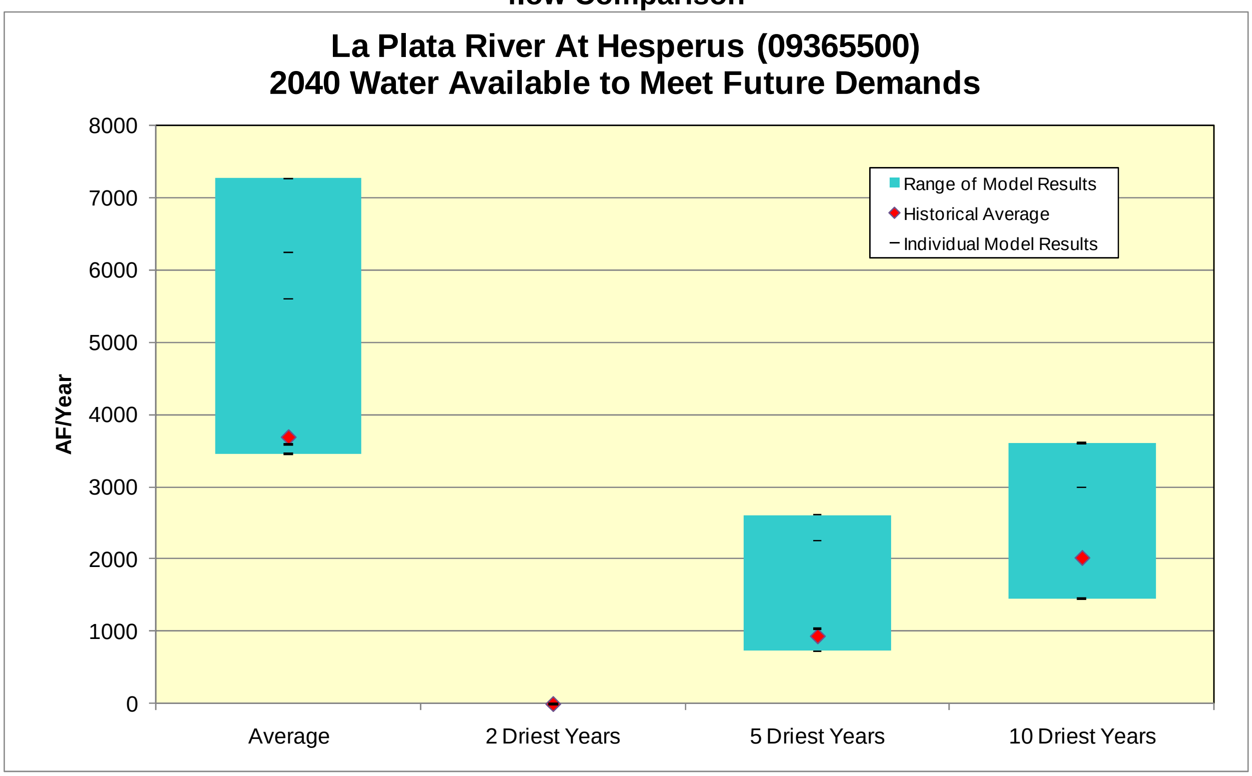


Figure F113 –2040 La Plata River at CO-NM State Line Water Available to Meet Future Demands Low-flow Comparison

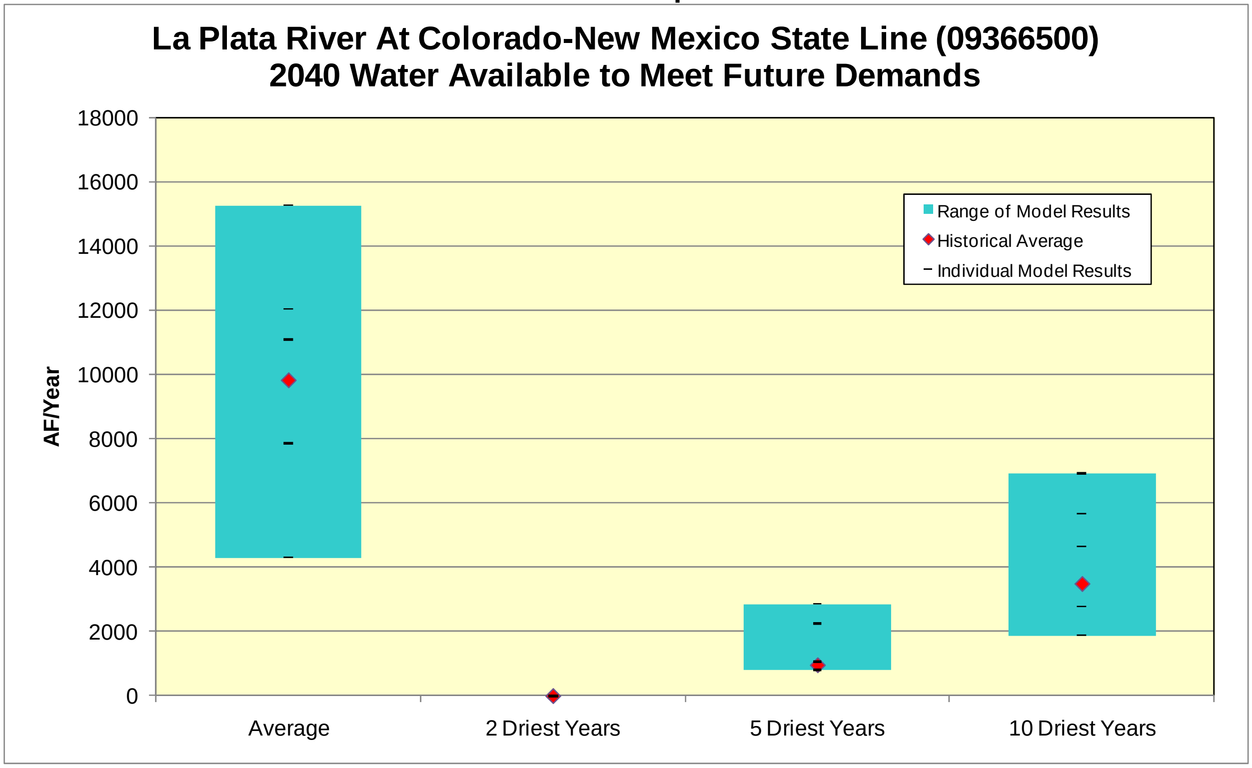


Figure F114 –2040 Mancos River near Towaoc Water Available to Meet Future Demands Low-flow Comparison

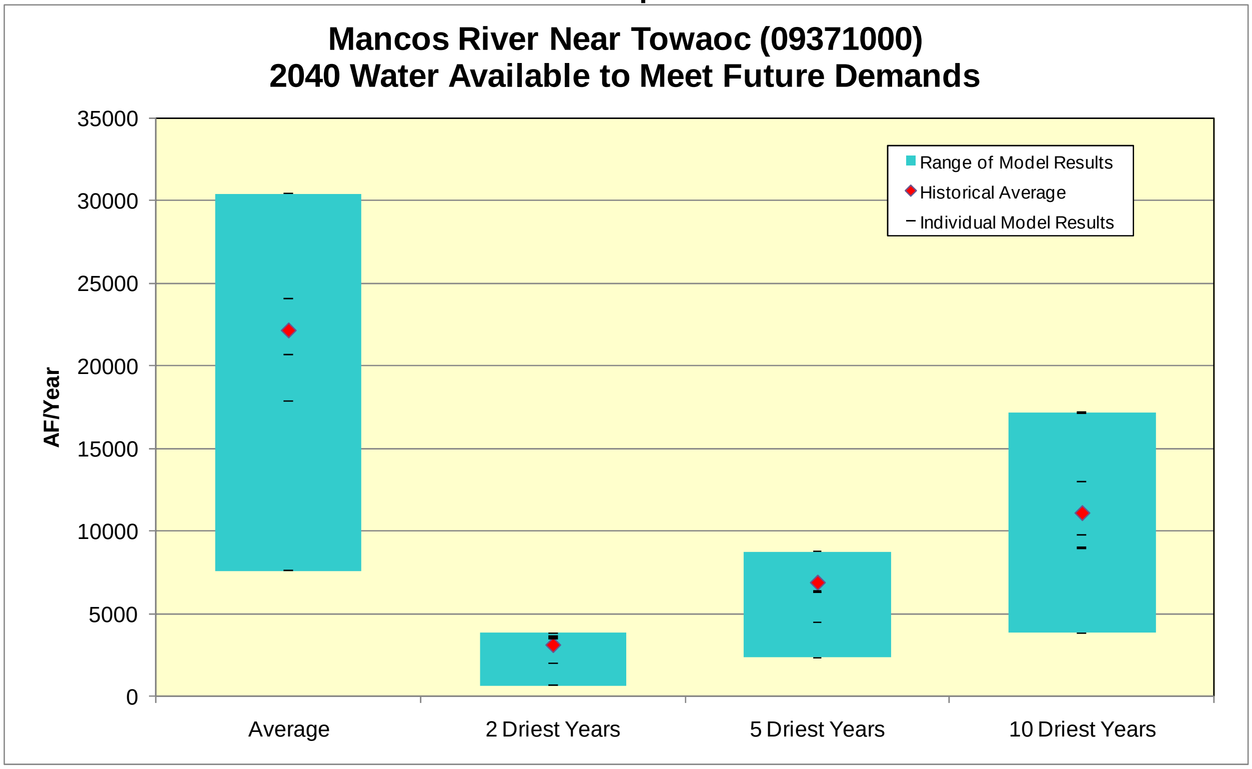


Figure F115 –2040 McElmo Creek near CO-UT State Line Water Available to Meet Future Demands Low-flow Comparison

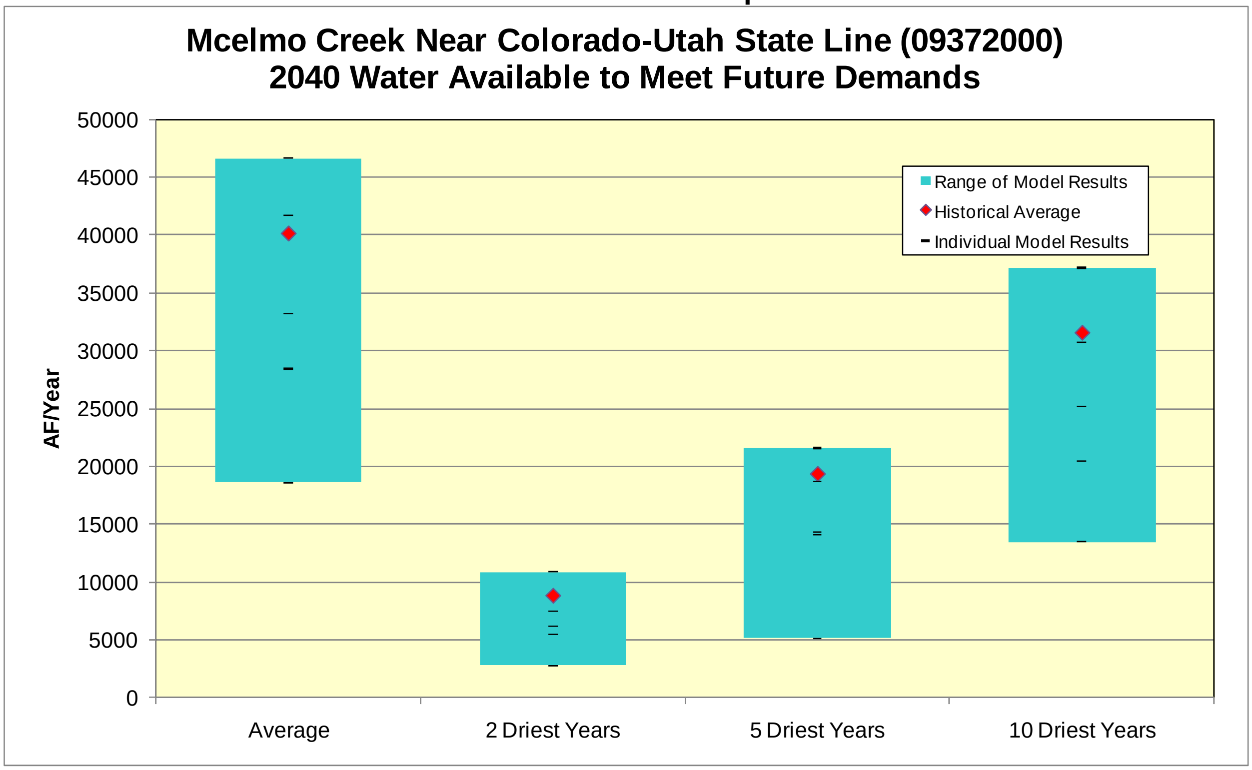


Figure F116 –2040 Dolores River near Bedrock Water Available to Meet Future Demands Low-flow Comparison

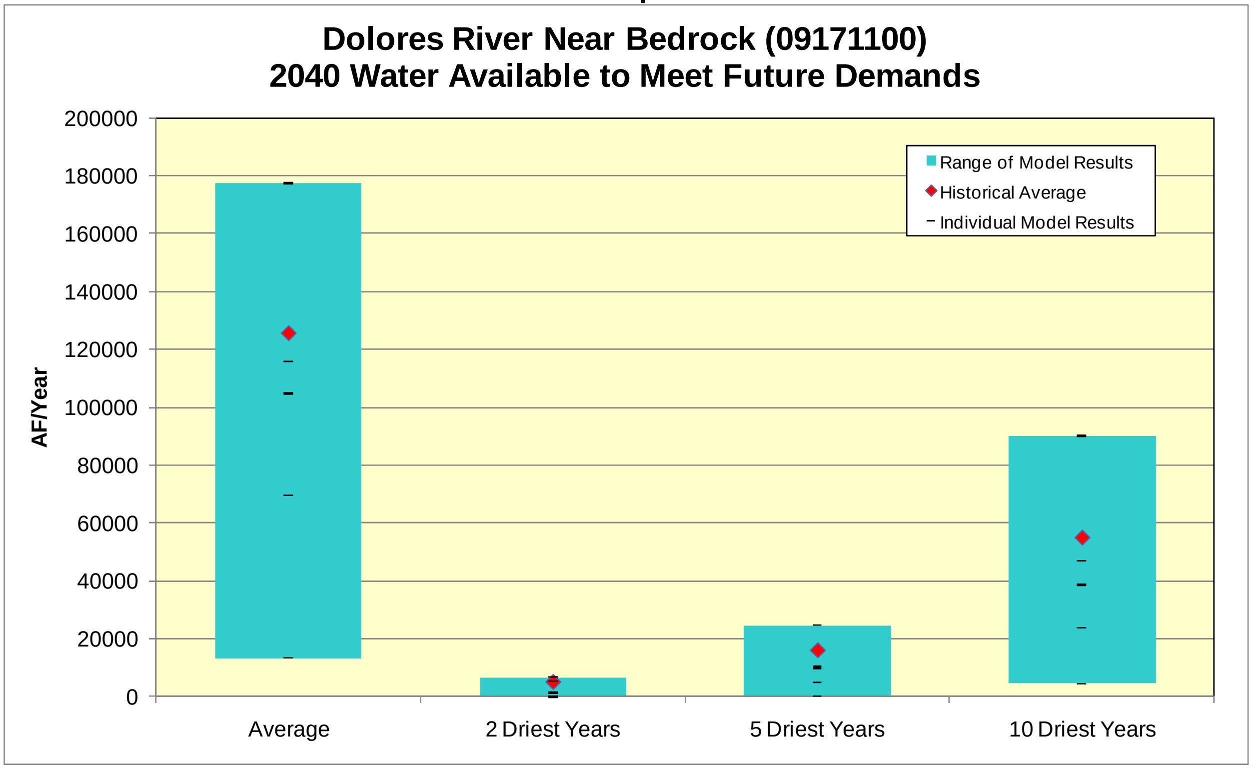


Figure F117 –2040 San Miguel River at Naturita Water Available to Meet Future Demands Low-flow Comparison

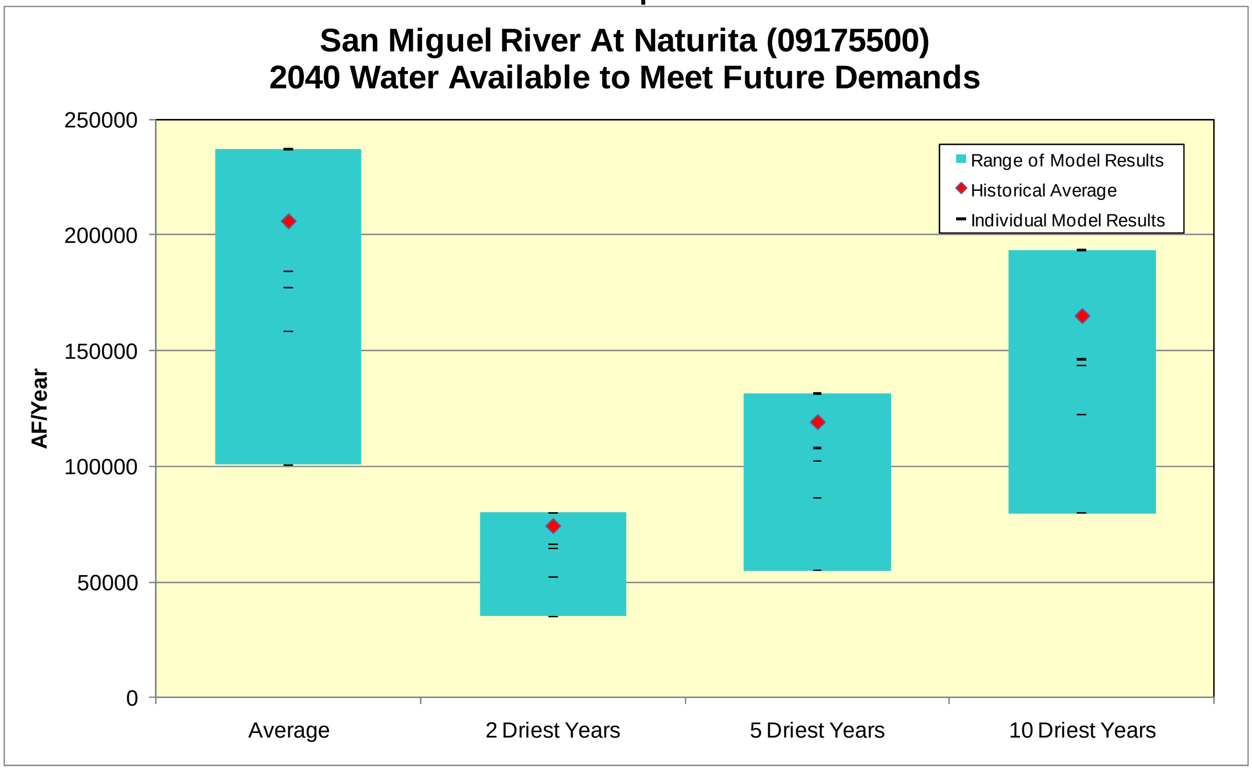


Figure F118 –2040 Yampa River below Stagecoach Reservoir Water Available to Meet Future Demands Low-flow Comparison

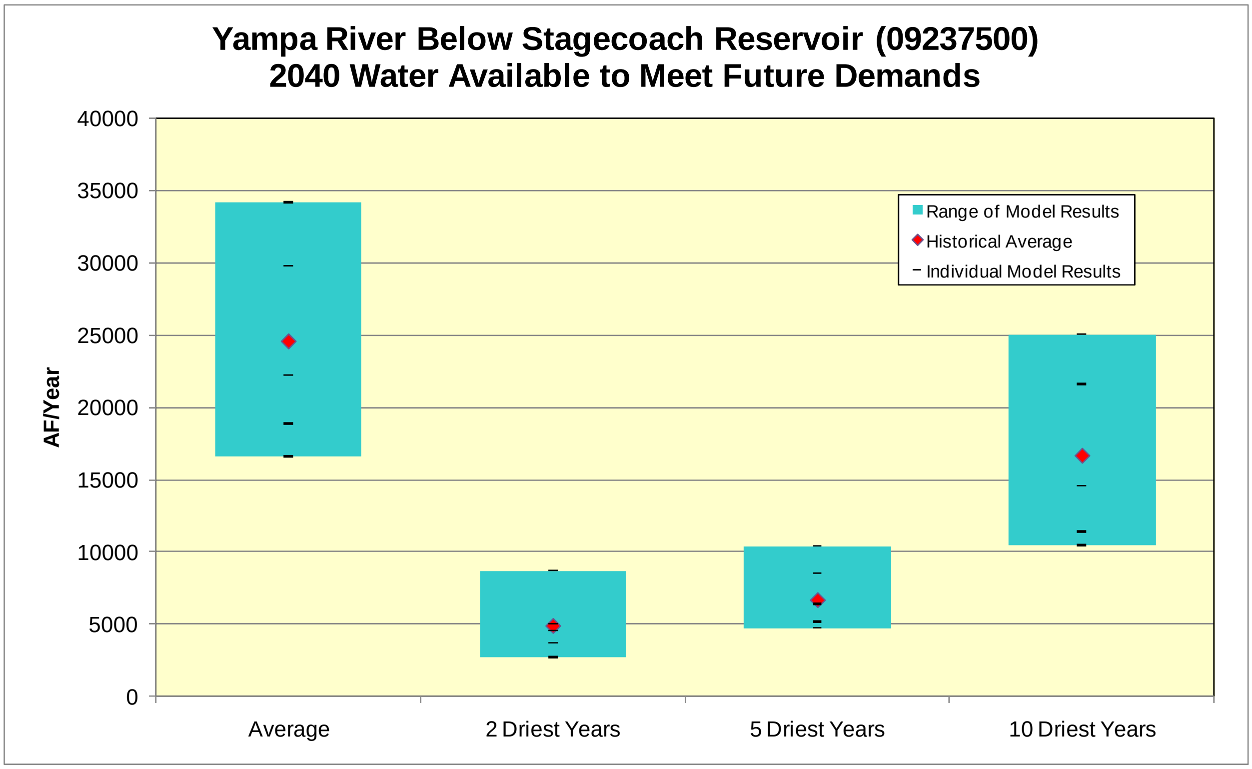


Figure F119 –2040 Elk River at Clark Water Available to Meet Future Demands Low-flow Comparison

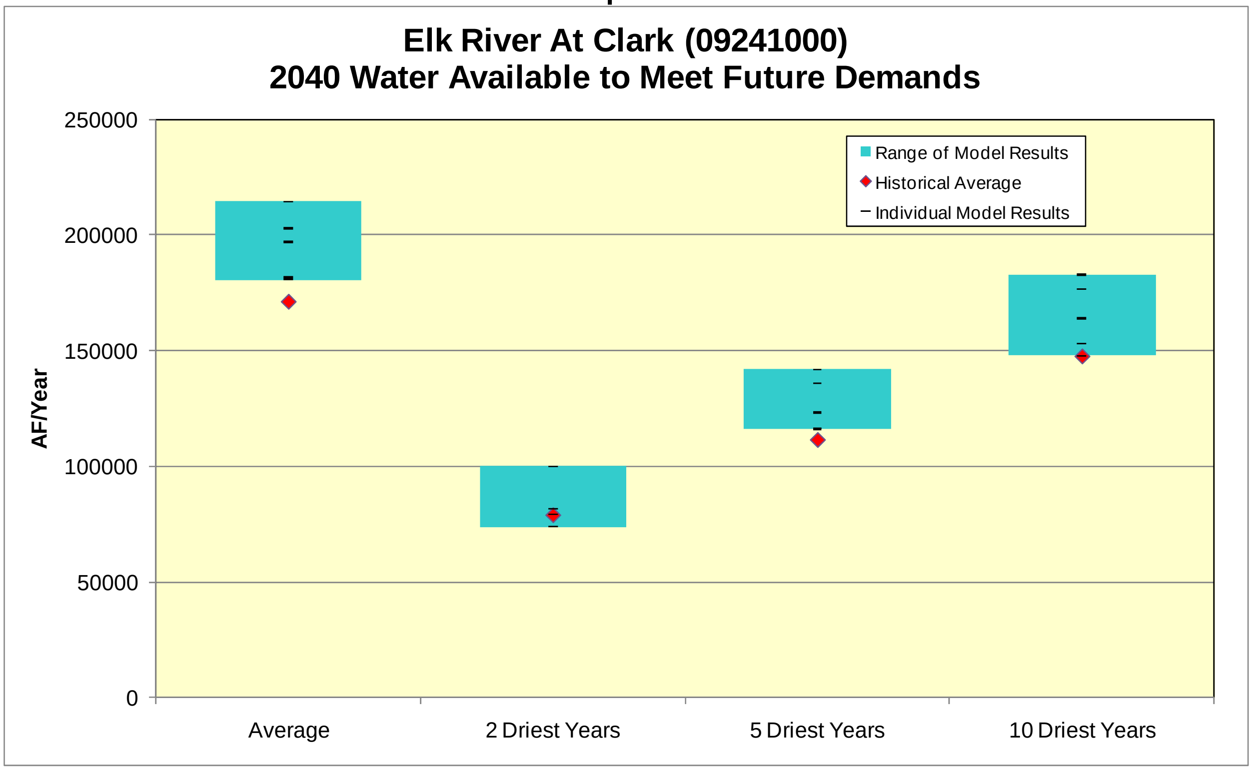


Figure F120 –2040 Elkhead Creek near Elkhead Water Available to Meet Future Demands Low-flow Comparison

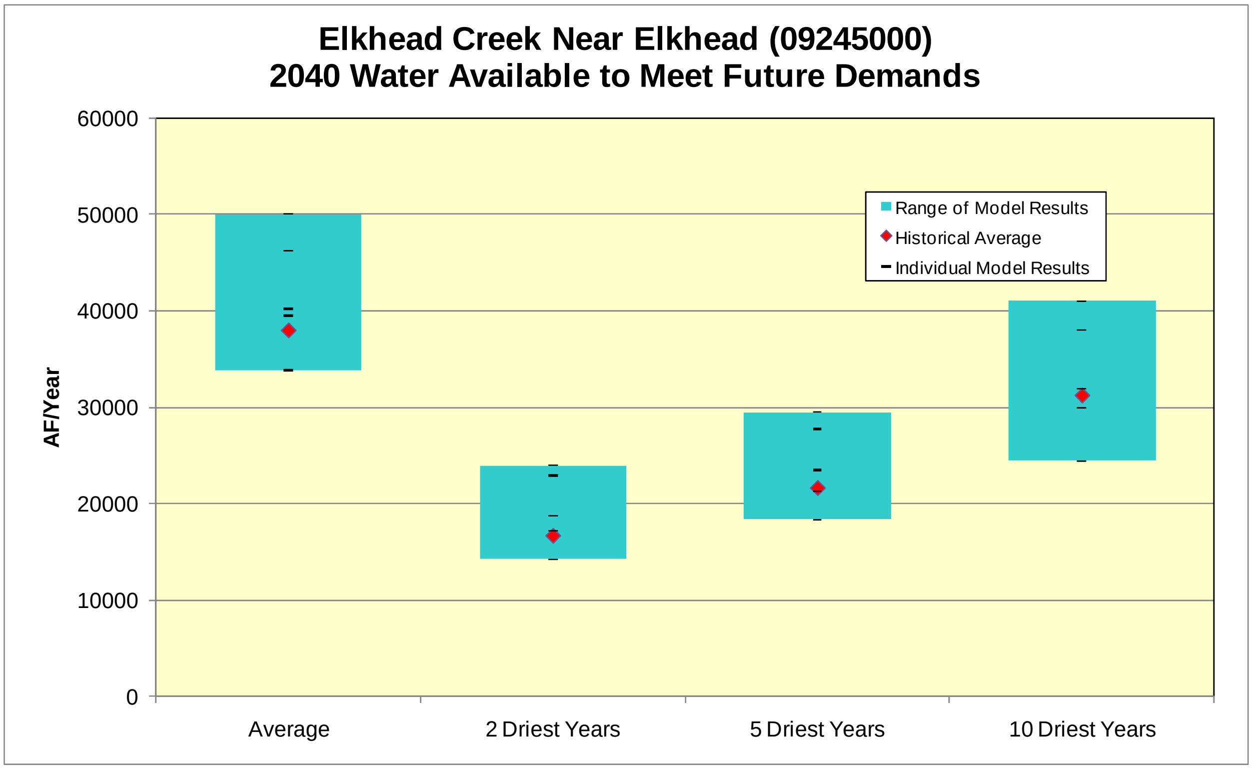


Figure F121 –2040 Williams Fork at Mouth, near Hamilton Water Available to Meet Future Demands Low-flow Comparison

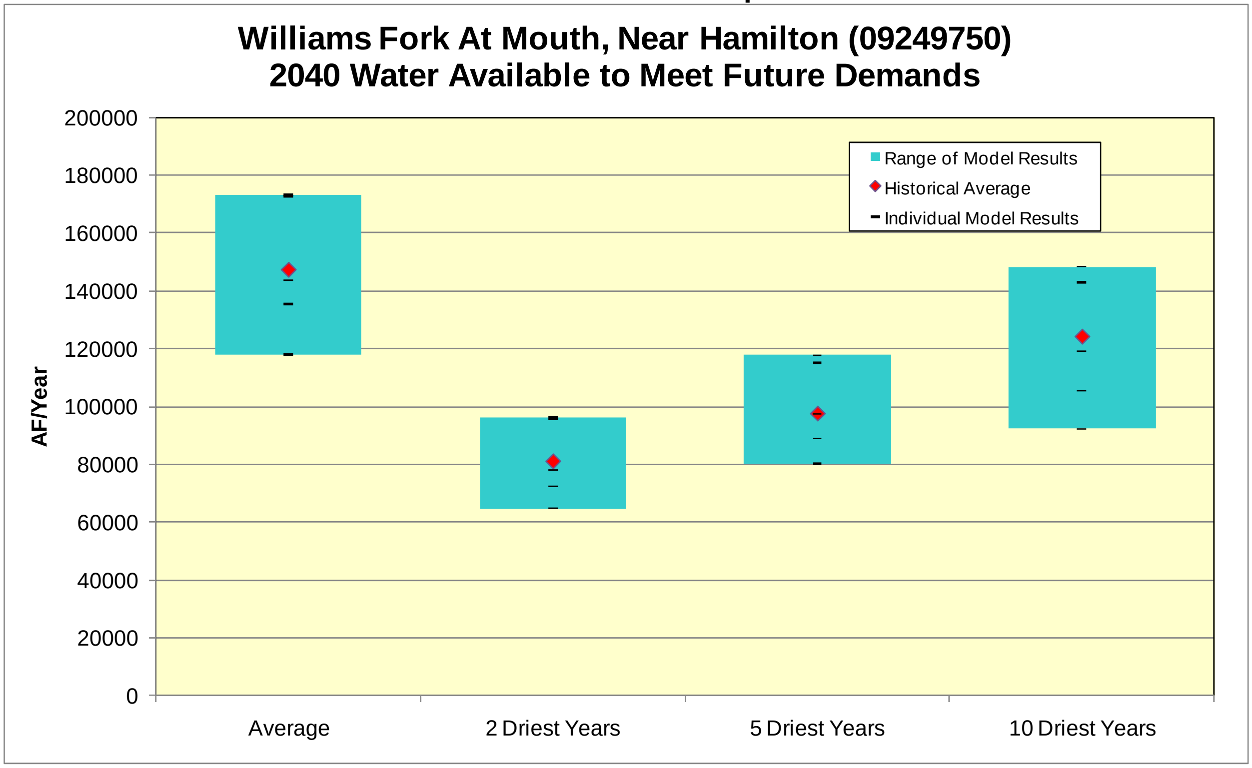


Figure F122 –2040 Yampa River near Maybell Water Available to Meet Future Demands Low-flow Comparison

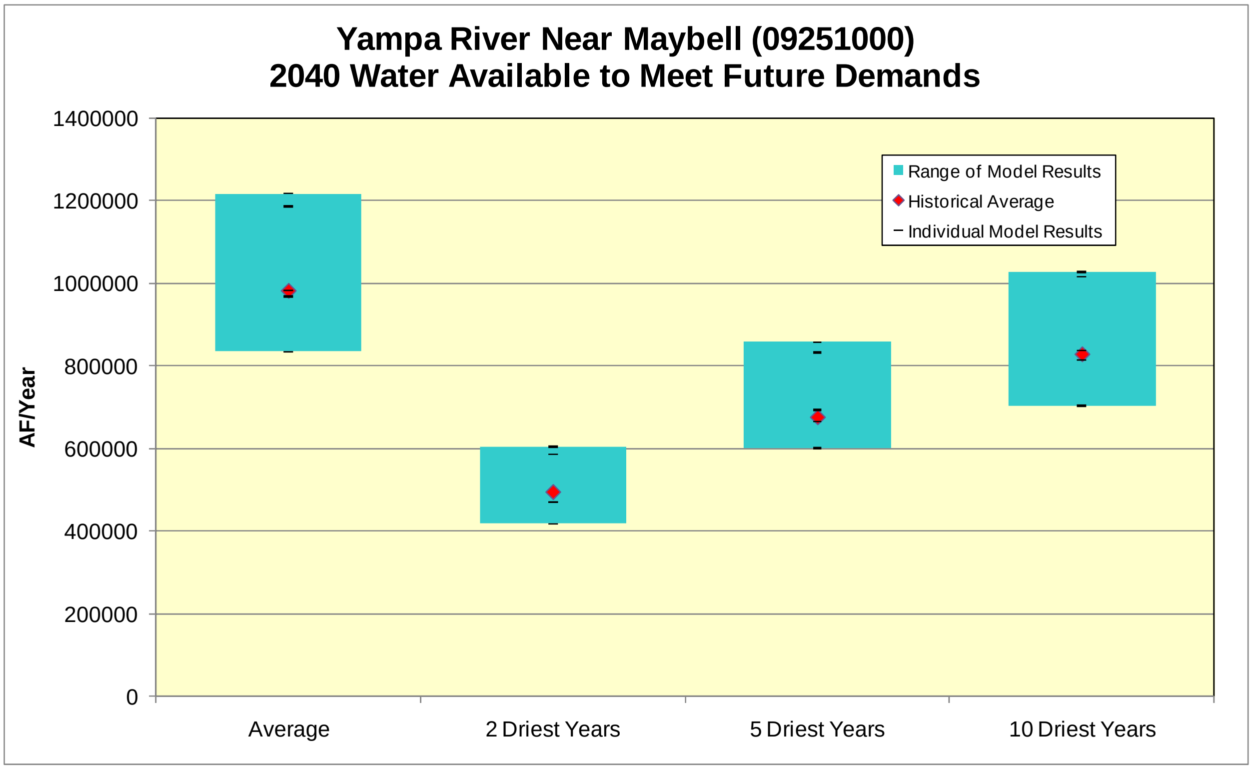


Figure F123 –2040 Little Snake River near Lily Water Available to Meet Future Demands Low-flow Comparison

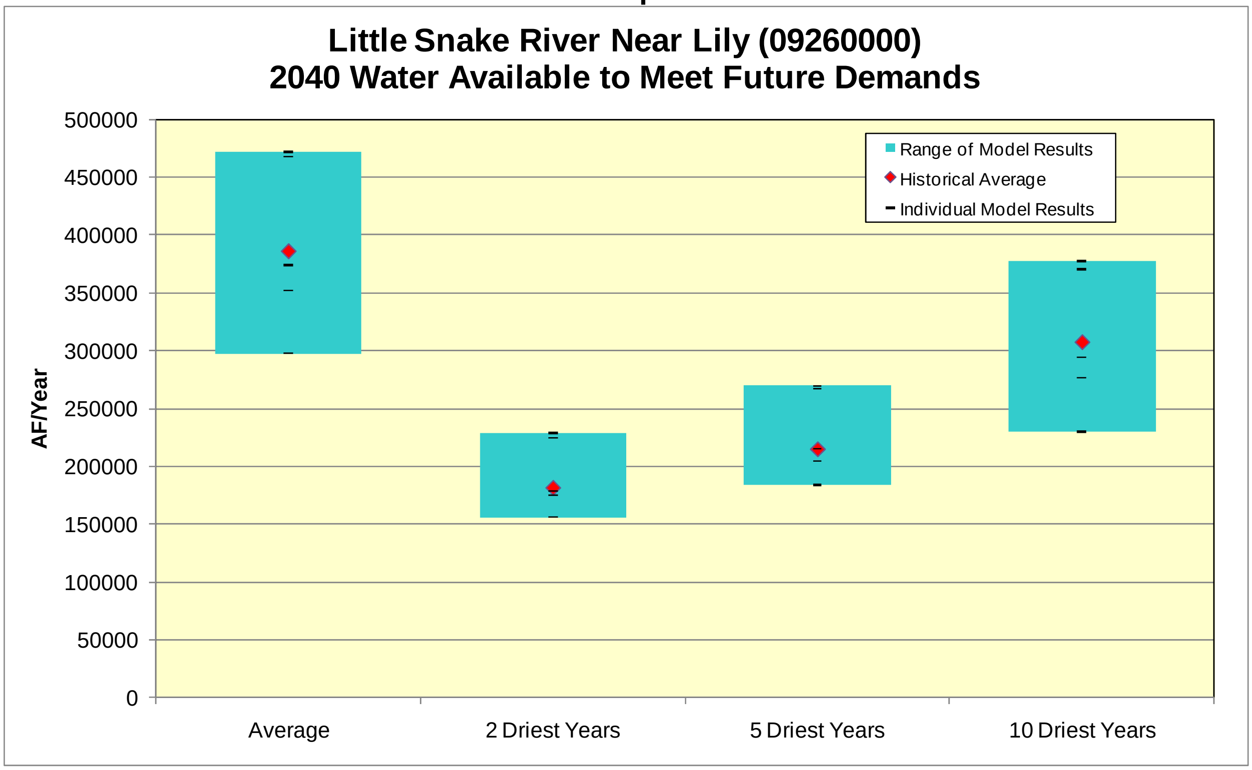


Figure F124 –2040 Yampa River at Deerlodge Park Water Available to Meet Future Demands Low-flow Comparison

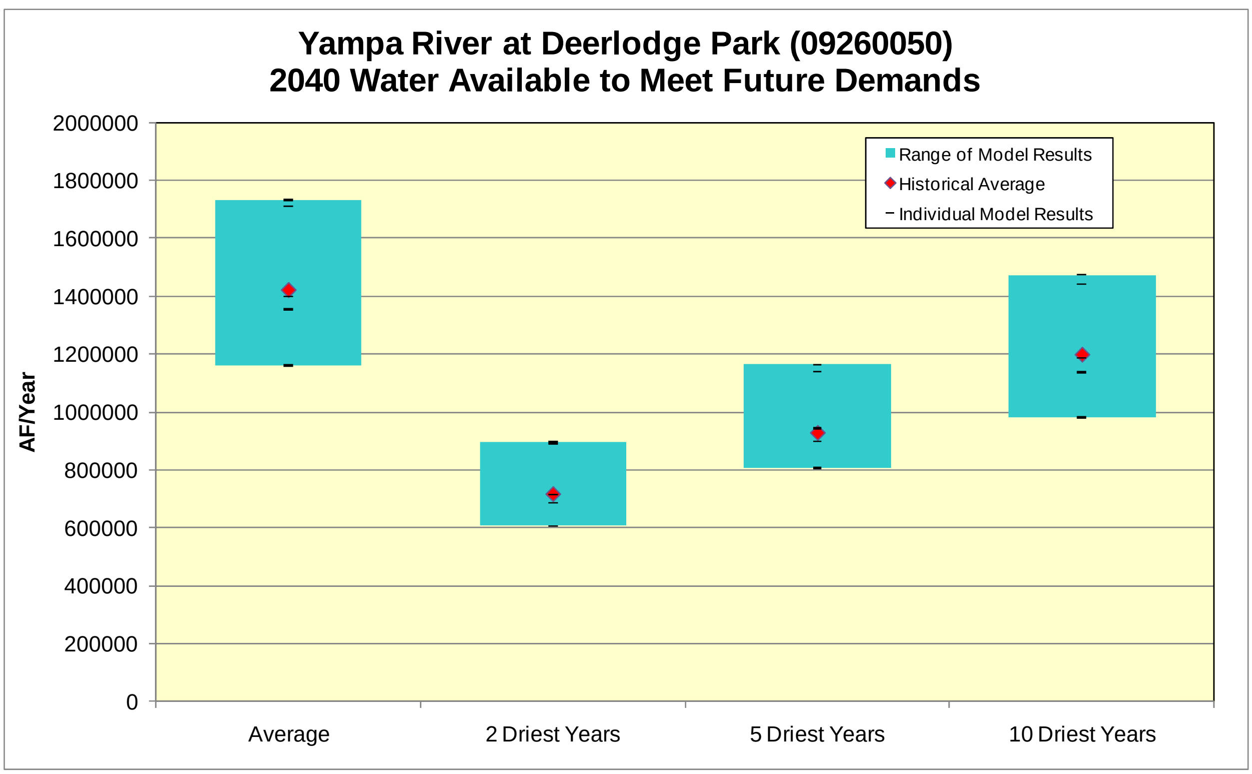


Figure F125 –2040 North Fork White River at Buford Water Available to Meet Future Demands Low-flow Comparison

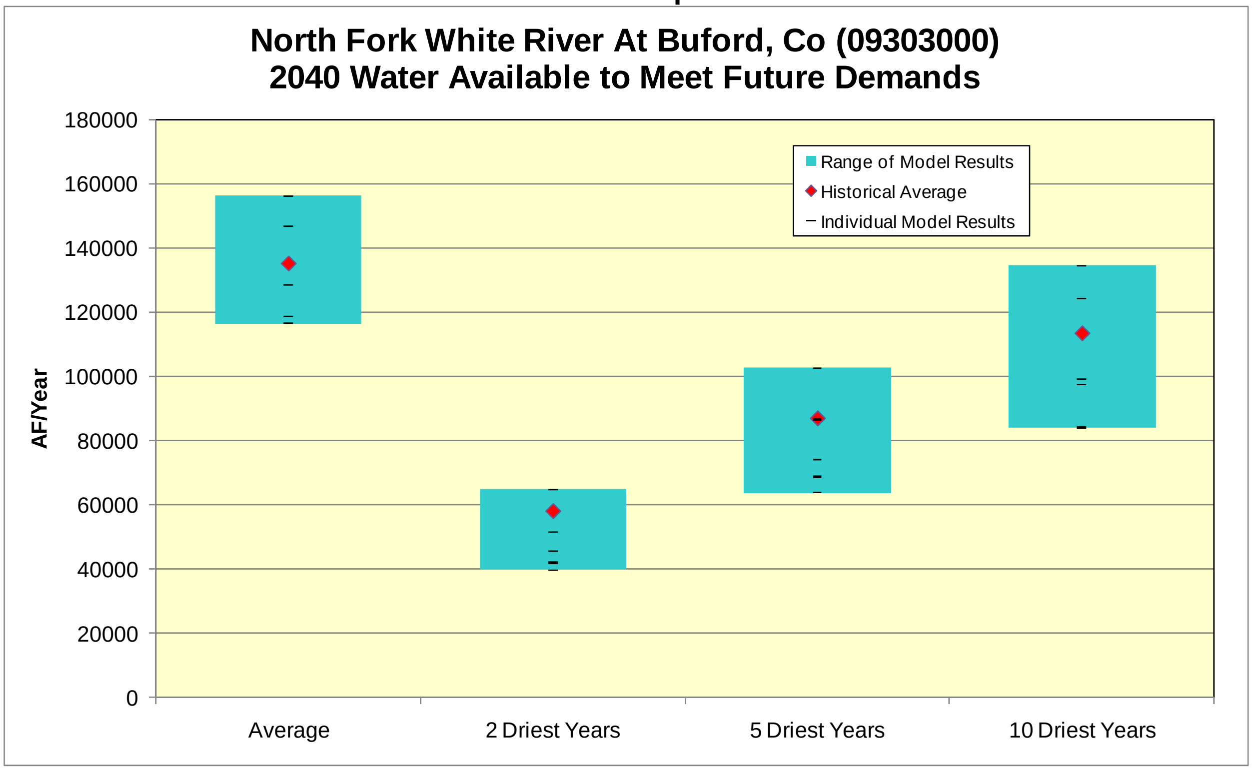


Figure F126 –2040 South Fork White River at Buford Water Available to Meet Future Demands Low-flow Comparison

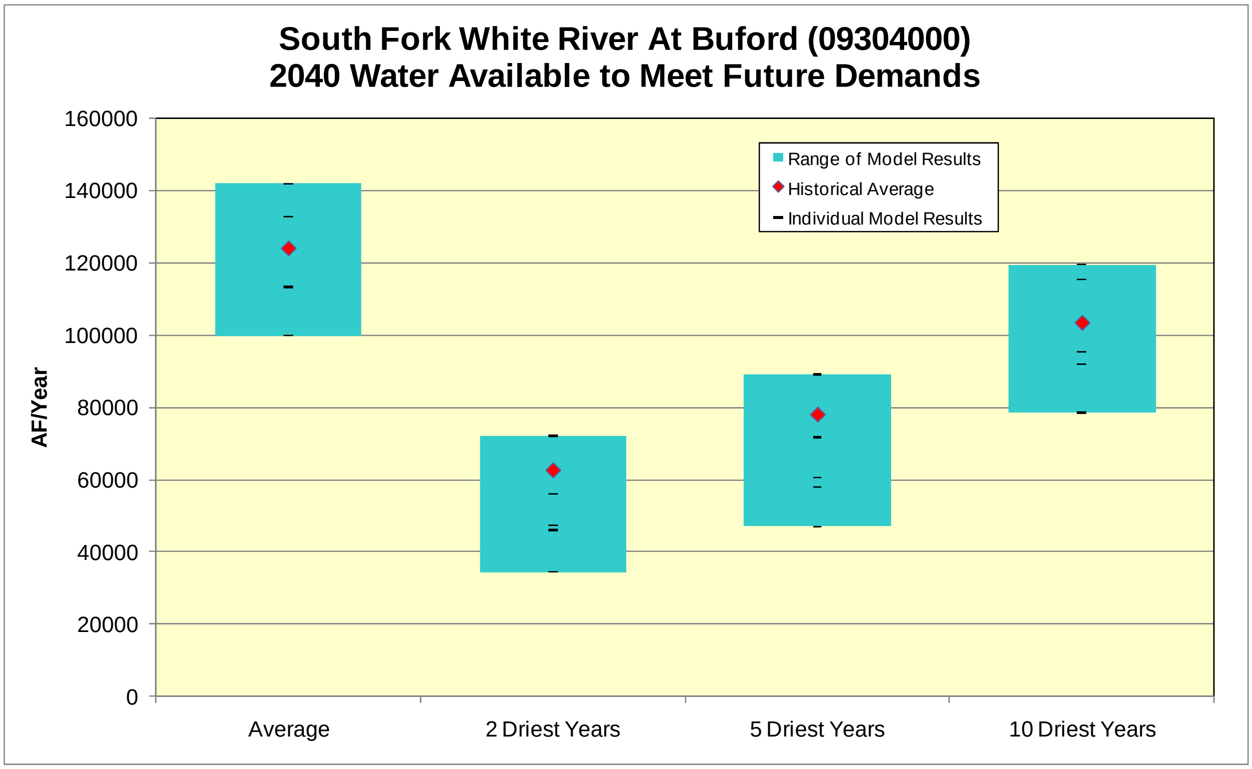


Figure F127 –2040 White River below Meeker Water Available to Meet Future Demands Low-flow Comparison

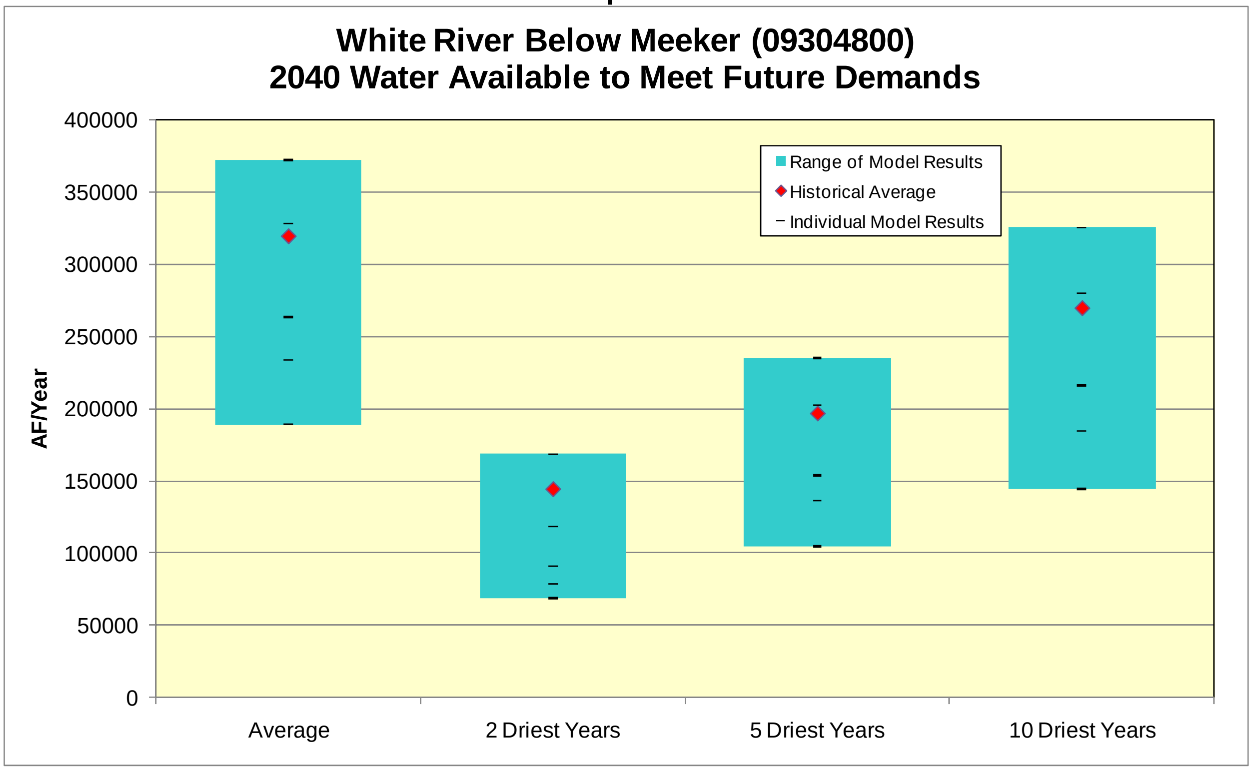


Figure F128 –2040 Piceance Creek at White River Water Available to Meet Future Demands Low-flow Comparison

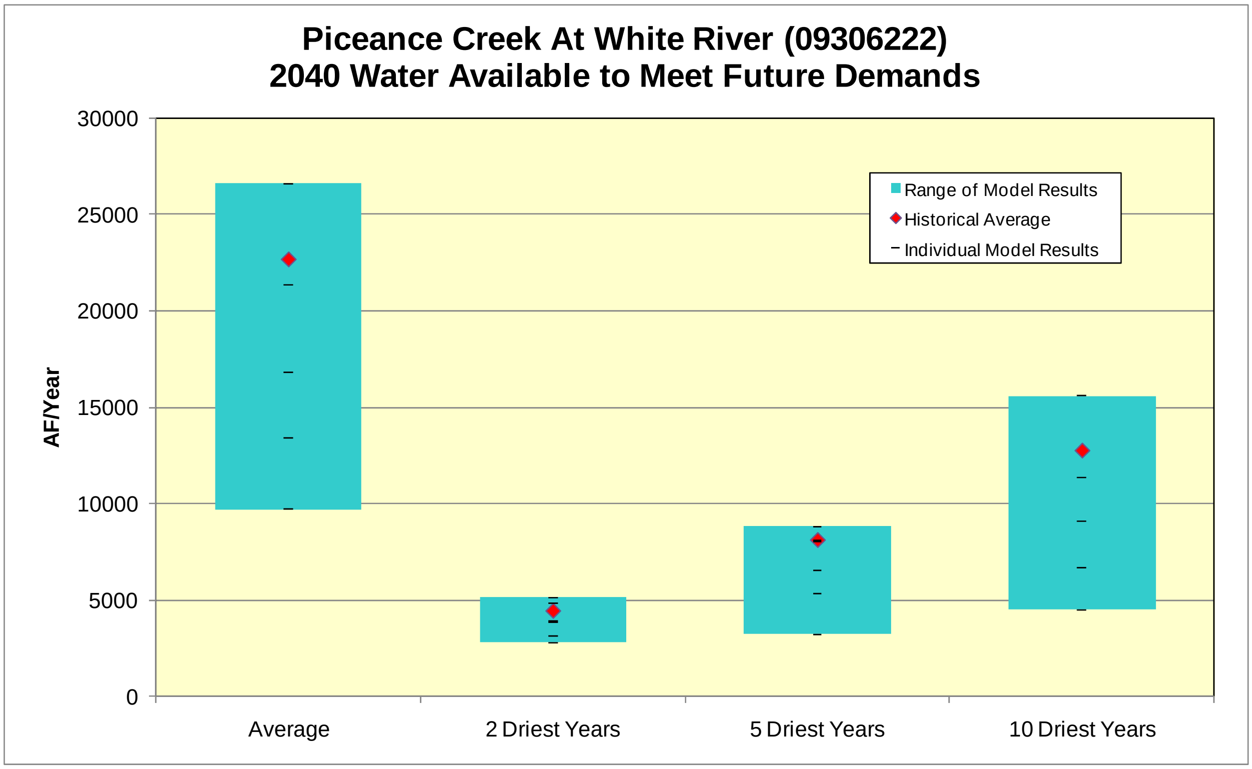


Figure F129 –2040 White River near CO-UT State Line Water Available to Meet Future Demands Low-flow Comparison

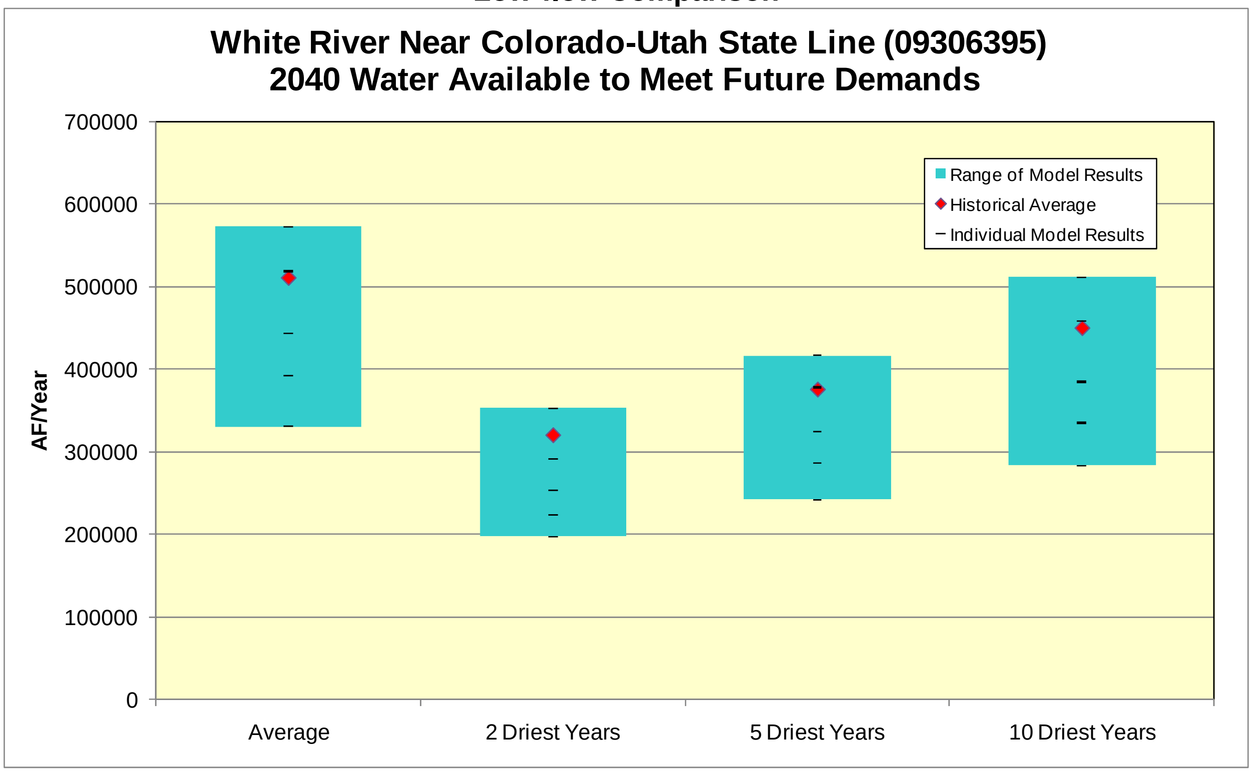


Figure F130 –2070 Colorado River near Grand Lake Water Available to Meet Future Demands Low-flow Comparison

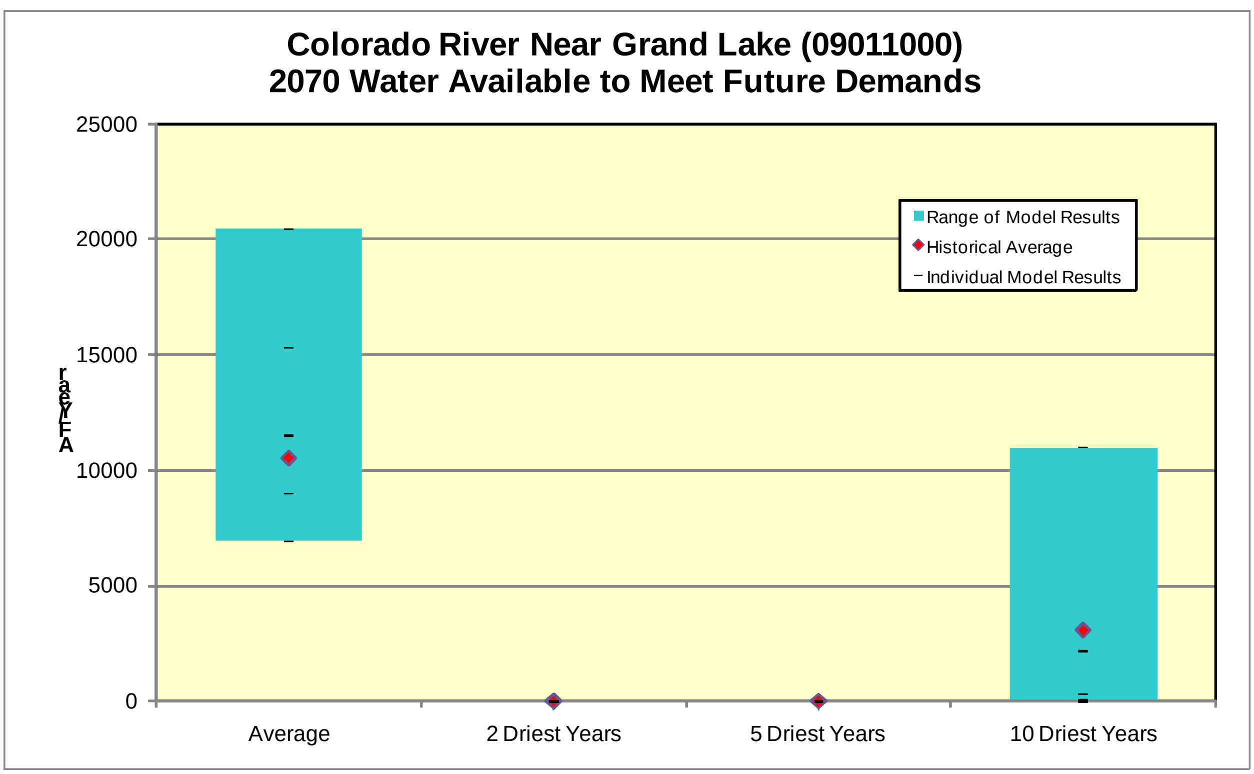


Figure F131 –2070 Muddy Creek at Kremmling Water Available to Meet Future Demands Low-flow Comparison

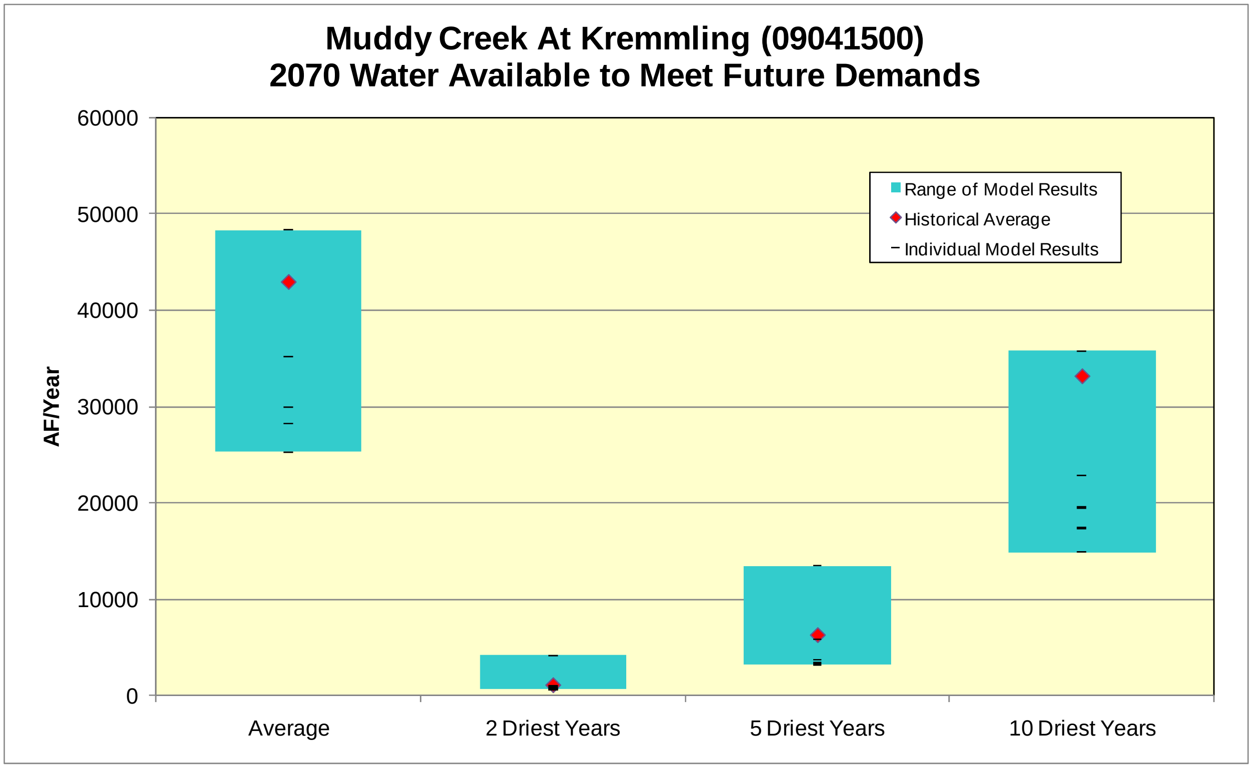


Figure F132 –2070 Blue River below Dillon Water Available to Meet Future Demands Low-flow Comparison

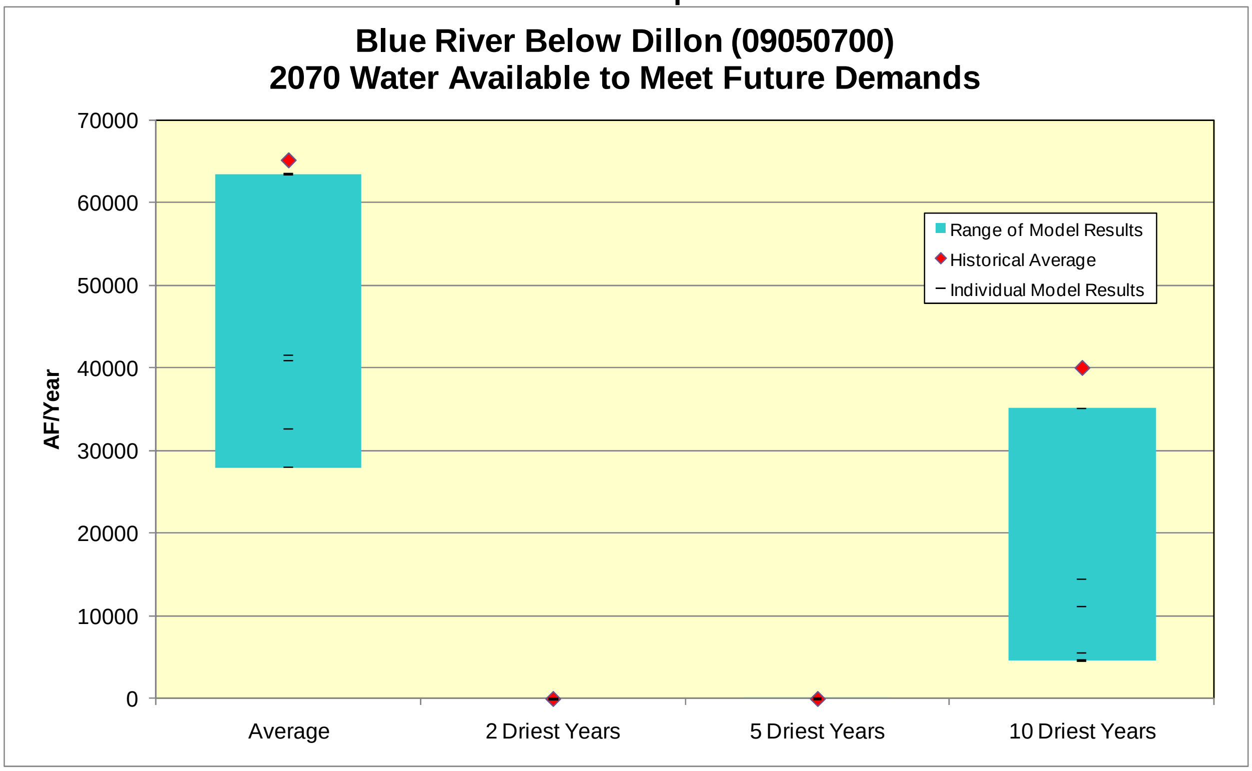


Figure F133 –2070 Blue River below Green Mountain Reservoir Water Available to Meet Future Demands Low-flow Comparison

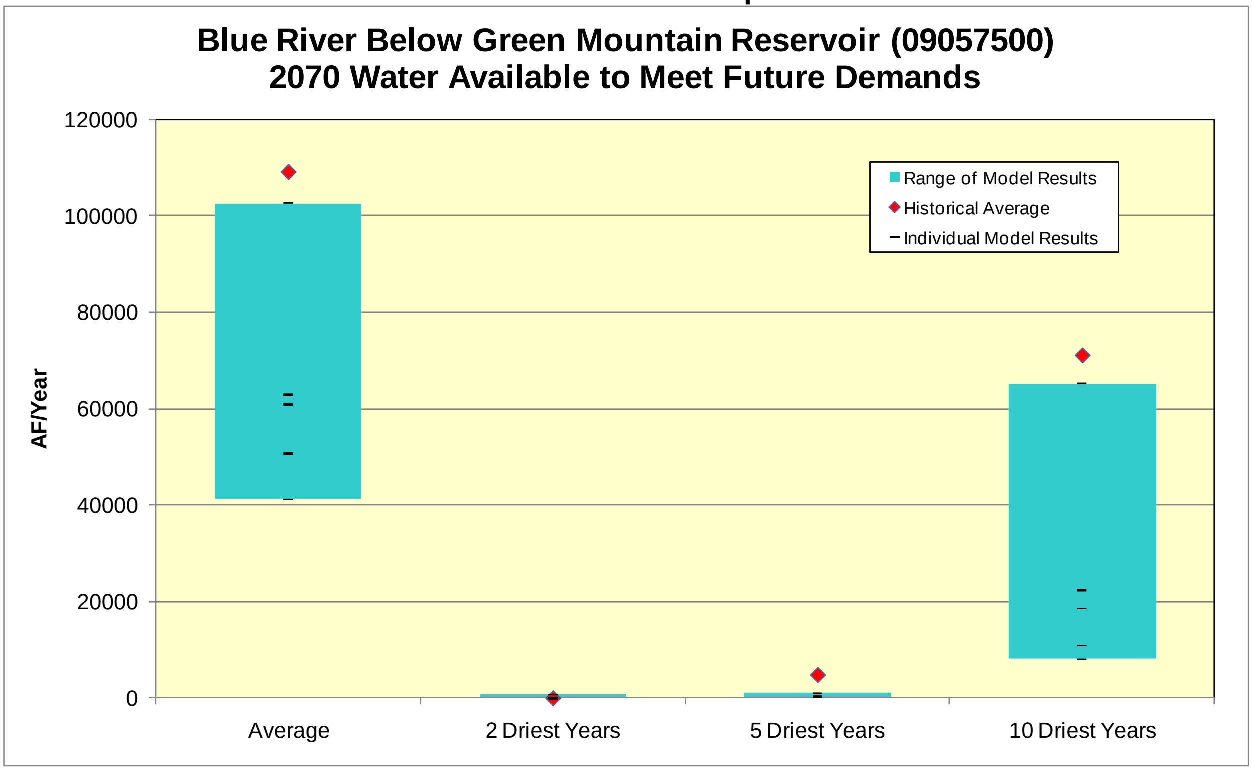


Figure F134 –2070 Eagle River below Gypsum Water Available to Meet Future Demands Low-flow Comparison

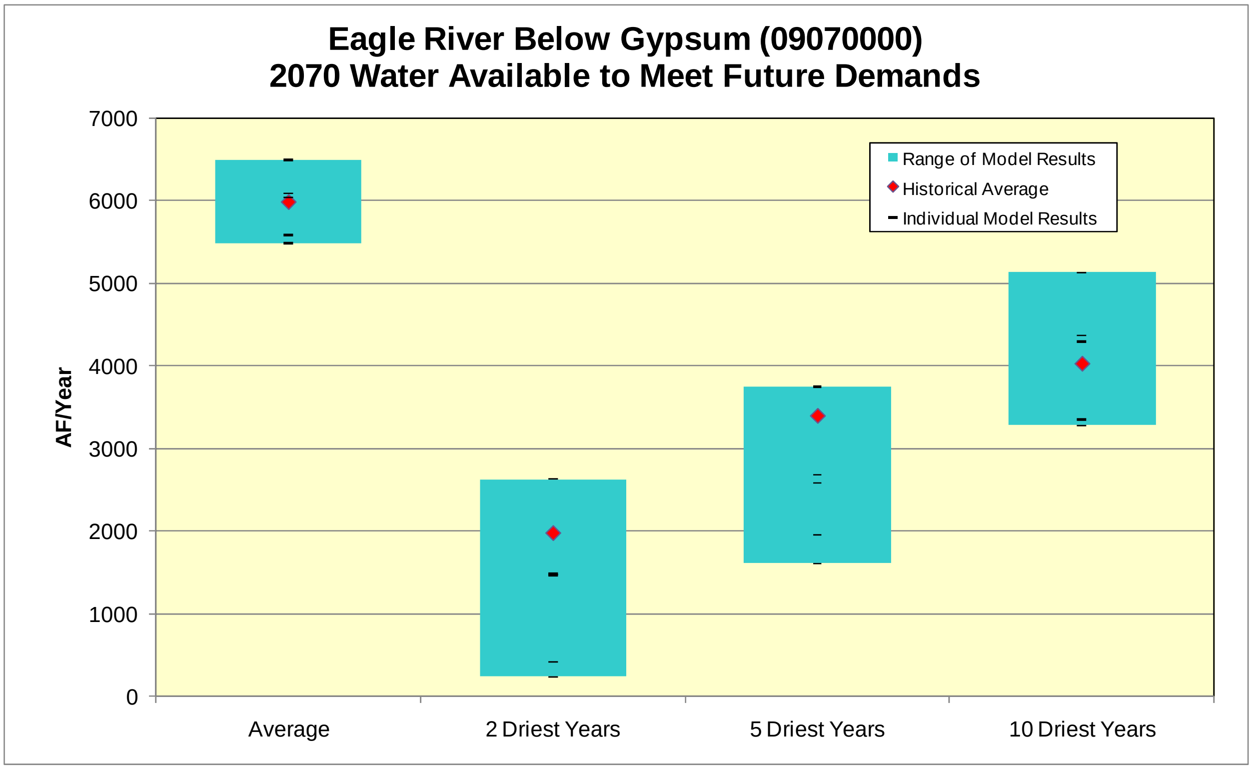


Figure F135 –2070 Colorado River at Dotsero Water Available to Meet Future Demands Low-flow Comparison

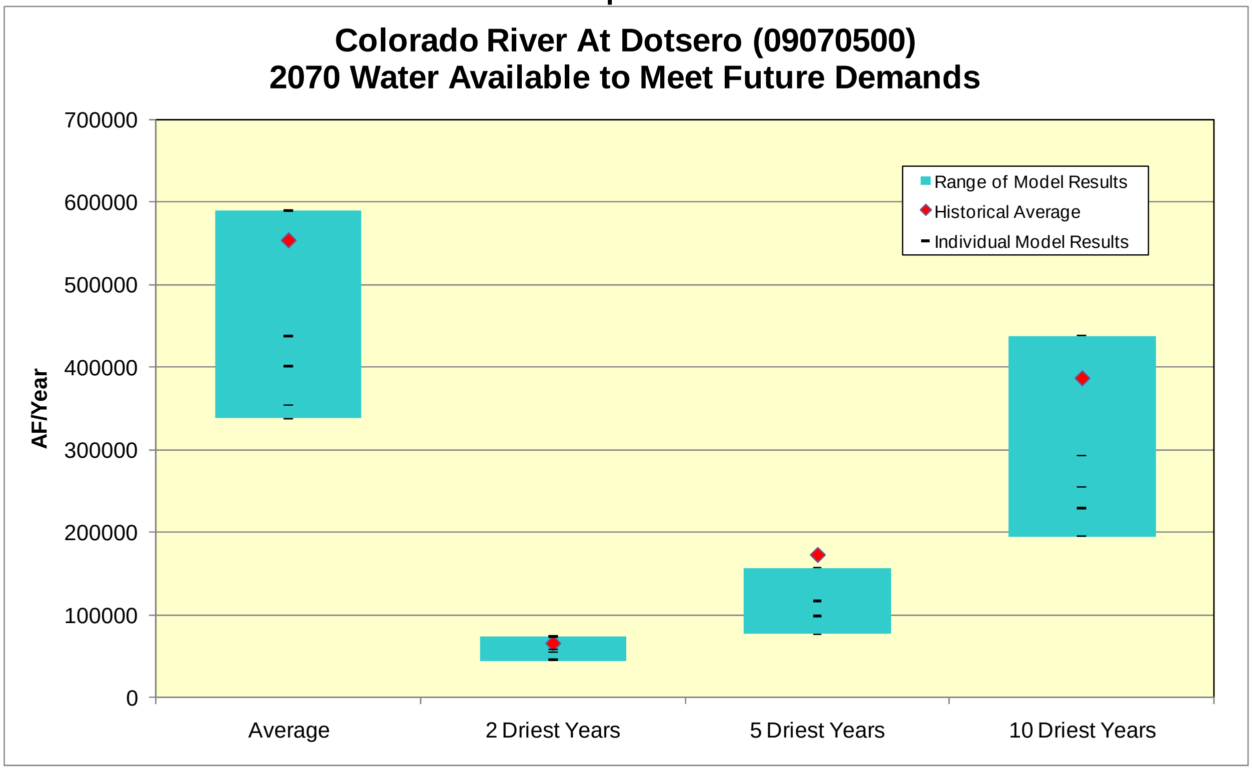
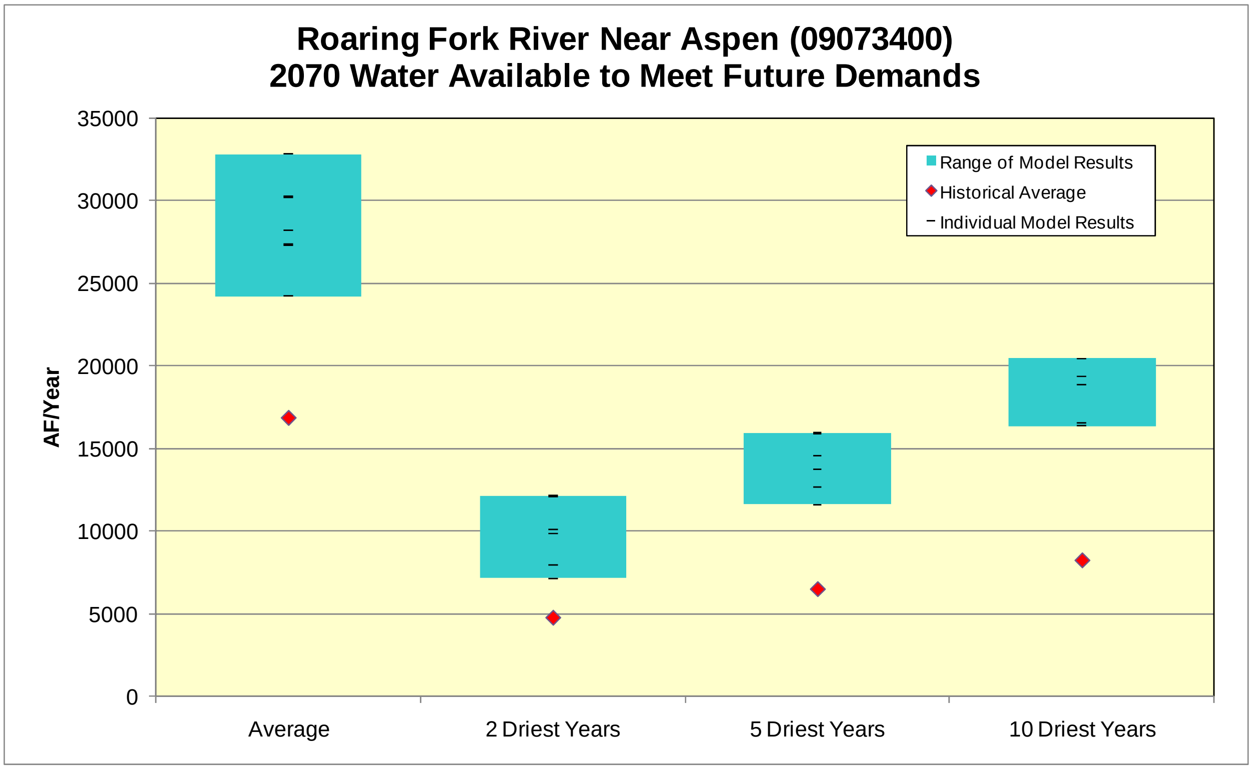


Figure F136 –2070 Roaring Fork River near Aspen Water Available to Meet Future Demands Low-flow Comparison



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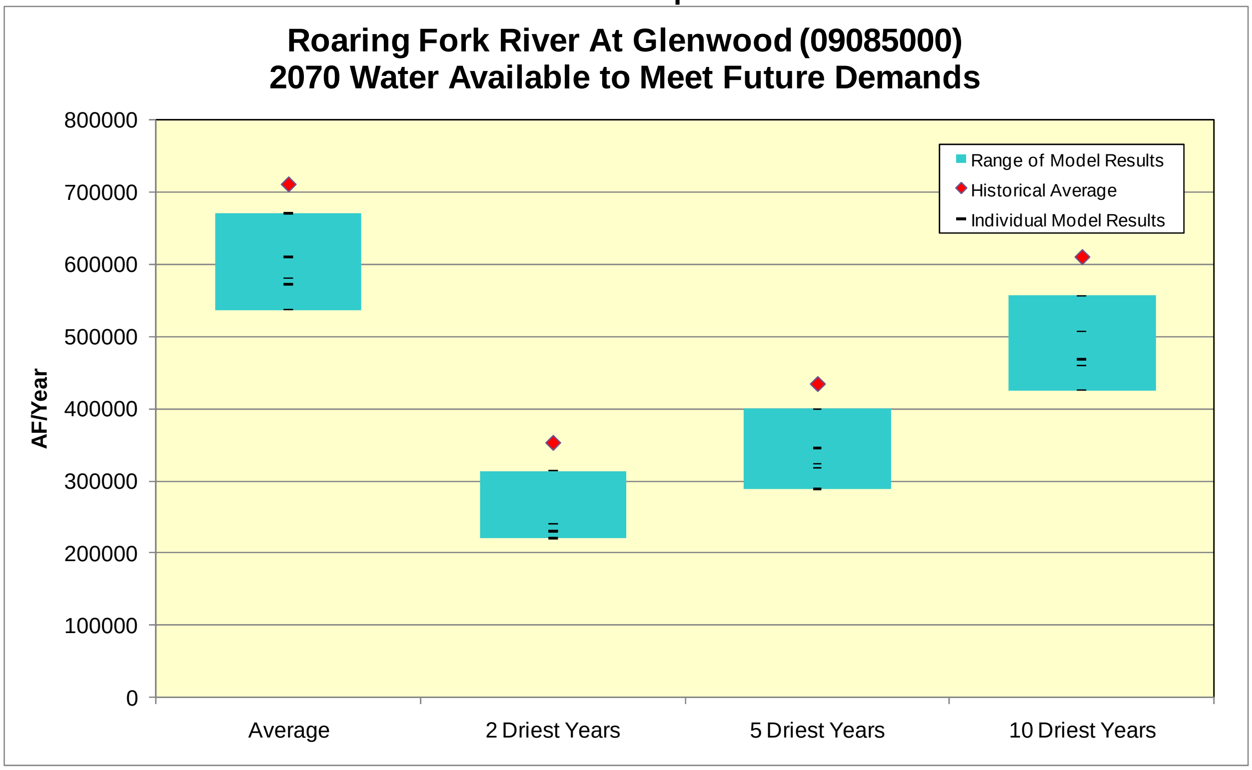

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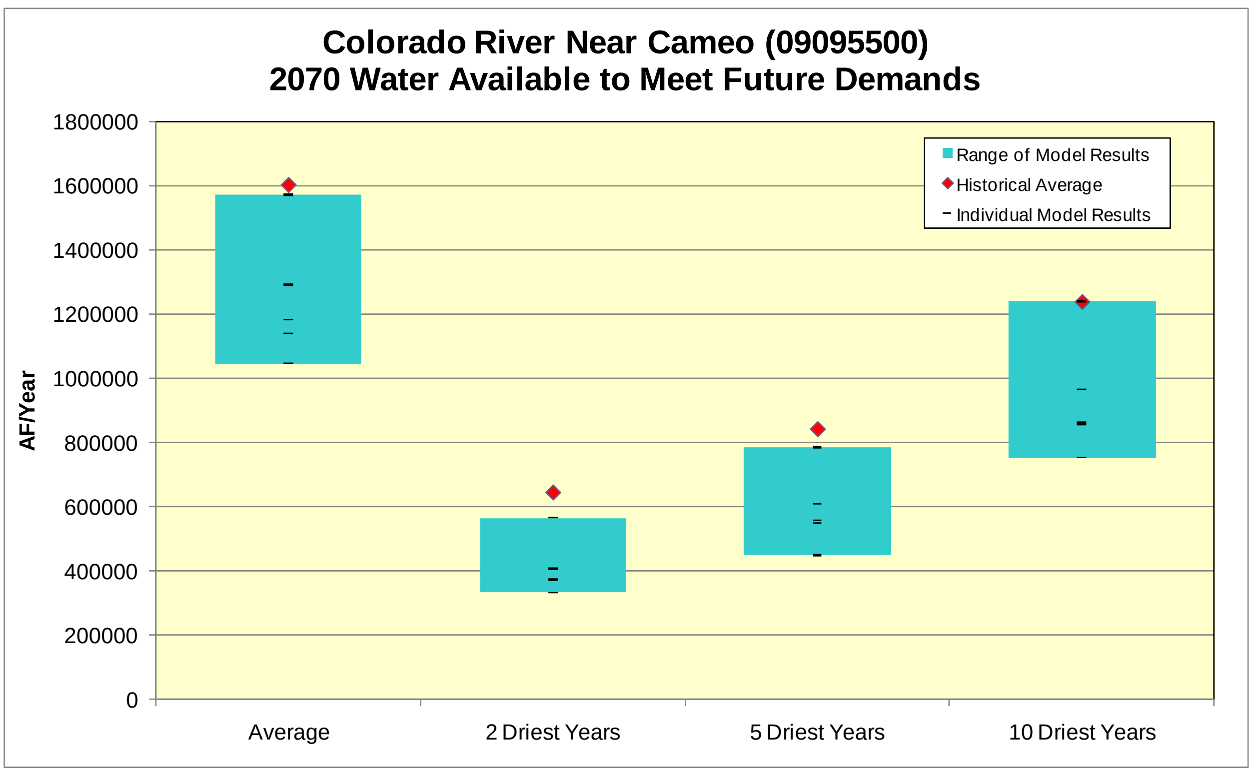

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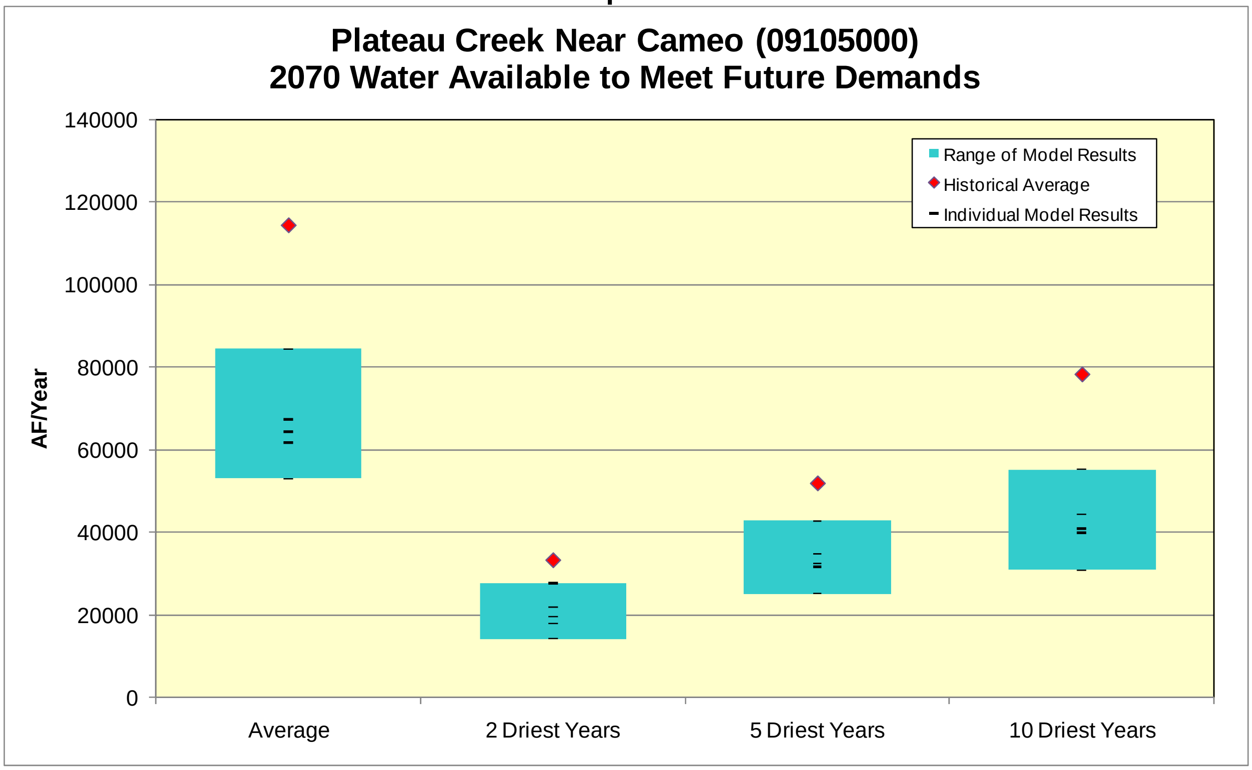

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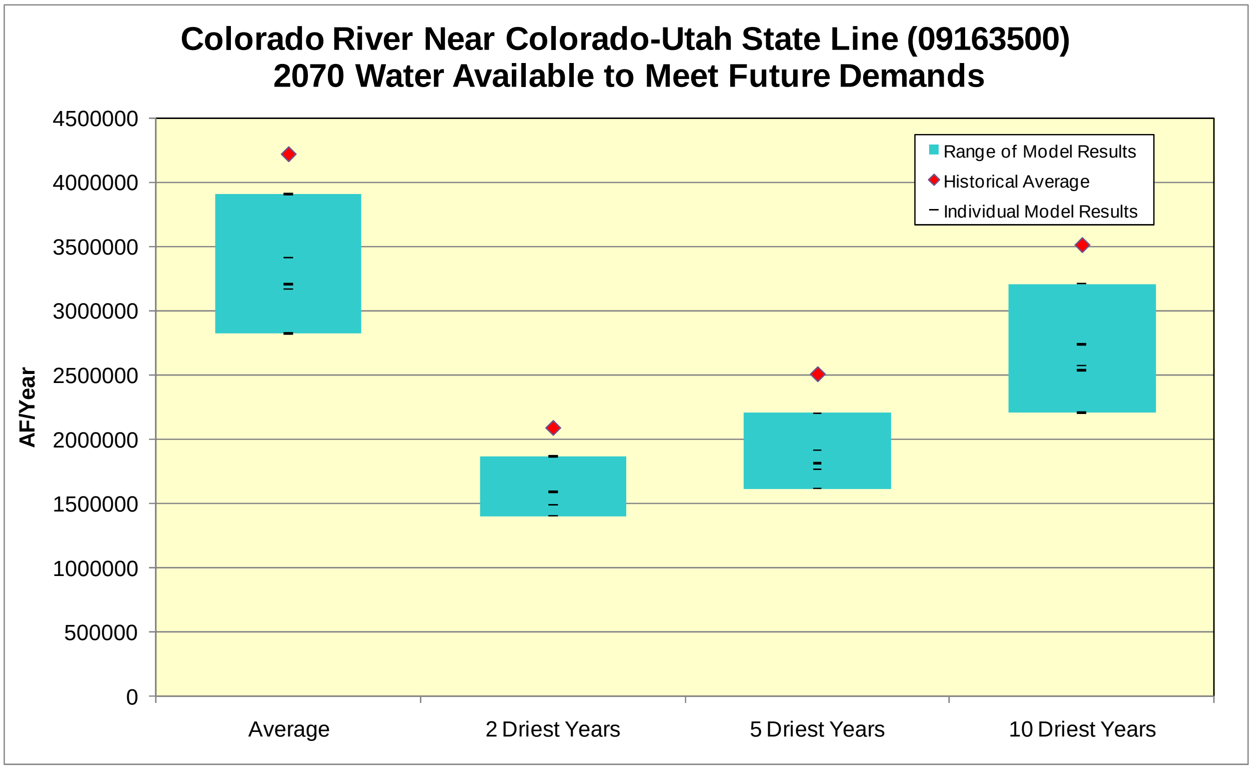

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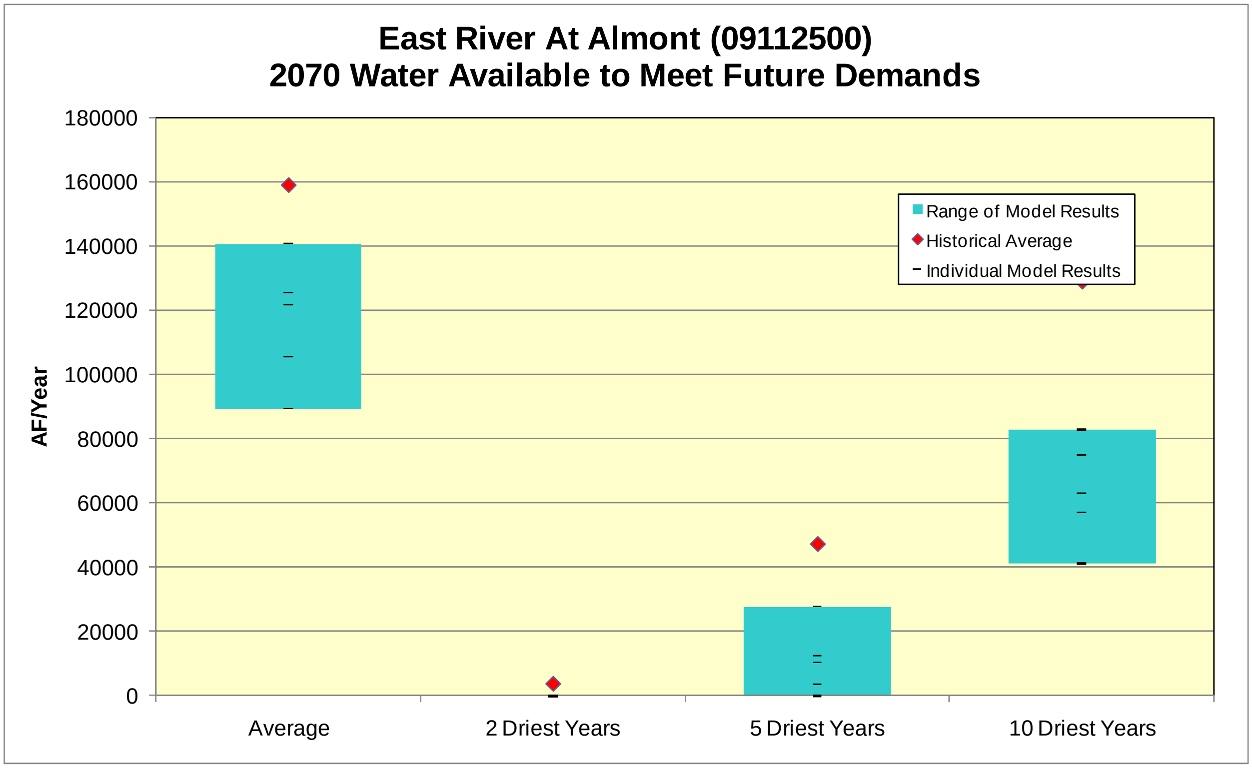

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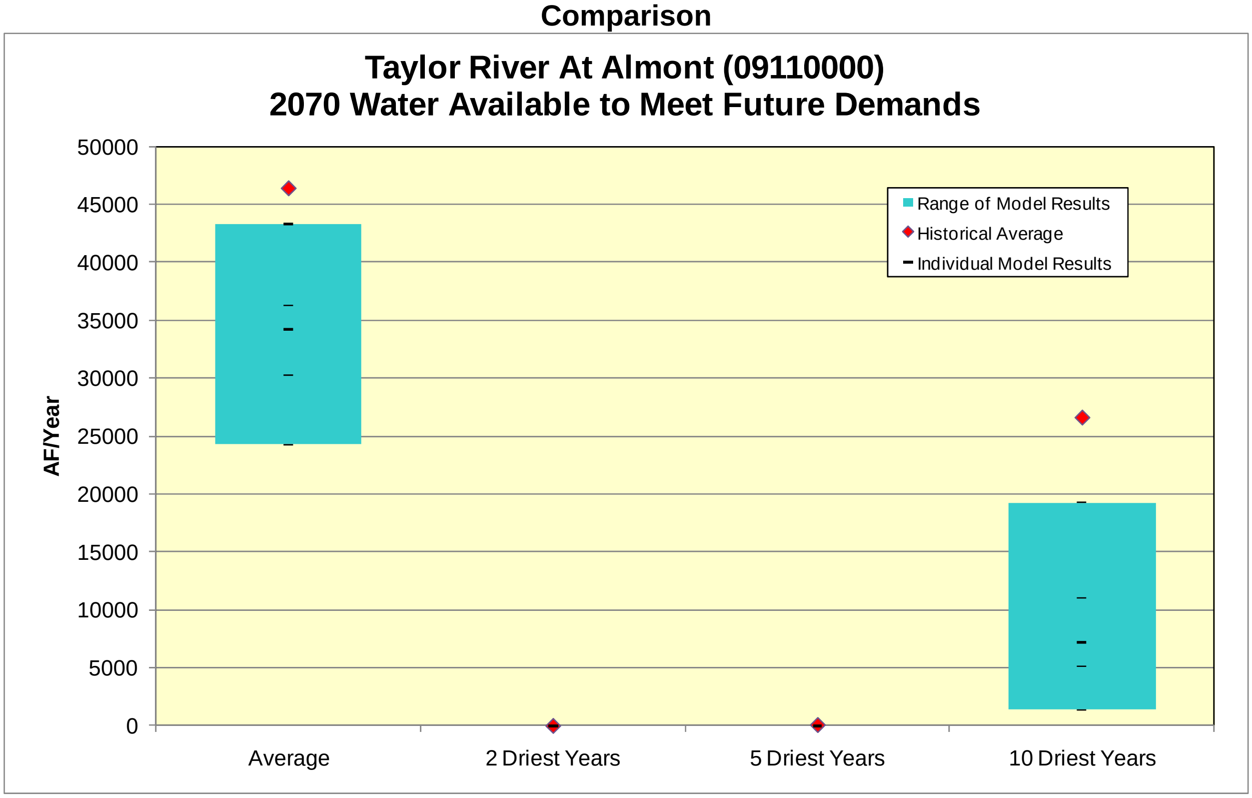

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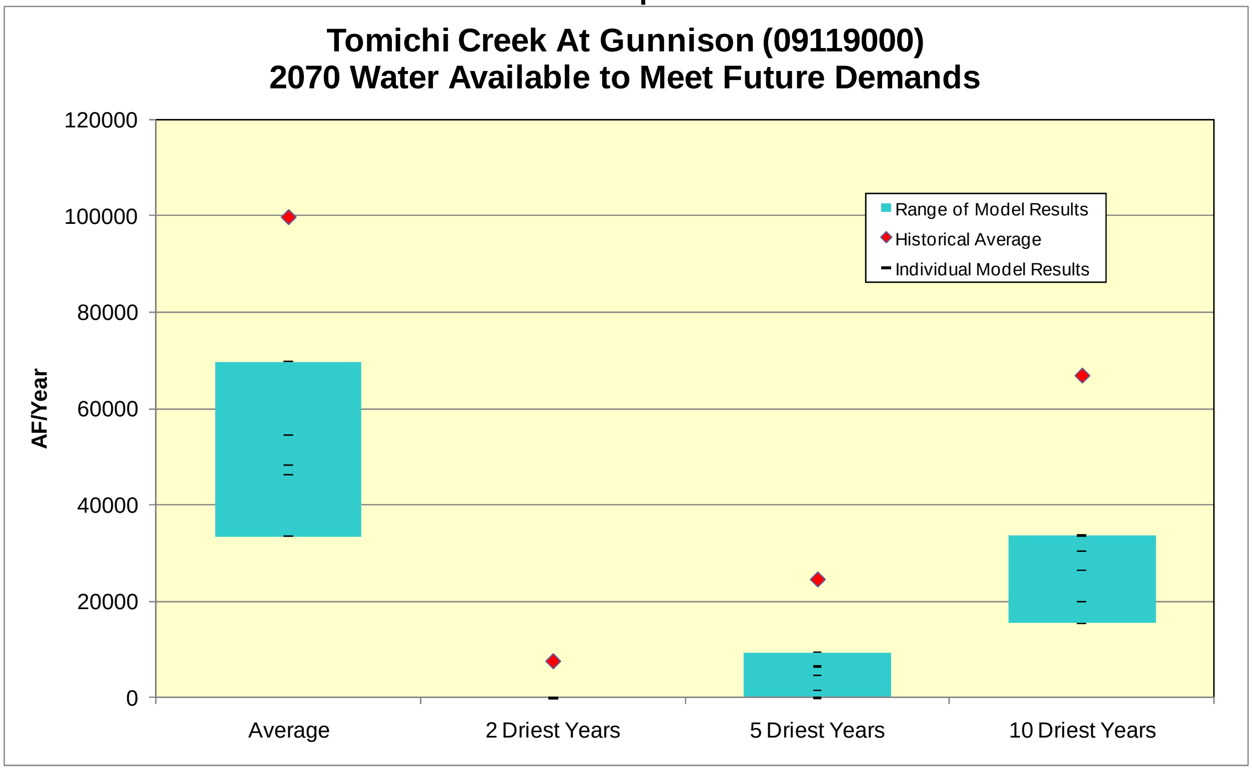

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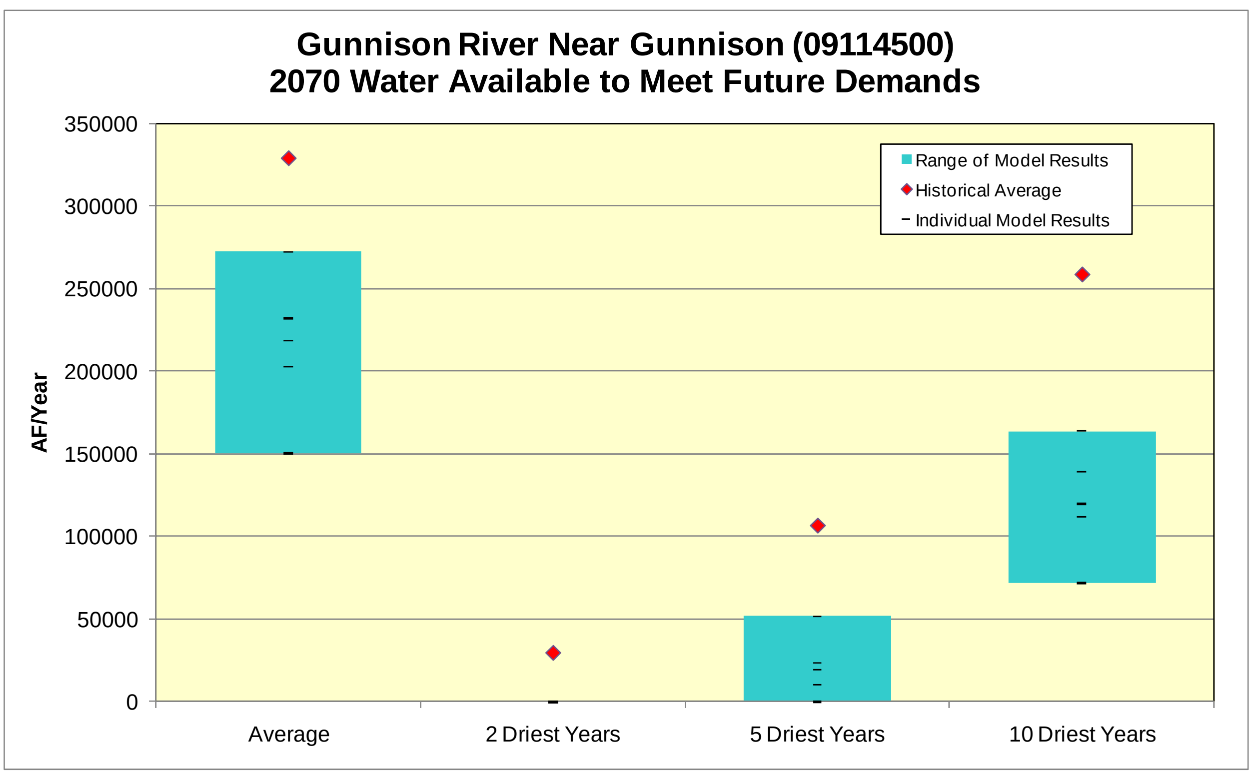

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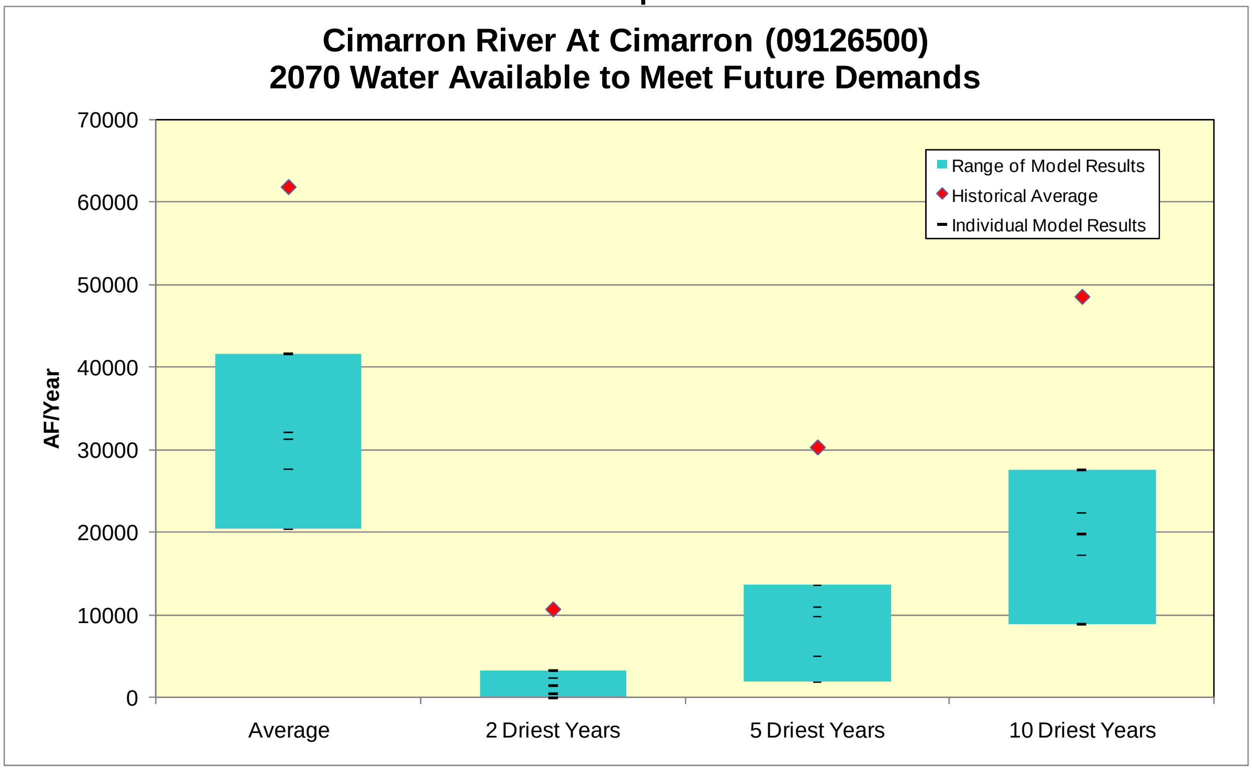

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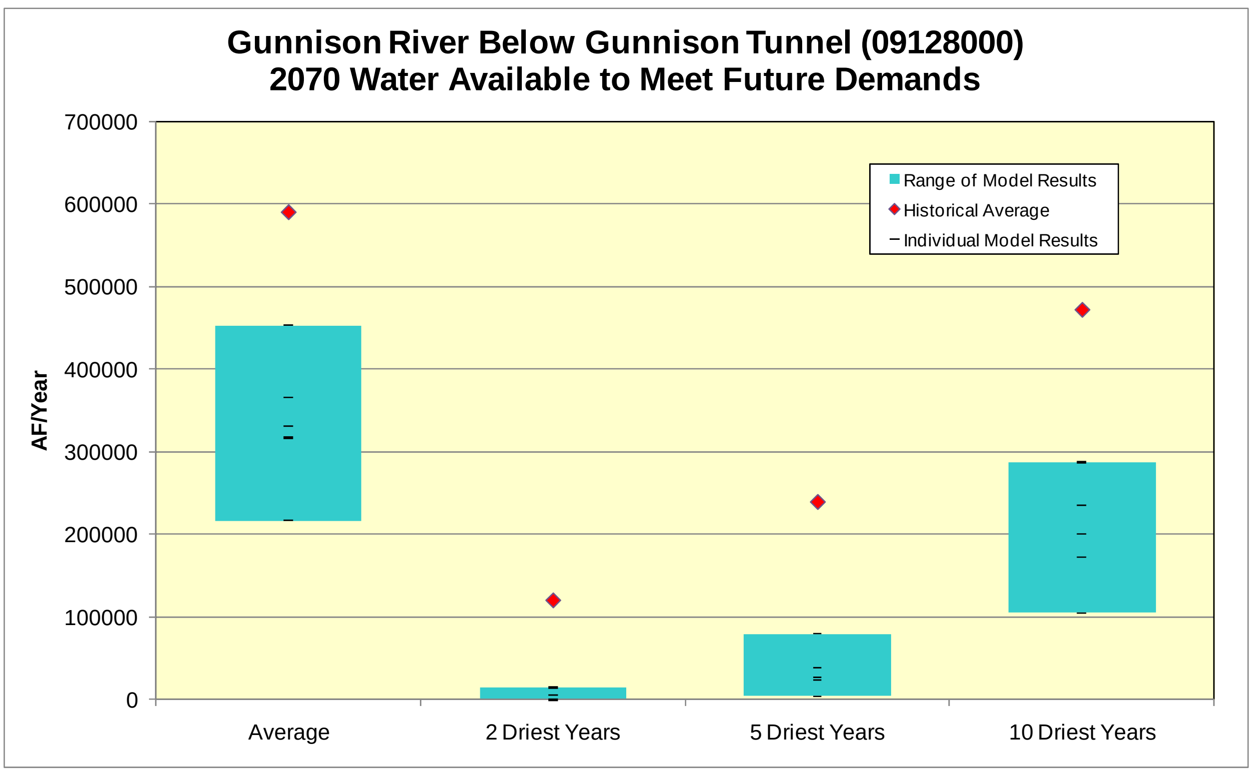

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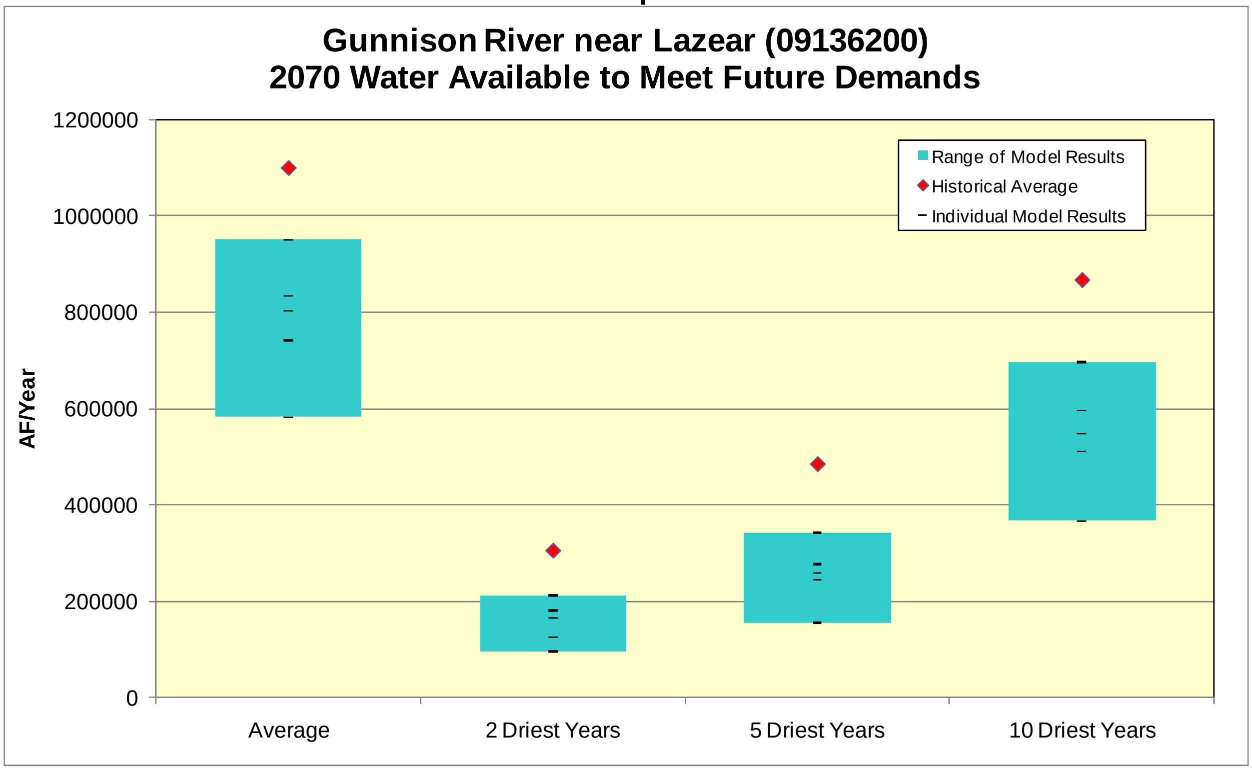

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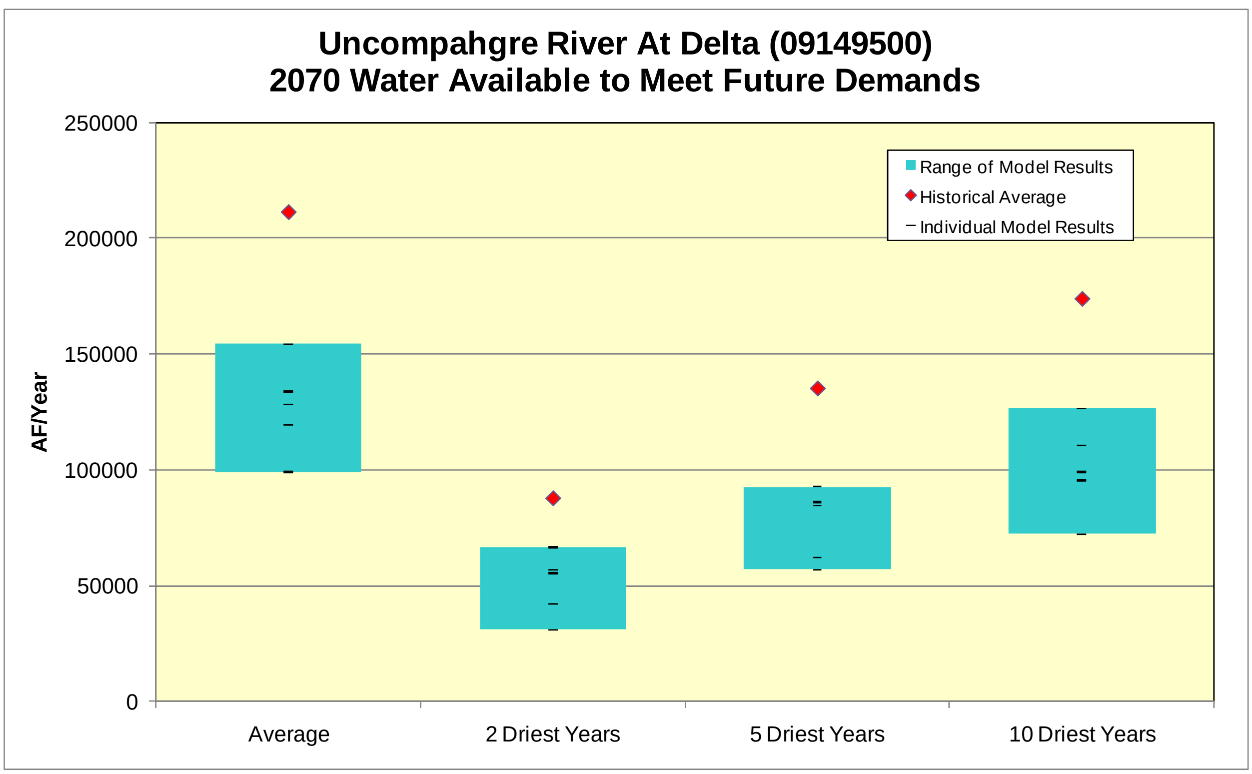

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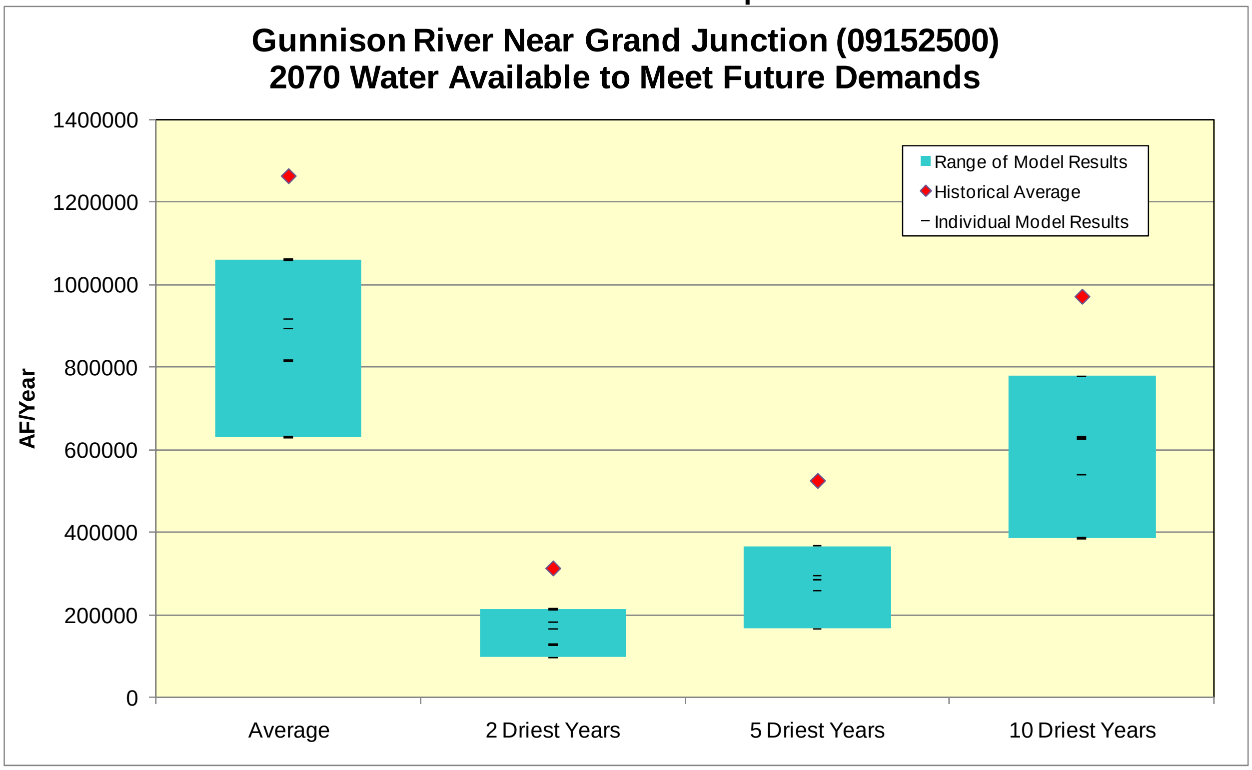

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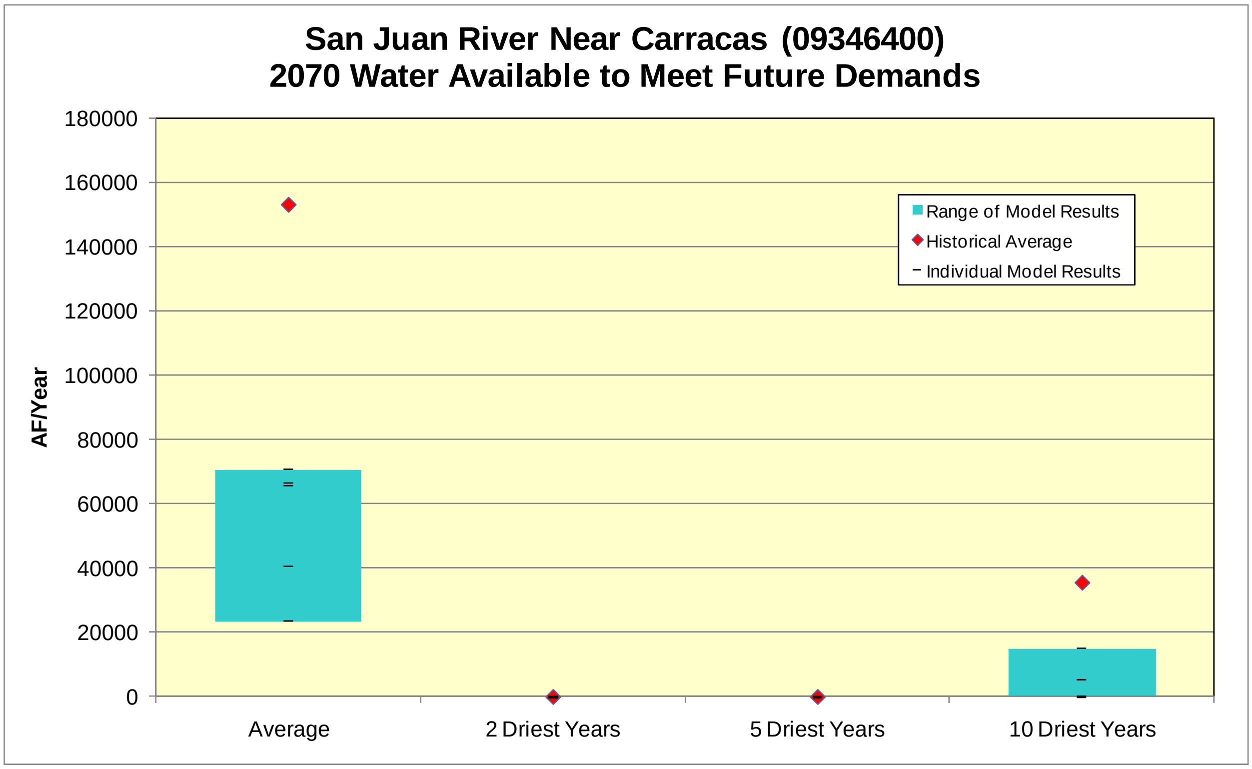

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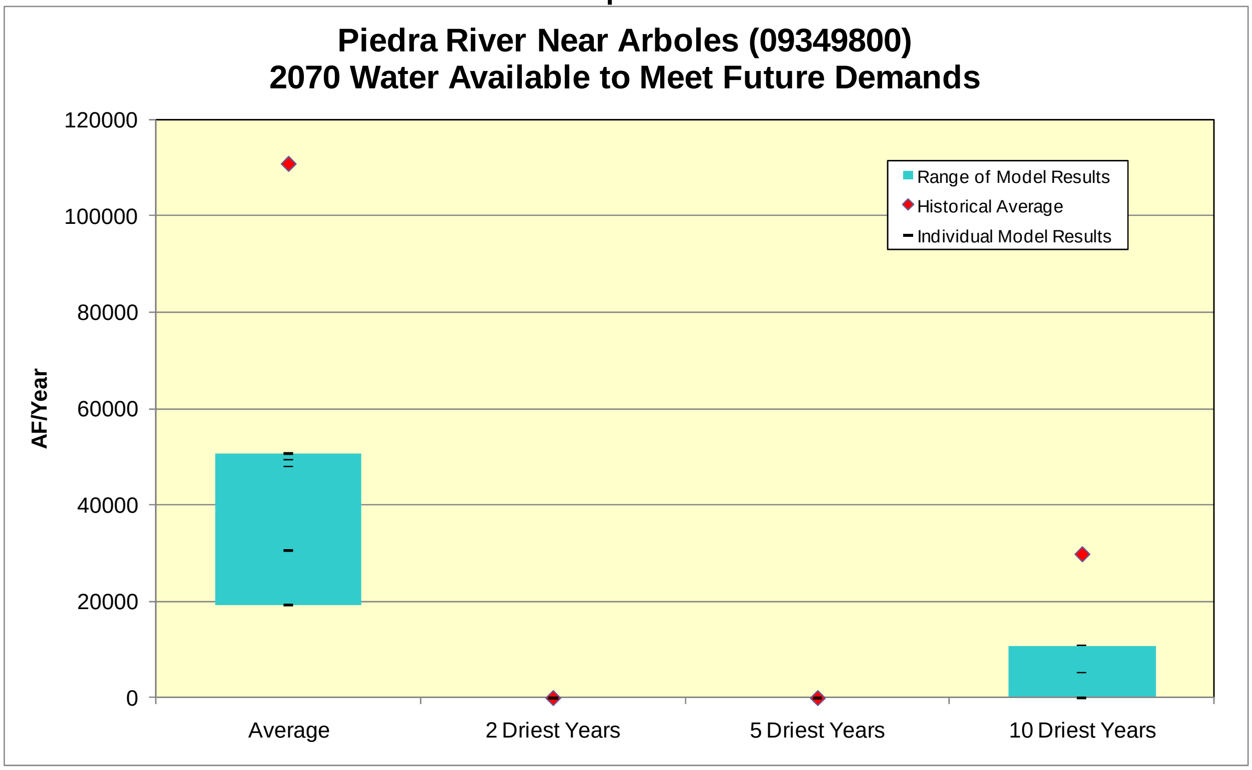

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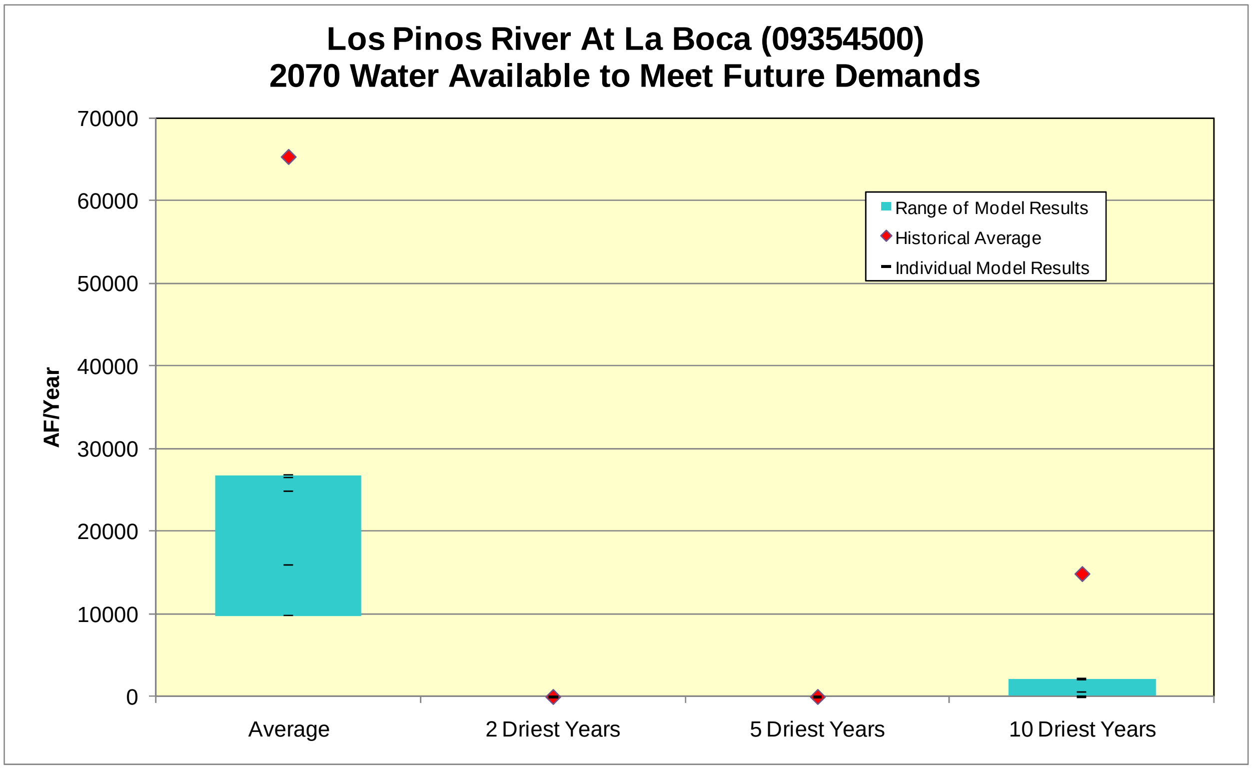

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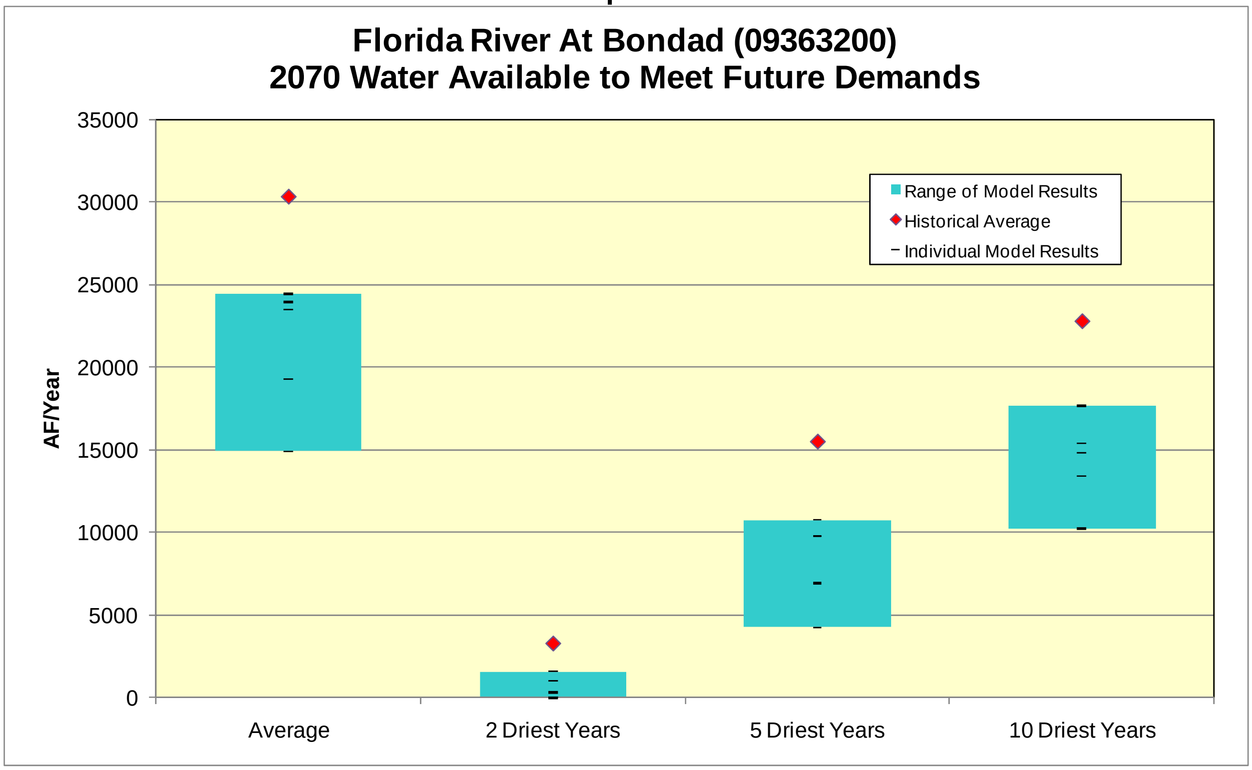

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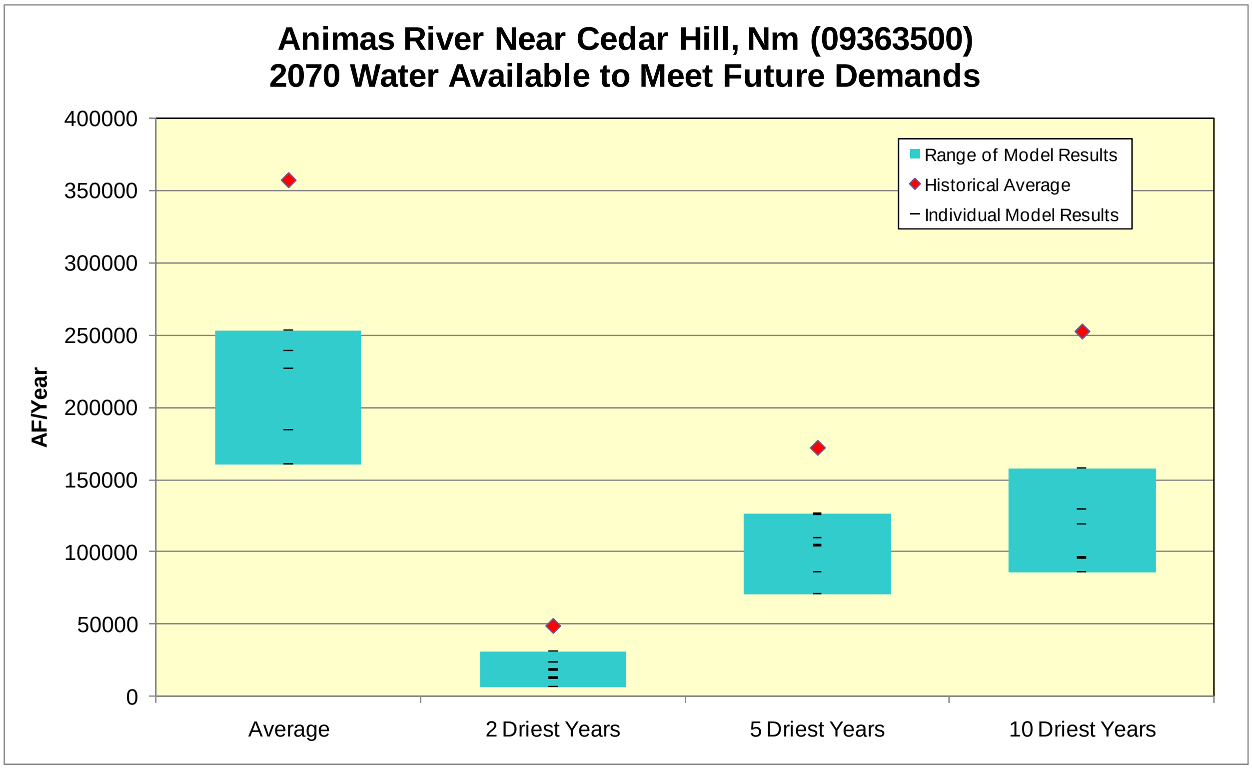

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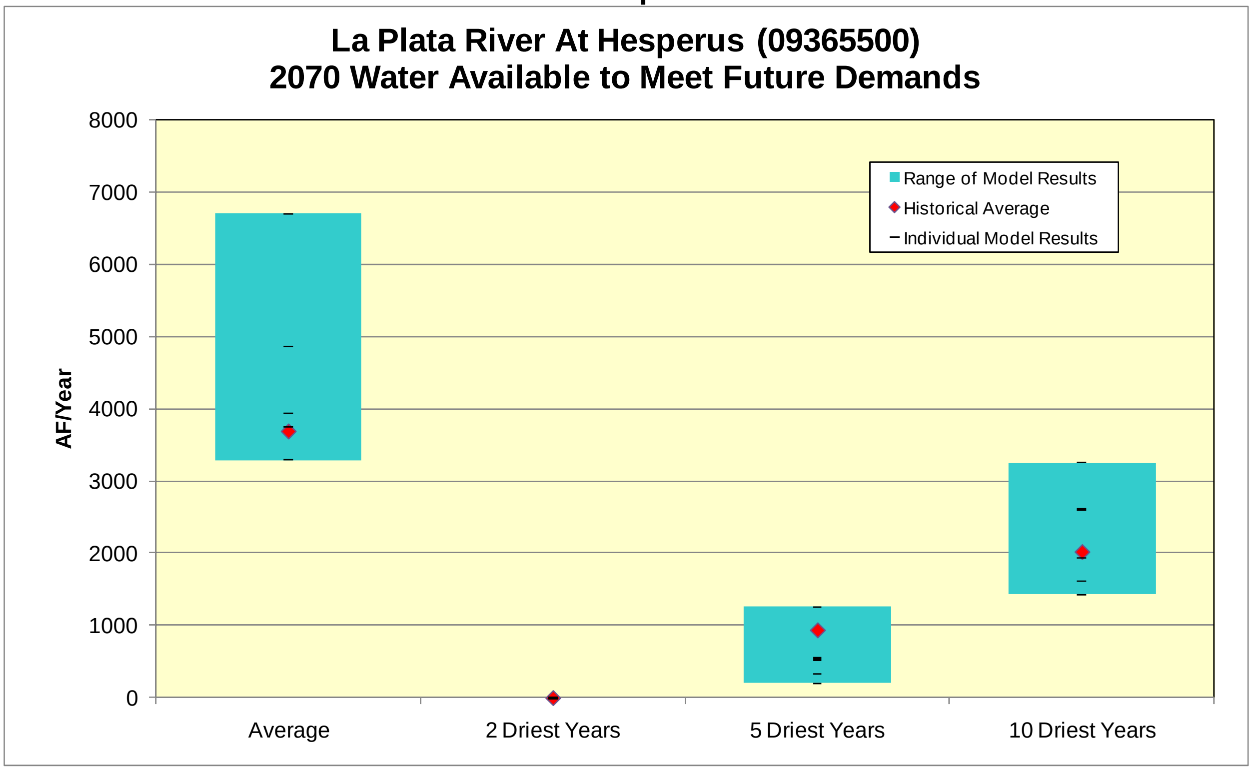

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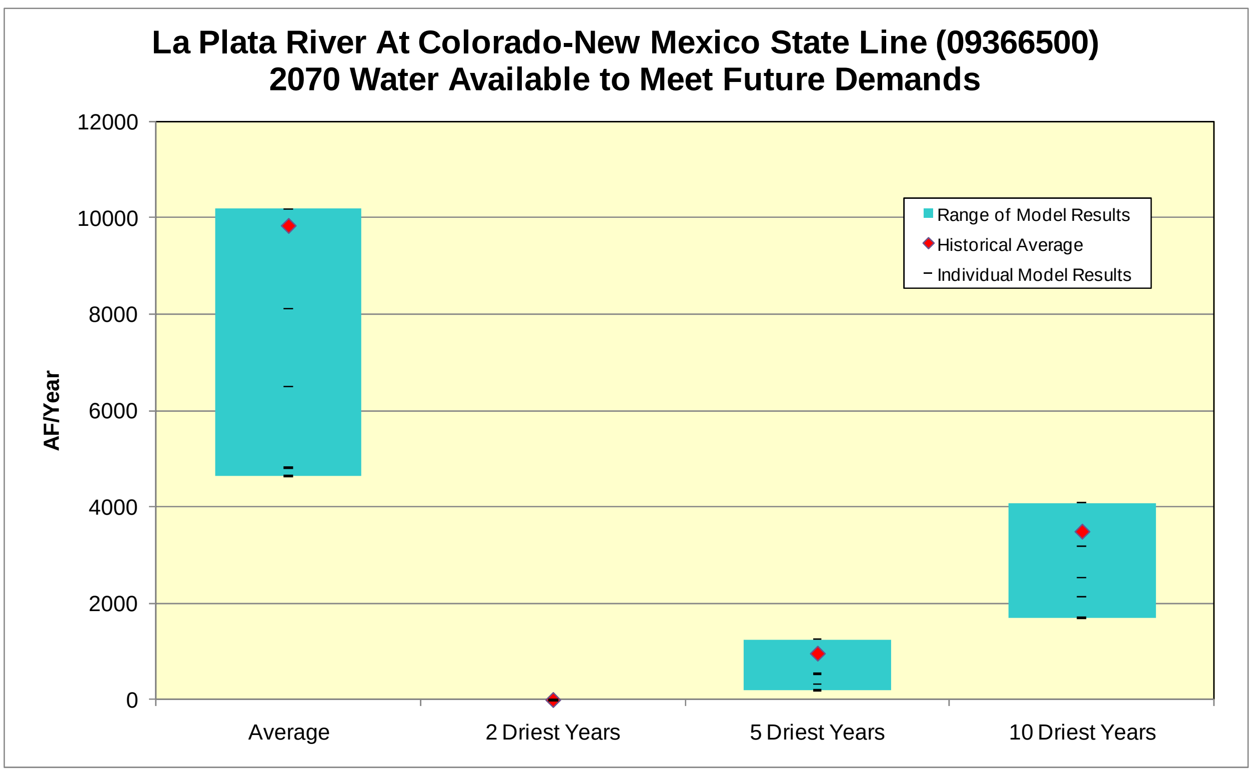

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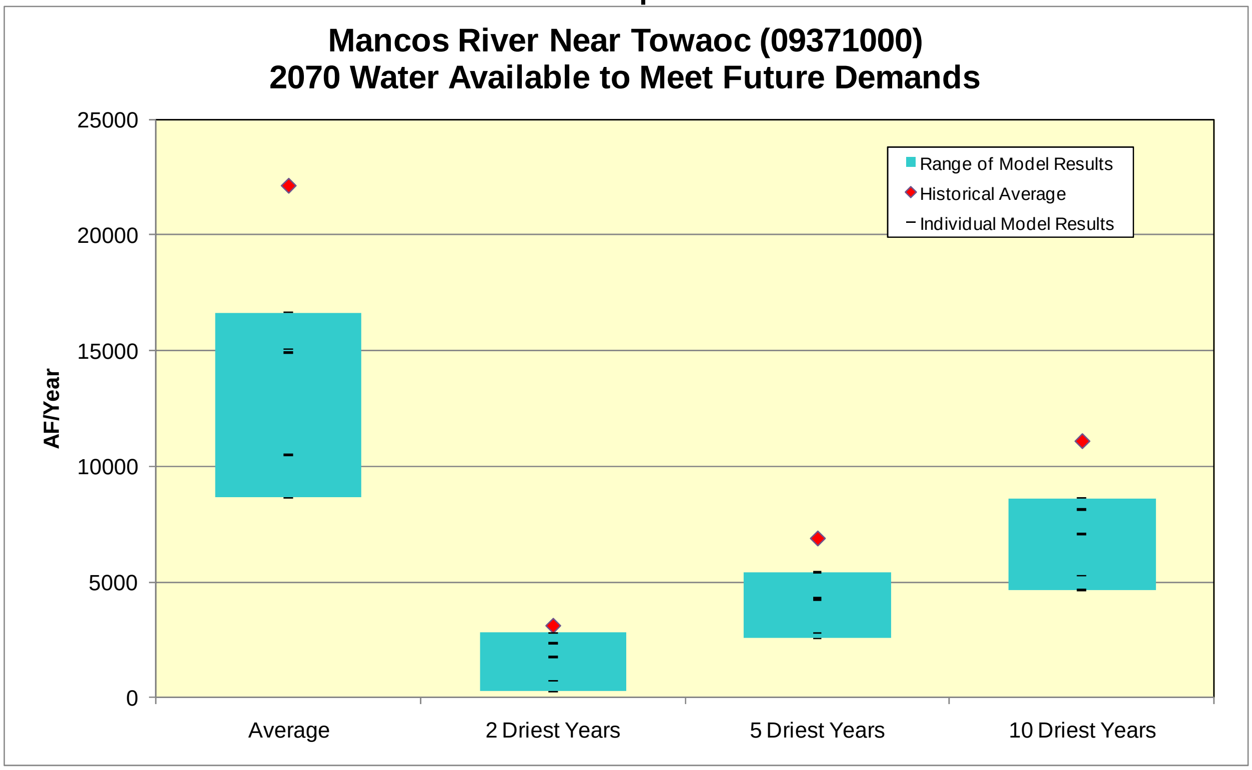

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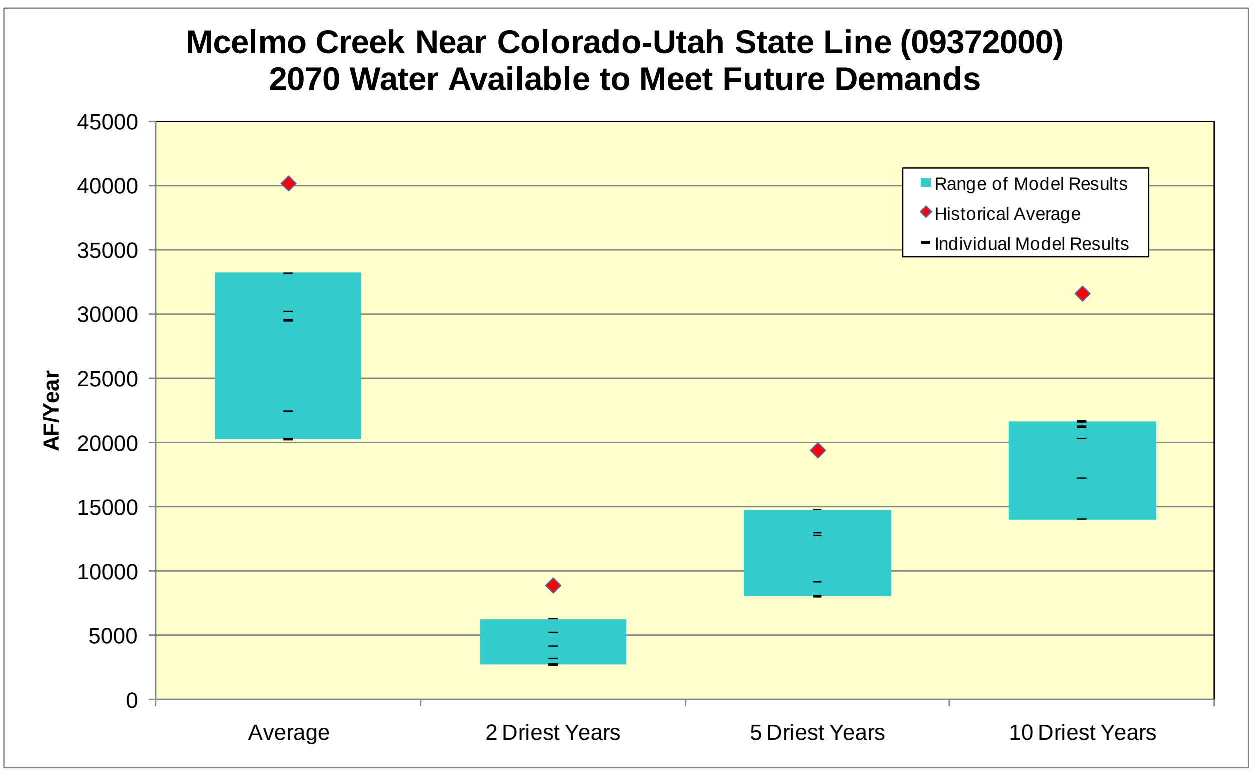

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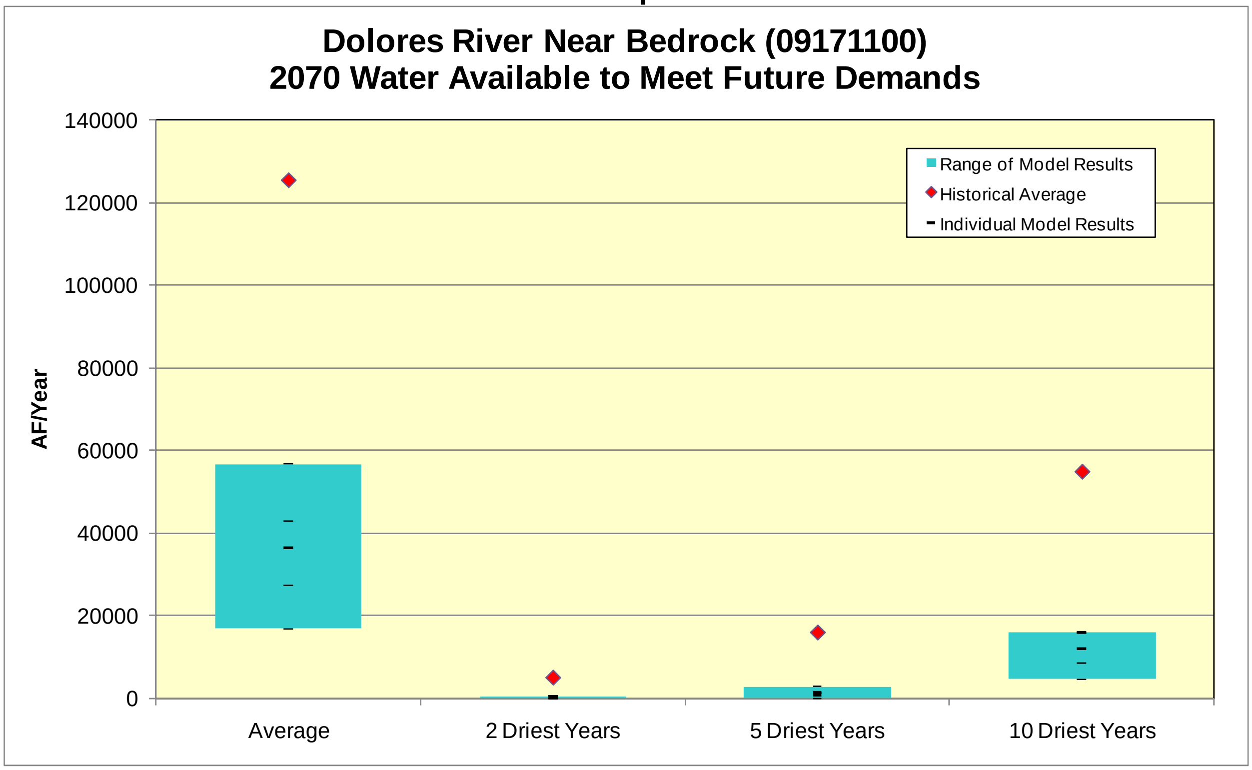

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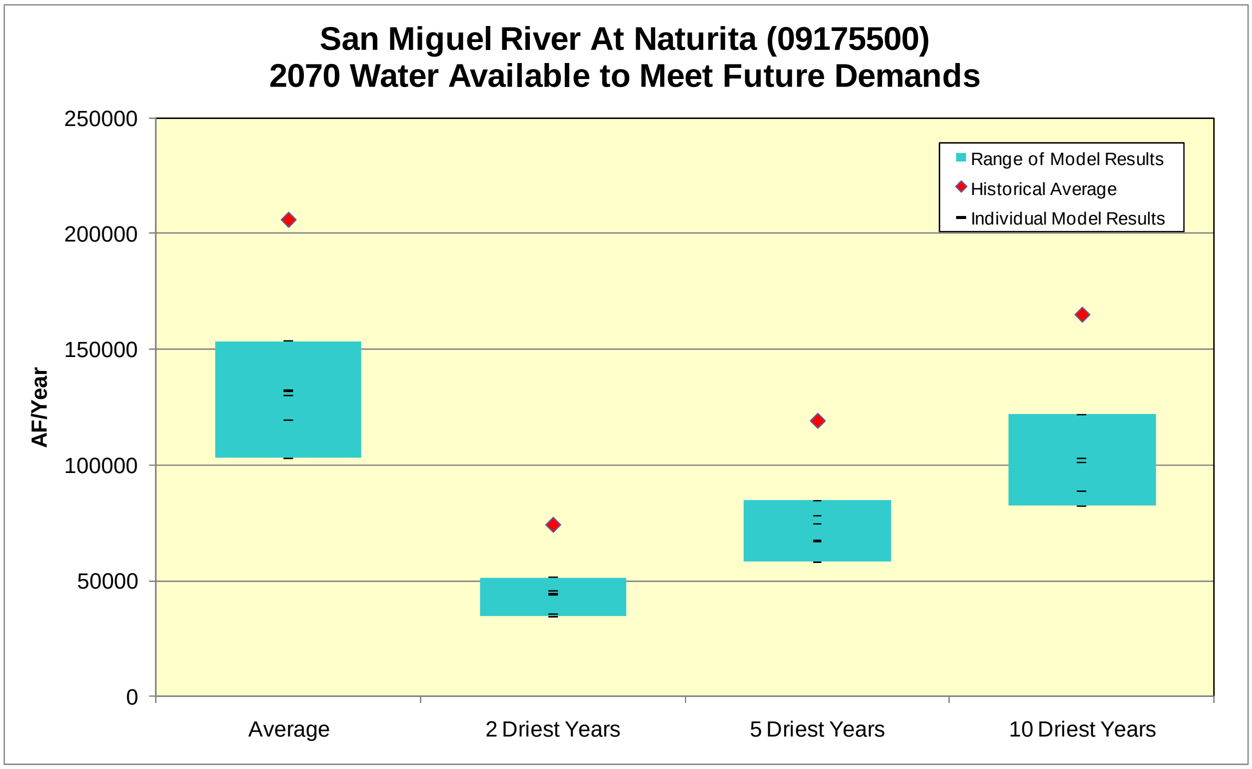

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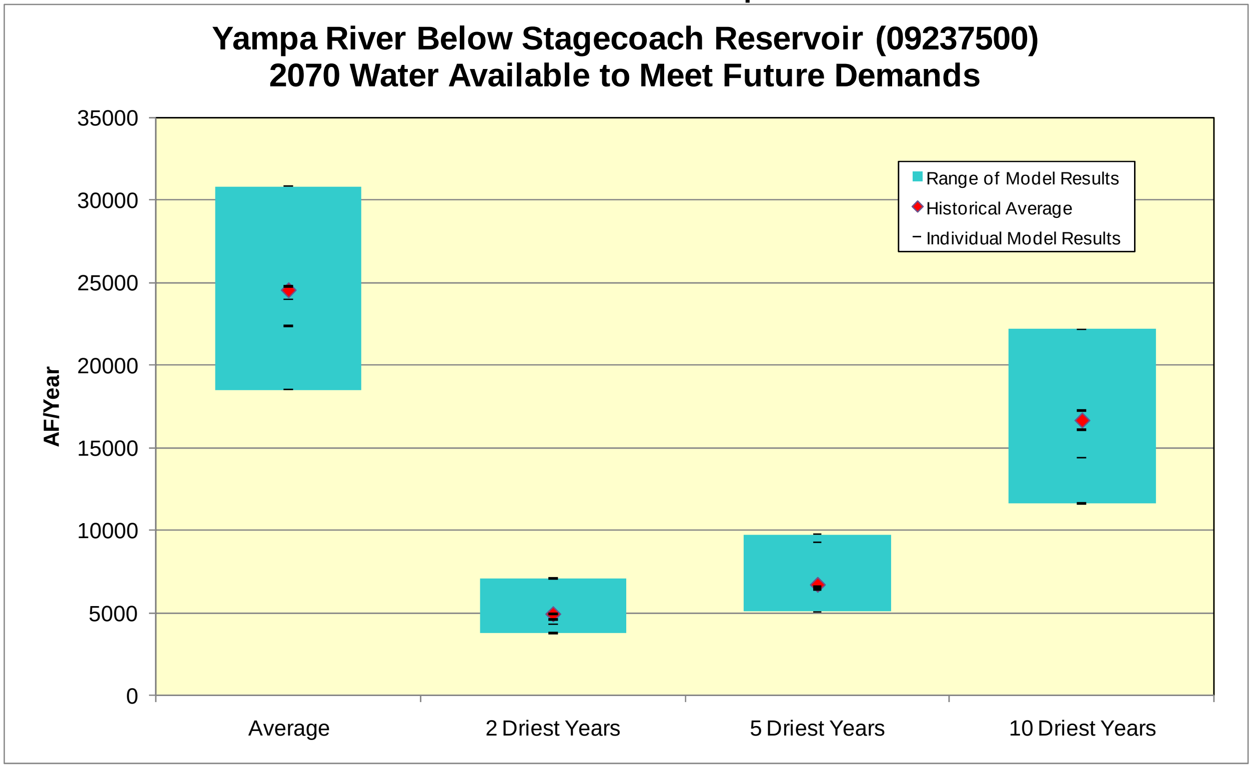

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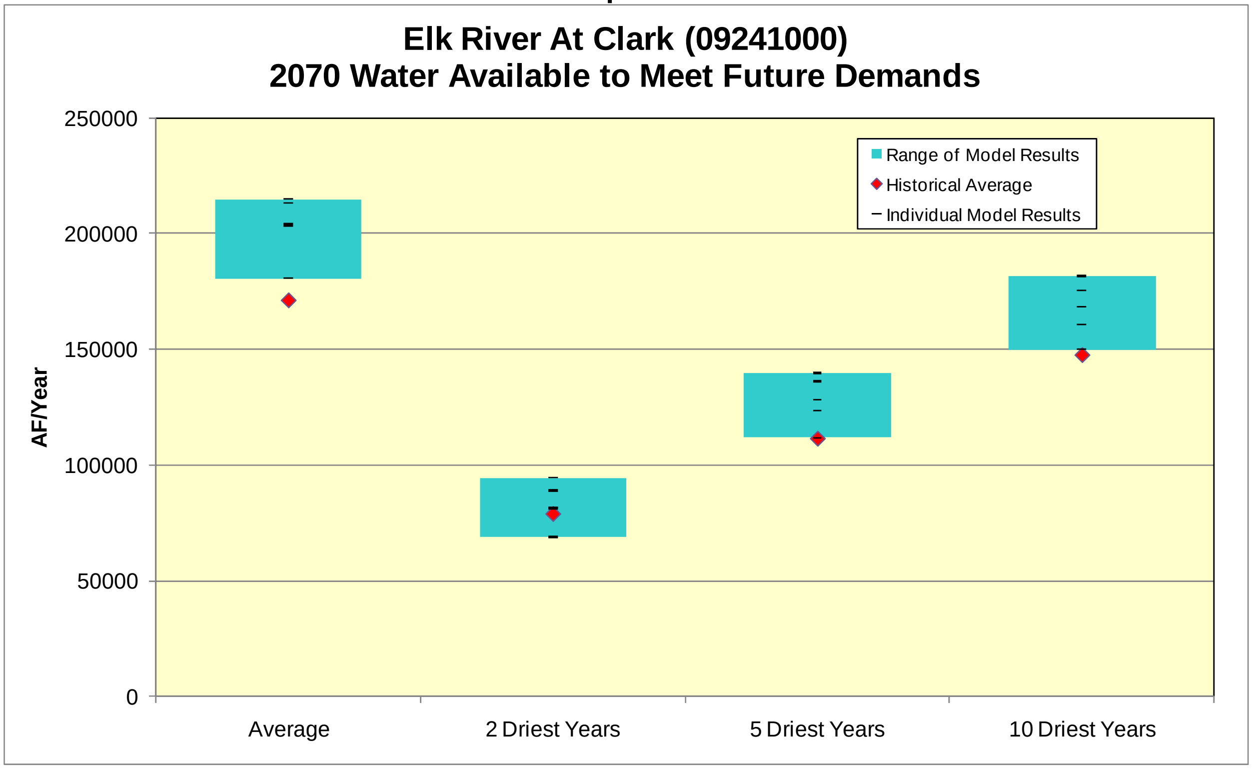

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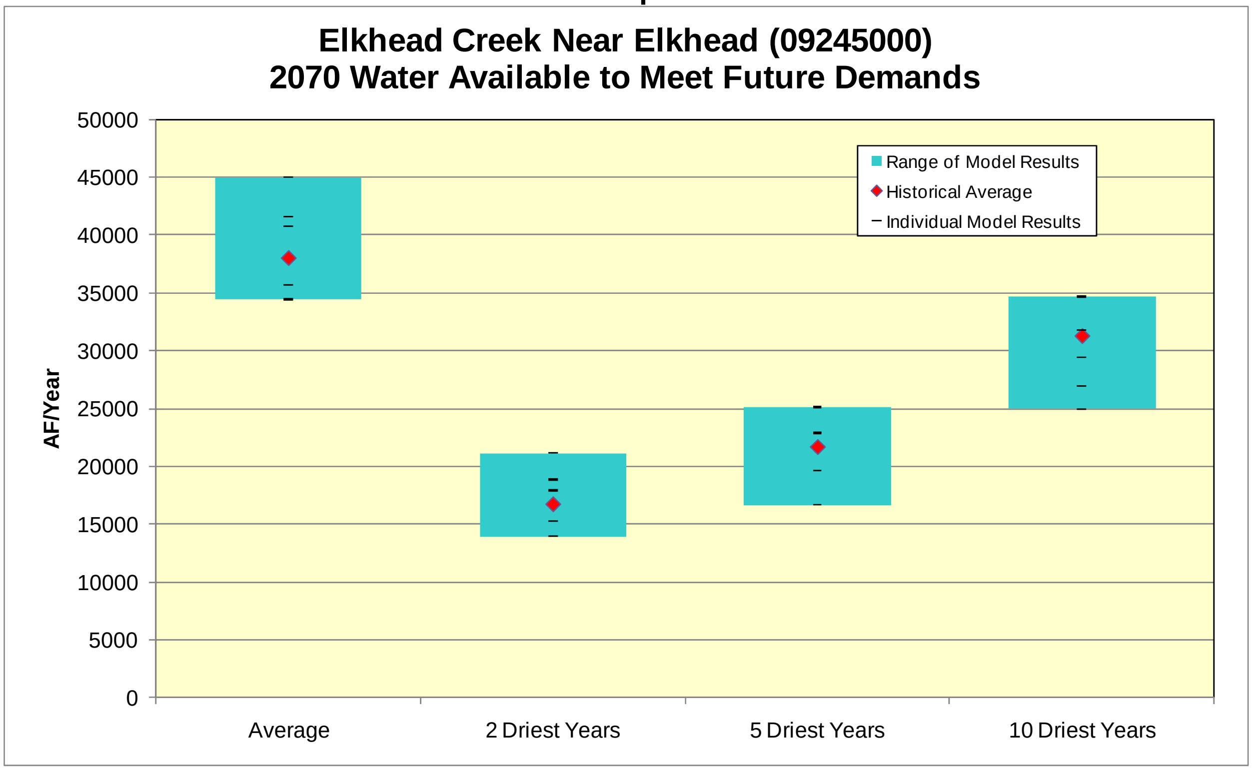

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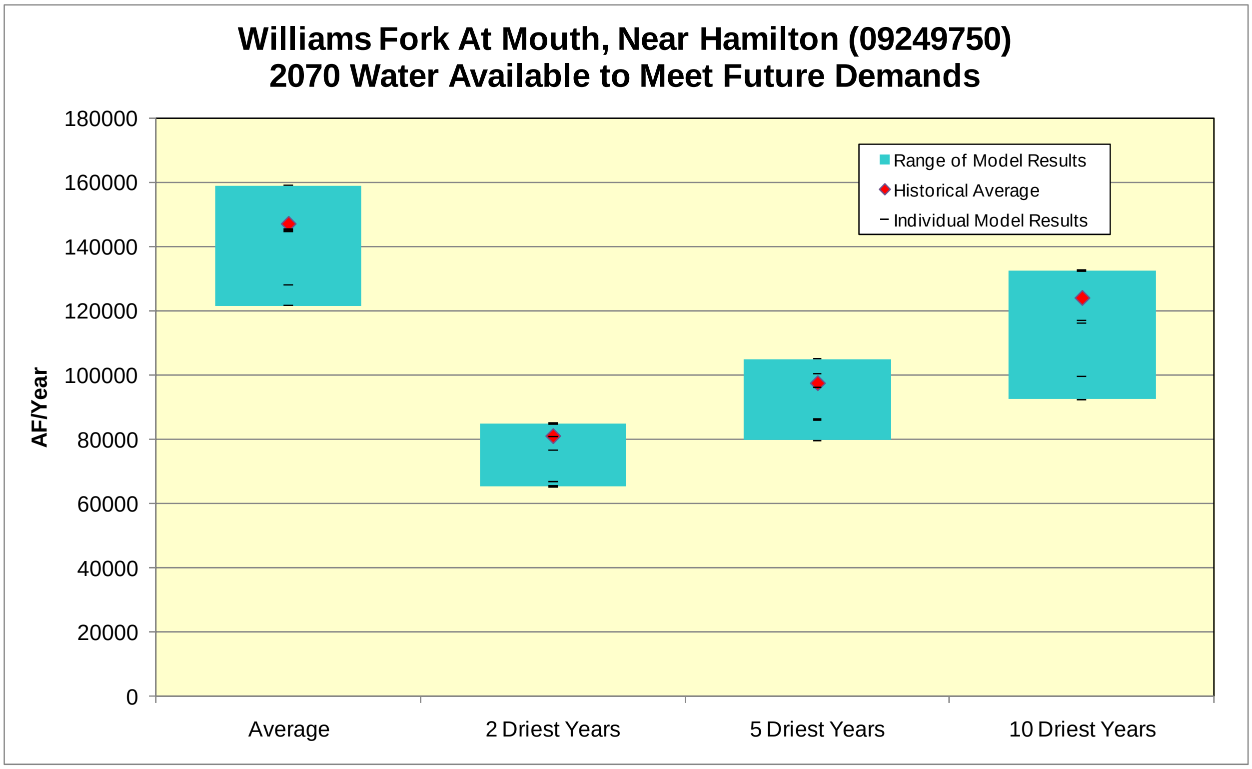

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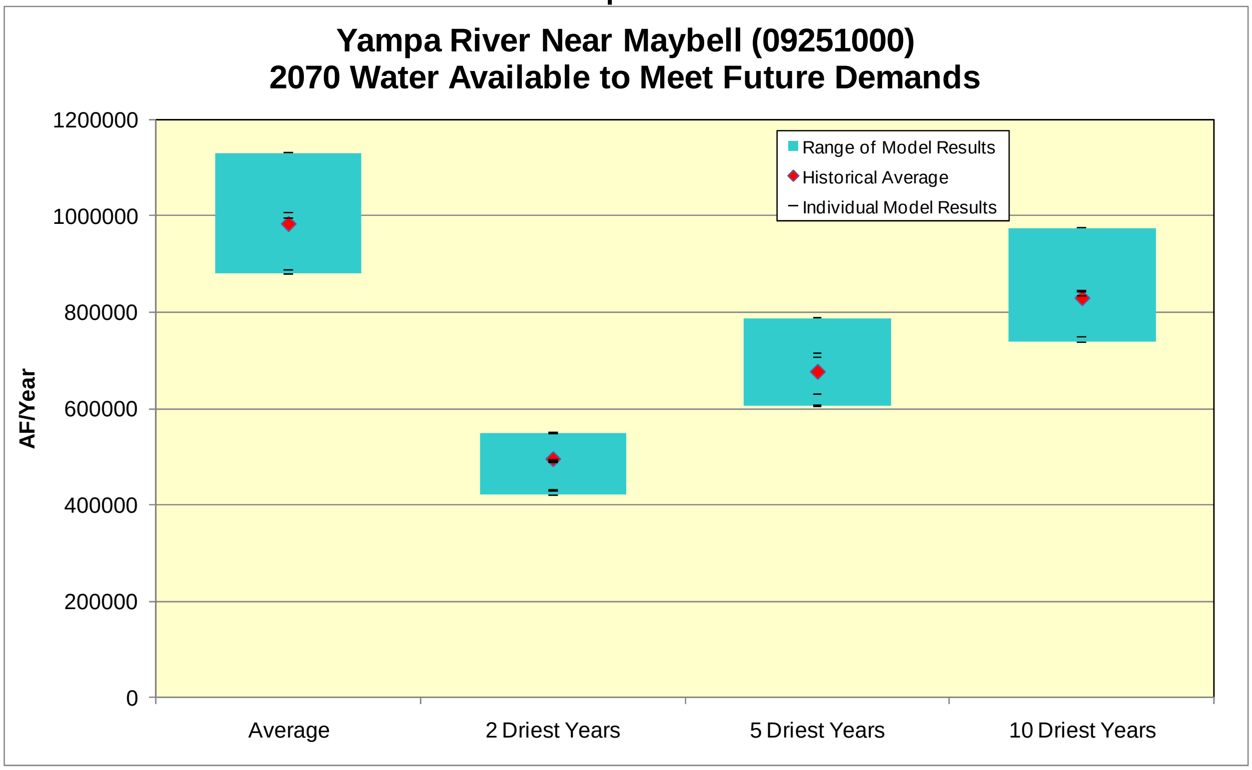

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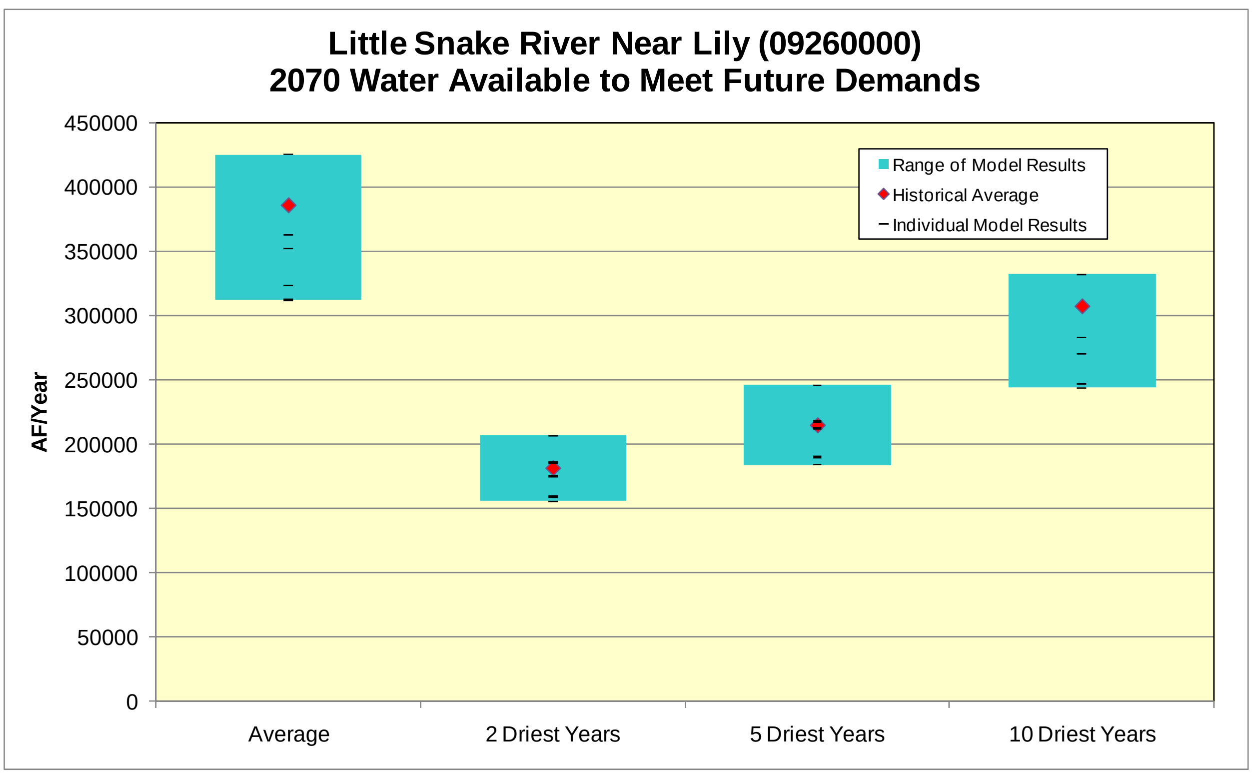

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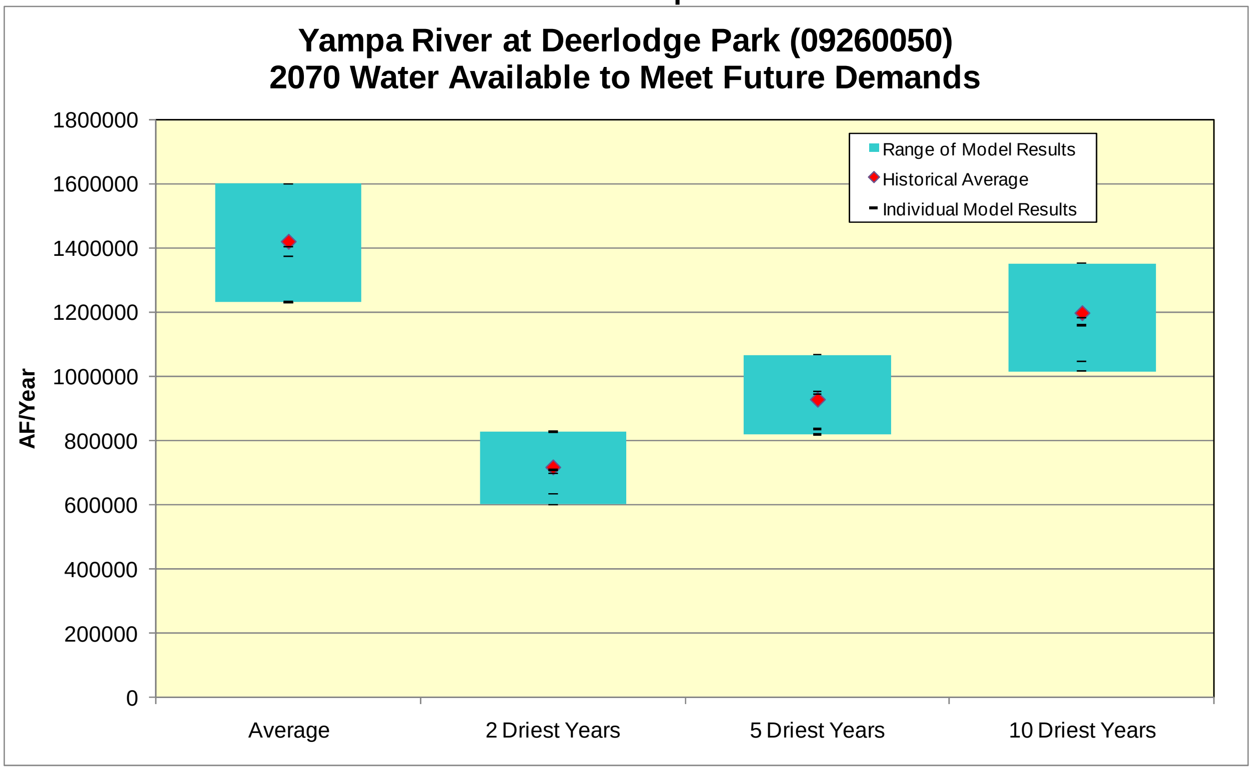

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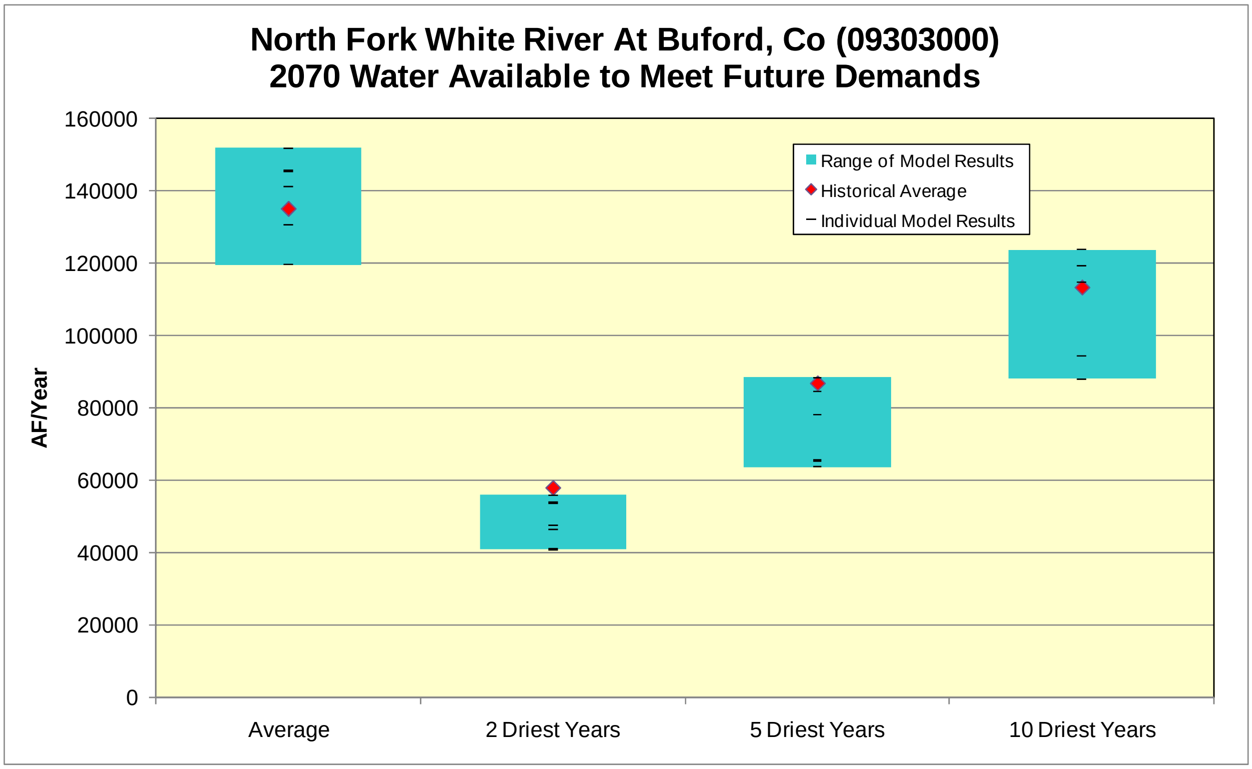

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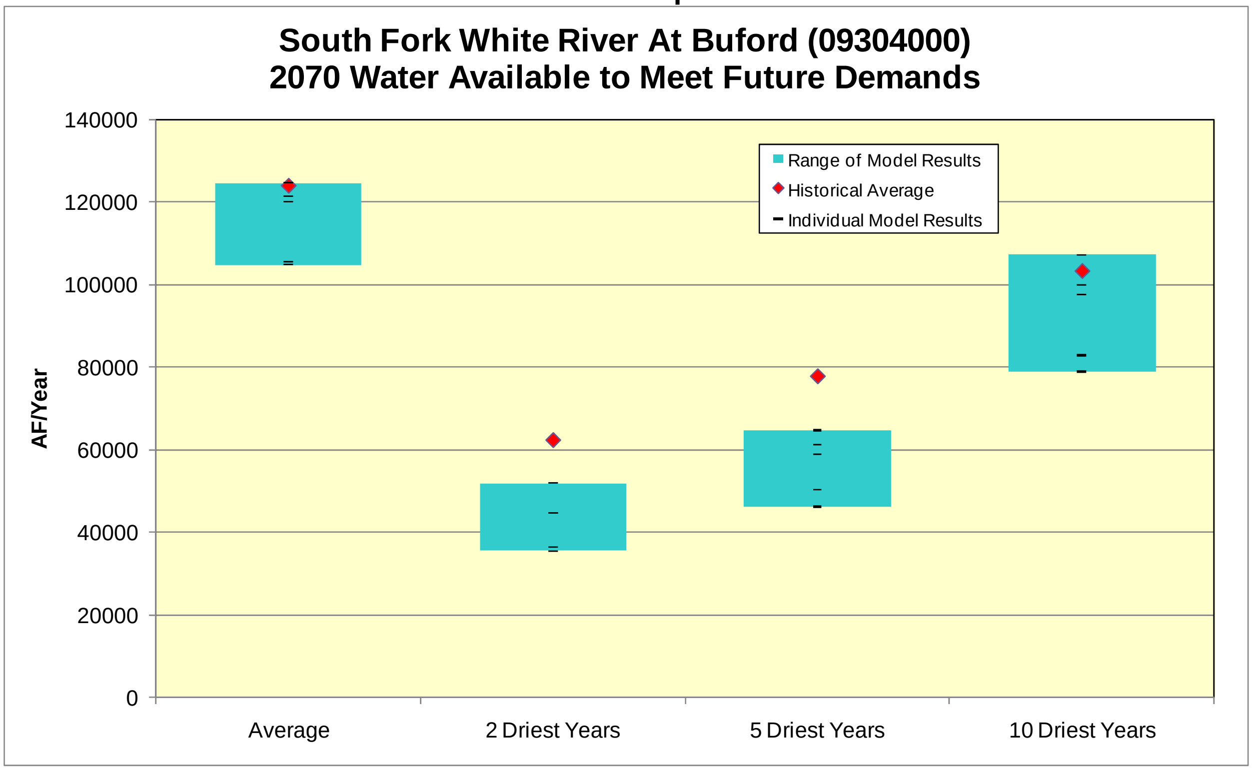

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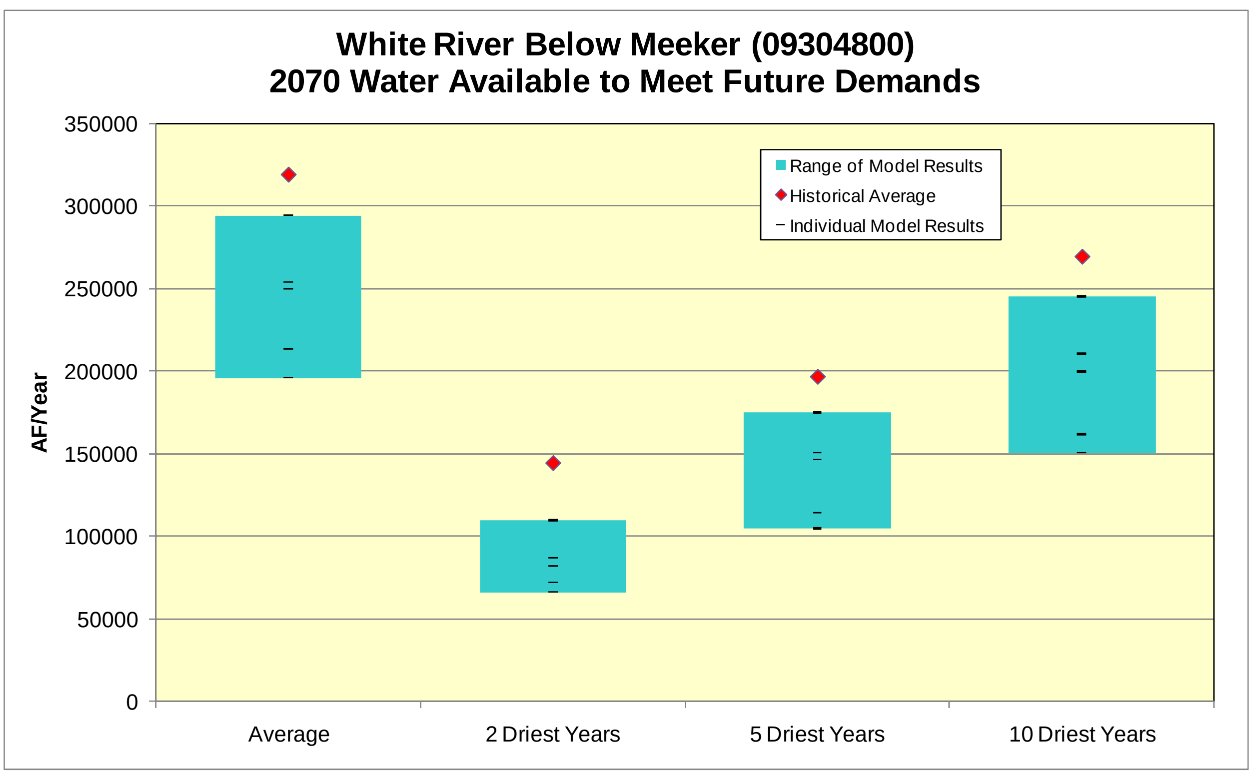

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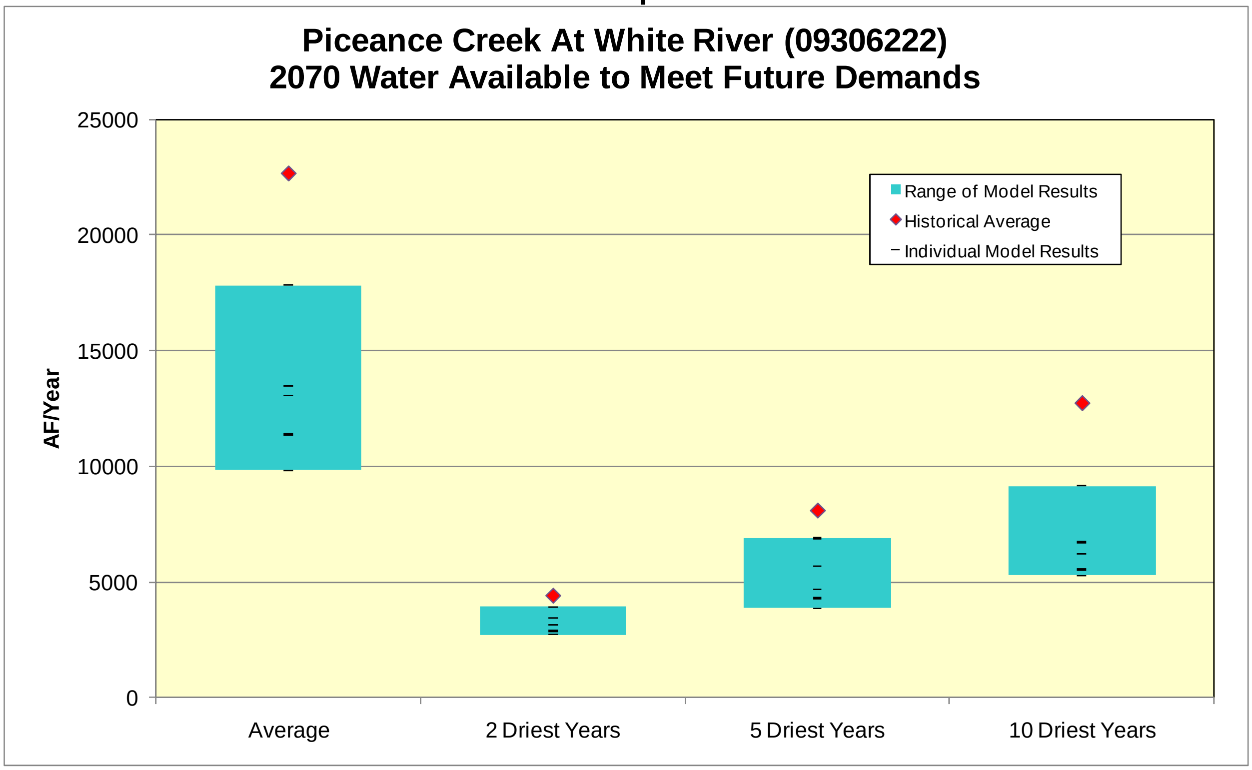

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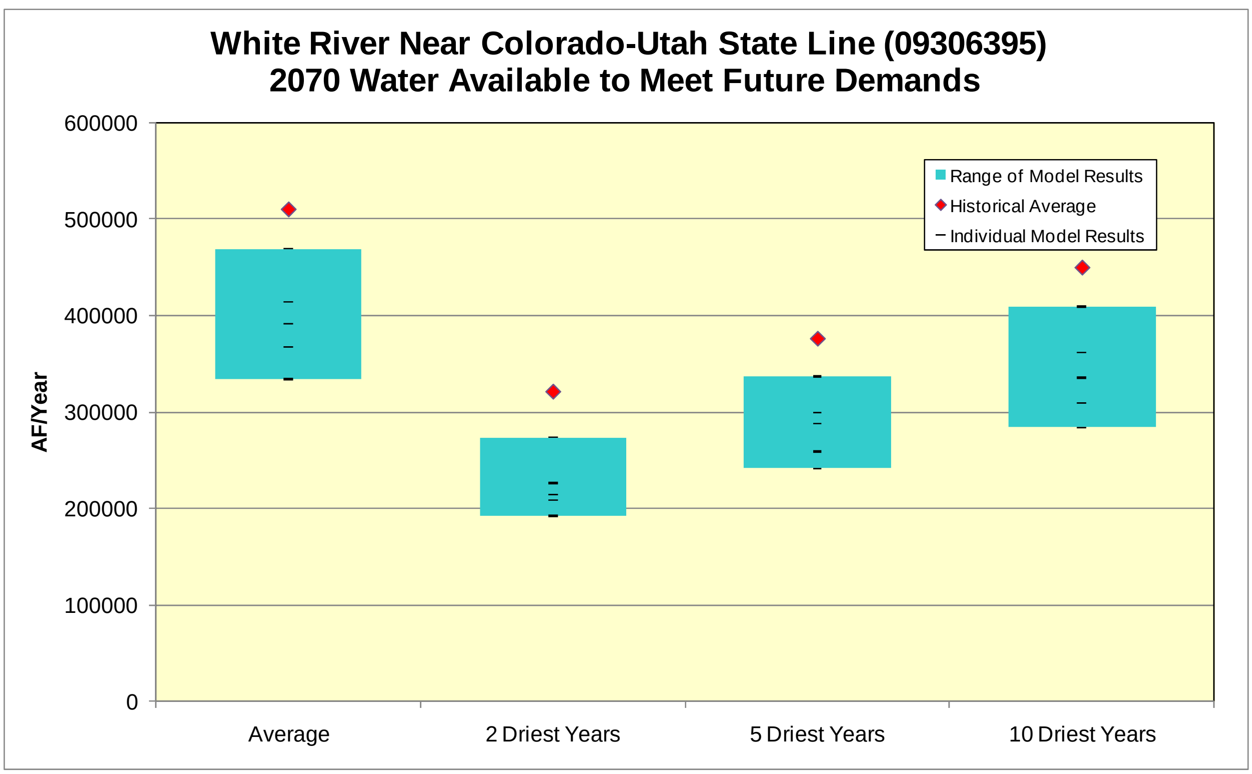

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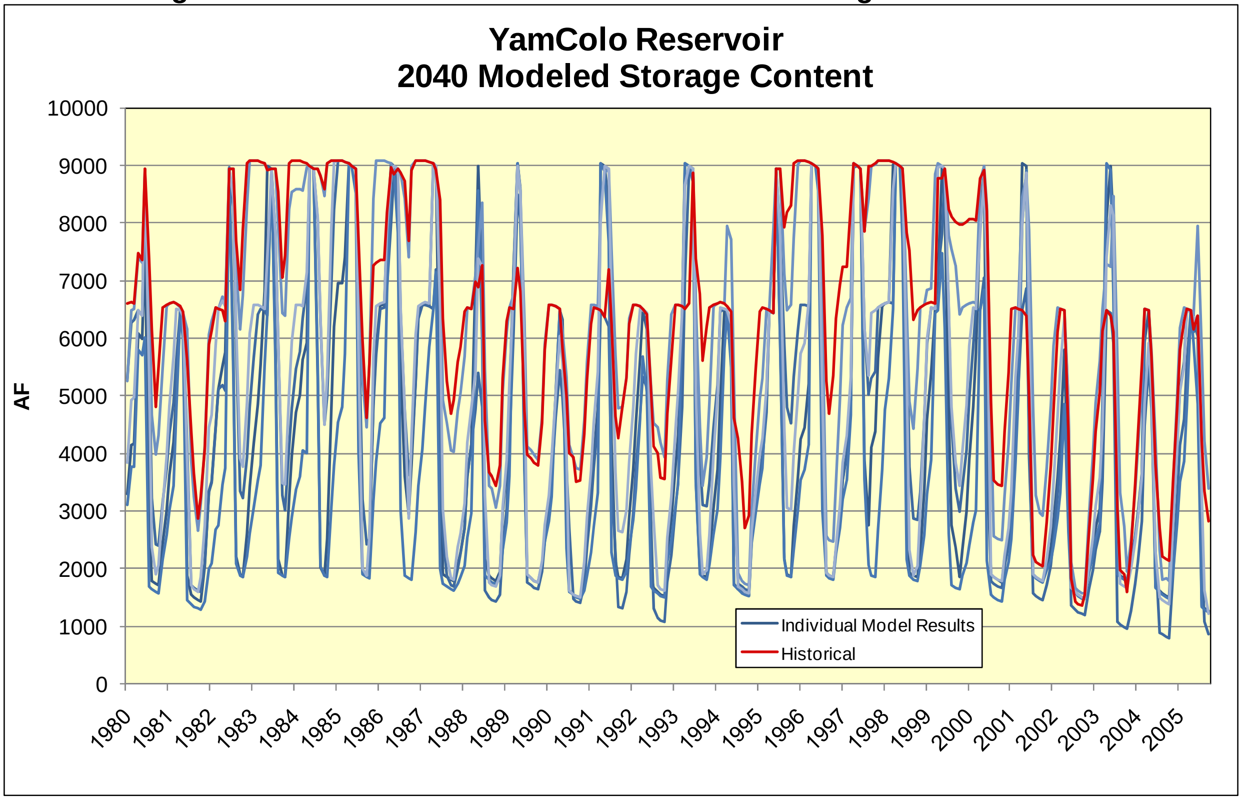

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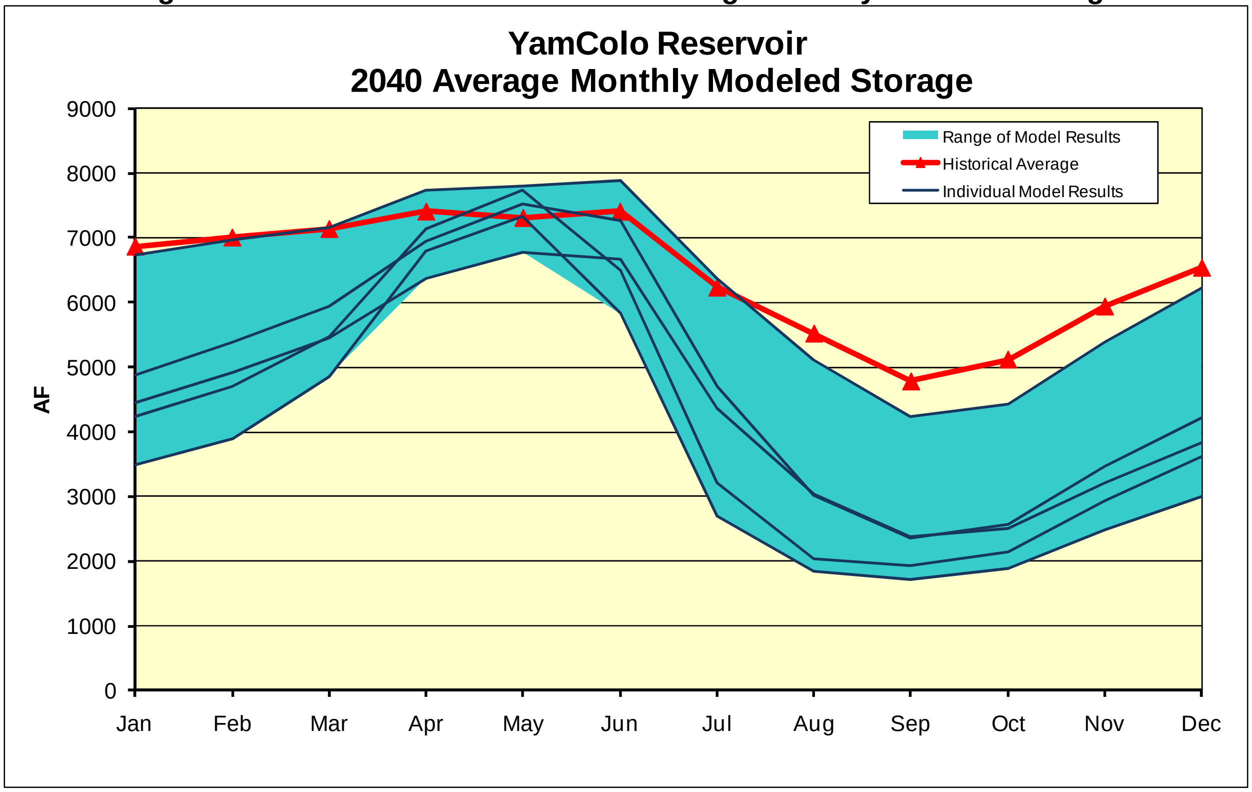

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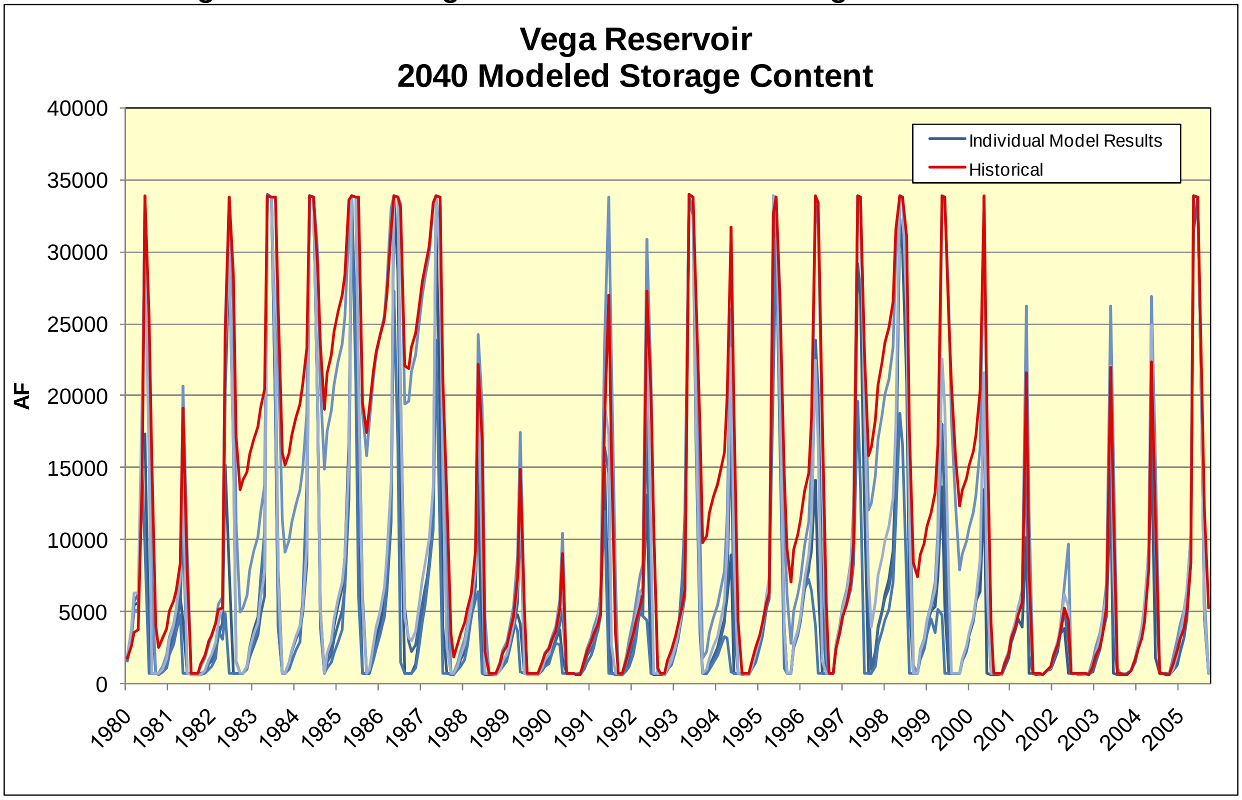

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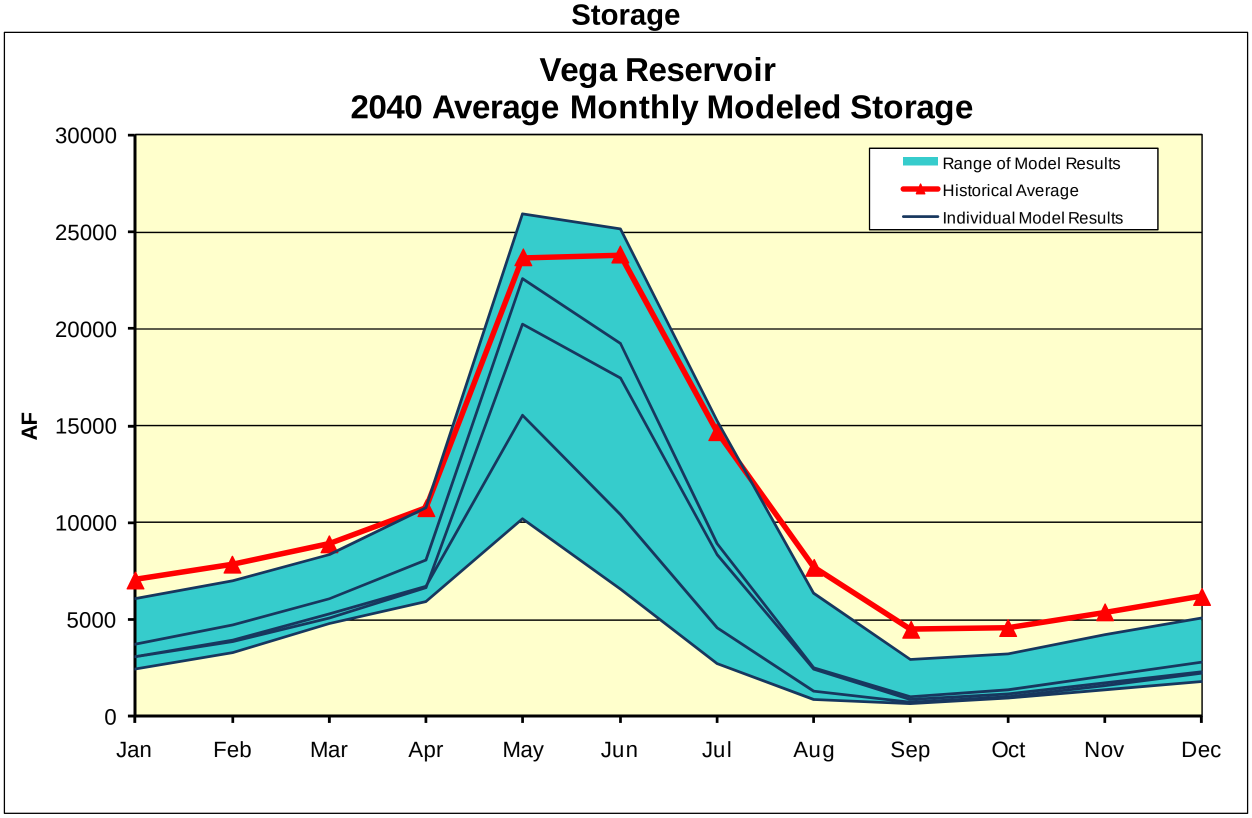

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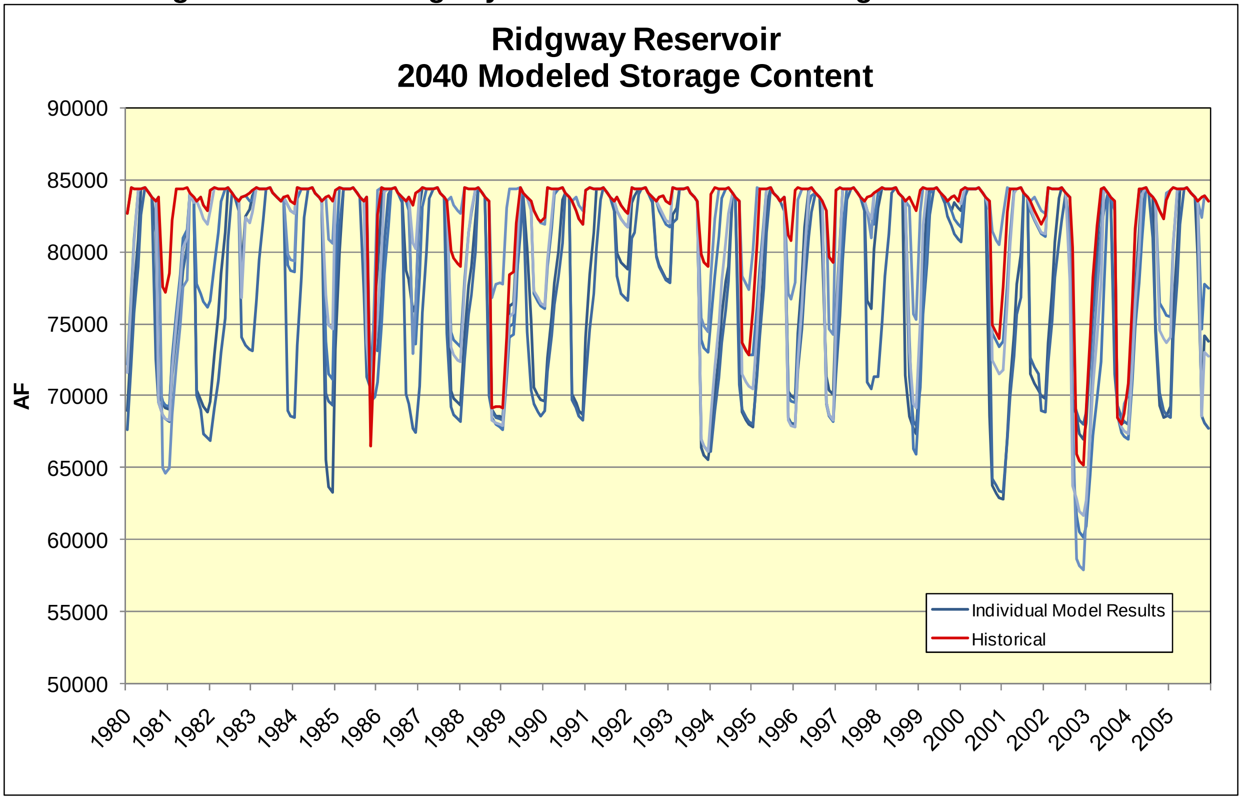

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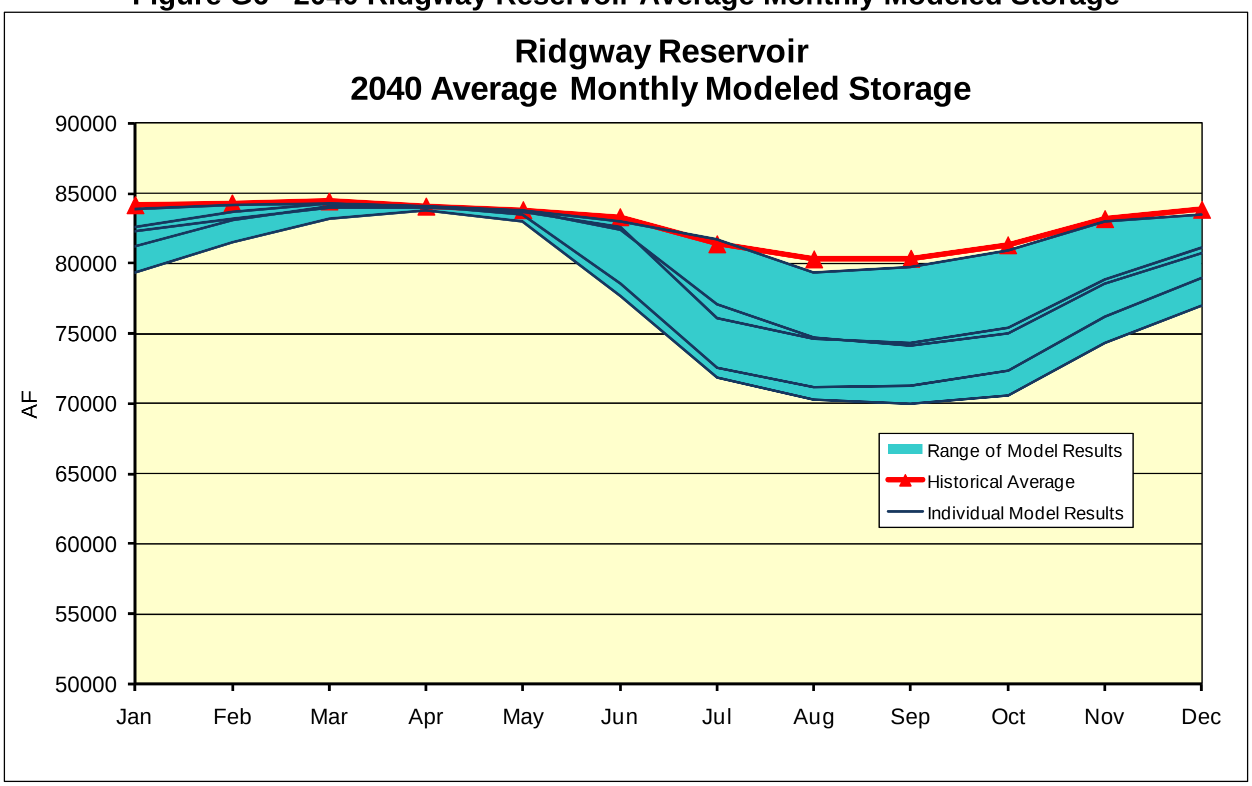

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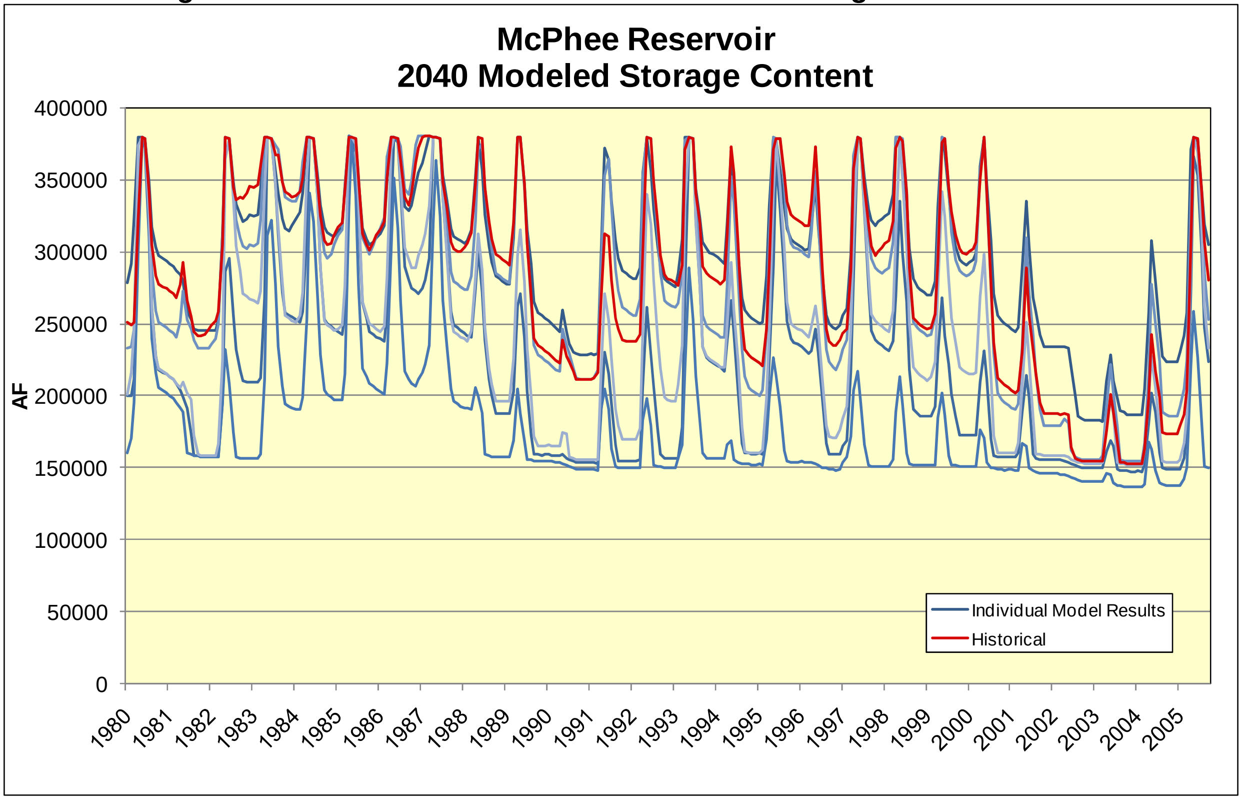

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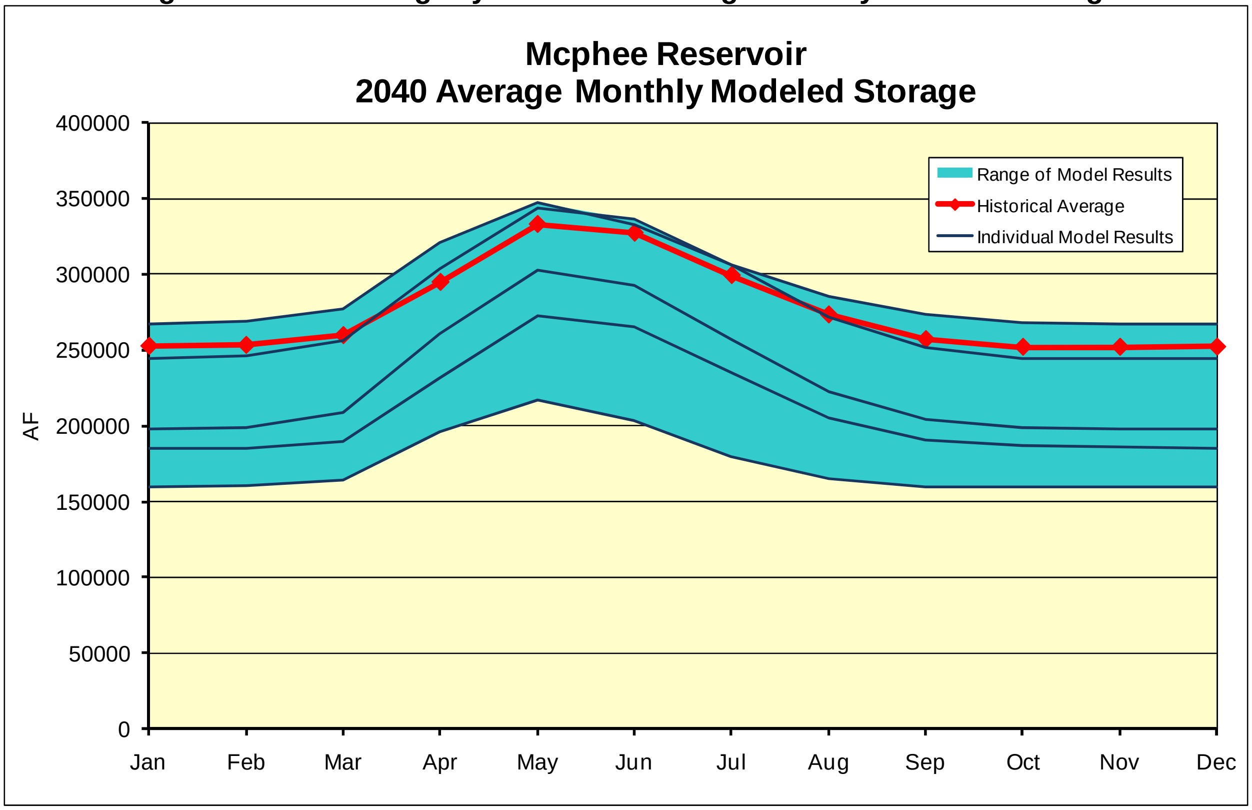

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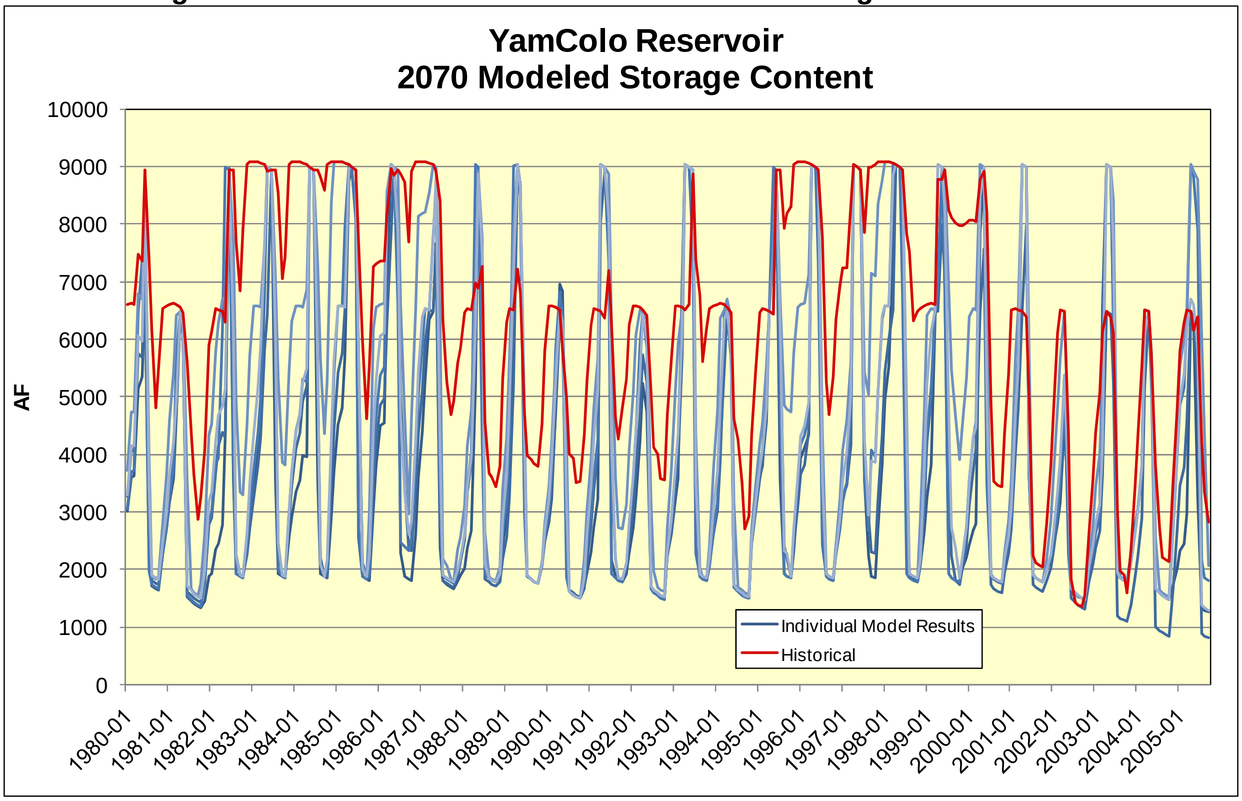

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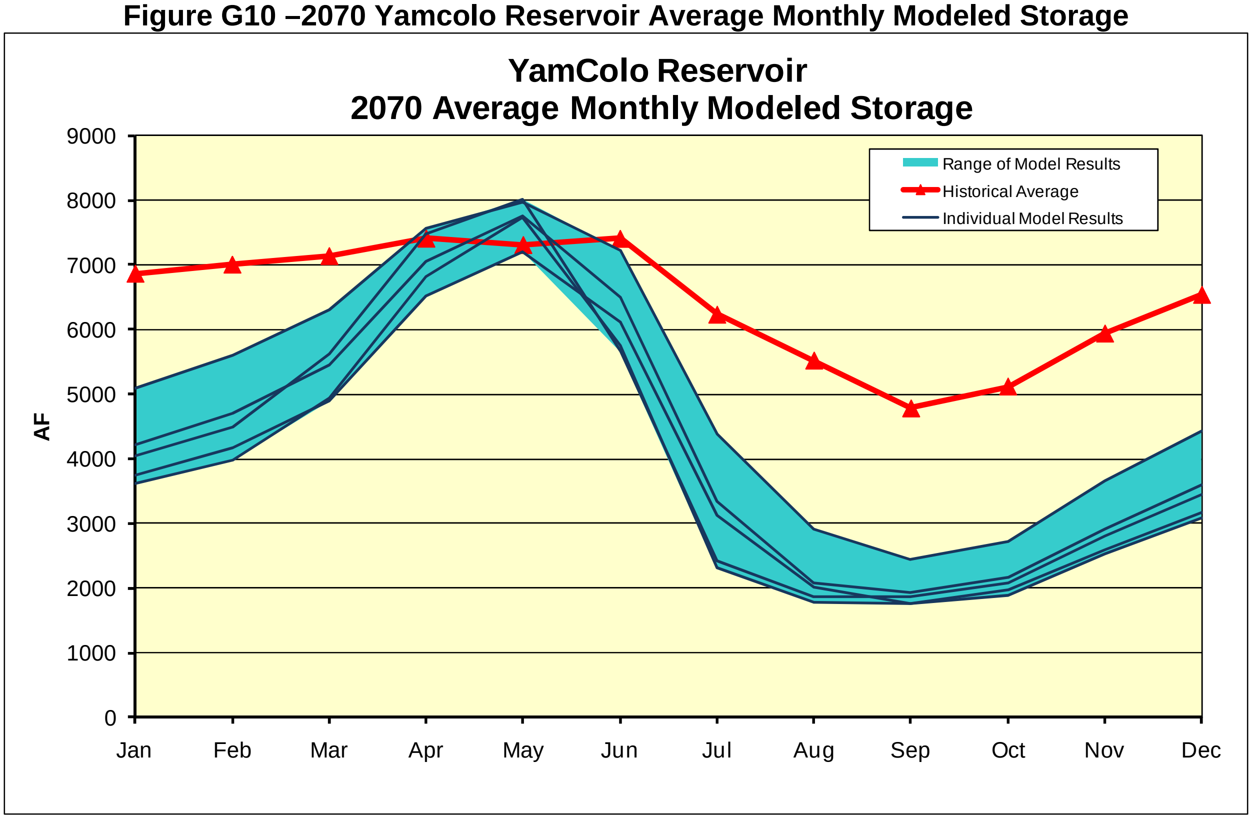

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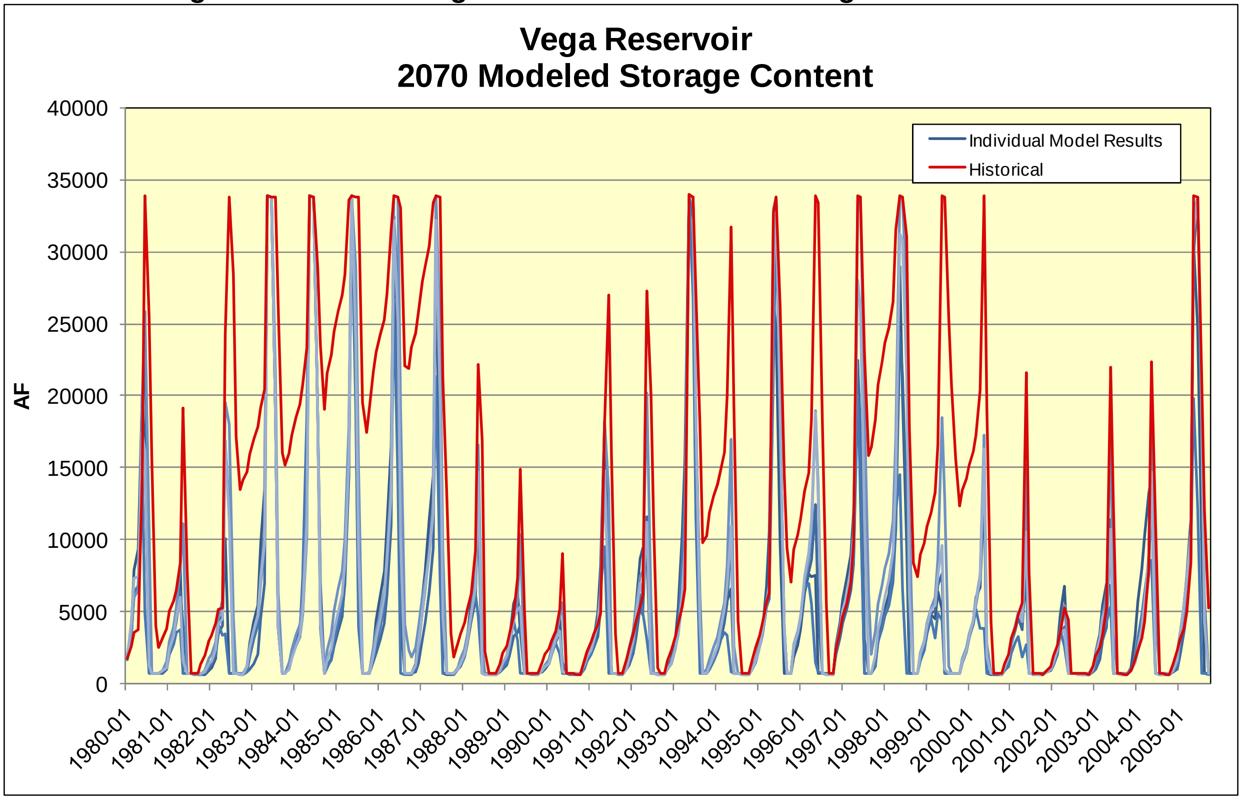

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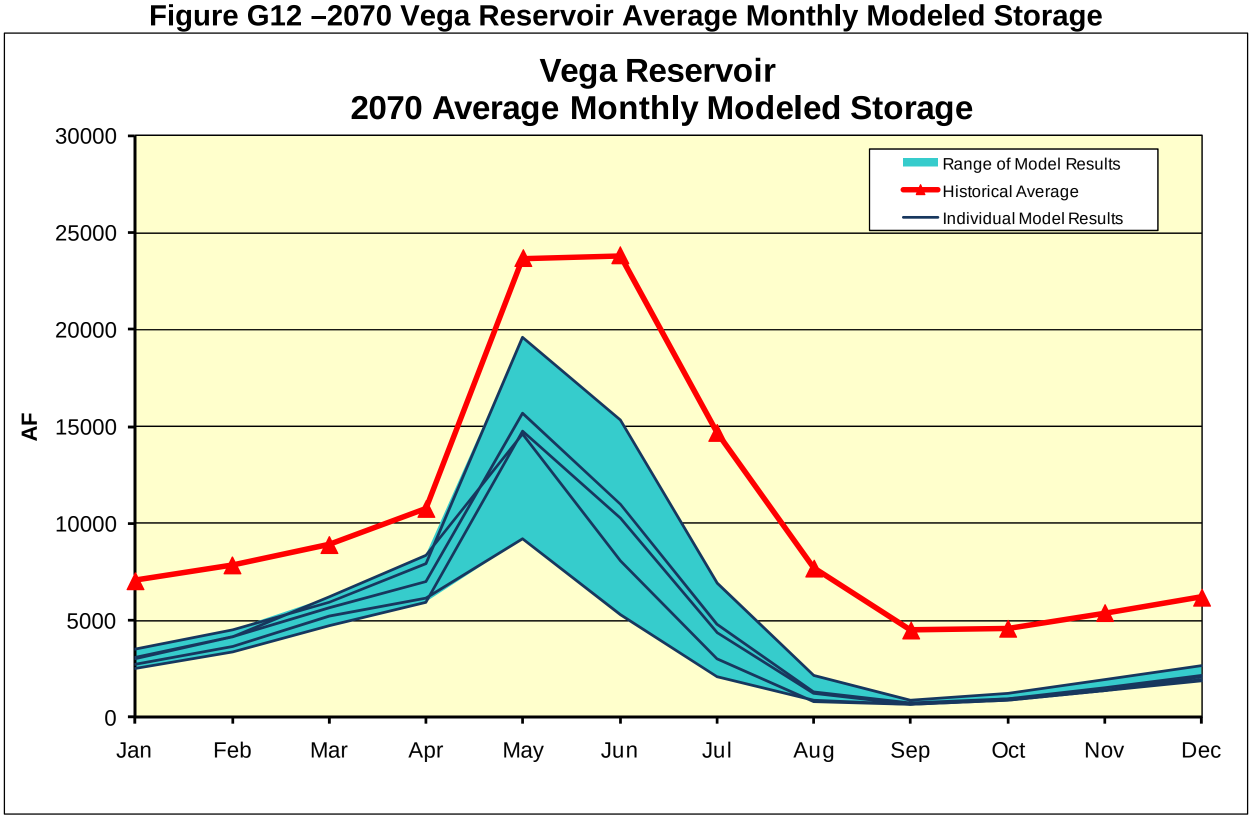

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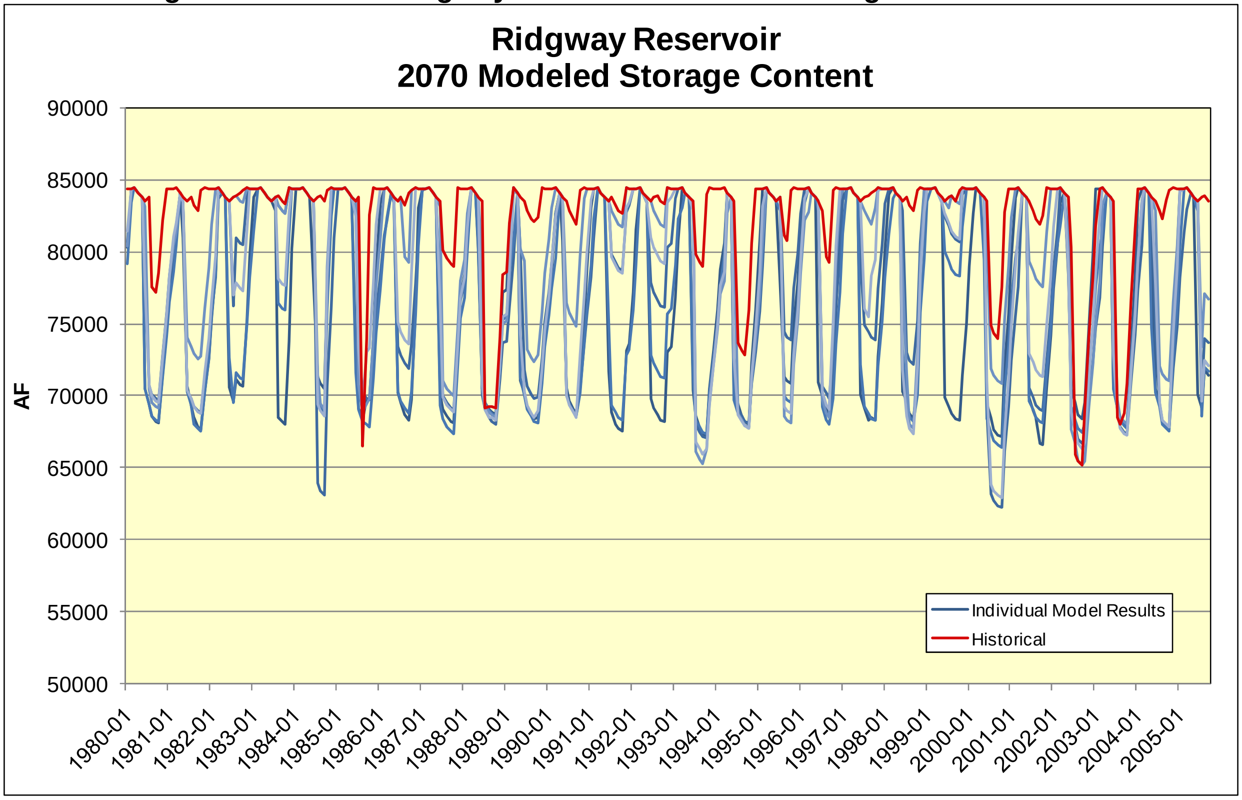

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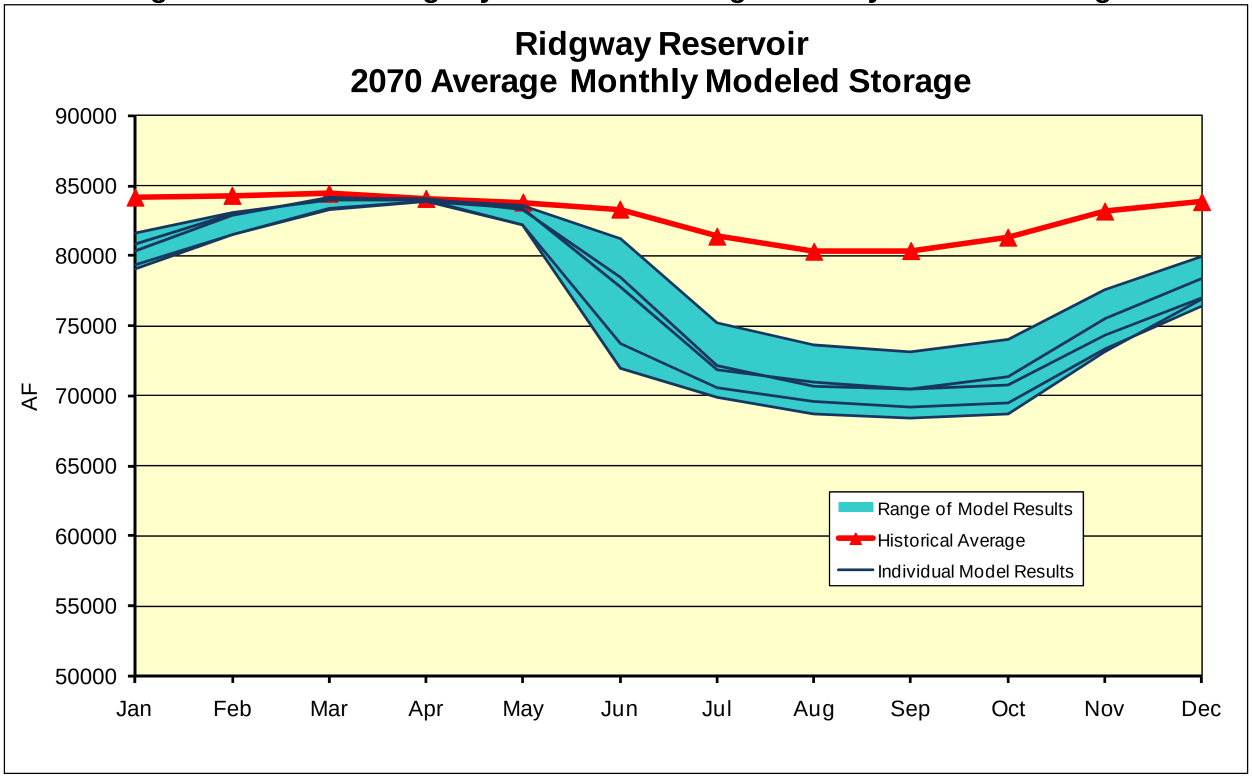

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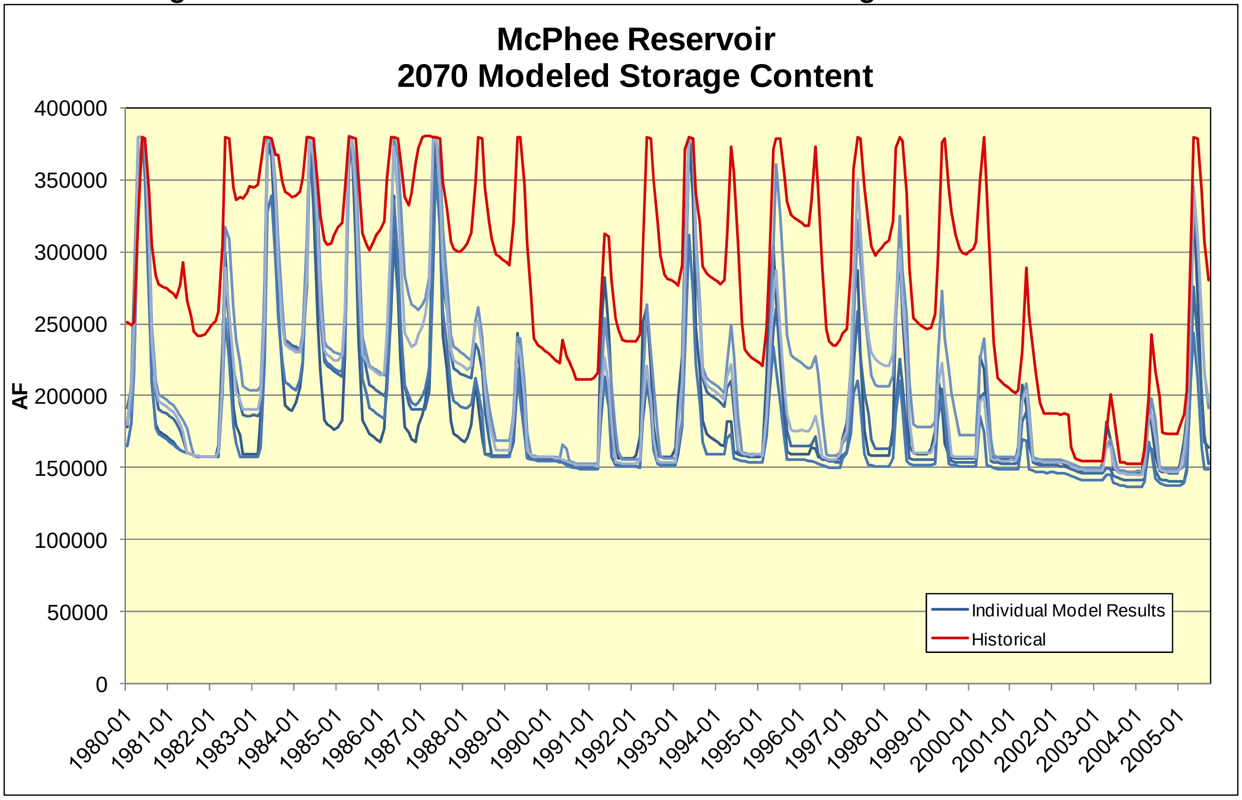

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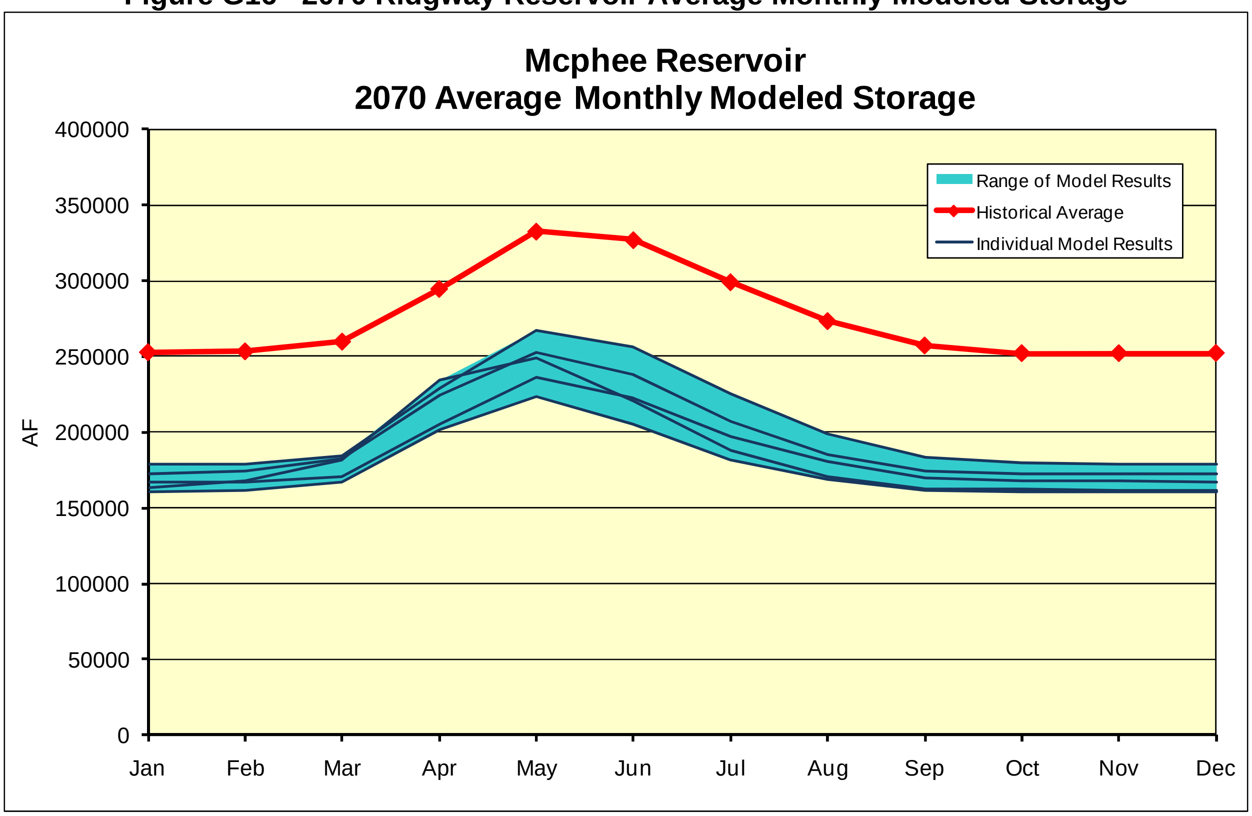

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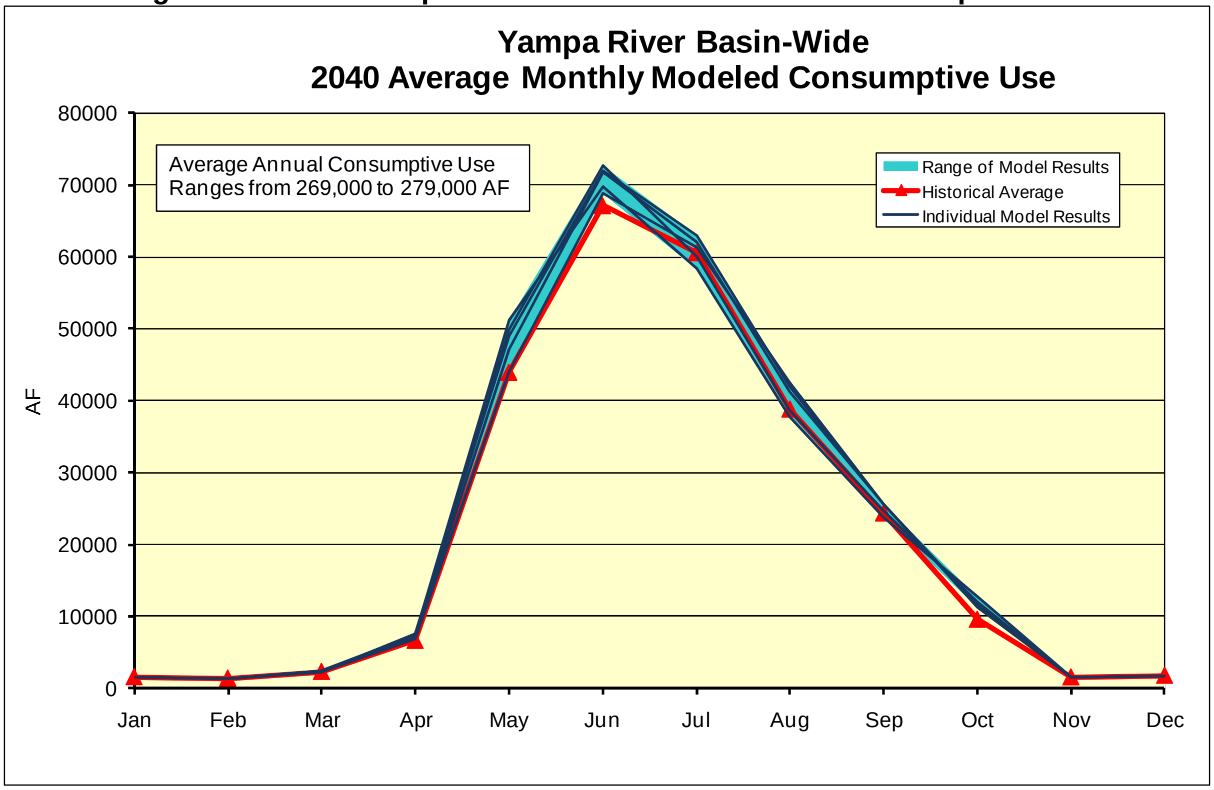

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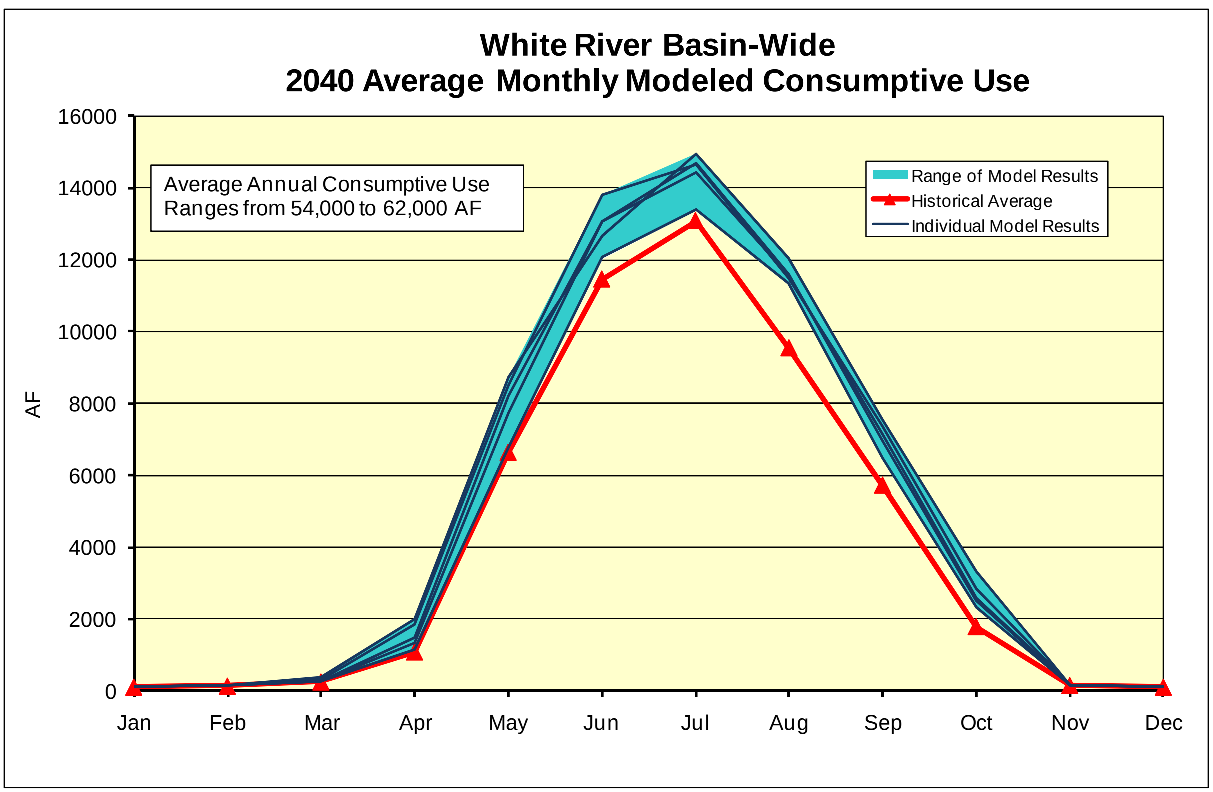

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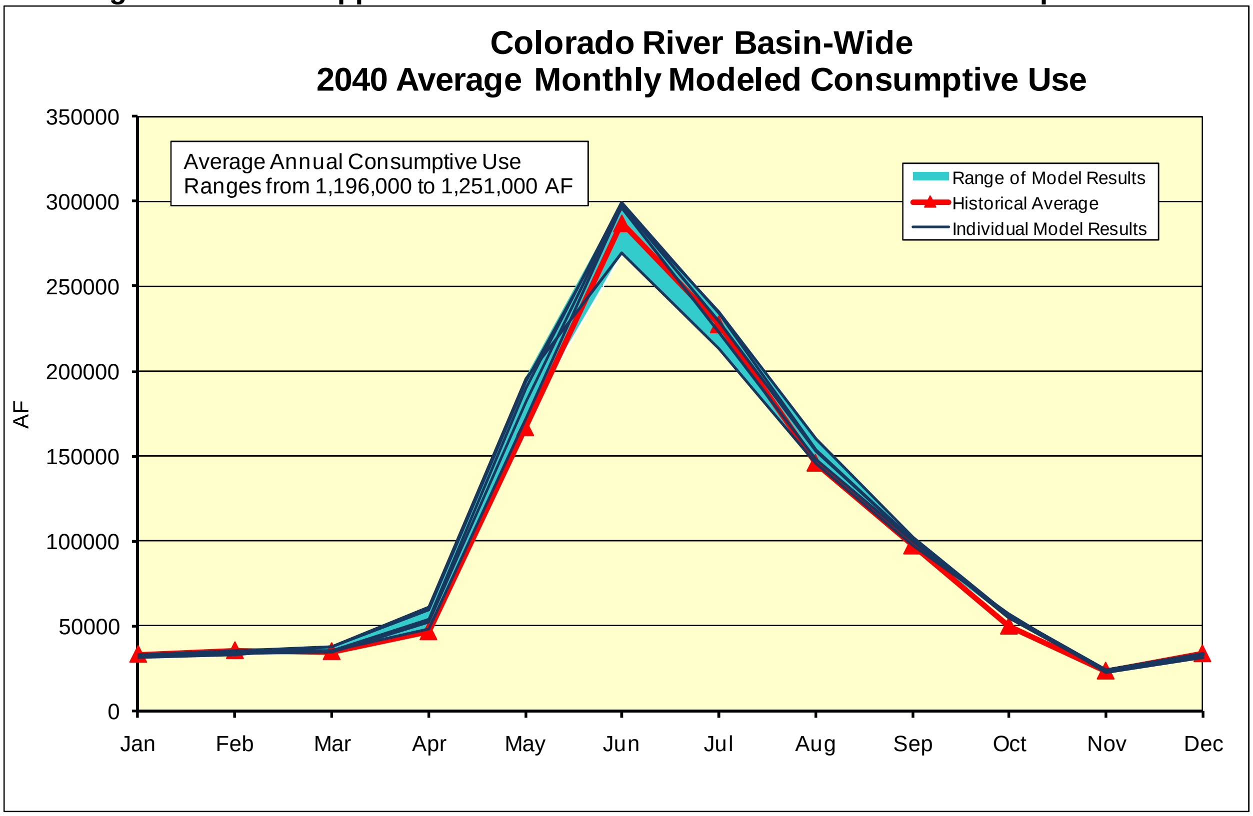

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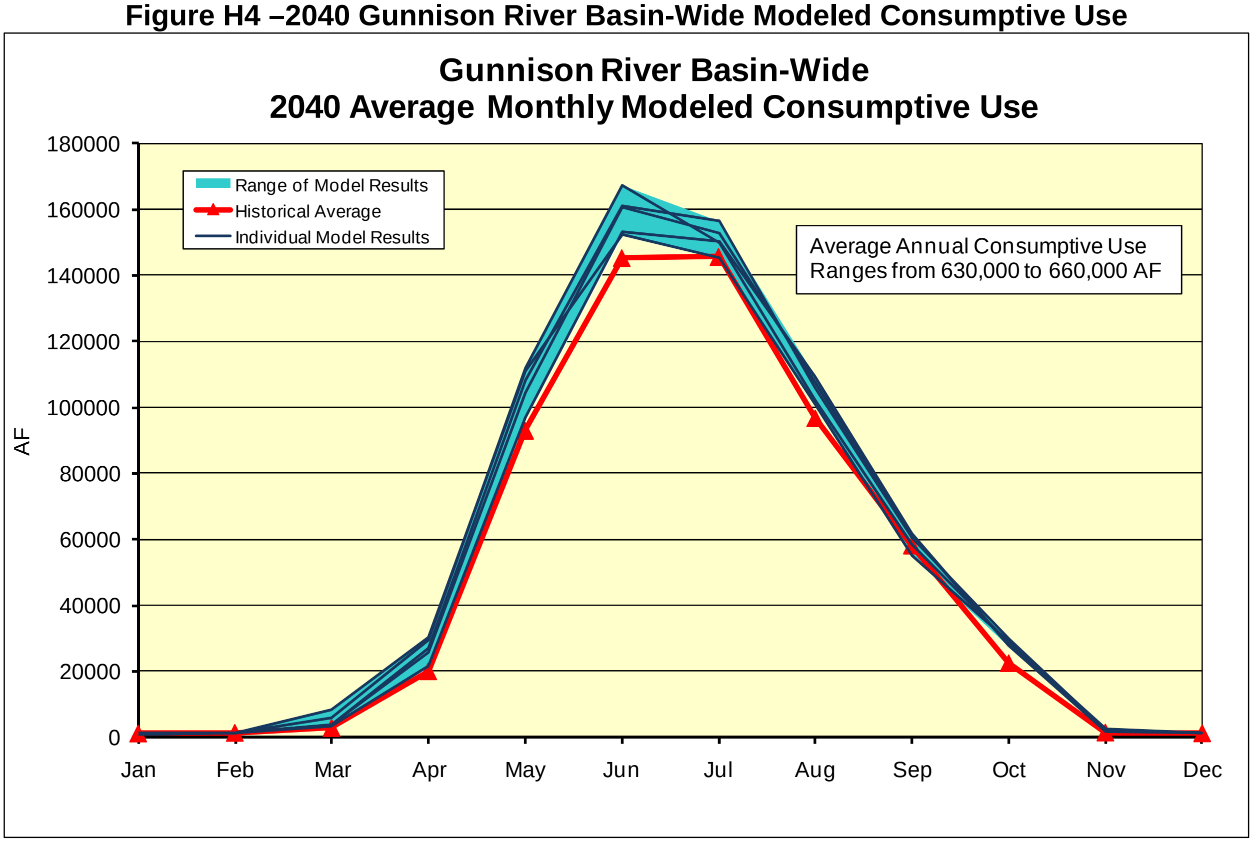

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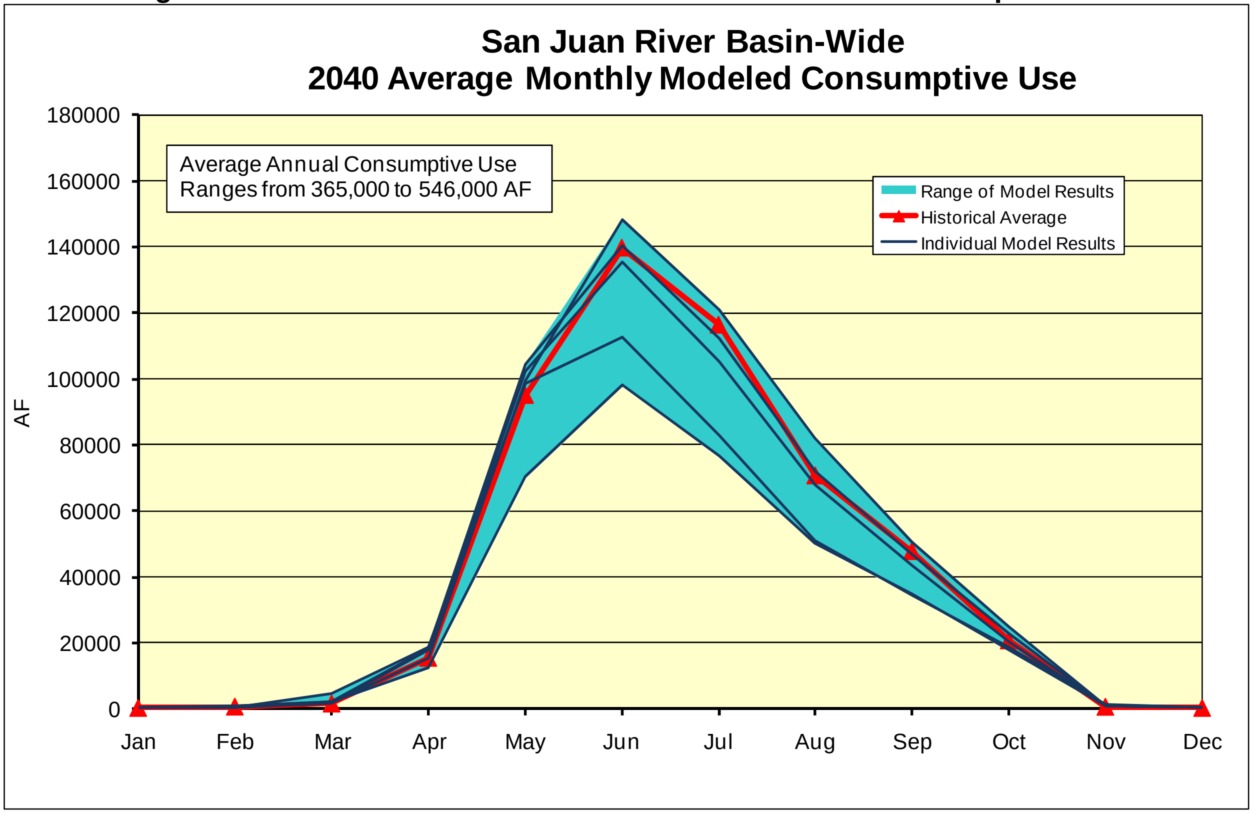

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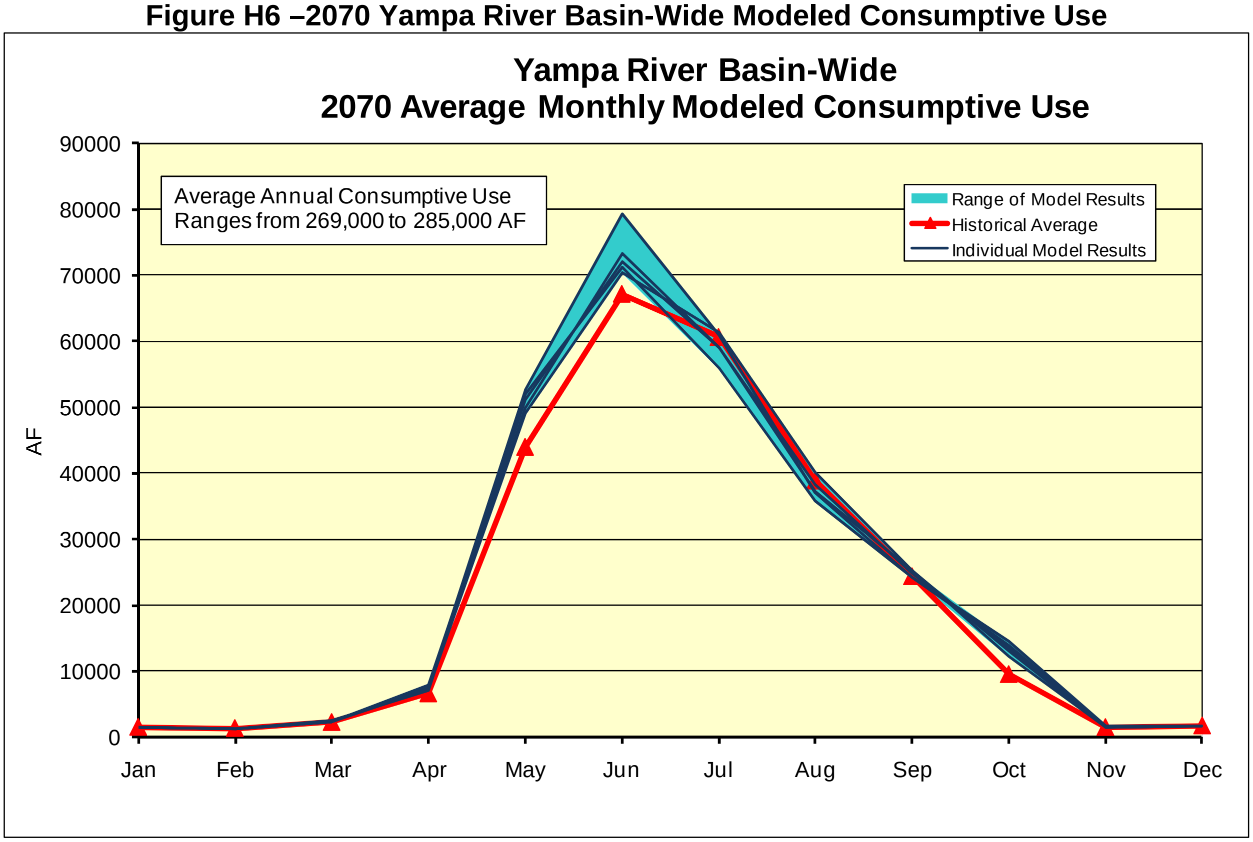

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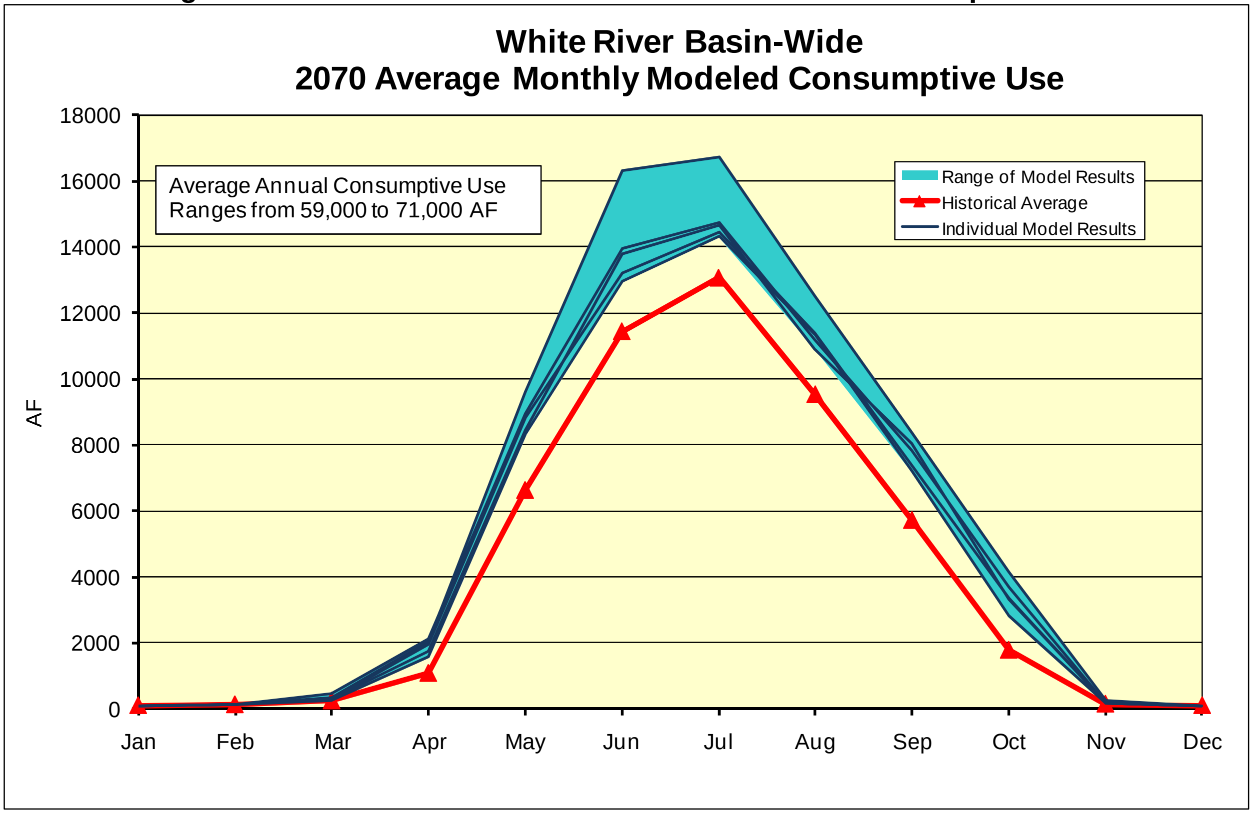

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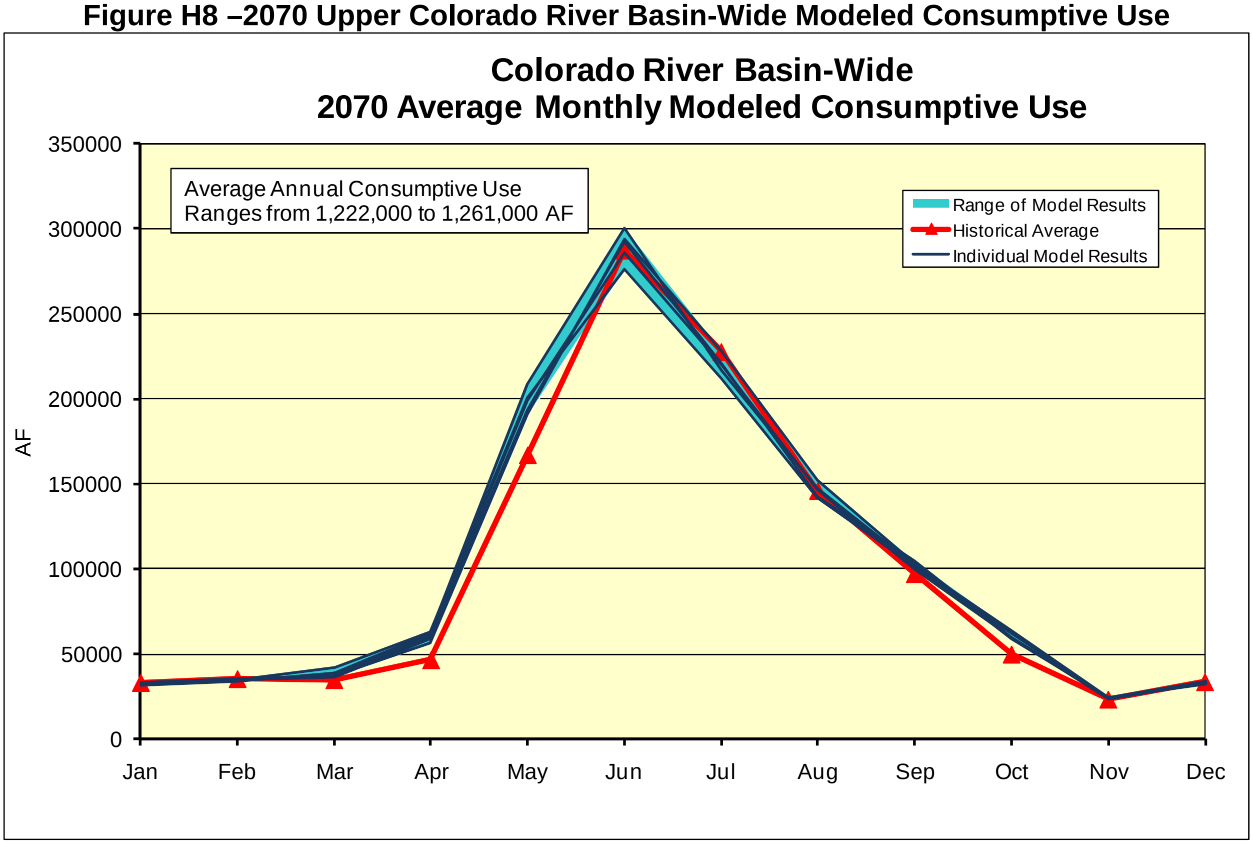

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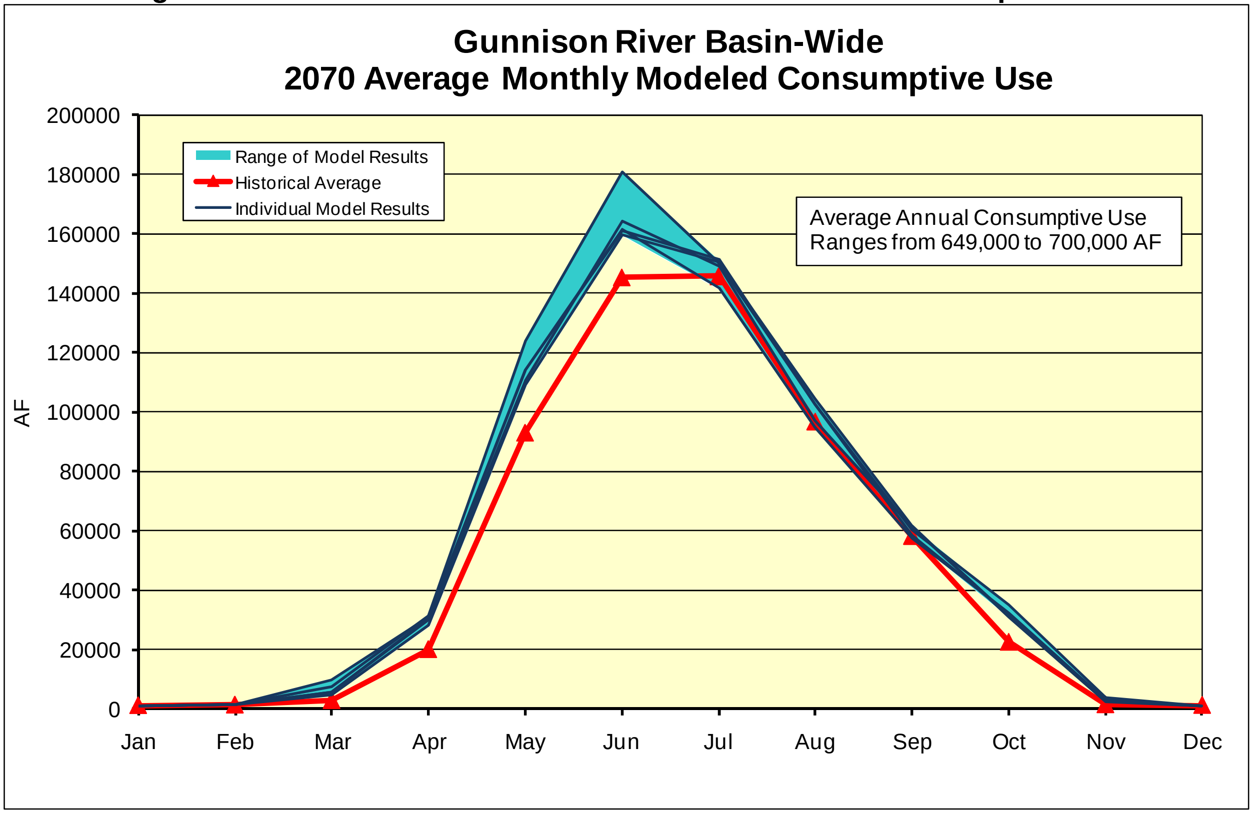

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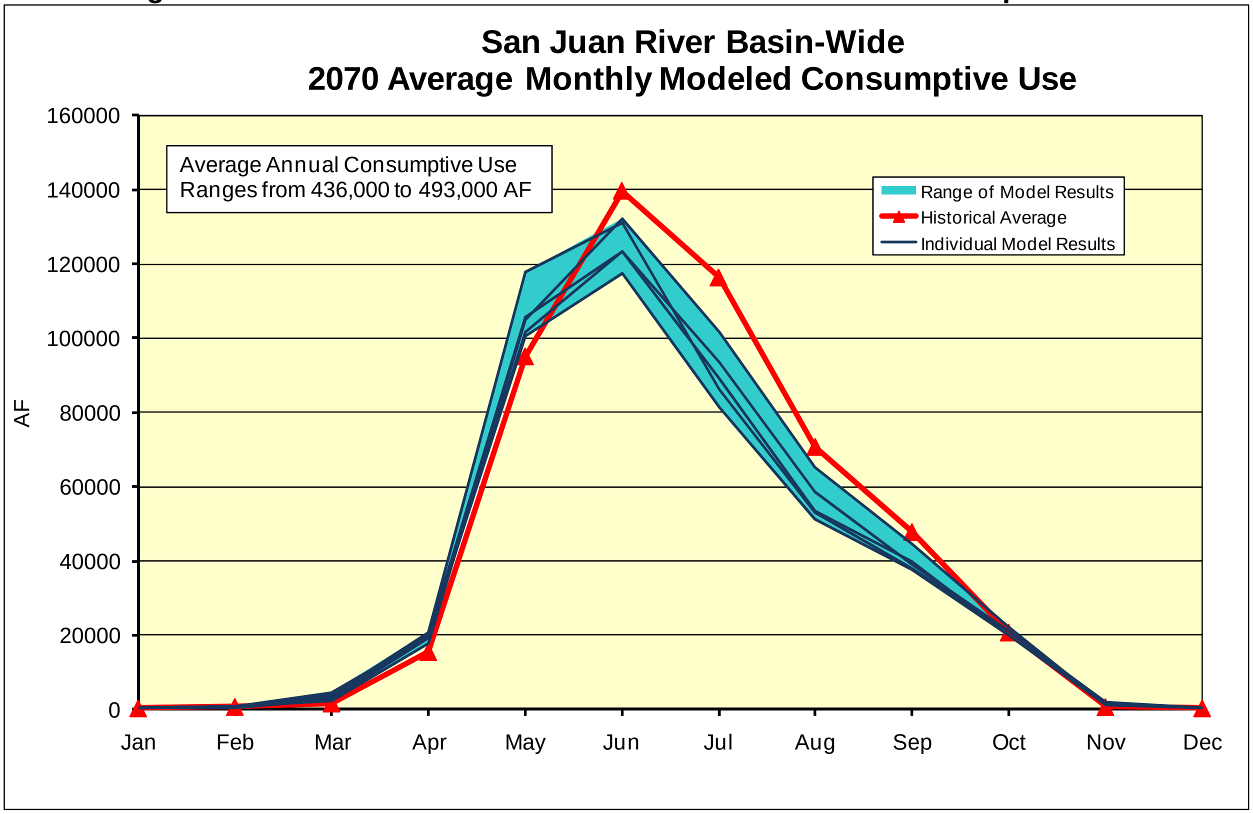

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