6 Assessment of System Effects Resulting from Development of Tribal Water

6.0 Introduction

A series of modeling simulations were performed to quantify effects to the Colorado River System resulting from a range of future tribal water development scenarios. A set of system reliability metrics (for example, key reservoir elevations, water deliveries to non-tribal water users, etc.) were identified to indicate the effects to the Colorado River System resulting from future water development by the Partnership Tribes.

This chapter describes the approach for conducting the effects assessment and an analysis of the results.

Key Terms

Key terms used in this chapter are defined below.

Colorado River System – The portion of the Colorado River and its tributaries within the United States.

Diversion point – Location on the Colorado River or its tributaries at which water is diverted for depletion or consumptive use.

Hydrologic shortage – Unmet demand that is not the result of any policy, such as prescribed shortage delivery reductions.

Natural inflow – Calculated as gaged flow corrected for the effects of upstream reservoirs and depletions.

Policy shortage – Unmet demand that is the result of a policy, such as prescribed shortage delivery reductions.

Simulation set – A collection of model simulations that share the same Tribal Water Development Scenario, Water Supply Scenario, and Reservoir Operation Policy.

System reliability metrics – Measurements that indicate the ability of the Colorado River System to meet water delivery needs under multiple future conditions.

Trace – A single model simulation

6.1 Approach

A framework was developed to assess the effects on the Colorado River System from varying levels of future tribal water development based on the Partnership Tribes' water development scenarios coupled with different hydrologic supply scenarios. The assessment approach adopted for the Tribal Water Study is similar to that used in the Colorado River Basin Water Supply and Demand Study (Basin Study) (Reclamation, 2012). This assessment was performed by following a five-step approach:

1. Identify tribal water development scenarios
2. Develop metrics to measure system effects
3. Configure Colorado River Simulation System (CRSS)
4. Develop modeling assumptions
5. Analyze results

6.1.1 Colorado River Simulation System

The simulation of the Colorado River System under the tribal water development scenarios prepared for the Tribal Water Study was performed using CRSS. CRSS is Reclamation's primary long-term planning tool for studying river operations and projected future demand in the Basin. CRSS is implemented in the commercial modeling software RiverWare™ developed by the University of Colorado (Zagona et al., 2001).

CRSS simulates the operation of the major reservoirs on the Colorado River and provides information regarding the projected future state of the system on a monthly basis. Output variables include the amount of water in storage, reservoir elevations, releases from the dams, the amount of water flowing at various points throughout the system, and diversions to and return flows from water users throughout the system. The simulation centers around a mass balance (or water budget) calculation which accounts for water entering the system, stored in the system, and leaving the system under different policy scenarios.

The model input for the Tribal Water Study included monthly natural inflows, various physical process parameters such as evaporation rates for each reservoir, and future diversion and depletion schedules for water users in the Basin States and the United Mexican States (Mexico). Policy "rulesets" allow CRSS to simulate the operation of the Colorado River mainstream reservoirs, including Lake Powell and Lake Mead, and allow projections of water depletion under different hydrologic scenarios.

6.1.2 Five-Step Approach

A five-step approach was used to assess potential effects to the Colorado River System resulting from future tribal water development. The following is a brief summary of each step and a description of how each fits within the overall assessment. These steps are described in detail in the identified sections.

Step 1 – Identify Tribal Water Development Scenarios (Section 6.2)

Four future water development planning scenarios were identified collaboratively with the Partnership Tribes as detailed in *Chapter 4 – Methodology for Assessing Current Tribal Water Use and Projected Future Water Development*. The identified planning scenarios were Current Water Development Trends (Scenario A), Slow Water Development Trends (Scenario B), and Rapid Water Development Trends (Scenarios C1 and C2). The tribal water development schedules were quantified to represent four plausible outcomes for future water development for the period from 2017 through 2060. The future water development schedules for each Partnership Tribe are presented in *Chapter 5 – Assessment of Current Tribal Water Use and Projected Future Water Development.*

Step 2 – Develop Metrics to Measure System Effects (Section 6.3)

Key system reliability metrics (metrics) that could be evaluated from CRSS output were identified to help understand effects to the system from future tribal water development. System reliability metrics considered in this Study included the ability to meet water delivery needs throughout the Basin under multiple future conditions.

Step 3 – Configure Colorado River Simulation System (Section 6.4)

CRSS and its associated inputs were configured to evaluate the Tribal Water Study metrics outlined in Step 2. These configurations included disaggregating the four tribal water development schedules for each Partnership Tribe as inputs in CRSS along with minor structural changes in CRSS to model Tribes' water use more accurately.

Step 4 – Develop Modeling Assumptions (Section 6.5)

Several modeling assumptions were needed to fully describe required model inputs. These assumptions included initial reservoir conditions, future water supply scenarios, reservoir operation policies, tribal water development schedules, and future water demand schedules for other water users.

Step 5 – Analyze Results (Section 6.6)

The metrics identified by Step 2 were evaluated and analyzed. To evaluate the metrics, CRSS was run using the Tribal Water Study's model configuration and assumptions. CRSS is a probabilistic model, so there are multiple future simulations analyzed for each metric. To understand the results, an analysis was conducted across the CRSS simulation outputs. Statistics for each metric were computed in order to explore how a metric changes in response to tribal water development, water supply, and reservoir operations policy.

6.2 Identify Tribal Water Development Scenarios

As previously described in *Chapter 4 – Methodology for Assessing Current Tribal Water Use and Projected Future Water Development*, four tribal water development scenarios were developed to capture the range of potential future water development for the Partnership Tribes. These scenarios incorporate the key influencing factors, and account for how these factors would be influenced under each scenario, given the scenario's respective theme. The scenarios and associated themes are listed below.

- **Current Water Development Trends (Scenario A)** – Current trends in on-reservation water development, governance, funding, and resolution of tribal claims remain the same.
- **Slow Water Development Trends (Scenario B)** – Decreased flexibility in governance of tribal water, levels of funding, and resolution of tribal claims slow tribal economic development. This results in a decline in the standard of living and delays resolution of tribal claims.
- **Rapid Water Development Trends (Scenarios C1 and C2)** – Increased flexibility in governance of tribal water allows innovative water development opportunities and increased funding availability leads to tribal economic development. This results in an increase in the standard of living, thereby contributing to the fulfilment of the purpose of the reservation as a homeland and supporting the future needs of tribal communities. Scenario C1 considers partial resolution of claims and/or implementation of decreed or settled rights; and Scenario C2 considers complete resolution of claims and implementation of decreed or settled rights within the Study timeframe.

6.3 Develop Metrics to Measure System Effects

Metrics were developed in collaboration with the Partnership Tribes to identify potential effects of tribal water development on the Colorado River System and non-tribal water users. Taking into account CRSS limitations, metrics were identified for both the Upper Basin and Lower Basin including water delivery shortages, Lake Powell inflow, Lake Powell elevation, Lake

Mead elevation, and water deliveries to non-tribal water users. Shortages were not evaluated on a per-tribe or a single water user basis, rather they are reported at the basin or sub-basin level. A majority of these metrics could be evaluated directly in CRSS; however, some required additional analysis of CRSS output or exploration of models other than CRSS such as StateMod, the State of Colorado's surface water allocation and accounting model capable of simulating various historical and future water management policies in a river basin (Colorado Water Conservation Board, 2017) .

The Tribal Water Study metrics are presented in Table 6-A, and described below.

TABLE 6-A
Metrics for Upper and Lower Basin System Effects Analysis

	Variable	Measurement	Source
Upper Basin Metrics	Inflow to Lake Powell	Volume in acre-feet per year	CRSS Output
	Lake Powell Elevation	Elevation in feet above mean sea level	CRSS Output
	Upper Basin Shortage	Volume in acre-feet per year Frequency of shortage volume per year	CRSS Output
	San Juan Sub-basin Historical Shortage Analysis	Volume in acre-feet per year	Additional Analysis
Lower Basin Metrics	Lake Mead Elevation	Elevation in feet above mean sea level	CRSS Output
	Lower Basin Hydrologic Shortage	Volume in acre-feet per year Frequency of shortage volume per year	CRSS Output
	Water Deliveries to Lower Basin Non-Tribal Users	Volume in acre-feet per year	CRSS Output
	Lower Basin Present Perfected Rights Analysis	N/A	Additional Analysis

6.3.1 Upper Basin Metrics and Analyses

Inflow to Lake Powell

The volume of water flowing into Lake Powell in acre-feet per year (AFY), as simulated by CRSS. This volume was calculated on an annual time step, at the end of each calendar year.

Lake Powell Elevation

The annual December 31st elevation at Lake Powell (feet above mean sea level [msl]).

Upper Basin Shortage

Upper Basin water delivery shortage was defined as the total requested diversion minus actual diversion in a given year for sub-basins that include water use by Partnership Tribes. These sub-basins include the Green River Basin, San Juan River Basin, and the sub-basin composed of intervening flows above Lake Powell and below the San Juan River, San Rafael River, Green River, and Colorado River Basin near Cisco, Utah. Upper Basin shortage was calculated with respect to total requested diversion because Indian reserved water rights are typically diversion-based in the Upper Basin. Shortages were tracked for both Partnership Tribes and non-tribal water users and analyzed as an aggregate annual percent shortage of the requested water diversion. This percent was calculated by dividing the shortage volume by the requested diversion and multiplying by 100. These annual percent shortages were evaluated by frequency across all traces and the annual minimum, median, and maximum percent shortage of total requested diversion.

San Juan Sub-basin Historical Shortage Analysis

A limitation of CRSS is that it does not represent individual water rights and therefore may not accurately represent the distribution of water delivery shortages to Partnership Tribes versus non-tribal water users.

The San Juan sub-basin and its tributaries were selected to illustrate what effects could occur in the Upper Basin in times of shortage because tribes in this sub-basin have complex reserved water rights as set forth in tribal decrees filed in Colorado Water Division 7 (see *Chapter 5 – Assessment of Current Tribal Water Use and Projected Future Water Development* for additional detail). Additional analysis was performed based on output from the State of Colorado's water allocation and accounting model, StateMod. Water deliveries in Colorado's portion of the San Juan sub-basin for calendar years 2008 and 2012, which represent recent years with relatively high and low water supplies in the Colorado River Basin, respectively, were modeled with StateMod to identify where shortages occurred and how Partnership Tribes, specifically the Southern Ute Indian Tribe and Ute Mountain Ute Tribe, and non-tribal water users were affected. Water demands for tribal users were then increased to each tribes' full San Juan sub-basin reserved water right, and the StateMod model was run again with the 2008 and 2012 hydrology. Results were analyzed to determine how water deliveries changed between the two model runs. New Mexico water deliveries from the San Juan sub-basin and its tributaries were not included in this analysis. *Appendix 6-1 – Methodology for Conducting San Juan Sub-basin Historical Shortage Analysis* describes the methodology used to estimate historical shortages under current and development of full Indian reserved water rights in the San Juan Sub-basin in Colorado.

6.3.2 Lower Basin Metrics and Analyses

Lake Mead Elevation

The annual December 31st elevation at Lake Mead (feet above mean sea level [msl]).

Lower Basin Hydrologic Shortage

In CRSS, shortage is divided into two portions, hydrologic shortage and policy shortage. Hydrologic shortage is defined as the unmet demand in the Lower Basin and Mexico that is not the result of any policy, such as the prescribed shortage delivery reductions in the *Record of Decision for Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead* (2007 Interim Guidelines) (DOI, 2007) or Intentionally Created Surplus (ICS) activity. For example, under the 2007 Interim Guidelines, policy shortages for the Lower Basin are based upon Lake Mead's elevation, which is divided into three levels. If there is demand for 9.0 million acre-feet per year (MAFY) of water from the Lower Basin States and Mexico, but Lake Mead is below 1,025 feet, and only able to deliver 8.0

MAF of water, there would be a total hydrologic shortage of 1.0 MAF. Under the 2007 Interim Guidelines, Lake Mead would be operating under a level three shortage and annual deliveries to the Lower Basin would be reduced by 625 thousand acre-feet (KAF). This policy shortage would account for 625 KAF of the 1.0 MAF shortage volume, and the remaining 375 KAF of shortage would be labeled hydrologic shortage. For the hydrologic shortage analysis, shortages were not broken out by state or by tribal and non-tribal water users but reported as total Lower Basin and Mexico shortage because CRSS does not account for how shortage would affect individual water users. Shortages in the Lower Basin are calculated with respect to total requested consumptive use. Shortages were analyzed as an aggregate annual percent shortage of the requested consumptive use. This percent was calculated by dividing the shortage volume by the requested consumptive use, and multiplying by 100. These annual percent shortages were evaluated by frequency across all traces and the annual minimum, median, and maximum percent shortage of total requested consumptive use.

Water Deliveries to Lower Basin Non-Tribal Users

Water deliveries to non-tribal water users are defined as consumptive use by non-tribal water users in the Lower Basin and Mexico. This metric was not broken out by water user but reported as a combined Lower Basin and Mexico value. Water deliveries to non-tribal users were computed by summing all consumptive use in the Lower Basin plus Mexico and subtracting the Lower Basin Partnership Tribes' consumptive use per the tribal water development schedules for that year.

Lower Basin Present Perfected Rights Analysis

In the Lower Basin, additional post processing was performed to better understand the Present Perfected Rights (PPRs) of Lower Basin Partnership Tribes, and the effect of water delivery shortages to Partnership Tribes. Analysis of this metric explored whether the hydrologic shortage magnitude is great enough to affect tribal PPR water rights holders and was performed as a qualitative discussion of potential effects on Partnership Tribes under existing law.

6.4 Configure Colorado River Simulation System

For use in CRSS, the Partnership Tribes' future water development schedules were disaggregated by each tribe's diversion points as currently represented in CRSS. The disaggregation was determined by analyzing tribal use by sub-basin in the Upper Basin, and by state in the Lower Basin, with the assistance of each tribe.

To include the Partnership Tribes' water development schedules in CRSS, each Upper Basin reach and Lower Basin State were matched to the corresponding tribal water diversion points within CRSS. For some Partnership Tribes, assumptions had to be used to disaggregate their water use because of a limited availability of information. The first disaggregation approach used a ratio methodology and was applied when future use information by reach was limited. In this case, water use schedules for Slow Water Development Trends (Scenario B), and Rapid Water Development Trends Scenarios (C1 and C2) were assigned for each diversion point by preserving the Current Water Development Trends (Scenario A) water use ratio. For example, if a tribe has two agricultural water diversions on a reach, under Scenario A, 30 percent of the total agricultural water use was assigned to the tribe's first diversion point and 70 percent to the tribe's second diversion point. For all other scenarios, the future agricultural water use was disaggregated over the two diversion points using this same ratio. The second disaggregation approach was used when there were multiple types of water use at a single diversion point for a tribe. This methodology maintained the ratios of water use types currently in the official CRSS model, which presently relies on the 2007 Upper Colorado River Commission (UCRC) schedule provided by the Upper Division States for all of the future water development scenarios. In both approaches, total water use in a given reach or state was not allowed to exceed the Partnership Tribe's quantified water right for that reach or state.

For non-tribal diversion points in CRSS, water use schedules were broken out from annual to monthly time steps by distributing annual water use to each month based on the monthly coefficients from the original CRSS water use schedules before adding the tribal water development schedules.

A structural change was made to CRSS to improve water delivery priority modeling on the Duchesne River, Utah. Because the Ute Indian Tribe has a senior water right on the Duchesne River, their diversion point was moved from the aggregate reach located below the Starvation Reservoir to the aggregate reach above the Starvation Reservoir. This configuration ensured that the Tribe's demands were met before non-tribal demands.

6.5 Develop Modeling Assumptions

As with any modeling effort, assumptions needed to be made to use the model. Some assumptions made for this analysis included the model simulation period and initial reservoir conditions. Key model simulation assumptions included future hydrology (using multiple future water supply scenarios, described below), water demands, and reservoir operations policy. These assumptions are similar to those incorporated into the Basin Study modeling efforts.

The modeling simulation period selected was from January 2017 through December 2060. CRSS simulations must begin in January due to model constraints and because it was not yet January 2017 when modeling occurred, a projection of Colorado River System conditions was needed. Reservoir starting conditions for CRSS were taken from Reclamation's *Operation Plan for Colorado River System Reservoirs, August 2016 24-Month Study Report* (Reclamation, 2016) and are consistent with the Lake Powell and Lake Mead initial reservoir conditions used for the August 2016 CRSS simulation as reported in, *The Colorado River System: Projected Future Conditions 2017-2021,* (Reclamation, 2016b).

Modeling assumptions included future water supply, water demands, and reservoir operations policy. The future water supply scenarios selected from the Basin Study for the Tribal Water Study were the Observed Natural Flow and the downscaled Global Climate Model scenarios. The Observed Natural Flow scenario was selected because it captures the recently updated observed historical flows. The Global Climate Model scenario was selected because it provides the largest plausible range of future natural flows in terms of both magnitude and length of sequences of wet and dry spells. The Observed Natural Flow water supply scenario assumes that future hydrologic trends and variability are similar to the past approximately 100 years. It uses the indexed sequential method (Ouarda et al., 1997) to resample the observed natural flow data from the historical natural flow record. This method can only generate hydrology inputs with observed flow magnitudes and sequences, and preserves historical data statistics. The Global Climate Model water supply scenario assumes that future climate will continue to warm with regional precipitation and temperature trends represented through an ensemble of future downscaled global climate model projections and simulated hydrology. The Global Climate Model scenario contains traces from 16 general circulation models with three emissions scenarios, and provides runoff projections based on the World Climate Research Program's Coupled Model Intercomparison Project Phase 3 (CMIP3) (Maurer et al., 2007) projected climate assumptions (see Basin Study, *Technical Report B – Water Supply Assessment* [Reclamation, 2012a]).

Water demands were represented for the Partnership Tribes and non-tribal water users. The Partnership Tribes used their individually-identified water development schedules (Current Water Development Trends [Scenario A]; Slow Water Development Trends [Scenario B]; Rapid Water Development Trends [Scenarios C1 and C2]). Non-tribal water users' demands were held consistent throughout all four water development scenarios ensuring that differences in model results between scenarios were only the result of future water development by the Partnership Tribes. The Upper Basin non-tribal demands were obtained from the 2007 UCRC schedule. The Lower Basin non-tribal demands were those used for the 2007 Interim Guidelines. Lower Basin non-tribal demands were increased or decreased for each tribal water development schedule to ensure consumptive use in the Lower Basin did not exceed the annual normal apportionment, giving the Lower Basin States an annual scheduled consumptive use volume of 7.5 MAF.

Two different reservoir operation policy sets were evaluated. Both policy sets operated Lake Powell and Lake Mead according to the 2007 Interim Guidelines between 2017 through 2026. After the expiration of the 2007 Interim Guidelines in 2026, two operational assumptions were considered. The first was that the Shortage, Surplus, and Coordinated Operations provisions of the 2007 Interim Guidelines would be extended through the Tribal Water Study's timeframe of 2060 (*Interim Guidelines Extended* policy). The second was that the operating rules revert to the rules of the No Action Alternative from the *Colorado River Interim Guidelines for Lower Basin Shortages and Coordinated Operations for Lake Powell and Lake Mead Final Environmental Impact Statement* (2007 Interim Guidelines Final EIS) (Reclamation, 2007) (*Interim Guidelines Expire in 2026* policy). These two reservoir operation policy sets were also used for the Basin Study analysis.

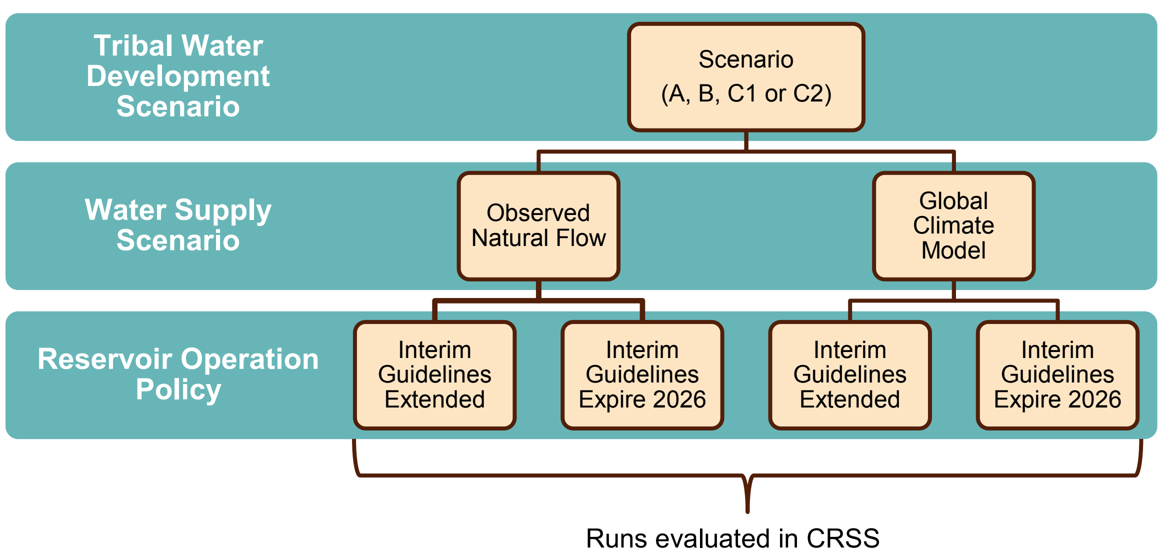
The reservoirs upstream of Lake Powell were operated to meet specific targets reflecting each reservoir's respective Record of Decision (ROD) for the entire modeling simulation period. Taylor Park, and Starvation reservoirs were operated in accordance with their existing rule curves (see *Appendix A, CRSS Model Documentation* [Reclamation, 2007]), but Fontenelle's operations rules in CRSS have been updated since the 2007 Interim Guidelines (Reclamation, 2012). In CRSS, the Aspinall Unit operations do not yet reflect the Record of Decision for the Aspinall Unit Operations Final Environmental Impact Statement (Reclamation, 2012b), and were operated in accordance with their previous rule curves, as published in the 2007 Interim Guidelines Final EIS) (see *Appendix A, CRSS Model Documentation* [Reclamation, 2007]). The operations rules for Navajo and Flaming Gorge reservoirs were modified in CRSS to meet specified downstream flow targets in accordance with the rules laid out in their respective RODs (Reclamation, 2006a and 2006b).

The four tribal water development scenarios were modeled with both water supply scenarios, and both reservoir operation policies, as shown in Figure 6-A. That is, each water development scenario was run with:

- Observed Natural Flow water supply scenario
    - *Interim Guidelines Extended* policy
    - *Interim Guidelines Expire in 2026* policy
- Global Climate Model water supply scenario
    - *Interim Guidelines Extended* policy
    - *Interim Guidelines Expire in 2026* policy

This provided a total of 4 simulation sets for each water development scenario. These four simulation sets were repeated for the four water development scenarios, which provided 16 simulation sets with a combined total of 1,752 simulations, also termed 'traces', which were evaluated in the analysis. Each trace reflected one combination of supply, development, and reservoir operation policy. Traces were grouped to explore the effects of tribal water development under the water supply scenarios, the tribal water development scenarios, and the reservoir operation policies.

FIGURE 6-A
Conceptual Representation of the Modeling Performed for a Given Development Scenario



6.6 Analyze Results

Upon configuring and simulating with the model, the 16 simulation sets provided 1,752 traces of data for analysis. These data were grouped by water supply scenario, tribal water development scenario, and reservoir operation policy and were analyzed for each metric to assess the effect of each tribal water development scenario. The following results are divided by Upper and Lower Basin, and contain the metrics and the results for the corresponding basin.

6.6.1 Upper Basin Modeling Results

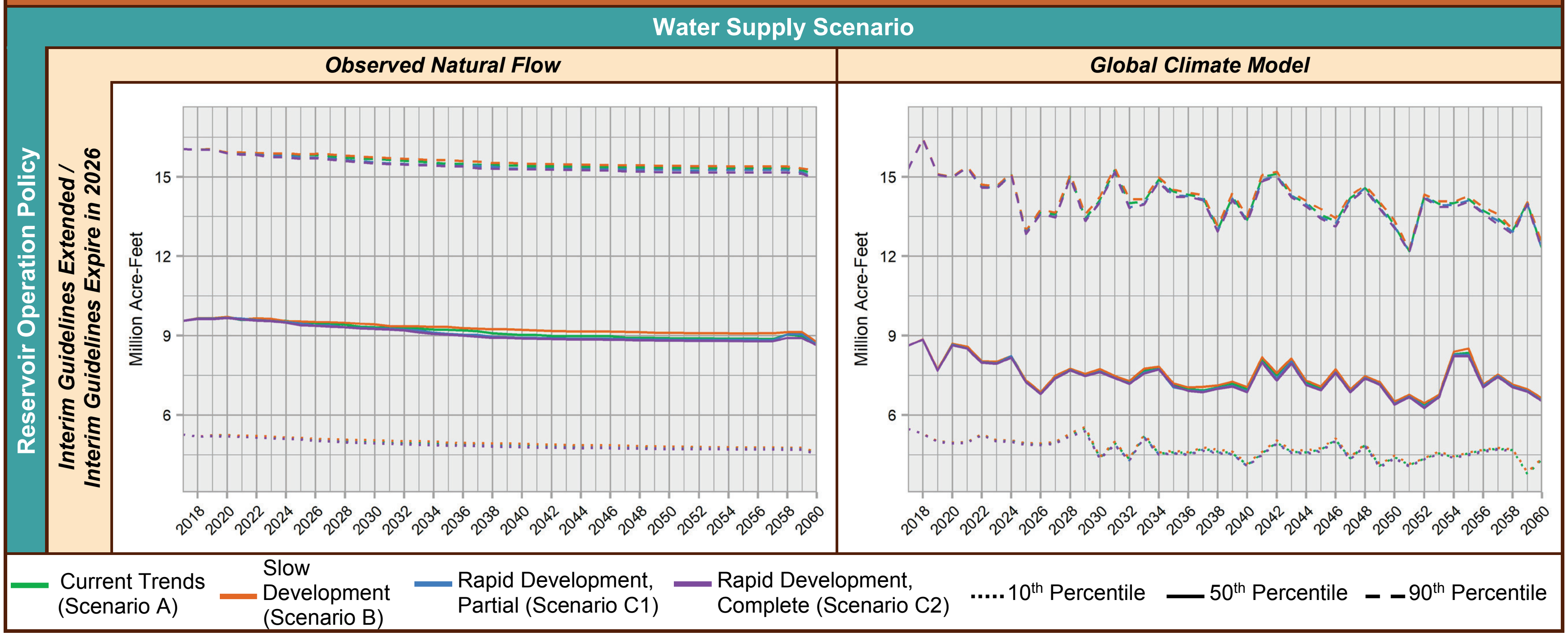
Figure 6-B is organized by supply scenario and Figure 6-C is organized by supply scenario and reservoir operations policy, with the Observed Natural Flow supply scenario used in the panels on the left, the Global Climate Model supply scenario used in the panels on the right, the *Interim Guidelines Extended* policy used in the panels on the top and the *Interim Guidelines Expire in 2026* policy used in the panels on the bottom. Figure 6-D is organized by supply scenario with the Observed Natural Flow supply scenario in the top panels and the Global Climate Model supply scenario in the bottom panels and further split by aggregate annual percent shortage as a frequency in the left panels, and as the minimum, median, and maximum aggregate annual shortage percent in the right panels.

Metric – Inflow to Lake Powell

Figure 6-B shows the inflow into Lake Powell across the model results. By 2060, the volume of water flowing into Lake Powell had annual ranges of 328 KAF for the Observed Natural Flow supply scenario (left panel) and 290 KAF (right panels) for the Global Climate Model supply scenario (right panels). These ranges resulted from differences between the inflow volume for Slow Water Development Trends (Scenario B), and Rapid Water Development Trends, Complete (Scenario C2). These scenarios define the range because they exhibit the slowest (Scenario B) and most rapid (Scenario C2) rates of tribal water development. A larger inflow volume range was experienced across water supply scenarios than across development scenarios, indicating the water supply scenarios exhibit more influence on inflow volume into Lake Powell than the tribal water development scenarios.

For this metric, the inflows for each water supply scenario do not vary by reservoir operating policy because these policies do not affect reservoir operations above Lake Powell. Therefore, Figure 6-B only shows results for the two water supply scenarios.

FIGURE 6-B
Annual Inflow into Lake Powell (2017 – 2060)



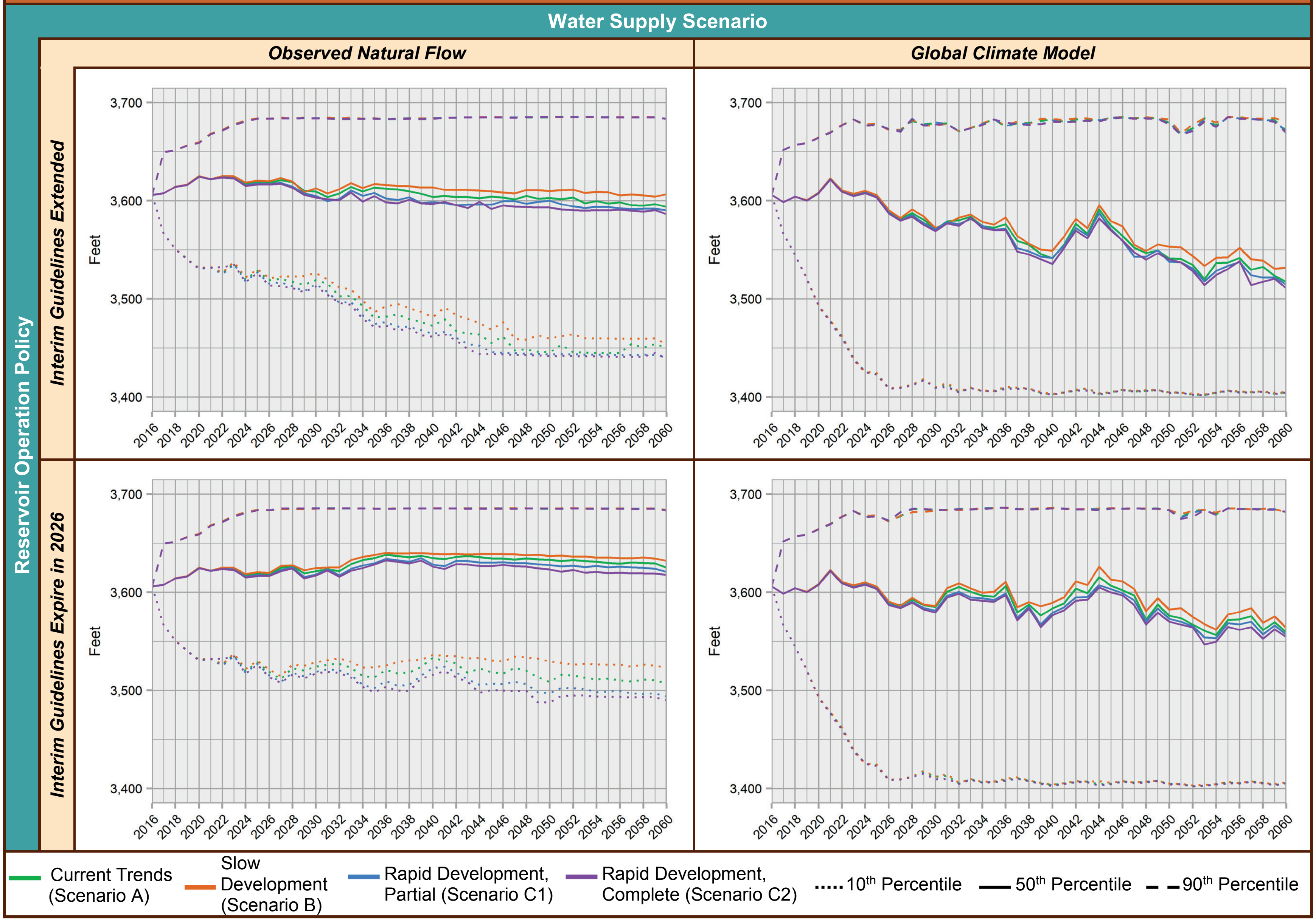
Metric – Lake Powell Elevation

Figure 6-C shows Lake Powell elevation across results. At the 50th percentile (solid line), the tribal water development schedules show a range of Lake Powell elevations. This range was bounded by Slow Water Development Trends (Scenario B), and Rapid Water Development Trends, Complete (Scenario C2), and displays differences in elevation as large as 21 feet by 2060. This difference was due to Upper Basin tribal water development.

Differences in elevations across the Observed Natural Flow supply scenario are more pronounced when Lake Powell is at lower water levels, such as those seen in the 10th percentile (dotted line). The 10th percentile represents the lowest 10% of elevations seen in the results for a given year. In Figure 6-C, the 10th percentile exhibits a range of 33 feet in the difference between Slow Water Development Trends (Scenario B) and Rapid Water Development Trends, Complete (Scenario C2), which again bound this range, by 2060. This comparison indicates that the system is more affected by Upper Basin tribal water development when water supplies are low.

Under the Global Climate Model scenario, the 10th percentile (dotted line) displays little effect from Upper Basin tribal water development, resulting in little to no range across the tribal water development scenarios. Under the Global Climate Model supply scenario this occurs because Lake Powell elevation is constrained as the reservoir approaches the dead pool elevation (3,370 feet), when the reservoir is unable to release water downstream.

FIGURE 6-C
Annual Lake Powell Elevation (2017 – 2060)

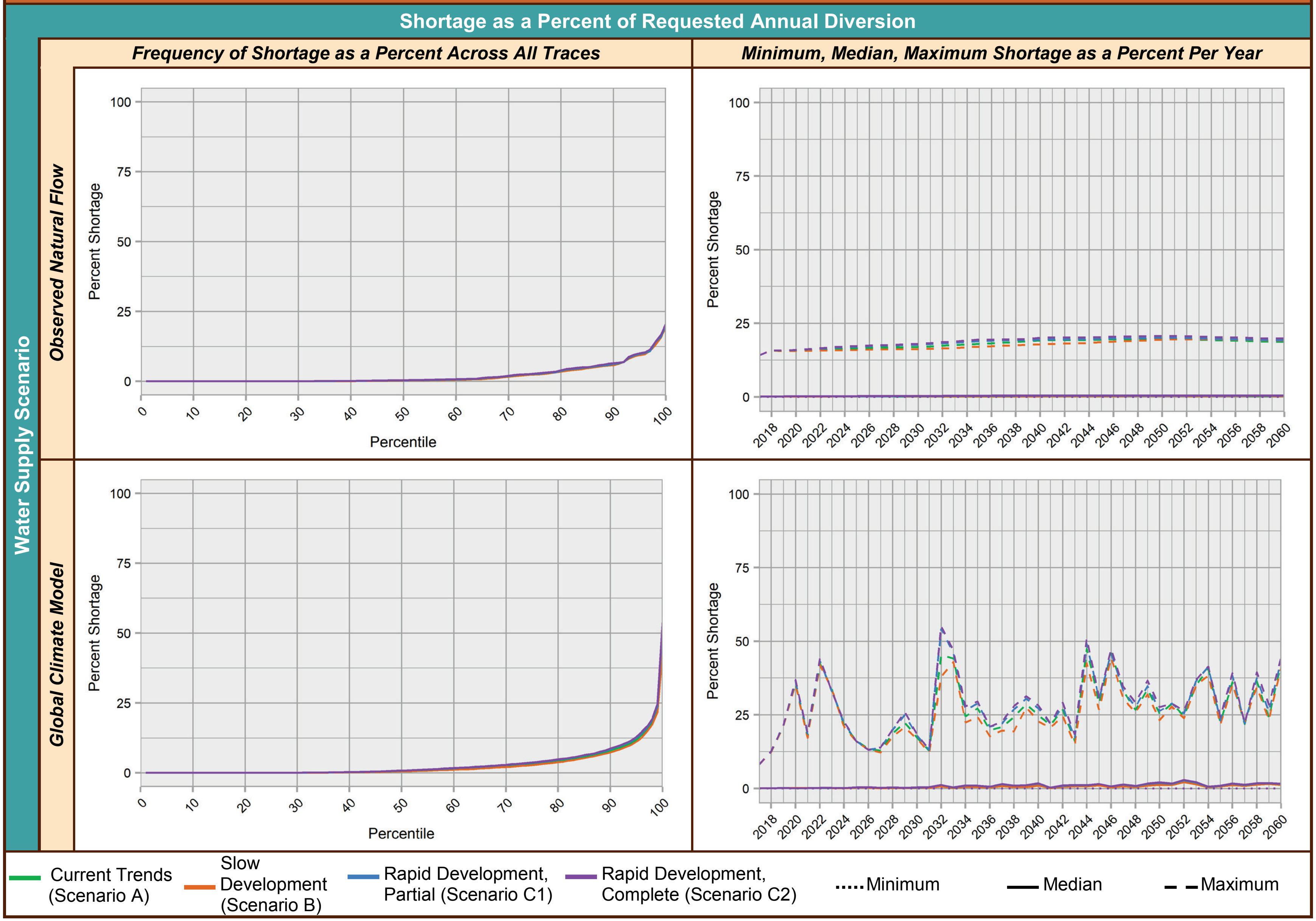


Metric – Upper Basin Shortage

Figure 6-D shows the aggregate annual percent shortage. The percent shortage represents the percent of the requested annual diversion that was not delivered. This metric provides context regarding the severity of the shortage volume with respect to demand. The left panels show the percent shortage as a frequency across all traces and the right panels show the annual minimum, median, and maximum percent shortage in the Upper Basin, seen across all impacted Upper Basin sub-basins. These sub-basins include the Green River and San Juan sub-basins, and their intervening flows. This shortage is shown as a percent of annual diversion requested. Results are further split out by supply scenario, with the Observed Natural Flow supply scenario in the top two panels and the Global Climate Model supply scenario in the bottom two panels. Because the modeled reservoir operation policies do not effect reservoir operations above Lake Powell, the results produced by both policy sets are identical for each supply scenario.

The Upper Basin experiences some level of shortage in all years because its water supplies are more dependent on natural streamflows, which are fed directly by snowpack and rainfall, and are affected by localized drought patterns. Across the development schedules, the Upper Basin Shortage metric showed greater variability due to water supply than to tribal water development, with little difference seen between the development schedules.

FIGURE 6-D
Upper Basin Percent Shortage of Diversion Requested



San Juan Sub-basin Historical Shortage Analysis

Tables 6-B and 6-C shows the depletion and shortage volumes for both tribal and non-tribal water use within Colorado's San Juan sub-basin for the years 2008 and 2012, respectively, as modeled using the State of Colorado's water allocation and accounting model, StateMod. Both the Southern Ute Indian Tribe and the Ute Mountain Ute Tribe have water rights in this sub-basin within the State of Colorado. Water uses within the New Mexico portion of the San Juan Basin were not considered for this analysis. Using each year's historical hydrology, water use was first modeled with the given year's actual tribal and non-tribal water use, and then a second model run was performed, in which tribal water use was increased to the Tribes' full reserved water right. This analysis was performed for both 2008 and 2012. The results were grouped geographically, with water use above the Archuleta USGS stream gage comprising one grouping, and water use between the Archuleta and Bluff USGS stream gage comprising the second grouping.

In the San Juan sub-basin, the year 2008 was a relatively wet year and the year 2012 was a relatively dry year. When compared to the average flow for the past 30 years (1985 to 2014), the year 2008 saw flows 134 percent greater than the average flow at the Archuleta stream gage and 122 percent greater at the Bluff stream gage. In contrast, the year 2012 saw flows 52 percent lower than average at the Archuleta stream gage and 48 percent lower at the Bluff stream gage. When moving from 2008 observed water use to the full development of tribal rights, the Tribes' water use increases, with depletions above Archuleta more than twice as large, and depletions from Archuleta to Bluff more than four times as large. Full development of tribal water rights did not cause additional tribal shortages above Archuleta; however non-tribal shortages increased by 246 acre-feet (AF) from the 2008 observed water use to the full development of tribal water rights, and increased by 6,310 AF in the 2012 analysis. From Archuleta to Bluff, the non-tribal shortages increased by 6,678 AF from the 2008 observed water use to the full development of tribal water rights, and increased by 13,571 AF in the 2012 analysis. Tribal shortages were also experienced in the Archuleta to Bluff reach when the Tribes' use was increased to full development of water rights, with the Ute Mountain Ute Tribe experiencing 3,681 AF of shortage in the 2008 and 2012 analyses. The non-tribal shortages seen in the 2012 analysis were larger than those seen in the 2008 analysis by approximately 20 to 24 percent, as the year 2012 experienced relatively dry conditions for the San Juan sub-basin.

TABLE 6-B
San Juan Basin in Colorado Depletion and Shortage Volumes for Tribal and Non-Tribal Water Users – 2008

Location	Tribal Depletions	Non-Tribal Depletions	Total Depletions	Tribal Shortages	Non-Tribal Shortages	Total Shortages
2008 Current Use Results – San Juan and tributaries in Colorado (AF)						
Above Archuleta	19,778[1]	128,121	147,889	0	3,155	3,155
Shortage as Percent of Use				*0%*	*14%*	*2%*
Archuleta to Bluff	15,808[2]	176,326	192,134	0	17,773	17,773
Shortage as Percent of Use				*0%*	*9%*	*8%*
2008 Tribal Full Water Right Use Results – San Juan and tributaries in Colorado (AF)						
Above Archuleta	42,656[1]	127,875	170,530	0	3,401	3,401
Shortage as Percent of Use				*0%*	*3%*	*2%*
Archuleta to Bluff	65,060[3]	168,648	233,708	3,681[4]	24,451	29,132
Shortage as Percent of Use				*5%*	*13%*	*11%*

[1] Southern Ute Indian Tribe
[2] 12,863 AF Ute Mountain Ute Tribe; 2,945 AF Southern Ute Indian Tribe
[3] 44,074 AF Ute Mountain Ute Tribe; 20,986 AF Southern Ute Indian Tribe
[4] Ute Mountain Ute Tribe Shortages

TABLE 6-C
San Juan Basin in Colorado Depletion and Shortage Volumes for Tribal and Non-Tribal Water Users – 2012

Location	Tribal Depletions	Non-Tribal Depletions	Total Depletions	Tribal Shortages	Non-Tribal Shortages	Total Shortages
2012 Current Use Results – San Juan and tributaries in Colorado (AF)						
Above Archuleta	19,778[1]	95,117	114,895	0	26,637	26,637
Shortage as Percent of Use				*0%*	*22%*	*19%*
Archuleta to Bluff	15,808[2]	148,619	164,427	0	59,727	59,727
Shortage as Percent of Use				*0%*	*29%*	*27%*
2012 Tribal Full Water Right Use Results – San Juan and tributaries in Colorado (AF)						
Above Archuleta	42,656[1]	88,807	131,463	0	32,947	32,947
Shortage as Percent of Use				*0%*	*27%*	*20%*
Archuleta to Bluff	65,060[3]	135,048	200,108	3,681[4]	73,298	76,979
Shortage as Percent of Use				*5%*	*35%*	*28%*

[1] Southern Ute Indian Tribe
[2] 12,863 AF Ute Mountain Ute Tribe; 2,945 AF Southern Ute Indian Tribe
[3] 44,074 AF Ute Mountain Ute Tribe; 20,986 AF Southern Ute Indian Tribe
[4] Ute Mountain Ute Tribe Shortages

6.6.2 Lower Basin Modeling Results

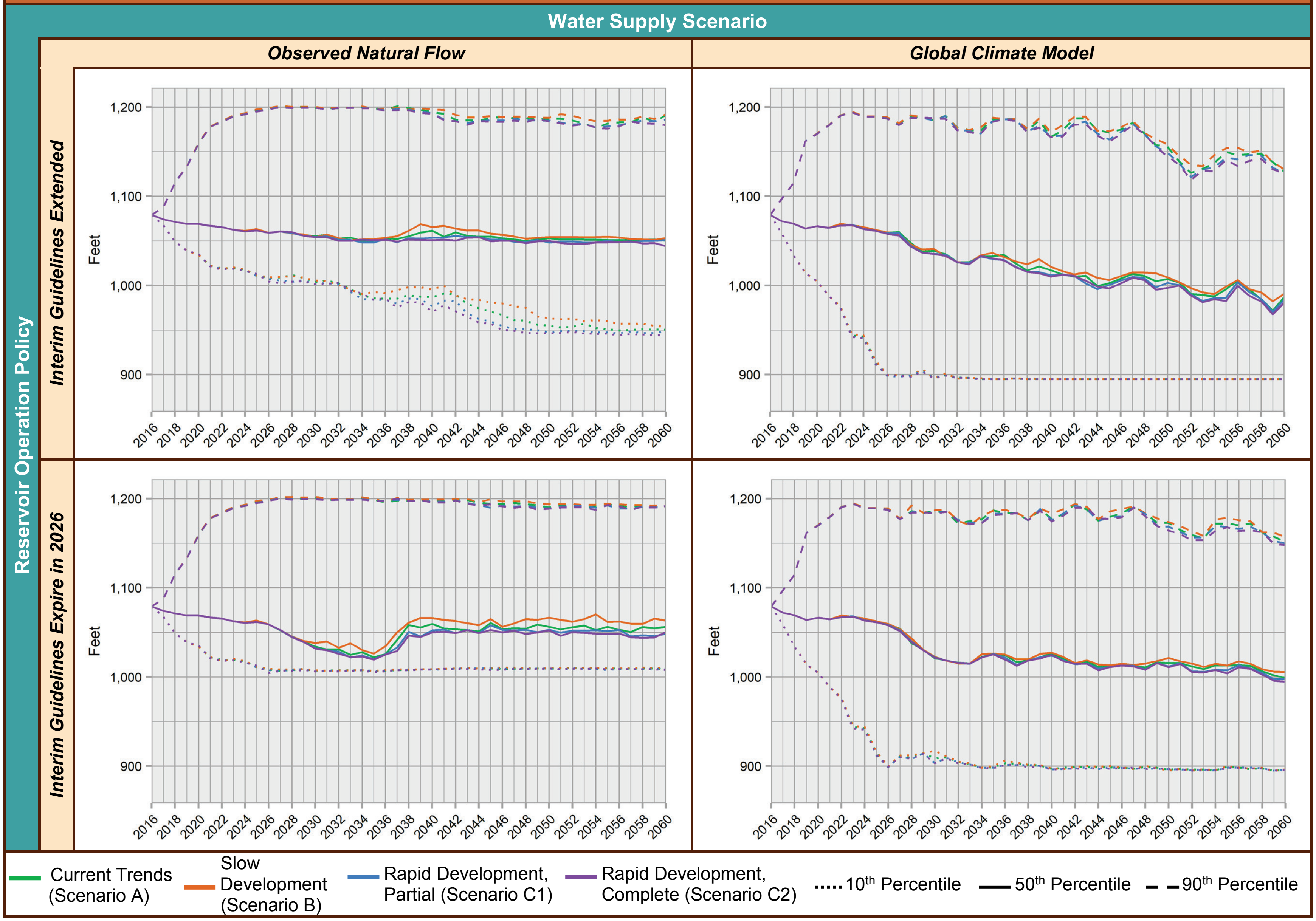
Metric – Lake Mead Elevation

Figure 6-E shows the Lake Mead elevations across the model results. The results were organized by supply scenario and reservoir operations policy, with the Observed Natural Flow supply scenario used in the panels on the left, the Global Climate Model supply scenario used in the panels on the right, the *Interim Guidelines Extended* policy used in the top panels and the *Interim Guidelines Expire in 2026* policy used in the bottom panels.

At the 50th percentile (solid line), the tribal water development schedules show a range of effects on Lake Mead elevations. This range was bounded by Slow Water Development Trends (Scenario B), and Rapid Water Development Trends, Complete (Scenario C2), and displays differences as large as 13 feet by 2060. This difference was driven by Upper Basin tribal water development, as was also seen at Lake Powell, because the Lower Basin uses its full normal apportionment and is not allowed to deplete above that apportionment. Tribal water development by the Lower Basin Partnership Tribes would move water use from non-tribal to tribal use as shown in Figure 6-H.

Lake Mead's elevation shows more differences as a result of water supply scenarios than it does as a result of Upper Basin tribal water development. At the 10th percentile (dotted line) there is generally little effect from Upper Basin tribal water development, resulting in little to no range across the tribal water development scenarios. Under the Global Climate Model supply scenario this occurs because Lake Mead elevation is constrained as the reservoir approaches the dead pool elevation (895 feet), when the reservoir is unable to release water downstream. When the Observed Natural Flow supply scenario is coupled with the *Interim Guidelines Expire in 2026* policy, this occurs because the elevation of 1,000 feet at Lake Mead is protected, constraining elevation variation after 2026. The Observed Natural Flow supply scenario under the *Interim Guidelines Extended* policy is the only scenario combination that does not exhibit these physical and policy constraints.

FIGURE 6-E
Annual Lake Mead Elevation (2017 – 2060)



Metric – Lower Basin Hydrologic Shortage

Figures 6-F and 6-G shows the aggregate annual percent of hydrologic shortage. The percent of hydrologic shortage represents the percent of the requested annual consumptive use that was not delivered. This metric provides context regarding the severity of the shortage volume with respect to demand. The left panels show the percent of hydrologic shortage as a frequency across all traces and the right panels show the annual minimum, median, and maximum percent of hydrologic shortage in the Lower Basin, seen across all Lower Basin States and Mexico, for the Observed Natural Flow supply scenario (Figure 6-F) and the Global Climate Model supply scenario (Figure 6-G). The results were further split by reservoir operations policy, with the *Interim Guidelines Extended* policy results in the top panels and the *Interim Guidelines Expire in 2026* policy results in the bottom panels.

For the Lower Basin generally, little change is seen in the percent of hydrologic shortage frequency and minimum, and median percent of hydrologic shortages due to tribal water development. Hydrologic shortage was more influenced by variations in water supply, with percent of hydrologic shortages seen at an increased frequency and magnitude under the Global Climate Model supply scenario (Figure 6-G) than the Observed Natural Flow supply scenario (Figure 6-F). This is because the Global Climate Model supply scenario's traces contain more low water supply years than contained in the Observed Natural Flow supply scenario.

Under the Observed Natural Flow supply scenario, hydrologic shortage only occurred under the *Interim Guidelines Extended* policy, and occurred less than five percent of the time. Hydrologic Shortage did not occur under the Interim Guidelines Expire 2026 policy because after 2026, the reservoir operating rules reverted to the rules of the No Action Alternative from the 2007 Interim Guidelines Final EIS. This alternative prevents Lake Mead's elevation from declining below 1,050 feet with approximately an 80 percent probability. Should Lake Mead's elevation continue to decline, the alternative imposes further reduction to keep Lake Mead's elevation above 1000 feet. This shortage is called a "policy" shortage (while not representing official policy of the Department of Interior with regard to future determinations). Because of the flexibility of this policy to reduce the volume of downstream deliveries as needed, hydrologic shortage was never achieved under the Observed Natural Flow supply scenario.

Further, under the Observed Natural Flow supply scenario, tribal water development affected the percent of maximum hydrologic shortage magnitude when it occurred, as seen in Figure 6-F (upper-right panel), providing a range of hydrologic shortage percentages at the maximum value for each year (dashed line). This range was bounded by Slow Water Development Trends (Scenario B), and Rapid Water Development Trends, Complete (Scenario C2), and displays a difference of approximately 23 percent (or 2.07 MAF) on average.

FIGURE 6-F
Lower Basin Hydrologic Shortage as Percent of Requested Consumptive Use, Observed Natural Flow Water Supply Scenario

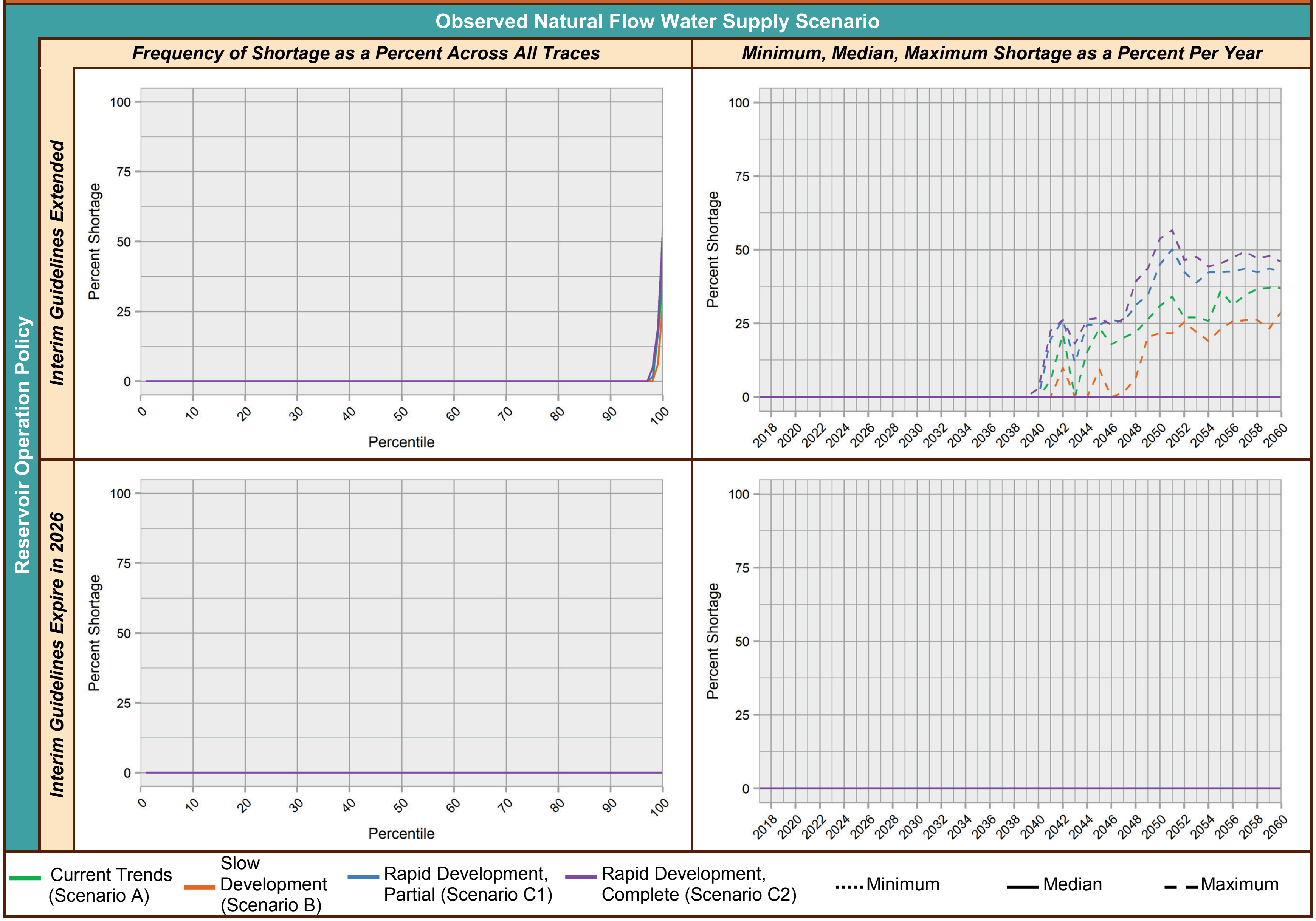
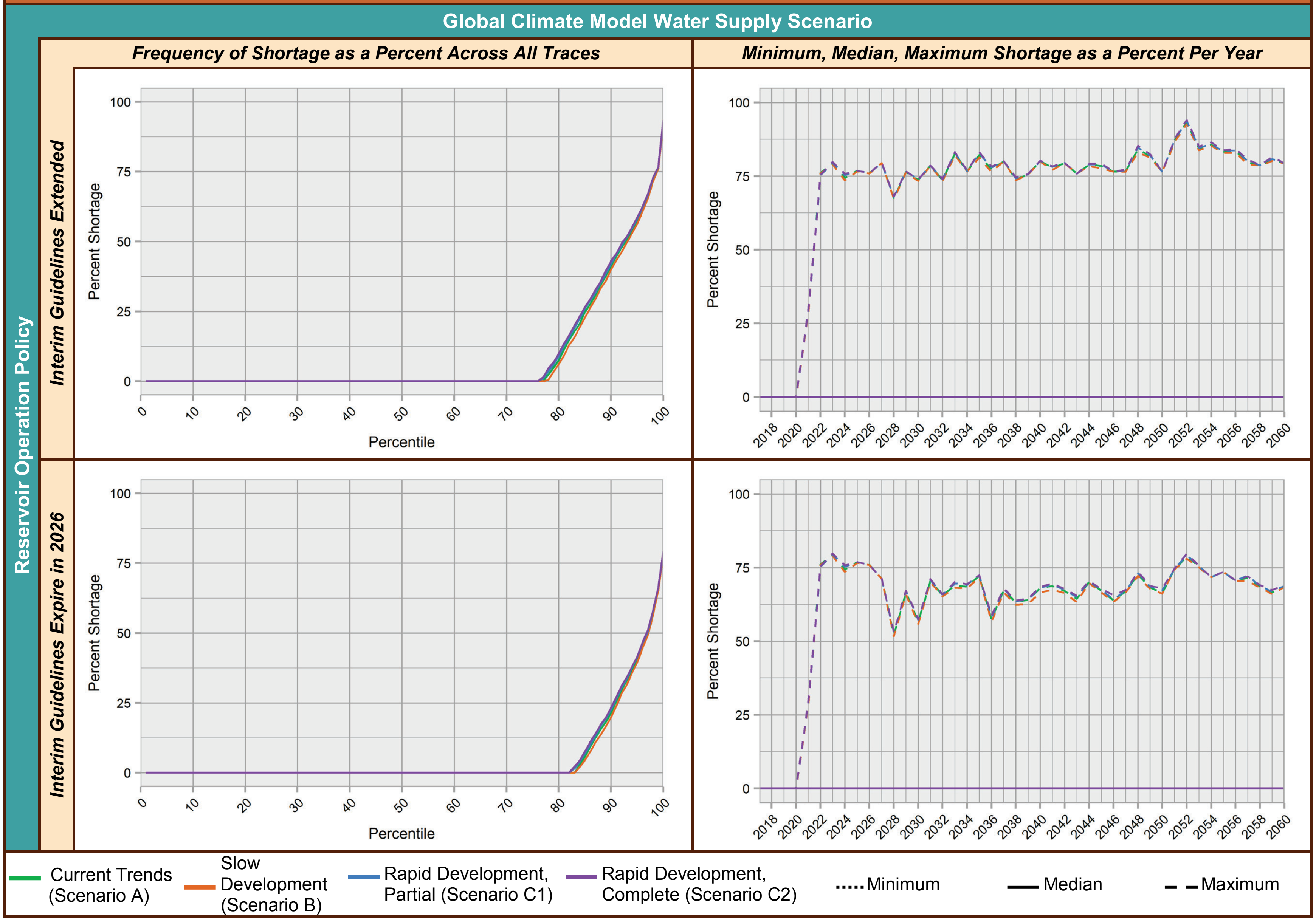


FIGURE 6-G
Lower Basin Hydrologic Shortage as Percent of Requested Consumptive Use, Global Climate Model Water Supply Scenario

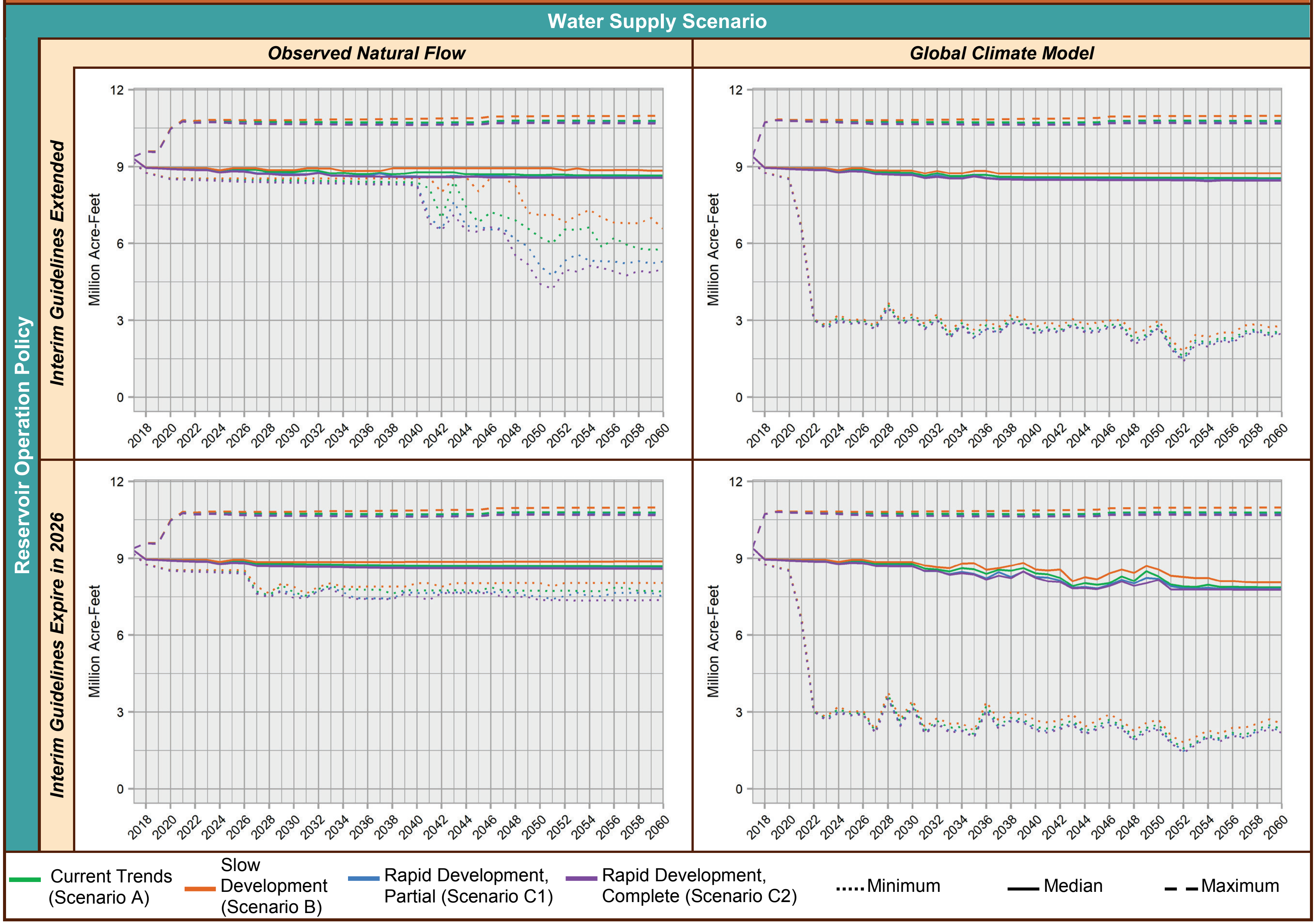


Metric – Water Deliveries to Lower Basin Non-Tribal Users

Figure 6-H shows the annual consumptive use of non-tribal water users in the Lower Basin and Mexico. Results are split out by supply scenario and reservoir operations policy, with the Observed Natural Flow supply scenario in the left panels, the Global Climate Model supply scenario in the right panels, the *Interim Guidelines Extended* policy in the top panels, and the *Interim Guidelines Expire in 2026* policy in the bottom panels.

Less of an effect was seen to non-tribal water users under Slow Water Development Trends (Scenario B) than seen in Current Water Development Trends (Scenario A), and Rapid Water Development Trends (Scenarios C1 and C2). This was because Scenarios A, C1, and C2 contain faster rates of tribal water development than Scenario B. In Figure 6-H, a slight decreasing trend is seen at the median non-tribal consumptive use across all water development scenarios, which corresponds with a shift in water use from non-tribal use to tribal use as the Lower Basin Partnership Tribes develop their water. Again, more variability was seen with respect to the Global Climate Model water supply scenario than with the tribal water development scenarios.

FIGURE 6-H
Lower Basin Non-Tribal Consumptive Use



Metric – Lower Basin Present Perfected Rights Analysis

The Partnership Tribes in the Lower Basin have some of the most senior water rights on the Colorado River, and in the event of insufficient mainstream water to satisfy all deliveries, the Secretary shall first provide for the satisfaction in full of all rights of the Chemehuevi Indian Reservation, Cocopah Indian Reservation, Fort Yuma Indian Reservation (Quechan Indian Tribe), Colorado River Indian Reservation, and Fort Mojave Indian Reservation.[1] Shortage effects on tribes are therefore dependent on the severity of the shortage in the Lower Basin versus the level of tribal water development. For example, if the Partnership Tribes developed their water to their full diversion rights and historical efficiencies were assumed, tribal water consumptive use would be 722 KAF. Therefore, the Lower Basin's shortage would have to exceed 6.78 MAF for the Partnership Tribes to be affected. Shortages greater than 6.78 MAF were seen in less than one percent of all years, and only occurred under Global Climate Model water supply scenario.

6.7 Summary

This analysis quantified the effects on the Colorado River System due to a range of future tribal water development scenarios. These water development scenarios were evaluated over two future water supply scenarios - one that assumes future streamflow will reflect what has been experienced in the past 107 years (1906-2012) and one that assumes lower average future streamflow and longer drought cycles as projected by global climate models.[2] While the Colorado River System was affected by the Partnership Tribes' development of tribal water, the future water supply scenarios had the greatest effect on the System.

In the Upper Basin, the tribal water development scenarios produced a range of Lake Powell inflow volumes by 2060, with the Observed Natural Flow supply scenario exhibiting an average annual inflow difference of 328 KAF across the tribal water development scenarios, and the Global Climate Model supply scenario exhibiting a range of 290 KAF. At Lake Powell, this translated into a 21-foot difference in elevation across the tribal water development scenarios at the 50th percentile. The effect of tribal water development on Lake Powell's elevation was more pronounced in traces that were water stressed, providing a 33 foot range across the tribal water development scenarios at the 10th percentile. However, Upper Basin shortage showed little variation due to tribal water development, and the shortage frequency and volume showed greater sensitivity to changes in water supply than it did to tribal water development.

In the Lower Basin, effects on water availability for all users due to tribal development were caused by tribal development in the Upper Basin. This is because the Lower Basin uses its full normal apportionment, and for this analysis, the Lower Basin was not allowed to deplete above that apportionment. The tribal water development in the Lower Basin was accounted for as a change in water use from non-tribal to tribal, and did not affect the overall water availability to the Lower Basin, but did affect the water availability to non-tribal users. Variations in Lake Mead elevation were seen across the tribal water development scenarios, with a 13-foot range in

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[1] *Arizona v. California,* 547 U.S. 150, 167 (2006).

[2] Recent modeling efforts in the Colorado River Basin have focused on flows based on the climate from 1988 to 2015, which encompasses the current drought period. The average flow in the Colorado River at Lees Ferry used in the Tribal Water Study was 14.9 MAF, while the average flow for the 1988 to 2015 period was 13.2 MAF, which is 13 percent lower. The average flow 2017 through 2060 at Lees Ferry under the Global Climate Model was projected as 13.6 MAF.

elevation at the 50^{th} percentile by 2060. Shortage volumes in the Lower Basin were primarily influenced by water supply, with little to no variation seen due to the tribal water development scenarios when modeled with the Global Climate Model supply scenario. The deliveries to non-tribal users were affected more by Current Water Development Trends (Scenario A) and two Rapid Water Development Trends (Scenarios C1 and C2) than they were by the Slow Water Development Trends (Scenario B). This is because Scenarios A, C1 and C2 included faster rates and larger volumes of tribal water development than did Scenario B.

The water supply scenarios had a noticeable influence on the metrics evaluated when the Colorado River System was water stressed. This was best exhibited with the Global Climate Model supply scenario, which contains more years of reduced supply than the Observed Natural Flow supply scenario. When the Colorado River System experienced high levels of water stress, the magnitude of shortages were large enough to minimize the influence of tribal water development seen on the metrics as compared with the water supply scenarios effects. In these instances water users in the Upper Basin, both the Partnership Tribes and non-tribal, could experience shortages regardless of the level of tribal water development. The effect of the water supply scenarios were particularly noticeable at Lake Powell. Under the Observed Natural Flow supply scenario, the range between the current, rapid, and slow water development scenarios was moderate for the Lake Powell inflow and elevation metrics. Under the Global Climate Model's supply scenario, water supplies were more stressed and the range between the tribal water scenarios for these same metrics was minimal because effects to the system were not due to tribal water development but rather due to restricted water availability.