Technical Memorandum

To: *Town of Weaverville, NC*

From: *CDM Smith*

Date: *January 2023*

Subject: *Reliable Yield Study of the Weaverville Water Intake on the Ivy River*

Executive Summary

The Town of Weaverville currently operates the Lawrence T. Sprinkle, Jr. Water Treatment Plant (WTP) that withdraws water from the Ivy River, approximately ten miles upstream from its confluence with the French Broad River. This study was commissioned to determine the amount of water that can be reliably withdrawn from the intake location on the Ivy River near the WTP, based both on historic hydrology and the possibility of future alterations to basin hydrology from climate change.

Reliable yield (also referred to as *safe yield* or *firm yield*) of a direct withdrawal of water from a river is the expected minimum available flow at the intake location during critical drought conditions (this Technical Memorandum uses this definition and another, with nearly identical results). The practice of reporting the reliable yield of a water supply source as a single value has largely been replaced with reporting a range of values that can be realized with full or nearly full reliability, assuming a water supplier can employ measures to provide water reliably during periods of hydrologic stress using alternate supplies, storage, or conservation.

The lowest daily flow in approximately 67 years of daily records at the United States Geological Survey (USGS) gage downstream of the Weaverville intake is 4.9 cubic feet per second (cfs) (3.2 million gallons per day [MGD]) in August of 2008. To calculate the reliable yield at the WTP intake on the Ivy River, and a range of values that can be realized with full or nearly full reliability, the daily flows at the USGS gage were scaled to the drainage area upstream of the WTP intake and analyzed with two methods.

Table 1 summarizes the findings of the study. Because Weaverville can initiate water conservation measures during severe droughts which would be expected to lower demand and reduce the amount withdrawn from the Ivy River, reliable yield is reported at levels that can be achieved from 95 percent to 100 percent of the time, based on the historical record.

Table 1. Reliable Yield Results Using Historical Hydrology

Percent of Time Available Based on Historic Hydrology	Reliable Yield Based on Minimum Available Flow [1]	
	Daily Analysis[2] (MGD)	Monthly Analysis (MGD)
100%	**2.6**	8.8
99%	**8.7**	10.6
95%	**12.8**	15.0

[1] Two independent techniques were employed to estimate reliable yield, and both yielded nearly equivalent results.
[2] CDM Smith recommends using the daily analysis results for planning purposes due to a lack of storage to buffer against low-flow days.

Interpretation: Based on the historical hydrologic record, Weaverville could reliably withdraw up to 8.7 MGD from its Ivy River Intake 99 percent of the time. This value increases to 12.8 MGD 95 percent of the time. The fully reliable yield of the river is 2.6 MGD, but over the historic period of record spanning approximately 67 years, this minimum flow is encountered on only one day. All other daily flows were higher.

Potential climate change impacts to water availability in the Ivy River are projected to be small, based on industry-standard application of Global Climate Models to the Ivy River system, as discussed later in this Technical Memorandum. Despite large projected increases in air temperature, projected changes to low Ivy River flows at the Weaverville WTP intake are minimal. This appears to be due to a generally increasing projected trend in monthly precipitation.

1.0 Introduction and Objectives

CDM Smith was retained by the Town of Weaverville to evaluate the reliable yield of the Ivy River at their water system intake for the Lawrence T. Sprinkle, Jr. WTP. The Ivy River (also referred to as Ivy Creek) is a tributary to the French Broad River. **Figure 1** illustrates the relative location of Weaverville, the Ivy River, the WTP intake, and the 112 square mile drainage area to the intake. The WTP is located approximately 1,300 feet south of the intake at 40 Sams Road, Weaverville, NC in Buncombe County.

The intake on the Ivy River is the primary source of drinking water for Weaverville, although the Town has an emergency interconnection with the Town of Mars Hill. The WTP has a currently permitted capacity of 1.5 MGD.

Neither the river itself nor the facilities at the WTP are equipped with appreciable storage of water. Thus, the amount of water available for withdrawal is approximately equal to the flow in the river on any given day. According to Weaverville's Local Water Supply Plan (LWSP), the finished water storage capacity in the distribution system is 3.9 million gallons (which includes a 0.25 million gallon clearwell). For this analysis, it is not considered as usable storage and does not factor into the reliable yield calculation.

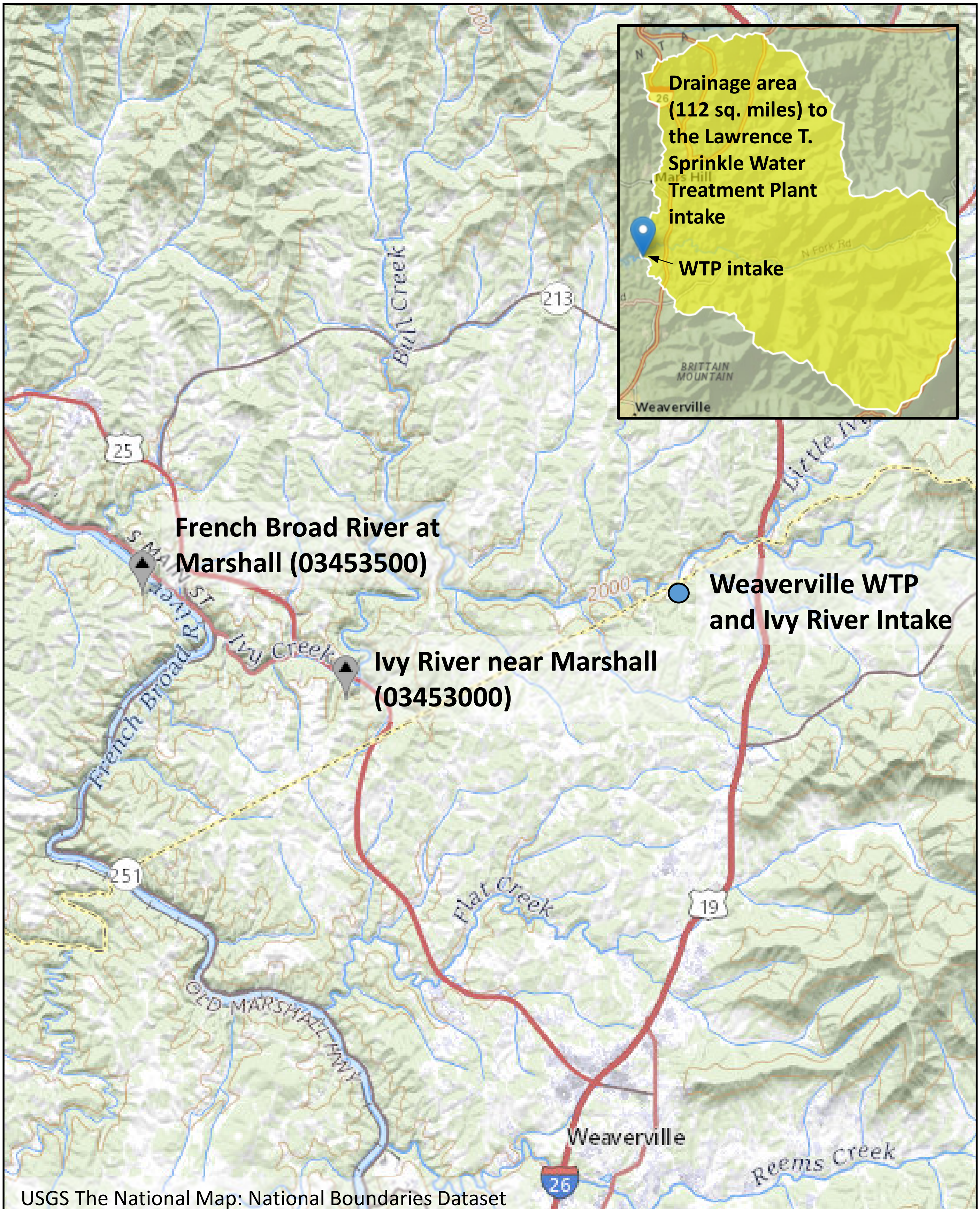


Figure 1
Ivy River and Weaverville Intake Location

The objective of this study is to evaluate the reliable yield associated with the WTP intake on the Ivy River. Two questions form the basis of this study:

- Given the historical hydrology of the Ivy River, how much water can Weaverville depend upon to be reliably available in the river?
- Does this value change when considering plausible future climate trends and their impacts on river hydrology in the region?

2.0 Reliable Yield

To answer these questions, the reliable yield of the Ivy River at the intake location is determined in this study. Reliable yield (also referred to as *safe yield* or *firm yield*) is defined and calculated differently and for different purposes across the U.S. For this study, reliable yield is calculated and presented in several ways. In the first and simplest approach, reliable yield is calculated as ***the expected minimum available flow at the intake location during critical drought conditions***. Reliable yield can also be determined with consideration of annual average demand. In this second approach, reliable yield is calculated and presented as ***the maximum annual average demand that can be satisfied during critical drought conditions with 100 percent reliability***. The concept of "annual average" is useful because it allows a reliable yield analysis to include considerations of monthly or seasonal demand variability, which is important because demand is frequently highest when supply is lowest.

It is also useful to analyze reliable yield as a function of potential future climate trends and of the percent of time a level of withdrawal would be available (if not 100 percent). This type of reliability analysis is particularly useful for water providers who have backup supplies, flexible operations from multiple sources, or conservation practices that can help reduce demand during droughts. Weaverville has one source of emergency water, but this is considered for emergency use only, and not supplemental water during low flow periods. However, Weaverville does have conservation measures that are employed during drought conditions, and hence the reliable yield is presented several ways, using both above approaches in this study: (1) the amount of water that can be relied upon 100 percent of the time based on the historical hydrologic record, (2) the amount of water that can be expected to be available with varying degrees of reliability (e.g., water is available 95 and 99 percent of the time), and (3) the amount of water that can be expected to be available considering future climate trends.

Weaverville's Water Shortage Response Plan demonstrates the codified measures that can be employed to reduce water usage during droughts. These include voluntary conservation measures for Phase I of the Response Plan, progressing to a mix of voluntary conservation measures and mandatory use restrictions for Phase II, followed by an increasing level of conservation and mandatory use restrictions of Phase III.

Three factors can potentially affect the yield such that examination of the historical flow record alone is not sufficient:

- Monthly or seasonal demand fluctuation, as noted above, which can cause a system to require more water during periods of typically lower flow levels
- Available storage either instream or off-line, which can provide buffering capacity against days, weeks, or months of excessively low flow in a river
- Regulatory requirements: Correspondence from the North Carolina Department of Health and Natural Resources (now known as the Department of Environmental Quality [NCDEQ]) contained in Appendix D of the *Draft Preliminary Engineering Report Town of Weaverville Water System Expansion* (WithersRavenel 2021) indicates that a continuous withdrawal of 4.0 MGD is allowed at the WTP intake location. The currency of this approval was confirmed through discussion with the NCDEQ as part of this study (Fred Tarver, personal communication, January 6, 2023).

For purposes of this study, only the first of these three factors will affect the reliable yield calculation, and only when calculating reliable yield using the second approach described above, since there is no appreciable storage and since the treatment capacity is not currently planned to exceed 4 MGD.

An important assumption in this work is that the intake configuration in the river channel is sufficient to capture all available flow even during times of extremely low flow, when the river narrows. The intake is located at the deepest location in the channel, which is where the river narrows during low flow. Therefore, it is assumed that the intake is configured sufficiently, and with enough head, to capture the extreme low flows, and treat the water that may be unusually turbid.

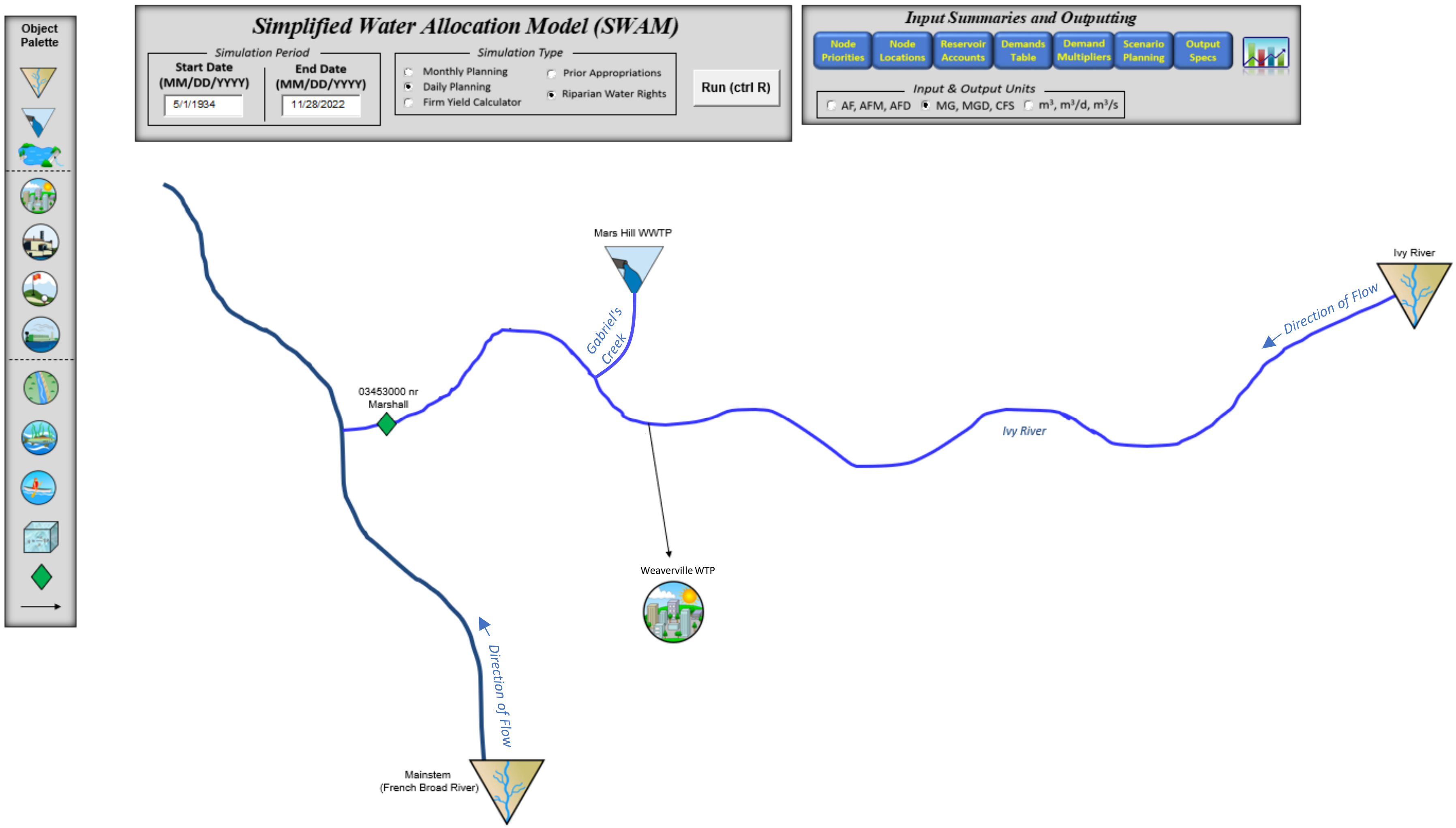
3.0 Analytical Methods

This section describes the data, tools, and assumptions used to determine the reliable yield of the Ivy River at the WTP intake and answer the two fundamental questions driving the study. The results of the analysis are presented in Sections 4.0 and 5.0.

3.1 SWAM Model

CDM Smith developed the Simplified Water Allocation Model (SWAM) to examine water availability and river dynamics as a function of documented surface water flow patterns and simulated withdrawal and return flows to river networks. SWAM is a hydrologic routing model that can help quantify the effects of water management on river systems. It is a visually based tool programmed within Microsoft Excel. SWAM has been deployed successfully in many locations, including the western U.S. and in the Carolinas as an integral element of the South Carolina State Water Planning process.

Figure 2 illustrates the basic construct of the SWAM model developed for this study. The elements include the Ivy River, the Town's WTP intake, the Mars Hill wastewater treatment facility discharge



This is a general depiction of the system and is not shown to scale.

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Figure 2
The Simplified Water Allocation Model (SWAM) Schematic for the Weaverville Reliable Yield Study

to Gabriel Creek, which empties into the Ivy River, the United States Geological Survey (USGS) gage on the Ivy River, and the French Broad River. Some of these elements are essential in computing the reliable yield for Weaverville, while others are effective in understanding downstream impacts of water withdrawals.

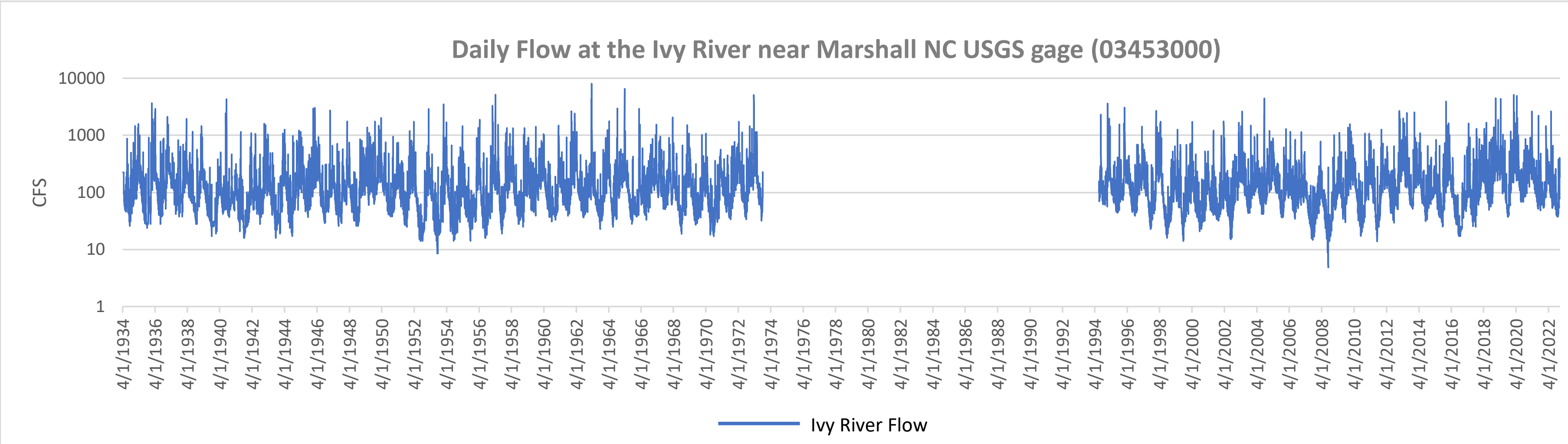
SWAM simulates flow and water management operations at either a daily or monthly timestep, for the period of record of available data (discussed below under “Hydrology”). For this study, results for both the daily and monthly analysis are presented.

3.2 Hydrology

The historical river flows in the Ivy River are well documented by the USGS streamflow gage 03453000: Ivy River near Marshall, NC. The record of daily and monthly flows extends from 1934-2022, with a 21 year gap from 1973-1994. **Figure 3** (top graph) illustrates the time history of daily flow at the gage and demonstrates that the lowest daily flow on record at the gage is 4.9 cubic feet per second (cfs) (3.2 MGD) in August of 2008.

Important to this study is understanding the likely flow patterns during the gap years of 1973-1994, to improve confidence that the available record includes the representative lowest flow for the entire time period. **Figure 3** (bottom graph) compares the available data from the Ivy River gage to the nearby USGS gaging station on the French Broad River near Marshall, NC (Station 03453500), which includes measured flow during the missing years of the Ivy River Record. **The figure illustrates that both the French Broad River (with the fuller record) and the Ivy River experienced their lowest daily flow in August of 2008, which suggests that the missing years in the Ivy River record are not likely to have caused greater stress than that observed in 2008, which will be the defining condition for reliable yield.**

Once the hydrologic record from the Ivy River gage was available and examined for appropriate representation of worst-case historical stress, the flows were scaled linearly upstream in the Ivy River, based on drainage areas, to estimate flows at the model upstream boundary. These boundary condition “headwater” flows are required by the model and provide the hydrologic inputs for downstream calculations. Prior to the scaling calculation, gaged flows were “unimpaired” to account for known upstream withdrawals (Weaverville) and discharges (Mars Hill treated wastewater). Weaverville’s NPDES discharge associated with the WTP was not accounted for in this analysis given its relatively insignificant volume (i.e., the maximum monthly average has been reported as 0.0256 MGD [WithersRavenel 2021]). Withdrawals and discharges were estimated back to 1997, using data provided by Weaverville. Flows at the WTP intake, which provide the basis for reliable yield calculations, are calculated by the model, for each simulation timestep, as a function of the headwater flows and drainage area ratios (headwater versus intake location). This entire process is an approximation technique and resulted in flow estimates at the intake of roughly 70 percent of flows at the USGS gage further downstream.



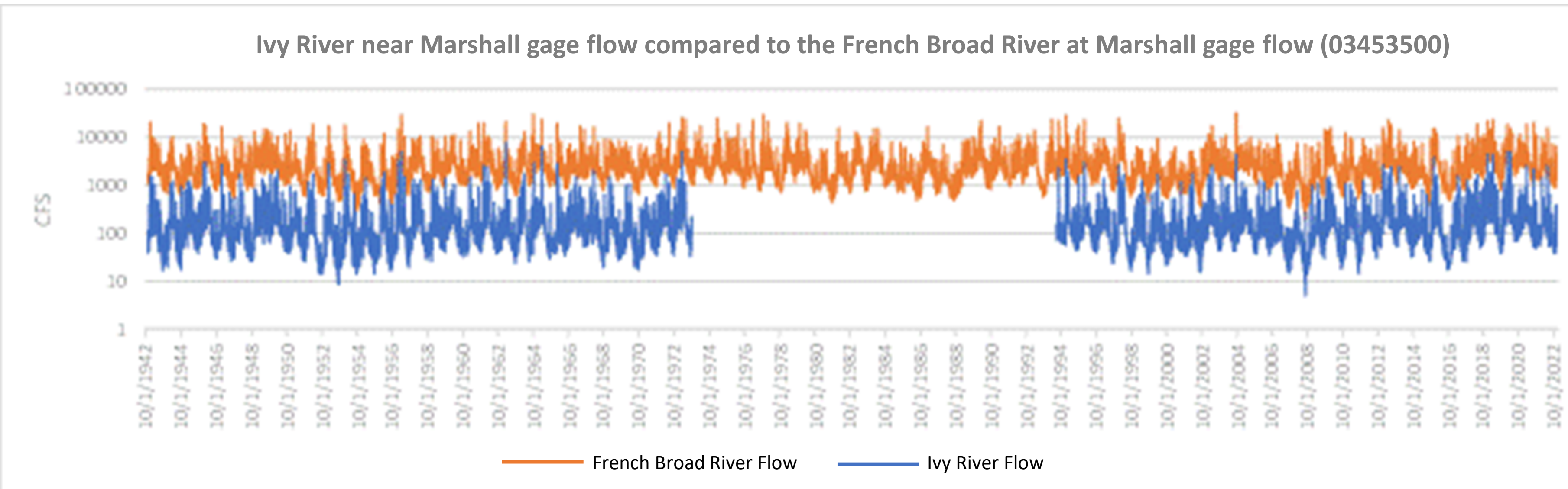


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Figure 3

Daily USGS Flow Records on the Ivy River near Marshall, NC and the French Broad River at Marshall, NC

Figure 4 illustrate the flow duration curves (often called "flow exceedance curves" representing the frequency of time that each level of flow is exceeded) for modeled daily and monthly flows at the Weaverville WTP intake, respectively. The graphs indicate how much water could be available with various levels of reliability and is the basis for identifying reliable yield using the first approach presented in Section 2.0.

3.3 Water Demand

The reliable yield of a water supply system is inherently independent of demand, since it is a measure of the upper limit of demand that can be met reliably. However, when evaluating reliable yield using the second approach (defined in Section 2.0), seasonal patterns in demand can and do affect reliable yield, since a higher percentage of average demand is usually occurring in summer months when river systems are most stressed. Recent average monthly demand patterns in Weaverville are illustrated in **Figure 5** as a percentage of current annual average demand.

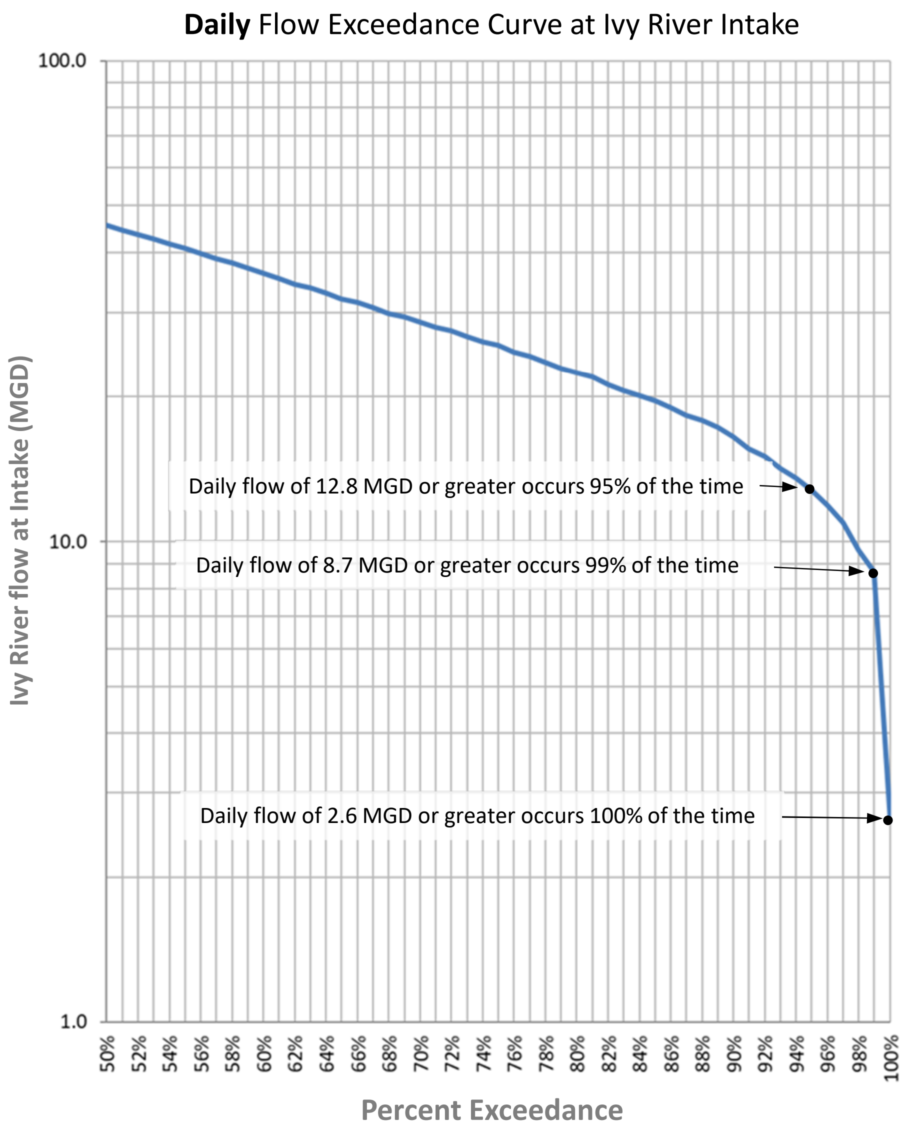
3.4 Calculating Reliable Yield

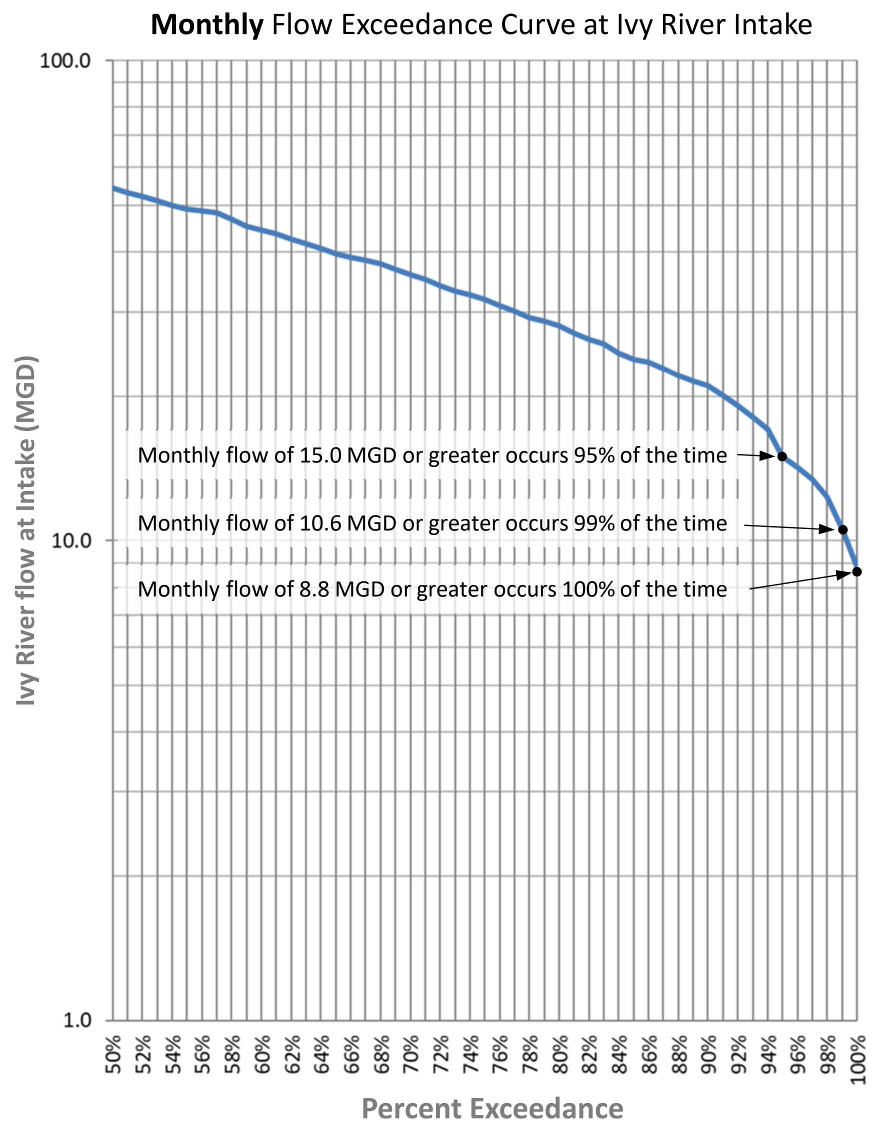
The expected minimum available flow at the intake location during critical drought conditions (first definition of reliable yield) was calculated by the model and is based on the approximately 67 years of Ivy River flow records from the USGS gage, scaled to the intake location, and accounting for historical withdraws (Weaverville) and discharges (Mars Hill) upstream of the gage. The reliable yield was determined on a *daily* and *monthly* average basis.

To calculate the reliable yield of the system using the second approach, Weaverville's average annual demand was increased incrementally beginning with very low demands, converted automatically to the monthly distribution of demand shown above, until the river was no longer able to satisfy the full demand all the time. In the simulation, this occurs in August 2008, as expected, as this is the month with the lowest *daily* flow.

The process was repeated using *monthly* average Ivy River flow data for the 1934-2022 period of record (minus the 21-year gap when no flow data was available). This was a less realistic representation of the system and would be more reflective of a system that had some buffering storage and was not dependent on day-to-day flow variability in the river. However, both sets of results are potentially useful and are reported for reference.

Reliability analyses were also conducted, such that beyond the reliable yield (available 100 percent of the time based on historical hydrology), minimum flows and average annual withdrawal levels were identified through simulation that would be available 99 percent of the time and 95 percent of the time. This could be useful, since Weaverville has access to emergency water through one interconnection with another local water system, and emergency water conservation measures during droughts will also serve as protection against higher annual withdrawal rates that are not otherwise sustainable all the time.





These graphs indicate, based on a daily (left) and monthly (right) analysis, how much water is available at the intake for 50 to 100 percent reliability.

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Figure 4
Flow Exceedance Curves at the Ivy River Intake

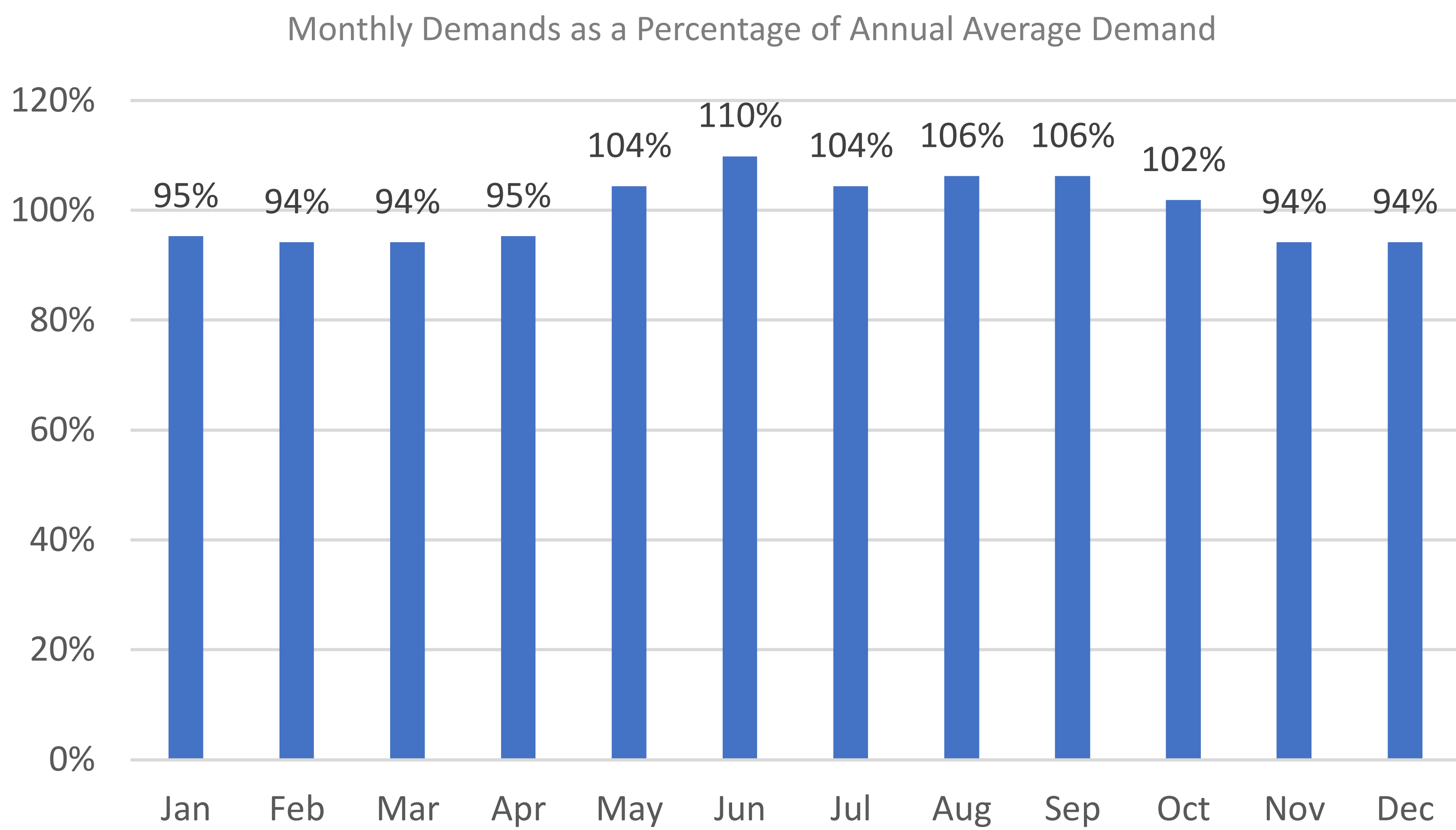

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Figure 5
Weaverville Monthly Demands as a Percentage of Annual Average Demand

4.0 Results and Discussion

The results of the analysis of reliable yield using both approaches and using *daily* and *monthly* flows are presented in **Figure 6** and **Table 2**. Because there is no appreciable raw water storage either at the intake or WTP, CDM Smith recommends using the *daily* reliable yield for planning purposes.

The following caveats apply to this analysis:

- No appreciable storage is assumed at the intake or before treatment at the WTP.
- There is sufficient head at the intake where the river narrows during low flow periods to withdraw the available flow.
- The water intake hydraulics are configured so that there is sufficient head to capture even the lowest flows in the river.

Table 2. Reliable Yield Results Using Historical Hydrology

Percent of Time Available Based on Historic Hydrology	Reliable Yield Based on Minimum Available Flow (first approach)		Reliable Yield Based on Maximum Annual Average Usage Being Satisfied (second approach)	
	Daily Analysis[1] (MGD)	Monthly Analysis (MGD)	Daily Analysis[1] (MGD)	Monthly Analysis (MGD)
100%	**2.6**	8.8	**2.5**	8.5
99%	**8.7**	10.6	**8.6**	10.4
95%	**12.8**	15.0	**13.7**	17.3

[1] CDM Smith recommends using the daily analysis results for planning purposes.

Based on the historical hydrologic record and the results in Table 2, the Town of Weaverville could reliably withdraw up to 8.7 mgd from its Ivy River Intake 99 percent of the time. This value increases to 12.8 mgd 95 percent of the time. The fully reliable yield of the river is 2.6 mgd, but over the historic period of record spanning approximately 67 years, this minimum flow is encountered on only one day. All other daily flows were higher.

When considering the reliable yield results based on maximum annual average usage (the second approach), it is important to note that the recent average monthly usage pattern was applied in the analysis. The monthly average usage corresponding to the calculated maximum annual demand of 2.5 MGD range from a low of 2.32 MGD (for February, March, November, and December) to a high of 2.71 MGD (for June). In August 2008, when the lowest historical flow occurred, the model's monthly average usage was 2.62 MGD.

Supplementally, the results were evaluated to determine how often critical low flows would be preserved in the river downstream of the intake. A standard benchmark flow is the "7Q10" flow,

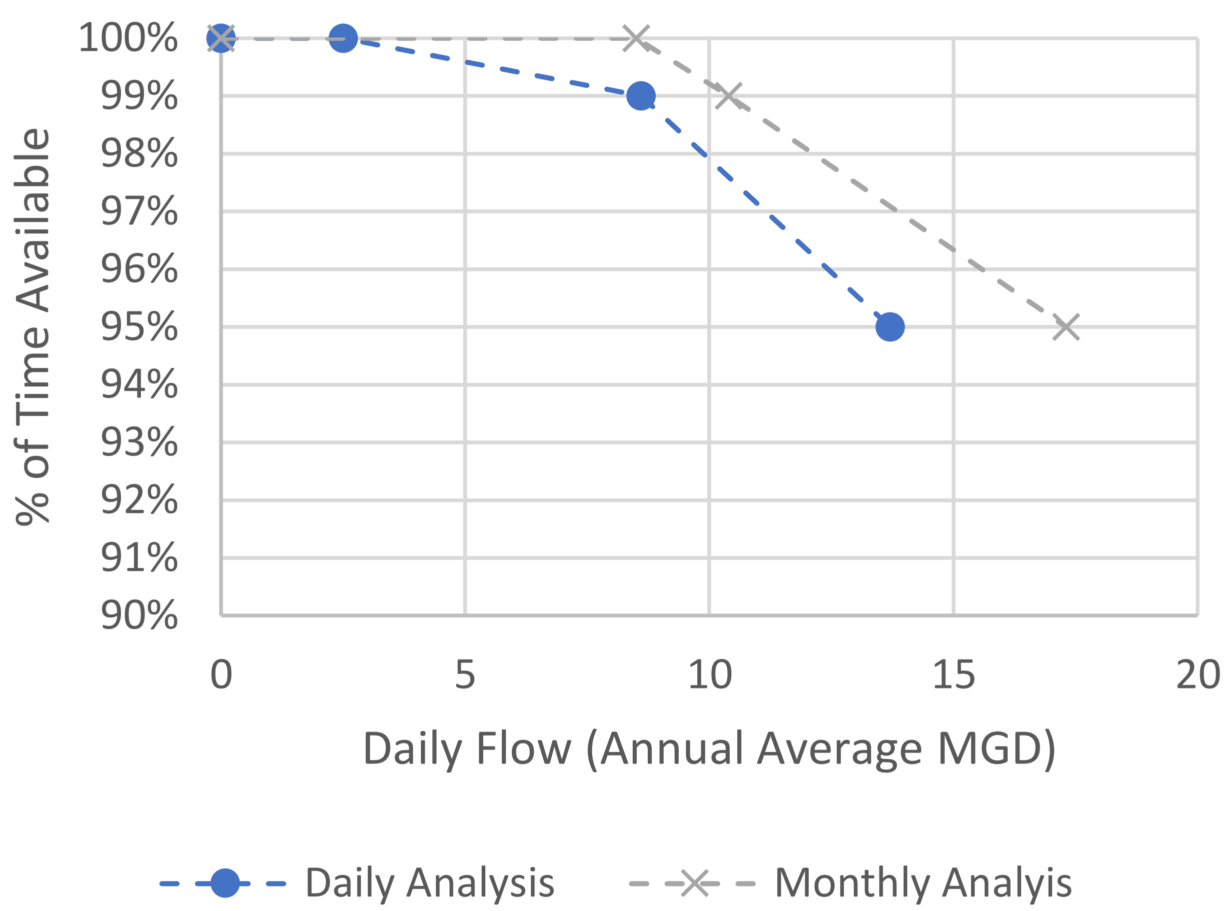

Figure 6
Reliable Yield Results Using Historical Hydrology

which represents the lowest 7-day average flow that occurs once every ten years. Based on the unimpaired flow estimates at the intake location used in the SWAM model, the calculated 7Q10 flow for the 67-year period of record is approximately 11.4 cfs at the intake (7.4 mgd). This compares favorably with the range of 7Q10 values recently calculated by the USGS at this location, which were 8.7 to 14.7 cfs, with an average value of 12.3 cfs (Weaver, 2022). It is understood that the USGS flow transposition methods differed from those in this study, and based on the calculated higher average 7Q10, were not as conservative overall.

Presented below in **Table 3** and **Figure 7** are results of how often the river maintains the 7Q10 flow, 50 percent of the 7Q10 flow, and 20 percent of the 7Q10 flow immediately downstream of the WTP intake. The analysis was conducted for withdrawals of 0 MGD, 2.5 average annual MGD (representing the reliable yield), and 3 MGD constant withdrawal.

Table 3. Percent of Time Low Flow Benchmarks Pass Downstream of the WTP Intake

Withdrawal at the Intake	7Q10 Passes Downstream (11.4 cfs)	50% of 7Q10 Passes Downstream (5.7 cfs)	20% of 7Q10 Passes Downstream (2.3 cfs)
0.0 MGD	99.6%	100.0%	100.0%
2.5 MGD Annual Average	97.8%	99.9%	100.0%
3.0 MGD Constant	97.4%	99.8%	99.9%

These results illustrate two important findings. First, under natural conditions (no withdrawal), the 7Q10 flow is not always maintained downstream. This is intuitive, since the statistic is representative of an event with a 10-year recurrence interval over 67 years, and we would expect to see some daily flow values that are lower than this, which we do. Second, the withdrawal pattern at the reliable yield (2.5 MGD annual average) still passes the 7Q10 flow downstream almost 98 percent of the time, while passing 50 percent and 20 percent of the 7Q10 flow (also useful benchmarks) downstream practically all the time (rounded to 99.9 percent and 100.0 percent, respectively). This suggests that withdrawing the reliable yield of 2.5 MGD as an annual average will have very little impact to the low flow patterns in the Ivy River. Similar conclusions can be drawn for the analysis of a constant withdrawal pattern of 3 MGD.

5.0 Climate Change Analysis

5.1 Approach and Methods

The objective of this task was to assess and quantify the potential for long-term changes to source water reliability as a function of projected climate change. A future climate scenario for the study site was developed utilizing a combination of state-of-the-art climate models and the available USGS flow gage data. The scenario is intended to represent a plausible climate future centered on a 2070 planning horizon. It uses a combination ("ensemble") of projections, spanning a wide range of

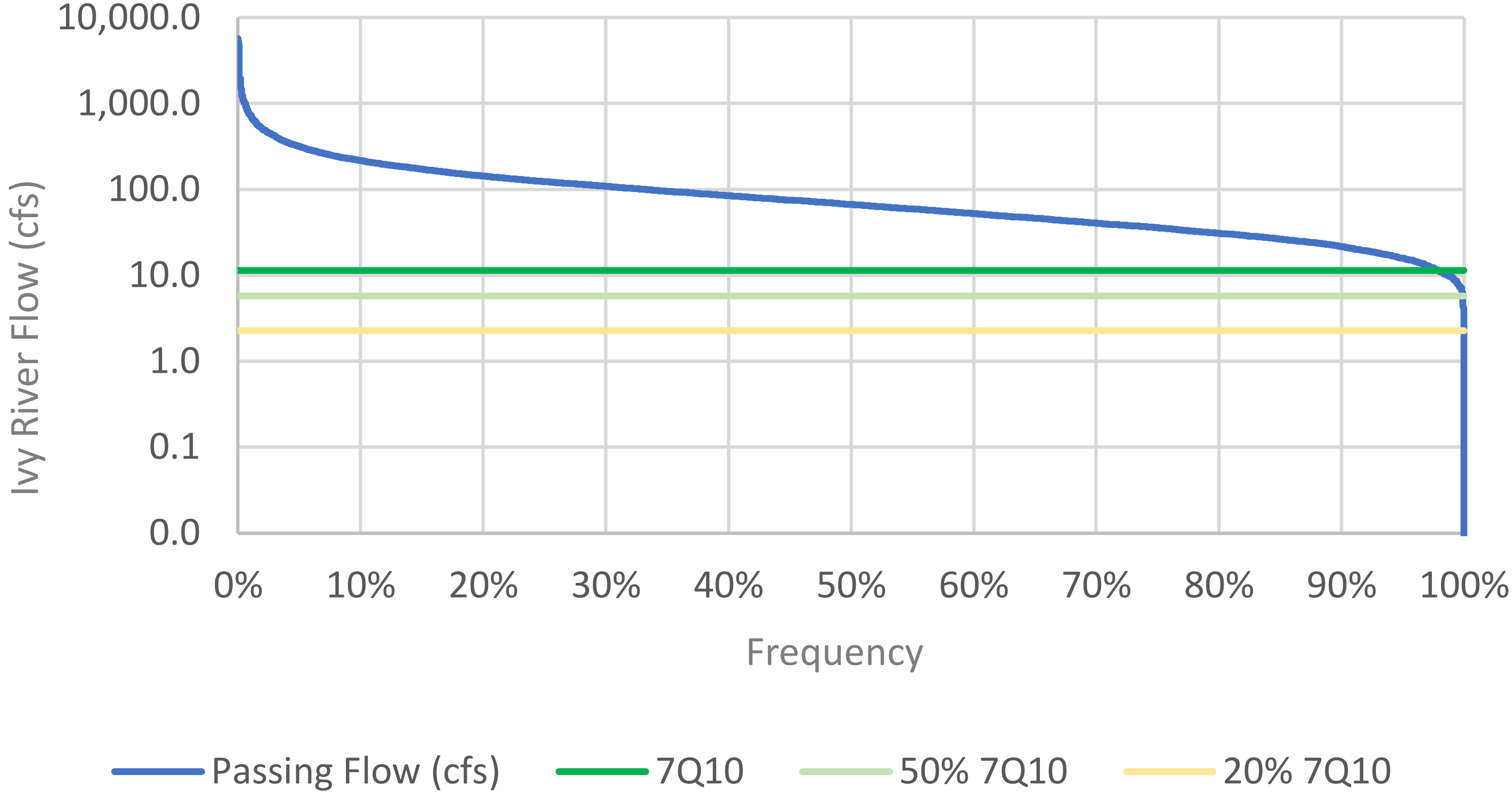

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Figure 7
Frequency of Passing Flow at the Ivy River WTP Intake at 2.5 MGD Average Annual Withdrawal

the best available climate models, with no attempt to identify the occurrence likelihood of any specific projections. The analysis was conducted on a monthly basis only, as future predictions of climate patterns can produce credible results at that scale, but daily predictions are less credible and deemed inadequate for this study.

Future climate projections for the study site have been summarized for this task using the full suite of available global climate model (GCM) projection data sets. These projections include monthly mean air temperature and monthly total precipitation, downscaled to a 1/8 degree latitude/longitude grid. These published data were obtained from public data portal maintained by the U.S. Bureau of Reclamation[1]. In addition to climate projections (temperature and precipitation), published "gridded runoff" projections, generated with the same set of GCMs as above, were obtained from the same data portal. Gridded runoff projections were developed by this consortium by routing precipitation and temperature projections through a macroscale rainfall-runoff model called the Variable Infiltration Capacity (VIC) model[2]. These runoff projections can be viewed as a surrogate for projected changes in surface water availability and flow rates. The runoff projections include both a direct runoff and baseflow component. It is these runoff projections that were ultimately used to modify flow records for the reliable yield analysis.

A total of 76 different climate model projections were downloaded for the period 2000 to 2100. A modeling "overlap" period of projections and a historical observed dataset (gridded to same 1/8th degree grid) were also obtained for the years 1950 to 1999. All projections represent the latest in scientific research and were developed under the World Climate Research Programme Coupled Model Intercomparison Project, Phase 5 (CMIP5). The CMIP5 data set includes 35 different climate models developed at research institutions around the world and applied across a range of model input assumptions. Rather than relying on one model, they are used in combination to develop a plausible future climate scenario for this study.

Climate model projections were obtained for a single, centrally located 1/8th degree grid cell for this analysis, as shown in **Figure 8**. The selected cell is considered representative of the study basin.

A 2070 planning horizon was selected for this work, in line with the long-term planning horizon of the Town. A sampling band of ± 10 years, centered on 2070, was used to capture "natural" year-to-year variability in the climate data, while still being representative of late 21st century climate trend projections. Charts depicting the GCM projections of annual air temperature and precipitation through 2070 are included in Attachment A (**Figures A-1** and **A-2**). Also included in Attachment A are the GCM projections of mean monthly air temperature and precipitation (**Figures A-3** and **A-4**).

[1] Available at: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/dcpInterface.html
[2] More information on the gridded runoff projections and the VIC modeling can be found at: http://gdo-dcp.ucllnl.org/downscaled_cmip_projections/techmemo/BCSD5HydrologyMemo.pdf

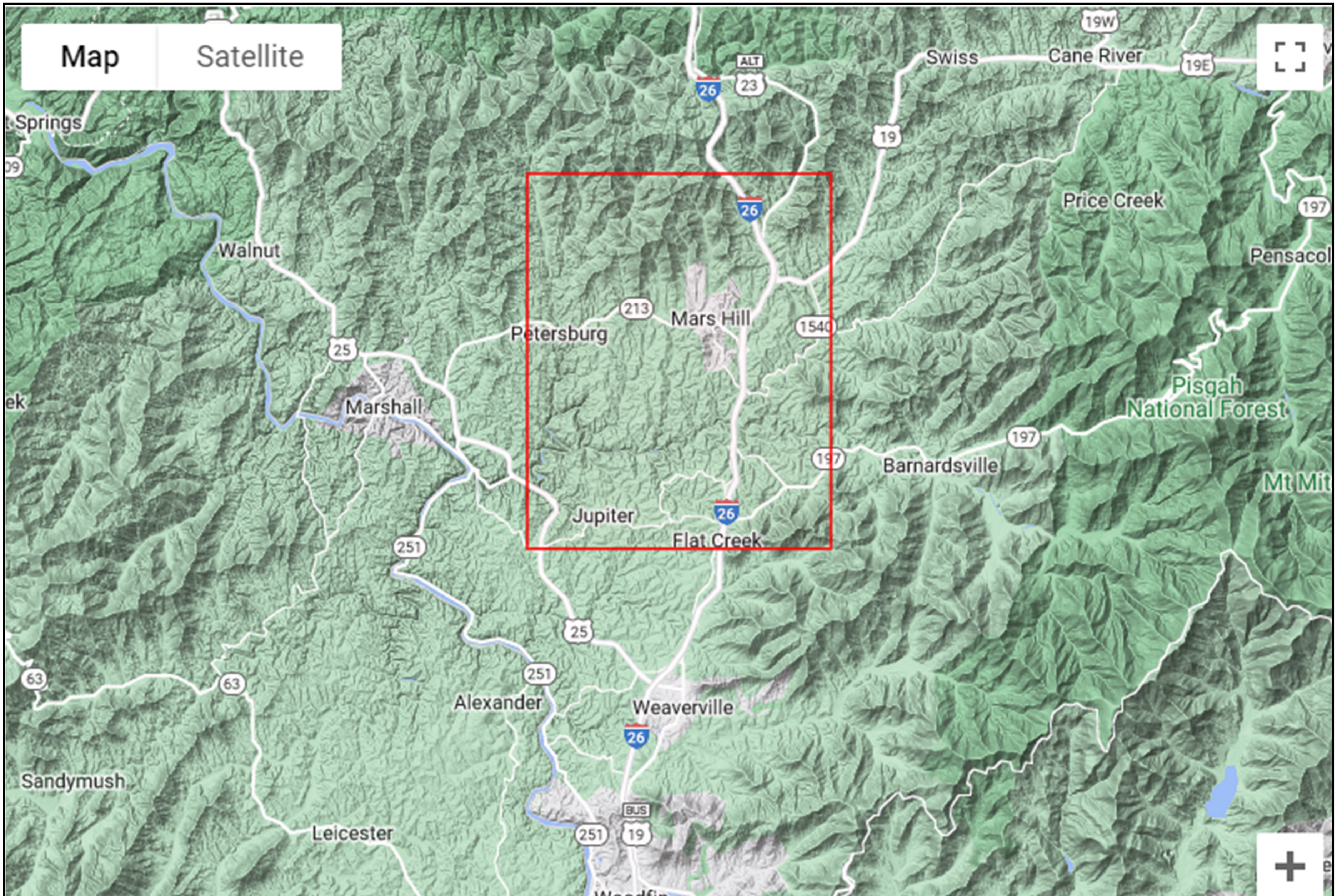


Figure 8
Representative Climate Model Projection Grid Cell

Climate model data were pooled into a single ensemble of projections, capturing the range and variability of all included climate models. For the developed ensemble, a method referred to as the "hybrid delta ensemble" (HDe) method (Bureau of Reclamation, 2010) was applied to adjust historical flow records to reflect the future climate projection data set. In this method, statistical adjustments are made to the historical gaged data set (1934–2022) based on relative changes predicted by the pooled GCM projections. In this way, this method preserves the month-to-month pattern of variability and many of the core statistics of the observed historical record in its forecast of future conditions. The method has been used extensively by the U.S. Bureau of Reclamation, and others, as a means of incorporating climate model projections into water resources planning studies.

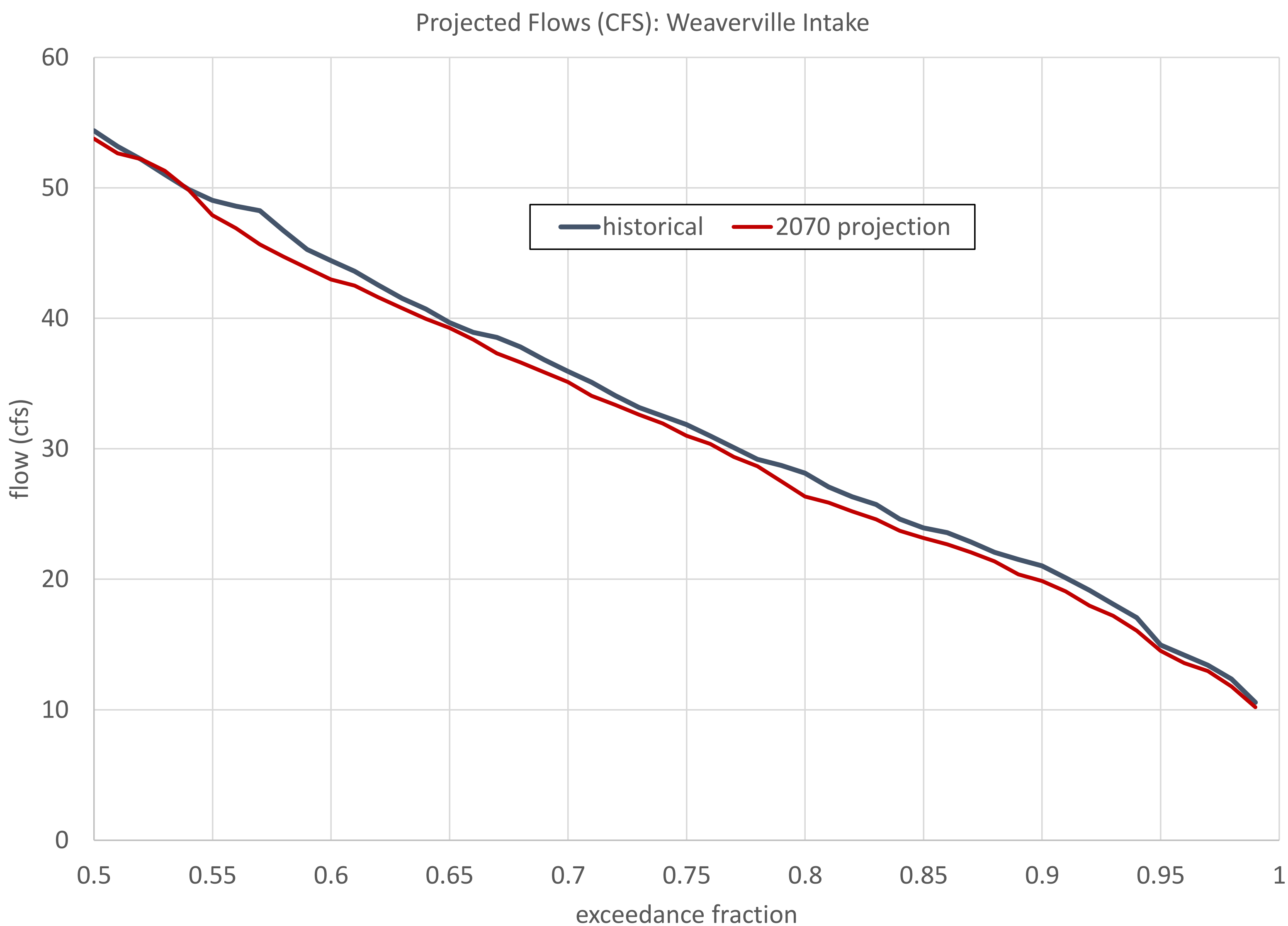
The "delta" in the HDe name refers to the difference between GCM forecasts of the future versus GCM hindcasts of the past. The "hybrid" term refers to the fact that the method uses a range of delta values to adjust the historical record based on relative climate conditions. For example, during wet observed periods, calculated deltas associated with wet modeled periods are used. Similarly, during observed dry periods, dry modeled period deltas are used to adjust the record. The advantages of this approach are that it is strongly tied to actual observed climate data (rather than using model projections by themselves) and it eliminates any overriding bias in the GCMs by using delta values (modeled versus modeled) rather than the projection data alone.

The result of the HDe method is a single set of monthly flows (1934–2022) that are reflective of 2070 conditions, as projected by climate models, but maintain the same pattern of variability observed in the historical record. **Figure 9** compares the flow exceedance curves (50th percentile to just below the 100th percentile) based on historical hydrology and projected 2070 climate change impacts at the Ivy River intake. **Despite large projected increases in air temperature, projected changes to low Ivy River flows at the Weaverville WTP intake are minimal. This appears to be due to a generally increasing projected trend in monthly precipitation, as incorporated into runoff projections by the macroscale hydrologic model described above.**

5.2 Reliable Yield Results with Climate Change through 2070

The reliable yield was computed with assumptions about possible climate change patterns in the future, as described above. Results of the monthly analysis are tabulated in **Table 4** and compared with results using historical hydrology in **Figure 10** for both the first and second approach to calculating reliable yield. The comparison shows that climate change projections result in very small reductions in flow, compared to historical hydrology.

Climate forecasting is highly uncertain, and results of analyses such as these should be used with acknowledgment of this uncertainty. In general terms, it may be most appropriate to use such analyses to simply ascertain whether future trends are likely to have a small, moderate, or significant impact on yield. In this case, based on the simplified approach applied here, projected climate change impacts on reliable yield at the WTP intake appear to be small or negligible.



Only 50th percentile flows and lower are shown

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Figure 9

Projected 2070 Monthly Flows with Climate Change Compared to Historical Baseline Flow

Table 4. Reliable Yield Results with Climate Change Through 2070

Percent of Time Available Based on Historical Hydrology	Reliable Yield Based on Minimum Available Flow (first approach)		Reliable Yield Based on Maximum Annual Average Usage Being Satisfied (second approach)	
	Daily Analysis[1] (MGD)	Monthly Analysis (MGD)	Daily Analysis[1] (MGD)	Monthly Analysis (MGD)
100%	**N/A**	8.6	**N/A**	8.5
99%	**N/A**	10.2	**N/A**	10.0
95%	**N/A**	14.5	**N/A**	16.6

[1] Only monthly analysis was conducted for climate change, as climate models cannot reliability estimate future day-to-day variations in precipitation and temperature.

6.0 Summary

Based on the historical hydrologic record, the Town of Weaverville could reliably withdraw up to 8.7 MGD from its Ivy River Intake 99 percent of the time. This value increases to 12.8 MGD 95 percent of the time. The fully reliable yield of the river is 2.6 MGD, but over the historic period of record spanning approximately 67 years, this minimum flow is encountered on only one day. All other daily flows were higher.

The reliable yield, therefore, based on the minimum available flow at the Ivy River intake (first approach) is 2.6 MGD, when considering historical *daily* flow records. The maximum annual average demand that can be satisfied through the most critical drought with 100 percent reliability (second approach) was identified is 2.5 MGD, based on a daily analysis of flows. Since no appreciable storage is present in the river or prior to treatment at the WTP, the daily analysis is a better representation of reliable yield than the analysis using monthly flows. Potential climate change impacts to water availability in the Ivy River are projected to be small, based on the ensembled results of current GCMs.

The results presented in this technical memorandum should be considered draft and are subject to change based on confirmation of the assumptions, possible additional analysis, and following discussion with Town of Weaverville staff. As outlined in Task 3 of CDM Smith's scope of work, additional model simulations may be performed at Weaverville's request to evaluate system reliability for future water demand projections.

7.0 References

Bureau of Reclamation. 2010. *Climate Change and Hydrology Scenarios for Oklahoma Yield Studies*. Technical Memorandum 86-68210-2010-01. U.S. Department of the Interior, Bureau of Reclamation

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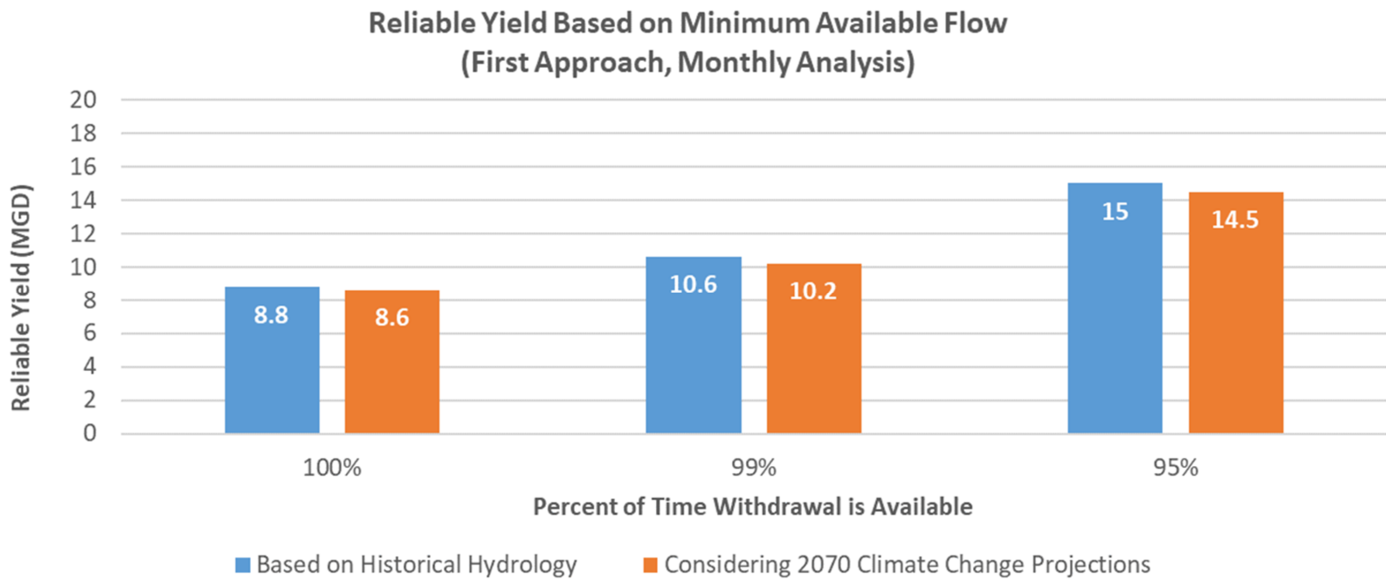

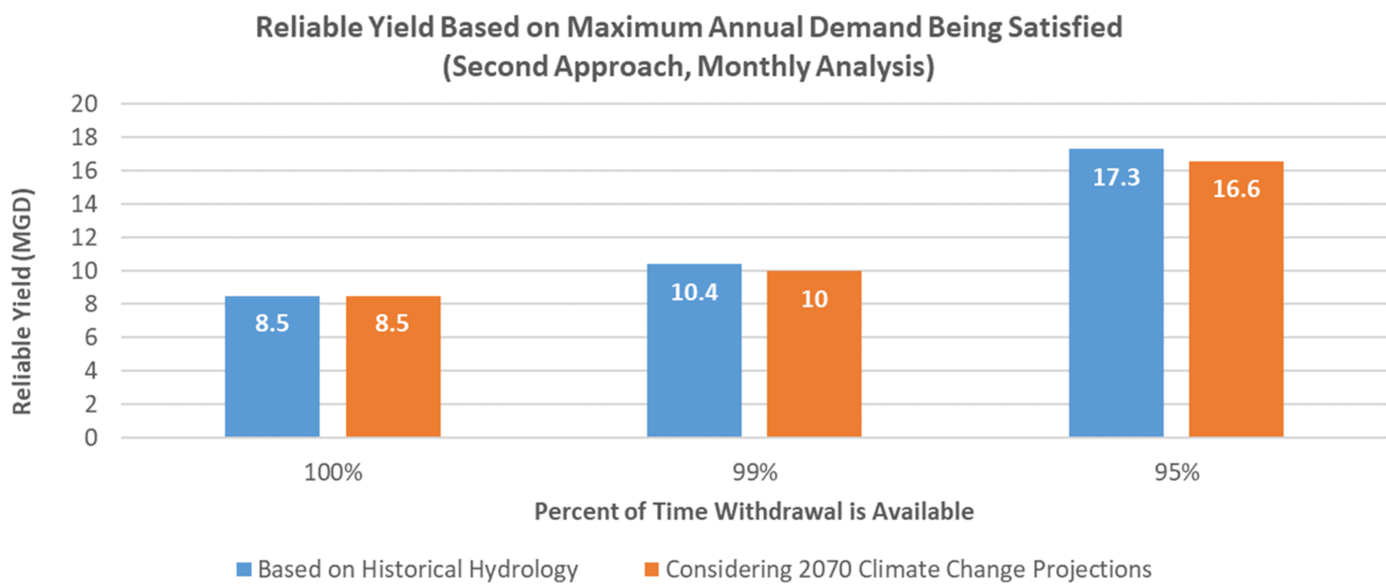

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Figure 10
Reliable Yield Comparison (Monthly Analysis) with Climate Change Through 2070

Attachment A

Global Climate Model Temperature and Precipitation Projections

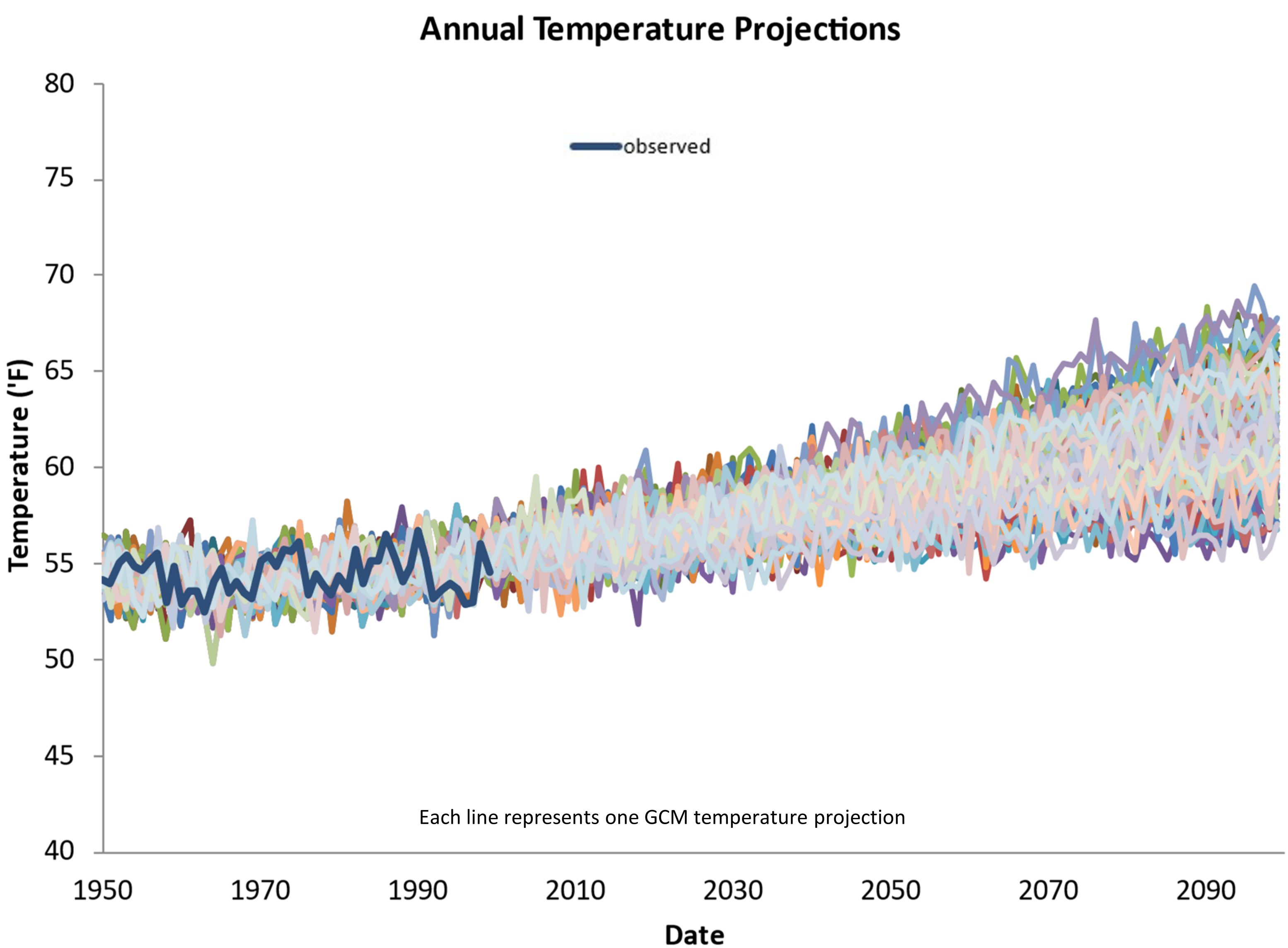

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Figure A-1
GCM Annual Temperature Projections Through 2070

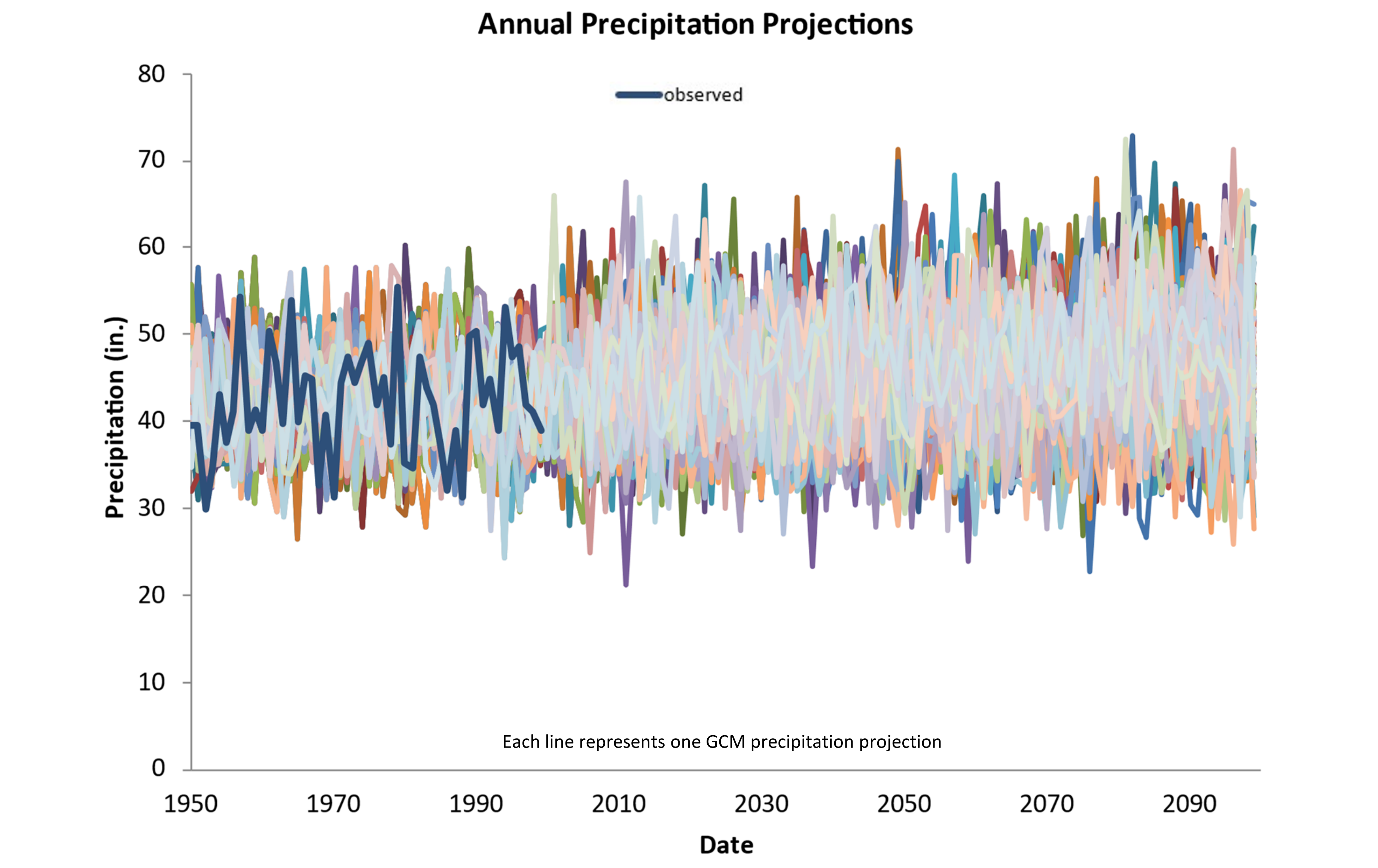

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Figure A-2
GCM Annual Precipitation Projections Through 2070

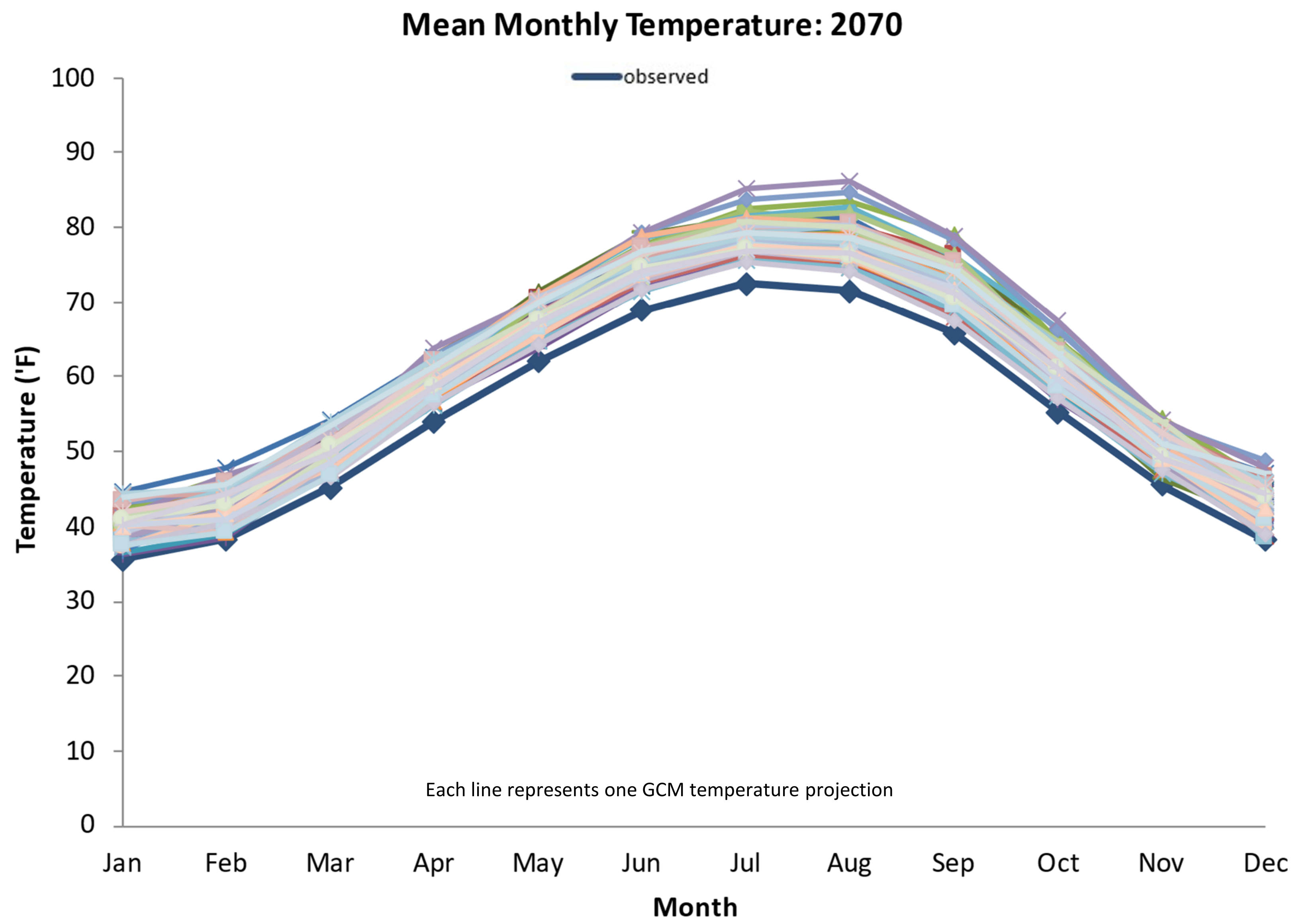

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Figure A-3
GCM Projections of Mean Monthly Air Temperature (2070)

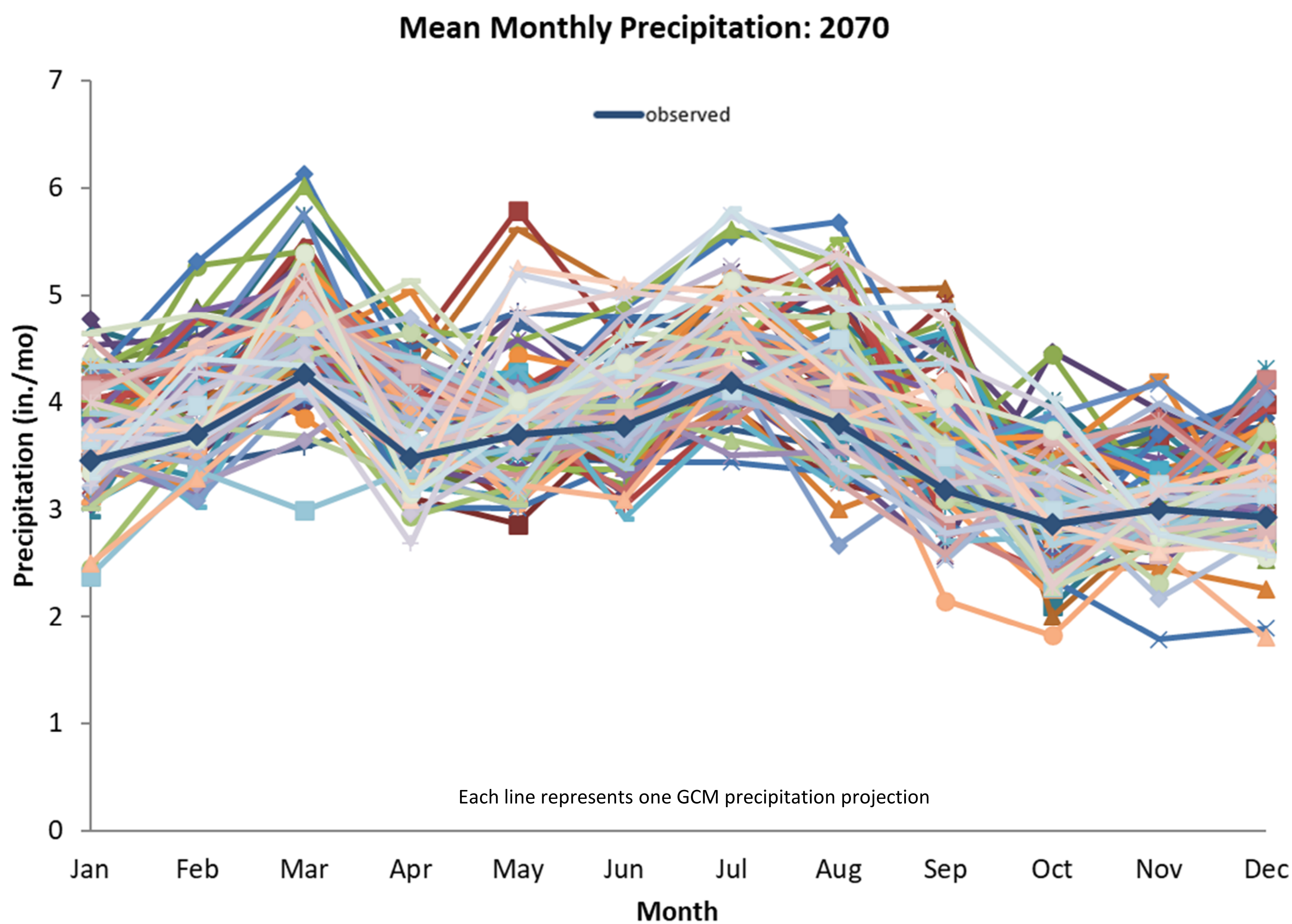

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Figure A-4
GCM Projections of Mean Monthly Precipitation (2070)