Estimated Depletion Reduction Calculation Methodology Report

Document No.: 251001233012_d88d63a3
Version: 2.2

Colorado River Authority of Utah
Management and Technical Consulting for Utah Demand Management Pilot Program
December 17, 2025

Jacobs

Estimated Depletion Reduction Calculation Methodology Report

Client name:	Colorado River Authority of Utah		
Project name:	Management and Technical Consulting for Utah Demand Management Pilot Program		
Document no.:	251001233012_d88d63a3	**Project no.:**	WXYB8600
Version:	2.2	**Project manager:**	Calah Worthen
Date:	December 17, 2025	**Prepared by:**	Jacobs Engineering Group, Inc.
File name:	Estimated Depletion Reduction Calculation Methodology_v2.2		

Document History and Status

Version	Date	Description	Author	Reviewed/Approved
1	2/7/2025	Version sent to the Authority for review	Drew Stock, Calah Worthen	Scott Morrison
1.1	2/27/2025	Responded to client comments (received 2/14); added *Discussion* section; reformatted into the Jacobs report; cleared redlines	Drew Stock, Calah Worthen	Scott Morrison
2	10/7/2025	Added methodology for multiple irrigation periods; added QA/QC section; added discussion on soil moisture calculation coefficients, median vs. average summary statistic, and look-back period; discussed post-season depletion and daily estimates used for provisional accounting; revised to 2026 irrigation-season timelines	Drew Stock, Jen Knapp, Burdette Barker	Lily Bosworth, Calah Worthen
2.1	11/19/2025	Revised monthly carry-over soil moisture calculation to include a maximum limit based on crop rooting depth and available water capacity. Revised annual calculation to be the sum of the monthly depletion estimates.	Eric Holmstead	Drew Stock
2.2	12/19/2025	Revised end-of-season conserved consumptive use calculation and updated variable names for readability.	Drew Stock	Lily Bosworth

Jacobs Technology Inc.

6440 S. Millrock Drive
Suite 300
Holladay, UT 84121
United States

T +1385.474.8500
www.jacobs.com

Contents

Appendix

Tables

Acronyms and Abbreviations

ΔD	depletion change from irrigated to fallowed condition
API	Application Programming Interface
Authority	Colorado River Authority of Utah
AWC	available water capacity
AWS	available water storage
CCU	conserved consumptive use
DMPP	Utah Demand Management Pilot Program
D_{after}	depletion from area when DMPP is implemented
DRO	depletion reduction opportunity
eeMETRIC	Google Earth Engine Implementation of the Mapping Evapotranspiration at High Resolution with Internalized Calibration
ET	evapotranspiration
ET_a	actual evapotranspiration
ET_{mon}	monthly crop evapotranspiration
$ET_{o,after}$	short-reference evapotranspiration for the after DMPP participation period
$ET_{o,preseason}$	short-reference evapotranspiration for depletion reduction opportunity period
$ET_{prev\ mon}$	previous month monthly crop evapotranspiration
ET_{win}	winter or nongrowing season evapotranspiration
FSA	Farm Service Agency
Jacobs	Jacobs Engineering Group Inc.
LEPA	low-elevation precision application
LESA	low-elevation spray application
MESA	mid-elevation sprinkler application
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resource Conservation Service
P_{eff}	effective precipitation
$P_{eff,\ mon}$	monthly effective precipitation
$P_{eff,\ prev\ mon}$	previous month monthly effective precipitation
P_{mon}	monthly precipitation

PRISM	Parameter elevation Regression on Independent Slopes Model
P_{win}	winter or nongrowing season precipitation
QA/QC	quality assurance and quality control
Reclamation	United States Bureau of Reclamation
RZ	crop rooting depth
SCPP	System Conservation Pilot Program
SDI	subsurface drip irrigation
SF	soil water storage factor
SM_{co}	carry-over soil moisture
$SM_{co, mon}$	monthly carry-over soil moisture
$SM_{co, prev mon}$	monthly carry-over soil moisture at start of previous month
SSURGO	Soil Survey Geographic Database
UCRB	Upper Colorado River Basin
UCRC	Upper Colorado River Commission
Upper Division States	Colorado, New Mexico, Utah, and Wyoming
USU	Utah State University
water year	October 1 through September 30 (designated by calendar year in which it ends)

1. Introduction

The Colorado River Authority of Utah (the Authority), in accordance with the Authority's *Colorado River Management Plan* (Authority 2022), is implementing an intrastate Utah Demand Management Pilot Program (DMPP) to begin during irrigation season 2025 (April 1 through October 31). The purpose of the DMPP is to identify opportunities and challenges associated with developing a full-scale, long-term agricultural demand management program in Utah. Specifically, the DMPP seeks to implement projects that achieve water conservation through reduced water depletion. Coordinating with the Utah Division of Water Rights to distribute and account for the reduced water depletion through a change application process on the subject water right(s) will help the Authority test demand management and maintain 1922 Colorado River Compact compliance.

In March 2024, the Authority hired Jacobs Engineering Group Inc. (Jacobs) and its subconsultant partners to assist in developing, administering, designing, and implementing the DMPP. This report summarizes the depletion reduction calculation methodologies used by Jacobs and its subconsultants for three types of eligible projects under the DMPP (temporary fallowing, irrigation system conversion, and storage forbearance).

This report specifies the assumptions and data sources used to support depletion reduction estimates for projects being implemented during the DMPP's project cycle 2, season 2026. This report, submitted as Version 2, builds upon Version 1, which summarized the methodology used in the DMPP's project cycle 1, beginning at irrigation season 2025. The methodology presented in this report will be used by the Authority to estimate post-season conserved consumptive use (CCU) for individual DMPP projects in project cycles 1 (2025-2026) and 2 (2026) and support provisional accounting for the Upper Colorado River Commission (UCRC) at the end of the 2025 and 2026 water years. Version 1.1 of this memo was used to calculate preseason depletion reduction opportunity (DRO) for project cycle 1.

2. Data Sources

Table 2-1 summarizes data sources used to calculate depletion reduction estimates for the DMPP's project cycle 2, which includes projects scheduled for implementation in 2026. These data sources directly support calculations and methods described in this report. Additional references are provided throughout this report.

Table 2-1. Summary of Key Data Sources Used in Depletion Reduction Calculations

Data Source	Timescale	Usage	Reference	Additional Notes
eeMETRIC (version 2.3 or latest version available through OpenET API)	Monthly gridded ET_a depths were obtained from OpenET API; underlying data are available at the daily timescale.	All ET_a values are estimates from OpenET's eeMETRIC model, not potential ET estimates. Monthly eeMETRIC data are used to derive ET_a inputs used in **Equations 1**, **2**, and **3**. The following forms of ET are used in this report: ▪ ET_a: Actual or growing season[a] ▪ ET_{win}: Nongrowing or winter season[a] ▪ ET_{mon}: Monthly ET	Melton et al. (2021)	OpenET provides satellite-based estimates of the total amount of water that is transferred from land surface to atmosphere through ET; it also provides the mean ET_a depth within each agricultural field boundary at the monthly timescale. OpenET uses area-weighted average of grid cells when aggregating polygon data (OpenET 2025a).
SSURGO	SSURGO soils data were downloaded annually and assumed constant throughout the entire, up to 7-year, look-back period.	AWS or its byproducts are used in **Equations 2**, **3**, and **4**.	NRCS (2024)	The variable *aws0150wta* in the SSURGO soils database represents the maximum amount of plant-available water a soil can hold in the top 59 inches (150 centimeters). This is the maximum depth AWS is reported in in the SSURGO database. When multiple soil classifications were found in the same agricultural field boundary, then the area-weighted AWS was used.
Hill et al. 1989 Depletion Equation	Irrigation-season data were used.	The equation to calculate annual depletion in inches (**Equation 1**) is from Hill et al. (1989); annual depletion (inches) is calculated as ET (during growing season), minus nongrowing season SM_{co} at start of irrigation season, minus P_{eff} (growing season).	Hill et al. (1989)	N/A

Data Source	Timescale	Usage	Reference	Additional Notes
Literature	Crop rooting depths were adjusted annually throughout the historical look-back period based on crops grown each year, for up to 7 years; if multiple crops with differing rooting depths were planted in same agricultural field during a single year, then average crop rooting depth was used.	**Equation 2** uses crop rooting depths (RZ) to calculate SM_{co}.	Crop rooting depths are based on Jacobs (2024a) in the Colorado River Basin; assumptions are based on CCC (2024), Sertse et al. (2019), Dharmasri et al. (1993), Allen et al. (2015), St. John et al. (2017), Pleasant (2023), and Franzen et al. (2005).	DMPP applicants provide crop names for entire look-back period. If a record of historical crop types is unavailable, then alfalfa is assumed due to its prevalence in Utah (UDWRe 2024).
FSA	Agricultural field boundaries were held constant throughout the look-back period.	Agricultural field boundaries summarize ET_a, AWS, precipitation, and acreages; depletion estimates are completed at the field-scale.	N/A	Geospatial layers showing agricultural field boundaries were obtained from the FSA by DMPP applicants.
PRISM Climate Group, Oregon State University	Monthly gridded precipitation depths were obtained from PRISM; underlying data are available at daily timescale.	The following precipitation data are used in **Equations 1**, **2**, and **3**. ▪ P_{eff}: Estimate of the portion of precipitation that supports plant growth during irrigation season ▪ P_{mon}: Monthly precipitation ▪ P_{win}: Winter or nongrowing season precipitation	PRISM Climate Group (2025)	PRISM Climate Group provides localized, P_{mon}. The gridded monthly results are used to derive P_{eff}, P_{mon}, P_{win}. Esri's zonal statistics tool (Esri 2024) was used to find the mean precipitation depth within each agricultural field boundary each month using the gridded precipitation data.

[a] Growing season is March 1 to October 31, and the nongrowing season is November 1 to March 31.

API = Application Programming Interface
AWS = available water storage
CCU = conserved consumptive use
DDMP = Utah Demand Management Pilot Program
DRO = depletion reduction opportunity
eeMETRIC = Google Earth Engine Implementation of the Mapping Evapotranspiration at High Resolution with Internalized Calibration
ET = evapotranspiration
ET_a = actual evapotranspiration
ET_{win} = nongrowing (winter) season evapotranspiration
ET_{mon} = monthly crop evapotranspiration
FSA = Farm Service Agency
Irrigation season = March 1 through October 31
NRCS = Natural Resource Conservation Service
P_{mon} = monthly precipitation
P_{win} = nongrowing season precipitation
P_{eff} = effective precipitation
PRISM = Parameter elevation Regression on Independent Slopes Model
SM_{co} = carry-over soil moisture
SSURGO = Soil Survey Geographic Database
Water year = Oct 1 through September 30 designated by the calendar year in which it ends

3. Methodology

This section describes the methodology used to estimate depletion, DROs, and potential diversion savings associated with implementing DMPP-eligible project types, specifically fallowing, irrigation system conversions, and storage forbearance projects. For the DMPP, depletion is the net removal of water from either the water source or hydrologic system. In theory, depletion from irrigation is the difference in consumptive water use between the irrigated condition and what would have occurred in the nonirrigated condition (Barker pers. comm. 2025a). DRO, for the DMPP, is defined as the volumetric increase in water estimated to remain in the system due to forgoing irrigation, converting to a higher efficiency irrigation system, or forgoing use of stored water. The terms depletion and CCU are used interchangeably in this report. DRO is used to describe preseason depletion saving potential, and CCU is used to describe end-of-season actual depletion savings.

3.1 Preseason Estimates

Depletion volumes are heavily influenced by the hydrologic condition of a given year. Because DRO estimates are derived in late fall for the following irrigation season, before most snowfall of a given water year, the hydrologic condition of the enrolled irrigation season is largely unknown. As a result, to determine preseason depletion estimates, this analysis looks back at a series of historical data to estimate DRO as a typical historical depletion volume. Preseason DRO estimates are based on the median annual depletion volume of a designated look-back period, typically the most recent 7 years. The following subsections outline the rationale for selecting the look-back period and describe the methods used to calculate both depletion and DRO volumes. Sample DRO estimates for both full and partial-season fallowing cases of a single field are provided in Appendix A.

3.1.1 Historical Depletion at the Field Scale

3.1.1.1 Estimating Depletion for Fallowing Projects and Provisional Accounting

Equation 1 provides the monthly depletion calculation at the field scale, based on the annual methodology presented by Hill et al. (1989). The eeMETRIC model (Melton et al. 2021) helps to determine actual evapotranspiration (ET_a) in this methodology, consistent with UCRC (2022). Monthly ET_a values are mean values within each field boundary using gridded ET_a data. Carry-over soil moisture (SM_{co}) and effective precipitation (P_{eff}) are computed as shown in **Equations 2a/2c** and **3**, respectively.

$$\text{Depletion (inches)} = ET_{mon} - SM_{co,\,mon} - P_{eff} \qquad \textbf{Equation 1}$$

Where:

ET_{mon} = monthly OpenET eeMETRIC actual evapotranspiration (inches) (Melton et al. 2021)
P_{eff} = monthly effective precipitation (inches)
$SM_{co,\,mon}$ = carry-over soil moisture at start of the month (inches)

For each field, the monthly depletion depth (inches) is converted to a volume in acre-feet by converting inches to feet and multiplying the depth by the field size in acres; monthly depletion volumes for any month the respective field is enrolled in the program within the irrigation season are summed; the resulting water year depletions are joined with the field boundary to create a field-scale depletion model, identifying the historical depletion volume based on the look-back period for each field included in DMPP applications. Winter SM_{co} for each field is calculated using winter/nongrowing season ET_a data (Melton et al. 2021), winter/nongrowing season precipitation data (PRISM Climate Group 2025), available water storage (AWS) for soil depth 0 to 59 inches (0 to 150 centimeters) (NRCS 2024), and crop rooting depths (provided in **Table 3-1**). Winter/nongrowing season precipitation and ET_a values are calculated by summing the monthly values for each parameter over the nongrowing season.

Table 3-1. Crop Rooting Depths

Crop	Rooting Depth (inches)
Alfalfa	54
Apples	42
Apricots	42
Barley	36
Beans	24
Berries	36
Canola	36
Cherries	42
Corn	36
Durum wheat	36
Field crop unspecified	36
Flaxseed	35
Grain/seeds unspecified	36
Grapes	36
Grass hay	24
Horticulture	24
Idle pasture	39
Melon	60
Mustard	47
Oats	36
Onion	30
Orchard unspecified	42
Pasture	39
Peaches	42
Potato	30
Pumpkins	60
Rye	36
Safflower	60
Sorghum	36
Soybeans	24
Spring wheat	36
Squash	24
Sugar beets	48
Sunflower	48
Triticale	36
Turfgrass ag	24
Vegetables	24
Watermelons	60
Winter wheat	36

Note: Crop rooting depths are based on Jacobs (2024a) and assumptions based on the CCC (2024), Sertse et al. (2019), Dharmasri et al. (1993), Allen et al. (2015), St. John et al. (2017), Pleasant (2023), and Franzen et al. (2005).

Equation 2a provides the SM_{co} calculation, consistent with Hill et al. (1989). However, ET_{win} is taken to be all ET_a during the winter months instead of only ET from the actively growing crop as done in Hill et al. (1989). This is an implicit assumption by Hill et al. that ET during the winter was small and is also a result of the limitation of the available modeling methods at the time, which were intended only for the crop while it was growing. The use of full winter ET_a in the present analysis will result in less SM_{co} than the equivalent Hill et al. data would have under some conditions but we do not believe there is sufficient justification for subsequently adjusting the assumed 67% P_{eff} in **Equation 2a**. Section 5.3 discusses the use of **Equation 2a**, which is the method currently applied by the Authority, and introduces **Equation 2b** as a potential alternative approach. Available water capacity (AWC) was computed as the ratio of the AWS and maximum soil depth of 59 inches (NRCS 2024). In **Equation 1**, winter SM_{co} is applied as $SM_{co,\ mon}$ in March of each year. SM_{co} values for subsequent months are calculated according to **Equation 2c**.

$$SM_{co} = minimum(0.67 * (P_{win} - 1.25 * ET_{win}), 0.75 * RZ * AWC) \qquad \textbf{Equation 2a}$$

Where:

SM_{co}	=	winter/nongrowing season carry-over soil moisture at start of irrigation season (inches)
P_{win}	=	winter/nongrowing season precipitation (inches)
ET_{win}	=	winter/nongrowing season evapotranspiration (inches)
RZ	=	crop rooting depth (inches) from Table 3-1
AWC	=	soil available water capacity (inch per inch)

For the first month of the irrigation season, SM_{co} is calculated per **Equation 2a**. For subsequent months, monthly SM_{co} ($SM_{co,\ mon}$) is calculated according to **Equation 2c** and expected to decrease over time. $SM_{co,\ mon}$ cannot fall below zero or exceed 0.75 * RZ * AWC, even in cases of high P_{eff}. Monthly effective precipitation ($P_{eff,\ mon}$) is calculated according to **Equation 3.**

$$SM_{co,\ mon} = MIN(MAX(SM_{co,\ prev\ mon} - ET_{prev\ mon} + P_{eff,\ prev\ mon}, 0), 0.75 * RZ * AWC) \qquad \textbf{Equation 2c}$$

Where:

$SM_{co,\ mon}$	=	carry-over soil moisture at start of month excluding March (inches)
$SM_{co,\ prev\ mon}$	=	carry-over soil moisture at start of previous month (inches)
$ET_{prev\ mon}$	=	previous month monthly crop evapotranspiration (inches)
$P_{eff,\ prev\ mon}$	=	previous month monthly effective precipitation (inches)
RZ	=	crop rooting depth (inches) from Table 3-1
AWC	=	soil available water capacity (inch per inch)

P_{eff} is an estimate of the portion of precipitation that supports plant growth during the irrigation season. P_{eff} is calculated monthly using methodology shown in **Equation 3**, consistent with the United States Department of Agriculture (USDA 1970). Total monthly precipitation (P_{mon}) was obtained from PRISM Climate Group (2025), and total monthly crop evapotranspiration (ET_{mon}) is assumed to be ET_a obtained from OpenET (2025a). Monthly P_{eff}, calculated from **Equation 3**, is used to calculate depletion using **Equation 1**.

$$P_{eff} = SF(0.70917 P_{mon}^{0.82416} - 0.11556)(10^{0.02426 ET_{mon}}) \qquad \textbf{Equation 3}$$

Where:

P_{eff}	=	monthly effective precipitation (inches)
SF	=	soil water storage factor
P_{mon}	=	monthly precipitation (inches)
ET_{mon}	=	monthly crop evapotranspiration (inches)

The soil water storage factor (SF) is defined by **Equation 4**, consistent with USDA (1970), which states the following: "the term D was generally calculated as 40 to 60 percent of the available soil water capacity in the crop root zone, depending on the irrigation management practices used." Original **Equations 3** and **5** were developed before sprinkler irrigation was common. For surface irrigation, best practice then—and, in many cases, now—is to deplete the soil to about 50 percent AWS and then refill to field capacity. This practice, however, is not reasonable for most sprinkler systems, especially center pivots, where water application typically occurs before water depletion from the soil reaches 50 percent AWS. A value of 40 percent of AWS strikes a balance between surface and sprinkler irrigation management practices and was used in this methodology (Barker pers. comm. 2025a). SSURGO AWS data (NRCS 2024) were obtained to support quantification of usable water storage (D in **Equation 4**) and is summarized as an area-weighted average within each DMPP applicant field boundary. Thus, the soil water SF was calculated at the field scale.

$$SF = 0.531747 + 0.295164D - 0.057697D^2 + 0.003804D^3 \qquad \textbf{Equation 4}$$

Where:

SF = soil water storage factor
D = usable soil water storage (inches)

The underlying depletion estimation methodology in this report (Hill 1989) is for use at the irrigation-season scale. While similar procedures can be used to estimate monthly depletion, the results of the depletion estimation methodology herein are considered accurate to the irrigation-season level because numerous short-term variables skew the estimates that tend to average out over a full season, such as heavy rainstorms and wind. However, monthly depletion estimates help to calculate DROs for partial-season fallowing projects and estimate daily scale CCU for provisional accounting (Section 3.2.3).

3.1.2 Fallowing Projects

After annual DROs are calculated, or monthly depletion estimates for all months enrolled in DMPP calculated are summed by year, field-scale DRO are estimated for fallowing and irrigation system conversion projects. To obtain a single annual DRO estimate per field, the median of a typically 7-year look-back period (refer to Table 3-2) is used. The look-back period excludes years when applicants fallowed their fields as part of participation in a conservation program (currently only the System Conservation Pilot Program [SCPP] is considered).

Table 3-2. Look-Back Periods

Condition	Look-Back Period
Default look-back period	2018 through 2024
1-year conservation program participation	2017 through 2024 excluding SCPP year (for example, 2017 through 2023 if field enrolled in SCPP in 2024, 2017 through 2022 and 2024 if field enrolled in SCPP in 2023)
2-year conservation program participation	2016 through 2024 excluding SCPP years (for example, 2016 through 2022 if field enrolled in SCPP in 2023 through 2024, 2016 and 2019 through 2024 if field enrolled in SCPP in 2017 through 2018)
3+-year conservation program participation	2016 through 2024 excluding SCPP years[a]

[a] This condition will result in a look-back period shorter than the recommended 7 years. SCPP was implemented in 2015 through 2018 and 2023 through 2024 (Authority 2025), so a minimum of 4 years of data would be used for any DRO estimate.

3.1.3 Irrigation System Conversions

For irrigation system conversions, historical depletion estimates are calculated at the field scale using the methodology presented in Section 3.1.1. DROs for irrigation system conversions are then estimated by multiplying the historical depletion estimate by a theoretical percentage change in depletion, based on the existing and proposed irrigation system. Depletion change percentages, based on studies in the Colorado River Basin (Jacobs 2024b) and Great Salt Lake Basin (USU et al. 2025), are listed in Table 3-3, with the underlying assumptions detailed in Table 3-4. To help align individual DMPP participants with these assumptions, particularly those related to reductions in irrigated acreage, additional field verification steps and coordination with applicants is recommended.

Table 3-3. Estimated Depletion Change Percentages for Irrigation System Conversions

Pre-Demand Management Pilot Program Irrigation System	Post- Demand Management Pilot Program Irrigation System	Depletion Change (percent)
Basin/border	Pivot/lateral MESA	0
	Pivot/lateral LEPA	-2
	Pivot/lateral LESA	-5
	SDI	-18
Pivot/lateral MESA	Pivot/lateral LEPA	-1
	Pivot/lateral LESA	-4
	SDI	-29
Wheel line, hand line, solid set	Pivot/lateral MESA	-16
	Pivot/lateral LEPA	-17
	Pivot/lateral LESA	-20
	SDI	-29

Sources: Jacobs 2024b; USU et al. 2025.

LEPA = low-elevation precision application
LESA = low-elevation spray application
MESA = mid-elevation sprinkler application
SDI = subsurface drip irrigation

Table 3-4. Irrigation System Conversion Assumptions

From	To	Assumptions
Basin/border	Pivot/linear MESA	▪ 21% reduction in irrigation area[a] ▪ 10% yield improvement[b] ▪ Change in area and yield linearly related to crop ET[c] ▪ 12% cap of MESA wind drift and evaporation losses[d]
	Pivot/linear LEPA	▪ 21% reduction in irrigation area[a] ▪ 10% yield improvement[b] ▪ Change in area and yield linearly related to crop ET[c] ▪ 12% cap of LEPA wind drift and evaporation losses[d]
	Pivot/linear LESA	▪ 21% reduction in irrigation area[a] ▪ 10% yield improvement[b] ▪ Change in area and yield linearly related to crop ET[c]
	SDI	▪ Field production held constant[e] ▪ 25% yield improvement[f] ▪ 22% water productivity (ton per crop ET in) improvement[f]

From	To	Assumptions
Pivot/linear MESA	Pivot/linear LEPA	▪ 12% cap of LEPA wind drift and evaporation losses[d] ▪ No change in geometry or yield
	Pivot/linear LESA	▪ No change in geometry or yield
	SDI	▪ Constant field production[e] ▪ 15% yield improvement[g] ▪ 22% water productivity (ton per crop ET in) improvement[h]
Wheel line, hand line, solid set	Pivot/linear MESA	▪ 21% reduction in irrigation area[a] ▪ 7% yield improvement[b] ▪ Change in area and yield linearly related to crop ET[c] ▪ 12% cap of MESA wind drift and evaporation losses[d]
	Pivot/linear LEPA	▪ 21% reduction in irrigation area[a] ▪ 7% yield improvement[b] ▪ Change in area and yield linearly related to crop ET[c] ▪ 12% cap of LEPA wind drift and evaporation losses[d]
	Pivot/linear LESA	▪ 21% reduction in irrigation area[a] ▪ 7% yield improvement[b] ▪ Change in area and yield linearly related to crop ET[c]
	SDI	▪ Constant field production[e] ▪ 22% yield improvement[g] ▪ 22% water productivity (ton per crop ET in) improvement[h]

Sources: Jacobs 2024b; USU et al. 2025.

[a] When applying a circular or semicircular irrigation pattern to a square field, the field corners fall outside of the irrigated area. Field corners represent 21% of the starting area and are not assumed to be irrigated following conversion to center pivot.
[b] Assumption based upon yield data included in O'Brien et al. (2000), Ehlig and Hagemann (1980), and Sanden et al. (2011).
[c] Assumption is supported by Lamm (2016).
[d] Assumption is per Jacobs (2024b).
[e] This likely program assumption supports the producer and maximizes the reduction in depletion. Production may be controlled by a reduction in irrigated area that offers a reduction in irrigation system costs.
[f] Assumption is per Montazar (2020).
[g] Difference of notes [f] and [b].
[h] Assumption based on gravity (surface)-to-SDI conversion in Montazar (2020) and supported by deficit irrigation results in Lamm (2016).

3.1.4 Storage Forbearance Projects

Depletion reduction volumes associated with reservoir storage forbearance applications[1] are estimated using same method applied in SCPP (UCRC 2024). Estimated volumes of water released from storage (acre-feet) is multiplied by combined efficiency factor to account for both conveyance and irrigation losses (**Equation 5**). Conveyance and irrigation efficiency factors are both estimated at 80 percent (20-percent loss was assumed for each), with a combined efficiency factor of 64 percent (Bosworth pers. comm. 2025).

$$\text{Depletion reduction (acre-feet)} = \text{Reservoir release volume (acre − feet)} * \text{conveyance efficiency} * \text{irrigation efficiency} \quad \textbf{Equation 5}$$

Where:

Conveyance efficiency = 80 percent (Bosworth pers. comm. 2025)
Irrigation efficiency = 80 percent (Bosworth pers. comm. 2025)

[1] Evaluations of the recommended depletion reduction methodology are ongoing for those applications involving both fallowing and storage forbearance projects. Sufficient information is not yet available to support those estimates.

3.2 End-of-Season Estimates

End-of-season depletion estimates typically require comparison with an irrigated condition or reference field to quantify changes in depletion resulting from DMPP activity. While DROs are calculated during preseason analysis using a historical look-back period, growing conditions during the DMPP season may differ from those in the look-back years. Factors such as weather, water supply, irrigation management, and crop type can vary year to year, thus, accounting for all potential differences is not feasible. Additionally, one objective of the DMPP water conservation quantification methods is to develop a method that is as automated, therefore, broadly applicable and reproducible, as reasonably possible. To that end, a scaling approach was employed. In this context, a scaling approach refers to a method used to adjust preseason DROs so that they better reflect the actual conditions during the DMPP activity year. Because the DRO is based on historical data from a look-back period, they may not accurately represent the specific environmental and management conditions of the current year. The scaling approach helps bridge that gap by applying a correction factor—in this case, the ratio of reference ET between the DMPP year and the look-back period.

3.2.1 Fallowing Projects and Irrigation System Conversions

After the irrigation season ends, the depletion reduction resulting from the DMPP project (CCU) is calculated as the difference in ET between the irrigated and nonirrigated conditions for the same time period: DMPP activity year (**Equation 6**). The nonirrigated condition is available as the OpenET eeMETRIC ET value for the project fields on the DMPP activity year, and the irrigated condition for the DMPP activity year is estimated by using a scaling method based on a method suggested for the Upper Colorado River Basin (UCRB) by Allen and Torres (2018) and included as a potential method for use in Utah by Barker et al. (2025). The purpose of the scaling factor is to approximate the ET of the current year, as influenced by that year's specific weather at the project field if the field had been irrigated. Because this value does not exist due to DMPP participation, the preseason DRO is scaled to the DMPP activity year based on the ratio between the reference ET of the activity year and the reference ET of the median DRO year within the look-back period for each month of the DMPP activity. Here, short-reference ET is used because it is available through OpenET and supported by the work by others referenced above. Short-reference ET is the estimated ET rate in inches across the growing season from a short-canopy reference crop, such as grass.

ET is used in **Equation 6** rather than depletion as a simplification because P_{eff} and SM_{co} are assumed to remain the same regardless of an irrigated or nonirrigated condition. Thus, the end-of-season conserved consumptive use is approximately equal to the difference in ET between the nonirrigated and irrigated conditions for the same time period as follows:

$$\text{CCU} \approx \left(\frac{ET_{o,after}}{ET_{o,preseason}}\right) * ET_{preseason} - ET_{after} \quad \textbf{Equation 6}$$

Where:

CCU = conserved consumptive use due to fallowing (inches per month)
ET_{after} = evapotranspiration from area when the DMPP is implemented (inches per month)
$ET_{preseason}$ = evapotranspiration for DRO period (inches per month)
$ET_{o,after}$ = short-reference evapotranspiration for after the DMPP participation period (inches)
$ET_{o,preseason}$ = short-reference evapotranspiration for DRO period (inches)

For each field, the monthly CCU depth (inches) is converted to a volume in acre-feet by converting inches to feet and multiplying the depth by the field size in acres; monthly CCU volumes for any month the respective field is enrolled in the program within the irrigation season are summed; the resulting water year CCUs are joined with the field boundary to create a field-scale CCU model, identifying the depletion savings for each field included in DMPP applications.

3.2.2 Storage Forbearance Projects

End-of-season depletion estimates of storage forbearance projects are equal to preseason estimates calculated according to **Equation 5**.

3.2.3 Provisional Accounting

The Upper Division States (Colorado, New Mexico, Utah, and Wyoming) acting through the UCRC entered into a Provisional Accounting Memorandum of Understanding (MOU) with the United States Bureau of Reclamation (Reclamation) in 2024. Under the UCRC-Reclamation Provisional Accounting MOU, participating entities are required to measure and record reductions in CCU resulting from qualifying activities, such as those contracted with the Authority through the DMPP. In addition, participants must account for transit losses between the location of the qualifying activity (Point A) and the storage reservoir (Point B), as well as evaporation losses occurring within the reservoir.

To support estimation of transit losses and storage losses, estimation of CCU on a daily timestep is required. Dailly CCU for fallowing projects can be derived by estimating monthly depletion per **Equation 1** and dividing the monthly depletion by the number of days per month (Barker pers comm. 2025b). The methodology used to calculate these daily depletion volumes for use in provisional accounting is most accurate at the irrigation-season level, so any results presented with these daily depletion volumes will have a high level of uncertainty at the subirrigation-season level. Although the irrigation season used in this analysis is March 1st through October 31st, under the UCRC-Reclamation Provisional Accounting MOU, CCU resulting from qualifying activities is reported by water year (October 1 through September 30).

3.3 Quantifying Diversion Savings

Diversion refers to the total volume of water withdrawn from a source for use, while depletion represents the portion of that water that is consumed and not returned to the system. For DMPP reporting, understanding both metrics is important: diversion helps characterize water use, while depletion is the key metric for quantifying CCU.

3.3.1 Preseason Depletion Reduction Opportunities and Enrollment Calculations

Preseason DRO estimates were used to determine the volume of water, needed for enrollment by DMPP participants to meet the estimated depletion reduction objective. These estimates were incorporated into **Equation 7**, which converts depletion volumes into diversion volumes using efficiency factors. To translate depletion into diversion, conveyance and irrigation efficiency factors were applied. Both were estimated at 80 percent, resulting in a combined efficiency factor of 64 percent (Bosworth pers. comm. 2025). This assumes a 20 percent loss for each component and reflects typical system performance in the region.

3.3.2 End-of-Season Diversion Reduction Estimates

End-of-season diversion reduction estimates are required to support UCRC-Reclamation provisional accounting, particularly for calculating transit losses. These estimates were derived by dividing the end-of-season depletion reduction volume by the combined efficiency factor as shown in **Equation 7**:

$$\text{Diversion reduction (acre} - \text{feet per year)} = \frac{\Delta D}{conveyance\ efficiency * irrigation\ efficiency} \quad \textbf{Equation 7}$$

Where:

ΔD	=	Depletion change from *irrigated* to *fallowed* condition (acre-feet per year)
Conveyance efficiency	=	80 percent (Bosworth pers. comm. 2025)
Irrigation efficiency	=	80 percent (Bosworth pers. comm. 2025)

4. Quality Assurance and Quality Control

Quality assurance and quality control (QA/QC) is an integral part of any project and is best described as a set of activities and procedures designed to assure the reliability and accuracy of data and results. In this project, QA/QC is addressed by establishing qualitative and quantitative checks.

A spreadsheet tool was developed to support QA and verification of both input data and preseason DROs. The spreadsheet independently checked the input data sources by comparing the data used in the analysis with similar data sources. The spreadsheet tool also independently calculated depletion estimates and compared the results with the estimates calculated by the Python script. Data sources used for independent comparison are listed in Table 4-1. Post-season depletion estimate checks are currently being added to the QA/QC spreadsheet tool. Live updates to the tool and supporting documentation are available through a GitHub repository managed by Jacobs, with access provided at the Authority's discretion.

Comparing analysis inputs and results with independent data sources helped to verify accuracy and build confidence in the methodology; it also ensured that the data used and outcomes produced are consistent with other trusted sources, supporting transparency and reliability in DMPP reporting. Jacobs, in coordination with the Authority, will continuously improve upon the methods described in this report.

Table 4-1. Summary of Key Data Sources Used in Depletion Reduction Calculations and Quality Assurance and Quality Control

Variable	Data Source Used in Analysis	Independent Data Source for Quality Assurance/ Quality Control
ET	eeMETRIC (version 2.3 or latest version available through OpenET API[a])	eeMETRIC (latest version available through OpenET FARMS[b])
Soil characteristic	SSURGO[c]	Web Soil Survey
Precipitation	PRISM Climate Group (2025)[d]	NOAA stations: ▪ USC00424342 Jensen, Utah ▪ USC00429368 Wellington 3 E, Utah
Crop rooting depth	Database referenced by Python script	Table 3-1
Field boundary	Database referenced by Python script	FSA via applicant

[a] Source: Melton et al. 2021.
[b] Source: OpenET 2025.
[c] Source: NRCS 2024.
[d] PRISM Climate Group 2025.

NOAA = National Oceanic and Atmospheric Administration

Table 4-2. describes each quality assurance indicator, applicable QA/QC component, how it is evaluated, and performance criteria goal. When DROs are calculated, the input data and calculations are thoroughly reviewed to evaluate precision, accuracy, repeatability, representativeness, and completeness of the results. As best practice, original data will never be edited or deleted. The data manager or QA/QC officer will conduct the review by applying data flags and associated comments in a series of new columns in the data. Flagged records should be retained in the project database but should not be included in subsequent data analysis and reporting efforts.

Table 4-2. Quality Assurance Indicators

Quality Assurance Indicator	Quality Assurance/ Quality Control Component	Evaluation Criteria
Precision: Measure of agreement among repeated measurements of same property under identical, or substantially similar, conditions; random error.	Data source and equation comparison	Values within 25 to 50% of similar independent data source or calculation
Accuracy: Degree to which measurement result conforms to correct value or standard.	Confirmation of Python code calculations	Comparison of Python code and independent Excel calculations
Comparability: Measure of confidence that one dataset can be compared with another.	Data source comparison	Values within 25 to 50% range of similar independent data source
Representativeness: Degree to which data accurately and precisely represent population characteristic, parameter variations at sampling point, process condition, or environmental condition.	Identification and confirmation or correction of outlier values	Values within 25 to 50% range of similar independent data source or calculation
Completeness: Measure of amount of valid data obtained compared with amount of data expected to be obtained.	Data source evaluation	Identification of input data that are not available; inputs should cover entire 2016 through 2024 time period and participant field spatial geography

Data review activities should consist of the following:

- Retrieve the most current input data for the independent QA/QC.
- Evaluate input data completeness and identify unavailable values; input values for field areas, crop rooting depths, and soil characteristics should be complete. Input values for ET_a and precipitation may not be complete based on data available. When data are not available, fill data gaps of less than 1 month by linear regression, and fill data gaps exceeding 1 month using a similar data source or nearby field on a case-by-case basis.
- Review input data to ensure values are within expected ranges. Expected ranges for some data sources are listed below. Compare the input data used in the depletion reduction calculations with the independent input data sources to identify potential outliers, issues with unit conversions, or erroneous data values. Evaluate these records using best professional judgment if individual data points should be flagged in the dataset.
  - Precipitation: 0 to 6 inches per month
  - ET: 0 to 10 inches per month
  - AWS: 2 to 12 inches
  - Crop rooting depth: 24 to 60 inches
  - Agricultural field boundaries: flagged if any geographic dimension is less than 200 meters; agricultural fields with a smallest dimension of less than 100 to 200 meters may be suffering from a low ET_a bias due to influence from adjacent nonirrigated fields. The Landsat thermal pixel is about 90 meters in width; therefore, fields with narrow edges could contain ET_a values biased by nonirrigated areas (Melton pers. comm. 2025). If an agricultural field has a small field dimension, and the ET_a value of the field appears to be less than the ET_a values of neighboring fields by a margin of 15 percent or more, the field may be biased by nonirrigated grid cells. In this case, the monthly ET_a depth values of the small-dimensioned field is overwritten with monthly ET_a depth values of a neighboring field of similar crop types and irrigation method.

- Review the units reported in the depletion reduction calculations and independent input data and make any necessary unit conversions (for example, precipitation in millimeters to precipitation in inches).
- Review depletion reduction calculations by comparing results developed using the Python script with results using the QA/QC tool; ensure values are within expected ranges. Flag values that are not within range in the QA/QC tool. If a value is not within the expected range, then identify and note the reason for the difference in depletion reduction results and adjust and recalculate, as needed.

OpenET data undergo constant improvement and versioning updates, which may occur mid-season. Additionally, precipitation data through PRISM are provisional for 6 months prior to finalization. As applicant compensation is determined before the irrigation season begins and not revisited after agreements are signed, provisional data are used to determine compensation. At the end of the season, a different approach is used to determine depletion savings. As a result, provisional data are used in the preseason depletion savings calculation and will not be reevaluated at the end of the season. Jacobs uses the latest data that are available at the time.

5. Discussion

This section provides a detailed evaluation of the methods and assumptions used to estimate DROs under the DMPP; it also compares the DMPP approach with that of the SCPP, explains the rationale behind key methodological choices, and assesses the implications of those choices for consistency, accuracy, and future application. This section also highlights areas of uncertainty and outlines considerations for improving future analyses.

5.1 Methodology Differences between the Demand Management and System Conservation Pilot Programs

The DMPP methodology varies from SCPP methodology in several ways, and these differences are listed in Table 5-1.

Table 5-1. Differences in Preseason Depletion Reduction Estimation Methodologies Used by the Demand Management and System Conservation Pilot Program

Demand Management Pilot Program	System Conservation Pilot Program
The baseline period was 7 years, based on professional judgment, which is considered to be a reasonable period to capture both wet and dry hydrologic conditions. Section 5.2 further explains why the 7-year baseline period was used in this analysis.	The baseline period was an 8-year span of 2016 through 2023 (Bosworth pers. comm. 2025).
Consumptive use from precipitation was calculated at the applicant field from P_{eff} and winter SM_{co}.	Consumptive use from precipitation was estimated at a nearby nonirrigated area of the same general area and similar properties (for example, a reference field). Thus, the applicant field depletion was estimated as consumptive use of applicant field less the consumptive use of reference field.
The baseline depletion reduction estimate was calculated as the median of the baseline period. Median values are commonly used by the NRCS when dealing with hydrologic data to limit the bias of rare, yet abnormal, weather phenomena (USDA 2025). Section 5.2 explains how the median statistics were chosen for this analysis.	Baseline DRO was calculated as average value over baseline period.
For split-season fallowing alternatives, only remaining winter SM_{co} was subtracted from the DRO estimate based on start of fallowing practices (early season or late season) and a comparison of ET and SM_{co} values.	For split-season fallowing alternatives, fields planned for irrigation before the fallow period began, water stored in the soil zone due to irrigation before fallowing began was estimated, because the crop would continue consuming that water during fallowing. The estimated consumptive use from the soil storage was subtracted from the total CCU (UCRC 2024).
For end-of-season CCU estimates, the ratio of short-reference ET between the activity year and look-back period is applied to the preseason DRO estimate and difference between this value and end-of-season depletion estimate at the project field is the resultant end-of-season CCU estimate for the project field.	The consumptive use of the participating field is quantified similarly to the preseason depletion estimate as difference between consumptive use of applicant field minus consumptive use of similar nonirrigated field. A nearby irrigated field (reference field) is used to estimate consumptive use from irrigated supplies by subtracting the consumptive use from the nearby nonirrigated field. The end-of-season CCU is the difference between consumptive use of reference field and consumptive use of participating field.

5.2 Summary Statistic Method and Look-Back Period Selection

The summary statistic method (median or mean) and look-back period were selected based on professional judgment. Using a look-back period of fewer than 3 years is unreasonable, as calculating a meaningful central tendency from fewer than three data points lacks statistical validity.

This section discusses the results of a simple statistical comparison used to evaluate both the look-back period and summary statistic method used to estimate DROs. Two look-back period options were considered:(1) 7-year look-back period as used for DMPP project cycles 1 and 2 and (2) 5-year look-back period used for an analysis in the Colorado River and Great Salt Lake Basins (Jacobs 2024b and USU et al. 2025, respectively). Similarly, two summary statistic methods were evaluated for selecting a representative DRO value from annual depletion estimates across the look-back period: (1) median used for DMPP project cycles 1 and 2 and (2) mean used in SCPP.

First, depletion was computed for areas within 30 fields throughout the UCRB in Utah for the years 2018 through 2024 (the most recent 7-year period). The selected areas were within at least 42 meters of the field boundaries to ensure that the shortwave Landsat pixels used in OpenET datasets were completely within the fields (42 meters is the length of the diagonal of a 30-meter by 30-meter pixel). However, for simplicity, precipitation was obtained from the gridMET dataset accessible through OpenET, and all fields were assumed to have a 48-inch-deep root zone with an AWC of 0.1 inch per inch.

A simple analysis of variance was performed using the 30 fields as replicate blocks, which were considered a random effect. The look-back period (7 years or 5 years) and the summary statistics method (mean or median) were treated as fixed effects in a two-by-two factorial analysis. The interaction between analysis period length and summary method was not significant. meaning that the main, or primary, effects of look-back period length and summary statistics method could be examined separately. No significant difference was found between using the mean or median to summarize the data; however, the difference between the 7- and 5-year periods was significant at the 5-percent probability level. Average depletion across all estimates when using the 5-year period was 31.2 inches per year, and the 7-year period resulted in an overall average estimate of 30.6 inches per year. This estimate is a difference of 0.5 inch per year (small discrepancies are because of rounding), which is less than 2-percent of the average 5-year value. This 0.5 inch is well within the uncertainty of ET, P_{eff}, and SM_{co}. The gridded weather datasets used for the ET_a and precipitation data also have nontrivial uncertainties.

Further analysis is pending to compare the 5- and 7-year look-back periods as predictors for the prediction period. The present analysis was deemed sufficient based on timelines related to the project cycle 2 application evaluation period.

Given the small magnitude of the difference and the need for consistency across both project cycles 1 and 2, continuing to use a 7-year look-back period and median as the summary statistic method is supported; this approach aligns with previous DMPP project cycles and helps maintain clarity and comparability in reporting, especially during overlapping implementation periods.

5.3 Carry-Over Soil Moisture Calculation

Using e of **Equation 2a** to estimate SM_{co} is based on professional judgment. In the formulation, Hill et al. (1989) assumes that 67-percent of P_{win} is effective, although limited justification is provided for this assumption. The lower effectiveness rate compared with summer precipitation (80 percent) may reasonably reflect runoff losses associated with snowmelt. Hill et al. (1989) further adjusts P_{win} by subtracting 125 percent of winter crop ET (ET_a). Crop ET was calculated only for the growing season, which sometimes extended into the defined winter period (beginning in October). For example, if the calculation season ended in September, but the crop continued growing into October, then 125 percent of October's ET_a was subtracted from the winter precipitation. The factor of 1.25 corresponds to the inverse of the summer P_{eff} rate (1 divided by 0.8) and was used to account for the portion of P_{win} that would have been effective during the growing season, had it extended past September.

Rearranging the equation helps clarify how these assumptions are applied:

$$SM_{co} = \max\{0, \min[0.84(P_{Win} - 0.80ET_{WIN}), 0.75Z_r AWC]\}$$ **Equation 2b**

Where:

SM_{co}	=	carry-over soil moisture
P_{win}	=	winter precipitation
ET_{win}	=	winter evapotranspiration
AWC	=	available water capacity

In this analysis, eeMETRIC ET_a data from OpenET were used to estimate ET across the full calendar year. One caveat assumption is that the eeMETRIC model performs reasonably well over frozen surfaces (most ET_a models are formulated only for nonfreezing conditions). Regardless, values of ET_a are typically sufficiently small in the winter such that errors as much as 100 percent are still of acceptable magnitude from a hydrologic perspective.

By using the Hill et al. (1989) SM_{co} equation and putting some confidence in the full ET_{win} for the adjustment, less precipitation is assumed effective than was used in the Bear River Basin. Further, any precipitation not contributing to ET_{win} is assumed to be 67 percent effective. Without any additional validation data, these assumptions are likely to be as justifiable as any other assumptions considering the uncertainties related with snowmelt hydrology.

The study area experiences conditions when ET_{win} will exceed 80 percent of P_{win} and the SM_{CO} will be zero. In cases where offseason P_{eff} is significant, SM_{CO} is limited to not exceed 75 percent of the plant-available water in the rootzone. The assumption is that a crop could end the year with heavily depleted soil (2025 is a good example because irrigation water was typically shut off early). If sufficient precipitation occurs during the following winter, then SM_{CO} should not be allowed to exceed what might feasibly be stored in the rootzone. The 75-percent multiplier is debatable, primarily because of the implicit assumption of filling the rootzone back up to field capacity by the end of the winter. Perhaps a value of 50 percent would be more conservative (from a SM_{CO} standpoint); however, underestimating SM_{CO} would overestimate potential conserved depletion, for which negative consequences from a basin standpoint are greater. Finally, based on the analyses, in some cases, all three paths of the SM_{CO} equation would be triggered in different locations and years in the UCRB in Utah.

5.4 Future Considerations

The P_{eff} calculation presented in **Equation 3** was developed by USDA in 1970. Since then, the Desert Research Institute, OpenET, and Barker et al. (2025) have evaluated different methods for estimating P_{eff}. Barker et al. (2025) suggest using the curve number method to estimate P_{eff} at the daily timescale. This approach is likely more accurate than **Equation 3** because it is geographically specific, although the computational lift to shift from a monthly to a daily timescale creates a hurdle. Additionally, Desert Research Institute and OpenET are developing P_{eff} raster data for the western United States, although the data are not currently available; these data could be used in the future to improve accuracy and reduce computations.

6. References

Allen, L.N. and A.F. Torres-Rua. 2018. *Verification of Water Conservation from Deficit Irrigation Pilot Projects in the Upper Colorado River Basin: Findings and Recommendations*. Report submitted to the Walton Family Foundation and S.D. Bechtel, Jr. Foundation. Utah State University, Logan, UT.

Allen, L. Niel, J. Earl Creech, Michael G. Pace, and Clark E. Israelsen. 2015. *Irrigation of Safflower in Northern Utah*. Utah State University Extension Peer-reviewed fact sheet. Accessed September 2024. https://extension.usu.edu/crops/research/irrigation-of-safflower-in-northern-utah.

Barker, Burdette, Matt Yost, Sena Bildim. 2025. *Quantifying Depletion Differences from Irrigation Practice Changes in Utah.* Prepared for Utah Department of Natural Resources Division of Water Rights. Accessed September 29, 2025. https://waterrights.utah.gov/Library/Misc_Reports/USU_20250513_QuantifyingDepletionDifferencesfromIrrigation.pdf.

Barker, Burdette. 2025a. Personal communication of Burdette Barker/Irrigation Specialist, Utah State University Extension Program with Drew Stock/Water Resource Engineer, Jacobs Engineering Group Inc. January.

Barker, Burdette. 2025b. Personal communication of Burdette Barker/Irrigation Specialist, Utah State University Extension Program with Drew Stock/Water Resource Engineer and Calah Worthen/Project Manager, Jacobs Engineering Group Inc. September.

Bosworth, Lily. 2025. Personal email communication between Lily Bosworth/Staff Engineer, Colorado River Authority of Utah and Scott Morrison/Project Manager, Jacobs Engineering Group Inc. February 7.

Canola Council of Canada (CCC). 2024. *Canola Growth Stages*. Accessed September 2024. https://www.canolacouncil.org/canola-encyclopedia/growth-stages/#:~:text=Root%20depth%2C%20like%20plant%20height,salinity%20and%20soil%20physical%20structure.

Colorado River Authority of Utah (Authority). 2022. *Colorado River Management Plan, Utah's Commitment toa Sustainable Water Future.* Accessed February 7, 2025. https://cra.utah.gov/wp-content/uploads/2022/07/Final-CRAU-Management-Plan.-1.pdf.

Colorado River Authority of Utah (Authority). 2025. *System Conservation Pilot Program (SCPP).* Accessed September 29, 2025. https://cra.utah.gov/system-conservation-pilot-program/.

Dharmasri, L.C., E. de Jong, and L.E. Cowell. 1993. *Effective rooting depth of mustard under dryland conditions*. Proc. Soils and Crops Workshop, Saskatoon Saskatchewan. Accessed September 2024. https://harvest.usask.ca/server/api/core/bitstreams/fc5e68a2-951c-4d34-9cfe-b5d2a383d449/content#:~:text=Roots%20were%20found%20at%20depths,at%20the%20lower%20slope%20position.

Ehlig, Carl F. and Robert W. Hagemann. 1980. *Sprinkler Irrigation Raises Yields-and Costs-of Imperial Valley Alfalfa. California Agriculture.* Accessed January 11, 2024. https://web.archive.org/web/20190429004221/http://calag.ucanr.edu/archive/?type=pdf&article=ca.v034n01p8.

Esri. (2024). ArcGIS Pro (Version 3.4) [Computer software]. Environmental Systems Research Institute. https://pro.arcgis.com/en/pro-app/3.4/tool-reference/spatial-analyst/zonal-statistics.htm.

Franzen, D.W., M. Anfirud, and P. Carson. 2005. *Sugarbeet rooting depth*. Sugarbeet Research and Extension Reports, Vol. 35, p. 105-108. Sugarbeet Res. and Ed. Bd. of MN and ND. Accessed September 2024. https://www.sbreb.org/wp-content/uploads/2018/09/Soil6.pdf.

Hill, R.W., C.E. Brockway, R.D. Burman, L.N. Allen, and C.W. Robison. 1989. *Field Verification of Empirical Methods for Estimating Depletion.* Research Report 125. Prepared for Utah Agricultural Experiment Station, Utah State University, Logan, Utah. https://extension.usu.edu//irrigation/files/Bear_River_Duty_Verification_1989.pdf

Jacobs Engineering Group Inc. (Jacobs). 2024a. *Water Demand Analysis.* Final Technical Memorandum. Prepared for Central Utah Water Conservancy District Agricultural Water Resiliency Plan Task Order No. 2, Subtask 2.2. May 6.

Jacobs Engineering Group Inc. (Jacobs). 2024b. *Quantify the Possible.* Final Technical Memorandum. Prepared for Central Utah Water Conservancy District Agriculture Water Efficiency Plan Task Order No. 2, Subtask 2.3. September 2024.

Lamm, Freddie. 2016. "Subsurface Drip Irrigation and Possibilities in Alfalfa." In: *Proceedings, 2016 California Alfalfa and Forage Symposium*, Reno, Nevada, November 29 – December 1, 2016. UC Cooperative Extension, Plant Sciences Department, University of California – Davis, California. Accessed January 11, 2024. https://www.ksre.k-state.edu/sdi/reports/2016/SDIPossibilitiesAlfalfa_Lamm16.pdf.

Melton, F.S., J. Huntington, R. Grimm, J. Herring, M. Hall, D. Rollison, T. Erickson et al. 2021. "OpenET: Filling a Critical Data Gap in Water Management for the Western United States." *Journal of the American Water Resources Association 1–24*. https://doi.org/10.1111/1752-1688.12956.

Melton, Forrest. 2025. Personal communication of Forest Melton/Project Scientist, National Aeronautics and Space Administration with Drew Stock/Water Resource Engineer, Jacobs Engineering Group Inc. February.

Montazar, Ali. 2020. "A Viability Assessment of Subsurface Drip Irrigation in the Desert Southwest." In: *Proceedings, 6th Decennial National Irrigation Symposium*, San Diego, California, December 6 – 8, 2021. Accessed January 11, 2024. https://elibrary.asabe.org/abstract.asp?aid=52890&t=2&redir=&redirType=.

Natural Resources Conservation Service (NRCS). 2024. Soil Survey Geographic (SSURGO) Database for Utah. Accessed September 2025. https://services.nacse.org/prism/data/get/us/800m/ppt/202509.

O'Brien, Daniel M., Freddie R. Lamm, Loyd R. Stone, and Danny H. Rogers. 2000. *The Economics of Converting from Surface to Sprinkler Irrigation for Various Pumping Capacities.* MF-2471. K*State Irrigation Management Series, y Agricultural Experiment Station and Cooperative Extension Service, Kansas State University, Manhattan, Kansas. November 2000. Accessed January 11, 2024. https://krex.k-state.edu/server/api/core/bitstreams/dccd2696-64d0-465e-ad26-b8f5467c56a8/content.

OpenET. 2025a. *Methodologies*. Accessed September 2025. https://etdata.org/methodologies/#:~:text=OpenET%20provides%20satellite%2Dbased%20estimates,and%20in%20some%20cases%2C%20precipitation.

OpenET. 2025b. *OpenET FARMS.* Accessed September 2025. https://farms.etdata.org.

Pleasant, Barabara. 2023. *Vegetable Root Depths Revealed: Use This Guide to Make Smarter Planting Decisions*. Accessed September 2024. https://www.growveg.com/guides/vegetable-root-depths-revealed-use-this-guide-to-make-smarter-planting-decisions/#:~:text=The%20longer%20a%20vegetable%20takes,to%20help%20them%20keep%20cool.

PRISM Climate Group, Oregon State University. 2025. Accessed September 2025. Obtained via web services. https://prism.oregonstate.edu/documents/PRISM_downloads_web_service.pdf.

Sanden, B., K. Klonsky, D. Putnam, L. Schwankl, and K. Bali. 2011. "Comparing Costs and Efficiencies of Different Alfalfa Irrigation Systems." In: *Proceedings, 2011 Western Alfalfa and Forage Conference*, Las Vegas, Nevada, December 11 – 13, 2011. UC Cooperative Extension, Plant Sciences Department, University of California – Davis. Accessed January 11, 2024. https://ucanr.edu/sites/Kern22/files/133511.pdf.

Sertse, Demissew, Frank M. You, Sridhar Ravichandran, and Sylview Cloutier. 2019. *The Complex Genetic Architecture of Early Root and Shoot Traits in Flax Revealed by Genome-Wide Association Analyses*. Front Plant Sci 10: 1483. Accessed September 2024. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6878218/.

St. John, Loren, Derek Tilley, and Terron Pickett. 2017. *Cover Crops for the Intermountain West*. USDA – Natural Resources Conservation Service, Boise, Idaho, Plant Materials Technical Note No. 67. Accessed September 2024. https://www.nrcs.usda.gov/plantmaterials/idpmctn13084.pdf.

United States Department of Agriculture (USDA). 1970. *Chapter 2: Irrigation Water Requirements.* Part 623 National Engineering Handbook.

United States Department of Agriculture (USDA). 2025. *Percent of Normal*. USDA Northwest Climate Hub. Accessed February 2025. https://www.climatehubs.usda.gov/hubs/northwest/topic/percent-normal#:~:text=Median%20is%20used%20exclusively%20by,30%2Dyear%20historical%20time%20period.

Upper Colorado River Commission (UCRC). 2022. *Resolution of the Upper Colorado River Commission. Consumptive Use Measurement in the Upper Colorado River Basin.* June 14, 2022. Accessed February 7, 2025. http://www.ucrcommission.com/wp-content/uploads/2022/07/2022-06-14-Resolution-Consumptive-Use-Measurement.pdf.

Upper Colorado River Commission (UCRC). 2024. *Colorado River System Conservation Pilot Program in the Upper Colorado River Basin.* Prepared for the Upper Colorado River Commission by UCRC staff and Wilson Water Group. June 2024. Accessed February 7, 2024. http://www.ucrcommission.com/wp-content/uploads/2024/06/2023_SCPP_Report_June2024.pdf.

Utah Division of Water Resources (UDWRe). 2024. *Data Collected with CDL Methodology: Water-Related Land Use Data 2017 through 2023.* Accessed September 2024. https://dwre-utahdnr.opendata.arcgis.com/pages/wrlu-data.

Utah State University Extension (USU), Jacobs Engineering Group Inc. (Jacobs), and M.Cubed. 2025. *Estimates of Technical and Economic Agricultural Depletion Reduction Opportunities in the Great Salt Lake Basin*. Draft Technical Memorandum. Prepared for Utah Division of Water Resources Agricultural Water Optimization and Leasing. September 2025.

Appendix A
Example Field Calculation

Appendix A. Example Field Calculation

This appendix outlines the calculation of full-season and split-season fallowing for an example field totaling approximately 90 acres (shown on Figure A-1); the calculation methodology followed is outlined in the report to which the appendix is included.

Figure A-1. Example Field

The calculation steps are as follows:

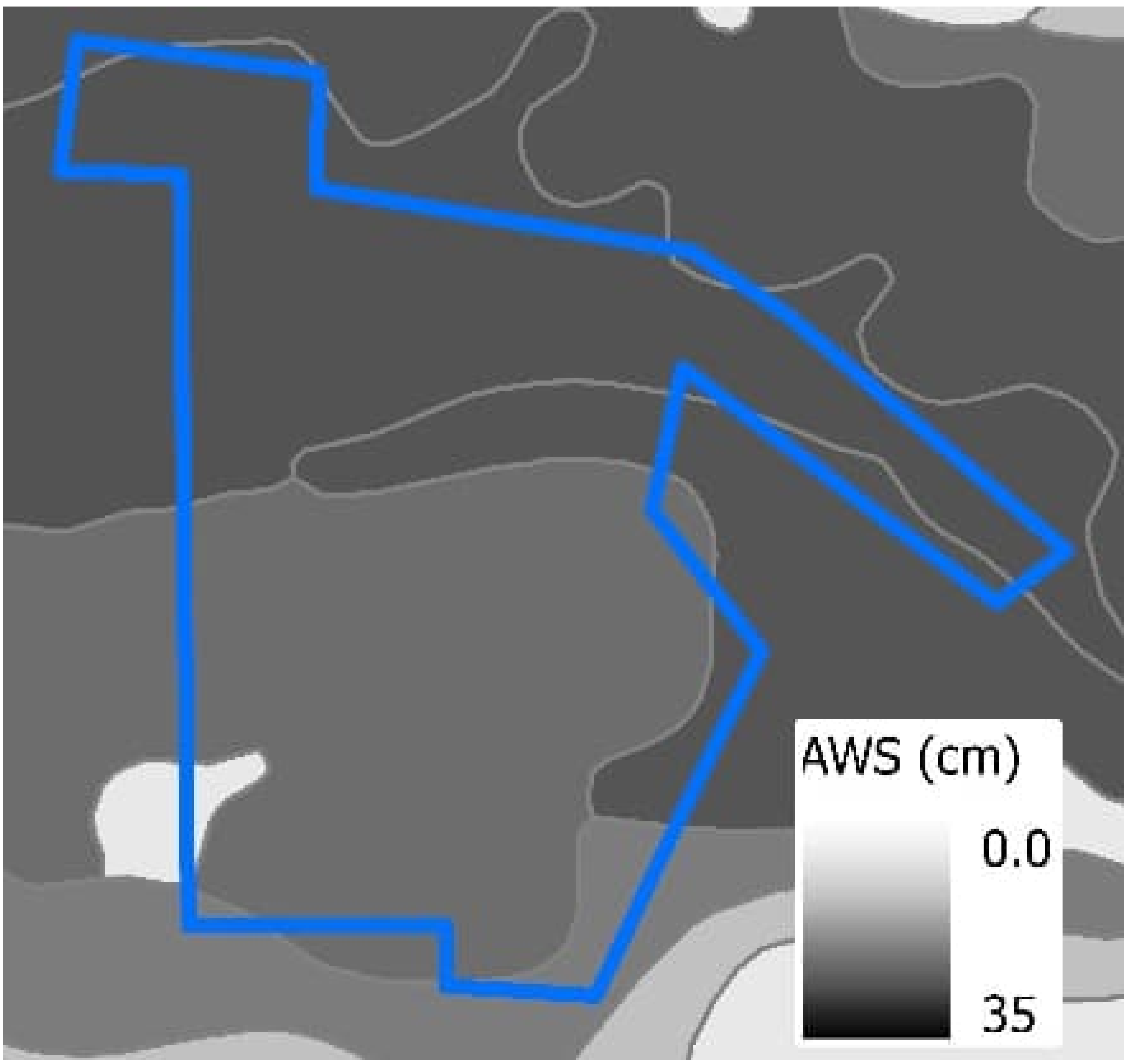
1. AWS in first 59 inches (150 centimeters) of soil is obtained from the *Web Soil Survey* (NRCS 2024). Using ArcPy tools in Python, the area-weighted average AWS is added as an attribute to field boundary layer. The area-weighted average AWS in first 59 inches (150 centimeters) of soil for example field is 9 inches (24 centimeters), as shown on Figure A-2 and summarized in Table A-1, where 2,138 acre-centimeters / 90 acres = 24 centimeters.

2. Usable soil water storage (D) was taken as 40 percent of the AWS. Therefore, D of the example field was 4 inches (40 percent of 9 inches, rounded to the nearest inch).

3. Soil water storage factor (SF) was then calculated based on **Equation 4**:

$$SF = 0.531747 + 0.295164*4 - 0.057697*4^2 + 0.003804*4^3 = 1 \qquad \textbf{Equation A1}$$

Figure A-2. Available Soil Water Storage



Source: NRCS 2024.

Table A-1. Available Water Storage for Example Field

Available Water Storage (centimeters)	Area (acres)	Available Water Storage x Area (acre-centimeters)
22	42	930
21	3	59
26	34	886
6	1	5
26	10	258
TOTAL	**90**	**2,138**

4. Spatial mean of OpenET's eeMETRIC ET_a and DAYMET precipitation data within each field boundary is obtained for each monthly timestep using zonal statistics in ArcPy. For July 2020, the example field received 0.2 inch of precipitation; this, ET was 5.3 inches. ET and precipitation summaries for the example field are presented in Effective precipitation (Peff) was calculated for every month of the growing season in the baseline period based on **Equation A2,** where SF of the example field equals 1 (from step 3 above):

$$\text{Peff} = 1 * (0.70917 P_{mon}^{0.82416} - 0.11556)(\ 100.02426 ETc) \quad \textbf{Equation A2}$$

For July 2020, the calculation results were as follows:

$$\text{Peff} = 1 * (0.70917 * 0.2^{0.82416} - 0.11556)(10^{0.02426*5.3}) = 0.1 \text{ inch}$$

Monthly Peff estimates are shown in Table A-4.

5. Table A-2 and Table A-3, respectively.

6. Effective precipitation (P_{eff}) was calculated for every month of the growing season in the baseline period based on **Equation A2**, where SF of the example field equals 1 (from step 3 above):

$$P_{eff} = 1 * (0.70917 P_{mon}^{0.82416} - 0.11556)(10^{0.02426 ET_c}) \quad \textbf{Equation A2}$$

For July 2020, the calculation results were as follows:

$$P_{eff} = 1 * (0.70917 * 0.2^{0.82416} - 0.11556)(10^{0.02426*5.3}) = 0.1 \text{ inch}$$

Monthly P_{eff} estimates are shown in Table A-4.

Table A-2. Evapotranspiration for Example Field, 2017 to 2023

Month	2017	2018	2019	2020	2021	2022	2023
	(inches)						
November[a]	0.7	0.5	0.8	0.7	0.3	1.2	0.3
December[a]	0.2	0.4	0.1	0.3	0.2	0.7	0.0
January	0.0	0.3	0.2	0.0	0.3	0.1	0.0
February	0.1	0.3	0.3	0.5	0.1	0.3	0.2
March	0.5	0.5	0.5	0.5	0.2	1.0	0.8
April	1.7	1.9	3.0	1.9	0.9	1.6	2.1
May	2.5	3.1	4.4	5.1	2.2	3.0	3.8
June	5.2	1.9	5.1	5.7	4.2	3.2	5.4
July	3.3	2.5	4.3	5.3	3.3	2.3	6.7

Month	2017	2018	2019	2020	2021	2022	2023
	(inches)						
August	3.6	1.8	3.5	3.9	3.8	2.8	5.7
September	2.9	1.9	2.7	2.3	3.7	3.1	3.5
October	1.5	0.9	1.5	1.7	2.7	2.4	1.9
ET_{win}[b]	**1**	**1.5**	**1.4**	**1.5**	**0.9**	**2.3**	**0.5**
ET[c]	**21.2**	**14.5**	**25**	**26.4**	**21**	**19.4**	**29.9**

Source: OpenET 2024.

[a] November and December values shown are for previous calendar year
[b] Sum of ET from November 1 to February 28/29 (winter).
[c] Sum of ET from March 1 to October 31.

ET_{win} = winter or nongrowing season evapotranspiration

Table A-3. Precipitation for Example Field

Month	2017	2018	2019	2020	2021	2022	2023
	(inches)						
November[a]	0.3	0.1	0.8	1.7	0.7	0.2	0.2
December[a]	1.1	0.1	0.3	1.6	0.5	1.6	0.9
January	2.2	0.7	1.2	0.2	0.5	0.0	2.2
February	0.5	0.3	1.6	0.4	0.4	0.9	0.2
March	1.5	0.5	2.0	1.6	0.6	0.6	1.7
April	0.2	0.8	0.7	0.1	0.8	0.2	0.0
May	0.3	0.8	2.2	0.0	0.1	0.1	0.7
June	0.3	0.5	0.3	0.9	0.6	0.7	0.8
July	1.4	0.7	0.3	0.2	1.5	0.1	0.6
August	0.9	1.0	0.2	0.0	2.0	0.9	2.1
September	1.3	0.0	0.4	0.0	0.8	2.1	0.3
October	0.0	3.4	0.1	0.0	2.0	0.4	0.3
P_{win}[b]	**4.1**	**1.2**	**3.9**	**3.9**	**2.1**	**2.7**	**3.5**

Source: DAYMET 2024.

[a] November and December values shown are for previous calendar year.
[b] Sum of precipitation from November 1 to February 28/29 (winter).

Table A-4. Effective Precipitation for Example Field

Month	2017	2018	2019	2020	2021	2022	2023
	(inches)						
November[a]	0.2	0.0	0.5	1.1	0.4	0.1	0.0
December[a]	0.7	0.0	0.2	1.0	0.3	1.0	0.6
January	1.3	0.4	0.8	0.1	0.3	0.0	1.3
February	0.3	0.2	0.9	0.2	0.2	0.5	0.0
March	0.9	0.3	1.2	1.0	0.4	0.4	1.0
April	0.1	0.5	0.5	0.0	0.5	0.1	0.0
May	0.1	0.6	1.6	0.0	0.0	0.0	0.5

Month	2017	2018	2019	2020	2021	2022	2023
	(inches)						
June	0.2	0.3	0.2	0.7	0.4	0.5	0.7
July	1.0	0.5	0.2	0.1	1.1	0.0	0.5
August	0.6	0.7	0.1	0.0	1.5	0.7	1.7
September	0.9	0.0	0.2	0.0	0.6	1.5	0.2
October	0.0	2.0	0.0	0.0	1.3	0.3	0.1

[a] November and December values shown are for previous calendar year.

7. Winter carry-over soil moisture (SM_{co}) was calculated according to Equation A3. The example field is a grass and alfalfa mix; therefore, the root zone depth for the entire field was assumed to be the average of the grass hay (24 inches) and alfalfa (54 inches) crop rooting depths, which equates to a rooting depth of 39 inches Effective precipitation (P_{eff}) was calculated for every month of the growing season in the baseline period based on **Equation A2**, where SF of the example field equals 1 (from step 3 above):

$$P_{eff} = 1 * (0.70917 P_{mon}^{0.82416} - 0.11556)(10^{0.02426 ET_c}) \quad \textbf{Equation A2}$$

For July 2020, the calculation results were as follows:

$$P_{eff} = 1 * (0.70917 * 0.2^{0.82416} - 0.11556)(10^{0.02426*5.3}) = 0.1 \text{ inch}$$

Monthly P_{eff} estimates are shown in Table A-4.

8. Table A-2). Because the crop composition of the example field does not vary from 2017 through 2023, a single root depth value is used; however, root depth can vary by year if the crop composition varies between irrigation seasons. AWC is equal to the AWS in the first 59 inches of soil (0.16 inch per inch for the example field). Winter (November through March) precipitation and ET_{win} values are summarized in Table A-3 and Effective precipitation (P_{eff}) was calculated for every month of the growing season in the baseline period based on **Equation A2**, where SF of the example field equals 1 (from step 3 above):

$$P_{eff} = 1 * (0.70917 P_{mon}^{0.82416} - 0.11556)(10^{0.02426 ET_c}) \quad \textbf{Equation A2}$$

For July 2020, the calculation results were as follows:

$$P_{eff} = 1 * (0.70917 * 0.2^{0.82416} - 0.11556)(10^{0.02426*5.3}) = 0.1 \text{ inch}$$

Monthly P_{eff} estimates are shown in Table A-4.

9. Table A-2, respectively. For 2020 at the example field, the resulting SM_{co} is as follows:

$$SM_{co} = minimum\left(0.67 * (3.9\ inches - 1.25 * 1.5 \text{ inches}), 0.75 * 39\ inches * 0.16 \frac{inch}{inch}\right) = minimum\ (1.9, 4.6) = 1.9 \text{ inches.} \quad \textbf{Equation A3}$$

The resulting winter SM_{co} values for the example field are listed in the month of March in Table A-5. Monthly SM_{co} values calculated according to Equation 2c are also included in Table A-5. An example calculation for the month of May 2020 is shown in **Equation A4**.

$$SM_{co,\ mon} = MIN(MAX(1.9 - 1.9 + 0, 0), 0.75 * 39 * 0.16) = MIN(0, 4.6) = 0 \text{ inches} \quad \textbf{Equation A4}$$

Table A-5. Monthly Carry-Over Soil Moisture for Example Field

Month	2017 (inches)	2018	2019	2020	2021	2022	2023
March	1.9	0.0	1.4	1.4	0.7	0.0	1.9
April	2.3	0.0	2.1	1.9	0.9	0.0	2.1
May	0.7	0.0	0.0	0.0	0.5	0.0	0.0
June	0.0	0.0	0.0	0.0	0.0	0.0	0.0
July	0.0	0.0	0.0	0.0	0.0	0.0	0.0
August	0.0	0.0	0.0	0.0	0.0	0.0	0.0
September	0.0	0.0	0.0	0.0	0.0	0.0	0.0
October	0.0	0.0	0.0	0.0	0.0	0.0	0.0

10. Monthly depletion was calculated at the field scale based on **Equation 2a**. To convert depletion from a depth to a volume, the depletion estimates were multiplied by the field area, which totaled 90 acres for the example field. Monthly depletion volumes for the irrigation season were summed up annually. Monthly and annual depletion estimates for the example field are shown in Table A-6. The depletion reduction opportunity (DRO) under the full-season fallowing alternative for this field was 114 acre-feet, which is the median value from the 7-year baseline period shown in Table A-6.

The approach for calculating the DRO of a split-season fallow closely followed the full-season fallow approach discussed previously with one key difference: depletion was calculated monthly. For this difference, winter SM_{co} was depleted starting in April. After cumulative irrigation-season ET exceeds the sum of the cumulative irrigation-season P_{eff} and winter SM_{co}, monthly depletion is equal to ET minus P_{eff} only, and winter SM_{co} is removed from the calculation. If applicants want to fallow their fields from June 15 to October 31, then their DRO for the year 2022 would be the sum of July through October and half of the June monthly depletion estimates (71 inches).

Table A-6. Depletion Estimates for Example Field

Month	2017 (inches)	2018	2019	2020	2021	2022	2023
March	0	2	0	0	0	5	0
April	0	11	3	0	0	11	0
May	13	19	21	38	13	23	25
June	38	12	37	38	29	20	35
July	17	15	31	39	17	17	47
August	23	8	26	29	17	16	30
September	15	14	19	17	23	12	25
October	11	0	11	13	11	16	14
Depletion[a]	**116**	**80**	**147**	**174**	**109**	**119**	**175**
6/15 through 10/31 Depletion	**85**	**44**	**105**	**117**	**82**	**71**	**132**

[a] Annual depletion equal to the sum of the monthly irrigation season depletion

[b] In this example, 2022 corresponded to the median depletion-value in the 7-year baseline period. So, the DRO for this field under the full-season fallowing alternative was approximately 119 acre-feet.

A.1 References

Daily Surface Weather and Climatological Summaries (DAYMET). 2024. Precipitation data for study area. National Aeronautics and Space Administration, Oak Ridge National Laboratory, Distributed Active Archive Center. Accessed August 2024. https://daac.ornl.gov/cgi-bin/dataset_lister.pl?p=32.

Natural Resources Conservation Service (NRCS). 2024. Web Soil Survey data download for project study area. Accessed September 2024. https://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.

OpenET. 2024. Public Google Bucket containing eeMETRIC and Ensemble modeled evapotranspiration from 2018-2024 in the provided project region. Accessed September 2024. https://console.cloud.google.com/storage/browser/utah-temp;tab=objects?project=openet&prefix=&forceOnObjectsSortingFiltering=false.