Water Resource Inventory

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Project no: W7Y49500
Attention: Colorado River Authority of Utah and Central Utah Water Conservancy District
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Executive Summary

A water resource inventory was completed across the study area, including Central Utah Water Conservancy District's (the District) service area, as well as Colorado River Basin (CRB) lands within Utah, as part of Task Order No. 2 of the Agricultural Water Resiliency Plan. Hydrologic basins were delineated in the District service area outside of the CRB, in the Upper Colorado River Basin (UCRB), and in the Lower Colorado River Basin (LCRB). Lands within these basins total nearly 30 million acres with approximately 895 thousand acres of agricultural lands.

CRB water supply models were investigated and summarized, and the range of historical and possible future natural flow to Lake Powell was estimated using the Colorado River Simulation System (CRSS) model. Four historical scenarios were investigated, driest, dry (10th percentile), wet (90th percentile), and wettest resulting in a range of natural flow volumes of 5.5 to 24.2 million acre-feet (maf). Possible future scenarios were estimated using the Coupled Model Intercomparison Project (CMIP) Phase 3 (CMIP3) multimodal dataset resulting in natural flow volumes to Lake Powell ranging from 4.1 maf to 44.3 maf.

With these CRB water supply scenarios, Utah agricultural depletions and related shortages were modeled in CRSS. Using historical water supply scenarios, Utah agricultural depletions ranged from 375 thousand acre-feet (kaf) to 785 kaf with corresponding shortages of 424 kaf and 14 kaf respectively for the driest and wettest scenarios. Using CMIP3 water supply scenarios, Utah agricultural depletions ranged from 310 kaf to 781 kaf with corresponding shortages of 489 kaf and 18 kaf respectively for the driest and wettest scenarios.

The Utah Division of Water Resource's (UDWRe) Water Budget Model (WBM) results were additionally investigated as part of the water resource inventory task. WBM yield results suggest the total water supply volume originating on UCRB lands range from 836 kaf to 3.5 maf and originating on study area lands in Utah range from 2.1 maf to 6.6 maf. WBM agricultural depletions range from 512 kaf to 731 kaf in the UCRB and 991 kaf to 1.3 maf across the study area for the available data record of 1989-2020. WBM yield informs the water supply originating on the respective lands, while CRSS includes water supplies that originated in other UCRB states. These datasets do not provide for a direct comparison of water supply results but rather, they summarize available water supply data relevant to the study area.

1. Objective

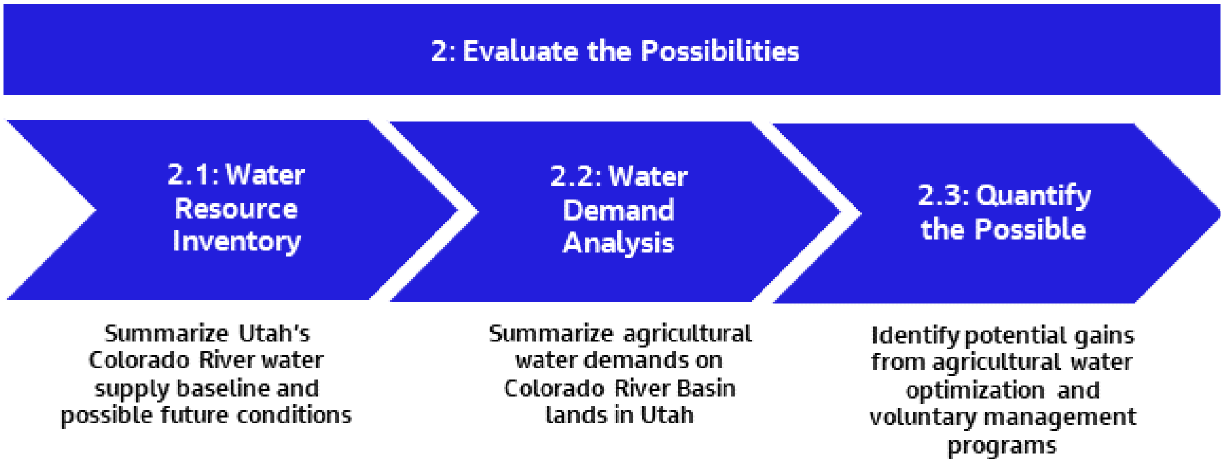
This *Water Resource Inventory Technical Memorandum* (TM) documents the available Colorado River water supply in Utah through an inventory of CRB and Utah water supply models and their outputs.

2. Introduction

In February 2023, the District contracted Jacobs Engineering Group Inc. (Jacobs) to complete Task Order No. 2 of their Agriculture Water Resiliency Plan to meet both the District's and Colorado River Authority's

(Authority) goal of evaluating potential programs, partnerships, outreach activities, and other efforts needed to make an investment in optimizing agricultural water use within the CRB lands in Utah. Task Order No. 2 was performed in part as an in-kind contribution to the Authority by the District due to complementary interests in Drought Mitigation Planning in the CRB. The Agriculture Water Resiliency Plan includes a key task, *Evaluate the Possibilities*; the *Evaluate the Possibilities* task includes three subtasks which are illustrated on Figure 1.

Figure 1. Summary of the *Evaluate the Possibilities* Task and Progression of Included Subtasks

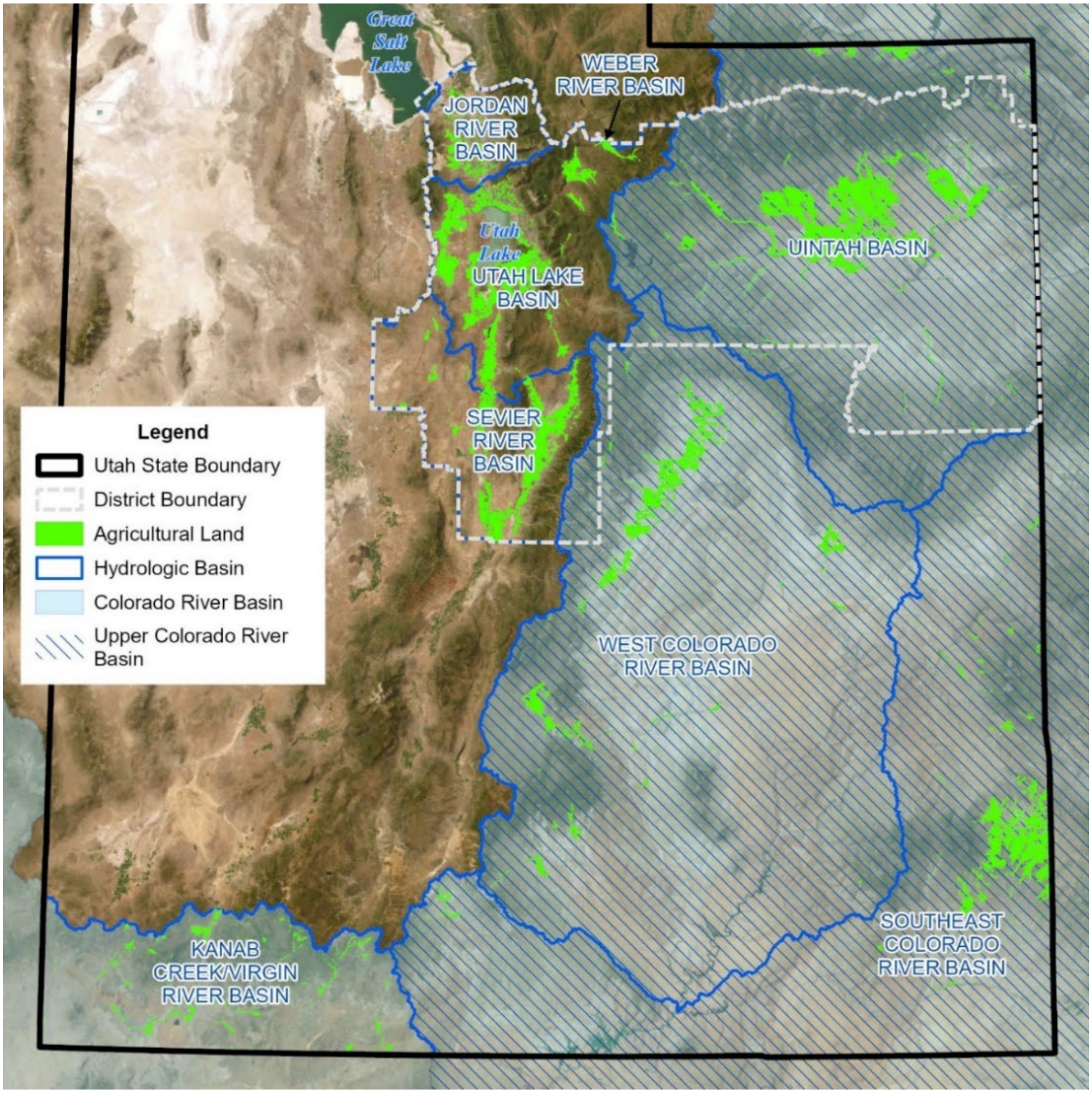


The purpose of the *Evaluate the Possibilities* task and its subtasks is to study the possibilities for reduced consumptive use in agriculture that promote resiliency for both farmers and Utah's supply of CRB water. This work was accomplished by evaluating available water supply, agricultural water demands, and potential gains from agricultural water optimization and voluntary demand management programs within the CRB lands in the state of Utah. The study area included the CRB lands in the state of Utah as well as the District's service area (where appropriate); results were further delineated by hydrologic basin. An overview of the CRB, District service area, included hydrologic basins, and agricultural lands are illustrated on Figure 2.

This TM documents the results of Subtask 2.1, Water Resource Inventory, and summarizes Utah's CRB water supply baseline and possible future conditions. The subtask activities are covered sequentially in this TM and are identified as originally scoped below:

1. Identify and summarize hydrologic basins in the CRB that fall within the state of Utah.
2. Identify and summarize CRB water supply models used by the Upper Colorado River Commission (UCRC), U.S. Bureau of Reclamation (Reclamation), and other Basin states.
3. Summarize the latest data from CRB water supply models to identify the range of expected water supply volume in wet and dry years (two scenarios); identify Utah's potential share of this volume in representative wet and dry years; and compare wet- and dry- year results against the UDWRe's available WBM results.
4. Using the latest data from CRB water supply models, estimate the volume of water in Utah's share available to agriculture during wet and dry years and compare estimates against historical water use statistics from UDWRe.
5. Summarize existing and emerging climate change models and resulting impacts in the CRB.
6. Calculate the resulting impacts on agricultural water supplies.
7. Summarize results with those from Task Order No. 1 to form a combined inventory of available water supplies in the District and CRB lands in Utah.

Figure 2. Hydrologic Basins and Agricultural Lands in the Colorado River Basin and District's Service Area



3. Colorado River Basin Hydrologic Basins in Utah

Subtask 2.1, Water Resource Inventory, began with delineating hydrologic basins within the study. Four basins include agricultural lands within the CRB in Utah, and an additional four basins include agricultural lands within the District's service area, according to UDWRe's 2021 Water Related Land Use dataset (UDWRe 2021a). These hydrologic basins, their associated acreages, and agricultural acreages are summarized in Table 1. Delineation of these hydrologic basins supports assessing and discussing opportunities for agriculture water resiliency programs and reduced agricultural consumptive use.

Table 1. Hydrologic Basins with Agricultural Areas within the Study Area

Hydrologic Basin	Acreage within Study Area[a]	Total Agricultural Acreage within Study Area[b]	Irrigated Agricultural Acreage within Study Area[c]
CRB Lands in Utah			
UCRB			
Uintah	6,965,857	279,196	257,181
West Colorado River	9,878,684	115,200	94,009
Southeast Colorado River	6,965,857	126,165	58,606
LCRB			
Kanab Creek/Virgin River	2,231,693	26,464	16,171
Total	**26,032,371**	**547,025**	**425,967**
District Service Area Outside of CRB			
Jordan River	497,446	14,949	10,997
Sevier River	1,435,475	136,451	119,831
Utah Lake	1,905,732	195,256	151,975
Weber River	6,503	1,106	1,097
Total	**3,845,156**	**347,762**	**283,900**

[a] West Desert Basin excluded from District service area basins due to not having any agricultural lands present.
[b] Areas include all agricultural land uses.
[c] Areas include actively irrigated fields through sprinkle, flood (surface), and drip methods and subirrigated fields; excludes dry crop, fallow, and idle field areas.

LCRB = Lower Colorado River Basin
UCRB = Upper Colorado River Basin

4. Colorado River Basin Water Supply Models

Three water supply models in the CRB were considered as part of this study, two of which simulate river operations: CRSS and Colorado River Midterm Modeling System (CRMMS); the third model maintained by UDWRe informs total available water supply: WBM. The two river simulation models are built in RiverWare™, a commercial river modeling platform developed by the Center for Advanced Decision Support for Water and Environmental Systems at the University of Colorado – Boulder. CRSS and CRMMS are maintained and continually updated by Reclamation's UCRB and LCRB regions.

4.1 Colorado River Simulation System

4.1.1 Overview

CRSS, which is built into the RiverWare™ software, is used to evaluate long-term studies (typically greater than 5 -year planning horizons), policy explorations, scenario comparisons, and supplementary resource analyses. The model runs on a monthly time-step and simulates 12 reservoirs through logic built into the model. The model is initialized in January by previous December conditions or from CRMMS projections. Input hydrology is in the form of natural inflows in the UCRB at 29 locations within CRSS. Multiple hydrologic ensembles (made up of multiple time-series traces) allow large ensembles of model outputs to be generated for statistical analysis over a wide range of plausible hydrologic future conditions. Water user demands are explicitly modeled and can be adjusted in the model separately from hydrology. UCRB depletion demands are based on the most current full diversion demands published by UCRC (2022).

4.1.2 Applicability to Study

CRSS applies to this study in two ways:

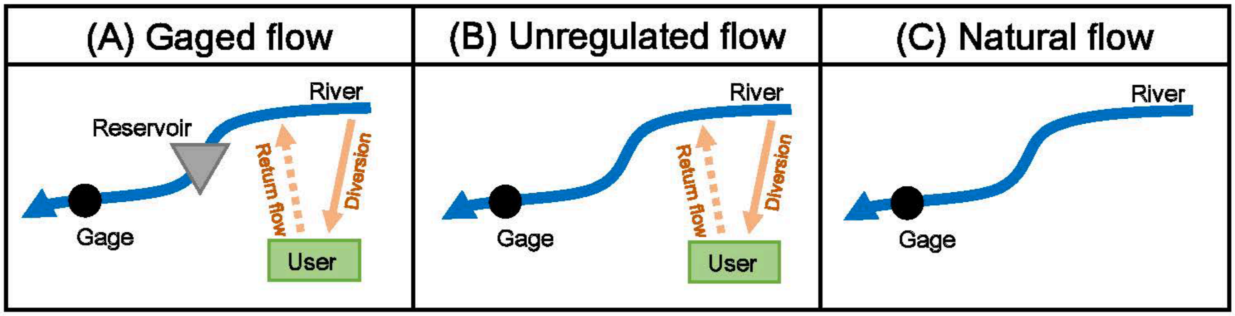
- CRSS can explicitly evaluate Utah agriculture user demands and water usage in the CRB study area.
- CRSS can model different policy scenarios.
- CRSS inputs allow varying ensembles of historic and future climate change hydrology conditions to be tested over a longer future time horizon. Therefore, multiple scenarios of water user usage can be analyzed.

4.2 Colorado River Midterm Modeling System

4.2.1 Overview

CRMMS is used for shorter time-horizon studies, such as the 2 -year and 5 -year probabilistic projections developed by Reclamation to understand the risk and uncertainty of future CRB system conditions. CRMMS runs on a monthly time-step and simulates 12 reservoirs through logic built into the model. Input hydrology is in the form of unregulated inflows in the UCRB produced by the Colorado Basin River Forecast Center. Unregulated inflows are flows that would have been observed at a location if no upstream reservoirs were present (Figure 3 presents a conceptual illustration of hydrologic inflow types). With unregulated inflows, water user demands are implicitly modeled because the usage is ‘baked into’ the hydrology between locations (with a few minor exceptions). For comparison, CRSS uses natural flows as hydrology inputs and represents water use demands explicitly.

Figure 3. Overview of Hydrology Input Methodologies



(A) Gage flow—Flow measured by a stream gage with actual reservoir operations and diversions.

(B) Unregulated flow—Flow that would have been observed at a stream gage if there were no upstream reservoirs present (includes evaporation and bank storage). These flows are input to the CRMSS model.

(C) Natural flow—Flow that would have been observed at a stream gage if there were no upstream reservoirs or diversion present. These flows are input to the CRSS model.

Source: Wheeler et al. (2019)

4.2.2 Applicability to Study

CRMMS is less applicable to this study than CRSS for the following reasons:

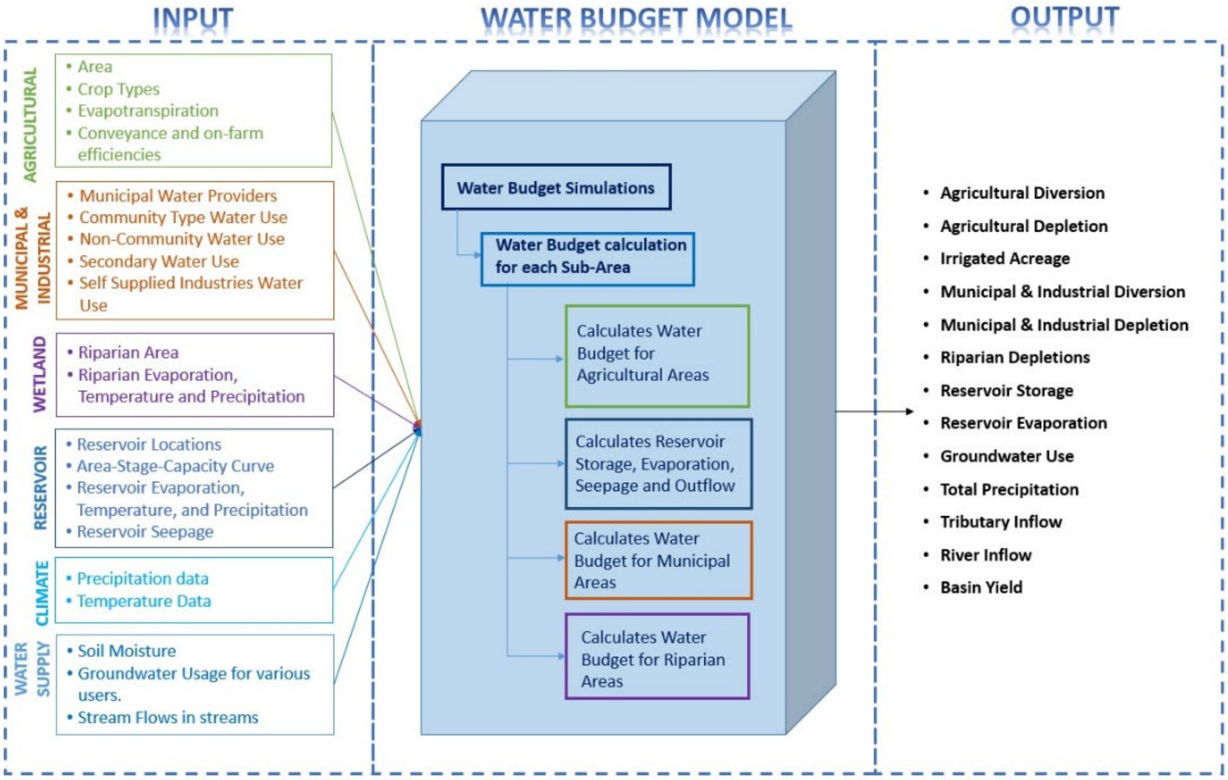
- CRMMS is an applicable model for analyzing shorter -time horizon evaluations that include more current operations, but it is less applicable to modeling longer -time horizon climate change runs as this study requires.
- Because water user demands are modeled implicitly, they cannot be analyzed separately from hydrology as this study requires.

4.3 Water Budget Model

4.3.1 Overview

Although primarily focused on agriculture, the WBM incorporates all water users and primarily quantifies the amount of surface and groundwater used by municipal, agricultural, and industrial sectors based on input data from several sources. The WBM also can be used to evaluate trends over time in land use and water conservation practices and changes in irrigation methods and yields. The WBM is complex, with multiple data inputs, such as precipitation, stream gage data, soil moisture, reservoir storage, and crop types. Inputs to the WBM are data that are often the results of other models. From the input data, model outputs, such as agricultural diversions and depletions, municipal and industrial diversions and depletions, precipitation, and yield, are available for each subarea (roughly the same size as a HUC12 watershed) in the State of Utah (UDWRe n.d.). WBM inputs and outputs are summarized in Figure 4.

Figure 4. Water Budget Model Inputs and Outputs



Source: UDWRe (n.d.)

4.3.2 Applicability to Study

WBM data have been integrated into this Subtask 2.1, Water Resource Inventory, in two areas:

- WBM information provides high -level water -supply information through its basin yield output, which is defined by UDWRe's WBM data "readme" file as precipitation minus natural system use (UDWRe 2022a). Historical CRB yield information is provided to supplement the wet and dry hydrology year results from applicable CRB simulation models. CRB yield notably informs the water supply originating on Utah's CRB lands, while the CRB simulation models include water supplies that originated in other UCRB states, so these datasets do not provide results for direct comparison but rather summarize available water supply data relevant to the study area.

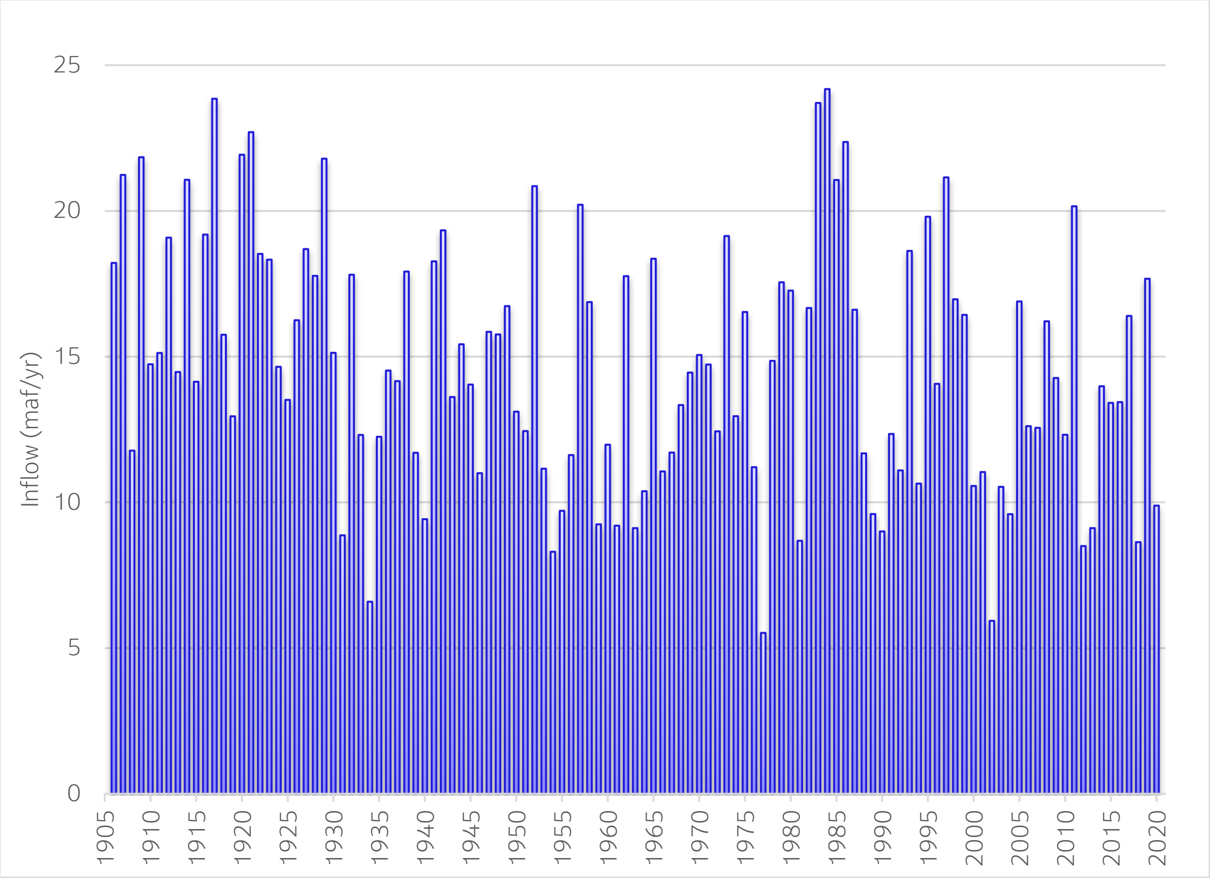
- WBM agricultural depletion data are compared with the water volume identified in applicable CRB simulation models that are available for agricultural uses in wet- and dry -year scenarios.

5. Range of Expected Water Supply Volume Based on Historical Record

5.1 Colorado River Simulation System

CRSS was used to gain an initial perspective of Utah's available water supply and agriculture water use in the CRB. The available water supply was evaluated using the historical record (1906 through 2020) of natural inflow into Lake Powell, which represents water supply from the UCRB. These data come from Reclamation's natural flow and salt data (Reclamation n.d.-a). Figure 5 shows the historical record from 1906 through 2020 and illustrates the modeled historical natural flow to Lake Powell; note that annual flow values are presented in terms of water year (WY) dates (October 1 through September 30).

Figure 5. Upper Colorado River Basin Historical Available Water Supply



Historical annual Lake Powell natural inflow volumes were ordered from least to greatest to inform selection of years to investigate further (shown on Figure 6). Only the wettest and driest years were initially considered, but to gain insight on more representative wet and dry years, the 90th percentile and 10th percentile years from the historical 1906 through 2020 record were also chosen. The wettest year was 1984, with a natural inflow volume of 24.2 maf, and the driest year was 1977, with a natural inflow volume of 5.5 maf. The 90th percentile year from the historical 1906 through 2020 record was 1985 at 21.1 maf, and the 10th percentile year was 1961 at 9.2 maf. Table 2 summarizes these selected years and flow values.

Figure 6. Ordered Historical Lake Powell Natural Inflow Years (1906 through 2020)

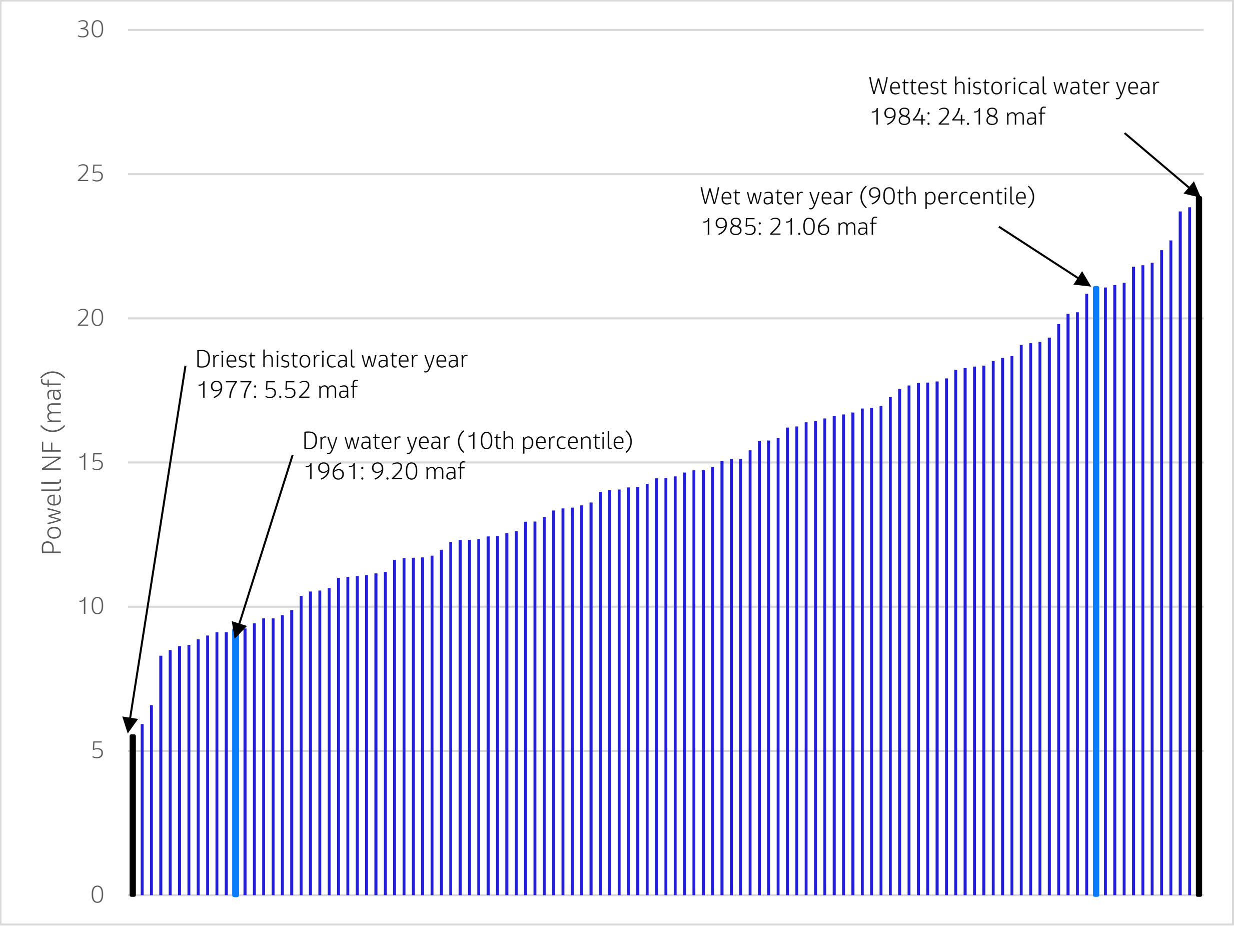


Table 2. Lake Powell Annual Water Year Natural Inflow for Selected Scenarios

Scenario	Natural Inflow (maf per year)
Wettest Year	24.2 (1984)
Wet Year (90th Percentile)	21.1 (1985)
Dry Year (10th Percentile)	9.2 (1961)
Driest Year	5.5 (1977)

The Subtask 2.1 scope of work included an interest in identifying Utah's potential share of the water supply available in both wet- and dry -year conditions. Article III.d of the *1922 Colorado River Compact* stipulates that the UCRB "shall not cause the flow of the river at Lee Ferry to be depleted below an aggregate of 75 maf for any period of ten consecutive years" (Reclamation n.d.-b), and per the 1948 UCRB Compact, Utah's "total quantity of consumptive use per annum apportioned in perpetuity to and available for use each year" is 23 percent after a 50 kaf reduction for use by Arizona (Reclamation n.d.-c). Additionally, Utah's total CRB demands, as published by the UCRC, range from 1.162 maf in 2030 to 1.347 maf in 2060 (UCRC 2022). During wet years, the amount of CRB water available to Utah would equal close to the state's full demands, depending on the distribution of precipitation. During dry years, available UCRB supply does not satisfy Utah's full demands, resulting in a shortage. For example, if the

10th percentile Lake Powell historical natural inflow volume of 9.2 maf were to occur, and 7.5 maf were released to the LCRB during that year, and carryover storage was not considered, then Utah's allocation of the resulting 1.7 maf available UCRB supply could be 0.39 maf.

5.1.1 Colorado River Simulation System Assumptions and Runs

Reclamation's CRSS (version 6, March 2023) in RiverWare™ was used to simulate CRB operations for the selected water supply years noted in Section 5.1. Using CRSS to model a single year is not the traditional purpose of CRSS and comes with some limitations, but it provides more opportunities for the purposes of this analysis than CRMMS. One such limitation is CRSS's calculation of water user shortages, the amount of water originally requested that was not received. Two issues arise that require caution when using the shortage values. The first is that the initial Upper Basin depletion requests are now 'full' demands in CRSS V6, in CRSS V5 the initial demands were already scaled back based on assumed shortage. Therefore, an Upper Basin water user's shortage may not closely follow reality because the modeled initial demand is higher. The second reason is that agricultural water user demands were used as a calibration variable to calibrate the model flows to actual gage flows for CRSS V6. Therefore, initial agricultural demands were modified (up or down) to calibrate the downstream flows and thus not accurately representing the full demand requested by the water user.

The CRSS model was run from January 2024 to December 2025 to output results for WY 2025. Following are key assumptions:

- **Initial conditions—**The initial conditions reflect December 31, 2023 projected conditions as reported in the January 2023 Most Probable 24-Month Study (Reclamation 2023) simulated with CRMMS.
- **Policy—**Operations are consistent with the *Record of Decision: Colorado River Interim Guidelines for Lower Basin Shortages and the Coordinated Operations of Lake Powell and Lake Mead* (Reclamation 2007), *Lower Basin Drought Contingency Plan* (Reclamation 2018), and Minute No. 323 to the 1944 U.S.-Mexico Water Treaty (Reclamation 2017).
- **UCRB demands—**UCRB demands were developed in coordination with the UCRC based on the *Updated 2016 Upper Division States Depletion Demand Schedule* (UCRC 2022) and provided as full demands.
- **LCRB demands—**LCRB demands were developed in coordination with the LRCB states and Mexico.

In CRSS, water users are represented by water user objects that store information such as name, demand, and model results like depletion and shortage. Utah has 61 different water users represented in the model in the following sectors: agriculture (30), energy (4), evaporation (9), exports from the CRB (5), and municipal and industrial (13). The 61 water users are listed in Appendix A.

CRSS inputs used for this study are water user demands, which are the amount of water requested by each user. Model results for this study include Utah's water user's depletions and shortages. A water user's depletion is the amount of actual water consumed by the water user and may or may not satisfy the requested water demand. A water user's shortage is the requested amount not received by the water user (demand minus depletion). For this study, the shortage represents a hydrologic shortage, meaning the water user was unable to fulfill its demand due to the lack of physical water available for diversion on that reach of the river. The input demand schedules assume an idealized case where all demands are fully met, but even during wet years, some geographic areas still experience hydrologic shortages due to variable precipitation distribution and spring snowpack.

5.2 Water Budget Model

WBM results provided by UDWRe allow water supplies that originate on study area lands, including Utah's CRB, to be identified. WBM subarea delineations and detailed results on the subarea scale were obtained from UDWRe (UDWRe 2023) and used to quantify the total water supply available for the study area. The native data available from UDWRe were adjusted to include lands within the study area. For each subarea intersected by the study area boundary, a percentage of the total lands within the study area was calculated. Then, for each of these affected subareas, the yield volumes (in acre-feet) were multiplied by the percentage of lands in the study area. The resulting yield volumes for each subarea were a proportion of the total volume based on the percentage of the subarea's lands in the study area.

Figure 7 shows the District service area yield results for 1989 through 2020, delineated into three categories: District service area lands outside of the CRB, UCRB lands, and LCRB lands. Subarea yield results were aggregated to calculate total yield for each category. The methodology to estimate yield is based strictly upon the percentage of land within the study area; the yield is not computed by hydrologic model for the actual drainages within the study area.

Figure 7. Historical Yield by Study Interest Area from the Utah Division of Water Resources Water Budget Model

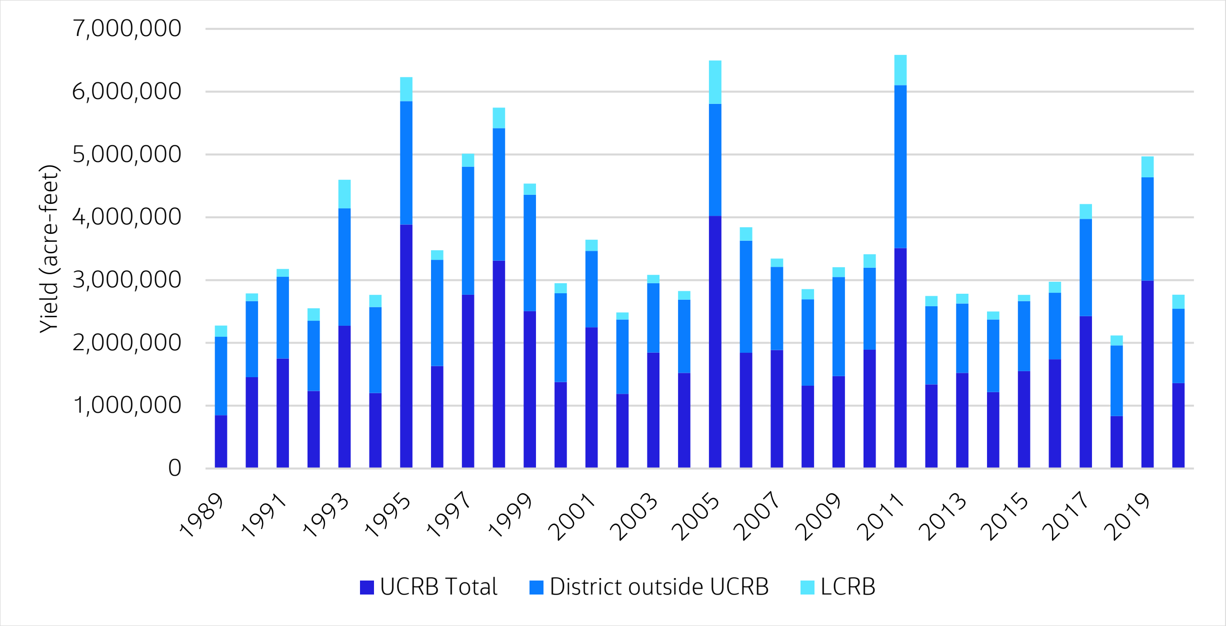


Figure 7 illustrates the yield totals for 1989 through 2020. Yields range from a low value of 2,118,797 acre-feet in 2018 to a high value of 6,584,650 acre-feet in 2011, with a median yield over the period of 3,130,296 acre-feet. Minimum total yield was 2,118,797 acre-feet in 2018 with 1,125,058 acre-feet occurring in the District outside of the CRB, 835,515 acre-feet occurring in the UCRB, and 158,224 acre-feet occurring in the LCRB. Maximum total yield was 6,584,650 acre-feet in 2011 with 2,591,524 acre-feet occurring in the District outside of the CRB, 3,511,609 acre-feet occurring in the UCRB, and 481,517 acre-feet occurring in the LCRB. These yield totals are listed in Table 3. District lands Outside of the CRB had greater yield than the other interest areas in 2018, yet this trend was not maintained in 2011, indicating that yield volumes are impacted by localized precipitation events, such as lake effect snow.

Table 3. Minimum, Maximum, and Median Yield in the 1989 through 2020 Period of Record within the Study Area

Yield	District Outside CRB (acre-feet)	UCRB (acre-feet)	LCRB (acre-feet)	Total Study Area (acre-feet)
Minimum (2018)	1,125,058	835,515	158,224	2,118,797
Median	1,314,795	1,685,662	175,733	3,130,296
Maximum (2011)	2,591,524	3,511,609	481,517	6,584,650

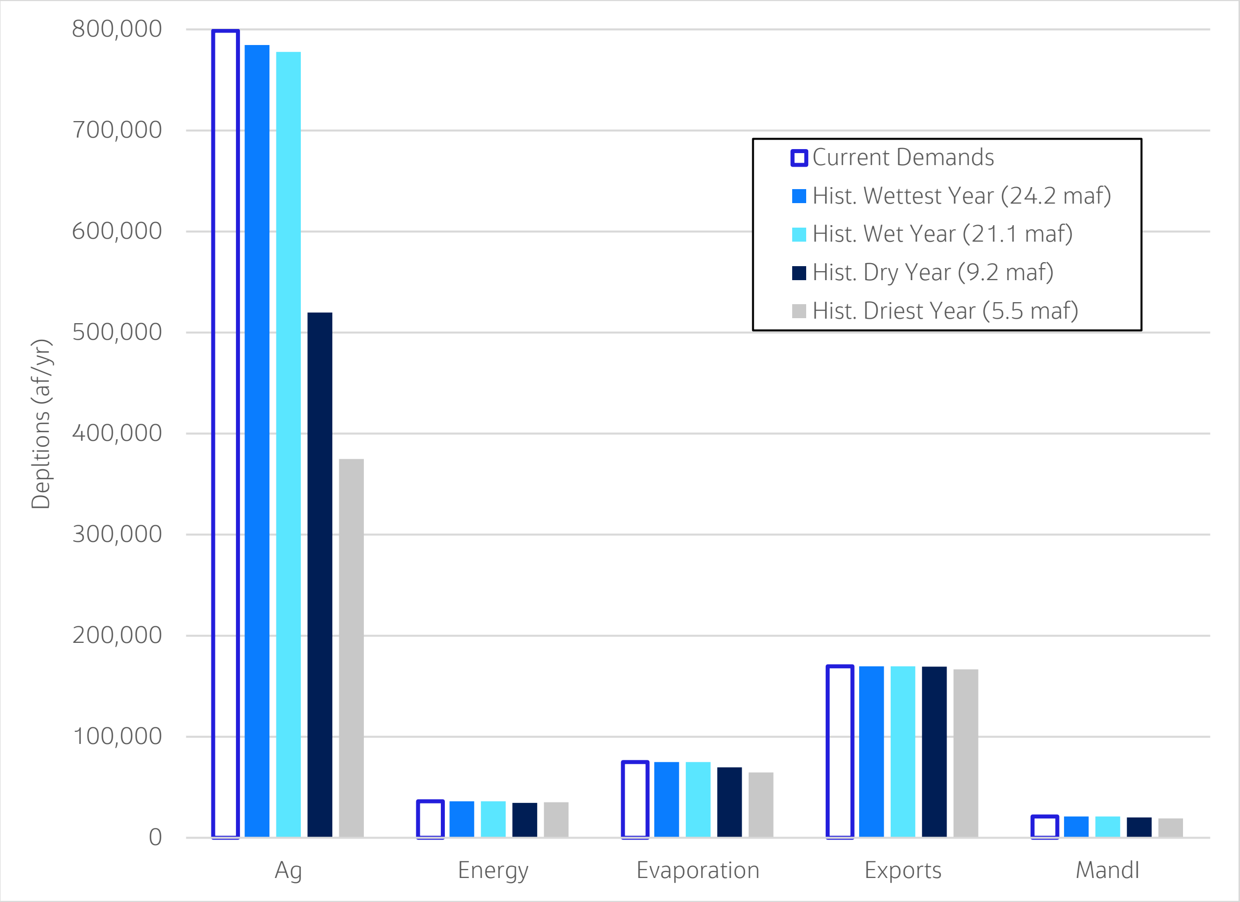
As discussed in Section 4.3.2, the natural inflow to Lake Powell modeled by CRSS includes water that originates from all UCRB states, and thus, the volumes reported are expected to be higher than WBM yield results. For example, the maximum natural historical inflow was estimated at 24.18 maf.

6. Estimate the Volume of Water Available to Agriculture

6.1 Colorado River Simulation System

Following the assumptions and approach detailed in Section 5.1.1, Utah's CRB depletions by sector were studied to estimate the volume of water that could be available to agriculture in Utah's portion of the CRB, as shown on Figure 8. Model results shown in the following figures and tables represent scenarios run for Water Year 2025 (October 1, 2024 to September 31, 2025) using the corresponding hydrology (wet/dry/etc.). To understand Utah's CRB depletions, Figure 8 compares sector depletions with current demands (open blue rectangles) (UCRC 2022). Within each sector, the depletions from each water supply scenario are compared with one another. In CRSS, a water user's depletion depends on the amount of available flow at the headgate. Therefore, model results indicate greater depletion volumes in wetter hydrologic scenarios.

Figure 8. Colorado River Simluation System Historical Scenario Results: Annual Utah Depletions by Sector



Note: CRSS modeled depletions apply to lands in the UCRB and may apply to District lands Outside the CRB to the extent that Exports are delivered to District lands outside of the CRB.

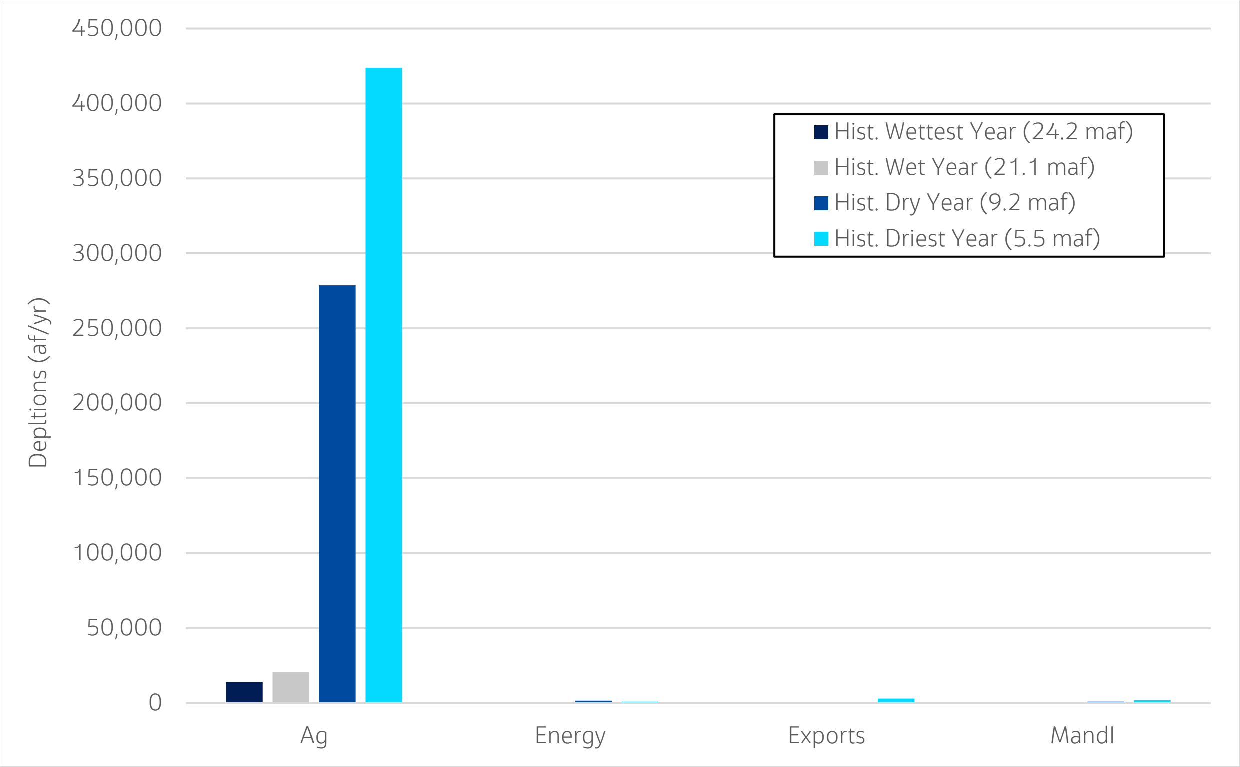
Depletions by the agricultural sector are greatest with values ranging from 375 kaf to 785 kaf during the driest and wettest years, respectively. Even during the wettest year, current demands are shown to exceed modeled depletions because location-specific hydrologic conditions in some cases are insufficient to meet all demands. Additional numerical depletion details are provided in Table 4.

Table 4. Colorado River Simulation System Historical Scenario Results: Current Demands Compared to Water Supply Scenario Depletions by Sector

Sector	Current Demands (af/yr)	Historical Scenarios (af/yr)			
		Wettest Year (24.2 maf)	Wet Year (21.1 maf)	Dry Year (9.2 maf)	Driest Year (5.5 maf)
Agriculture	798,565	784,511	777,744	519,861	374,802
Energy	36,163	36,161	36,161	34,496	35,209
Evaporation	74,916	74,916	74,909	69,769	64,571
Exports	169,609	169,607	169,607	169,432	166,613
Municipal and Industrial	21,132	21,124	21,117	20,151	19,213

As discussed in Section 5.1.1, shortages (demand minus depletion) were additionally investigated, and results are shown on Figure 9. Figure 9 compares Utah's shortages by sector for each water supply scenario. CRSS model results indicate that agricultural demands experience the largest shortage, and the drier the scenario investigated, the greater the resulting shortage. CRSS model results do not indicate the shortage to storage that occurs during dry hydrologic conditions. These shortages may affect export volumes in subsequent years. Table 5 summarizes the numerical details illustrated on Figure 9.

Figure 9. Colorado River Simulation System Historical Scenario Results: Annual Utah Water Supply Scenario Shortages by Sector



Note: CRSS modeled shortages apply to lands in the UCRB and may apply to District lands Outside the CRB to the extent that Exports are delivered to District lands outside of the CRB.

Table 5. Colorado River Simulation System Historical Scenario Results: Utah Water Supply Scenario Shortages by Sector

Sector	Historical Water Supply Scenarios (af/yr)			
	Wettest Year (24.2 maf)	Wet Year (21.1 maf)	Dry Year (9.2 maf)	Driest Year (5.5 maf)
Agriculture	14,056	20,823	278,705	423,762
Energy	3	3	1,667	954
Exports	2	2	176	2,996
Municipal and Industrial	11	18	982	1,920

Agricultural demands experience the greatest shortage compared with other sectors with shortages ranging from 14 kaf in the wettest historical scenario to 424 kaf in the driest historical scenario modeled.

6.2 Water Budget Model

The availability of agricultural depletion data from CRSS and UDWRe's WBM allows the model outputs to be compared for the UCRB. This comparison is for informational purposes only and not intended to gauge the relative accuracy of either method.

To compute WBM agricultural depletions for the study area, the native data available from UDWRe was adjusted. For each subarea intersected by the study area boundary with agricultural depletions occurring outside of the study area, a percentage of the total agricultural lands within the study area was calculated. Then, for each of these affected subareas, the total agricultural depletion volumes (in acre-feet) were multiplied by the percentage of agricultural lands in the study area. The resulting agricultural depletion volumes for each subarea were a proportion of the total volume based on the percentage of the subarea's agricultural lands in the study area. Although this approach is identified as a possible source of error in depletion estimates based on UDWRe WBM results, an analysis conducted as part of Task Order No. 1 (Jacobs 2023) indicates the error is negligible.

The range of agricultural depletions within the UCRB for both CRSS and WBM results is presented in Table 6 for the available historical record in both model cases.

Table 6. Range of Agricultural Depletions from Colorado River Simulation System and Water Budget Model

Depletion	CRSS (Historical Wettest and Driest Year Results)	Water Budget Model[a] (1989 through 2020)
Minimum	375 kaf (driest historical year)	512 kaf (2002)
Median	Scenario not investigated	631 kaf
Maximum	785 kaf (wettest historical year)	731 kaf (2006)

[a] WBM results exclude field boundaries classified as 'dry crop' in the Irrigation Methods field, and 'fallow/idle' 'idle' and 'idle pasture' in the Description field. For the 1989-2016 period of record, the proportion of agricultural land in each subarea intersecting the District's boundary was assumed to be a constant value based on review of the proportion estimates for the 2017-2020 period of record (see Appendix B).

Table 6 provides the depletion totals for CRSS and WBM record of results for the UCRB. Depletions range from a low value of 375 kaf during the driest historical scenario to a high value of 785 kaf during the wettest historical scenario for the CRSS results and a low value of 512 kaf to a high value of 731 kaf with a median depletion over the period of 631 kaf for the WBM results.

7. Existing and Emerging Climate Change Models and Resulting Water Supply Impacts on the Colorado River Basin

7.1 Summary of Existing and Emerging Climate Change Models

To evaluate future climate change impacts on CRB streamflows modeled in CRSS, different CMIP climate change hydrology datasets were considered (WCRP 2007, 2013, and 2022). The CMIP3 multimodel dataset comprises 112 unique climate projections generated using sixteen global circulation models. These datasets were coupled with three emissions scenarios (high, medium, and low), and the projections were then used to develop hydrologic inputs into CRSS, producing 112 unique sequences of future streamflow. This hydrology set was developed during the *Colorado River Basin Water Supply and Demand Study* (Reclamation 2012) and has been widely used for long term studies in the basin. The CMIP Phase 5 (CMIP5) multimodel dataset became available in 2012 and was developed into CRSS hydrology. The overall average is wetter than the CMIP3 and has not been widely accepted. The CMIP Phase 6 (CMIP6) multimodel dataset is available but has not yet been developed for use in CRSS. For these reasons, the CMIP3 hydrology dataset was used for climate change evaluations in this study.

Future climate change impacts to WBM Yield and Depletion volumes were estimated using a high-level estimate of a possible 10-percent reduction in future water supplies as reported in the 2021 *Utah State Water Plan* (UDWRe 2021).

7.2 Water Supply Impacts Due to Climate Change

7.2.1 Colorado River Simulation System

As noted above, the climate change water supply hydrology using the CMIP3 multimodel dataset has 112 sequences or traces of possible future streamflow, each spanning from 2025 to 2060. For comparison, this means 4,043 occurrence years (112 traces multiplied by 36 years) are possible to analyze, resulting in a large range of possible future hydrologic conditions to consider in the study. This sequence of possible future occurrences is compared with the single historical sequence spanning 1906 through 2020 (115 years). Natural inflow to Lake Powell is used to indicate the UCRB water supply. CMIP3 and historical annual WY natural inflow to Lake Powell are shown in compared boxplots on Figure 10. As shown, the overall average of CMIP3 natural inflow volume is lower than the historical sequence. CMIP3 shows lower natural inflow volumes for the extreme dry years as well, yet shows wet occurrences that exceed those from the historical scenario set.

From the CMIP3 model runs, four water supply scenarios (4 years) were identified for this study. Consistent with the historical scenarios, they include wettest, wet, dry, and driest years. Table 7 compares the historical and CMIP3 water supply volumes.

Figure 10. Historical vs. CMIP3 Lake Powell Natural Inflow Boxplots

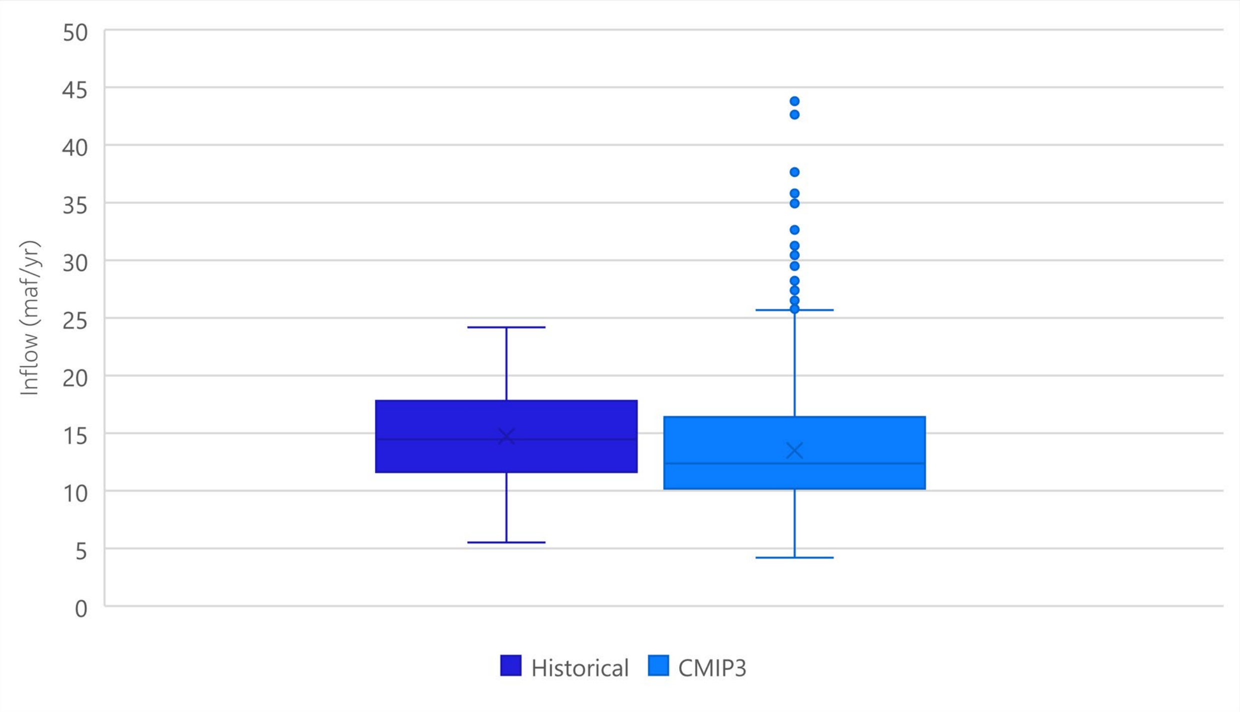


Table 7. Annual Water Year Lake Powell Natural Inflow Historical vs. CMIP3

Water Supply Scenario	Historical (maf)	CMIP3 (maf)
Wettest year	24.2 (1984)	44.3
Wet year (90th percentile)	21.1 (1985)	20.1
Dry year (10th percentile)	9.2 (1961)	8.4
Driest year	5.5 (1977)	4.1

Reasonably similar results were found for the wet, dry, and driest year, with CMIP3 natural inflow volume being lower in all cases than the corresponding historical record year volumes. For the wettest year, CMIP3 provided a significantly larger inflow volume of 44.3 maf compared with 24.2 maf for the historical dataset.

During the wet and wettest years identified during the CMIP3 analysis, the amount of CRB water available to Utah would likely meet the state's full demands, depending upon the distribution of precipitation and resulting streamflow. During dry years, the UCRB supply would not be enough to satisfy Utah's full demands, resulting in a shortage. For example, if the 10th percentile Lake Powell historical natural inflow volume of 8.4 maf were to occur, and 7.5 maf was released to the LCRB in that year, and carryover storage was not considered, then Utah's allocation of the resulting 0.9 maf available UCRB supply could be 0.2 maf.

7.2.2 Water Budget Model

UDWRe is currently developing two new hydrologic models, a complex Variable Infiltration Capacity (VIC) model and a Routing Application for Parallel Computation of Discharge (RAPID) model, to simulate climate change impacts to water supply in Utah. Until these models are completed, limited data exists to estimate the impact a changing climate will have on future yield volumes in Utah. The *Utah State Water Plan* (UDWRe 2021b) was released in 2021 and includes a high-level estimate for water supply reduction of 10-percent. This reduction estimate has been applied to yield volumes presented in Section 5.2 to generate a range of possible future yield results, see Table 8.

Table 8. Minimum and Maximum Future Yield Estimated Using the Water Budget Model Period of Record Results

Yield	District Outside CRB (acre-feet)	UCRB (acre-feet)	LCRB (acre-feet)	Total Study Area (acre-feet)
Minimum	1.0 maf	752 kaf	142 kaf	1.9 maf
Maximum	2.3 maf	3.2 maf	433 kaf	5.9 maf

Applying a 10-percent reduction assumption to historical WBM yield data leads to potential future available yield volumes which range from 1.9 maf to 5.9 maf across the study area.

7.3 Agricultural Water Supply Impacts in Utah due to Climate Change

7.3.1 Colorado River Simulation System

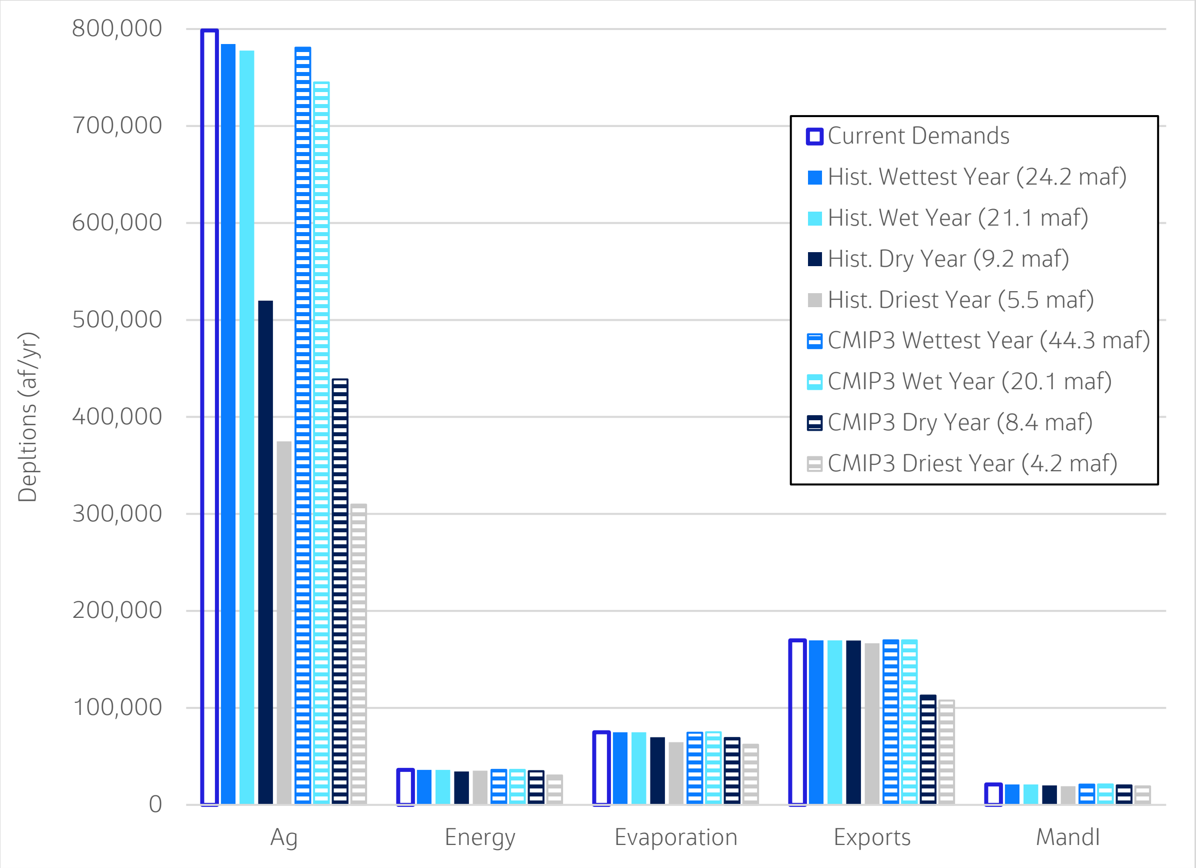
CRB depletions by sector were studied to estimate the volume of water available to agriculture under the CMIP3 climate change scenarios. Table 9 and Figure 11 compare the CMIP3 modeled Utah depletions with the historical modeled findings presented in Section 5.1.

Similar to the historical WY scenario depletions, the CMIP3 WY scenario depletions show the agriculture depletions to be the greatest of all the sectors and the most variability depending on water supply in the UCRB. The wettest -year scenarios of both the historical and CMIP3 show similar depletions because most demand has been fulfilled for these cases. Even during the wettest CMIP3 scenario with a natural flow of 44.3 maf, current demands remain unable to be fully met because they assume an idealized hydrologic case, and because some areas in the CMIP3 are still expected to experience a shortage due to variable distribution of snow and/or precipitation. The CMIP3 wet-, dry-, and driest -year scenarios show lower agriculture depletions than the corresponding historical scenarios studied, which indicates that water availability to support depletions under these scenarios is expected to decline based on the CRSS results. Figure 12 presents the CMIP3 modeled Utah shortages compared with the historical modeled findings presented in Section 5.1.

Table 9. Colorado River Simulation System Historical and CMIP3 Scenario Results: Utah Depletions by Sector

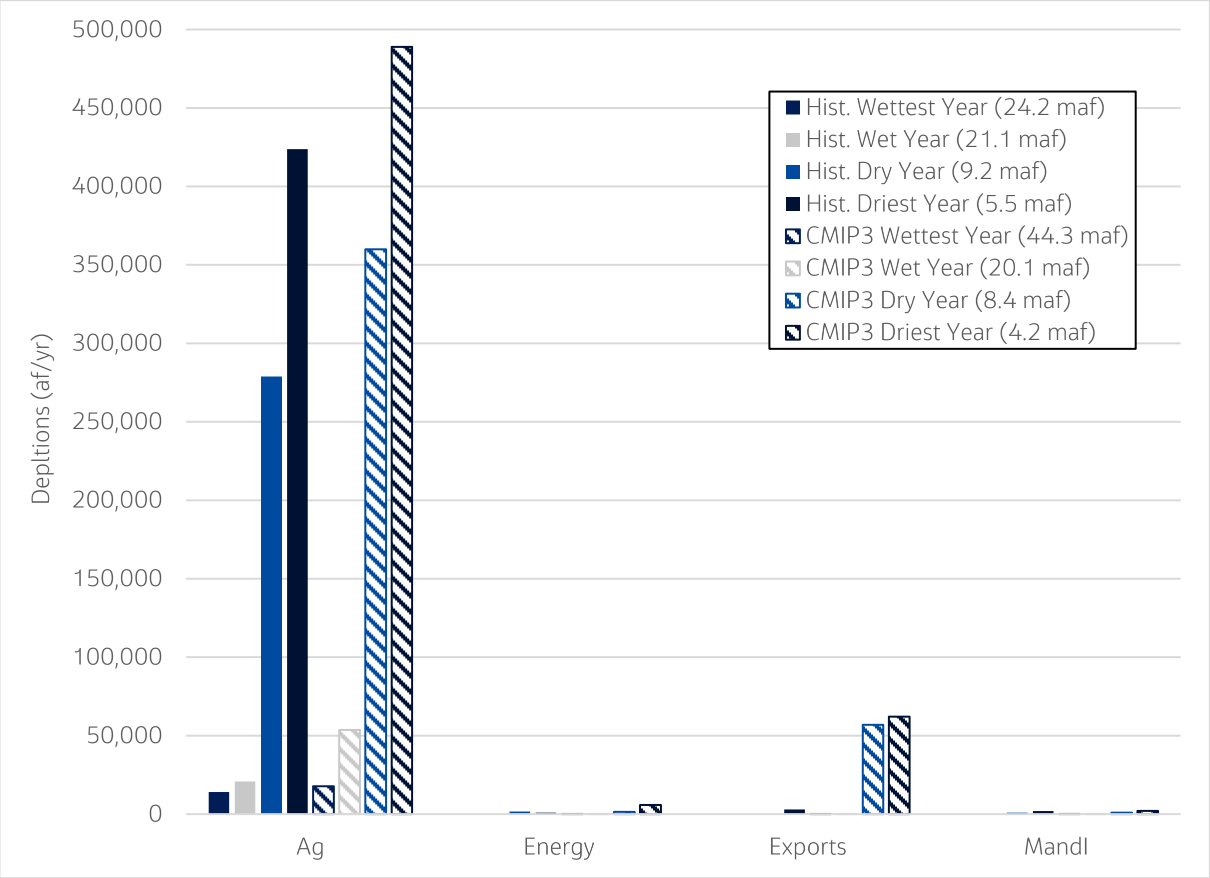
Sector	Current Demands	Historical Scenarios				CMIP3 Scenarios			
		Wettest Year 24.2 maf	Wet Year 21.1 maf	Dry Year 9.2 maf	Driest Year 5.5 maf	Wettest Year 44.3 maf	Wet Year 20.1 maf	Dry Year 8.4 maf	Driest Year 4.2 maf
Agriculture	798,565	784,511	777,744	519,861	374,802	780,816	744,959	438,640	309,690
Energy	36,163	36,161	36,161	34,496	35,209	36,161	36,161	34,767	30,326
Evaporation	74,916	74,916	74,909	69,769	64,571	74,366	74,916	68,927	61,940
Exports	169,609	169,607	169,607	169,432	166,613	169,607	169,607	112,672	107,511
Municipal and Industrial	21,132	21,124	21,117	20,151	19,213	20,983	21,124	20,159	19,097

Figure 11. Colorado River Simulation System Historical and CMIP3 Scenario Results: Annual Utah Depletions by Sector



Note: CRSS modeled depletions apply to lands in the UCRB and may apply to District lands Outside the CRB to the extent that Exports are delivered to District lands outside of the CRB.

Figure 12. Colorado River Simulation System Historical and CMIP3 Scenario Results: Annual Utah Shortages by Sector



Note: CRSS modeled shortages apply to lands in the UCRB and may apply to District lands Outside the CRB to the extent that Exports are delivered to District lands outside of the CRB.

Similar to the historical scenario results, the agricultural depletions in the CMIP3 water supply scenarios experience the largest shortage of the sectors included in CRSS. Shortages in the CMIP3 scenarios were greater in all scenarios, compared with the historical results, due to variations in distribution of precipitation and resulting flows in this hydrology when compared to historical, as detailed in Table 10.

Table 10. Colorado River Simuluation System Historical and CMIP3 Scenario Results: Utah Shortages by Sector

	Historical Scenarios				CMIP3 Scenarios			
Sector	Wettest Year 24.2 maf	Wet Year 21.1 maf	Dry Year 9.2 maf	Driest Year 5.5 maf	Wettest Year 44.3 maf	Wet Year 20.1 maf	Dry Year 8.4 maf	Driest Year 4.2 maf
Agriculture	14,054	20,821	278,704	423,763	17,749	53,606	359,925	488,875
Energy	2	2	1,667	954	2	2	1,396	5,837
Evaporation	0	7	5,147	10,345	550	0	5,989	12,976
Exports	2	2	177	2,996	2	2	6,937	62,098
Municipal and Industrial	8	15	981	1,919	149	8	973	2,035

7.3.2 Water Budget Model

As discussed in Section 7.2.2, limited data currently exists to predict the impact a changing climate may have on Utah's future yield volumes. Similarly, the impact to future agricultural supplies is not well understood. Consistent with Section 7.2.2, a reduction estimate of 10-percent per the *Utah State Water Plan* (UDWRe 2021b) has been applied to depletion volumes presented in Section 6.2 to generate a range of possible future depletion results, see Table 11.

Table 11. Minimum and Maximum Future Depletions Estimated Using the Water Budget Model Period of Record Results

Depletion	District Outside CRB (acre-feet)	UCRB (acre-feet)	LCRB (acre-feet)	Total Study Area (acre-feet)
Minimum	313 kaf	461 kaf	33 kaf	892 kaf
Maximum	489 kaf	658 kaf	46 kaf	1.1 maf

Applying a 10-percent reduction assumption to historical WBM depletion data leads to potential future depletion volumes which range from 892 kaf to 1.1 maf across the study area.

8. Combined Inventory of Available Water Supplies for the District Service Area and Colorado River Basin Lands in Utah

A combined inventory of available water supplies for District service area lands outside of the CRB and UCRB and LCRB lands has been provided in Table 12. Both WBM and CRSS results described herein have been incorporated to summarize the total available supply, total available supply to agriculture, and total agricultural shortage.

Table 12. Summary of Water Supply Results

Area/Model	Historical Driest	Historical Wettest	Climate Change Driest	Climate Change Wettest
Total Available Supply				
District Service Area Outside of CRB Model: WBM	1.1 maf (minimum yield, 1989 through 2020)	2.6 maf (maximum yield, 1989 through 2020)	1.0 maf[a]	2.3 maf[a]
Utah's UCRB Model: WBM	836 kaf (minimum yield, 1989 through 2020)	3.5 maf (maximum yield, 1989 through 2020)	752 kaf[a]	3.2 maf[a]
Utah's UCRB Model: CRSS	Uncertain[b]	1.162 maf to 1.347 maf[c]	Uncertain[b]	1.162 maf to 1.347 maf[c]
Utah's LCRB Model: WBM	158 kaf (minimum yield, 1989 through 2020)	482 kaf (maximum yield, 1989 through 2020)	142 kaf[a]	434 kaf[a]
Total Available Supply to Agriculture				
District Service Area Outside of CRB Model: WBM	347 kaf (minimum depletion, 1989 through 2020)	543 kaf (maximum depletion, 1989 through 2020)	312 kaf[a]	489 kaf[a]
Utah's UCRB Model: WBM	512 kaf (minimum depletion, 1989 through 2020)	731 kaf (maximum depletion, 1989 through 2020)	460 kaf[a]	657 kaf[a]

Area/Model	Historical Driest	Historical Wettest	Climate Change Driest	Climate Change Wettest
Utah's UCRB Model: CRSS	375 kaf	785 kaf	310 kaf	781 kaf
Utah's LCRB Model: WBM	36 kaf (minimum depletion, 1989 through 2020)	51 kaf (maximum depletion, 1989 through 2020)	32 kaf[a]	46 kaf[a]
Total Agriculture Shortage				
District Service Area Outside of CRB Model: WBM	Uncertain[d]	Uncertain[d]	Uncertain[d]	Uncertain[d]
Utah's UCRB Model: WBM	Uncertain[d]	Uncertain[d]	Uncertain[d]	Uncertain[d]
Utah's UCRB Model: CRSS	424 kaf	14 kaf	489 kaf	18 kaf
Utah's LCRB Model: WBM	Uncertain[d]	Uncertain[d]	Uncertain[d]	Uncertain[d]

[a] These values represent 10-percent potential decrease in water supplies per the *Utah State Water Plan* (UDWRe 2021b).
[b] Theoretical supply available during dry years is uncertain due to unknown delivery from storage to support LCRB obligations.
[c] Total available supply likely to be consistent with the *Depletion Demand Schedule* (UCRC 2022), see additional discussion in Sections and 7.2.1.
[d] The UDWRe WBM does not calculate agricultural shortage.

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Appendix A

Colorado River Simulation System Utah Water Users

Table A-1. Colorado River Simulation System Utah Water Users

Aggregate Diversion Site	Water User	Sector
AgUsesGrowthAbvGreendale	UTAgriculture	Agriculture
AgUsesGrowthAbvGreenRiverConfluence	Agriculture	Agriculture
AgUsesGrowthAbvGreenRUT	Agriculture	Agriculture
AgUsesGrowthAbvPowell	Agriculture	Agriculture
AgUsesGrowthAbvRandlette	Agriculture	Agriculture
AgUsesGrowthBtwnGreendaleAndOuray	Agriculture	Agriculture
AgUsesGrowthDoloresRAbvCisco	UTAgriculture	Agriculture
AgUsesGrowthSanRafael	Agriculture	Agriculture
AgUsesGrowthSanRafaelToColorado	Agriculture	Agriculture
AgUsesGrowthWhiteRiverBlwWatson	Agriculture	Agriculture
AgUsesPLAbvGreendale	UTAgriculture	Agriculture
AgUsesPLAbvGreenRiverConfluence	Agriculture	Agriculture
AgUsesPLAbvGreenRUT	Agriculture	Agriculture
AgUsesPLAbvPowell	Agriculture	Agriculture
AgUsesPLAbvRandlette	Agriculture	Agriculture
AgUsesPLBtwnGreendaleAndOuray	Agriculture	Agriculture
AgUsesPLDoloresRAbvCisco	UTAgriculture	Agriculture
AgUsesPLSanRafael	Agriculture	Agriculture
AgUsesPLSanRafaelToColorado	Agriculture	Agriculture
AgUsesPLWhiteRiverBlwWatson	Agriculture	Agriculture
UTAgUsesGrowthSanJuan	Agriculture	Agriculture
UTAgUsesPLSanJuan	Agriculture	Agriculture
AgUsesGrowthAbvGreenRUT	AgricultureTribal	Agriculture
AgUsesGrowthBtwnGreendaleAndOuray	AgricultureTribal	Agriculture
AgUsesGrowthWhiteRiverBlwWatson	AgricultureTribal	Agriculture
AgUsesPLAbvGreenRUT	AgricultureTribal	Agriculture
TribalAgUsesGrowthAbvStarvation	AgricultureTribal	Agriculture
TribalAgUsesPLAbvStarvation	AgricultureTribal	Agriculture
TribalUsesGrowthSanJuanBlwBluff	AgricultureTribal	Agriculture
TribalUsesPLSanJuanBlwBluff	AgricultureTribal	Agriculture
EnergyUsesBtwnGreendaleAndOuray	Energy	Energy
EnergyUsesPriceRiver	Energy	Energy
EnergyUsesSanRafael	Energy	Energy
EnergyUsesWhiteRiverBlwWatson	Energy	Energy
MiscUseBtwnGreendaleAndOuray	Evaporation	Evaporation
MiscUsesAbvGreendale	UTEvaporation	Evaporation
MiscUsesAbvGreenRiverConfluence	Evaporation	Evaporation

Aggregate Diversion Site	Water User	Sector
MiscUsesAbvGreenRUT	Evaporation	Evaporation
MiscUsesAbvPowell	Evaporation	Evaporation
MiscUsesAbvRandlette	Evaporation	Evaporation
MiscUsesDoloresRAbvCisco	UTEvaporation	Evaporation
MiscUsesSanRafael	Evaporation	Evaporation
UTMiscUsesSanJuan	Evaporation	Evaporation
ExportUsesAbvPowell	Exports	Exports
ExportUsesDuchesne	Exports	Exports
ExportUsesPriceRiver	Exports	Exports
ExportUsesSanRafael	Exports	Exports
ExportUsesULS	Exports	Exports
MandIUsesPriceRiver	MandI	Municipal and Industrial
MiscUseBtwnGreendaleAndOuray	MandI	Municipal and Industrial
MiscUsesAbvGreendale	UTMandI	Municipal and Industrial
MiscUsesAbvGreenRiverConfluence	MandI	Municipal and Industrial
MiscUsesAbvGreenRUT	MandI	Municipal and Industrial
MiscUsesAbvPowell	MandI	Municipal and Industrial
MiscUsesAbvRandlette	MandI	Municipal and Industrial
MiscUsesDoloresRAbvCisco	UTMandI	Municipal and Industrial
MiscUsesSanRafael	MandI	Municipal and Industrial
UTMiscUsesSanJuan	MandI	Municipal and Industrial
MandIUsesBlwBluff	MandITribal	Municipal and Industrial
MiscUsesAbvGreenRUT	MandITribal	Municipal and Industrial
MiscUsesAbvRandlette	MandITribal	Municipal and Industrial

Appendix B

Proportional Estimates for Water Budget Model Depletions

Appendix B. Proportional Estimates for Water Budget Model Depletions

There are 62 WBM subareas that are completely within or intersect the District's boundary. Depletion volumes associated with subareas that are completely within the District's boundary are used directly in WBM data aggregations. Depletion volumes for each WBM subarea were assumed to be a proportion of the total depletion volume based on the percentage of the subarea's agricultural lands in the District's service area. For the 2017-2020 period of record, the yearly proportion of active agricultural lands in District's boundary was calculated using UDWRe WRLU

data sets (UDWRe 2017; 2018; 2019; 2020). Total agricultural land use excludes field boundaries classified as 'dry crop' in the Irrigation Methods field of the WRLU datasets, and 'fallow/idle' 'idle' and 'idle pasture' in the Description field. WRLU data collected by UDWRe prior to 2017 was collected using a different methodology, and therefore proportional estimates cannot be reliably completed. Consequently, for those subareas that intersect the District's boundary, the proportion of agricultural lands in the District's boundary was based on review of the 2017-2020 WRLU proportions (Table B-1).

Table B-1. Proportion of Agricultural Lands Assumed to be Within the District's Boundary for Subareas that Intersect the District's Boundary

Subarea Name	2017 Proportion	2018 Proportion	2019 Proportion	2020 Proportion	Min	Max	Mean	Proportion Used in Calculations
Crouse Creek	0%	0%	34%	34%	0%	34%	17%	0%; assumed agricultural lands were idle prior to 2017
Fool Creek	6%	7%	7%	5%	5%	7%	6%	6% (mean of 2017-2020 period of record)
Joes Valley	0%	0%	3%	3%	0%	3%	1%	0%; assumed agricultural lands were idle prior to 2017
Kamas Valley	8%	9%	9%	9%	8%	9%	9%	9% (mean of 2017-2020 period of record)
Mini Maud	68%	67%	74%	76%	67%	76%	71%	71% (mean of 2017-2020 period of record)
Sevier Bridge	54%	59%	58%	58%	54%	59%	57%	57% (mean of 2017-2020 period of record)
Strawberry River	0%	0%	100%	100%	0%	100%	50%	0%; assumed agricultural lands were idle prior to 2017

Table B-1 does not include the 36 subareas where the proportion in the 2017-2020 period of record was 100%, or the 19 subareas where the proportion in the 2017-2020 was 0%. For these subareas, the historic proportion was reflective of the 2017-2020 WRLU datasets. As a result of the proportional assumptions detailed in Table B-1 for years prior to 2017, the WBM results may not account for depletions occurring in subareas assumed to not include agricultural lands.