Quantify the Possible

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Attention:	Colorado River Authority of Utah Central Utah Water Conservancy District
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Executive Summary

The Evaluate the Possibilities subtasks identify opportunities for reduced consumptive use in agriculture that promote resiliency for both farmers and Utah's supply of Colorado River water. This Quantify the Possible Technical Memorandum (TM) summarizes the five primary activities of Subtask 2.3 that seek to build upon the agricultural depletion estimates developed using remote sensing data in Subtask 2.2 by investigating opportunities to reduce that depletion through irrigation system conversions and crop changes within the study area, which comprises Colorado River Basin (CRB) lands in Utah and Central Utah Water Conservancy District (District) service area lands.

Irrigation system conversions were investigated to identify opportunities for depletion reduction. The Utah Water Related Land Use (WRLU) dataset was used to identify candidate flood (surface)- and sprinkler-irrigated fields for conversions. Conversions from surface (assumed to employ basin or border methods based on a literature review of predominant irrigation methods in Utah) to mid-elevation spray application (MESA), low-elevation spray application (LESA), low-energy precision application (LEPA), and subsurface drip irrigation (SDI) and conversions from sprinkler (assumed to employ the MESA pivot method based on a literature review of predominant irrigation methods in Utah) to LEPA, LESA, and SDI were investigated using assumptions more specifically described in the sections to follow.[1] Depletion reduction estimates resulting from these conversions are summarized in Table ES-1. Considering these estimated depletion reductions, conversions from surface and sprinkler irrigation to SDI were forwarded for further analysis to determine an upper threshold of depletion reduction possible through irrigation system conversions.

Table ES-1. Estimated Depletion Change Results for Investigated Conversions[a]

From	To	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

[a] These results are theoretical in nature and based on assumptions relevant to this study; actual results may vary.

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

[1] Although wheel-line to pivot MESA conversions are supported by agricultural optimization programs in the state of Utah and expected to result in a reduction in depletion based on the data in Table 2, assumptions included in this analysis more specifically identified in Table 4 and discussed in Task Order #1 *Quantify the Possible Technical Memorandum* (Jacobs 2023) negate this opportunity and, thus, these conversions are not specifically investigated.

Field-scale depletion estimates from Subtask 2.2 for water years 2017 through 2020 were used as the basis for quantifying the opportunities for depletion reduction through irrigation system conversions to SDI. Surface-irrigated fields were adjusted down by 18 percent, and sprinkler-irrigated fields adjusted down by 29 percent. The resulting upper threshold of opportunity to reduce depletion within the study area was approximately 222 thousand acre-feet (kaf) with 134 kaf in the Upper CRB (UCRB). If fully realized, these conversions would reduce agricultural depletions in the study area and UCRB by approximately 23 percent.

The 222 kaf of opportunity for depletion reduction through irrigation system changes from surface and sprinkler to SDI is not without some of the following practical and administrative challenges:

- SDI systems are susceptible to damage from rodents. Field flooding is used in some cases for mitigation, reducing the overall opportunity for depletion savings.
- Germination in SDI is typically supported by alternative irrigation methods such as surface or sprinkler. Water applied via these methods is expected to reduce the overall opportunity for depletion savings.
- For MESA to SDI conversions, an increase in irrigation system management and maintenance can also be expected, which is a potential drawback.
- The opportunity for depletion reduction through conversions to SDI assume field production does not increase. Administrative controls will be needed to reduce irrigated area to maintain pre-conversion production. These controls add program management burden to the administering agency.
- Proficiency with current irrigation practices and lack of knowledge related to SDI systems may be a barrier to change.
- Empirical data that quantify depletion savings aligned with SDI installations in Utah are lacking. Research specific to SDI installations in Utah is recommended to further refine depletion savings estimates.

The opportunity to reduce agricultural depletion through crop changes was also investigated. Forage crops were the focus of opportunity, specifically alfalfa and grass hay, due to their prevalence in Utah. *Consumptive Use of Irrigated Crops in Utah* (Hill 1998) was used as a basis to quantify the estimated depletion reduction, assuming a change from alfalfa and grass hay to spring grain. The total estimated depletion reduction assuming all alfalfa and grass hay are changed to spring grain, an no double cropping is occurring, was approximately 185 kaf, a 19-percent reduction in baseline[2] depletion for water years 2017 through 2020. Internationally exported alfalfa and grass hay were also considered. Between 2017 and 2020, the fraction of production internationally exported in the state of Utah ranged from 22 percent to 32 percent; 2022 was a particularly low export year, with only 12 percent of forage exported. The opportunity for depletion reduction through conversion of the internationally exported portion of alfalfa and grass hay to spring grain was 52 kaf on average across water years 2017 through 2020, with only 22 kaf of opportunity in 2022. Changing the exported portion of alfalfa and grass hay to spring grain would reduce the baseline depletion across the study area by 5 percent for water years 2017 through 2020 and 2 percent for water year 2022.

Consistent with irrigation system conversions, crop changes from alfalfa and grass hay are not without practical challenges which may include:

- **Producer needs—**Much forage grown in Utah is used within the state to support livestock, often used on the farm where it's grown. If farmers switch their livestock feed crop, then that feed needs to be replaced or livestock production decreased.
- **Crop demand—**Market demand has a role in choices made by producers with respect to crops grown. Producers grow crops that have demand to support their sale. Price and revenue generation are also considered.

[2] The term *baseline* is used to identify the estimated remote sensing-based depletion volume of a field in its current or baseline condition, before any irrigation system conversion or crop change has occurred.

- **Market location—**Similar to demand, producers consider the distance to market for the crops they grow. Considering spring grain that is harvested for grain, a grain elevator is needed within proximity of the farm where transportation doesn't become cost prohibitive.
- **Equipment—**Changing crops likely results in a need to replace current equipment with that needed to support new crop production. This requires capital investment and may require the producer to build knowledge in the operation of new equipment.
- **Producer risk—**Change is often accompanied by inherent risk. Changing crops may come with risk related to the considerations above and crop resilience to weather and crop's ability to thrive in the field's soil conditions.

Following quantification of the opportunities to reduce agricultural depletion through irrigation system conversions and crop changes, baseline and reduced depletion scenarios were evaluated against the projected future available water supply to agriculture in Utah's UCRB. Reducing agricultural depletion through irrigation system conversions and crop changes reduces risk of a supply shortage to agriculture but on average, results for water years 2017 through 2020 indicate that shortages are still likely to occur. Although supply shortage to agriculture may occur in the 10th percentile water supply condition and expected to occur in the minimum water supply condition, reducing agricultural depletion through irrigation system conversion and crop changes increases the volume of water supply that may be provided to a downstream beneficial use such as system storage, reducing risk of supply shortage to agriculture in future years. Thus efforts to reduce agricultural depletion are recommended to improve resiliency for both producers and the District and Colorado River Authority of Utah (Authority) alike.

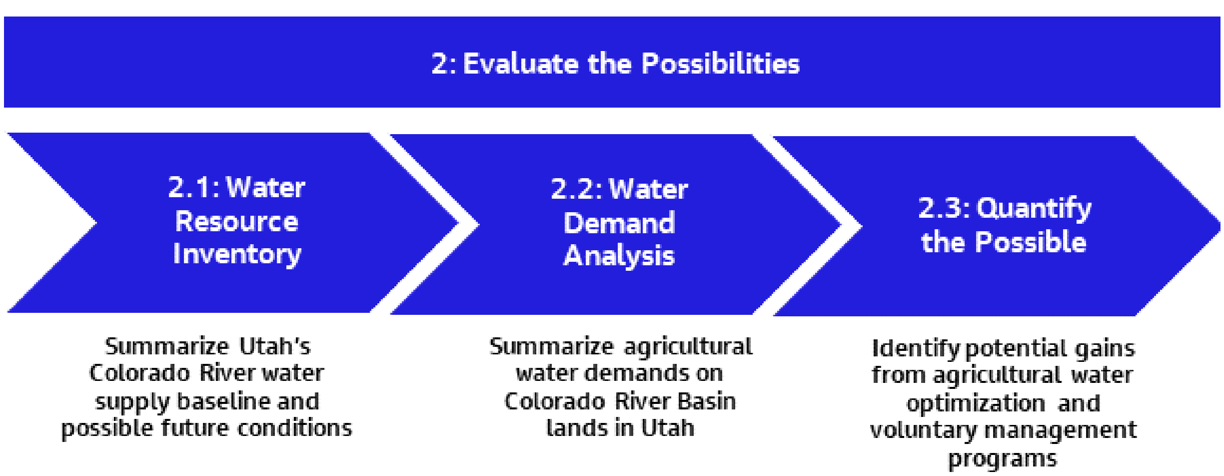
1. Objective

The objective of this *Quantify the Possible TM* is to calculate and summarize theoretical opportunities for reduced depletion within the study area, comprising CRB lands in Utah and District service area lands.

2. Introduction

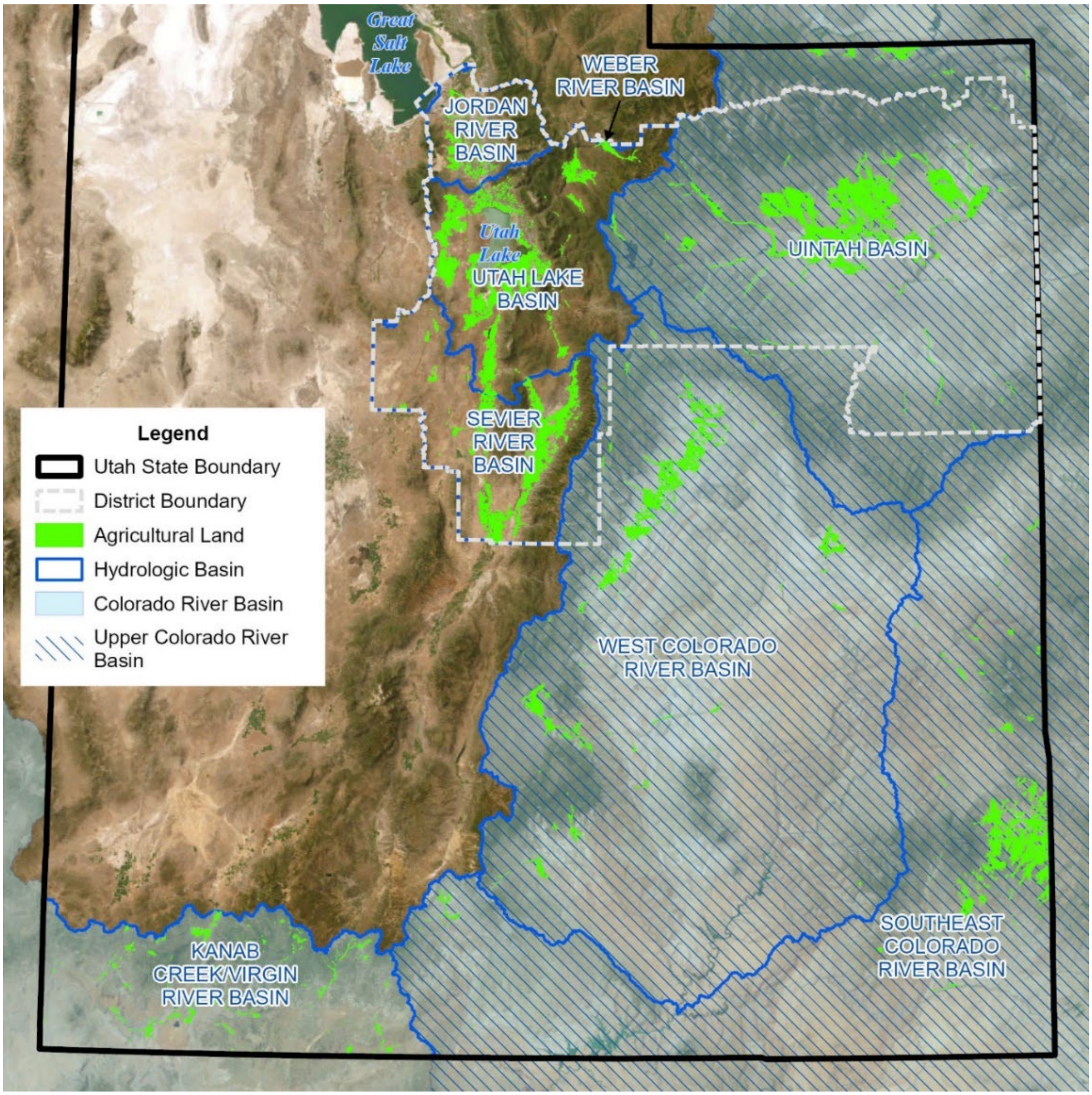
During February 2023, the District contracted Jacobs Engineering Group Inc. (Jacobs) to complete Task Order No. 2 (TO2) of their Agriculture Water Resiliency Plan to meet both the District's and Authority's goal to evaluate potential programs, partnerships, outreach, and other efforts needed to make an investment in optimizing agricultural water use within the CRB lands in Utah. TO2 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 objective, *Evaluate the Possibilities* (Task 2), which includes the three subtasks identified on Figure 1.

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



The *Evaluate the Possibilities* subtasks identify opportunities for reduced consumptive use in agriculture that promote resiliency for both farmers and Utah's supply of Colorado River water. The evaluations considered available water supply, agricultural water demands, and potential gains from agricultural water optimization and voluntary demand management programs within the study area. The study area includes District service area lands and the CRB lands in the state of Utah; results were further delineated where appropriate by interest areas, including District service area lands falling outside of the UCRB (identified as District), District Service lands within the UCRB (identified as District/UCRB), UCRB lands falling outside of the District's service area (identified as UCRB) and Lower Colorado River Basin lands in Utah (identified as LCRB). An overview of the CRB, *included* hydrologic basins, and agricultural lands are provided in the map on Figure 2.

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



This *Quantify the Possible TM* documents the results of Subtask 2.3, including summarizing theoretical opportunities for reduced depletion within the study area. The subtask activities included in the project scope of work and covered in this TM are as follows:

1. Calculate and summarize the theoretical opportunities for reductions in depletion.

   a. Off-farm—Summarize water balance studies performed by Jacobs in the CRB and any new literature sources not previously available or identified as part of the District's Agricultural Water Resiliency Plan developed under Task Order No. 1 (TO1).

   b. On-farm—Using available Google Earth Engine implementation of the Mapping Evapotranspiration at high Resolution with Internalized Calibration model (eeMETRIC) based consumptive use of irrigation water (CU_{irr})[3] data from OpenET (2017 through 2020) and results from Subtask 2.2, use assumptions identified in the District's Agricultural Water Resiliency Plan developed under TO1 and subsequent lessons learned and available tools to summarize a range of field-scale theoretical depletion reductions possible in the study area for 2017 through 2020 water years. Characterize by irrigation method.

      Compare range in basin-scale eeMETRIC based depletion results from OpenET against range in depletion data from the Utah Division of Water Resources (UDWRe) historical Water Budget Model (WBM) results; extrapolate OpenET results if range is materially narrower than UDWRe's historical WBM results.

2. Using available eeMETRIC based CUirr data from OpenET and results from Subtask 2.2, identify the opportunity for reduced depletion on marginal lands for water years 2017 through 2020. Investigate and characterize how the exclusion of subirrigated lands impacts the overall opportunity.

3. Perform a retrospective analysis of the OpenET eeMETRIC based CUirr data and results from Subtask 2.2 to identify the following:

   a. Basin-scale depletion trends resulting from changes to irrigation methods and crop types.

   b. Field-scale depletion changes resulting from changes in irrigation method and crop type. UDWRe's historical WRLU datasets will be used to identify fields that have undergone changes in irrigation method and crop type. Characterize changes in depletion resulting from changes made on subirrigated lands (if any).

      Compare retrospective analysis results with theoretical results for reduced depletion through changes in irrigation method. Summarize how these analyses inform the reality of depletion changes following changes in irrigation method and how administrative controls may have influenced the resulting changes.

4. Summarize the opportunity for reduced depletion results from TO1 and TO2.

5. Discuss how the opportunities for reduced depletion in the study area relate to the study area supply and demand results from Subtasks 2.1 and 2.2.

[3] For this analysis and TM, the terms *CU_{irr}* and *depletion* are equivalent.

3. Subtask Activities

3.1 Calculate and Summarize Theoretical Opportunities for Depletion Reductions

3.1.1 Off-Farm

A detailed discussion regarding opportunities for reduced consumptive use through off-farm improvements within the District's service area was completed under TO1 (Jacobs 2023). Much previous discussion and takeaways are similarly relevant to the CRB. As a result and per the subtask activity descriptions in Section 2, the discussion herein will be focused on a summary of water balance studies performed by Jacobs in the CRB and any new literature sources not previously available or identified as part of TO1.

California's Water Conservation Act of 2009 (SB X7-7) requires agricultural water suppliers serving more than 25,000 irrigated acres (excluding recycled water deliveries) to adopt and submit to California Department of Natural Resources an agricultural water management plan (CDWR 2024). Since California's Water Conservation Act was passed in 2009, Jacobs has supported irrigation districts and canal companies in completing agricultural water management plans that have included water balances to identify supplies, losses, and overall conveyance efficiencies. Table 1 provides examples of such water balances.

Table 1. Average Annual District Level Water Balances for Three San Joaquin Valley Irrigation Districts

Uses and Losses	Irrigation Supplier A[a]		Irrigation Supplier B		Irrigation Supplier C	
	Annual Volume (acre-feet)	Percent of Supply	Annual Volume (acre-feet)	Percent of Supply	Annual Volume (acre-feet)	Percent of Supply
Canal and reservoir seepage	54,350	21	18,558	6	176,043	33
Canal and reservoir evaporation	8,670	3	4,531	2	10,601	2
Operational spills	24,770	10	52,088	18	38,645	7
On-farm deliveries	147,290	57	168,674	57	232,300	44
Other deliveries (for example, municipal)	2,250	9	51,257	17	68,098	13
Total demands	**257,580**	**100**	**295,107**	**100**	**525,687**	**100**
Systemwide conveyance efficiency[b]	**66 percent**		**75 percent**		**57 percent**	

[a] Suppliers names have been omitted for privacy.
[b] Overall systemwide efficiency = (on-farm deliveries + other deliveries) / total supplies into canal system.

Table 1 illustrates conveyance efficiency results that range from 57 percent to 75 percent, at the upper end of the range reported by Hill (1998) of 30 percent to 80 percent. Of the categories that do not support deliveries, *canal and reservoir seepage and operational spills* do not typically lead to basin-scale depletions. Regarding the suppliers detailed, these districts manage water for conjunctive use of surface and groundwater, and thus, canal seepage losses and deep percolation of on-farm applied water are used to offset District and private (on-farm) groundwater pumping for groundwater sustainability. As a result, the opportunity to reduce depletion in the Table 1 cases is contained to the small volumes of canal and reservoir evaporation.

As reported in TO1, canal lining presents operational benefits and reduced water losses for the farmers or irrigation districts in the affected area but often does not result in conserved water at the basin scale for downstream beneficial use unless associated with a transbasin diversion where a reduction in diverted water does lead to a reduction in basin depletion. As the District and the Authority consider off-farm opportunities to reduce study area depletion, detailed water balances are recommended to better quantify the off-farm losses before project selection. When this TM was prepared, no additional literature sources were identified as part of TO2 that expand upon data previously presented in TO1.

3.1.2 On-Farm

Support for producers to conduct on-farm optimization improvements has grown significantly in the state of Utah over recent years. Current programs, including the National Resources Conservation Service Environmental Quality Incentives Program (NRCS 2024), Utah Department of Agriculture and Food Agricultural Water Optimization Program (UDAF 2024), and Upper Colorado River Commission System Conservation Pilot Program (UCRC 2024), provide opportunities for Utah producers to receive financial support in relation to meeting specific objectives, including the following:

- Water use optimization
- Conserved ground and surface water
- Maintaining or improving agricultural production
- Water conservation innovation
- Resiliency to drought and a changing climate
- Water quality improvements
- Increased soil health
- Reduced soil erosion and sedimentation

As the District and Authority strive to understand and identify opportunities that reduce consumptive use in agriculture, promoting resiliency for both farmers and Utah's supply of Colorado River water, the focus of this study is specific to irrigation system conversions (Section 3.1.2.1) and crop changes (Section 3.1.2.2) that lead to a reduction in depletion.[4]

3.1.2.1 Irrigation System Conversions

Approach

The opportunity for depletion reductions through irrigation system conversions was evaluated as follows:

1. Identifying the predominant surface and sprinkler irrigation methods used in Utah (fields identified with irrigation methods flood and sprinkler in the State of Utah's WRLU dataset were aligned with predominant methods to establish the *Convert From* condition)

2. Investigating irrigation system conversions that may result in a reduction in depletion, which establish the *Convert To* condition

3. Defining conversion assumptions for each conversion identified in Step 2

4. Calculating an example field to determine the theoretical change in water diverted and depleted for each conversion investigated

5. Identifying irrigation system conversions that result in a material reduction in depletion and forwarding these conversions for further analysis to estimate the opportunity for depletion reduction in the study area

The predominant surface and sprinkler irrigation methods in Utah were identified by reviewing *Agricultural Irrigated Land and Irrigation Water Use in Utah* (Barker et al. 2022). Predominant methods were determined to be *basin/border* for surface irrigation and *center pivot* and *lateral move* for sprinkler irrigation; these predominant methods establish the *Convert From* condition in quantifying the

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[4] Depletion is defined as the quantity of water diverted and consumed that is lost to the hydrologic system through said use. Depleted water does not return to the surface water sources or underground aquifers via seepage, drainage, or other methods but is consumed in the growth of plants, evaporation, and transmission away from the area (UDWRi 2024).

opportunity for depletion reductions through irrigation system conversions for flood (surface) and sprinkler irrigated fields included in the analyzed 2017 through 2020 WRLU datasets.

After the *Convert From* conditions were established, Table 2 was reviewed to identify irrigation system conversions that may result in a reduction in depletion. The conversions selected to investigate further are summarized in Table 3. To develop estimates of depletion reduction that may result from the conversions identified in Table 3, assumptions relevant to an agricultural resiliency program administered by the District and/or Authority were considered and identified through literature review and conversations with the project team and representatives from Utah State University (USU). These assumptions are summarized in Table 4. Following identification of relevant assumptions, a series of calculations, more specifically described in Appendix A, was performed on an example field to determine the change in depletion that would be expected for each conversion. The calculations included the efficiency and loss fraction data presented in Table 2, and assumptions identified in Table 4. The summarized results of these calculations are included in Table 5.

Review of the results in Table 5 indicates that all irrigation system conversions are expected to lead to a reduction in diversion as a result of a reduction in crop production (Basin/Border to Pivot conversions due to reduction in irrigated area), improvements in application efficiency, or both. Depletion reductions proved to be more difficult to achieve when including the assumptions and employing the calculation methods of this study. Conversions from surface (basin/border) and sprinkler (pivot/lateral MESA) to SDI were forwarded for further analysis to determine the upper threshold of opportunity for reductions in depletion within the study area.

Results

The analysis to estimate reductions in depletion resulting from irrigation system conversion build upon previous analyses that estimated field-scale depletion within the study area for water years 2017 through 2020 (Jacobs 2024). In summary, depletion volume estimates were calculated for each field included in the WRLU dataset for water years 2017 through 2020 via one of two methods:

- **Method 1—**For fields in the study area where an effective precipitation data value from the Desert Research Institute (DRI) was available (Pearson pers. Comm. 2023), depletion was calculated in accordance with Appendix G, *Upper Colorado River Basin OpenET Intercomparison Summary* to *Assessing Agricultural Consumptive Use in the Upper Colorado River Basin* (DRI 2022), of *Assessing Agricultural Consumptive Use in the Upper Colorado River Basin:* Phase III Report (WWG 2022).
- **Method 2—**For fields in the study area where an effective precipitation data value from DRI was not available, depletion was calculated consistent with *Field Verification of Empirical Methods for Estimating Depletion* (Hill et al. 1989).

Given that the WRLU dataset identifies irrigation methods for each field in the dataset, including flood (surface), sprinkler, drip, subirrigated, and dry-crop (dryland or rainfed), the surface and sprinkler irrigated fields could be identified. Applying an18-percent reduction in estimated depletion for surface irrigated fields and a 29-percent reduction to sprinkler irrigated fields allows for a reduction volume to be calculated for each candidate field that results from a conversion to SDI. The results of this analysis are summarized in Tables 6 and 7, and illustrated on Figures 3, 4, and 5.

Table 2. Assumptions for On-Farm Conversion

Type	Irrigation System	Irrigation Efficiency (percent)	Primary Destination of Water Losses	Irrigation Efficiency Range (percent)	Fraction Losses to Deep Percolation	Fraction Losses to Wind Drift and Evaporation	Fraction Losses to Runoff	Fraction Short-Term Losses	Fraction Forever Losses
Drip	SDI	98	DP	85 to 100	1	0	0	0.020	0.000
	Surface drip	95	DP	80 to 90	1	0	0	0.050	0.000
	Mobile drip irrigation	96	DP	80 to 90	1	0	0	0.040	0.000
Sprinkle	Pivot/linear LEPA	86	WDE	80 to 97	0.1	0.9	0	0.136	0.122
	Pivot/linear LESA	90	WDE	80 to 97	0.05	0.95	0	0.098	0.093
	Microsprinkler	74	WDE	80 to 90	0.15	0.85	0	0.256	0.218
	Undertree orchard	80	WDE	75 to 93	0.05	0.95	0	0.202	0.192
	Pivot/linear MESA	78	WDE	75 to 90	0.05	0.95	0	0.216	0.205
	Solid set sprinklers	71	WDE	70 to 80	0.05	0.95	0	0.288	0.273
	Hand move	67	WDE	60 to 90	0.05	0.95	0	0.335	0.318
	Wheel line	67	WDE	65 to 85	0.05	0.95	0	0.335	0.318
	Big gun	57	WDE	50 to 70	0.05	0.95	0	0.430	0.409
	Pivot/linear (top of pipe)	57	WDE	50 to 70	0.05	0.95	0	0.430	0.409
Surface	Basin	80	DP, RO	75 to 90	1	0	0	0.200	0.000
	Border	78	DP, RO	70 to 85	0.9	0	0.1	0.225	0.002
	Graded Furrow	78	DP, RO	75 to 85	0.85	0	0.15	0.225	0.003
	Contour border	78	DP, RO	75 to 80	0.9	0	0.1	0.225	0.002
	Furrow	70	DP, RO	60 to 75	0.8	0	0.2	0.300	0.006
	Corrugation	68	DP, RO	65 to 75	0.9	0	0.1	0.320	0.003
	Wild Flood	50	DP, RO	40 to 60	0.9	0	0.1	0.500	0.005

Source: USU (2024).

DP= deep percolation
LEPA = low-energy precision application
LESA = low-elevation spray application
MESA = mid-elevation spray application
WDE = wind drift and evaporation
RO = run off

Table 3. Irrigation System Conversions Investigated for Depletion Reduction

Convert From	Convert To
Basin/border	Pivot/linear MESA
	Pivot/linear LEPA
	Pivot/linear LESA
	SDI
Pivot/linear MESA	Pivot/linear LEPA
	Pivot/linear LESA
	SDI

Note: Irrigation conversions to investigate further were selected based upon current trends (surface to center pivot), practical considerations (pivot/linear MESA to pivot/linear LEPA/LESA), and interest in estimating the greatest possible opportunity for depletion reduction (subsurface drip).

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

Table 4. Investigated Irrigation System Conversion Assumptions

From	To	Assumptions
Basin/border	Pivot/linear MESA	▪ 21-percent reduction in irrigation area[a] ▪ 10-percent yield improvement[b] ▪ Change in area and yield linearly related to ETc[c] ▪ 12-percent cap of MESA WDE losses[d]
	Pivot/linear LEPA	▪ 21-percent reduction in irrigation area[a] ▪ 10-percent yield improvement[b] ▪ Change in area and yield linearly related to ETc[c] ▪ 12-percent cap of LEPA WDE losses[d]
	Pivot/linear LESA	▪ 21-percent reduction in irrigation area[a] ▪ 10-percent yield improvement[b] ▪ Change in area and yield linearly related to ETc[c]
	SDI	▪ Field production held constant[e] ▪ 25-percent yield improvement[f] ▪ 22-percent water productivity (ton per ETc in) improvement[f]
Pivot/linear MESA	Pivot/linear LEPA	▪ 12-percent cap of LEPA WDE losses[d] ▪ No change in geometry or yield
	Pivot/linear LESA	▪ No change in geometry or yield
	SDI	▪ Constant field production[e] ▪ 15-percent yield improvement[g] ▪ 22-percent water productivity (ton per ETc in) improvement[h]

[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 percent 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 *Quantify the Possible TM* (Jacobs 2023).
[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 note f and b
[h] Assumption based on gravity (surface)-to-SDI conversion in Montazar (2020) and supported by deficit irrigation results in Lamm (2016).

ET_c = crop evapotranspiration
LEPA= low-energy precision application
LESA= low-elevation spray application
MESA = mid-elevation spray application
SDI = subsurface drip irrigation
WDE = wind drift and evaporation

Table 5. Estimated Diversion and Depletion Change Results for Investigated Conversions[a]

From	To	Diversion Change[b] (percent)	Depletion Change (percent)
Basin/border	Pivot/lateral MESA	-12	0
	Pivot/lateral LEPA	-21	-2
	Pivot/lateral LESA	-24	-5
	SDI	-34	-18
Pivot/lateral MESA	Pivot/lateral LEPA	-9	-1
	Pivot/lateral LESA	-13	-4
	SDI	-35	-29

[a] These results are theoretical in nature and based on assumptions relevant to this study; actual results may vary.
[b] *Diversion Change* in this case is synonymous with a change in applied water volume; conveyance efficiencies are not considered.

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

Table 6. Summary of Depletion Reduction Opportunity through Irrigation System Conversion, Water Years 2017 through 2020

Interest Area	Depletion Reduction Opportunity (acre-feet)			
	2017	2018	2019	2020
District	**74,332**	**79,212**	**75,729**	**98,786**
Sprinkler to SDI	54,830	58,840	56,854	74,272
Surface to SDI	19,501	20,372	18,875	24,514
District/UCRB	**85,066**	**78,034**	**87,868**	**101,825**
Sprinkler to SDI	60,005	58,377	62,419	74,856
Surface to SDI	25,061	19,657	25,450	26,969
UCRB	**42,840**	**40,167**	**47,394**	**53,833**
Sprinkler to SDI	34,165	32,836	37,264	44,115
Surface to SDI	8,675	7,331	10,130	9,718
LCRB	**4,889**	**5,522**	**5,749**	**7,285**
Sprinkler to SDI	3,478	3,936	4,115	5,257
Surface to SDI	1,410	1,585	1,634	2,028
Total	**207,127**	**202,934**	**216,740**	**261,728**

District = District service area lands falling outside the UCRB
District/UCRB = District service area lands within the UCRB
UCRB = UCRB lands falling outside the District's service area
LCRB = Lower Colorado River Basin lands (in Utah)
SDI = subsurface drip irrigation

Table 7. Summary of Interest Area Depletions, Before and After Irrigation System Conversion, for Water Years 2017 through 2020

Interest Area	Depletion (acre-feet)			
	2017	2018	2019	2020
District				
Baseline	343,024	361,217	358,736	454,520
Following conversion	268,692	282,006	283,007	355,734
District/UCRB				
Baseline	383,355	341,637	402,403	454,755
Following conversion	298,288	263,604	314,535	352,930
UCRB				
Baseline	172,355	159,223	194,306	215,895
Following conversion	129,515	119,055	146,913	162,062
LCRB				
Baseline	21,532	24,223	26,380	33,000
Following conversion	16,644	18,701	20,631	25,716
Baseline total	**920,266**	**886,300**	**981,825**	**1,158,170**
Following conversion total	**713,139**	**683,366**	**765,086**	**896,442**
Depletion reduction (percent)	**23**	**23**	**22**	**23**

District = District service area lands falling outside the UCRB
District/UCRB = District service area lands within the UCRB
UCRB = UCRB lands falling outside the District's service area
LCRB = Lower Colorado River Basin lands (in Utah)

Figure 3. Summary of Depletion Reduction Opportunity through Irrigation System Conversion, Water Years 2017 through 2020

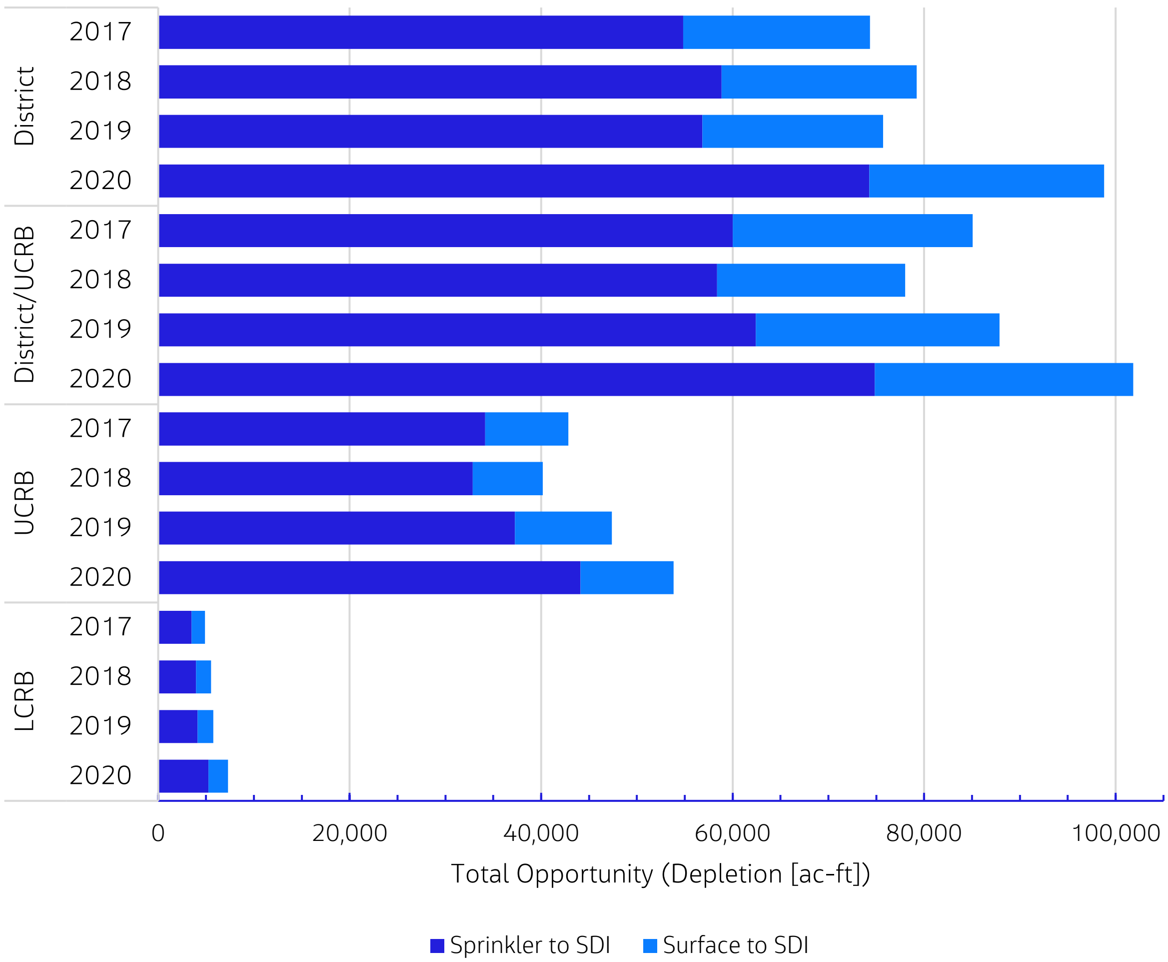


Figure 4. Summary of Interest Area Depletions Before and After Irrigation System Conversion, Water Years 2017 through 2020

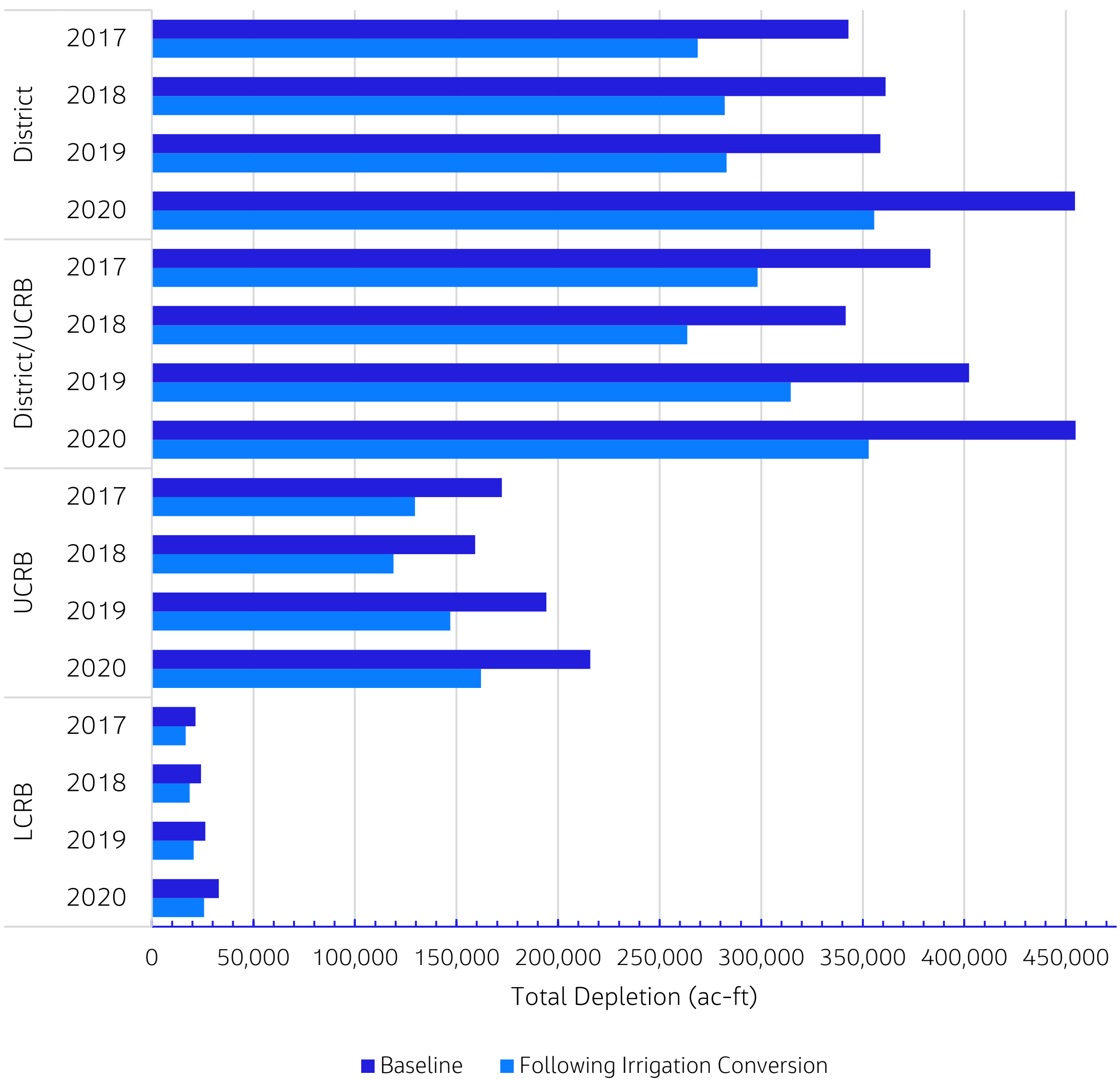
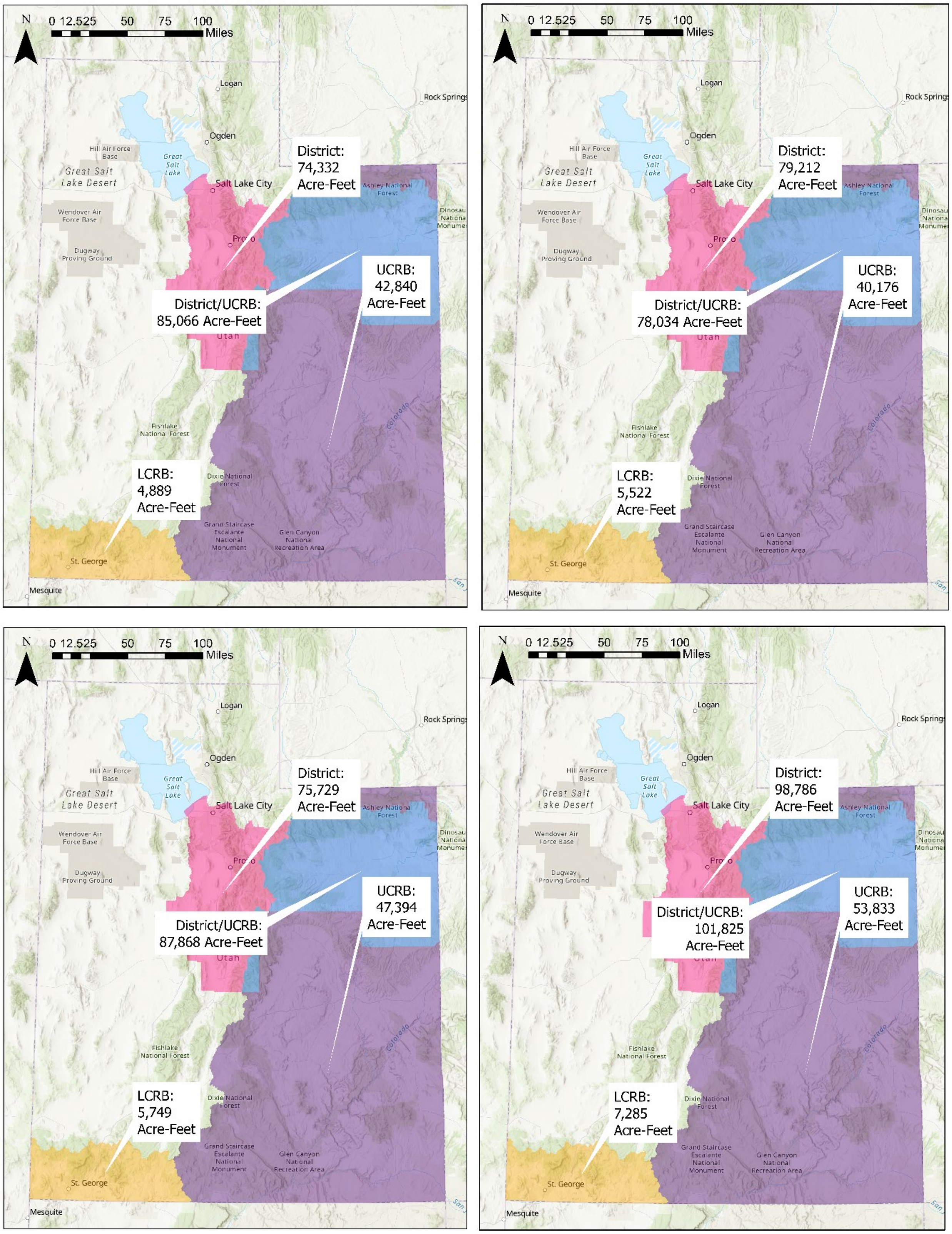


Figure 5. Depletion Reduction Opportunity through Irrigation System Conversion in 2017 (top left), 2018 (top right), 2019 (bottom left), and 2020 (bottom right)



The study area opportunity for depletion reduction through conversion of all flood (surface) and sprinkler irrigated fields identified in the WRLU dataset varied from a minimum of 202,934 acre-feet in 2018 to a maximum of 261,728 acre-feet in 2020. This opportunity represents a 22-percent to 23-percent reduction in the estimated baseline depletion for water years 2017 through 2020. The fields located within the District and UCRB (identified as District/UCRB fields) present the greatest opportunity for depletion reduction (101,825 acre-feet in 2020); the lands in the LCRB present the least opportunity (7,285 acre-feet in 2020).

Due to the opportunity investigation being limited to 2017 through 2020 water years[5], historical agricultural depletion data using UDWRe's WBM results (Jacobs 2024) was reviewed to better characterize the range in annual depletion reduction opportunity available. WBM based estimates suggest a range of depletion across water years 1989 through 2020 of 991,038 acre-feet to 1,266,328 acre-feet. Comparison with remote sensing based depletion estimates suggest WBM results exceed remote sensing based results by between 1 percent and 21 percent. Remote sensing based depletion volumes were extrapolated to quantify a broader range of opportunity that would align with depletion volumes ranging from the WBM minimum minus 21 percent to the WBM maximum minus 1 percent. The extrapolated depletion volumes range between 784 kaf and 1,248 kaf and thus, assuming a 23-percent reduction opportunity through irrigation system changes, an opportunity range of 180 kaf to 287 kaf would be expected.

Discussion

The estimations for depletion reduction through irrigation system conversions presented herein are based on assumptions that are specifically relevant to an irrigation optimization program that may be administered by the District and/or Authority. The results are not intended to categorically prescribe reductions in depletion that will result from the conversions investigated as actual results on individual fields may vary. Rather, the results are intended to identify irrigation system conversions that are likely to result in reductions in depletion that the District and/or Authority may wish to include in future investment programs supporting agricultural resiliency in their jurisdictional areas.

The 222 kaf of average opportunity identified across water years 2017 through 2020 represents **an upper threshold of depletion reduction that may be achieved through irrigation system conversions in the study area**. This upper threshold assumes that all fields currently irrigated through flood (surface) and sprinkler irrigation, as identified in the WRLU datasets, are converted to SDI. The 222 kaf of opportunity for depletion reduction through irrigation system changes from surface and sprinkler to SDI is not without practical challenges and may be reduced to overcome these challenges. Practical challenges include the following:

- Increased rodent activity can cause extensive leaks in SDI systems (Lamm 2016). Mitigation may include additional irrigation of fields (Lamm et al. 2012).
- SDI system leaks may be hard to locate due to water following a burrow path for a considerable distance before surfacing (Lamm 2016).
- Alternative irrigation methods are needed to improve crop germination (Lamm et al. 2012).
- For MESA to SDI conversions, an increase in irrigation system management and maintenance can be expected.
- The opportunity for depletion reduction through conversions to SDI assume field production does not increase. Administrative controls will be needed to reduce irrigated area to maintain pre-conversion production. These controls add program management burden to the administering agency.

[5] This is driven by limited availability of datasets to support the depletion quantification methods presented in the *Water Demand Analysis TM* (Jacobs 2024)

- Empirical data that support quantification of depletion savings associated with SDI installations in Utah are lacking. Research specific to SDI installations in Utah is recommended to further refine depletion savings estimates.
- Proficiency with current irrigation practices and lack of knowledge related to SDI systems may be a barrier to change.

Additional irrigation of fields for rodent control and improved germination in SDI systems are not considered in the 222 kaf of depletion reduction opportunity, and thus, the opportunity in practice may be lower.

Although many of the irrigation system conversions investigated resulted in reductions in depletion that are likely too small to accurately quantify, they nearly all resulted in more significant reductions in diversion[6] (applied water) volume. Reducing the volume of water diverted for irrigation has notable benefits, including the following:

- **Improved transparency of water distribution** (water management) related to the water that is not diverted and remains in the river, tributary, or canal reach.
- **Source water quality is improved** by reducing return flows and the included constituents such as salinity and nutrients returning to stream/river network.
- **Improved water management for the producer** is achieved through reduction in water losses that result from improved efficiency of the irrigation system.

This study and other existing studies indicate that SDI presents an opportunity to reduce irrigation depletions. Emerging work by USU and others looks to shed additional light on this topic in the state of Utah in the coming years. In the meantime, careful consideration should be given to potential projects including site characteristics, water augmentation needs, and implementation costs to evaluate the opportunity that SDI offers.

3.1.2.2 Crop Changes

Approach

The opportunity for depletion reductions through crop changes was evaluated as follows:

1. Reviewing publicly available information to identify methodology and data to support quantification of depletion reduction through crop changes (a crop change from commonly grown forages, alfalfa, and grass hay to a spring grain, such as spring wheat, was the crop change selected for analysis; additional discussion is provided in this section.)
2. Summarizing depletion associated with fields growing alfalfa and grass hay per WRLU datasets and depletion quantification methods outlined in the Water Demand Analysis TM (Jacobs 2024)
3. Using consumptive use station net irrigation requirement data in Hill (1994) and location data to pair each candidate field in the WRLU dataset with the nearest consumptive use station, quantifying the field-scale depletion reduction opportunity for converting alfalfa and grass hay fields to spring grain, and aggregating results across the study area
4. Performing a literature review to specifically consider the portion of forage crops in Utah that are internationally exported as a focus for depletion reduction through crop changes[7]

[6] Diversion change in Table 5 is synonymous with a change in volume of water applied; conveyance efficiencies are not considered

[7] Internationally exported forage crops were specifically investigated to understand the opportunity to reduce depletion associated with crops that do not directly support food or livestock production in the United States.

5. Quantifying the depletion reduction opportunity for converting the exported portion of alfalfa and grass hay fields to spring grain in the study area

Publicly available data were reviewed to support depletion quantification through crop changes. *Consumptive Use of Irrigated Crops in Utah* (Hill 1994) is a widely used resource in the state of Utah for quantifying crop irrigation requirements and is a common basis used by the Utah Division of Water Rights to quantify maximum potential depletion of irrigation water rights. Hill (1994) also includes data tables for various locations across the state (consumptive use stations) that include net irrigation requirements (required irrigation water exclusive of effective precipitation and carry-over soil moisture, generally consistent with depletion herein) for various crops. Crop data varies across the included tables but generally include higher consumptive crops alfalfa, pasture, and other hay, and lower consumptive crops such as spring grains (spring wheat). Spring grains offer an opportunity to reduce on-farm depletion and can be successfully grown in Utah's climate and on its agricultural lands (included in Hill 1994). Intersecting field locations and crop type from Utah's WRLU datasets with crop irrigation requirements from Hill (1994) provided a basis for quantifying depletion reduction opportunity for a change from alfalfa or grass hay to spring grain.

Table 8 summarizes depletion associated with fields growing alfalfa and grass hay per WRLU datasets using remote sensing based depletion quantification methods summarized in the *Water Demand Analysis TM* (Jacobs 2024). These tabulated depletions, ranging from 642 kaf to 829 kaf across the study area, form the basis for the depletion reduction opportunity through crop changes from alfalfa and grass hay to spring grain. Although the focus of this study has been on water years 2017 through 2020, data for the 2022 water year is additionally presented due to variability in the portion of Utah's forage crop that is internationally exported and the relevance of this depletion data to the export analysis below.

Table 8. Depletion Associated with Alfalfa and Grass Hay by Interest Area

Interest Area	Depletion of Alfalfa and Grass Hay (acre-feet)				
	2017	2018	2019	2020	2022
District	253,545	268,187	261,187	326,181	257,533
District and UCRB	222,197	222,464	240,492	290,878	267,700
UCRB	150,359	141,565	169,287	187,611	152,917
LCRB	16,200	18,120	18,810	24,266	18,579
Total	**642,301**	**650,336**	**689,776**	**828,936**	**696,729**

District = District service area lands falling outside the UCRB
District/UCRB = District service area lands within the UCRB
UCRB = UCRB lands falling outside the District's service area
LCRB = Lower Colorado River Basin lands (in Utah)

Study area depletion totals for alfalfa and grass hay crops across water years 2017 through 2020 and 2022 range from 642,301 acre-feet to 828,936 acre-feet. These depletion volumes serve as the basis for quantifying the opportunity for depletion reduction through crop changes. Field-scale depletion reduction opportunities for converting alfalfa and grass hay fields to spring grain were quantified using the following steps:

1. Identifying the nearest consumptive use station for each field
2. Calculating percent reduction in net irrigation requirement (Net Irr. in.) resulting from a crop change from either alfalfa or grass hay[8] to spring grain and applying the calculated reduction to the remote sensing based depletion volume of each field

[8] Where *other hay* was not an available crop, *pasture* data were used as a replacement.

3. Aggregating the individual field-scale opportunities to the interest area (District, District/UCRB, UCRB, LCRB)

Following aggregation, the interest area results serve as an upper threshold of opportunity for crop changes in the study area, assuming all alfalfa and grass hay fields undergo a conversion to spring grain and no double cropping occurs. Next, after the upper threshold of opportunity is quantified, a constrained approach was taken by focusing strictly on the portion of depletion aligned with forage crops that are understood to be exported to international markets. Literature was reviewed to identify the portion of forage crops in Utah that are internationally exported; the results of this review are summarized in Table 9.

Table 9. Production and Export Value Data for Hay and Forage Crops in Utah

Year	Total Production Value, Hay (USD)[a]	International Export Value, Hay (USD)[b]	Fraction of Production Exported (percent)	International Export Value, Forage (USD)[c]	Fraction of Production Exported (percent)
2017	347,356,000	N/A	N/A	76,858,065	22
2018	364,085,000	N/A	N/A	107,854,255	30
2019	460,326,000	129,240,582	28	145,715,152	32
2020	445,730,000	131,044,209	29	124,236,662	28
2021	499,148,000	115,306,204	23	107,634,452	22
2022	752,924,000	77,878,924	10	88,011,864	12

[a] Source: USDA (2024a)
[b] Source: USDA (2024b)
[c] Source: USCB (2024)

N/A = not applicable
USD = 2024 United States dollars

The data in Table 9 illustrates the variability in percentage of export value of hay/forage crops in the state of Utah. 2022 showed a significant decline in the fraction of exported value of forage production in Utah, possibly driven by reduced demand from international importers, and drought conditions and the need to utilize a greater percentage of the production for livestock within Utah or other states. As a result, the 2022 water year has been included in the presentation of baseline depletion data for study area fields growing alfalfa and grass hay in Table 8 and the results to follow.

Results

Field-scale reductions in depletion resulting from crop changes were quantified and aggregated by interest area. These results, presented in Table 10, serve as an upper threshold of opportunity for crop changes in the study area, assuming all alfalfa and grass hay fields undergo a conversion to spring grain, and no double cropping occurs. Results focused on the exported portion of the alfalfa and grass hay grown across the study area are presented in Table 11. The combined results are illustrated in Figure 6, showing the relative comparison of opportunity for each water year.

The upper threshold of opportunity for depletion reduction through crop changes range from a minimum of 168,823 acre-feet in 2017 to a maximum of 221,347 in 2020. Fields located in the District service area and outside of the CRB provide the greatest opportunity for depletion reduction; fields in the LCRB present the least opportunity for depletion reduction. Focusing strictly on the exported portion of alfalfa and grass hay crops, the opportunity for depletion reduction ranges from a minimum of 22,310 acre-feet in 2022 to a maximum of 61,977 acre-feet in 2020. 2022 experienced a significantly lower percentage of exported forage crops compared to the other years investigated, which led to the reduction in opportunity presented.

Table 10. Depletion Reduction Opportunities Resulting from Alfalfa-to-Spring Grain and Grass Hay-to-Spring Grain Crop Changes across Study Area

Interest Area	Depletion Reduction Opportunity (acre-feet)				
	2017	2018	2019	2020	2022
District	**67,315**	**73,049**	**66,138**	**88,587**	**68,166**
Alfalfa to spring grain	60,327	65,527	57,948	80,269	60,864
Grass hay to spring grain	6,988	7,522	8,190	8,318	7,303
District/UCRB	**47,463**	**49,520**	**50,968**	**64,401**	**62,512**
Alfalfa to spring grain	38,611	40,952	40,681	53,563	53,372
Grass hay to spring grain	8,853	8,568	10,287	10,838	9,139
UCRB	**46,323**	**42,416**	**51,805**	**56,953**	**8,369**
Alfalfa to spring grain	42,316	38,153	47,958	52,868	8,096
Grass hay to spring grain	4,007	4,263	3,847	4,085	273
LCRB	**7,722**	**8,600**	**8,822**	**11,406**	**46,870**
Alfalfa to spring grain	7,466	8,295	8,540	11,103	45,030
Grass hay to spring grain	256	305	282	303	1,841
Total	**168,823**	**173,585**	**177,733**	**221,347**	**185,917**

Note: Where depletion increased as a result of the proposed crop change based on consumptive use station data, these fields were omitted from the analysis (approximately 2 percent of fields across the years investigated).

District = District service area lands falling outside the UCRB
District/UCRB = District service area lands within the UCRB
UCRB = UCRB lands falling outside the District's service area
LCRB = Lower Colorado River Basin lands (in Utah)

Table 11. Depletion Reduction Opportunities Resulting from Alfalfa-to-Spring Grain and Grass Hay-to-Spring Grain Crop Changes across Study Area Assuming Only Exported Portion is Converted[9]

Interest Area	Depletion Reduction Opportunity (acre-feet)				
	2017	2018	2019	2020	2022
District	**14,809**	**21,915**	**21,164**	**24,804**	**8,180**
Alfalfa to spring grain	13,272	19,658	18,543	22,475	7,304
Grass hay to spring grain	1,537	2,257	2,621	2,329	876
District/UCRB	**10,442**	**14,856**	**16,310**	**18,032**	**7,501**
Alfalfa to spring grain	8,494	12,286	13,018	14,998	6,405
Grass hay to spring grain	1,948	2,570	3,292	3,035	1,097
UCRB	**10,191**	**12,725**	**16,578**	**15,947**	**1,004**
Alfalfa to spring grain	9,310	11,446	15,347	14,803	971
Grass hay to spring grain	882	1,279	1,231	1,144	33
LCRB	**1,699**	**2,580**	**2,823**	**3,194**	**5,624**
Alfalfa to spring grain	1,643	2,489	2,733	3,109	5,404
Grass hay to spring grain	56	92	90	85	221
Total	**37,141**	**52,076**	**56,875**	**61,977**	**22,310**

District = District service area lands falling outside the UCRB
District/UCRB = District service area lands within the UCRB
UCRB = UCRB lands falling outside the District's service area
LCRB = Lower Colorado River Basin lands (in Utah)

[9] The results presented assume that the statewide percentage of internationally exported forage applies to the study area.

Figure 6. Depletion Reduction Opportunities Resulting from Alfalfa-to-Spring Grain (Spring Wheat) and Grass Hay-to-Spring Grain Crop Changes across Study Area

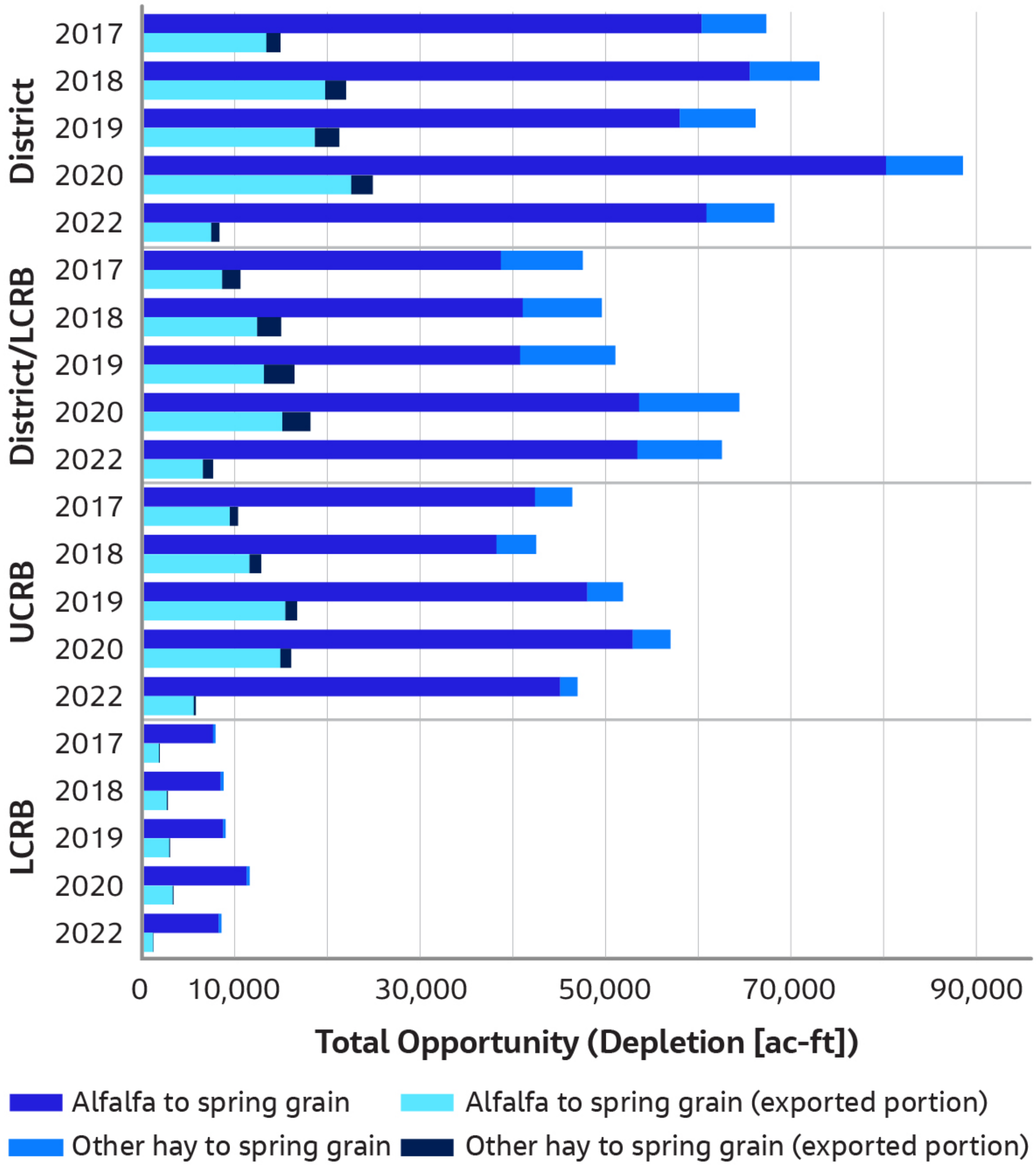


Table 12 and Figure 7 summarize study area depletions for the investigated conversion scenarios. The data presented includes the baseline condition (no crop changes), following conversion of all alfalfa and grass hay crops in the study area (upper threshold), and following conversion of only the exported portion of alfalfa and grass hay.

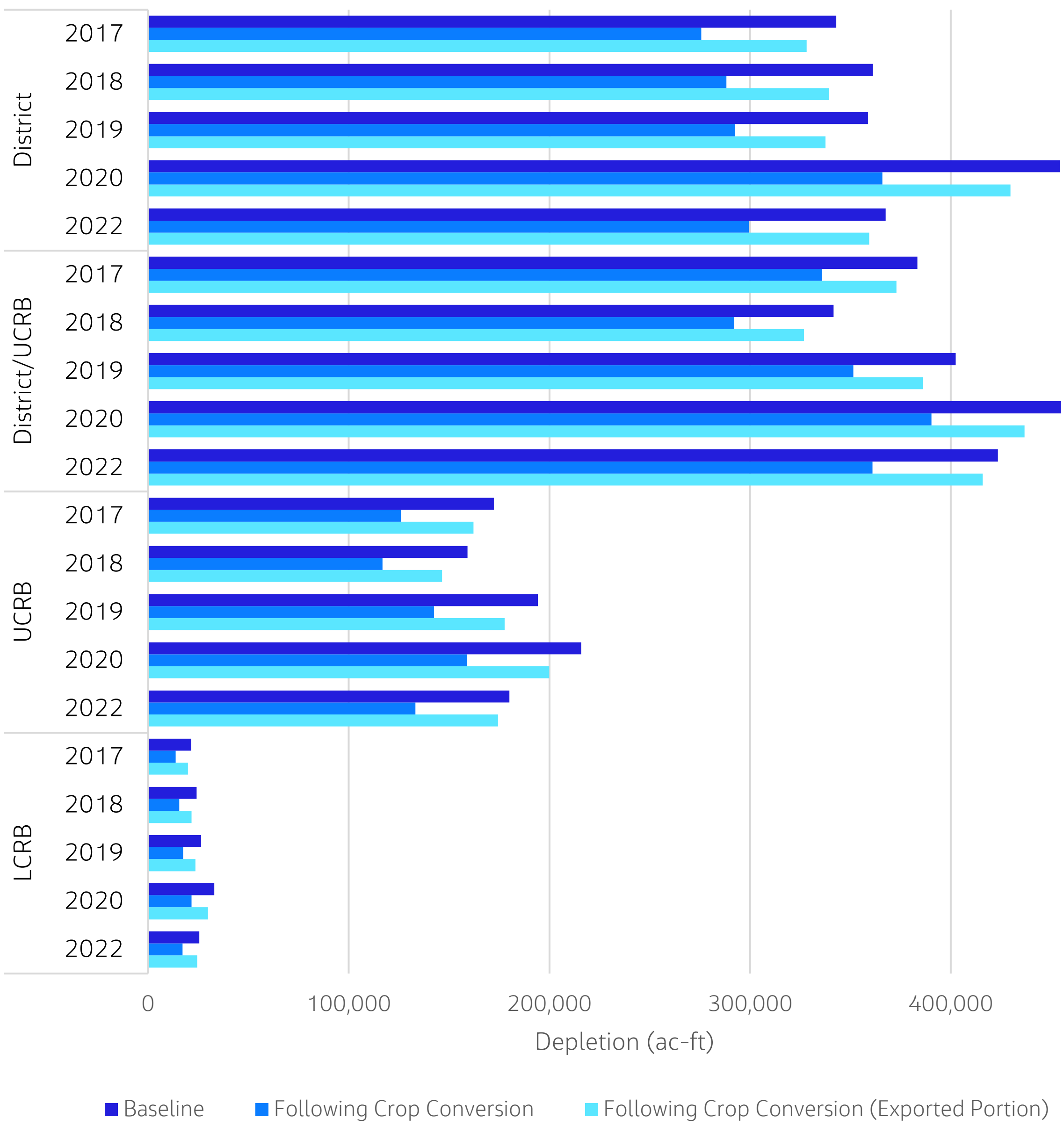
The study area opportunity for depletion reduction through conversion of all alfalfa and grass hay represents an 18-percent to 20-percent reduction in the estimated baseline depletion for water years 2017 through 2020 and 2022. Focusing strictly on the exported portion of alfalfa and grass hay crops, crop changes represents a 2-percent to 6-percent reduction in the estimated baseline depletion for water years 2017 through 2020 and 2022.

Table 12. Interest Area Depletions before and after Crop Conversion, Water Years 2017 through 2020

Interest Area	Depletion (acre-feet)				
	2017	2018	2019	2020	2022
District					
Baseline	343,024	361,217	358,736	454,520	367,530
Following crop conversion	275,709	288,169	292,598	365,932	299,363
Following crop conversion (exported portion)	328,214	339,303	337,571	429,715	359,350
District/UCRB					
Baseline	383,355	341,637	402,403	454,755	423,464
Following crop conversion	335,891	292,117	351,435	390,354	360,952
Following crop conversion (exported portion)	372,913	326,781	386,093	436,723	415,962
UCRB					
Baseline	172,355	159,223	194,306	215,895	180,094
Following crop conversion	126,032	116,807	142,501	158,942	133,224
Following crop conversion (exported portion)	162,164	146,498	177,729	199,948	174,470
LCRB					
Baseline	21,532	24,223	26,380	33,000	25,545
Following crop conversion	13,810	15,622	17,559	21,595	17,177
Following crop conversion (exported portion)	19,834	21,642	23,557	29,807	24,541
Baseline total	**920,266**	**886,300**	**981,825**	**1,158,170**	**996,633**
Following conversion total	**751,443**	**712,715**	**804,092**	**936,823**	**810,716**
Depletion reduction (percent)	**18**	**20**	**18**	**19**	**19**
Following conversion exported portion total	**883,125**	**834,224**	**924,951**	**1,096,193**	**974,323**
Depletion reduction exported portion (percent)	**4**	**6**	**6**	**5**	**2**

District = District service area lands falling outside the UCRB
District/UCRB = District service area lands within the UCRB
UCRB = UCRB lands falling outside the District's service area
LCRB = Lower Colorado River Basin lands (in Utah)

Figure 7. Interest Area Depletions before and after Crop Conversion, Water Years 2017 through 2020



Discussion

The estimations for depletion reduction through crop change presented herein are focused on conversions from alfalfa and grass hay to spring grain. If all alfalfa and grass hay crops are converted, a reduction of approximately 20 percent of study area depletions may be realized. As is the case for irrigation system conversions, changing crops include the following practical concerns that constrain the overall opportunity:

- **Producer needs**—Much forage grown in Utah is used within the state to support livestock, often used on the farm where it's grown. If farmers switch their livestock feed crop, then that feed needs to be replaced or livestock production decreased..

- **Crop demand—**Market demand has a role in choices made by producers with respect to crops grown. Producers grow crops that have demand to support their sale. Price and revenue generation are also considered.
- **Market location—**Similar to demand, producers consider the distance to market for the crops they grow. Considering spring grain, a grain elevator is needed within proximity of the farm where transportation doesn't become cost prohibitive.
- **Equipment—**Changing crops likely results in a need to replace current equipment with that needed to support new crop production. This requires capital investment and may require the producer to build knowledge in the operation of new equipment.
- **Producer risk—**Change is often accompanied by inherent risk. Changing crops may come with risk related to the considerations above and crop resilience to weather and crop's ability to thrive in the field's soil conditions.

Although other crop conversions are possible, conversion to spring grain was the focus of this study due to readily available information related to crops that are currently grown in Utah. Other options may exist but the considerations to change need to be understood. Lastly, exported forage has come under recent scrutiny in Utah (Maffly and Eddington 2022). Focusing crop changes on the exported portion of alfalfa and grass hay grown in the state was investigated. This may offer an opportunity to simultaneously improve public perception of agriculture in Utah and reduce agricultural water depletions. Results indicate that approximately a 5-percent reduction in depletion is possible, but this opportunity is particularly susceptible to water supply and market factors and results assume that the statewide percentage of internationally exported forage applies to the study area. In 2022, the opportunity for depletion reduction was estimated at just 2 percent due to drought conditions, associated lower crop production, and limited forage available for export.

3.2 Identify the Opportunity for Reduced Depletion on Marginal Lands

As introduced in the *Water Demand Analysis TM* (Jacobs 2024), lands identified as Class 6 and 7 in the National Resources Conservation Service Land Capability Classification datasets are of special interest to the District and the Authority. These lands may be better suited candidates for future agricultural water resiliency and demand management programs than the Class 1 through 5 lands due to these lands having the least suitability for cultivation aside from Class 8 lands, which are precluded from commercial plant production. The field-scale depletion estimates were intersected with the Land Capability Classification dataset (USDA 2016) to identify depletion occurring on these less suitable lands for cultivation. Table 13 summarizes the estimated depletion volume occurring on Class 6 and 7 lands within the study area and includes delineation of the subirrigated portion of these depletions. The largest opportunity for reduced depletion occurs on the actively irrigated fields, those that are not identified as subirrigated in the WRLU dataset.

3.3 Retrospective Depletion Analysis

In addition to identifying depletion reduction opportunities within the study area, this study sought to perform a retrospective analysis (or lookback) of actual changes in depletion caused by changes in irrigation method and crop type. Further, how these actual changes in depletion compare with the theoretical opportunity presented herein were evaluated. The retrospective analysis was performed at both the basin and field scales, and results are discussed in the following subsections.

Table 13. Baseline Depletion, Depletion on Actively Irrigated Lands, and Depletion on Subirrigated Lands on Land Capability Classification 6 and 7 Fields, Water Years 2017 through 2020

Interest Area	Baseline Depletion Totals on Land Capability Classification 6 and 7 Fields (acre-feet)			
	2017	2018	2019	2020
District	**7,073**	**7,341**	**8,070**	**10,578**
Actively irrigated	5,658	5,777	5,603	7,431
Subirrigated	1,415	1,564	2,467	3,146
District/UCRB	**58,951**	**42,943**	**59,709**	**65,832**
Actively irrigated	56,396	40,987	56,379	62,457
Subirrigated	2,554	1,956	3,330	3,375
UCRB	**17,671**	**14,949**	**19,963**	**21,743**
Actively irrigated	16,187	13,935	18,056	19,979
Subirrigated	1,484	1,014	1,907	1,764
LCRB	**0**	**0**	**0**	**0**
Actively irrigated	0	0	0	0
Subirrigated	0	0	0	0
Total	**83,695**	**65,233**	**87,742**	**98,153**
Total actively irrigated	**78,242**	**60,699**	**80,038**	**89,867**
Total subirrigated	**5,453**	**4,534**	**7,704**	**8,286**

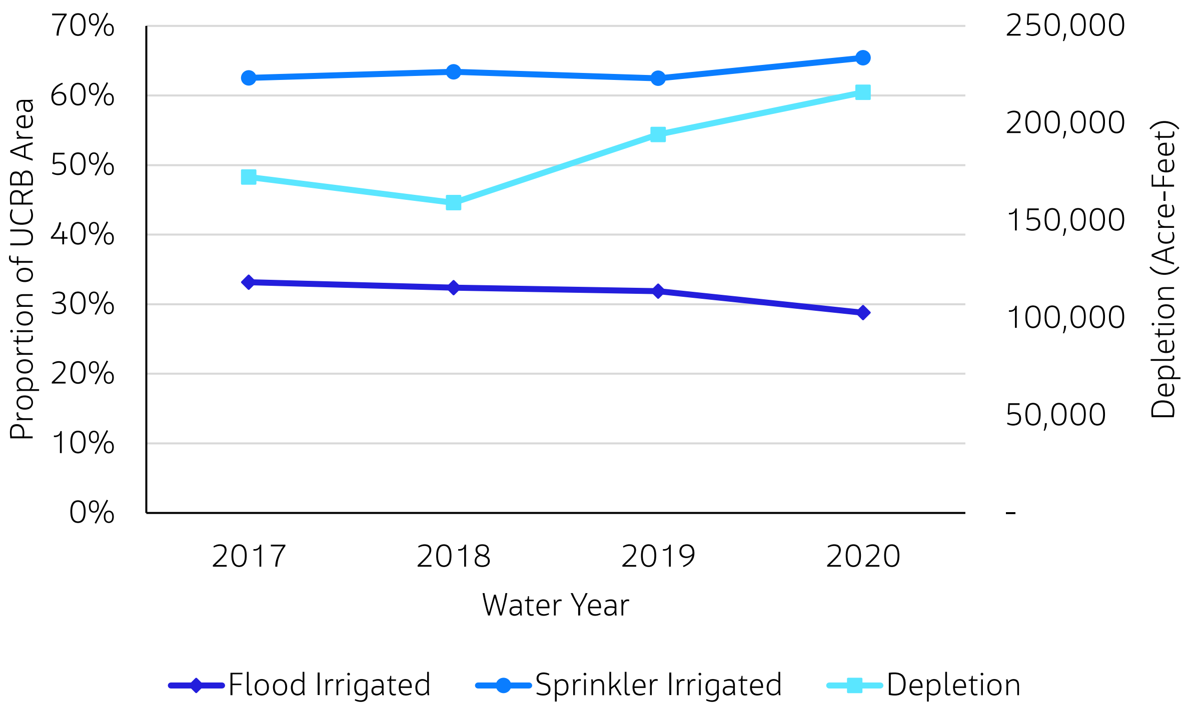
District = District service area lands falling outside the UCRB
District/UCRB = District service area lands within the UCRB
UCRB = UCRB lands falling outside the District's service area
LCRB = Lower Colorado River Basin lands (in Utah)

3.3.1 Basin Scale

The basin-scale retrospective analysis first sought to characterize changes in irrigation methods and crops grown within the study area across water years 2017 through 2020 to support the subsequent identification of trends resulting from these changes. A detailed review was performed for each interest area, District, District/UCRB, UCRB, and LCRB to identify any discernable trends in irrigation system conversions and crop changes for water years 2017 through 2020 (Appendix B provides additional details).

WRLU data indicates that declines in acreage proportions of flood (surface) and sprinkler irrigation methods were offset by increases in subirrigated proportions for all but the UCRB interest area for water years 2017 through 2020. Conversions to the subirrigated irrigation method is likely caused by a field attribute change by the UDWRe based on a site inspection. These changes are not investigated further for resulting changes in depletion. An apparent conversion of 3 percent of UCRB field area from flood (surface) to sprinkler was identified, with the remaining 1.5-percent conversion of flood (surface) area to subirrigated area. Figure 8 illustrates this proportional change in irrigated area from flood (surface) to sprinkler along with estimated UCRB depletion (Jacobs 2024) across the same period. The variability in depletion across water years 2017 through 2020 indicates no trend or correlation is apparent between the changes in irrigation method from flood (surface) to sprinkler and resulting depletion. Further, and for the same reason, no apparent trend or correlation between the changes in crop type and resulting depletion are expected.

Figure 8. Proportion of Acreage by Irrigation Method across Water Years 2017 through 2020 Compared with Depletion for the Upper Colorado River Basin Interest Area



3.3.2 Field Scale

The field-scale retrospective analysis is an attempt to characterize depletion changes associated with fields that underwent an irrigation conversion or a crop conversion in the 2017 through 2020 period of record. To identify fields that were appropriate to include in the retrospective analysis, the 2017 through 2020 WRLU datasets were spatially joined and subsequently screened using multiple criteria in an attempt to isolate the effects of irrigation and crop conversions on field-scale depletion totals. Data screening criteria serve to produce statistical analyses that better represent true depletion changes due to conversion rather than depletion changes due to external factors such as hydrologic or meteorological variability.

A spatial join of WRLU datasets was needed to establish a unique identifier for each field that was consistent over time. This allowed for a direct evaluation of irrigation methods and crop descriptions at each field. Using a 0.01-acre tolerance for the spatial join of WRLU files (2017 through 2020) resulted in a loss of 17 percent of the records in the 2017 data (18-percent loss by area), with the majority of that loss occurring on the first spatial join of 2017 to 2018. WRLU data layers had been previously filtered to remove any fallow/idle lands, meaning if a field was fallowed between 2017 through 2020, then it was removed from the final joined layer, even if it was later cultivated.

The resulting spatially joined dataset was further screened to identify fields with 3 consecutive years of an irrigation or crop conversion to provide the best opportunity to interpret a resulting trend in depletion. For irrigation system conversions, the crop description had to have stayed the same in all 4 years of data to allow for an 'apples-to-apples' comparison of depletion totals.

Screening by the following criteria, using attribute data in the WRLU datasets, resulted in only 25 fields for the retrospective field-scale analysis:

- Conversion from flood (surface) to drip for 3 consecutive years (0 records)
- Conversion from sprinkler to drip for 3 consecutive years (0 records)

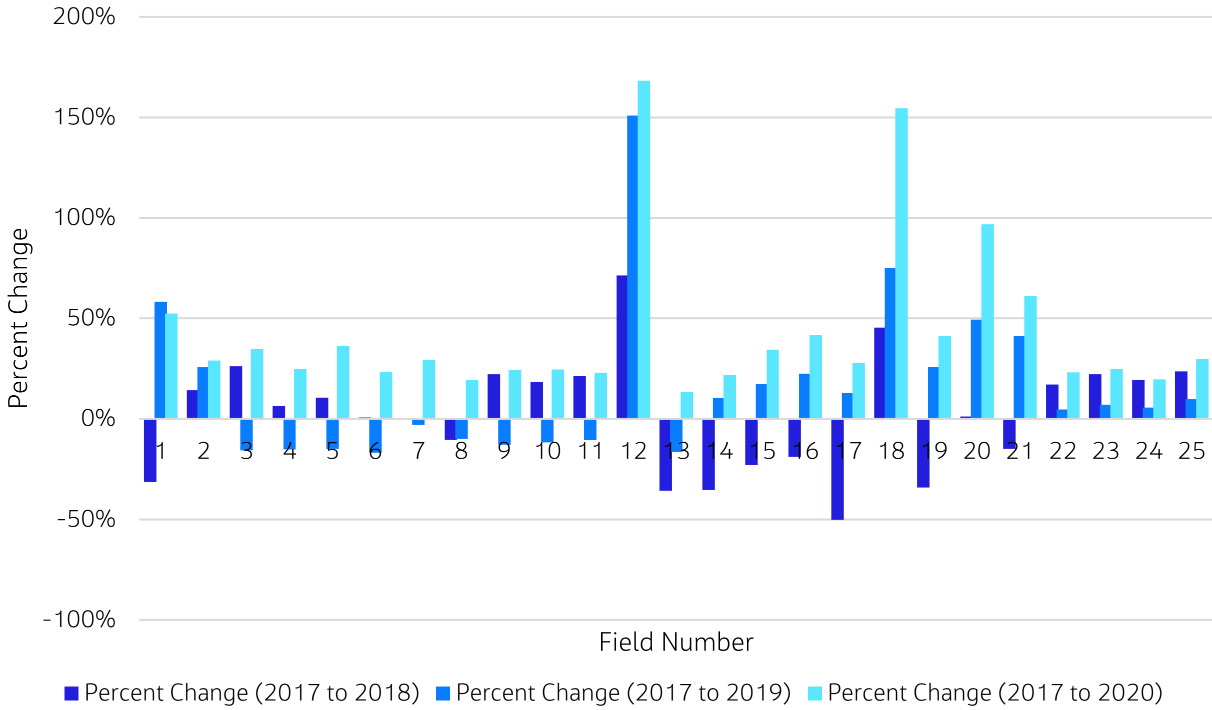
- Conversion from flood (surface) to sprinkler (36 records):
  - Consistent crop description in all 4 years (21 records in UCRB, 4 records in District/UCRB, for a total of 25 records)
  - Conversion from alfalfa to spring grain for 3 consecutive years (0 records)
  - Conversion from grass hay to spring grain (0 records)

The expected depletion change associated with the conversion from surface (assumed to be basin/border) irrigation to sprinkler (assumed to be pivot/lateral MESA) irrigation is between 0 and 1 percent (rounded down to 0 in Table 5), a change too small to attribute (with any significance) to irrigation conversion, even after removing covariate effects such as site-specific soil moisture, precipitation, and water management considerations. A detailed statistical analysis such as this would be outside the scope and purpose of this TM and was, therefore, not pursued. However, depletion data from the 25 fields that converted from flood (surface, assumed to be basin/border) irrigation to sprinkler (assumed to be pivot/lateral MESA) irrigation were evaluated with an aim to identify changes in field-scale depletion totals between 2017 and 2020.

For each field, a percent change was calculated between baseline depletion (2017) and depletion following conversion (2018, 2019, and 2020), Figure 9 provides these results. On average, depletion volumes changed by ±23 percent between 2017 and 2018, ±26 percent between 2017 and 2019, and +43 percent between 2017 and 2020. Depletion at all fields increased by an average 43 percent between 2017 and 2020. Thus, Figure 9 illustrates that annual field-scale depletion is highly variable. No apparent trends in depletion can be attributed to conversion from flood (surface) to sprinkler irrigation for two main reasons: (1) estimated depletion change resulting from a conversion from surface (assumed to be basin/border) to sprinkler (assumed to be pivot/lateral MESA) (approximately 0 percent) is too small to be accurately detected using the available data, and (2) site-specific administrative controls and climate variability influence annual depletion more than conversion from surface (basin/border) to sprinkler (pivot/lateral MESA). Additional field-scale depletion data are needed at fields that underwent an irrigation system conversion from sprinkler (assumed to be pivot/lateral MESA) to drip (assumed to be SDI) (expected depletion change of -29 percent) to inform the discussion.

No crop conversions from alfalfa to spring grain or grass hay to spring grain were identified. However, crop conversions occurring on subirrigated fields were evaluated as part of the field-scale retrospective; 2,633 individual subirrigated fields were in the spatially joined WRLU data files (2017 through 2020). Of the 2,633 subirrigated fields, 748 grew grass hay the whole time and 1,872 fields were pasture the whole time. Four fields converted from grass hay to pasture for 3 consecutive years and nine fields converted from pasture to grass hay for 3 consecutive years. Estimated depletion between these two crop types is similar, with an estimated difference in depletion of approximately 5 percent. The investigation into depletion changes occurring as a result of crop changes on subirrigated lands was not pursued further because of insufficient data quantity (grass hay to pasture [n=4] and pasture to grass hay [n=9]) and reasons discussed above: that external factors like climate and water management have a larger effect on annual depletion variability.

Figure 9. Percent Change in Depletion Following Irrigation Conversion from Flood (Surface) to Sprinkler Irrigation at 25 Individual Fields in the UCRB



3.4 Summarize the Opportunity for Reduced Depletion Results from Task Orders No. 1 and No. 2

The opportunity to reduce agricultural depletion in TO1 largely focused on reducing the unrecoverable (evaporative) losses of on-farm application of irrigation water within the District's service area. These losses aggregate to approximately 73 kaf of opportunity within the District or approximately 10 percent of the total estimated depletion.

The opportunity analysis performed in TO2, and detailed herein, included a more detailed investigation into likely depletion changes resulting from irrigation system conversions. This detailed investigation incorporated the latest irrigation system efficiency and loss information (Table 2), relevant methodology from USU's recently released Irrigation Conversion Water Savings Destination Calculator (USU 2024), and relevant reports related to SDI conversions (Montazar 2020, Lamm 2016). As a result of this analysis, the opportunity to reduce agricultural depletion through irrigation system conversions was determined to grow to greater than 20 percent of the estimated agricultural depletion within the (expanded) TO2 study area, or approximately 222 kaf across the water years 2017 through 2020 investigated.

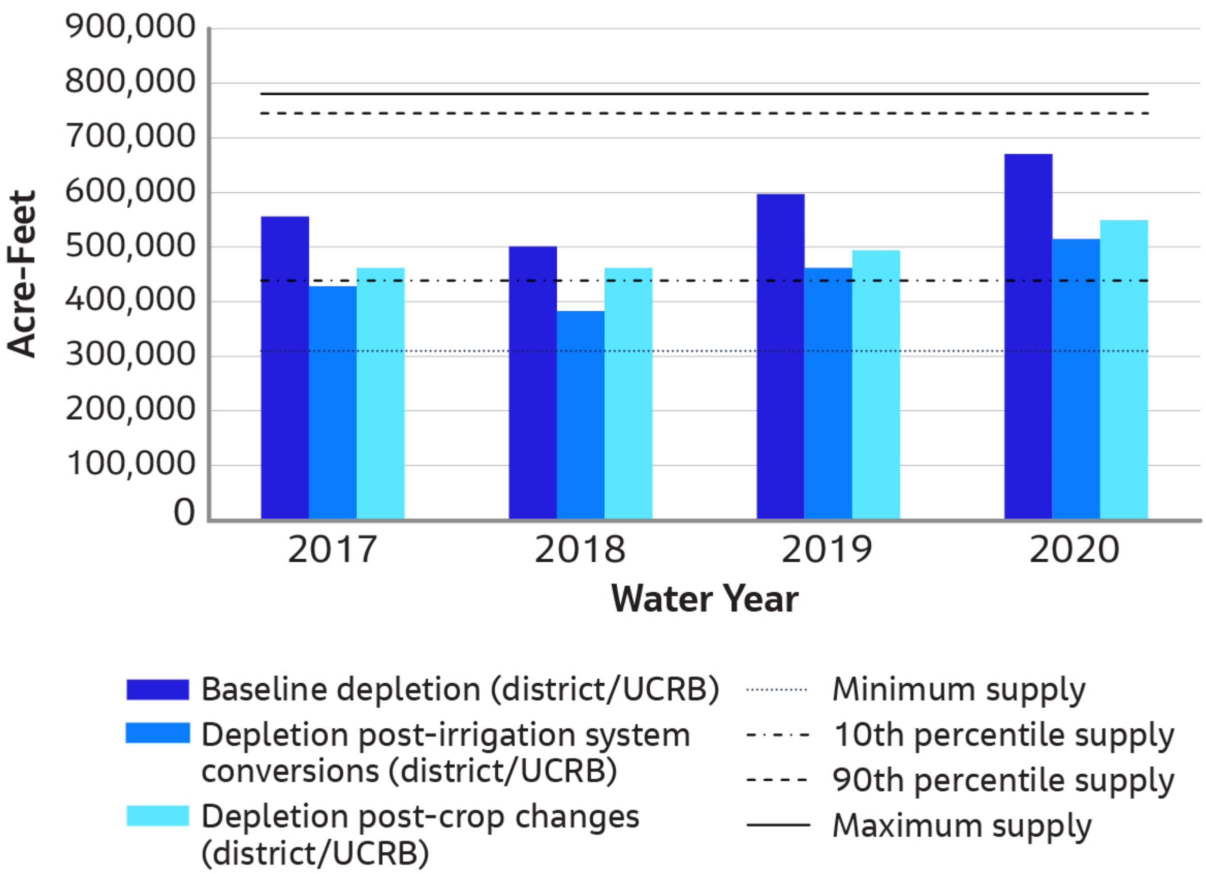
TO2 additionally investigated the opportunity to reduce depletion through crop changes, specifically through changing from alfalfa and grass hay to spring grain. This opportunity was determined to be less than 20 percent of the total depletion and approximately 185 kaf across the study area.

3.5 Compare Opportunity for Depletion Reduction to Study Area Supply and Demand Results from Subtasks 2.1 and 2.2

The final activity of the Subtask 2.3, Quantify the Possible, is a review of how the opportunities for reduced depletion in the study area relate to the available supply and the agricultural depletion estimated in previous subtasks. Subtask 2.2 concluded with a summary of historical agricultural depletion from both the WBM and remote sensing-based results with Colorado River Simulation System (CRSS) modeled future estimated agricultural depletions overlayed to indicate the potential for future supply shortages to agriculture in the UCRB. Building on this previous summary, the most appropriate data for comparison here are a summary of 2017 through 2020 agricultural depletions, opportunities to reduce depletion through irrigation system conversions and crop changes, and future estimated agricultural depletions as modeled by CRSS for the UCRB to illustrate how opportunities to reduce depletion may alleviate future water supply shortages to agriculture. Importantly, a focus on the UCRB is needed here to incorporate CRSS model results of projected future supply to agriculture.

Figure 10 provides a side-by-side comparison of these aforementioned datasets. CRSS modeled future estimated agricultural depletions include the minimum, 10th percentile, 90th percentile, and maximum depletion volumes based on projected available supply to using the Coupled Model Intercomparison Project Phase 3 multimodal dataset (WCRP 2007).

Figure 10. Summary of Baseline Depletion and Resulting Depletion Following Irrigation System Conversions and Crop Changes for 2017 through 2020 Water Years Overlayed with Future Estimated Agricultural Depletions Sourced by UCRB Water Supply (minimum, 10th percentile, 90th percentile, and maximum supply to agriculture based on CRSS CMIP3 model results)



A comparison of potential future agricultural depletions sourced by UCRB water supply modeled in CRSS and estimated agricultural depletions pre- and post-reduction through irrigation system conversion and crop changes from remotely sensed methods indicate future supplies are likely adequate to serve agricultural demands during wet years and hydrologic shortage will likely prevent the baseline historical depletions from being fulfilled in dry years. Figure 10 illustrates that reducing agricultural depletion through irrigation system conversions and crop changes reduce supply shortage risk but on average, results for water years 2017 through 2020 indicate that shortages may still occur under the 10th percentile and minimum supply scenarios, based on the model results presented.

Although supply shortage to agriculture is possible in the 10th percentile case and expected in the minimum supply case, reducing agricultural depletion through irrigation system conversion and crop changes increases the volume of water supply that may be provided to a downstream beneficial use such as system storage, reducing risk of supply shortage to agriculture in future years. Thus efforts to reduce agricultural depletion are recommended to improve resiliency for both producers and the District and Authority alike.

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Appendix A
Depletion Calculation Details

Appendix A. Depletion Calculation Details

Figure A-1. Conversion from Surface (Basin/Border) to Sprinkler (Pivot/Lateral MESA)

(green)	Assumptions gathered from literature sources
(yellow)	Calculated values
(blue)	Inputs from field scale depletion model

Assumptions

Efficiencies and Losses[a]

	Efficiency	Loss Fractions			
		DP	WDE	RO	Fraction Unrecoverable Losses
Basin	80%	1	0	0	0.000
Border	78%	0.90	0	0.10	0.002
Combined Basin/Border	79%	0.95	0	0.05	0.001
Pivot MESA	78%	0.05	0.95	0.00	0.209

Sprinkler WDE[b]	12%
Reduction in Irrigated Area[c]	21%
Yield Improvement[d]	10%

Conversion Calculations

	From: Basin/Border	To: MESA	%Change[e]
Field Size (ac)	160	⑦ 126	
Application Efficiency	79%	78%	
Unrecoverable Losses	0%	12%	
Recoverable Losses	21%	10%	
Applied Water (ac-ft)	① 316	⑨ 277	⑬ -12%
ET Applied Water (ac-ft)	② 250	⑧ 216	
ET Applied Water (in)	③ 18.7	⑥ 20.6	
Recovered Water (ac-ft)	④ 66	⑩ 28	
Unrecovered Water (ac-ft)	⑤ 0	⑪ 33	
Total Depletion (ac-ft)	250	⑫ 249	⑭ 0%

Sources & Notes:

[a] http://irrigation.wsu.edu/Content/ConversionCalculator.html

[b] Sprinkler WDE capped at 12% per Quantify the Possible (Jacobs, 2023), in alignment with Consumptive Use of Irrigated Crops in Utah (Hill, 1998). Leads to unrecoverable losses in the converted condition to equal 12%

[c] Assumed reduction due to not irrigating corners when pivot placed on square field

[d] Assumption based upon yield data included in O'Brien, Lamm, Stone, Rogers (2000), Ehlig, Hagemann (1980), and Sanden, Klonsky, Putnam, Schwankl, Putnam (2011). Yield varies linearly with ET Applied Water (Lamm 2016).

[e] Negative percent change represents a reduction

Calculation Details:

Note: unless specified, convert from equations are utilizing values from the convert from column; convert to equations are using values from the convert to column.

Convert From:

① $\text{Applied Water (ac-ft)} = \frac{\text{Total Depletion (ac-ft)}}{\text{Application Efficiency (\%)} + \text{Unrecoverable Losses (\%)}}$

② $\text{ET Applied Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Application Efficiency}$

③ $\text{ET Applied Water (in)} = \frac{\text{Applied Water (ac-ft)} * 12(\frac{in}{ft})}{\text{Field Size (ac)}}$

④ $\text{Recovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Recoverable Losses (\%)}$

⑤ $\text{Unrecoverd Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Unrecoverable Losses (\%)}$

Convert To:

⑥ $\text{ET Applied Water (in)} = \text{Convert From ET Applied Water (in)} * (1 + \text{Yield Improvement (\%)})$

⑦ $\text{Field Size (ac)} = \text{Convert From Field Size (ac)} * (1 - \text{Reduction in Irrigated Area (\%)})$

⑧ $\text{ET Applied Water (ac-ft)} = \frac{\text{ET Applied Water (in)}}{12\,(\frac{in}{ft})} * \text{Field Size (ac)}$

⑨ $\text{Applied Water (ac-ft)} = \frac{\text{ET Applied Water (ac-ft)}}{\text{Application Efficiency (\%)}}$

⑩ $\text{Recovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Recoverable Losses (\%)}$

⑪ $\text{Unrecovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Unrecoverable Losses (\%)}$

⑫ $\text{Total Depletion (ac-ft)} = \text{ET Applied Water (ac-ft)} + \text{Unrecovered Water (ac-ft)}$

Percent Change:

⑬ $\text{Percent Change Applied Water (\%)} = -\left(1 - \left(\frac{\text{Convert To Applied Water (ac-ft)}}{\text{Convert From Applied Water (ac-ft)}}\right)\right)$

⑭ $\text{Percent Change Total Depletion(\%)} = -\left(1 - \left(\frac{\text{Convert To Total Depletion(ac-ft)}}{\text{Convert From Total Depletion(ac-ft)}}\right)\right)$

Figure A-2. Conversion from Surface (Basin/Border) to Sprinkler (Pivot/Lateral LEPA)

	Assumptions gathered from literature sources
	Calculated values
	Inputs from field scale depletion model

Assumptions

Efficiencies and Losses[a]

		Loss Fractions			
	Efficiency	DP	WDE	RO	Fraction Unrecoverable Losses
Basin	80%	1	0	0	0.000
Border	78%	0.90	0	0.10	0.002
Combined Basin/Border	79%	0.95	0	0.05	0.001
Pivot LEPA	86%	0.10	0.90	0.00	0.126

Sprinkler WDE[b]	12%
Reduction in Irrigated Area[c]	21%
Yield Improvement[d]	10%

Conversion Calculations

	From: Basin/Border	To: LEPA	%Change[e]
Field Size (ac)	160	⑦ 126	
Application Efficiency	79%	86%	
Unrecoverable Losses	0%	12%	
Recoverable Losses	21%	2%	
Applied Water (ac-ft)	① 316	⑨ 251	⑬ -21%
ET Applied Water (ac-ft)	② 250	⑧ 216	
ET Applied Water (in)	③ 18.7	⑥ 20.6	
Recovered Water (ac-ft)	④ 66	⑩ 5	
Unrecovered Water (ac-ft)	⑤ 0	⑪ 30	
Total Depletion (ac-ft)	250	⑫ 246	⑭ -2%

Sources & Notes:

[a] http://irrigation.wsu.edu/Content/ConversionCalculator.html

[b] Sprinkler WDE capped at 12% per Quantify the Possible (Jacobs, 2023), in alignment with Consumptive Use of Irrigated Crops in Utah (Hill, 1998). Leads to unrecoverable losses in the converted condition to equal 12%

[c] Assumed reduction due to not irrigating corners when pivot placed on square field

[d] Assumption based upon yield data included in O'Brien, Lamm, Stone, Rogers (2000), Ehlig, Hagemann (1980), and Sanden, Klonsky, Putnam, Schwankl, Putnam (2011). Yield varies linearly with ET Applied Water (Lamm 2016).

[e] Negative percent change represents a reduction

Calculation Details:

Note: unless specified, convert from equations are utilizing values from the convert from column; convert to equations are using values from the convert to column.

Convert From:

① $\text{Applied Water (ac-ft)} = \frac{\text{Total Depletion (ac-ft)}}{\text{Application Efficiency (\%)} + \text{Unrecoverable Losses (\%)}}$

② $\text{ET Applied Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Application Efficiency}$

③ $\text{ET Applied Water (in)} = \frac{\text{Applied Water (ac-ft)} * 12(\frac{\text{in}}{\text{ft}})}{\text{Field Size (ac)}}$

④ $\text{Recovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Recoverable Losses (\%)}$

⑤ $\text{Unrecoverd Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Unrecoverable Losses (\%)}$

Convert To:

⑥ $\text{ET Applied Water (in)} = \text{Convert From ET Applied Water (in)} * (1 + \text{Yield Improvement (\%)})$

⑦ $\text{Field Size (ac)} = \text{Convert From Field Size (ac)} * (1 - \text{Reduction in Irrigated Area (\%)})$

⑧ $\text{ET Applied Water (ac-ft)} = \frac{\text{ET Applied Water (in)}}{12\ (\frac{\text{in}}{\text{ft}})} * \text{Field Size (ac)}$

⑨ $\text{Applied Water (ac-ft)} = \frac{\text{ET Applied Water (ac-ft)}}{\text{Application Efficiency (\%)}}$

⑩ $\text{Recovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Recoverable Losses (\%)}$

⑪ $\text{Unrecovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Unrecoverable Losses (\%)}$

⑫ $\text{Total Depletion (ac-ft)} = \text{ET Applied Water (ac-ft)} + \text{Unrecovered Water (ac-ft)}$

Percent Change:

⑬ $\text{Percent Change Applied Water (\%)} = -(1 - (\frac{\text{Convert To Applied Water (ac-ft)}}{\text{Convert From Applied Water (ac-ft)}}))$

⑭ $\text{Percent Change Total Depletion(\%)} = -(1 - (\frac{\text{Convert To Total Depletion(ac-ft)}}{\text{Convert From Total Depletion(ac-ft)}}))$

Figure A-3. Conversion from Surface (Basin/Border) to Sprinkler (Pivot/Lateral LESA)

(green)	Assumptions gathered from literature sources
(yellow)	Calculated values
(blue)	Inputs from field scale depletion model

Assumptions

Efficiencies and Losses[a]

		Loss Fractions			
	Efficiency	DP	WDE	RO	Fraction Unrecoverable Losses
Basin	80%	1	0	0	0.000
Border	78%	0.90	0	0.10	0.002
Combined Basin/Border	79%	0.95	0	0.05	0.001
Pivot LESA	90%	0.05	0.95	0.00	0.095

Reduction in Irrigated Area[b]	21%
Yield Improvement[c]	10%

Conversion Calculations

	From: Basin/Border	To: LESA	%Change[d]
Field Size (ac)	160	⑦ 126	
Application Efficiency	79%	90%	
Unrecoverable Losses	0%	10%	
Recoverable Losses	21%	1%	
Applied Water (ac-ft)	① 316	⑨ 240	⑬ -24%
ET Applied Water (ac-ft)	② 250	⑧ 216	
ET Applied Water (in)	③ 18.7	⑥ 20.6	
Recovered Water (ac-ft)	④ 66	⑩ 1	
Unrecovered Water (ac-ft)	⑤ 0	⑪ 23	
Total Depletion (ac-ft)	250	⑫ 238	⑭ -5%

Sources & Notes:

[a] http://irrigation.wsu.edu/Content/ConversionCalculator.html

[b] Assumed reduction due to not irrigating corners when pivot placed on square field

[c] Assumption based upon yield data included in O'Brien, Lamm, Stone, Rogers (2000), Ehlig, Hagemann (1980), and Sanden, Klonsky, Putnam, Schwankl, Putnam (2011). Yield varies linearly with ET Applied Water (Lamm 2016).

[d] Negative percent change represents a reduction

Calculation Details:

Note: unless specified, convert from equations are utilizing values from the convert from column; convert to equations are using values from the convert to column.

Convert From:

① $\text{Applied Water (ac-ft)} = \frac{\text{Total Depletion (ac−ft)}}{\text{Application Efficiency (\%)+Unrecoverable Losses (\%)}}$

② $\text{ET Applied Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Application Efficiency}$

③ $\text{ET Applied Water (in)} = \frac{\text{Applied Water (ac−ft)} * 12 (\frac{in}{ft})}{\text{Field Size (ac)}}$

④ $\text{Recovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Recoverable Losses (\%)}$

⑤ $\text{Unrecoverd Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Unrecoverable Losses (\%)}$

Convert To:

⑥ $\text{ET Applied Water (in)} = \text{Convert From ET Applied Water (in)} * (1+ \text{Yield Improvement (\%)})$

⑦ $\text{Field Size (ac)} = \text{Convert From Field Size (ac)} * (1- \text{Reduction in Irrigated Area (\%)})$

⑧ $\text{ET Applied Water (ac-ft)} = \frac{\text{ET Applied Water (in)}}{12 (\frac{in}{ft})} * \text{Field Size (ac)}$

⑨ $\text{Applied Water (ac-ft)} = \frac{\text{ET Applied Water (ac−ft)}}{\text{Application Efficiency (\%)}}$

⑩ $\text{Recovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Recoverable Losses (\%)}$

⑪ $\text{Unrecovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Unrecoverable Losses (\%)}$

⑫ $\text{Total Depletion (ac-ft)} = \text{ET Applied Water (ac-ft)} + \text{Unrecovered Water (ac-ft)}$

Percent Change:

⑬ $\text{Percent Change Applied Water (\%)} = -(1 - (\frac{\text{Convert To Applied Water (ac−ft)}}{\text{Convert From Applied Water (ac−ft)}}))$

⑭ $\text{Percent Change Total Depletion(\%)} = -(1 - (\frac{\text{Convert To Total Depletion(ac−ft)}}{\text{Convert From Total Depletion(ac−ft)}}))$

Figure A-4. Conversion from Surface (Basin/Border) to Subsurface Drip Irrigation

(green)	Assumptions gathered from literature sources
(yellow)	Calculated values
(blue)	Inputs from field scale depletion model

Assumptions

Efficiencies and Losses[a]

		Loss Fractions			
	Efficiency	DP	WDE	RO	Fraction Unrecoverable Losses
Basin	80%	1	0	0	0.000
Border	78%	0.90	0	0.10	0.002
Combined Basin/Border	79%	0.95	0	0.05	0.001
SDI	98%	1.00	0.00	0.00	0.000

Yield Improvement[b]	25%
Reduction in Irrigated Area[c]	20%
Water Productivity Improvement[d]	22%
Precipitation (in)[e]	0.0

	Yield (ton/ac)
Basin/Border[f]	3.93
SDI[g]	4.91

Conversion Calculations

	From: Basin/Border	To: SDI	%Change[h]
Yield (ton/ac)	3.93	4.91	
Water Productivity (ton/in)	⑥ 0.210	⑦ 0.255	
Field Size (ac)	160	⑧ 128	
Application Efficiency	79%	98%	
Unrecoverable Losses	0%	0%	
Recoverable Losses	21%	2%	
Applied Water (ac-ft)	① 316	⑪ 209	⑮ -34%
ET Applied Water (ac-ft)	② 250	⑩ 205	
ET Applied Water (in)	③ 18.7	⑨ 19.2	
Recovered Water (ac-ft)	④ 66	⑫ 4	
Unrecovered Water (ac-ft)	⑤ 0	⑬ 0	
Total Depletion (ac-ft)	250	⑭ 205	⑯ -18%

Sources & Notes:

[a] http://irrigation.wsu.edu/Content/ConversionCalculator.html

[b] Per Montazar (2020)

[c] Assumed field production held constant. Calculated from field sizes in Conversion Calculations.

[d] Per Montazar (2020)

[e] Precipitation has negligible impact on results at typical values for study area, assumed zero.

[f] Yield data based on data from National Agricultural Statistics Service

[g] 25% yield improvement over gravity per Montazar (2020)

[h] Negative percent change represents a reduction

Calculation Details:

Note: unless specified, convert from equations are utilizing values from the convert from column; convert to equations are using values from the convert to column.

Convert From:

① $\text{Applied Water (ac-ft)} = \frac{\text{Total Depletion (ac-ft)}}{\text{Application Efficiency (\%)} + \text{Unrecoverable Losses (\%)}}$

② $\text{ET Applied Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Application Efficiency}$

③ $\text{ET Applied Water (in)} = \frac{\text{Applied Water (ac-ft)} * 12 (\frac{in}{ft})}{\text{Field Size (ac)}}$

④ $\text{Recovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Recoverable Losses (\%)}$

⑤ $\text{Unrecoverd Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Unrecoverable Losses (\%)}$

⑥ $\text{Water Productivity (ton/in)} = \frac{\text{Yield (ton/ac)}}{\text{ET Applied Water (in)} + (0.8 * \text{Precipitation (in)})}$

Convert To:

⑦ $\text{Water Productivity (ton/in)} = \text{Convert From Water Productivity (ton/in)} * (1 + \text{Water Productivity Improvement (\%)})$

⑧ $\text{Field Size (ac)} = \text{Convert From Field Size (ac)} * \frac{\text{Convert From Yield (ton/ac)}}{\text{Convert To Yield (ton/ac)}}$

⑨ $\text{ET Applied Water (in)} = \frac{\text{Yield (ton/ac)}}{\text{Water Productivity (ton/in)}} - (0.8 * \text{Precipitation (in)})$

⑩ $\text{ET Applied Water (ac-ft)} = \frac{\text{ET Applied Water (in)}}{12 (\frac{in}{ft})} * \text{Field Size (ac)}$

⑪ $\text{Applied Water (ac-ft)} = \frac{\text{ET Applied Water (ac-ft)}}{\text{Application Efficiency (\%)}}$

⑫ $\text{Recovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Recoverable Losses (\%)}$

⑬ $\text{Unrecovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Unrecoverable Losses (\%)}$

⑭ $\text{Total Depletion (ac-ft)} = \text{ET Applied Water (ac-ft)} + \text{Unrecovered Water (ac-ft)}$

Percent Change:

⑮ $\text{Percent Change Applied Water (\%)} = -(1 - (\frac{\text{Convert To Applied Water (ac-ft)}}{\text{Convert From Applied Water (ac-ft)}}))$

⑯ $\text{Percent Change Total Depletion(\%)} = -(1 - (\frac{\text{Convert To Total Depletion(ac-ft)}}{\text{Convert From Total Depletion(ac-ft)}}))$

Figure A-5. Conversion from Sprinkler (Pivot/Lateral MESA) to Sprinkler (Pivot/Lateral LEPA)

(green)	Assumptions gathered from literature sources
(yellow)	Calculated values
(blue)	Inputs from field scale depletion model

Assumptions

Efficiencies and Losses[a]

		Loss Fractions			
	Efficiency	DP	WDE	RO	Fraction Unrecoverable Losses
Pivot MESA	78%	0.05	0.95	0.00	0.209
Pivot LEPA	86%	0.10	0.90	0.00	0.126

Sprinkler WDE[b]	12%
Reduction in Irrigated Area[c]	0%
Yield Improvement	0%

Conversion Calculations

	From: MESA	To: LEPA	%Change[d]
Field Size (ac)	160	7 160	
Application Efficiency	78%	86%	
Unrecoverable Losses	12%	12%	
Recoverable Losses	10%	2%	
Applied Water (ac-ft)	1 333	9 302	13 -9%
ET Applied Water (ac-ft)	2 260	8 260	
ET Applied Water (in)	3 19.5	6 19.5	
Recovered Water (ac-ft)	4 33	10 6	
Unrecovered Water (ac-ft)	5 40	11 36	
Total Depletion (ac-ft)	300	12 296	14 -1%

Sources & Notes:

[a] http://irrigation.wsu.edu/Content/ConversionCalculator.html

[b] Sprinkler WDE capped at 12% per Quantify the Possible (Jacobs, 2023), in alignment with Consumptive Use of Irrigated Crops in Utah (Hill, 1998). Leads to unrecoverable losses in the converted condition to equal 12%

[c] Assume yield with LEPA consistent with MESA

[d] Negative percent change represents a reduction

Calculation Details:

Note: unless specified, convert from equations are utilizing values from the convert from column; convert to equations are using values from the convert to column.

Convert From:

1 $\text{Applied Water (ac-ft)} = \frac{\text{Total Depletion (ac-ft)}}{\text{Application Efficiency (\%)} + \text{Unrecoverable Losses (\%)}}$

2 $\text{ET Applied Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Application Efficiency}$

3 $\text{ET Applied Water (in)} = \frac{\text{Applied Water (ac-ft)} * 12(\frac{\text{in}}{\text{ft}})}{\text{Field Size (ac)}}$

4 $\text{Recovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Recoverable Losses (\%)}$

5 $\text{Unrecoverd Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Unrecoverable Losses (\%)}$

Convert To:

6 $\text{ET Applied Water (in)} = \text{Convert From ET Applied Water (in)} * (1 + \text{Yield Improvement (\%)})$

7 $\text{Field Size (ac)} = \text{Convert From Field Size (ac)} * (1 - \text{Reduction in Irrigated Area (\%)})$

8 $\text{ET Applied Water (ac-ft)} = \frac{\text{ET Applied Water (in)}}{12\,(\frac{\text{in}}{\text{ft}})} * \text{Field Size (ac)}$

9 $\text{Applied Water (ac-ft)} = \frac{\text{ET Applied Water (ac-ft)}}{\text{Application Efficiency (\%)}}$

10 $\text{Recovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Recoverable Losses (\%)}$

11 $\text{Unrecovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Unrecoverable Losses (\%)}$

12 $\text{Total Depletion (ac-ft)} = \text{ET Applied Water (ac-ft)} + \text{Unrecovered Water (ac-ft)}$

Percent Change:

13 $\text{Percent Change Applied Water (\%)} = -(1 - (\frac{\text{Convert To Applied Water (ac-ft)}}{\text{Convert From Applied Water (ac-ft)}}))$

14 $\text{Percent Change Total Depletion(\%)} = -(1 - (\frac{\text{Convert To Total Depletion(ac-ft)}}{\text{Convert From Total Depletion(ac-ft)}}))$

Figure A-6. Conversion from Sprinkler (Pivot/Lateral MESA) to Sprinkler (Pivot/Lateral LESA)

(green)	Assumptions gathered from literature sources
(yellow)	Calculated values
(blue)	Inputs from field scale depletion model

Assumptions

Efficiencies and Losses[a]

		Loss Fractions			
	Efficiency	DP	WDE	RO	Fraction Unrecoverable Losses
Pivot MESA	78%	0.05	0.95	0.00	0.209
Pivot LESA	90%	0.05	0.95	0.00	0.095

Sprinkler WDE[b]	12%
Reduction in Irrigated Area[c]	0%
Yield Improvement	0%

Conversion Calculations

	From: MESA	To: LESA	%Change[d]
Field Size (ac)	160	⑦ 160	
Application Efficiency	78%	90%	
Unrecoverable Losses	12%	10%	
Recoverable Losses	10%	1%	
Applied Water (ac-ft)	① 333	⑨ 289	⑬ -13%
ET Applied Water (ac-ft)	② 260	⑧ 260	
ET Applied Water (in)	③ 19.5	⑥ 19.5	
Recovered Water (ac-ft)	④ 33	⑩ 1	
Unrecovered Water (ac-ft)	⑤ 40	⑪ 27	
Total Depletion (ac-ft)	300	⑫ 287	⑭ -4%

Sources & Notes:

[a] http://irrigation.wsu.edu/Content/ConversionCalculator.html

[b] Sprinkler WDE capped at 12% per Quantify the Possible (Jacobs, 2023), in alignment with Consumptive Use of Irrigated Crops in Utah (Hill, 1998). Leads to unrecoverable losses in the converted condition to equal 12%

[c] Assume yield with LESA consistent with MESA

[d] Negative percent change represents a reduction

Calculation Details:

Note: unless specified, convert from equations are utilizing values from the convert from column; convert to equations are using values from the convert to column.

Convert From:

① $\text{Applied Water (ac-ft)} = \frac{\text{Total Depletion (ac-ft)}}{\text{Application Efficiency (\%)} + \text{Unrecoverable Losses (\%)}}$

② $\text{ET Applied Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Application Efficiency}$

③ $\text{ET Applied Water (in)} = \frac{\text{Applied Water (ac-ft)} * 12(\frac{in}{ft})}{\text{Field Size (ac)}}$

④ $\text{Recovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Recoverable Losses (\%)}$

⑤ $\text{Unrecoverd Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Unrecoverable Losses (\%)}$

Convert To:

⑥ $\text{ET Applied Water (in)} = \text{Convert From ET Applied Water (in)} * (1 + \text{Yield Improvement (\%)})$

⑦ $\text{Field Size (ac)} = \text{Convert From Field Size (ac)} * (1 - \text{Reduction in Irrigated Area (\%)})$

⑧ $\text{ET Applied Water (ac-ft)} = \frac{\text{ET Applied Water (in)}}{12\ (\frac{in}{ft})} * \text{Field Size (ac)}$

⑨ $\text{Applied Water (ac-ft)} = \frac{\text{ET Applied Water (ac-ft)}}{\text{Application Efficiency (\%)}}$

⑩ $\text{Recovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Recoverable Losses (\%)}$

⑪ $\text{Unrecovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Unrecoverable Losses (\%)}$

⑫ $\text{Total Depletion (ac-ft)} = \text{ET Applied Water (ac-ft)} + \text{Unrecovered Water (ac-ft)}$

Percent Change:

⑬ $\text{Percent Change Applied Water (\%)} = -\left(1 - \left(\frac{\text{Convert To Applied Water (ac-ft)}}{\text{Convert From Applied Water (ac-ft)}}\right)\right)$

⑭ $\text{Percent Change Total Depletion(\%)} = -\left(1 - \left(\frac{\text{Convert To Total Depletion(ac-ft)}}{\text{Convert From Total Depletion(ac-ft)}}\right)\right)$

Figure A-7. Conversion from Sprinkler (Pivot/Lateral MESA) to Subsurface Drip Irrigation

Conversion from Pivot/Linear MESA to SDI

(green)	Assumptions gathered from literature sources
(yellow)	Calculated values
(blue)	Inputs from field scale depletion model

Assumptions

Efficiencies and Losses[a]

		Loss Fractions			
	Efficiency	DP	WDE	RO	Fraction Unrecoverable Losses
Pivot/Linear MESA	78%	0.05	0.95	0.00	0.209
SDI	98%	1.00	0.00	0.00	0.000

Sprinkler WDE[b]	12%
Yield Improvement[c]	15%
Reduction in Irrigated Area[d]	12%
Water Productivity Improvement[e]	22%
Precipitation (in)[f]	0.0

	Yield (ton/ac)
Pivot/Linear MESA[g]	4.33
SDI[h]	4.92

Conversion Calculations

	From: Pivot MESA		To: SDI		%Change[i]	
Yield (ton/ac)		4.33		4.92		
Water Productivity (ton/in)	6	0.222	7	0.270		
Field Size (ac)		160	8	141		
Application Efficiency		78%		98%		
Unrecoverable Losses		12%		0%		
Recoverable Losses		10%		2%		
Applied Water (ac-ft)	1	333	11	218	15	-35%
ET Applied Water (ac-ft)	2	260	10	214		
ET Applied Water (in)	3	19.5	9	18.2		
Recovered Water (ac-ft)	4	33	12	4		
Unrecovered Water (ac-ft)	5	40	13	0		
Total Depletion (ac-ft)		300	14	214	16	-29%

Sources & Notes:

[a] http://irrigation.wsu.edu/Content/ConversionCalculator.html

[b] Sprinkler WDE capped at 12% per Quantify the Possible (Jacobs, 2023), in alignment with Consumptive Use of Irrigated Crops in Utah (Hill, 1998). Leads to unrecoverable losses in the converted condition to equal 12%

[c] Difference in yield per g and h below

[d] Assumed field production held constant. Calculated from field sizes in Conversion Calculations.

[e] Per Montazar (2020)

[f] Precipitation has negligible impact on results at typical values for study area, assumed zero.

[g] 10% yield improvement over surface methods assumption based upon yield data included in O'Brien, Lamm, Stone, Rogers (2000), Ehlig, Hagemann (1980), and Sanden, Klonsky, Putnam, Schwankl, Putnam (2011)

[h] 25% yield improvement over gravity per Montazar (2020)

[i] Negative percent change represents a reduction

Calculation Details:

Note: unless specified, convert from equations are utilizing values from the convert from column; convert to equations are using values from the convert to column.

Convert From:

1 $\text{Applied Water (ac-ft)} = \frac{\text{Total Depletion (ac-ft)}}{\text{Application Efficiency (\%)} + \text{Unrecoverable Losses (\%)}}$

2 $\text{ET Applied Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Application Efficiency}$

3 $\text{ET Applied Water (in)} = \frac{\text{Applied Water (ac-ft)} * 12(\frac{\text{in}}{\text{ft}})}{\text{Field Size (ac)}}$

4 $\text{Recovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Recoverable Losses (\%)}$

5 $\text{Unrecoverd Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Unrecoverable Losses (\%)}$

6 $\text{Water Productivity (ton/in)} = \frac{\text{Yield (ton/ac)}}{\text{ET Applied Water (in)} + (0.8 * \text{Precipitation (in)})}$

Convert To:

7 $\text{Water Productivity (ton/in)} = \text{Convert From Water Productivity (ton/in)} * (1 + \text{Water Productivity Improvement (\%)})$

8 $\text{Field Size (ac)} = \text{Convert From Field Size (ac)} * \frac{\text{Convert From Yield (ton/ac)}}{\text{Convert To Yield (ton/ac)}}$

9 $\text{ET Applied Water (in)} = \frac{\text{Yield (ton/ac)}}{\text{Water Productivity (ton/in)}} - (0.8 * \text{Precipitation (in)})$

10 $\text{ET Applied Water (ac-ft)} = \frac{\text{ET Applied Water (in)}}{12\ (\frac{\text{in}}{\text{ft}})} * \text{Field Size (ac)}$

11 $\text{Applied Water (ac-ft)} = \frac{\text{ET Applied Water (ac-ft)}}{\text{Application Efficiency (\%)}}$

12 $\text{Recovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Recoverable Losses (\%)}$

13 $\text{Unrecovered Water (ac-ft)} = \text{Applied Water (ac-ft)} * \text{Unrecoverable Losses (\%)}$

14 $\text{Total Depletion (ac-ft)} = \text{ET Applied Water (ac-ft)} + \text{Unrecovered Water (ac-ft)}$

Percent Change:

15 $\text{Percent Change Applied Water (\%)} = -(1 - (\frac{\text{Convert To Applied Water (ac-ft)}}{\text{Convert From Applied Water (ac-ft)}}))$

16 $\text{Percent Change Total Depletion(\%)} = -(1 - (\frac{\text{Convert To Total Depletion(ac-ft)}}{\text{Convert From Total Depletion(ac-ft)}}))$

Appendix B
Retrospective Analysis Data

Table B-1. Percent Change in Proportions Compared to 2017 by Irrigation Method

Interest Area	2017 through 2018	2017 through 2019	2017 through 2020
District			
Drip	0.0	0.0	0.0
Flood (Surface)	-0.5	-0.8	-1.1
Sprinkler	0.0	-1.2	-1.0
Subirrigated	0.4	2.0	2.2
District/UCRB			
Flood (Surface)	0.0	-1.1	-1.9
Sprinkler	0.4	-0.5	0.3
Subirrigated	-0.4	1.6	1.6
LCRB			
Drip	0.0	0.4	0.5
Flood (Surface)	-0.2	-3.2	-4.3
Sprinkler	0.3	-3.8	-3.2
Subirrigated	0.0	6.6	7.0
UCRB			
Drip	0.0	0.0	0.0
Flood (Surface)	-0.8	-1.3	-4.4
Sprinkler	0.9	-0.1	2.9
Subirrigated	-0.1	1.3	1.5

District = District service area lands falling outside the UCRB
District/UCRB = District service area lands within the UCRB
UCRB = UCRB lands falling outside the District's service area
LCRB = Lower Colorado River Basin lands (in Utah)

Table B-2. Percent Change in Proportions Compared to 2017 by Crop Group

Interest Area	2017 through 2018	2017 through 2019	2017 through 2020
District			
Field crops	-1.9	0.3	-0.4
Garden	0.0	-0.1	-0.1
Grain/seeds	0.9	-0.4	-0.6
Hay/turf	0.4	-3.9	-3.0
Orchard	0.0	0.0	0.1
Pasture land	0.7	4.0	4.0
Small fruit	0.0	0.0	0.0
District/UCRB			
Field crops	0.1	0.0	-0.4
Garden	0.0	0.0	0.0
Grain/seeds	-0.5	-0.5	0.0
Hay/turf	3.3	3.1	4.5
Orchard	0.0	0.0	0.0
Pasture land	-2.9	-2.6	-4.1
Small fruit	0.0	0.0	0.0
LCRB			
Field crops	-0.4	-0.4	0.5
Garden	0.0	-0.2	-0.2
Grain/seeds	0.0	1.0	-0.6
Hay/turf	3.4	-1.9	0.5
Orchard	0.1	-0.3	-0.2
Pasture land	-3.1	1.8	0.1
Small fruit	0.1	0.0	0.1
UCRB			
Field crops	-0.4	-0.2	0.5
Garden	0.0	0.0	0.0
Grain/seeds	-0.6	0.5	1.3
Hay/turf	1.0	2.3	1.4
Orchard	0.0	0.0	0.0
Pasture land	0.0	-2.5	-3.2
Small fruit	0.0	0.0	0.0

District = District service area lands falling outside the UCRB
District/UCRB = District service area lands within the UCRB
UCRB = UCRB lands falling outside the District’s service area
LCRB = Lower Colorado River Basin lands (in Utah)