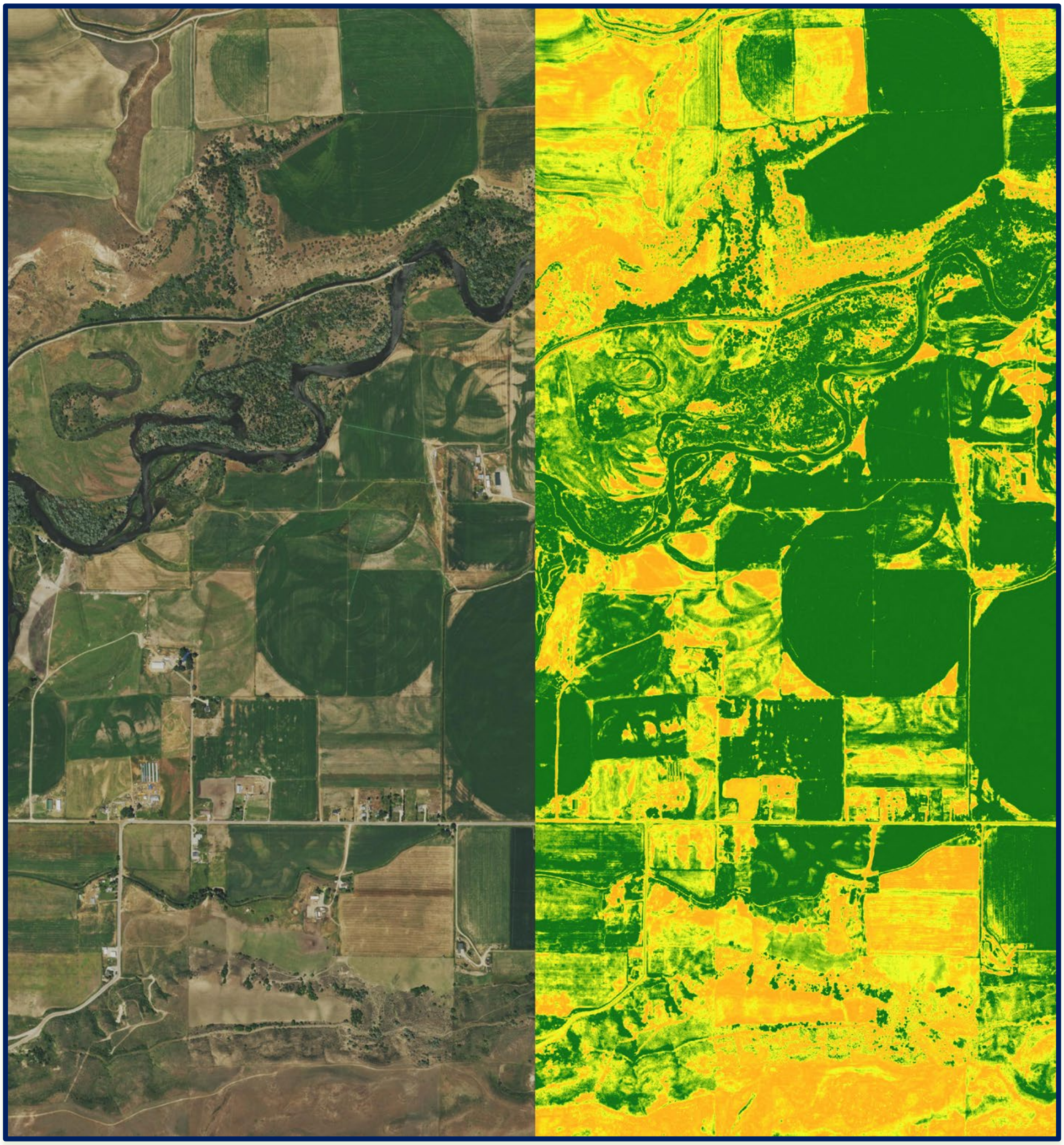
2019 DEPLETIONS UPDATE



April 18, 2023

Cover Photo

Shown on the cover of this report is an image from the USDA National Agricultural Imagery program taken in 2019 from an agricultural area in the Bear River Basin. The right-side of this image shows the Normalized Difference Vegetation Index (NDVI) calculated from this same NAIP imagery. In simple terms, higher NDVI values, shown in green, are associated with plant health and density. NDVI data was one variable helpful in determining irrigated agriculture and can be used to better understand actual evapotranspiration.

Executive Summary

The Amended Bear River Compact (1980) recognized existing water rights as of January 1, 1976, and then authorized the development of additional water above Stewart Dam and in the Lower Division. The allocation included the right to store water, use water, and deplete water, including groundwater. The depletions associated with the grant of these rights are to be determined by a Commission-approved procedure.

The three Bear River States first developed and adopted procedures and depletion estimates for a depletions update which was completed in 1992 and was based on 1990 uses. A second depletions update was completed in 2014 and was based on 2009 uses. This current depletions update effort is based on 2019 uses.

In making these depletion estimates, the Commission's Technical Advisory Committee (TAC) was tasked with analyzing changes in irrigated acres, determining the best depletion rate for the depletion estimates, developing a common factor to be used for supplemental depletions, determining the depletions associated with municipal and industrial uses, and determining the depletions associated with reservoir evaporation.

The total depletions within each state above Stewart Dam and within the Lower Division were tabulated and compared to the Compact-granted depletion allocations (see Figure 1). No state was found to be exceeding its depletion allocations. The TAC has suggested improvements and recommendations to be made in future depletion updates.

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Introduction

The Bear River Commission charged its Technical Advisory Committee (TAC) with updating its depletion estimates pursuant to the Amended Bear River Compact (Compact) and the Commission's approved *Procedures for Depletion Estimates* (Depletion Procedures). The last depletion estimates were accepted by the Commission in April, 2014 and were based on 2009 irrigation and water usage data and 2010 census data. The TAC has now updated the depletion estimates through 2019 and submits its findings, methodologies and recommendations to the Commission. Figure 1 below shows a summary of the TAC's estimates of depletion amounts pursuant to the Compact.

This update is based on a review of new acres irrigated and acres taken out of irrigation since January 1, 1976, both new full supply and supplemental supply, as well as an estimate of municipal and industrial uses (M&I) and reservoir evaporation. The three states' technical staff worked cooperatively on a methodology to update irrigated acreage maps and account for supplemental supply acres. Each state prepared its own, though similar, report on M&I usage and reservoir evaporation estimates. This update is based on the Commission's approved Depletion Procedures.

Issues encountered during the effort included: issues discovered in the original 1976 base maps; problems with comparing 1976 and 2009 GIS data sets with 2019 data sets of much finer detail; concerns with depletion values and uncertainty with depletion rates for post-1976 supplemental acreage depletion values. At several stages through the effort, the TAC received feedback and direction from the Management Committee and the Commission. This report preserves for the Commission the TAC's efforts, findings and recommendations for future depletions update efforts.

Bear River Commission

Estimated Annual Depletions (Acre-Feet)[1]

Changes from January 1, 1976, to December 31, 2019

ABOVE STEWART DAM

State	Allocation	Agricultural Depletions	M&I Depletions	Reservoir Evaporation	Total Depletions	Remaining Allocation
Utah	13,000	5,839	-8	582	6,413	6,587
Wyoming	13,000	5,058	826	140	6,024	6,976
Idaho	2,000	1,150	3	0	1,153	847

LOWER DIVISION

State	Allocation	Agricultural Depletions	M&I Depletions	Reservoir Evaporation	Total Depletions	Remaining Allocation
Idaho	125,000[2]	16,387	245	11	16,643	108,357
Utah	275,000[3]	-16,879	11,543	0	-5,336	275,000

[1]Any reductions in pre-1976 depletions are reflected in the above numbers.

[2]First right under Compact. Compact grants additional rights.

[3]Second right under Compact. Compact grants additional rights.

Figure 1 – Summary table of depletion amounts

Background

The Compact recognized water applied to beneficial use prior to January 1, 1976. The Compact allows for additional depletion amounts to Idaho and Utah in the Lower Division. Determination of the post-January 1, 1976, depletion usage is to be determined by a "Commission-approved procedure." The Compact also provides for additional storage above Stewart Dam and provides that the depletions associated with this storage, as well as post-January 1, 1976, surface and groundwater development above Stewart Dam, should also be determined by a Commission-approved procedure. The Commission first made an estimate of depletion amounts pursuant to the Compact through 1990. Preceding this effort, the Commission had contracted with Utah State University, in cooperation with the University of Idaho and the University of Wyoming, to estimate irrigation depletion requirements for sub-basins within the Bear River system. That resulted in a report titled "*Duty of Water Under the Bear River Compact: Field Verification of Empirical Methods for Estimating Depletion*." Further, the Commission approved a three-state mapping project to determine irrigated acreage as of January 1, 1976. This effort, completed in 1992, resulted in base maps showing irrigated acreage throughout the Bear River Basin. Also pursuant to this effort, the Commission adopted procedures for determining depletion amounts. Then, pursuant to those procedures and the data obtained for depletion rates and irrigated acreages, each of the three states prepared an estimate of its depletion amounts. This effort included the following reports which were submitted to, and approved by, the Commission at its April 1992 annual meeting (copies of these reports are found within the Commission's meeting minutes).

"Bear River Compact Base Mapping" (Idaho), April 1992 Commission Minutes, Appendix F.

"1976 Base Map Verification" (Utah), April 1992 Commission Minutes, Appendix G.

"Wyoming's Bear River Basin Base Mapping Project & Estimated Increased Depletions, January 1, 1976 through January 1, 1990," April 1992 Commission Minutes, Appendix H.

"Estimated Depletions (1976-1990) for the Utah Portion of the Bear River Basin as Defined by the Amended Bear River Compact," April 1992 Commission Minutes, Appendix I.

"Idaho – Estimation of New and Supplemental Irrigation Acreage since 1976 for the Bear River Compact," April 1992 Commission Minutes, Appendix J.

The Commission-approved Depletion Procedures called for updating of the depletion efforts every five years in the Central Division of Idaho and every ten years elsewhere, or as determined by the Commission. In 2010 the Commission commenced a new effort to update the depletions. It was based on 2009 aerial photography and 2010 census data. The effort included updated mapping and updates to the Depletion Procedures. The effort was concluded in 2014 and the depletion estimates were adopted by the Commission at its April 2014 annual meeting. The estimates, along with supporting materials and methodologies employed, are found in a technical memorandum titled *2009 Depletions Update, April 15, 2014,* which is on the Commission's website. This present effort is the Commission's first update of the depletion estimates since the 2009 depletion estimates.

Agricultural Depletions

Methodology

The depletion estimates were updated by multiplying the added and subtracted irrigated acres by their corresponding depletion rates for full supply acres for each subbasin. Common methods for mapping, and determining added and subtracted acres by subbasin, were developed by a GIS group with representatives from each state. The commonly employed methods are found in Appendix A. GridET was employed to estimate depletions for added and subtracted acres in each subbasin (see Appendix B of this report). Depletions associated with developed projects to provide a supplemental supply were estimated by each state. Because Woodruff Narrows Reservoir provides supplemental water to users in both Utah and Wyoming, modeled estimates for depletions associated with this project are included in Appendix C. Depletions associated with individual lands which now receive a supplemental supply were estimated by multiplying the full supply depletion rates by 40%.

The TAC had an extended discussion regarding the variability in irrigation from year to year. Considered were the options of tabulating the "actual" irrigation found in a given year versus the "permitted" irrigated acres. It was believed that the "actual" may underestimate the depletions as it may not include some fields which were generally irrigated but just not in the year that the survey was made. It was also believed that a tabulation of the "permitted" acres would overstate the depletions as some of these acres have not yet been put to beneficial use. After review and input from the Commission, the TAC determined that the reported changes in irrigated acres should be tied to the acres with recent historical beneficial use irrigation rather than what was found in the specific year for which the data were tabulated or what was permitted. The definition of acres with recent historical beneficial use would include those acres that have been irrigated within the previous 5-year period or are expected to be developed and beneficially irrigated within the following 5-year period. Acres that are permitted without recent historical beneficial use such as acres in CRP, permanently fallowed or converted to non-agricultural uses (e.g. a parking lot or an industrial facility), may be considered unused and not count towards the depletion estimates within that subbasin.

Irrigated Acres (Full Supply)

To determine the actual change of irrigated acreage (positive or negative) a GIS analysis was completed to map and define irrigated acreage prior to 1976 and what acreage has since come into production or was no longer irrigated in 2019. To accomplish this, a combination of historical mapping data, GIS data created during the 2009 mapping effort, and data available in 2019, were used to better define both 1976 and 2019 irrigated land. The bulk of this work was done using the 2018/2019 USDA National Agriculture Imagery Program (NAIP) imagery. For this effort, two different categories of lands were identified: lands which were not irrigated prior to January 1, 1976 but are now being irrigated (added acres), and lands which were irrigated prior to 1976 and which are no longer irrigated (subtracted acres). Both categories are needed to determine separate depletion rates and then to apply the corresponding depletion to that acreage. Appendix A describes the shared GIS methods used to accomplish this effort. Appendices D, E and F include specifics from each state.

Idaho

Idaho followed the general methodology described above. Multiple sources of supporting imagery and datasets were available and used to update the line work and identify new irrigation. Land use classification was reviewed by Public Land Survey sections using the available resources to confirm actual changes.

A water right search was conducted as supporting evidence for areas of added depletion. Field verification was completed during the summer of 2021 in targeted areas where imagery or water right review was inconclusive.

A more detailed report on Idaho's efforts to update the irrigated acres and changes since 1976 can be found in Appendix D.

Utah

The State of Utah also followed the general methodology as described above. Multiple sources of supporting imagery and other data were available and used to update the line work and identify new irrigation or areas that went out of production. Land use classifications were reviewed using the available resources to confirm actual changes. A water right search was conducted as supporting evidence for areas of added depletion which is described below.

A more detailed report on Utah's efforts to update the irrigated acres and changes since 1976 can be found in Appendix E.

Wyoming

Along with the general methodology described above, Wyoming also performed an additional step in the mapping process. Water right permits of record in the Bear River Basin were queried from the Wyoming State Engineer's Office water rights database. The permits resulting from that query included both groundwater and surface water permits. The associated permit maps were scanned and the images georeferenced into ArcMap. The irrigation associated with each permit was mapped to create an irrigated acreage layer, with each feature corresponding to a permit number. This layer was used as an additional reference for the mapping described above.

A more detailed report on Wyoming's efforts to update the irrigated acres and changes since 1976 can be found in Appendix F.

Irrigated Acres (Supplemental Supply)

The Depletion Procedures also call for estimates of the additional depletion associated with the supplemental supply developed for acres irrigated with pre-1976 water rights. The Depletion Procedures identify two different categories of supplemental supplies, namely 1) project development, which would include things such as building of a reservoir or other projects to provide supplemental water to an area, and 2) other development, which would be determined to be the smaller supplemental supplies generally for individual fields or farms. The Depletion Procedures provide that for the project development, the states are to prepare a report identifying the amount of additional depletion associated with the project development. In this memo, under the Utah section, is found an evaluation of the following three projects: Woodruff Narrows, Woodruff Creek and Porcupine Reservoirs. Wyoming users also receive supplemental supplies from the Woodruff Narrows Reservoir, Sulphur Creek and several other smaller reservoirs. The depletions associated with the supplemental supply from Woodruff Narrows Reservoir was determined by running the Utah Division of Water Resources' Woodruff Narrows Reservoir Simulation Model Update, May 2021 (Woodruff Narrows Model) for both Utah and Wyoming (see Appendix C). In Idaho, two supplemental projects were identified, namely, Twin Lakes Canal Company's use of waters from Deep Creek and the Malad Valley Irrigating Company's development of Devil Creek.

All other supplemental water usage in the three states was found to fall under the "other development" category. The 1992 determination of depletion associated with the other development required the application of the depletion rates associated with a full water supply to be multiplied by a shortage rate for each sub-basin. The shortage rates were based on a study performed in the 1970s identifying deficiencies in water supply to meet water requirements. For the 1992 depletions update, Idaho used a different shortage rate than the states of Utah and Wyoming.

Because the use of subbasin shortage rates was called into question as a method for dealing with the additional depletions associated with individual supplemental water rights, for the 2009 depletions update effort it was determined by the Commission that the TAC should re-examine this previously used methodology. Upon review, it was determined that each state would estimate, on a case-by-case basis, the depletions associated with water rights which have been developed since 1976. This led to the creation of three different methods and called into question the consistency of the findings.

Therefore, for the 2019 depletions update effort, the Commission directed that the TAC develop either a common method or a common number (factor or percentage) to determine the depletions associated with supplemental water rights. The TAC initiated its efforts by identifying the diversion and depletion data available in each state. In this review it found that there are not presently common data sets available in the three states to make comparable calculations. It then set out to develop a potential common method for which data could be acquired. The State of Wyoming spent several years tracking supplemental water usage and developed several potential methods that could, with time, be applied within the other two states to estimate depletions associated with supplemental water rights. Each of the methods tracked the time that the supplemental water right was used. One employed diversion amounts multiplied by an efficiency factor whereas the other tracked the ET rate from an AgriMet Station during the period that the supplemental water right was needed. Several issues wrestled with by the TAC include: 1) determining an appropriate irrigation efficiency rate given the great variability in soil types, 2) deciding on whether production under a supplemental water right should count as a depletion even when such production was made more out of convenience than necessity, 3) determining the period of supplemental usage when supplemental sources, such as a well, were intermittently used, 4) deciding whether supplemental usage should only be counted when the Bear River is in interstate regulation, and 5) deciding what years should be included in the average (i.e. all years including years when there is no supplemental usage or only the dry years when supplemental usage is the greatest).

Idaho similarly used some of the methods developed by Wyoming by determining the period of supplemental use from power records. Though the results from both states varied by area and from year to year, in general the estimated depletion amounts centered around between 35% to 40% of the full supply depletion rates. Utah analyzed supplemental use on a case-by-case basis and found varying depletion amounts, that when averaged, fell within the range encountered in Wyoming and Idaho. Recognizing that this effort is only a depletion estimate and not a real-time accounting of depletions, the TAC recommended that for this depletions update effort, a factor of 40% of the full-supply depletion estimates described above be applied to the acres found to have a post-1976 supplemental water supply.

It should be noted that the supplemental supply accounting only applies to those acres which received a supplemental supply after 1976, but which were irrigated with an original supply prior to 1976. The reason for this is that if the original supply for the acres was based upon post-1976 development, the state would have already been charged for a full supply depletion for those acres and hence, charging for a supplemental supply in addition to the full supply would be overcharging the depletion amount.

The sections below describe each states' efforts to estimate depletions associated with developed storage projects as well as their application of the 40% depletion rate to the individual lands which have a post-1976 supplemental water supply.

Idaho

A review of water rights also included determining new supplemental irrigation. If a water right with a priority date between 1976 and 2019 overlaid land that had a pre-1976 water right, and appeared irrigated in 2019, the acreage for the supplemental water right was counted. There were instances where authorized acres under the supplemental right did not appear irrigated in 2019, but imagery from prior years did show evidence of irrigation. These were treated on a case-by-case basis in determining supplemental acreage.

The Cub River Irrigation Company, Malad Valley Irrigation Co., Inc, and Twin Lakes Canal Company in the Lower Division of Idaho have post-1976 water rights that are not included in the supplemental acreage totals. They are calculated separately as projects.

Water right 13-7481 is held by the Twin Lakes Canal Company to divert water from Deep Creek into Twin Lakes Reservoir. The water right authorizes 4,040 acre-feet to be diverted to storage during the non-irrigation season to be used for irrigation within the canal company service area. The water right did not authorize additional capacity for the reservoir nor additional acres within the service area. Historical records available at IDWR regarding the operation of the reservoir are limited but suggest that the reservoir was filled annually prior to the approval of the permit. Consultation with canal company officials confirmed that the water right has seen very limited use in the past due to pumping costs and availability of water, so it is still best characterized as an alternate source rather than a supplemental supply of water. Consequently, no new depletion is associated with this water right. Canal company officials also said that the company is interested in finding ways to further develop the use of water under this water right. It is recommended that this water right be reviewed as part of future depletion estimates to evaluate if diversions from Deep Creek provide a supplemental supply of water within the service area.

Water right 13-7279 is held by Cub River Irrigation Company to divert 25 cfs from the Bear River. Water rights 13-2066 and 13-7279 cover the full 125 cfs capacity at Cub River Irrigation Company pumping station. Water district records show that Cub River Irrigation Company has historically (pre-1976) diverted less than 125 cfs, therefore no new depletion is associated with this water right.

Water right 15-7167 is held by Malad Valley Irrigation Company to divert from Spring Creek into Crowther Reservoir. The water right authorizes 959 acre-feet to be diverted to storage during the non-irrigation season to be used for irrigation within the canal company service area. According to a 2016 IDWR memo, this right could be filed as a beneficial use claim in a future adjudication for irrigation storage with a priority date of when Malad Valley irrigation took ownership of the reservoir in the 1950s. This water right is not included as a supplemental depletion because it has been in use since the 1950s even though on paper the water right priority is post-1976.

Permit 15-7178 is held by the Malad Valley Irrigating Company to divert water from Devil Creek into Devil Creek Reservoir. The permit authorizes 700 acre-feet to be diverted to storage during the non-irrigation season to be used for irrigation within the canal company service area. The permit does not authorize additional capacity for the reservoir or additional acres within the service area. The permit currently provides an alternate storage location for two other reservoirs owned by Malad Valley Irrigating Company that have storage restrictions due to dam safety concerns. Because the permit provides an alternate storage location for pre-1976 storage rights, no new depletion is associated with the permit. The permit required that proof of beneficial use be submitted in May 2013. An extension was granted in 2021, so it is recommended that the permit status be reviewed as part of future depletion studies to evaluate if the storage situation changes such that diversions from Devil Creek under water right 15-7178 provide a supplemental supply of water within the service area.

Utah

Supplemental water rights for the 2019 irrigated acreage were determined in a two-part process: 1) A search was ran on the Utah Division of Water Rights' database and all water rights with a filing date after 1976 were selected and reviewed by division staff; 2) Using GIS, the place of use for each water right was compared to the Commission's 1976 base maps to determine if it needed to be classified as a new or supplemental right. A water right with a post-1976 priority date and covered under 1976 base maps was classified as supplemental. If acreage was not covered by the base maps, then the right was classified as new. Project supplemental rights were evaluated as well as supplemental supplies for individual water rights.

For project calculations, the Woodruff Narrows Model was run for the period 2015-2019 by the Utah Division of Water Resources (included in Appendix C of this report). It is noted that in prior depletion updates, the Woodruff Narrows Model included up to 3,000 acre-feet of water allocated to industrial uses which were deemed to be 100% consumptive. The Chevron plant is the only facility which currently uses water from the Woodruff Narrows Reservoir and that usage is now covered fully by original Compact storage allocations. Therefore, for the 2019 depletions update the industrial use portion of the model was set to 0 acre-feet which then made the 3,000 acre-feet available in the model to be allocated for supplemental irrigation uses. The total increased depletion from the Woodruff Narrows Reservoir enlargement is 6,873 acre-feet. The total is split between Utah (83%) and Wyoming (17%). The total increased depletion of 6,873 acre-feet includes 701 acre-feet of increased evaporation and 6,172 acre-feet of increased depletion associated with the supplemental irrigation of lands.

From the updated simulation, the total depletion for Utah (83%) is 5,705 acre-feet. Of that, 582 acre-feet is attributed directly to Woodruff Narrows Reservoir evaporation and the remaining 5,123 acre-feet is attributed to supplemental usage.

The Woodruff Creek Reservoir enlargement had been approved, but was not built, and the water right appropriation has since lapsed. Therefore, no additional depletion is associated with their post-1976 filing. The Porcupine Reservoir enlargement amounted to an additional 396 acre-feet; therefore, the maximum depletion associated with their new supplemental water right would be 396 acre-feet.

Utah estimated supplemental supply depletions for individual water rights based on applying the TAC recommended supply rate of 40% of the full supply to the supplemental acres as shown in Appendix B. The sole supply depletion value was calculated by multiplying acres by the depletion rate times the supply depletion factor.

Wyoming

Wyoming reviewed its supplemental and additional water rights from 2015-2019 to find an average amount of supplemental use in the Bear River Basin within Wyoming. Supplemental supply in Wyoming is defined as another water supply from a separate surface water source which supplements the original irrigation water supply. Additional supply in Wyoming is defined as an additional water supply from a separate groundwater source which supplements the original irrigation water supply. Hereafter, the term supplemental supply will be used to refer to both supplemental supply and additional supply.

There are 5,950 post -1976 permitted supplemental acres. The supplemental water rights associated with 2,807 of these acres either have never been developed or have not been recently used, some of which will not likely be used in the near future. The remaining 3,143 acres have a developed supplemental supply.

Calculations were made using a common uniform method adopted by the Bear River Commission for accounting of supplemental water use. Supplemental water use is calculated using a subbasin full water supply consumption value multiplied by 40% (five-year average).

Wyoming Supplemental Irrigation Water Usage by Subbasin (2019)		
Subbasin	Number of Acres (Acres)	Depletion (Acre-Feet)
Cokeville	2,125	1.062
Thomas Fork	983	460
Evanston	35	17

Figure 2 – Tabulation of Wyoming supplemental acres and associated depletions by subbasin (2019).

The following depletion amounts were calculated for delivery of reservoir water to irrigated lands and accounted for in the supplemental irrigation depletions:

Woodruff Narrows Reservoir – 1,049 acre-feet. The Woodruff Narrows Model was used to simulate the amount of post compact storage. The total amount that was derived for supplemental use depletion from the computer simulation was 6,172 acre-feet. Wyoming's portion of this total is 17% or 1,049 acre-feet of depletion accounted to Wyoming. Woodruff Narrows Reservoir is located in the Evanston sub-basin.

Sulphur Creek Reservoir – 0.00 acre-feet. No depletion was taken on this facility because the average total storage used, less the original compact storage allocated to this facility in combination with the unbuilt compact storage and carryover from previous year this facility, never exceeded the 4,036 acre-feet. Wyoming has a remaining un-built, original compact storage allocation of 4,036 acre-feet.

Heber/Broadbent Reservoir – 0.00 acre-feet. This facility receives both Bear River water and Green River water. No depletion was taken on this facility because the average amount of Green River water imported into the Bear River Basin for this facility is greater than the average acre-feet used by this facility and the Ben Reservoir combined.

Ben Reservoir – 0.00 acre-feet. This facility receives both Bear River water and Green River water. No depletion was taken on this facility because the average amount of Green River water imported into the Bear River Basin for this facility is greater than the average acre-feet used by this facility and the Heber/Broadbent Reservoir combined.

Coy Reservoir – 15.82 acre-feet. To calculate the depletion amount, the reservoir surface evaporation loss amount (4.2 acre-feet, see Reservoir Evaporation section) was subtracted from the total available capacity (full) minus original compact storage amount (26.90 acre-feet) minus carryover from previous year. It was assumed that half of that amount would be depleted from the lands and assuming a 50% efficiency rate, resulted in a total depletion rate of 15.82 acre-feet. This facility was originally allocated 26.9 acre-feet of original compact storage, in 2017 the owner requested an enlargement application along with a portion of the 4,100 acre-feet of remaining unbuilt storage be allocated to this reservoir. Wyoming granted both these requests giving this facility another 63.7 acre-feet totaling 113.7 acre-feet of original compact allocation to this reservoir. For the calculations for this report years 2015-2017 will be subject to the 26.9 acre-feet amended compact space. The 2018 and 2019 values were calculated using the increased total of 113.7 acre-feet of Original Compact Storage allocation which resulted in zero depletion in 2018 and 2019.

The total of depletion taken for the above-mentioned reservoirs is 1,120 acre-feet.

Depletion Rates

As was indicated above, in 1982 the Commission hired university staff in the three states to complete an analysis of depletion rates based on the then crop mixes in the various sub-basins within the Bear River Basin. That culminated in a 1989 report which has been specifically referenced in the Commission's Depletion Procedures. The 2009 depletions update used a similar method but with updated subbasin depletion rates provided by Utah State University pursuant to a contract with the State of Utah.

As part of this depletions update effort, the TAC reviewed several methodologies for estimating ET from irrigated lands. It wrestled with the more traditional methods which estimate "potential ET" versus newer methods which seek to estimate "actual ET." After studying the matter and consulting with the Commission's Management Committee, it was decided that GridET (described in Appendix B) would be employed for the 2019 depletions estimates, but that the TAC should continue to monitor developments with OpenET (described in Appendix G) as this methodology is refined.

In determining the average depletion rate by subbasin for post January 1, 1976 acres, the average of the field specific ET amounts over the five years was averaged over the full subbasin. However, in determining the subbasin ET values for subtracted acres, because irrigation was no longer occurring and hence, ET rates could not be directly measured, the average of the ET rates for all existing fields was determined and used for subtracted acres. Thus, the ET rates for added and subtracted acres are slightly different for each subbasin because the added rate includes only post January 1, 1976, acres and the subtracted rate includes all acres within the subbasin. The below table, which is more fully described in Appendix B, lists these depletion rates. These rates were used by all three states in the depletion estimates.

	Bear River Irrigation Depletion Rates by Subbasin (acre-feet/acre)										
	Evanston 01	Randolph 02	Cokeville 03	Thomas Fork 04	Bear Lake 05	Soda 06	Oneida 07	Cache Valley 08	Malad 09	Tremonton 10	Brigham City 11
Rate for Added Acres	1.24	1.36	1.25	1.17	1.15	1.09	1.17	1.35	1.46	1.46	1.63
Rate for Subtracted Acres	1.30	1.34	1.28	1.22	1.20	1.09	1.18	1.43	1.52	1.45	1.54

Figure 3 – Estimated irrigation depletion rates by subbasin. Based on average 2015 – 2019 crop mixes.

Estimate of Irrigation Depletions

Based on the above-described methodology, each state determined the number of full supply and supplemental supply irrigated acres added since January 1, 1976, within each sub-basin. These acres are found in the table below. The columns shown as “Irrig.” represent acres developed since 1976 and receiving a full irrigation supply, whereas the columns shown as “Supp. Irrig.” represent acres which were irrigated prior to 1976, but which since January 1, 1976, also receive an additional or supplemental water supply.

Tabulation of Added Irrigated Acres by Subbasin (1976 - 2019)						
	Idaho		**Utah**		**Wyoming**	
	Irrig.	Supp. Irrig.	Irrig.	Supp. Irrig.	Irrig.	Supp. Irrig.
Subbasin	(ac)	(ac)	(ac)	(ac)	(ac)	(ac)
Above Stewart Dam						
Evanston			20	-	608	
Randolph			728	2,244	-	-
Cokeville	-	-	38	-	4,480	1,782
Thomas Fork	313	752			826	983
Bear Lake	510	-				
Subtotal	**823**	**752**	**785**	**2,244**	**5,914**	**2,765**
Lower Division						
Bear Lake	1,083	848	202	284		
Soda	1,055	187				
Oneida	2,102	829				
Cache Valley	2,202	2,238	3,865	5,605		
Malad	3,925	6,157				
Tremonton	2,227	959	3,466	629		
Brigham City			175	810		
Subtotal	**12,595**	**11,219**	**7,709**	**7,328**	**-**	**-**

Figure 4 – Table of added full and supplemental supply acres (1976 – 2019).

Figure 5 below shows a similar tally for the full supply acres which were irrigated prior to 1976 but which are no longer under irrigation. These subtracted acres are used to calculate a reduction in depletions since 1976 for each subbasin.

Tabulation of Subtracted Irrigated Acres by Subbasin (1976 - 2019)						
	Idaho		**Utah**		**Wyoming**	
	Irrig.	Supp. Irrig.	Irrig.	Supp. Irrig.	Irrig.	Supp. Irrig.
Subbasin	(ac)	(ac)	(ac)	(ac)	(ac)	(ac)
Above Stewart Dam						
Evanston			12	-	2,647	-
Randolph			1,036	-	-	-
Cokeville	-	-	127	-	814	-
Thomas Fork	43	-			352	-
Bear Lake	86					
Subtotal	**129**	**-**	**1,175**	**-**	**3,813**	**-**
Lower Division						
Bear Lake	748	-	731	-		
Soda	266	-				
Oneida	365	-				
Cache Valley	2,204	-	14,901	-		
Malad	1,245	-				
Tremonton	19	-	6,132	-		
Brigham City			723	-		
Subtotal	**4,847**	**-**	**22,487**	**-**	**-**	**-**

Figure 5 – Table of subtracted full supply acres (1976 – 2019).

Figure 6 below shows the net of the added and subtracted acres in each subbasin.

Tabulation of the Net of Added and Subtracted Irrigated Acres by Subbasin (1976 - 2019)						
	Idaho		**Utah**		**Wyoming**	
	Irrig.	Supp. Irrig.	Irrig.	Supp. Irrig.	Irrig.	Supp. Irrig.
Subbasin	(ac)	(ac)	(ac)	(ac)	(ac)	(ac)
Above Stewart Dam						
Evanston			8	-	-2,039	508
Randolph			-308	2,244	0	0
Cokeville	-	-	-89	-	3,666	1,782
Thomas Fork	270	752		-	474	983
Bear Lake	424	-		-		
Subtotal	**694**	**752**	**-390**	**2,244**	**2,101**	**3,273**
Lower Division		- -				
Bear Lake	335	848	-529	284		
Soda	789	187	0	-		
Oneida	1,737	829	0	-		
Cache Valley	-2	2,238	-11,036	5,605		
Malad	2,680	6,157	0	-		
Tremonton	2,208	959	-2,666	629		
Brigham City			-548	810		
Subtotal	**7,748**	**11,219**	**-14,778**	**7,328**	**-**	**-**

Figure 6 – Table showing the net of the added and subtracted acres by subbasin (1976 - 2019).

The full supply added acres were then multiplied by the corresponding depletion rates from Figure 3 to estimate the depletions. Similarly, the full supply subtracted acres were multiplied by their corresponding subbasin depletion rates and then the added and subtracted depletion amounts were netted (the number of added acres (positive values) were added to the number of subtracted acres (negative values) within each subbasin. For the supplemental acres, the number of added acres were multiplied by the corresponding full supply depletion rates for their subbasin and then this product was multiplied by 40% to compute the estimated supplemental depletions. In addition, specific depletion estimates were made for supplemental projects as described above. The estimated total agricultural depletions are shown, by subbasin, in Figure 7 below.

Tabulation of Total Estimated Change in Irrigation Depletions by Subbasin (1976 - 2019)									
	Idaho			**Utah**			**Wyoming**		
	Full	Supplemental		Full	Supplemental		Full	Supplemental	
	Irrig.	Projects	Individual	Irrig.	Projects	Individual	Irrig.	Projects	Individual
Subbasin	(af)	(af)	(af)	(af)	(af)	(af)	(af)	(af)	(af)
<u>Above Stewart Dam</u>									
Evanston				9		0	-2,693	1,049	253
Randolph				-398	5,123	1,221	0		0
Cokeville	0		0	-116		0	4,557		891
Thomas Fork	315		353				540		462
Bear Lake	482		0						
Subtotal	**797**	**0**	**353**	**-505**	**5,123**	**1,221**	**2,403**	**1,049**	**1,606**
<u>Lower Division</u>									
Bear Lake	347		389	-642		130			
Soda	862		82						
Oneida	2,029		388						
Cache Valley	-162		1,213	-16,030	396	3,037			
Malad	3,846		3,597						
Tremonton	3,234		562	-3,843		368			
Brigham City				-825		528			
Subtotal	**10,156**	**0**	**6,231**	**-21,339**	**396**	**4,064**			

Figure 7 – Table of change in irrigation estimated depletion (1976 - 2019).

The following is an explanation by state as to unique circumstances regarding the calculation of the above-estimated depletion amounts.

Idaho

During Idaho's review, irrigated lands were identified with a source of surface water originating from an adjacent compact division or from groundwater that is not tributary to the Bear River. The map inserted below shows three irrigated areas located outside the established compact division boundary from which water is diverted.

The area northwest of Grace is located outside the Bear River hydrologic boundary, but those lands are irrigated by surface water originating from the Bear River or tributaries in the Lower Division. This irrigated land is identified as "Irrigated by surface water from Lower Division" on Figure 8. The lands are irrigated by Last Chance Canal and Farmers Land and Irrigation Corp. Last Chance Canal diverts water from the Bear River. Farmers Land and Irrigation Corp. diverts water from Big Spring Creek and Soda Creek, which are tributaries to the Bear River.

The area mostly west of Stewart Dam designates lands located outside the Central Division that are irrigated by surface water originating from the Bear River in the Central Division. This irrigated land is identified as "Irrigated by surface water from Central Division" on Figure 8. The extent of this area was changed since the 1992 Depletions Study report because this area in that report included the Montpelier Irrigation Co. service area, but the company diverts water from Montpelier Creek which is tributary to the Bear River in the Lower Division. Other minor changes since 1992 are attributed to the use of GIS tools and more clearly defined water right places of use.

Irrigated land northwest of Soda Springs was identified as new irrigation since 1976 from a groundwater source. This irrigated land is identified as "Groundwater Divide Places of Use" on Figure 8. According to a paper published by the Idaho Geological Survey (Martin, M., Wylie, A., Otto, B. "Hydrogeologic Analysis of the Water Supply for Bancroft, Caribou County, Idaho." Idaho Geological Survey, Information Circular 61., 2005), the groundwater divide between the Portneuf and the Bear River Basins is located along the Last Chance Canal Company Extension Canal. These acres were not counted as new depletions because the source is not from the Bear River Basin.

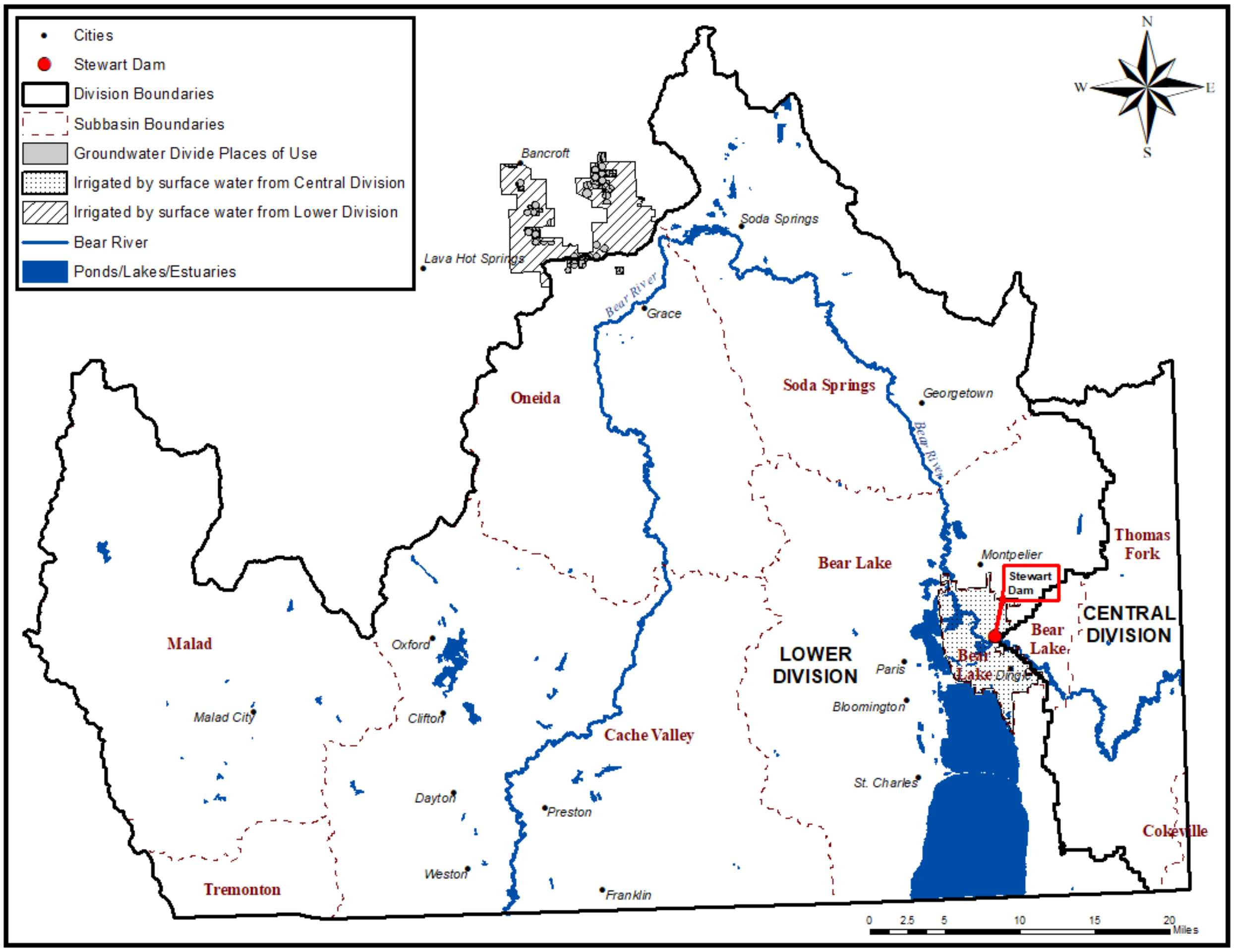

Figure 8 – Map showing areas using water diverted from adjacent compact division or from groundwater that is not tributary to the Bear River

Utah

Depletion estimates for new acres that are considered "full supply" were determined using depletion rates found in Figure 3 for the Evanston, Randolph, Bear Lake, Cache Valley, Tremonton, and Brigham City subbasins in Utah.

Wyoming

Depletion amounts for Wyoming were determined using the depletion rates found in Figure 3 for the Evanston, Randolph, Cokeville and Thomas Fork subbasins.

Municipal and Industrial Depletions

Pursuant to the Commission's Depletion Procedures, all three states estimated municipal depletions by multiplying the change in population since January 1, 1976, connected to public or community water system by the common depletion rate of 0.11 acre-feet per capita. Idaho and Wyoming used water right data to determine industrial usage, whereas Utah used reported user-supplied industrial usage values. Detail as to methodology and findings relative to M&I usage is contained within the three state sections below.

Idaho

Municipal Depletions

Depletion of water for municipal uses was estimated based on Section II.B. of the Depletion Procedures. A depletion rate of 0.11 acre-feet per capita was used for the Bear River Basin. Population data were obtained from the 2020 U.S. Census for populations connected to a public or community water system based on data provided by the Idaho Department of Environmental Quality (Idaho DEQ Source Water Assessment & Protection). The values are:

Idaho Tabulation of Change in Municipal Depletions by Water System (1976 - 2020)

County	Water System	Population (People) 1976	2020	Change '76 - '20	Depletion (ac-ft)
Bear Lake County	Bloomington	183	199	16	1.8
	Georgetown	522	503	-19	-2.1
	Montpelier	3,052	2,643	-409	-45.0
	Paris	619	541	-78	-8.6
	St. Charles	208	161	-47	-5.2
Caribou County	Grace	1,168	920	-248	-27.3
	Soda Springs	3,925	3,133	-792	-87.1
Franklin County	Clifton	192	413	221	24.3
	Dayton	230	510	280	30.8
	Franklin	450	1,025	575	63.3
	Preston	3,632	5,591	1,959	215.5
	Weston	295	511	216	23.8
Oneida County	Malad	2,045	2,299	254	27.9
	Total	**16,521**	**18,449**	**1,928**	**212.1**

Figure 9 – Changes in population and municipal depletions in Idaho.

The net population increase of 1,928 results in a net increase in municipal depletion from 1976 to 2020 of 212 acre-feet per year in the Idaho portion of the Bear River Basin. All the municipal depletion within Idaho was in the Lower Division. IDWR identified four municipal systems that were not associated with census population data (Aspen Creek Water Co., Bear Lake West Home Owner Assn., Bear Lake West Property Owners Assn., and Cub River Acres). These municipal systems were not included in the depletion estimates but should be reviewed in future municipal depletion analyses to determine if they are associated with census population data.

Industrial Depletions

A water right search was completed to identify industrial or commercial uses in the Idaho portion of the basin. Only seven water rights were identified with a priority date of 1976 or later. Two of these seven water rights are at the permitting stage of the water right license process. These two water rights recently filed for an extension due to lack of development and therefore they were not included in the industrial use depletion calculation. The water rights and permits are summarized below.

Idaho Tabulation of Change in Industrial Depletions by User (1976 - 2020)

Owner	Water Right	Priority Date	Depletion (AF)	Division
Toone Daily Farm Inc	13-7220	10/14/1977	11	Lower
Parson Ready Mix	11-7262	5/21/1981	2.9	Central
J.R. Simplot Co.	11-7438	12/16/1981	21.5	Lower
PacifiCorp	13-7934	3/9/2015	0	Lower
Robert Timmons	13-7576	12/13/2012	0	Lower
Plymouth Peak	15-7259	5/21/2013	0	Lower
Sam's Hollow Water Co.	11-7796	10/7/2014	0	Lower
		Total	**35.4**	

Figure 10 – Changes in industrial depletions in Idaho.

The net increase in industrial depletions from 1976 to 2019 is 35.4 acre-feet per year in the Idaho portion of the Bear River Basin. The Central Division in Idaho has 2.9 acre-feet of industrial depletion, and the Lower Division in Idaho has 32.5 acre-feet of depletion.

Water Right Licenses

Water right 13-7220 is a licensed groundwater right in the name of Toone Dairy Farm Inc. with a priority date of October 14, 1977. The right authorizes a diversion rate of 0.07 cfs for commercial, domestic and stockwater water uses for a dairy farm. Water use for the stockwater and commercial portions of this right is limited to a volume of 11 acre-feet per year. Water use for stockwater and commercial purposes is considered to be fully consumed. The point of diversion for the right is located in the Lower Division.

Water right 11-7262 is a licensed groundwater right in the name of Parson Ready Mix with a priority date of May 21, 1981. The right authorizes a diversion rate of 0.25 cfs for industrial water use for a cement mixing plant. Water use for this right is limited to a volume of 2.9 acre-feet per year. The water use is considered to be fully consumed. The point of diversion for the right is located in the Central Division.

Water right 11-7438 is a licensed groundwater right in the name of J.R. Simplot Co. with a priority date of December 16, 1981. The right authorizes a diversion rate of 2.8 cfs for industrial water use for a phosphate processing plant. Water use for this right is limited to a volume of 21.5 acre-feet per year. The water is used for a slurry with the phosphate and is transported out of the basin. Th water use is considered to be fully consumed. The point of diversion for the right is located in the Lower Division.

Water right 13-7934 is a licensed surface water right in the name of PacifiCorp with a priority date of March 9, 2015. The right authorizes a diversion rate of 0.24 cfs for industrial water use for a pipeline corrosion prevention system. Water use for this right is limited to a volume of 174 acre-feet per year. The water is applied to a small parcel of land to keep a buried anode bed wet to facilitate electrical conductivity for a corrosion prevention system. The water use is considered to be non-consumptive. The point of diversion for the right is located in the Lower Division.

Water right 13-7576 is a licensed surface water right in the name of Robert Timmons and Barbara Senter with a priority date of December 13, 2012. The right authorizes a diversion rate of 0.80 cfs for commercial water use for hot tubs and pools. Water use for this right is limited to a volume of 580.7 acre-feet per year. The water is passed through hot tubs and pools near Maple Grove Hot Springs and returned to the Bear River. The water use is considered to be non-consumptive. The point of diversion for the right is located in the Lower Division.

Water Right Permits

Water right permit 15-7259 is a groundwater permit in the name of Plymouth Peak LLC with a priority date of May, 21, 2013. The permit authorizes a diversion rate of 0.23 cfs for commercial water use for a convenience store, truck plaza, RV park, and motel. The water is intended to be used for a truck plaza and other amenities, but an extension of the permit was granted through October 1, 2023. Due to a lack of infrastructure development verified with

2019 satellite imagery, this water right permit has no consumptive use for this depletion study. The point of diversion for the permit is located in the Lower Division. This water permit should be reviewed for the next depletion study.

Water right permit 11-7796 is a groundwater permit in the name of Sam's Hollow Water Co. with a priority date of October 7, 2014. The permit authorizes a diversion rate of 0.080 cfs for commercial water use for a subdivision. The water is intended to be used for a parcel of land near Highway 89 that is zoned for commercial use. Verbal communication with Sam's Hollow Water Co. indicates no development has occurred. Due to the lack of infrastructure development this water right permit has no consumptive use for this depletion study. The point of diversion for the permit is located in the Lower Division. This water permit should be reviewed for the next depletion study.

Utah

Municipal Depletions

Depletion of water for municipal uses was estimated using an assumed depletion rate of 0.11 ac-ft per person per year, derived by the Bear River Commission approved methodology in the Depletion Procedures. This depletion rate was then multiplied by the change in population from 1976 to 2020, with 2020 estimates derived from the 2020 U.S. Census. Population for Lower Rich County was adjusted to account for the increase in

Utah Tabulation of Change in Municipal Depletions by County (1976 - 2020)

		Population (People)			
County	**Division**	**1976**	**2020**	**Change '76 - '20**	**Depletion (ac-ft)**
Rich County	Upper Division	797	726	-71	-7.8
	Lower Division	1,934	8,745	6,811	749.2
Cache County	Lower Division	48,402	127,320	78,918	8,681.0
Box Elder County	Lower Division	10,712	24,295	13,583	1,494.1
	Change in Upper Division	797	726	-71	-7.8
	Change In Lower Division	61,048	160,360	99,312	10,924.3
	Total	**61,845**	**161,086**	**99,241**	**10,916.5**

Figure 11 – Changes in population and municipal depletions in Utah.

population during the summer tourism season. The adjustment was made with municipal, commercial and industrial connections reported by Utah Division of Water Rights and the estimated number of persons per household from the 2020 U.S. Census.

Industrial Depletions

The depletion estimates for industrial use shown below in Figure 10 was estimated based on 2020 water use data collected by the Utah Division of Water Rights for self-supplied industries. Consumptive use factors from the 1992 state report to the Bear River Commission were applied to the Depletion Procedures for each self-supplied water user. Total containment, self-supplied industry diversions are considered completely (100%) depleted. The total increase in depletion for self-supplied industrial uses in Utah in the Lower Division between 1976 and 2020 is 619 acre-feet. There is no industrial use of water in Utah above Stewart Dam.

Utah Tabulation of Change in Industrial Depletions by User (1976 - 2020)

Self-supplied Industry	**1976 Depletion (AF)**	**2020**			**1976 - 2020 Change in Depletion (AF)**
		Diversion (AF)	**C.U. factor**	**Depletion (AF)**	
Cache County					
Casper's Ice Cream		48.3	0.15	7.2	
Gossner Foods, Inc		237.8	0.15	35.7	
Pepperidge Farms, Inc.		65.6	0.12	7.9	
JB Swift & Co.		8.4	0.15	1.3	
Staker Parsons		202	1	202	
Cache County Total	**85**			**254**	**169**
Box Elder County					
Nucor Steel Corp.		589.8	1	589.8	
Box Elder County Total	**140**			**589.8**	**449.8**

Figure 12 – Changes in industrial depletions in Utah.

Wyoming

Municipal Depletions

There are three municipalities in the Bear River Basin in Wyoming: Evanston, Cokeville, and the Town of Bear River. Wyoming utilized the process developed by Utah and adopted by the Bear River Commission in the Depletion Procedures dated April 19, 2016.

For the 1976 estimate, population data for Evanston and Cokeville were obtained from the Wyoming Department of Administration and Information, Division of Research and Statistics. For the 2010 estimate, population data for the three municipalities were obtained from the 2010 census. For the 2020 estimate, population data for the three municipalities were obtained from the 2020 census. The net change from 1976 was multiplied by 0.11 acre-feet per capita with an outcome of 822.91 acre-feet of municipal depletion.

Wyoming Tabulation of Change in Municipal Depletions by Community (1976 - 2020)

County	Water System	Population (People) 1976	2020	Change '76 - '20	Depletion (ac-ft)
Unita County	Evanston	4,751	11,747	6,996	769.6
	Town of Bear River	0	522	522	57.4
Lincoln County	Cokeville	539	502	-37	-4.1
	Total	**5,290**	**12,771**	**7,481**	**822.9**

Figure 13 – Changes in population and municipal depletions in Wyoming.

The net population increase of 7,481 results in a net increase of 822.91 acre-feet.

Industrial Depletions

Wyoming utilized an in-depth review of industrial depletions for this 2019 depletions update. All industrial water rights were researched, and a majority were field inspected to verify usage.

In the 2009 depletions report, Chevron's Carter Creek Gas Plant, now owned by Hilcorp, was the greatest amount of industrial depletion. It was once again found to be the greatest industrial depletion in 2020; however, because this was part of the original compact allocation under the 1975 permit, it should have not been included in the previous reports. The change of use of this water was completed by Order Record 27, page 1. Even though the Chevron's Carter Creek Gas Plant water is not included as part of the industrial total in this report, the amount of water used was still obtained and averaged from 2017, 2018, 2019, and 2020, with an average of 79 acre-feet being utilized per year.

Many of the rights included in the 2009 report were for welding shops, truck maintenance shops, etc. Those have now been connected to the Town of Bear River's Joint Powers Board pipeline and they are included in the municipal depletions. One water right was found to still be utilizing a ground water well to serve industrial purposes under permit number 128377W, which used 2.76 acre-feet in 2020.

The other industrial use documented in 2009 was the Union Pacific Railroad's Altamont UPPR housing. Upon inspection in the winter of 2021, this area was found to be abandoned. For a summary of Wyoming's industrial depletions, please see the following table:

Wyoming Tabulation of Changes in Industrial Depletions by User (1976 - 2020)

	Depletion (acre-feet)		
Industrial User	**1976 - 1990 Change**	**2020**	**Change '76 - '20**
Whitney Canyon Gas Plant	225.0	0.0	0.0
Altamont-UPRR Housing	4.0	0.0	0.0
Other	15.0	2.8	2.8
Total	**244.0**	**2.8**	**2.8**

Figure 14 – Changes in industrial depletions in Wyoming.

The table above shows a decrease in Wyoming's industrial depletions of 241.2 acre-feet per year since the 1990 report and an increase of 2.8 acre-feet since 1976.

Reservoir Evaporation

It is recognized that in granting the additional depletion allocations under the Compact, both above and below Stewart Dam, often the construction of reservoirs would be required for storage of non-irrigation season water for later release, use and depletion. The TAC recognizes that such reservoirs, whether constructed for the purpose of providing irrigation, municipal or industrial waters, will evaporate water off their surfaces. Therefore, separate and in addition to a depletion associated with usage of the waters described above, a calculation needs to be made for the depletion associated with the reservoir evaporation. Hence, in the section below, each state has identified reservoirs constructed both above and below Stewart Dam pursuant to these provisions of the Compact and the estimated evaporation depletion associated therewith. In some instances, the additional depletion allocation was used to expand or enlarge existing reservoirs. In these instances, the TAC determined that the appropriate depletion allocation should be based on the estimated increased surface area and, therefore, evaporative depletion associated with the enlargement. The evaporative depletion associated with Woodruff Narrows Reservoir was calculated with the Woodruff Narrows Model which uses GridET for evaporation calculations (see Appendix C). The depletion amounts reported below by each state are in addition to the depletion amounts calculated in the above sections which are associated with the use of such waters.

Idaho

A water right search for post-January 1, 1976, irrigation, municipal or industrial storage uses identified a single small reservoir to be counted as a new depletion due to evaporation from the reservoir. Water right license No. 13-7277 authorizes storage of 12.1 acre-feet of water for irrigation use with a source from Oxford Slough Creek within the Cache Valley sub-basin in the Lower Division. The reservoir is approximately 4 acres in surface area. Using an evaporation rate of 2.62 acre-feet/acre per year for shallow ponds from the Preston weather station (http://data.kimberly.uidaho.edu/ETIdaho/), the depletion due to evaporation is estimated to be 10.5 acre-feet per year.

Utah

Woodruff Creek – A water right had been approved for reservoir enlargement of 5,400 acre-feet, but the project has not been built and the application lapsed, so there is no increase in reservoir surface area.

Porcupine – The Dam was structurally upgraded in 2001. In doing so, the storage capacity was increased from approximately 12,800 acre-feet to 13,196 acre-feet with no appreciable increase in reservoir surface area. The maximum depletion was accounted for under the new supplemental water right such that no additional depletion need be taken for reservoir evaporation.

Woodruff Narrows Reservoir – 582 acre-feet. This number is derived from the updated computer run using the Woodruff Narrows Model. The total reservoir evaporation from this reservoir is 701 acre-feet, of which 83% or 582 acre-feet is allocated to Utah's depletions.

Wyoming

The following are evaporation amounts taken for three Wyoming reservoirs, listed below:

Woodruff Narrows Reservoir 119 acre-feet. This number is derived from the updated computer run performed using the Woodruff Narrows Model. The total reservoir evaporation from this reservoir is 701 acre-feet, of which 17% or 119 acre-feet is allocated to Wyoming's depletions.

Sulphur Creek Reservoir – 0.00 acre-feet. No depletion for reservoir evaporation was taken on this facility because the average total storage used, less the original compact storage allocated to this facility, in combination with the unbuilt compact storage that can be transferred to this facility, never exceeded 4,036 acre-feet.

Heber/Broadbent Reservoir – 0.00 acre-feet. This facility receives both Bear River water and Green River water. No depletion for reservoir evaporation was taken on this facility because the average amount of Green River water imported into the Bear River Basin for this facility is greater than the average capacity used from this facility and the Ben Reservoir combined.

Ben Reservoir – 0.00 acre-feet. This facility receives both Bear River water and Green River water. No depletion for reservoir evaporation was taken on this facility because the average amount of Green River water imported into the Bear River Basin for this facility is greater than the average capacity used of this facility and the Heber/Broadbent Reservoir combined.

Coy Reservoir – an average of 4.20 acre-feet annually. This facility was originally allocated 26.9 acre-feet of Amended Compact storage. In 2017 the owner requested a portion of the 4,100 acre-feet of remaining unbuilt storage be allocated to this reservoir in conjunction with an enlargement application. Wyoming granted the allocation request along with the enlargement application giving this facility another 63.7 acre-feet totaling 113.7 acre-feet of original Compact allocation. The calculations in this report include evaporation amounts on the 26.9 acre-feet of amended compact storage from 2015-2017. 2018 and 2019 were not subject to evaporation depletion because the entire reservoir is now filled with original Compact storage and so it will not need to be considered in the future.

Bonneville Reservoir – 16.6 acre-feet. This number was calculated using the average surface area of the active capacity of the reservoir. That number was then multiplied by 2 (the number, in feet, of evaporative loss for the area in which the reservoir is located).

The total depletion amount for reservoir evaporation for Wyoming reservoirs is 140 acre-feet.

Preservation of GIS Data

Data relevant to the final GIS mapping effort used in the 2019 depletions effort will be archived by the individual states on a centrally shared Google Drive which is maintained and housed by Wyoming's State Engineer's Office. Individual states will also store copies of these data separately within their own networks.

The primary folder for GIS data shall be entitled BRC_GIS_Final2019 and the directory structure beneath it shall consist of five sub-folders: one sub-folder for 2019 GIS data (named Bear_River_Compact_2019), one sub-folder for 2009 GIS data (named Bear_River_Compact_2009), and one sub-folder for each state. The contents of each sub-folder follow.

Within the Bear_River_Compact_2019 sub-folder shall be a primary file geodatabase entitled BRC_Cropmix2019.gdb. This file geodatabase shall contain separate featureclasses (subsets) for each state's 2019 land classification; three featureclasses delineating the 2019 divisions, subbasin, and transbasin boundaries; and a featureclass of each state's data unioned (combined) into a single layer that was used for extracting ET and ultimately estimating depletion rates. This folder will also house a pdf report of the shared GIS methods used by all of the states and CDL lookup table translating the USDA Cropland Data Layer (CDL) classifications to GRIDET classifications.

Within the Bear River Compact 2009 sub-folder shall be another file geodatabase entitled Bear_River_2009.gdb. This file geodatabase shall contain separate featureclasses for each state's 2009 land classification. The Bear River Compact 2009 sub-folder shall also contain the final data from the 2009 analysis and related reports.

The individual state sub-folders shall contain documentation of the methods deployed by each state along with any data, figures, or files they believe should be preserved for future efforts and documentation.

Recommendations on Future Updates

Based on the efforts performed and the experience gained in making this depletions update, the following are recommendations for future depletions updates.

- Significant progress was made in defining water rights place of use since the 2009 effort causing much disagreement between the 2009 classifications and current classifications. It is likely these improvements will continue. While the 2019 classifications should be used as a starting point in the next process, it should be recognized that further reclassifications may be necessary and what has been classified as pre-1976 irrigated acreage or post-1976 irrigated acreage may need to be reclassified.

- The GIS effort was the most time-consuming process in this update. States should discuss any effort that can be made to maintain and update a dataset to be used in this process in the future.

- Estimating the increased depletion associated with supplemental water rights has continued to prove difficult. There is not a common dataset to distinguish supplemental irrigation and provide for the use of a common methodology amongst the states. The depletions associated with supplemental supplies can vary widely from year-to-year and the methodology is not intended to dictate individual state administration. The TAC should continue to attempt the development of a common methodology for post-1976 supplemental water right depletion amounts with an eye towards methods which could make calculations in real-time. Upon determining a methodology, the states should then provide recommendations to collect the needed data in the future.

- The ET values used in developing the depletion rates are based on GridET values. The TAC should review in the future the pre- and post-1976 acres to be included in the added and subtracted acreage averages. Looking to the future, the next depletions update, and future real-time management may use methods being developed under OpenET. The TAC should continue to closely follow the OpenET development and review opportunities and issues from time to time. As the use of OpenET methodologies becomes more promising, the Management Committee should consider its use for depletion estimates.

- Future ET calculations, regardless of methodology, will be more accurate if there are more weather stations and eddy covariance stations within the basin, particularly above Stewart Dam. The TAC should look for ways to support appropriate additional instrumentation.

- In 2016 the Commission updated the Depletion Procedures with a common method for the determination of municipal depletions. The per capita depletion values were determined from a review of the then available water use data. The TAC should review the prior data and findings and provide an update to the Commission if it is determined that the values have changed.

- Before the next depletions update, the TAC should review the elements and methodologies included in the updated Woodruff Narrows Model, including the potential use for industrial purposes.

- After considering the above, the TAC should create a timeline for review of specific depletion components.

Appendix A
Description of GIS Mapping Efforts

Bear River Commission Mapping Update (2019)
Shared Methods
10/24/2022

The Bear River Commission (BRC) GIS sub-committee was tasked to provide GIS data to aid in the 2019 Bear River Compact water depletion effort. The Amended Compact granted additional allocations of water beyond that “applied to beneficial use” before January 1, 1976. It did NOT grant to a state any specific volume of depletion pre-1976 plus an additional volume post-1976. It only defined and limited the additional amount. Therefore, this analysis must define the change in use since 1976 rather than measure against an absolute value.

This analysis to determine depletion estimates relies on comparing 1976 and 2019 landtype classifications and noting areas of misclassifications in the original map data layer. Classifications are denoted by Landtype76 and Landtype19 columns. Comparing Landtype76 and Landtype19 determines the Change19 column. Change19 is used to determine what land has come into production since 1976 and what 1976 irrigated land has come out of production.

Classifications (Landtype76/Landtype19)

The Bear River Commission (BRC) has requested that land be classified into six categories: irrigated land (IR), non-irrigated land (NI), urban land (URB), water (WA), sub-irrigated, wetland, and riparian land (WE), and other land (OTH). Each classification is defined below.

1) IR- Any land with an irrigation right, this is largely agricultural land, but can also be riparian areas, wetlands, and more. If the land clearly will no longer be irrigated, for example it has been developed for housing/industry, or there is a long record of abandonment, these can be removed from this category. However, in general, fallow/idle land with a water right should be treated as IR.

2) NI- Agriculture without a water right, dry agriculture, this may have significant crossover with OTH depending how dry pasture/rangeland is defined

3) URB- Land developed for urban use, this includes buildings, roads, pavement, urban turfgrass, and more.

4) WA- Waterbodies include rivers, lakes, streams and other forms of natural or unnatural waterbodies.

5) WE- This can be both agricultural and non-agricultural land that is influenced by a high-water table in proximity to a waterbody. As noted above, if this area has a water right it should be classified as IR instead.

6) OTH- Mainly wildland, however if there is confusion in the classification this can also be used as a catch-all to land that is not irrigated.

Change19

The Change19 column is used to determine how the data is used to calculate depletions. This column is determined by comparing the Landtype76 column to the Landtype19 column or used to amend the 1976 classification. Each State used their own methods to validate these changes which are documented in separate reports. Six types of changes are used in the 2019 BRC Depletions Estimates, four from the 2009 analysis: 1) Added, 2) Subtracted, 3) Reclass, and 4) Null and two new to this analysis 5) Transfer Add, and 6) Transfer Sub. How Change19 is attributed will be further defined below.

1) Added

Polygons labeled as Added are defined as any polygon where the 1976 classification is any classification other than IR, these include NI, URB, WA, WE, and OTH, and are now classified as IR. Added polygons will be used to estimate post 1976 depletions for the Bear River Compact.

Examples:

- Previous wildland was classified as OTH in 1976, since 1976 a pivot has gone in and the land is now irrigated.

2) Subtracted

Polygons labeled as Subtracted will be used to subtract acres based on basin-wide depletion rates that can be used as credits towards post 1976 depletions. The basin-wide depletion rates are calculated for each basin based on all polygons where Landtype19 is IR no matter the Change19 classification. In this analysis these polygons represent any polygon moving from the IR classification in 1976 to NI, URB, WA, WE, and OTH in 2019.

Examples:

- An irrigated field in 1976 has been developed for housing.
- An irrigated field in 1976 has been abandoned for the past seven years, with no evidence that it will be irrigated in the near future.

3) Reclass

Mapping is an imperfect exercise, and new information will always be available to contradict decisions made in previous mapping efforts. Reclass will allow states to redefine the 1976 classification to the 2019 classification. For example if the 1976 classification is NI and the 2019 classification is IR the polygon would normally be Added. However, new information shows this had a pre-1976 water right attached to it and old imagery supports this claim. By “reclassifying” this polygon it can be inferred that this polygon should not be counted toward new depletions because it was irrigated pre-1976.

Examples:

- The 1976 basemap included a road within irrigated land. New data and mapping techniques have delineated the road separate from the irrigated land, leaving small polygons or slivers that represent the road. This sliver of a polygon representing the road has a 1976 classification of IR, but in actuality, never changed and should therefore be reclassified as URB.

4) Transfer Add

It was determined that Reclass may not be specific enough in the case of water right transfers. This is where a pre-1976 water right is transferred to another piece of land. Transfer Add signifies the polygon gained a 1976 water right and despite not being irrigated pre-1976, a pre-1976 water right has been transferred from a different area to that piece of land. This land will not be counted towards post-1976 depletions.

Examples:

- A 70 acre field that was classified as Other in 1976 is now irrigated, however it is using a water right that was previously applied to a different 70 acre field nearby. The field that was irrigated in 1976 is no longer irrigated and the water right place of use has been transferred to another area.

5) Transfer Sub

Likewise this is land that had a pre-1976 water right, but the water right is no longer attached to this land. This land will not be subtracted from pre-1976 depletions. If in the future this land is irrigated again it will be Added and count towards post 1976 depletions despite having been irrigated pre-1976.

Examples:

- A 70 acre field that was classified as IR in 1976 is no longer irrigated and its water right is now being applied to a different 70 acre field nearby.

6) Null

Polygons given no classification, shown as NULL, either have no change in the Landtype classifications or the change is not relevant to water being used. In other words, Landtype76 and Landtype19 do not change or were never and are still not classified as IR. This land will be ignored in the analysis.

Examples:

- A housing development (URB) was constructed on land previously classified as OTH.

BRC_classification_2019

Each state provided a dataset, State_BRC_classification_2019, with the Landtype76, Landtype19, and Change19 columns. These are included in the final geodatabase. The exact methods to accomplish this differed slightly per state and will be included in separate documents. The methods to combine the three state features into a single feature and define the final columns are discussed below.

Crop Mix Calculation

Once each state provided their data with Landtype and Change columns defined, the crop mix calculation could begin. To make the depletion calculation easier, the three state's data were merged into a single dataset using the ESRI Merge tool. An ESRI Spatial Join was then used to determine the Division, and Subbasin based on the center of each polygon. The BRC_Divisions_Subbasins_Trans, defined below, was used in this operation. In order to reduce the number of intermediate datasets, the data was then pulled into R. The 2015-2019 Cropland Data Layer (CDL) was also pulled in and the majority statistic was extracted from each polygon to create a single dataframe with the OBJECTID and the five years of CDL data shown in the Class_Name## columns (Class_Name15, Class_Name16, ect.) (USDA 2022). Next a lookup table "brc_lu19", included in the final database, was used to translate the Class_Name## columns to CU_Catergory## columns (Table 1). CU_Category are values that the Grid_ET model can interpret for the final depletion calculation. These data were then joined by OBJECTID in Arcpro to create the final dataset.

Divisions and Subbasins

The final dataset includes four features in the final geodatabase defined below. All four features were included in the final 2009 dataset.

- BRC_Basin_Bndry- A single extent of the area of interest (AOI), excludes one area considered outside the hydraulic basin.
- BRC_Divisions- Divides BRC_Basin_Bndry between States and Divisions.
- BRC_Divisions_Subbasins- Further divides BRC_Divisions by subbasin

- BRC_Divisions_Subbasins_Trans- Includes transbasin diversions, expanding the AOI and redefining divisions to represent where the water is sourced.

The AOI for this study spans three states: Idaho, Utah, and Wyoming. Three Divisions (Upper, Lower, and Central Divisions) form the hydraulic extent of the AOI. The Divisions are further split into 11 subbasins. Subdividing 11 subbasins within three Divisions among the three states creates 22 uniquely defined areas. (Figure 1).

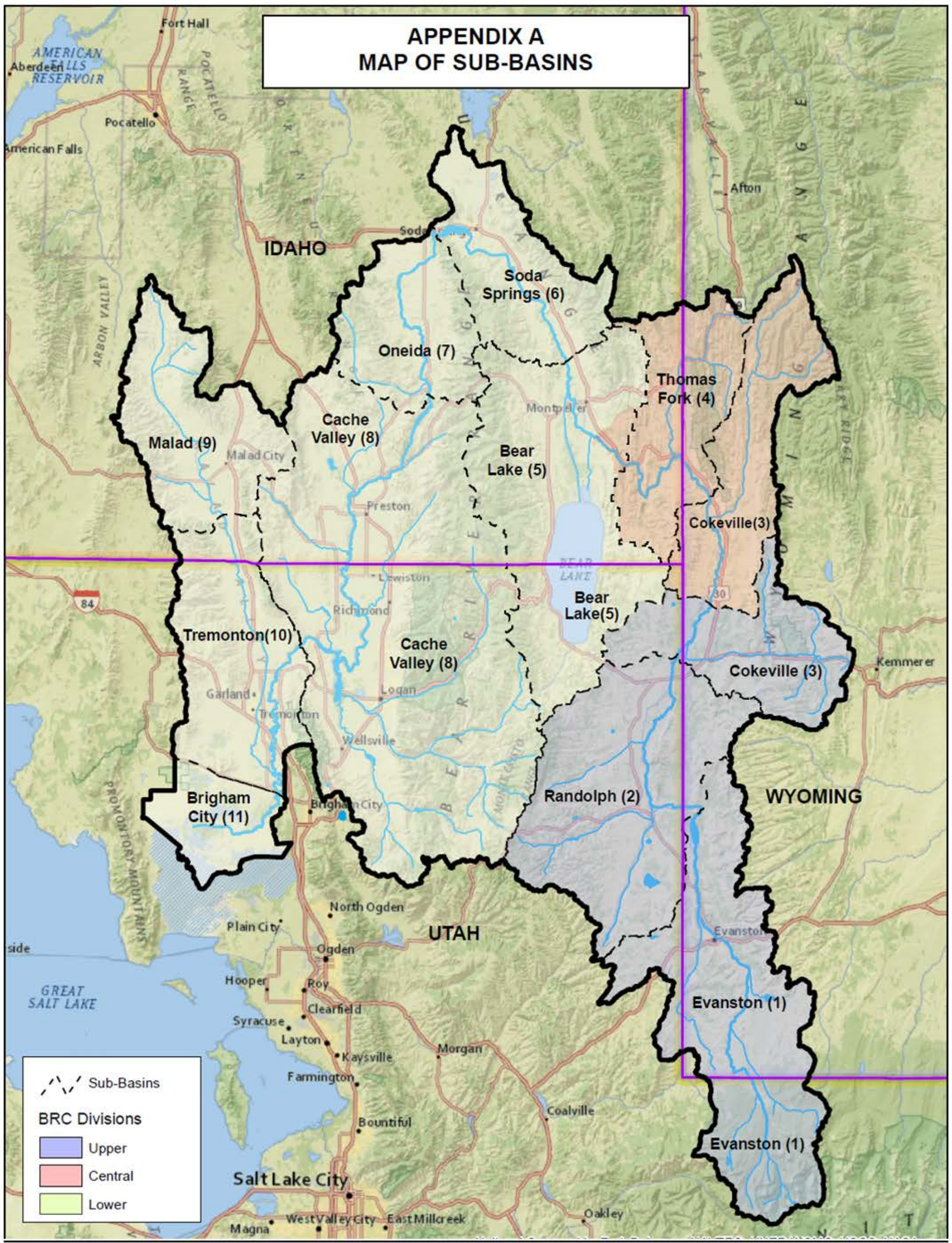

Figure 1. Subbasin boundaries of the Bear River split between three divisions and states.

Two areas differ from their true hydraulic location due to transbasin diversions. These are classified in the Division “Lower Ctrl-IR”, which despite being in the Lower Basin uses Central Water. Lower-Add is in the Snake River Basin to the north, but uses Lower Basin Water.

Division and Subbasin Edits

Two areas of the division and subbasin features were edited to better reflect what surface water is used on specific fields (Figure 2). The first area in question expands the Lower Ctrl-IR division of the Bear Lake subbasin. This area, despite being in the Lower division, gets Central division water. The second area expands the Central Bear. The end effect is 47.7 acres of “Added” land going to the Central Bear and 47.7 acres of “Added” land leaving the Lower Bear.

Table.1 Look up table translating Cropland Data Layer (CDL) classifications to classifications used in Grid_ET (CU_Category) to calculate depletions.

CDL	**CU_Category**	**CDL**	**CU_Category**
Alfalfa	Alfalfa (Dairy)	Mustard	Safflower
Apples	Apples or Cherries	Oats	Barley
Barley	Barley	Onions	Onion
Barren	Pasture	Open Water	Pasture
Canola	Spring Grain	Other Crops	Garden
Christmas Trees	Garden	Other Hay/Non Alfalfa	Other Hay
Corn	Corn	Peas	Garden
Deciduous Forest	Other Hay	Potatoes	Potato
Developed/High Intensity	Pasture	Pumpkins	Melon
Developed/Low Intensity	Pasture	Radishes	Garden
Developed/Med Intensity	Pasture	Rye	Spring Grain
Developed/Open Space	Pasture	Safflower	Safflower
Dry Beans	Potato	Shrubland	Pasture
Durum Wheat	Spring Grain	Sod/Grass Seed	Turfgrass
Evergreen Forest	Pasture	Sorghum	Sorghum

Fallow/Idle Cropland	None	Spring Wheat	Spring Grain
Grassland/Pasture	Pasture	Sweet Corn	Corn
Herbaceous Wetlands	Pasture	Triticale	Spring Grain
Herbs	Garden	Winter Wheat	Winter Wheat
Lentils	Garden	Woody Wetlands	Pasture
Mixed Forest	Pasture		

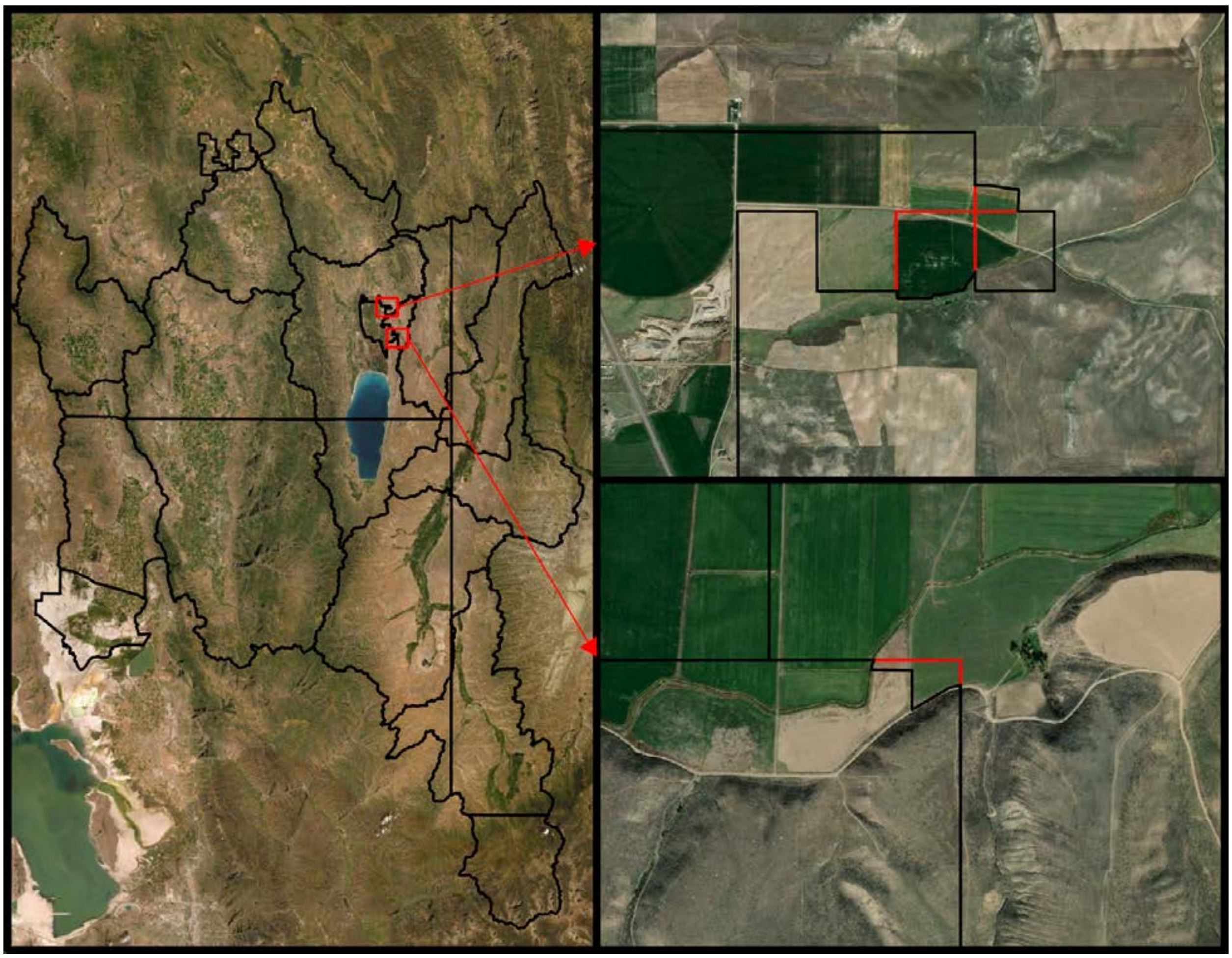

Figure 2. The Bear River Basin boundaries (left) were edited from 2009 to better represent where water is used. The upper-right part of the figure shows the old Lower Ctrl-IR division boundary in red expanded to the new boundary in black. The lower-left part shows the Central Bear boundary expanded.

References

USDA (2022). National Agricultural Statistics Service Cropland Data Layer. https://nassgeodata.gmu.edu/CropScape/. Accessed: 4/1/2022

Appendix B
Description of GridET Update and Calculations

State of Utah

SPENCER J. COX
Governor

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Lieutenant Governor

Department of Natural Resources

JOEL FERRY
Executive Director

Division of Water Resources

CANDICE A. HASENYAGER
Division Director

TO: Bear River Commission Technical Advisory Committee

FROM: Jake Serago, PE; Clay Lewis, PE, PhD

SUBJECT: GridET Background and Estimated Agricultural Depletion Rates

DATE: February 3, 2023

For the 2019 Bear River Commission Depletion Study, estimates of depletion rates in the Bear River basin were made using the GridET (Lewis and Allen, 2017) algorithm and software. Supported by the Utah Divisions of Water Resources and Water Rights, GridET has been calibrated to weather stations sited in representative conditions in Utah to estimate alfalfa reference evapotranspiration from NLDAS gridded weather drivers (Cosgrove et al., 2003) on an hourly time step and at an arbitrary spatial resolution. For numerous land covers, potential evapotranspiration is calculated from crop curves for climatically-controlled growing season start and end dates on a daily time step. For a crop like alfalfa, cuttings are also simulated throughout the season. Open water evaporation is estimated through an aerodynamic method for deep systems. Effective precipitation and depletion rely on daily DAYMET precipitation grids (Thorton et al., 2022). Fully open-sourced, GridET software uses GDAL/OGR for geospatial functionality and is cross platform.

Depletions are estimated using the ASCE Standardized Reference ET Equation, precipitation, winter carry-over soil moisture storage, crop type and growing season length. Reference ET is primarily a function of temperature, solar radiation, dewpoint temperature and wind speed.

$$ET_{rs} = \frac{0.408\,\Delta(R_n - G) + \gamma \frac{C_n}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)}$$

Where ET_{rs} is the standardized reference evapotranspiration (mm/d or mm/hr) for a “tall” crop (denoted by the subscript “rs”), Δ is the slope of the saturation vapor pressure versus temperature curve (kPa/°C), R_n is the calculated net radiation at the crop surface (MJ/ m^2/d or MJ/ m^2/hr), G is soil heat flux (MJ/ m^2/d or MJ/ m^2/hr) assumed to be zero for daily calculation time steps herein, γ is the psychrometric constant (kPa/°C), C_n is the numerator constant (changes with time step and reference crop type) (K mm s^3/Mg/d or K mm s^3/Mg/hr), T is mean temperature for the calculation interval (daily or hourly) (°C), u_2 is mean wind speed for the calculation interval at a height of 2 m above the ground (m/s), e_s is the saturation vapor pressure at 2 m above the ground (kPa), e_a is the mean actual vapor pressure at 2 m above the ground (kPa), C_d is the denominator constant which changes with time step and reference type (s/m).

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Annual average climate and soil variables over the years 2015 – 2019 are shown in Figure 1 for each of the administrative subbains. Although the relationship between climate variables and depletion rates is non-linear, much can be inferred by observing the graphs.

For example, the Evanston subbasin experiences relatively high winds, lower humidity, lower precipitation and high solar radiation. Despite having the lowest temperatures and shortest growing season, the depletion rate for this subbasin is less than Cache Valley but greater than Oneida.

Current depletion rate estimates are higher than they have been in previous years for most sub-basins (see Figure 2). The depletion rates for acres which were removed and rates for acres added are presented in Table 1. There are several reasons that the rates are higher.

1. Rates are computed using an average from 2015-2019 whereas previous rates included multiple decades, such as the very wet decade of the 1980s, in computing the mean.

2. In previous studies, rates for each subbasin were subjectively selected based on
    a. Available weather stations (could be 1 or more). Weather station data is often incomplete or missing due to malfunctioning sensors and needs to be cleaned or filled. The gridded data provides a much better base dataset than weather stations.
    b. If data from multiple stations were used then a method to utilize data from multiple stations had to be determined.
    c. It is important to understand that in previous studies there were individual stations with rates higher than the average rates computed for the current study but those stations were not included in computing the subbasin mean.

3. The current method improves the spatial representation through the use of gridded data. National Weather Service (NWS) station sites had gaps filled with the nearest North American Regional Reanalysis (NARR) pixel and were individually calibrated to nearby electronic weather station (EWS) datasets. The National Land Data Assimilation System (NLDAS) dataset that GridET uses is based on NARR and more advanced interpolation techniques including other data.

4. GridET calculates reference evapotranspiration on an hourly time step whereas the previous method used a daily time step, which could have missed many of the higher rates.

    a. The effects from the change in timestep could result in either higher or lower rates than those computed with average daily weather data. For example, since reference ET is zero at night, if the weather parameters are relatively greater at night than averaged across the whole day then the daily summed hourly reference ET will be lower than the daily calculated reference ET.

5. The higher resolution DAYMET data set was selected to represent spatial and temporal distribution of rainfall, to which the depletion equation is highly sensitive. Reference ET has increased but so has the precipitation as compared to past studies.

6. GridET accounts for slope and aspect using an advanced algorithm for solar estimations.

7. GridET uses an improved method (USDA) for calculating effective precipitation.

Although scientific knowledge, data sources and computational resources improve every decade, GridET currently represents the best overall reference evapotranspiration-based estimates that the field can produce and is not apt to change significantly in future studies.

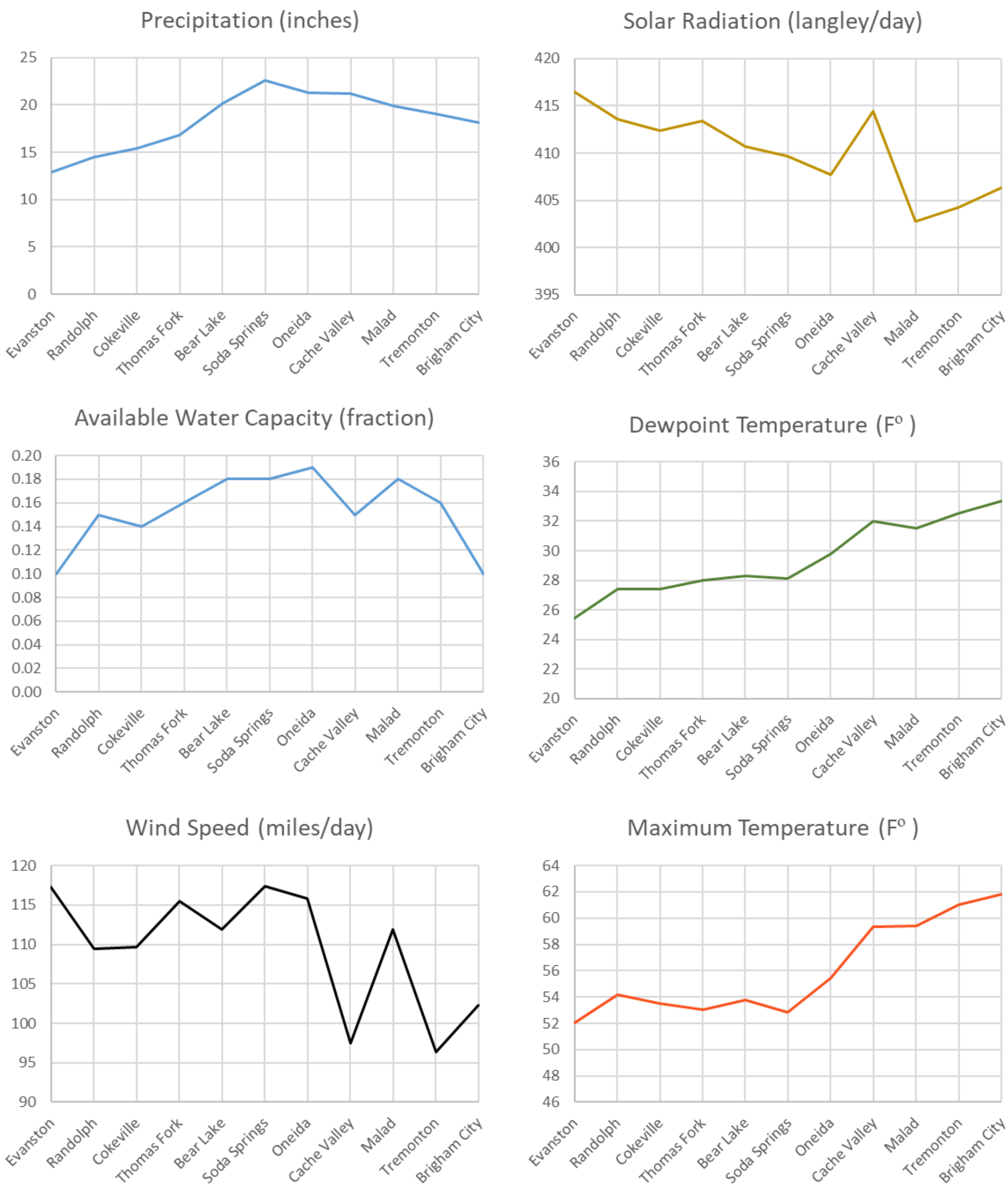

Figure 1 - Average annual (2015-2019) climate variables used in GridET for each subbasin

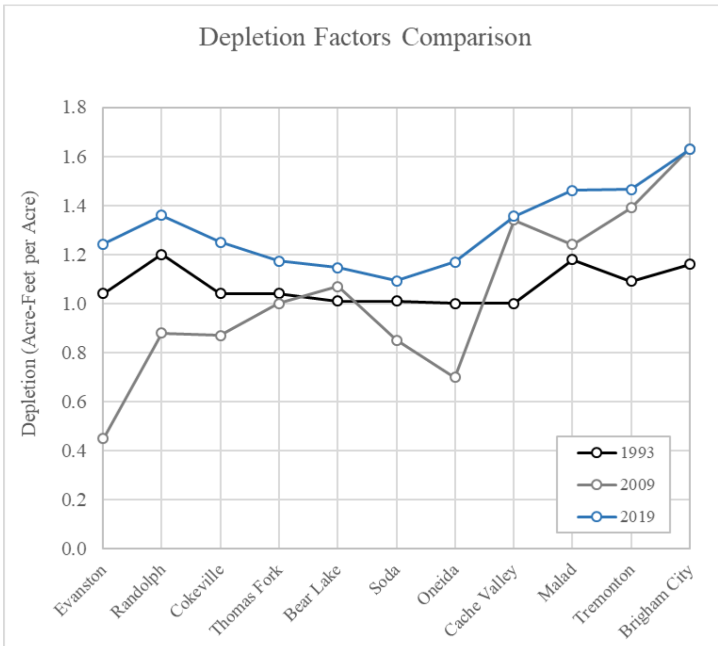

Figure 2 Current pre-final depletion rates and rates from previous studies

Table 1 – Estimated depletion using GridET and the BRC Crop Mix Map for post January 1, 1976 lands for subbasins in the Bear River Basin. Potential evapotranspiration rates are means of rates from 2015-2019.

ESTIMATED DEPLETION FOR POST JANUARY 1, 1976
LANDS FOR SUBBASINS OF THE BEAR RIVER BASIN

Based on average (2015 - 2019) crop mixes
and updated ET rates from Utah Division of
Water Resources' GridET program (2022)

		SUBBASIN										
		Evanston 01	Randolph 02	Cokeville 03	Thomas Fork 04	Bear Lake 05	Soda 06	Oneida 07	Cache Valley 08	Malad 09	Tremonton 10(b&c)	Brigham City 10(a)
Added	AF/A	1.24	1.36	1.25	1.17	1.15	1.09	1.17	1.35	1.46	1.46	1.63
Subtracted	AF/A	1.30	1.34	1.28	1.22	1.20	1.09	1.18	1.43	1.52	1.45	1.54

References

Cosgrove, B. A., Lohmann, D., Mitchell, K. E., Houser, P. R., Wood, E. F., Schaake, J. C., ... & Meng, J. (2003). Real-time and retrospective forcing in the North American Land Data Assimilation System (NLDAS) project. *Journal of Geophysical Research: Atmospheres*, 8(D22).

Lewis, C. S., & Allen, L. N. (2017). Potential crop evapotranspiration and surface evaporation estimates via a gridded weather forcing dataset. *Journal of Hydrology*, 546, 450-463.

Thornton, M. M., Shrestha, R., Wei, Y., Thornton, P. E., Kao, S., & Wilson, B. E. (2022). Daymet: daily surface weather data on a 1-km grid for North America, Version 4. ORNL DAAC, Oak Ridge, Tennessee, USA.

Appendix C
Woodruff Narrows Reservoir Supplemental Depletions and Evaporation

Woodruff Narrows Reservoir Simulation Model Update

March 2023

SUMMARY OF WORK

We converted the UDWRe Woodruff Narrows ResSim (Fortran) model used in the previous depletion study into a RiverWare model and made improvements to the:

1. Policy rules to account for Bear Lake storage restrictions, conservation storage and flood control.
2. Representation of the outlet and spillway hydraulics.
3. Evaporation method to utilize monthly output from GridET for open water in place of the previous method which used a table of average monthly net evaporation rates
4. Simulation start date from 1941 to 1980 and the end date from 2013 to 2020 to coincide with availability of GridET data and to include more recent inflow data.

The new model modifies the representation of reservoir hydraulics and operations. It also uses monthly evaporation rates from GridET for open water using the effective pool depth. It uses streamflow and weather data from 1980 – 2020.

Average annual evaporation volumes from the Fortran model, as reported in the 2009 Depletion Study, are presented in Table 1 along with results from the RiverWare model. The pre-enlargement scenario uses a different reservoir configuration with the same input data. Average annual net evaporation volume from the reservoir between 2015-2019, for the pre-enlargement scenario is 2909 acre-feet. For the post-enlargement configuration, the new model yields an average annual evaporation volume from the reservoir of 3610 acre-feet. Using the new model, the difference between the pre- and post-enlargement is an increase of 701 acre-feet. Comparatively, the Fortran model yields volumes of 2075 and 3087 acre-feet for the pre- and post-enlargement scenarios, respectively, for an increase of 1012 acre feet. The change between the previous and current model versions is -311 acre-feet.

Table 1 – Average annual evaporation calculated from two different reservoir models for the pre-enlargement and post-enlargement scenarios.

Model	Pre	Post	Diff
ResSim (1941 - 2013)	2075	3087	**1012**
RiverWare (2015 - 2019, GridET)	2909	3610	**701**

Supplemental project irrigation depletion is computed by comparing streamflow between the pre- and post-enlargement scenarios, downstream of Woodruff Narrows water users. The total change in annual streamflow from 2015-2019 is an increase of 6,873 acre-feet, of which 701 acre-feet is from evaporation. The remaining 6,172 acre-feet is allocated to supplemental project irrigation. Utah's portion (83%) of the supplemental depletion is 5,123 acre-feet and Wyoming's (17%) is 1,049 acre-feet.

Table 2 – Difference of average total annual depletion between pre-enlargement and post-enlargement scenarios. Total depletion is divided into evaporation and supplemental irrigation.

	Mean Annual Depletion (ac-ft; 2015-2019		
	Total	Evaporation	Supplemental Project
Utah	5705	582	5123
Wyoming	1168	119	1049
Total	6873	701	6172

The original Woodruff Narrows Reservoir was constructed in 1961 to provide supplemental irrigation water for approximately 40,000 acres of meadow hay in Upper Bear River Valley in Utah and Wyoming. The total storage capacity of the reservoir was 28,100 acre-feet, of which 22,500 acre-feet was used for irrigation, 4,000 acre-feet was used for fish conservation for maintaining a minimum flow release from the reservoir of 10 cfs to the main stem of the Bear River during the non-irrigation season, and 1,600 acre-feet was dead storage used for fish conservation in the reservoir. Of the 22,500 acre-feet of storage for irrigation 18,240 acre-feet was generally used as active storage each year, and 4,260 acre-feet was reserved for hold-over storage for the use in drought years. Eighty-three percent of the storage water is allocated to Utah water users and seventeen percent is allocated to Wyoming users.

An updated computer run simulating the original Woodruff Narrows Reservoir operation under normal operating conditions and both original and enlarged dams for the 1980-2020 period was developed. A 50% irrigation efficiency was assumed for the simulation, with 50% of the return flow occurring in the diverting month, 30% of the 2nd month and the remaining 20% the 3rd month. Unlike the previous model, municipal or industrial water use was assumed to be zero

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COMPARISON TO OBSERVED DATA

Several shortcommings were identified in the representation of reservoir operations during the conversion from Fortran to RiverWare. Subsequently, corrections were made to the RiverWare ruleset and model structure that improved the ability to simulate historic reservoir elevations as shown in Figure 1. Reservoir storage for the post-enlargement period is compared with reservoir elevations observed during the period when both timeseries are availabe. A close match between simulated and observed reservoir storage indicates that the updated model represents actual system well. However, the new model underestimates storage approximately 20% of the time. Typically this overestimation occurs when the reservoir is between 11.5 KAF and 25 KAF because of the simplistic way that the model accounts for holdover storage.

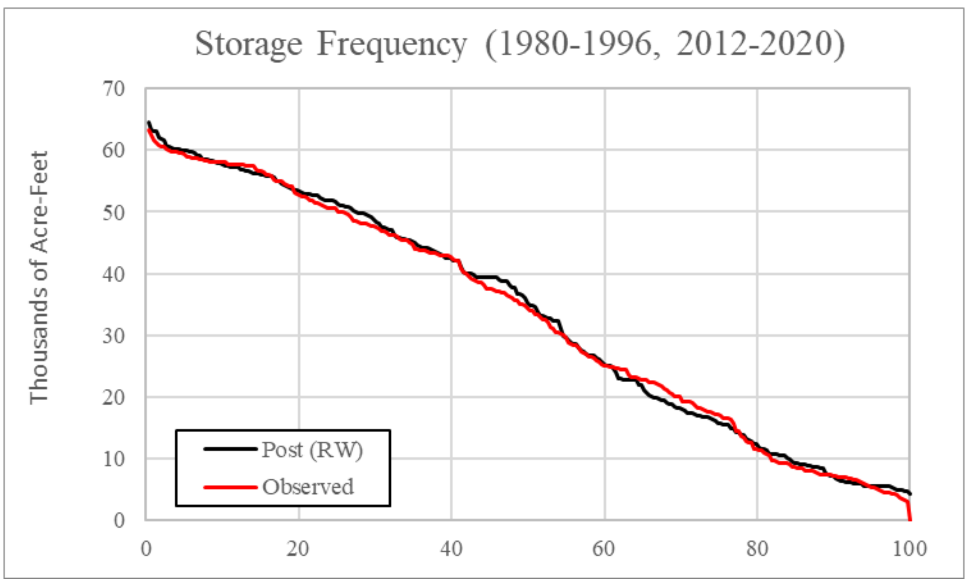

Figure 1 – Frequency of Woodruff Narrows reservoir storage during 1980 – 1996 and 2012 – 2020 as observed and simulated using the updated RiverWare (RW) model.

COMPARISON TO PREVIOUS MODEL

The same inflow hydrograph is used in both models during the overlapping simulation period (1980-2013). The same agricultural and M&I demand schedules are used in both models, except that the Fortran model did not include the M&I demand in the pre-enlargement scenario whereas the RiverWare model does include the M&I demand in the pre-enlargement.

Model rules that determine storage targets, storage limitations and reservoir releases were modified in the new model. Those modifications include the Bear Lake storage restriction (for post-enlargement scenario only), conservation storage goals, and flood control releases. The effect of changing the simulation period and improving the operational rules , using the same evaporation method as the previous model, resulted in changes to average annual net evaporation volumes of +4% and -10% for the pre- and post-enlargement scenarios. The difference between scenarios was 616 acre-feet, which is 396 acre-feet , or 39% lower than the difference of 1012 estimated form the previous study.

Storage between models and scenarios is compared in Figure 2 for the overlapping simulation period which overlaps between models and observed data (1980 – 1996). Simulated storage in Figures 1 and 2 used the updated evaporation method. The Fortran model overestimates storage 55% of the time and fails to simulate spillway releases resulting in underestimation of the storage 13% of the time. Storage above the 75th percentile is well captured by both models. Overall, the new model simulates the actual system (post-enlargement) better than the previous model.

No comparison is made between observed and simulated reservoir contents for the pre-enlargement scenario since the updated model was not configured to run prior to the enlargement project (pre-1980). Such a comparison is unnecesary because the ability to replicate pre-enlargement operations is inconsequential since the depletion procedure compares evaporation during the post-enlargement period to a hypothetical scenario which uses the same hydrology and evaporation rates with a pre-enlargement reservoir capacity and operational targets. Nevertheless, simulated storage from the pre-enlargement scenario is compared to that of the previous model in Figure 2. The new model results in more storage when the water elevation is above the spillway and when the reservoir is at or below 12 KAF. With the new model, storage between the two scenarios is the same when the reservoir levels are low – below 10 KAF,which occurs 20% of the time. Whereas, storage between the scenarios simulated with the Fortran model were the same less than 5% of the time.

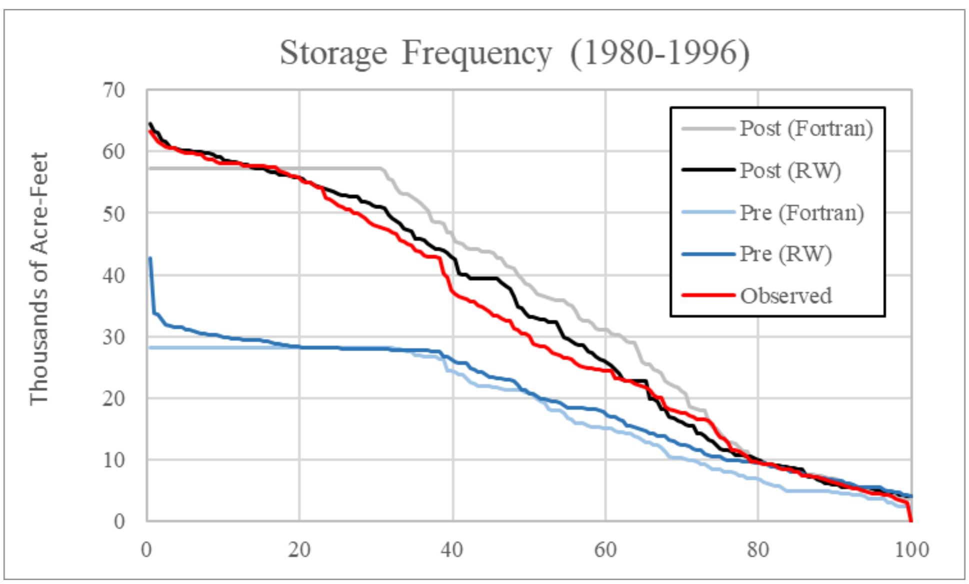

Figure 2 – Frequency of Woodruff Narrows reservoir storage during 1980 – 1996 as observed, simulated using both the updated RiverWare (RW) and Fortran models for both the pre-enlargement and post-enlargement scenarios

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EVAPORATION RATE

Monthly evaporation rates for both shallow and deep water at the location of Woodruff Narrows reservoir were extracted from GridET then applied within the new model. The monthly evaporation used during simulation assumed varies logarithmically with effective reservoir depth which is computed as the quotient between surface area and volume. The relationship between reservoir stage and the effective depth used in the evaporation equation is graphed in Figure 3. Monthly precipitation was also extracted from GridET then used within the model to compute net evaporation rates. Average monthly net evaporation rates from GirdET are plotted in Figure 5.

Timeseries of effective monthly net evaporation rates (computed post-facto as a factor of effective reservoir depth) used in the post-enlargement scenario of the new model are plotted in Figure 4 for each month of the simulation. Along with the fixed monthly rates used in the Fortran model for both pre- and post-enlargement scenarios. One significant difference between the rates is that those used in the Fortran model do not fall below zero. However, in the new model net rates during winter are frequently negative due to the low potential evaporation rate and the relatively high amount of precipitation. Monthly effective net evaporation rates from the updated model for the two scenarios are directly compared in Figure 6, which shows a predominant equivalence between the two scenarios but a slight tendency for higher rates in the pre-enlargement scenario, especially for the highest range of net evaporation rates.

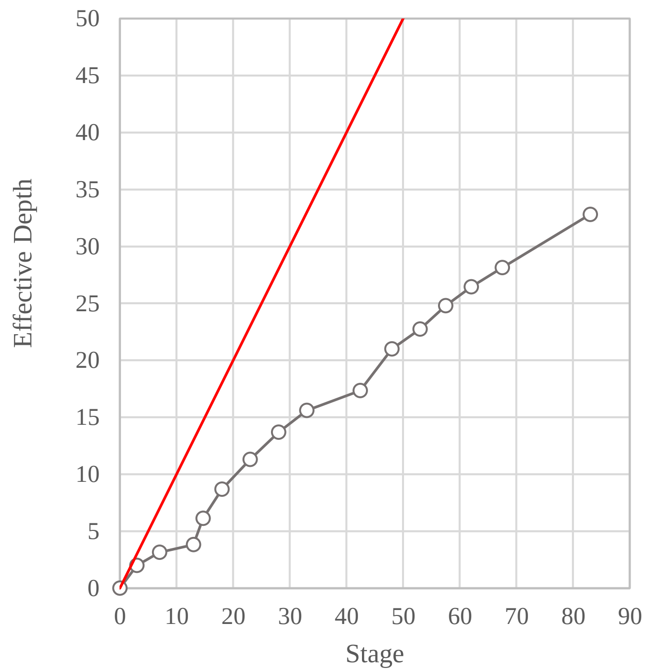

Figure 3 – Relationship between reservoir stage and effective depth used to compute the evaporation rate

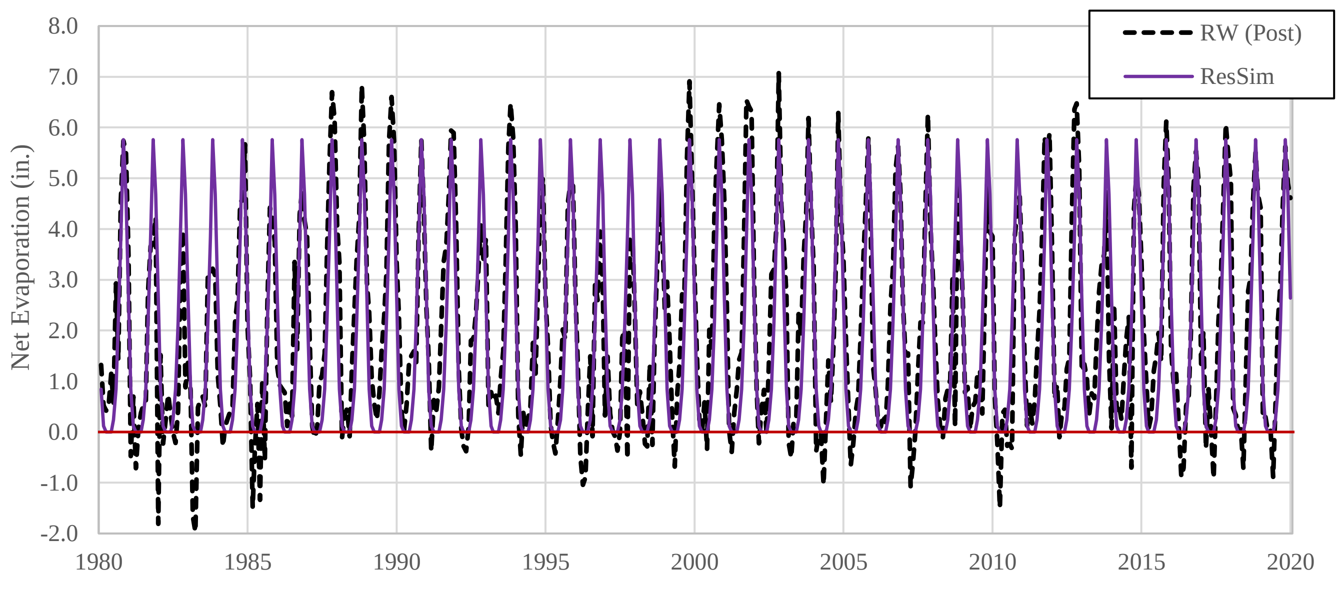

Figure 4 – Monthly net effective evaporation rates computed in RiverWare for the post-enlargement scenario and the Fortran model for both scenarios.

Table 3 and Figure 7 summarize the monthly timeseries into monthly averages to compare between the fixed average monthly rates used in the Fortran model and the averge effective rates computed from simulation of the two scenarios using the new model. Rates for the two scenarios used in the new model differ because they are functions of effective reservoir depth which is dependent on the reservoir water surface elevation which in turn is a function of the hydraulic representation of the reservoir and parameters governing the reservoir operations.

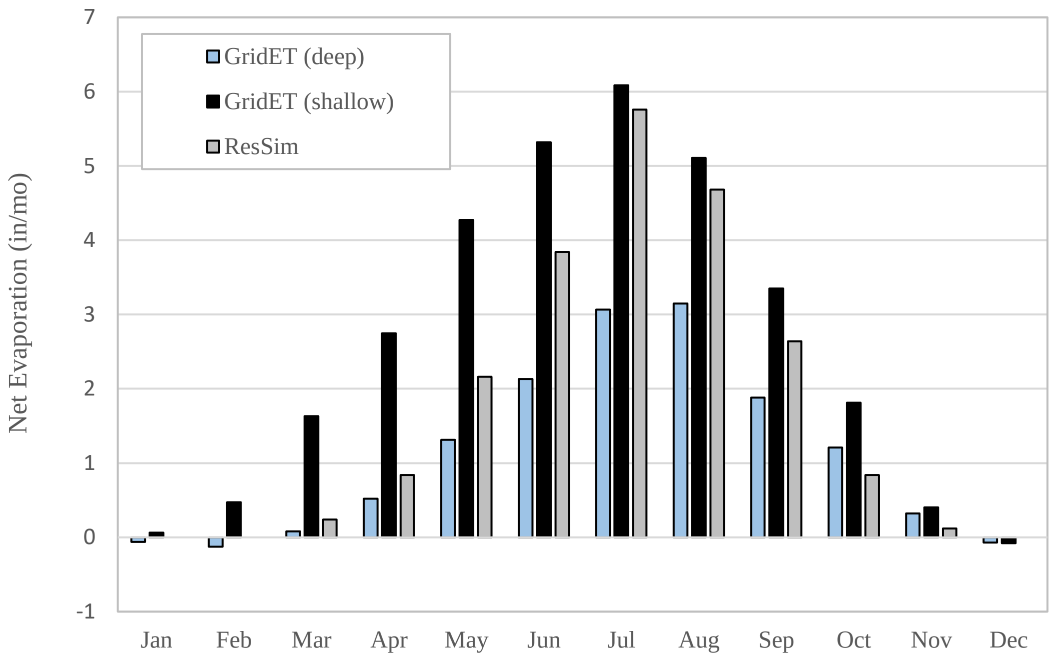

Figure 5 – Average monthly net evaporation rates for deep and shallow open water bodies computed using the GridET software program. Net evaporation rates used in ResSim are plotted for comparison.

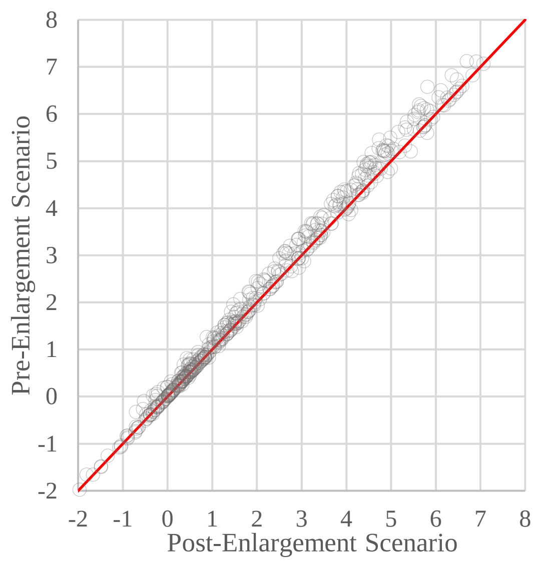

Figure 6 – Monthly net effective evaporation rates for the two scenarios computed using Grid ET open water evaporation and effective reservoir depth

As shown in Table 3, the average annual evaporation rate increased by 4.5 and 3 inches for the pre- and post-enlargement scenarios, respectively. Those translate to 21% and 14% increases over the rates used in the Fortran model for the pre- and post-enlargement scenarios, respectively.

Total annual evaporation volumes simulated for both enlargement scenarios using the new and previous models are compared in Figure 8. Typically, rates from the previous model exceed those from the new model because net during many winter months the net evaporation rate was negative due to significant amounts of precipitation. The negative monthly net evaporation was not captured in the previous model because it used fixed monthly averages with minima of zero. Rates from the new model exceed those of the previous model also because rates for shallow open water are higher than fixed monthly averages and the average effective reservoir depth is 17 feet in the post-enlargement scenario and thus is more closely classified as shallow which are much higher than the rates for shallow open water as shown in Figure 5.

Table 3 – Average monthly effective net evaporation rates for the two scenarios computed using the updated model compared to those from ResSim

Month	RiverWare		ResSim
	Pre	Post	
Jan	0.1	0.1	0.0
Feb	0.3	0.3	0.0
Mar	1.2	1.1	0.2
Apr	1.8	1.7	0.8
May	2.7	2.5	2.2
Jun	4.4	4.1	3.8
Jul	5.7	5.4	5.8
Aug	4.7	4.6	4.7
Sep	2.8	2.7	2.6
Oct	1.4	1.3	0.8
Nov	0.3	0.3	0.1
Dec	0.0	0.0	0.0
Annual	25.6	24.1	21.1

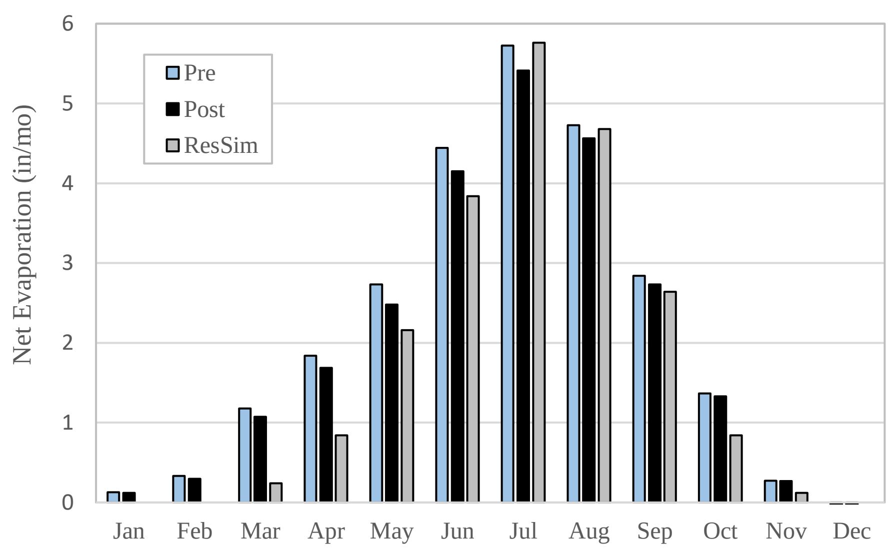

Figure 7 – Average monthly effective net evaporation rates for pre- and post-enlargement scenarios using the updated model compared to the fixed monthly rates used for both scenarios in the previous model

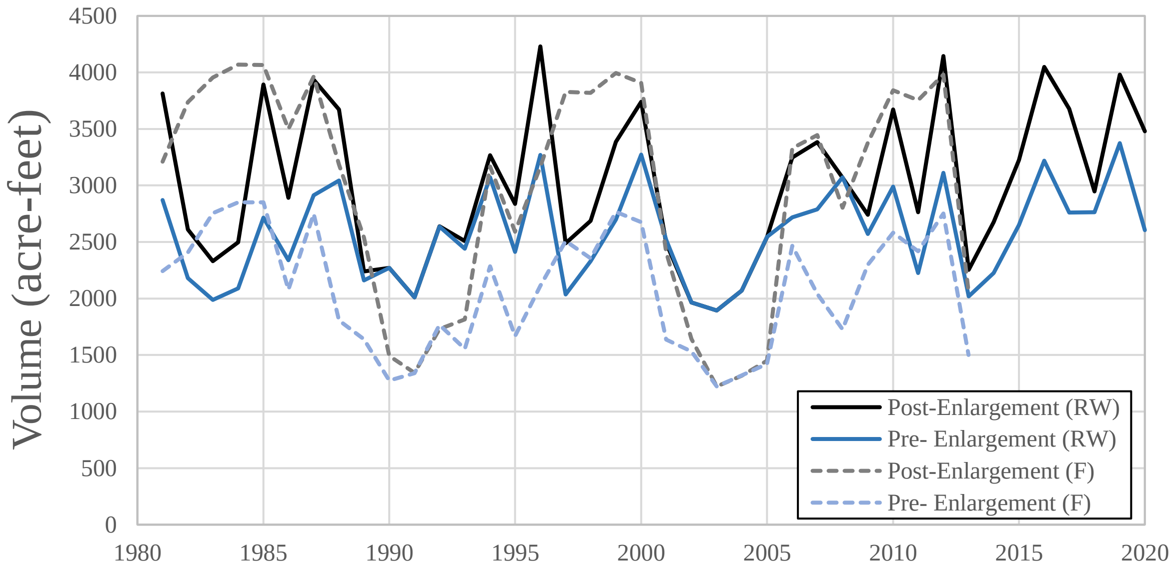

Figure 8 – Annual net evaporation volume for both scenarios computed using the Fortran and RiverWare models

CONCLUSION

This study has estimated a difference in average annual evaporation due to enlargement of the dam that is less than the quantity estimated in the previous study. The difference estimated from this study is 701 acre-feet, whereas the difference from the previous study was 1012 acre-feet. This is a 31% reduction in the estimated increase in evaporation resulting from enlargement of the dam. Accordingly, the evaporative depletion allocation to each state resulting from the dam enlargement project is 582 acre-feet for Utah (83%) and 119 acre-feet for Wyoming (17%). Note that the time periods used for the two studies are inconsistent. The previous study used averages from 1941-2013, whereas this study uses 2015-2019 to be consistent with other depletion calculations.

Supplemental project irrigation depletion is computed by comparing streamflow between the pre- and post-enlargement scenarios, downstream of Woodruff Narrows water users. The total change in annual streamflow from 2015-2019 is an decrease (depletion) of 6,172 acre-feet, of which 701 acre-feet is from evaporation. The remaining 6,172 acre-feet is allocated to supplemental project irrigation. Utah's portion (83%) is 5,123 acre-feet and Wyoming's (17%) is 1,049 acre-feet.

The reduction in the change of evaporation between scenarios is a result of an improved simulation model which better represents the reservoir hydraulics and operations. Without changing the evaporation data or method, the effect from changing the simulation period, improving the modeled hydraulics, and updating the operations resulted in a 4% increase in average annual net evaporation for the pre-enlargement scenario and a 10% decrease for the post-enlargement scenario. Estimated change to average annual net evaporation from the reservoir resulting exclusively from the change to the evaporation method and data is a 20% and 8% increase for the pre- and post-enlargement scenarios, respectively.

Two factors contribute to the disproportionate increase between the scenarios. They are are 1) the improved temporal detail of weather data timeseries which captures effects of high winter and spring prepcipitation and 2) the reduced evaporation due to higher reservoir elevations and the resultant reduction of heat storage. Overall, the average monthly evaporation rates from GridET are higher, however, the availability of estimates of historic monthly rates allows the model to capture effects of high precipitation for some months which are averaged out of the rates used in the Fortran model. The impact of this factor is greater for the post-enlargement scenario because the post-enlargement scenario results in both a lower evaporation rate due to the larger effective depth and a larger surface area than the pre-enlargement scenario.

Net evaporation rates computed using the method employed in the new model are inversely related to reservoir depth. Therefore, effective rates are generally higher in the pre-enlargement scenario when the effective depth of the reservoir remains lower than it is in the post-enlargement scenario, except for dry years when the reservoir elevations are the same or similar in both scenarios.

Appendix D
Details of Specific Idaho Efforts

Idaho Portion Bear River Compact Depletion Report

INTRODUCTION

This report describes the methodology used to produce the Idaho portion of the 2019 Bear River Basin land use map classification. It lists the datasets used for compiling the land use classification as well as the various techniques used in photo interpretation and GIS analysis.

DATASETS

<u>VECTOR datasets</u>

Utah provided a preliminary land classification for the entire Bear River Compact (BRC) area including Wyoming and Idaho as part of their annually published Water Related Land Use (WRLU) project. Utah's methodology in determining a land use classification utilizes an R script to annually update their WRLU data and coordinate field visits to verify changes. A minimal number of field visits were conducted in Idaho and Wyoming. Utah provided this dataset to Idaho as a preliminary starting point with the recommendation and understanding that Idaho would verify land use classifications and line geometry based on its own internal decision-making processes. This "preliminary" dataset provided by Utah contained additional attributes not used by the Bear River commission.

In the initial stages of our review, Idaho experimented with a Random Forest (RF) methodology to classify land use. RF uses the Normalized Difference Vegetation Index (NDVI), Landsat Satellite Thermal Band, and Sentinel Satellite Synthetic Aperture Radar (SAR) data as input. The output is a 30-meter raster. The Random Forest methodology uses training sites of known land use to determine land use over a larger area. Idaho used approximately 500 training sites to calibrate the Random Forest methodology for the 2019 Depletion Study.

In addition to Utah's R-script enabled land classification and Idaho's Random Forest methodology, two other land use classifications were considered – the original 1976 land use classification and the 2009 land use classification. To minimize the need for turning on and off layers within the GIS project, observe the differing results from the four land classification methodologies, and allow for easier tabular comparison of the four landuse determinations, the Zonal Statistics tool in ArcGIS was implemented. The Zonal Statistics tool in ArcGIS analyzes multiple input datasets and outputs computations performed on selected zones. The zones for this analysis were defined as field polygons.

Idaho rasterized the 1976 land use classification, the 2009 land use classification, and the 2019 WRLU vector datasets to 1-meter resolution rasters. The 2019 RF classification was already a rasterized dataset but was resampled to 1-meter resolution. The Zonal Statistics tool calculated the majority land use for each field polygon based on values in the 1976 classification, 2009 classification, 2019 WRLU classification, and RF classification rasters. The Zonal Statistics tool eliminates multiple land use types (speckling) within an agricultural field polygon by assigning the polygon the land use of the majority of the pixels falling within the polygon. The output of the Zonal Statistics tool was a 2019 polygon dataset with an attribute table containing four additional columns with the land use from the 1976 classification, 2009 classification, 2019 WRLU classification, and RF classification.

RASTER datasets

Natural color and color-infrared imagery acquired through the National Agricultural Inventory Program (NAIP) was heavily utilized for this project. NAIP imagery from various years was available. The 2019 Idaho NAIP has 60-centimeter resolution and was used as the primary source for determining current land use and editing field boundaries. Although only a snapshot in time, the initial land use assessment was made by examining the 2019 NAIP imagery. Plant vigor and crop details are better revealed in a color-infrared band. Fields that appear to be irrigated and have an intense red infrared color were classified as irrigated. However, "wetlands/naturally sub-irrigated pasture and hay" also are an intense red color but may or may not be "irrigated." Water rights and temporal satellite imagery is helpful in differentiating between wetlands/sub-irrigated land and irrigated land.

False-color Sentinel satellite imagery was also utilized to determine irrigation status, mainly to see temporal changes in field conditions early and late in the irrigation season. Wet soils on bare ground are easily distinguishable on Sentinel imagery. Sentinel data is downloaded from Google Earth Engine and processed in-house into 3-band false-color images with a 10-meter resolution. Sentinel uses the Military Grid Reference System (MGRS). The Idaho portion of the Bear River Compact project area is covered by the T12TUM, T12TUN, T12TVM, T12TV MGRS tiles. The irrigation season of use for water rights in the Bear River Compact project area is from April 1 or April 15 (depending on location) to October 31. Imagery for the months of May-September were typically reviewed with a heavy emphasis on ground conditions during the summer months of June, July, and August. Irrigation practices were identified by sequencing thru multiple satellite images during the season of use.

Since Landsat satellite imagery was readily accessible in-house, NDVI was utilized as an additional reference in determining irrigation status. NDVI is a simple numerical indicator that can be used to analyze remote sensing data. It is directly related to photosynthetic capacity and energy absorption. NDVI values fall between -1.0 (water) and +1.0 (dense, photosynthetically active vegetation). It was determined that high NDVI values were not always indicative of irrigated cropland due to extensive wetland conditions along the Bear River and its tributaries. Further interpretation of imagery, verification in the field, and review of water rights was required to determine irrigation practices in these areas.

The National High Altitude Photography (NHAP) program was coordinated by the United States Geologic Survey as an interagency project to acquire cloud-free aerial photographs at an altitude of 40,000 feet above mean terrain elevation. The NHAP program was operational from 1980 to 1989 and included black and white aerial photographs at a scale of 1:80,000 and color-infrared aerial photographs at a scale of 1:58,000. Idaho used an image service to access the color-infrared NHAP imagery (https://tiles.arcgis.com/tiles/LLVEmB8Lsae3Um4s/arcgis/rest/services). This image service was helpful in determining historical conditions and verifying 1976 land use classifications. Although the imagery was not collected in 1976, it was an indispensable resource nonetheless as it provided much better resolution than the 1976 58-meter Landsat imagery.

Black and white Digital Ortho Quarter Quads (DOQQs) were occasionally used as a reference, mostly for historical perspective. Seventy percent of the images for the DOQQ dataset have dates from 1992 with the remaining images having dates from 1993 and 1994.

SUPPORTING LAND COVER datasets

To further refine the interpretation, data from the National Agricultural Statistics Service (NASS) 2019 Idaho Cropland Data Layer (CDL) was utilized. NASS data are compiled nationwide, county by county, and as a raster, geo-referenced, crop-specific land cover dataset with 30-meter ground resolution.

OTHER SUPPORTING Datasets

National Hydrologic Database flow lines for the Bear River Basin were used to help determine the location of canals, ditches, and streams in making irrigation determinations. This dataset helped highlight hydrologic details that may have gone unnoticed by looking at the imagery alone.

A map service from the U.S. Fish and Wildlife Service was utilized to determine Wetlands, Emergent Wetlands, Forest/Shrub Wetlands, and Inland Waters (https://www.fws.gov/wetlands/arcgis/rest/services).

The in-house spatial datasets used to locate the place of use (POU) and point of diversion (POD) for all active water right applications, permits, rights, and transfers in basins 11, 13, and 15 provided justification for potentially reclassifying the original 1976 base map. Basins 11, 13, and 15 were not included in the Snake River Basin Adjudication (SRBA) but will be a part of the Bear River Basin Adjudication (BRBA) that will commence in 2022. Water rights were easily categorized based on their priority date: pre-1976, between 1976 and 2009, and post-2009. The reason for the intermediate priority date category between 1976 and 2009 was to identify changes that occurred in water right POUs since the analysis was completed for the 2009 Depletion Study. In that analysis, there was only pre-1976 water rights and post-1976 water rights. There have been substantial changes in the water right POUs since the 2009 analysis, and we expect water right POU changes to continue to occur with the forthcoming adjudication.

BOUNDARIES AND SUBBASINS

The boundary of the Bear River Compact was created by using IDWR administrative basin boundaries, which are derived from USGS 1:24k quadrangle series maps.

The Biennial report from the April 1992 Bear River Commission meeting minutes (Appendix F, page 3) states:

> "Compact divisions in Idaho are the Central and Lower. A surface water boundary, between the Central and Lower divisions, was developed to distinguish lands irrigated by surface water diverted from the Central Division but are located in the Lower Division (below Stewart Dam). The area mostly west of Stewart Dam designates lands located outside the

> Central Division but are irrigated by surface water originating from the Bear River in the Central Division. Subbasin boundaries were taken from a research report (#125 by Hill et al.), transferred to 1:100,000 topographic maps, and manually digitized. Subbasins are those areas described in report #125 for which unique consumptive water use was developed. Division and subbasin boundaries were edited to follow the PLSS QQ lines so each QQ and water right clearly falls into one division and subbasin."

Division and subbasin boundaries for the 2009 Depletion Study were re-created using 4th and 5th field hydrologic unit boundaries (HUCs) and quarter/quarter public land survey boundaries (primarily around the groundwater and Central/Bear Lake subbasin boundaries). Division and subbasin boundaries from 2009 were replicated and used for the 2019 Depletion Study.

GIS ANALYSIS PROCEDURE USED TO DETERMINE LAND USE CHANGE SINCE 1976

Photointerpretation and GIS analyses were completed by Margie Wilkins, GIS Analyst II with the Idaho Department of Water Resources. IDWR began the 2019 Depletion Study analysis with the 2019 WRLU dataset provided by Utah. Idaho digitized and incorporated additional rivers, roads, and urban areas into the dataset. Idaho also made edits to delineate where water right POU shapes overlap or divide field boundaries. The land use classifications as determined in the 1976 base map, the 2009 depletion review, Utah's 2019 WRLU, and IDWR's 2019 RF data (described in the vector datasets section above) were joined to the attribute table. A new field was created in the attribute table for the 2019 land use classification. Initially, the 2019 land use classification was set to the classification determined by the random forest classification. A methodical review was then performed section by section through all townships using 2019 NAIP, 2019 Sentinel imagery, 2019 Landsat imagery, NDVI, and when appropriate other supplemental spatial information as noted above to determine the 2019 land use classification. Confidence in the accuracy of the RF methodology began to wane during this initial review, and Idaho chose to switch to manual photointerpretation to determine land use classifications.

Water right POUs played a large role in designating a field as irrigated cropland. If there was no evidence of water being applied in 2019 and yet a water right POU was in place for the field, then the previous five years were investigated to determine irrigation status. Review of the previous five years was completed primarily using NDVI, aerial imagery, satellite imagery, or the CDL. Frequently, one of the previous five years showed some evidence of irrigation and the field was classified as irrigated land; otherwise, a non-irrigated cropland designation was assigned. If there was no evidence of water being applied in 2019 and no water right POU was present, but the imagery suggested an irrigated crop (presence of healthy vegetation), then further review was conducted.

As was the case in the 2009 Depletion Study, errors in the 1976 land use classification were identified - most likely due to less sophisticated technology and the lower resolution imagery and datasets available in the 1990s. IDWR staff extensively relied on the NHAP imagery to determine legitimate land use changes between the 1976 classification (which appears to contain errors) and the 2019 classification. In the 2019 analysis, an earnest effort was made to use the term "RECLASS" to denote areas where the original 1976 base map was in error. Therefore, it should be noted that a more thorough use of the "RECLASS" designation is used in this 2019 analysis compared to the 2009 analysis.

WATER RIGHT ANALYSIS PROCEDURE USED TO DETERMINE NEW & SUPPLEMENTAL ACREAGE

NEW IRRIGATION

A review of all Idaho water rights within the Bear River drainage was conducted and the data separated into three groups based on priority date: a) water rights with priority dates pre-1976, b) water rights with priority dates between 1976 and 2009, and c) water rights with priority dates post-2009. The POUs for these water rights were rasterized to 1-meter resolution. Using the Zonal Statistics tool, every field was attributed so that if a majority of the field was covered by a water right it was attributed with a value of "1", if a field was not covered in any way by a water right its value remained "Null", and if a field was partially covered by a water right it was attributed with a "0". This method of attributing the fields was not considered final, but merely allowed for easier tabular comparisons and querying. It also highlighted fields that required additional vector editing and helped refine areas of "ADDED" and "REMOVED" irrigation for the final tally.

Land considered to be new irrigation based on water right information was compared against the results of the manual photointerpretation for land classification. Land where a water right priority date review suggested new irrigation, but GIS review had not initially found to be irrigated, was flagged and given a second review by GIS staff to correct any misclassifications.

Land where the GIS classification suggested new irrigation, but there was no corresponding water right was also reviewed again by water right agents and GIS staff until there was consensus on a classification. In some cases, this resulted in changing the classification. In other cases, it involved conducting a deeper investigation to confirm if irrigation was occurring without a water right.

In our 2019 review, we found instances where land had been designated as "ADDED" in the 2009 analysis but was not designated as " ADDED" in the 2019 analysis. This situation was often caused by water users updating their pre-1976 water right place of use. The Bear River Adjudication claims process will allow users to update their pre-1976 water right if they can fulfill the requirements for doing so such as clarifying the location of the place of use from nominal quarter-quarter sections to specific locations or by presenting historical evidence that the water right has been in use since 1976.

Special attention was paid to land classified as non-irrigated in 1976 but covered by a pre-1976 water right, and land classified as irrigated in 1976, but not covered by a pre-1976 water right. After extensive comparisons between 2019 imagery and the NHAP imagery were made to determine if irrigation practices changed on the land, a value of "ADDED", "SUBTRACTED", or "RECLASS" was assigned to the "CHANGE_19" attribute. To accommodate one situation in which a place of use was transferred from one location to another but did not amount to additional depletion, we assigned a value of "TRANSF ADD"(155 acres in the Central Division) .

Two half pivots located west of Soda Springs, just south of the highway were identified as new irrigation since 1976 from a groundwater source. According to a paper published by the Idaho Geological Survey (Martin, M., Wylie, A., Otto, B. "Hydrogeologic Analysis of the Water Supply for Bancroft, Caribou County, Idaho." Idaho Geological Survey, Information Circular 61., 2005), the groundwater divide between the Portneuf and the Bear River Basins is located south of the pivots.

These acres were not counted as a new depletion because the source is not from the Bear River Basin.

SUPPLEMENTAL IRRIGATION

A review of water rights also included determining new supplemental irrigation. If a water right with a priority date between 1976 and 2019 overlaid land that had a pre-1976 water right, and appeared irrigated in 2019, the acreage for the supplemental water right was counted. There were instances where authorized acres under the supplemental right did not appear irrigated in 2019, but imagery from prior years did show evidence of irrigation. These were treated on a case-by-case basis in determining supplemental acreage.

Idaho used the method developed by Wyoming to calculate supplemental water right depletions. The Wyoming method estimates volume of water depleted using the number of days a pump is on during regulation in the Central Division, the number of acres, and a depletion rate in acre-feet per acre per day. To apply this method, IDWR utilized power consumption records provided by Utah Power for the supplemental water rights within the Central Division. Most of the post-1976 supplemental rights in the Bear River Basin in Idaho are from a groundwater source, and most deliver water by pumping to a sprinkler system. Power records from the years 2010 to 2020 were used to estimate depletions. Staff used water right records, county tax lot ownership records, aerial imagery, and data from the 2009 and 2019 depletion analysis to match power records with specific wells. This allowed IDWR to determine irrigated acreage, type of irrigation system, pump horsepower, flow rate, overlapping water rights, and the number of wells per system. Results were not calculated for every supplemental system because some of the wells could not be matched to power records, some systems were diesel or gas-powered, and some systems included multiple wells or water rights.

Monthly power usage (KWh) was converted to days by determining the horsepower of the electric pump and converting power usage to the number of days the pump was running. The pump run time was then incorporated into the Wyoming method as the number of days the pump was running during the irrigation season. IDWR staff also spoke with the supplemental water users to have users estimate the number of days each year they use their supplemental irrigation wells. The estimates received through verbal communication generally agreed with power record analysis.

A weighted average of depletion per supplemental acre was calculated based on the total depletion and acreage irrigated with the supplemental water rights. The depletion was only estimated for four of the seven supplemental water rights in the Central Division using the Wyoming method, but those four water rights represent almost half of the total acreage identified as supplemental since 1976 in the Central Division. The results of the depletion estimates are 0.36 acre-feet per acre on average for 2010 through 2020 in the Idaho Central Division. This estimate was similar to Wyoming's supplemental depletion analysis results. A significant variable of Wyoming's method is counting days only during regulation. This limits the supplemental use in most years, except for very dry irrigation seasons when regulation is occurring the entire irrigation season. Another important factor in the Wyoming depletion method is use of a depletion rate of 0.017 acre-feet per acre per day. This value is based on the month of August, which may overestimate depletions when it is used for an entire irrigation season.

The per acre supplemental depletion rates calculated individually by the three states were all similar. The Technical Advisory Committee recommended that for the 2019 Depletion Study all three states should use 0.4 acre-feet per acre for supplemental depletions. Idaho applied this rate to the total number of acres identified as supplemental in the land classification effort. This included those systems that converted a post-1976 supplemental water right to primary use on lands identified as irrigated prior to 1976. If the pre-1976 primary water rights have been retained but are unused on those acres, the net increase in depletion since 1976 should be the difference between the pre-1976 primary right depletion and the post-1976 total depletion. Our best estimate of that increase in depletion is to apply the 0.40 acre-feet per acre to those acres. If the pre-1976 water rights have been moved to some previously un-irrigated land, the new acreage depletion would have been counted as new irrigation in the land classification effort. In that case, the net increase in depletion since 1976 is the new acreage depletion plus the post-1976 total depletion on the original acres minus the pre-1976 primary right depletion on the original acres. The result is the same and is estimated by applying the 0.4 acre-feet per acre depletion to the acreage originally identified as supplemental.

In the Central Division, 752 supplemental acres deplete 353 acre-feet per year. In the Lower Division, 11,219 acres deplete 6,231 acre-feet per year.

FIELD VERIFICATION

Limited field verification was completed by IDWR staff. Matt Anders and Ethan Geisler verified irrigation/non-irrigation for selected areas in the Central Division in July 2021.

Acres by Subbasin for Irrigated Cropland and Wetlands/Naturally Sub-irrigated Pasture and Hay

	ADDED ACREAGE (ac)	SUBTRACTED ACREAGE (ac)	NET IRRIGATED ACREAGE
Bear Lake subbasin	510	86	424
Thomas Fork subbasin	313	43	270
Cokeville subbasin	0	0	0
TOTAL	**823**	**129**	**694**
LOWER DIVISION			
Bear Lake subbasin	1,083	749	335
Cache Valley subbasin	2,202	2,204	-2
Malad subbasin	3,925	1,245	2,680
Oneida subbasin	2,102	365	1,737
Soda Springs subbasin	1,055	266	789
Tremonton subbasin	2,227	19	2,208
TOTAL	**12,595**	**4,847**	**7,748**

Supplemental Water Rights and Acreage by Division and Subbasin

Division	Subbasin	Water Right	Priority Date	Acres
Central	Thomas Fork	11-7120A	5/25/1977	2.0
Central	Thomas Fork	11-7120C	5/25/1977	5.2
Central	Thomas Fork	11-7121	6/10/1977	74.8
Central	Thomas Fork	11-7130	8/10/1977	237.5
Central	Thomas Fork	11-7135	9/27/1977	91.9
Central	Thomas Fork	11-7155	12/11/1978	192.7
Central	Thomas Fork	11-7325	7/28/1983	36.0
Central	Thomas Fork	11-7673	5/25/1977	2.0
Central	Thomas Fork	11-7674	5/25/1977	122.0
Lower	Bear Lake	11-7051	8/18/2010	166.8
Lower	Bear Lake	11-7119	6/12/1997	303.4
Lower	Bear Lake	11-7125	8/24/1977	63.0
Lower	Bear Lake	11-7147	6/5/1978	75.0
Lower	Bear Lake	11-7158	5/14/1979	2.6
Lower	Bear Lake	11-7162	5/22/1979	24.6
Lower	Bear Lake	11-7168	7/18/1979	2.2
Lower	Bear Lake	11-7355	5/31/1985	45.0
Lower	Bear Lake	11-7357	4/16/1986	1.0
Lower	Bear Lake	11-7374	4/5/1989	92.0
Lower	Bear Lake	11-7384	5/9/1990	2.0
Lower	Bear Lake	11-7391	2/13/1991	70.5
Lower	Soda Springs	11-7284	3/22/1982	178.0
Lower	Soda Springs	11-7309	2/9/1983	7.6
Lower	Soda Springs	11-7362	10/20/1994	1.0
Lower	Oneida	13-7147	1/19/1977	287.0
Lower	Oneida	13-7161	4/15/1977	230.0
Lower	Oneida	13-7198A	6/20/1977	193.0
Lower	Oneida	13-7391	5/12/1983	1.0
Lower	Oneida	13-8023	6/28/2018	85.6
Lower	Oneida	29-10310	4/1/1980	32.5
Lower	Cache Valley	13-7116	6/23/1988	163.0
Lower	Cache Valley	13-7134	8/20/1976	52.2
Lower	Cache Valley	13-7148	2/24/1977	149.0
Lower	Cache Valley	13-7156A	9/6/1977	81.0
Lower	Cache Valley	13-7156B	9/6/1977	111.4
Lower	Cache Valley	13-7157	3/26/1984	52.1
Lower	Cache Valley	13-7173	4/29/1977	52.2
Lower	Cache Valley	13-7174	5/2/1977	11.8
Lower	Cache Valley	13-7180	5/5/1977	79.0

Lower	Cache Valley	13-7187	1/26/1999	20.7
Lower	Cache Valley	13-7203	7/12/1977	5.0
Lower	Cache Valley	13-7249	2/27/1979	2.0
Lower	Cache Valley	13-7253	4/30/1979	1.0
Lower	Cache Valley	13-7254	12/17/1980	10.5
Lower	Cache Valley	13-7255	7/27/1979	72.7
Lower	Cache Valley	13-7277	3/14/1980	10.2
Lower	Cache Valley	13-7349	9/4/1981	102.2
Lower	Cache Valley	13-7373	3/21/1983	1.0
Lower	Cache Valley	13-7389	5/24/1983	447.5
Lower	Cache Valley	13-7392	5/27/1983	52.9
Lower	Cache Valley	13-7394	7/16/1983	25.0
Lower	Cache Valley	13-7401	7/14/1983	10.0
Lower	Cache Valley	13-7464	8/6/1989	110.1
Lower	Cache Valley	13-7465	11/23/1989	8.0
Lower	Cache Valley	13-7469	12/20/1989	137.5
Lower	Cache Valley	13-7476	10/29/1990	185.0
Lower	Cache Valley	13-7488	3/15/1991	9.3
Lower	Cache Valley	13-7491	1/9/1992	8.0
Lower	Cache Valley	13-7695	5/4/1977	44.0
Lower	Cache Valley	13-7696	5/4/1977	22.0
Lower	Cache Valley	13-8089	7/14/1983	202.0
Lower	Malad	15-7033	8/5/1976	70.1
Lower	Malad	15-7036	3/21/1977	134.5
Lower	Malad	15-7048	10/6/1978	4.8
Lower	Malad	15-7056	10/18/1978	11.0
Lower	Malad	15-7083	8/5/1982	8.1
Lower	Malad	15-7085	9/20/1982	54.0
Lower	Malad	15-7090	5/28/1983	68.0
Lower	Malad	15-7091	5/29/1983	10.0
Lower	Malad	15-7094	6/7/1983	0.3
Lower	Malad	15-7108	9/28/1988	212.5
Lower	Malad	15-7110	12/30/1988	145.0
Lower	Malad	15-7115	12/21/1989	24.0
Lower	Malad	15-7118	2/25/1990	99.9
Lower	Malad	15-7120	1/23/1990	14.5
Lower	Malad	15-7121	1/23/1990	0.0
Lower	Malad	15-7127	3/29/1991	91.6
Lower	Malad	15-7129	5/29/1991	77.5
Lower	Malad	15-7130	7/22/1991	16.8
Lower	Malad	15-7146	9/20/1994	2.0

Lower	Malad	15-7147	10/3/1994	90.0
Lower	Malad	15-7150	4/24/1995	48.0
Lower	Malad	15-7153	4/9/1996	119.1
Lower	Malad	15-7154	8/12/1996	58.6
Lower	Malad	15-7155	9/30/1996	115.9
Lower	Malad	15-7156	11/19/1996	68.0
Lower	Malad	15-7158	3/31/1997	34.2
Lower	Malad	15-7171	2/1/1999	9.9
Lower	Malad	15-7174	4/23/2000	144.5
Lower	Malad	15-7175	8/30/1999	9.0
Lower	Malad	15-7176	9/30/1999	71.2
Lower	Malad	15-7179	4/10/2000	3.4
Lower	Malad	15-7189	8/2/2000	520.5
Lower	Malad	15-7190	8/29/2000	47.4
Lower	Malad	15-7191	9/11/2000	38.0
Lower	Malad	15-7192	12/18/2000	37.2
Lower	Malad	15-7195	3/6/2001	339.0
Lower	Malad	15-7223	2/26/2002	192.0
Lower	Malad	15-7224	4/26/2002	96.5
Lower	Malad	15-7226	5/29/2002	15.3
Lower	Malad	15-7227	6/3/2002	22.3
Lower	Malad	15-7228	6/7/2002	2.1
Lower	Malad	15-7229	7/18/2002	63.2
Lower	Malad	15-7230	7/8/2002	170.0
Lower	Malad	15-7231	7/17/2002	171.0
Lower	Malad	15-7236	12/10/2002	10.0
Lower	Malad	15-7237	12/6/2002	30.1
Lower	Malad	15-7240	2/8/2003	157.0
Lower	Malad	15-7242	3/5/2003	7.0
Lower	Malad	15-7243	2/26/2004	57.2
Lower	Malad	15-7244	4/21/2003	67.3
Lower	Malad	15-7246	6/30/2003	13.1
Lower	Malad	15-7247	6/16/2003	66.0
Lower	Malad	15-7253	9/25/2003	34.7
Lower	Malad	15-7254	11/20/2003	56.0
Lower	Malad	15-7255	12/4/2003	4.8
Lower	Malad	15-7256	12/17/2003	36.0
Lower	Malad	15-7258	4/29/2004	10.0
Lower	Malad	15-7264	8/16/2004	52.0
Lower	Malad	15-7265	8/23/2004	185.0
Lower	Malad	15-7267	6/4/2008	58.6

Lower	Malad	15-7270	4/5/2005	12.9
Lower	Malad	15-7275	12/16/2005	28.7
Lower	Malad	15-7280	4/12/2006	131.0
Lower	Malad	15-7291	7/5/2007	128.6
Lower	Malad	15-7294	11/1/2007	22.0
Lower	Malad	15-7298	9/26/2007	111.8
Lower	Malad	15-7314	10/3/2008	11.0
Lower	Malad	15-7320	3/3/2009	119.8
Lower	Malad	15-7347	8/22/2011	104.2
Lower	Malad	15-7365	1/24/2014	87.3
Lower	Malad	15-7367	5/25/2013	138.8
Lower	Malad	15-7369	10/19/2013	42.5
Lower	Malad	15-7370	8/22/2011	104.2
Lower	Malad	15-7373	11/26/2013	185.0
Lower	Malad	15-7379	6/24/2014	5.5
Lower	Malad	15-7381	8/5/2014	24.0
Lower	Malad	15-7383	10/6/1978	2.0
Lower	Malad	15-7384	10/6/1978	12.0
Lower	Malad	15-7402	3/11/2015	2.0
Lower	Malad	15-7408	12/18/2000	67.6
Lower	Malad	15-7441	7/5/2007	63.0
Lower	Malad	15-7442	7/5/2007	64.0
Lower	Malad	15-7460	9/20/1994	7.5
Lower	Malad	15-7462	9/20/1994	4.0
Lower	Malad	15-7463	9/20/1994	6.5
Lower	Malad	15-7470	4/28/1995	114.5
Lower	Malad	15-7477	6/4/2008	30.0
Lower	Malad	15-7481	8/30/1999	6.0
Lower	Malad	15-75	8/1/1988	28.0
Lower	Malad	15-78	5/10/1992	117.0
Lower	Tremonton	15-7028	4/13/1976	30.4
Lower	Tremonton	15-7037	3/28/1977	75.9
Lower	Tremonton	15-7134	12/30/1991	97.2
Lower	Tremonton	15-7135	12/13/1991	13.7
Lower	Tremonton	15-7136	2/21/1992	68.0
Lower	Tremonton	15-7142	1/19/1994	97.2
Lower	Tremonton	15-7143	4/26/1994	116.4
Lower	Tremonton	15-7149	4/20/1995	4.4
Lower	Tremonton	15-7284	1/29/2007	128.0
Lower	Tremonton	15-7346	8/8/2011	181.7
Lower	Tremonton	15-7382	9/4/2014	41.6

Lower	Tremonton	15-7389	10/10/2014	104.8

Appendix E
Details of Specific Utah Efforts

Utah Bear River Commission GIS Mapping Effort

Introduction

The purpose of the Bear River Commission (BRC) GIS group is to map the extent of irrigated land in the Bear River Basin. Through this effort the acreage of land that has come into irrigation since 1976 will be calculated. This added irrigated land, representing post-76 irrigated land, will be used to calculate new depletion rates. Land that is found to be no longer irrigated will be used to subtract the depletion rates calculated in a previous study representing pre-1976 depletion rates. In doing this process, this team will come to a better understanding of how each state is using water in relation to this inter-state compact.

Utah will produce a single feature in a feature geodatabase (UT_BRC_classification_2019). This feature will have the following columns (Landtype76, Landtype19, Change19, Subbasin, Division, State, Acres). Through this feature, irrigated land that has come into production representing post-76 irrigated land and pre-76 irrigated land that is no longer in production will be defined. Each state followed a shared methodology and definitions described in Appendix A, below Utah's specific methods for producing this dataset are defined.t. Also relevant to understanding the use of these data are how the crop-mix (Appendix A) and subsequent depletions (Appendix B) are calculated from this mapping effort.

Methods

Input Data

Two datasets were used to create Utah's 2019 Bear River Commission (BRC) dataset. These were the 2009 Bear River Commission dataset and the 2019 Water Related Land Use (WRLU) dataset (UDWRe 2022). The 2019 WRLU was primarily created from the 2018 USDA National Aerial Imagery Program (NAIP) (USDA 2019). Idaho and Wyoming both had access to the 2019 NAIP imagery, which was not flown for Utah and 2018 represented the closest time period. Both datasets needed to be manipulated for the purpose of this study by creating the Landtype19 and Change19 columns defined in Appendix A The 2019 WRLU data were used as a starting point in creating the Landtype19 column. This column defines the six BRC classifications discussed above. This was created using the R (R Core Team 2022) script below:

```
WRLU$landtype19<-
ifelse(WRLU$IRR_Method=="Subirrigated"|WRLU$Description=="Riparian","WE",
ifelse(WRLU$Description=="Dry Land/Other","OTH",ifelse(WRLU$IRR_Method%in%
c("Drip","Sprinkler","Flood")&!WRLU$Description%in%c("Urban","Turfgrass Urban"),"IR",
ifelse(WRLU$IRR_Method=="Dry Crop","NI",ifelse(WRLU$Description%in%c("Water","Wet
Flats","Sewage Lagoon"),"WA","URB")))))
```

In more simple wording, this script states that sub-irrigated and riparian land will be called WE, Dry Land/Other (mainly wildland) will be called OTH, irrigated agricultural land will be called IR, dry agriculture will be called NI, water will be called WA, and everything else will be called URB.

For a better understanding of how these WRLU columns are defined please see the WRLU report (UDWRe 2022).

Union Data

With Landtype19 defined, a Union (ESRI 2022) was run between the 2009 BRC data and the 2019 WRLU data. This Union provided more data to further refine the Landtype19 classification. Since the 2009 BRC study, the Utah Division of Water Resources has refined the WRLU linework each year. Because of this, polygons have been removed and/or reshaped. The Union defines each of these small shifts and changes in the data which creates a chaotic layer with thousands of small slivers. However, these small slivers represent small shifts in the data that were implemented so that each field is more accurately represented. For example, an agricultural field includes a portion of the neighboring highway in 2009, and in 2019, the polygon has been reduced to exclude the highway, and a new polygon now represents that highway (Figure 1). These small shifts contribute to more precise numbers for this analysis.

Figure 1. Small slivers created from the union between the 2019 and 2009 data. The small red sliver on the bottom left corner shows land previously labeled as irrigated land in 1976 and a road in 2019. The sliver running north and other black slivers represent no change, but the polygons to represent these agricultural fields shifted slightly over time.

LandType19

The first step in reclassifying Landtype19 with the unioned data relates to sub-irrigated fields labeled IR in 2009. In this scenario, the field should still be classified as IR, not WE, when the field is still sub-irrigated. This is done by defining where the 2019 IRR_Method == ‘Sub-irrigated’ and Landtype09==’IR’, and then labeling Landtype19==‘IR’. There are also numerous waterbodies and wetlands that have irrigation rights, for example to create wetlands for waterfowl, these need to be reclassified from WA to IR. These rows were reattributed where Landtype09==’IR’ and Landtype19 %IN% c(‘WA’, ‘RIP’) and IRR_Method!= ‘Sub-irrigated’. The majority of this selection represented small slivers as discussed above. There were fewer large polygons in this selection and in these cases, it was easy to manually check and change this classification. These changes were largely close to the Great Salt Lake (Figure 2).

Figure 2. The red polygons above mostly represent sub-irrigated, wetlands, and riparian areas near the Great Salt Lake that were called irrigated in 1976 and initially classified as either WE or WA. These were manually reclassified back to IR.

There are a number of small polygons on the edge of Idaho and Wyoming that were labeled Utah in 2009, and newer county data suggest these are now Idaho. To be consistent with 2009/1976 these are being attributed as Utah and Landtype19 was manually classified.

The Union left many polygons where Landtype09 was undefined. These scenarios generally accounted for small differences in linework. In these cases, Landtype09 was set to equal Landtype19, except where Landtype19==’IR’. In this scenario, where Landtype19==’IR’, Landtype09 was defined as OTH because these small changes in field boundaries should be accounted for in the 2019 depletion numbers.

In the opposite scenario, Landtype19 was undefined. This scenario also contained small differences, but also accounted for large polygons that have been removed from the WRLU dataset. These polygons have been removed because the land is no longer irrigated. In almost every case represented here, the land has been converted to or was already urban. So, where Landtype09==’IR’ Landtype19 was set to URB. The remaining polygons were set to Landtype09.

Water Rights Check

With Landtype19 set, two intermediate features were created using a subset of data where irrigation has been removed and another where irrigation has been added. Both features were further subset to remove polygons where the Shape_Area/ Shape_Length<5.5. This query removed the majority of slivers from changes in linework to simplify the workload. The features were then sent to the Utah Division of Water Rights to be checked. Water Rights returned the two features with a new column stating where they disagreed with our data. These discrepancies were manually checked and generally accepted, finalizing the Landtype19 classification.

Landtype76 & Landtype09 Reclass

The 2009 BRC study allowed researchers to reclassify the original 1976 classification. In the dataset this was denoted in the column Change09==’reclass’. Landtype76, however, was still classified with the original classification, so in order to compare the reclassified 1976 data Landtype76 where Change09==’reclass’ was set to equal Landtype09.

Landtype76 & Landtype19 Reclass

As was discussed above in the Union section, there are thousands of slivers in the data. If these were left unchecked changes in acres may occur where there was no real change, but the data now reflects the ground more accurately. For example in Figure 1 the red sliver was always a road and never irrigated land, so this sliver should not be subtracted, but rather reclassified.

The sheer number of these slivers makes checking individual scenarios impossible and instead logic was applied to query and reattribute these scenarios. Slivers were selected where

Shape_Area/Shape_Length was less than 5.5 and Landtype76!=Landtype19. This selected 22,751 polygons representing 3,540 acres. Without this change 401 acres of slivers would have been added to depletion rates and 2,506 acres of slivers would have been subtracted. This represents 0.2 percent of the added acreage and 0.7% of subtracted acreage. While a small percentage of this is likely true and should not be reclassified, the majority should be reclassified so these slivers are not counted toward depletion numbers.

Change19 & Finalization

With Landtype76 and Landtype19 finalized, Change19 was calculated. For this calculation, polygons were selected where Landtype76==‘IR’ and Landtype19!=‘IR’ to define Change19==’Subtract’. In the opposite logic, Landtype76!=‘IR’ and Landtype19==’IR’ were attributed with Change19==’Added’. For slivers the area:length ratio of less than 5.5 was used to set Change19== ‘Reclass’ where Landtype76!=Landtype19. No transfers were documented. With the data finalized, the remaining WRLU and the 2009 BRC analysis columns were removed to clean-up the final data product and the Acres column was recalculated from the Shape_area column.

References

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Supplemental Irrigation Depletion

Utah Method for Evaluating Depletion for Supplemental Water Rights

Supplemental water rights are those that also supply lands already covered by pre-1976 Bear River Compact water rights. “Project” rights, as in the case of Woodruff Narrows Reservoir, are handled separately. “Other” rights are considered on a case-by-case basis based on acres irrigated and depletion rates in their corresponding sub-basin. Previous updates for 1990 and 2009 used “shortage” rates or individual “supply” rates determined at the field level in contacts with irrigators while reviewing water rights that were presented in a table.

For the present update, the water right table was reviewed and updated adding new water rights and applying appropriate depletion rates and supply rates. In an effort to achieve a “common method” between the states, an agreed upon supplemental supply rate of 40% of the full supply for new lands was applied to supplemented lands. The following table shows supplemental depletion amounts in comparison to 2009 amounts. The differences are from added water rights, updated depletion rates in the sub-basins and the agreed upon supplemental supply rate of 40%.

Calculated Values of Depletion for Supplemental Post-1976 Appropriations Out of the Bear River Drainage in Utah

						2009		2019		
Water Right #	**Name**	**Priority (Y-M-D)**	**Acres**	**Sole supply acres**	**Depletion (af/ac)**	**"Supply" Depl. Factor**	**Depletion (acre-feet)**	**TAC Depl. Factor**	**Depletion (acre-feet)**	Notes
	Upper Division									
21-1471	Barker	19820811	*31.73	0.00	1.24	0%	0.00	40%	0.00	Not in Use: reservoir sedimented in
Evanston Subbasin			**0**						**0**	
23-3463	Tingey	19770210	110.30	80.00	1.36	77%	115.52	40%	60.01	
23-3519	Tingey	19780621		*10.00		9%				same acreage as 23-3463
23-3589	Schultess	19810106	363.10	15.00	1.36	4%	20.40	40%	197.56	
23-3472	Schultess	19770513	63.50	56.00	1.36	14%	12.09	40%	34.55	
23-3473	Muir	19770513	93.80	49.71	1.36	53%	67.62	40%	51.04	
23-3486	Argyle	19770706	203.79	153.25	1.36	13%	36.04	40%	110.88	
23-3518	Tingey	19780621	172.60	90.00	1.36	52%	122.42	40%	93.91	
23-3608	Stacey	19810514	303.29	67.79	1.36	16%	66.01	40%	165.02	Added
23-3615	Rich County	19810611	5.10	5.10	1.36	100%	6.94	40%	2.77	Added
23-3691	Gray	19870319	7.60	1.20	1.36	16%	1.63	40%	4.14	
23-3721	Brown Trust	19891214	240.00	120.00	1.36	50%	163.23	40%	130.58	
23-3757	Peart Ranch	19950809	152.16	70.47	1.36	46%	95.85	40%	82.79	Added
23-3815	K-Ron Ranch	20020703	90.00	11.50	1.36	13%	15.64	40%	48.97	Added
23-3901	Peart Land	20090309	405.00	140.00	1.36	35%	190.43	40%	220.36	Added
23-3930	GR Peart	20130715	33.33	33.33	1.36	100%	45.34	40%	18.13	Added
Randolph Subbasin			**2244**	**893**		39.8%	**959**		**1221**	
Upper Division Totals			**2244**				**959**		**1221**	

	Lower Division									
23-3576	Nebeker	19800822	*266.00	26.03	1.15	0.0%	0.00	40%	0.00	Not in Use: reservoir does not fill right
23-3591	Johnson	19810120	21.60	20.00	1.15	92.6%	22.92	40%	9.90	
23-3666	Falula Farms	19840210	262.00	60.00	1.15	22.9%	68.75	40%	120.08	
	Bear Lake Subbasin		**284**	**80**		**28.2%**	**92**		**130**	
25-6688	Robbins Trust	19751022	31.00		1.35	0%	0.00	40%	16.80	Not in Use
25-6829	Lower	19760304	56.60	20.00	1.35	35%	27.10	40%	30.67	
25-7151	USU	19770129	96.00	15.00	1.35	47%	60.97	40%	52.02	
25-7329	Benson Trust	19770331	46.50	18.00	1.35	7%	4.41	40%	25.20	
25-7330	Thalman	19770404	29.20		1.35	30%	11.87	40%	15.82	
25-7387	Francis	19770512	28.90	20.00	1.35	69%	27.09	40%	15.66	
25-7393	Wood	19770505	28.90	8.00	1.35	28%	10.84	40%	15.66	
25-7415	Riley Smith Irr	19770526	119.10	30.00	1.35	25%	40.34	40%	64.54	
25-7416	Swenson	19770527	24.00		1.35	0%	0.00	40%	13.01	
25-7430	Humphreys	19770610	11.20	5.00	1.35	10%	1.52	40%	6.07	
25-7446	JB Herefords	19770711	97.05	23.25	1.35	0%	0.00	40%	52.59	
25-7469	Karren	19770803	65.00	40.00	1.35	15%	13.21	40%	35.22	
25-7556	Graham	19771122	8.20		1.35	11%	1.22	40%	4.44	
25-7563	Buttars	19771209	84.70	9.80	1.35	12%	13.77	40%	45.90	
25-7564	MGT Properties	19771213	132.98	90.00	1.35	68%	122.50	40%	72.06	
25-7569	Armstrong	19771222	82.00	40.00	1.35	25%	27.77	40%	44.44	
25-7575	Wheeler	19780110	65.10	6.00	1.35	10%	8.82	40%	35.28	
25-7577	Nielsen	19780113	24.30	4.00	1.35	10%	3.29	40%	13.17	
25-7579	Wangsgard	19780118	171.10	38.00	1.35	0%	0.00	40%	92.72	
25-7654	Gibbons	19780615	6.30	3.30	1.35	52%	4.44	40%	3.41	
25-7706	Beecher	19780905	6.30	0.40	1.35	50%	4.27	40%	3.41	
25-7866	Skidmore	19781121	623.00	300.00	1.35	15%	126.60	40%	337.60	
25-7888	Buttars	19790110	87.30	26.90	1.35	15%	17.74	40%	47.31	
25-8010	Lunday	19790608	145.30	5.00	1.35	3%	5.91	40%	78.74	
25-8013	Matthews	19790614	14.40		1.35	7%	1.37	40%	7.80	
25-8015	Dorius	19790613	8.70	6.00	1.35	25%	2.95	40%	4.71	
25-8028	Reese	19790709	41.60	38.00	1.35	30%	16.91	40%	22.54	
25-8044	Alder Farm	19790809	5.70	5.00	1.35	75%	5.79	40%	3.09	
25-8062	Spackman	19790924	39.40	10.00	1.35	0%	0.00	40%	21.35	
25-8077	James	19791026	16.62	2.00	1.35	12%	2.70	40%	9.01	
25-8098	Skidmore	19800125	46.80	3.50	1.35	8%	4.76	40%	25.36	
25-8151	USU	19800414	94.00	60.00	1.35	0%	0.00	40%	50.94	
25-8174	Adams Trust	19800703	9.60	4.00	1.35	42%	5.46	40%	5.20	
25-8187	Campbell	19800813	4.25		1.35	0%	0.00	40%	2.30	
25-8191	Johnson	19800828	8.75		1.35	12%	1.42	40%	4.74	
25-8228	LDS Nibley	19810128	2.80		1.35	100%	3.79	40%	1.52	
25-8237	Kimball Trust	19810219	15.90		1.35	0%	0.00	40%	8.62	
25-8249	Lewis Trust	19810302	12.90		1.35	0%	0.00	40%	6.99	
25-8263	Munk	19810324	378.70	223.30	1.35	50%	256.52	40%	205.22	
25-8268	Inovasis	19810409	150.40	75.40	1.35	28%	57.05	40%	81.50	
25-8272	Lindley	19810414	363.20	55.00	1.35	8%	39.36	40%	196.82	
25-8281	Rosehill Dairy	19810504	35.70	30.00	1.35	0%	0.00	40%	19.35	
25-8297	Benson Trust	19810623	52.20	40.00	1.35	7%	4.95	40%	28.29	
25-8311	Spackman	19810727	128.10	31.50	1.35	59%	102.39	40%	69.42	

25-8348	James	19801118	31.20	4.00	1.35	13%	5.49	40%	16.91
25-8385	WDCI	19820608	513.20	210.00	1.35	41%	285.05	40%	278.10
25-8396	Hardman	19820726	319.20	317.90	1.35	25%	108.11	40%	172.97
25-8397	Munk	19820726	158.90	68.10	1.35	18%	38.75	40%	86.11
25-8446	Logan City	19820902	13.20		1.35	30%	5.36	40%	7.15
25-8505	Bingham	19830602	33.10		1.35	0%	0.00	40%	17.94
25-8583	Skabelund	19840608	44.50	5.00	1.35	11%	6.63	40%	24.11
25-8636	Bliesner	19840917	6.30		1.35	15%	1.28	40%	3.41
25-8668	Merrill	19850418	5.00		1.35	0%	0.00	40%	2.71
25-8685	Logan	19850621	27.80	14.00	1.35	50%	18.83	40%	15.06
25-8714	Humphreys	19860123	5.90		1.35	10%	0.80	40%	3.20
25-8724	Wheeler Ranch	19860311	138.40		1.35	37%	69.37	40%	75.00
25-8853	Buttars	19870619	87.30		1.35	16%	18.92	40%	47.31
25-8860	Alliance	19870817	35.20	10.00	1.35	0%	0.00	40%	19.07
25-8869	Shill Trust	19870903	3.00		1.35	32%	1.30	40%	1.63
25-8872	Hyclone Labs	19871002	6.18	2.56	1.35	50%	4.19	40%	3.35
25-8894	Shupe	19880329	68.00	53.00	1.35	0%	0.00	40%	36.85
25-8908	Beckstrom	19880607	11.14	5.00	1.35	10%	1.51	40%	6.04
25-8927	Kyriopoulos	19880823	20.32	13.42	1.35	66%	18.17	40%	11.01
25-8944	Smithfield	19881031	69.20		1.35	58%	54.37	40%	37.50
25-8948	Allsop	19881220	122.00	15.20	1.35	12%	19.83	40%	66.11
25-8949	Archibald	19881221	74.83		1.35	26%	26.36	40%	40.55
25-8977	Jensen	19890328	3.00		1.35	0%	0.00	40%	1.63
25-9012	R&J Farms	19891016	308.40	70.00	1.35	23%	96.09	40%	167.12
Cache Valley Subbasin			**5605**	**2075**		37.0%	**1820**		**3037**
29-2220	Washakie	19770818	62.50	25.00	1.46	3%	2.75	40%	36.61
29-2298	Clark Trust	19780830	5.00		1.46	0%	0.00	40%	2.93
29-2344	Godfrey	19790525	44.99	15.00	1.46	33%	21.74	40%	26.36
29-2388	3M Farms	19800103	100.30	53.00	1.46	0%	0.00	40%	58.76
29-2731	Richards	19810515	2.02	0.97	1.46	19%	0.56	40%	1.18
29-2766	Cole Trust	19810928	78.10	54.00	1.46	70%	80.06	40%	45.75
29-2781	Alexander	19820226	35.30	15.30	1.46	43%	22.23	40%	20.68
29-2815	Flying Mule Shoe	19821130	26.26	21.60	1.46	82%	31.54	40%	15.38
29-2979	Tuleview	19831201	5.80	1.40	1.46	0%	0.00	40%	3.40
29-3002	Richards	19840531	32.33	25.05	1.46	81%	38.35	40%	18.94
29-3819	Denton John	19950925	96.06	80.00	1.46	83%	116.76	40%	56.27
29-3847	Blade Land	19960905	65.70	37.20	1.46	57%	54.84	40%	38.49
29-4142	Zollinger	20020521	34.48	17.48	1.46	51%	25.75	40%	20.20
29-4295	Steed Trust	20060206	40.00		1.46	0%	0.00	40%	23.43
Tremonton Subbasin			**629**	**346**		55.0%	**395**		**368**
29-2165	Ferry	19770401	80.75	20.00	1.63	25%	32.89	40%	52.62
29-2166	Ferry	19770401	172.60	91.60	1.63	53%	149.03	40%	112.47
29-2521	Ferry	19800626	96.27	21.27	1.63	22%	34.50	40%	62.73
29-2532	Ferry	19800825	70.67		1.63	20%	23.03	40%	46.05
29-3550	Carter	19890706	89.30	58.80	1.63	66%	96.02	40%	58.19
29-3559	Walker	19890919	22.80		1.63	0%	0.00	40%	14.86
29-3582	Mickelsen	19900321	150.00		1.63	25%	61.09	40%	97.75
29-3849	US Fish & Wildl	19960917	60.00	17.20	1.63	29%	28.35	40%	39.10
29-4176	Clark	20021203	67.24	49.89	1.63	75%	82.16	40%	43.82

Brigham City Subbasin	**810**	**259**	32.0%	**507**	**528**
Box Elder County (Lower Division)	**1438**	**605**	42.0%	**902**	**896**
Lower Division Totals	**7327**			**2813**	**4063**

Notes:

Column G: Sole Supply acres are limitations on the water right determined at the time of the filing or the proof.

Column H: "Supply" Depletion factors are from Appendix B of the 2009 Depletion Update and were derived on a case-by-case basis using sole supply values and/or information from water users.

Column I: Depletion value (af/ac) are the Et values adopted by the Commission.

Column J: Depletion = Acres x Depletion x Sole Supply Depletion factor. These are shown for comparison of 2009 report methodology.

Column K: "TAC" Depletion factors were agreed upon by the States as a common methodology.

Column L: Depletion = Acres x Depletion x TAC Depletion factor.

Appendix F
Details of Specific Wyoming Efforts

Wyoming Summary

Frequency	Description_1976 of 1976 Geometry	ACRES
223	Irrigated Cropland	64074
31	Non-Irrigated Cropland	5831
250	Other	2278
24	Urban	984
204	Water	1512
460	Wetlands/natural sub-irrigation	21607
2	No code	16
1192	**Total**	**96302**

Table 1.

Frequency	Description_1976 of 2009 Geometry	ACRES
350	Irrigated Cropland	62181
22	Non-Irrigated Cropland	5277
7	Other	412
2	Urban	249
11	Water	3671
98	Wetlands/natural sub-irrigation	22848
151	No code	3150
490	**Total**	**97788**

Table 2.

Table 1. and Table 2. are displaying the results of increased accuracy with more modern technology and methods used to compare the 1976 results with 2009 geometry; used in the 2009 Depletions Report (Appendix C) Lantype76 is used again to derive 'Added' and 'Subtracted' irrigation (IR) lands for 'Change19' further described on Page F-4.

Figure 1a.

Figure 1b.

Figure 1a. and 1b. also provide background as an example of data refinement in the 2009 Depletions Report (Appendix C); specifically roads, buildings and water being reclassified and shown with a yellow boundary in Figure 1b.

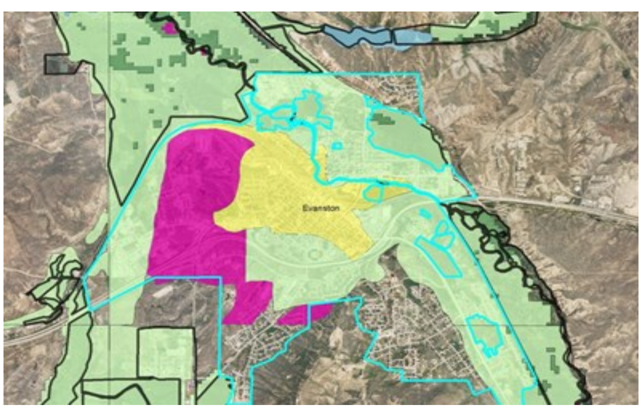

Figure 2

Frequency	Description_2009 of 2009 Geometry	ACRES
281	Irrigated Cropland	69025
35	Non-Irrigated Cropland	6443
1	Other	789
21	Urban	5452
91	Water	4121
212	Wetlands/natural sub-irrigation	11959
641	**Total**	**97789**

Table 3

Figure 2. illustrates background of the 2009 geometry (black lines) as assigned in 1976 classifications (colored pixels). Table 3. summarizes the 2009 classification and 2009 geometry to address discrepancies when a direct 1976 to 2009 comparison by polygon is made. This background from the 2009 Depletions Report (Appendix C) laid the framework for continued improvements made with next generation imagery and methods in the 2019 Depletions Report.

Figure 3a.

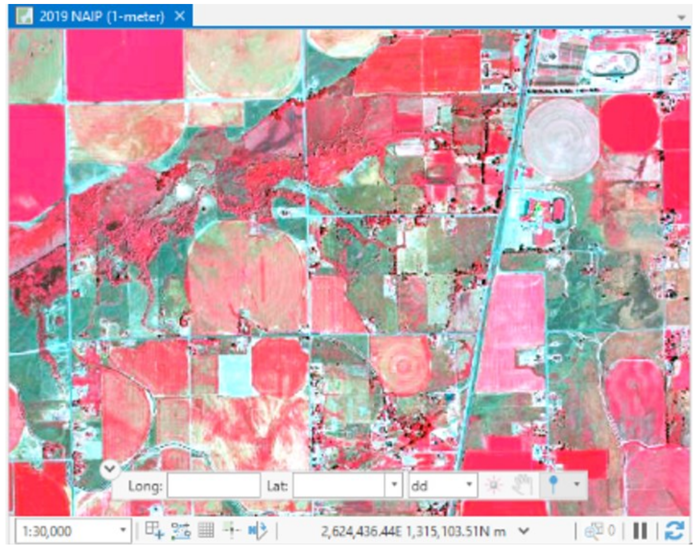

Figure 3b.

In the 10 years between the 2009 Depletions Report and the 2019 Depletions Report similar improvements in imagery and methods enabled the TAC to continue increasing the analysis of what truly exists on the ground for each state. Figure 3 a. and 3 b. are examples of 2019 Landsat and 2019 NAIP (1 meter) imagery Wyoming used to compare to imagery used in the 2009 Depletions Report.

It is important to note that the Amended Compact only defined and limited additional amounts, not a specific volume.
Therefore, for the 2019 Depletions Update Report it is necessary to continue to compare Landtype76 to current data, in this report Landtype19, to derive 'Change19', as described in Appendix A of this report.

Comparing the 1976 and 2019 landtype classifications resulted in the identification of misclassified lands either by error or changes. More shifts in data were produced by the Union of the 2009 BRC data and the 2019 WRLU data.

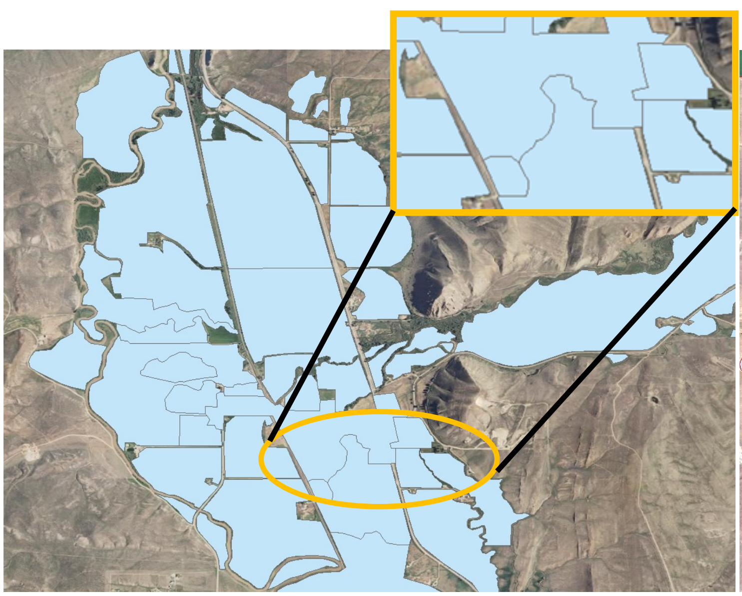

Figure 4a.

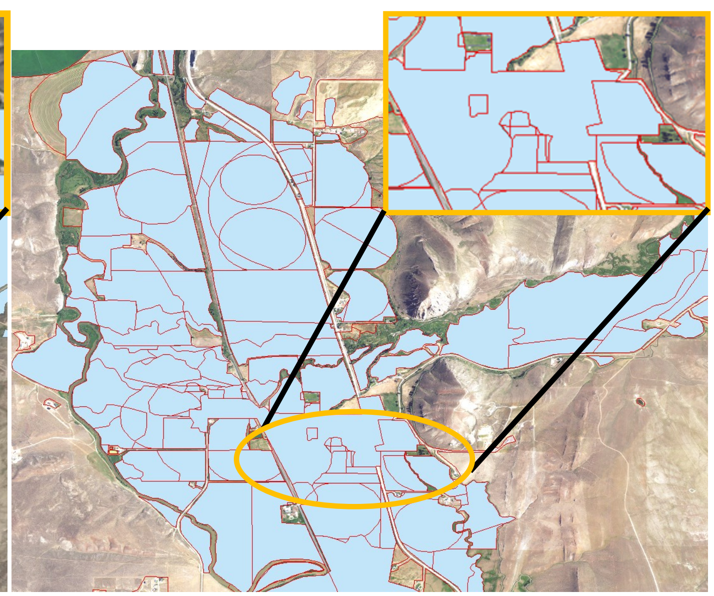

Figure 4b.

Figure 4a. shows 2009 imagery and 2009 land classifications in blue with black parcel outlines. Figure 4b. shows 2019 imagery, the 2009 land classifications in blue, and the 2019 land classifications post Union outlined in red to illustrate more identifiable field boundaries illustrating the increased frequency in parcels, and other changes captured in the Change19 data.

Frequency	Landuse_2019 of 2019 Geometry	ACRES
1175	Irrigated Cropland	69,587
92	Non-Irrigated Cropland	2,712
223	Other	7,815
355	Urban	12,146
411	Water	5,375
416	Wetlands/natural sub-irrigation	13,112
2,471	**Total**	**110,746**

Table 4.

Table 4. is the summary of the Landuse_2019 with 2019 Geometry. When compared to historical records the frequencies and acres change, dramatically in some cases; illustrated in Figure 4a. and 4b. Individual parcels are now more distinguishable, as are field boundaries and boundaries between land type categories. Wyoming used water right data within Wyoming's water right database, *ePermit,* the most modern maps of current geometry, improved imagery, and ground truthing to define the 6 types of change laid out by the TAC team: 1) Added, 2) Subtracted, 3) Reclass, and 4) Null and two new to this analysis 5) Transfer Add, and 6) Transfer Sub.

One other specific change in data Wyoming needed to confirm was due to the reclassification of Landtype2019 with the addition of 'sub-irrigated' lands. In this process lands formally classified as WE (wetland) but exist solely because of irrigation water, or lands that are wetlands but have irrigation rights for maintaining wetlands for habitat were reclassified as IR (irrigation) with an IRR_Method equaling 'Sub-Irrigated'. Lands that were identified as undefined in the process were individually reviewed and determined as needing updating in line-work ,further land use change confirmation.

Landuse_YR/ of YR Geometry	LU76/76G Frequency	LU76/09G Acres	LU76/709G Frequency	LU76/09G Acres	LU09/09G Frequency	LU09/09G Acres	LU19/19G Frequency	LU19/19G Acres
Irrigated Cropland	223	64074	350	62181	281	69025	1175	69,587
Non-Irrigated Cropland	31	5831	22	5277	35	6443	92	2,712
Other	250	2278	7	412	1	789	223	7,815
Urban	24	984	2	249	21	5452	355	12,146
Water	204	1512	11	3671	91	4121	411	5,375
Wetlands/natural SI	460	21607	98	22848	212	11959	416	13,112
No Code	2	16	151	3150				
Total	**1192**	**96302**	**490**	**97788**	**641**	**97789**	**2,471**	**110,746**

Table 5.

Table 5. Compares the data sets from 1976 –2019. Table 5. provides a comparison but also shows that landuse and geometry changes with the evolving methods in depletion methods have made improvements in the accuracy of results.

CENTRAL DIVISION	Added Acreage	Acreage taken out of Production (Subtracted)	Net change	Depletion Rate (af)	Depletion (af)
Cokeville	3277	-276	3001	+1.25 -1.28	3742.97
Thomas Fork	824	-350	474	+1.17 -1.22	537.08
TOTAL	4101	-626	**3475**		**4280.05**
UPPER DIVISION					
Cokeville	1467	-563	**904**	+1.25 -1.28	**1113.11**
Evanston	608	-2648	**-2040**	+1.24 -1.30	**-2688.48**
Randolph	0	0	**0**	+1.36 -1.34	**0**
TOTAL	2075	-3211	**-1136**		**-1575.37**

Table 6.

If the classification from Landtype76 changed from any other classification than 'Irrigated'(IR) to IR in Change19 it is considered 'Added'. If any Landtype76 classification IR changed to any of the other 5 classifications in Change19 it is now considered 'Subtracted'. Once Wyoming confirmed Landtype76 and Landtype19 the results were used to calculate Change19. With the CDL data 2016-2020 the new CropMix was computed with methods agreed upon by all three states Wyoming, Utah, and Idaho. The 'Added' and 'Subtracted' acres were then multiplied by the appropriate 'Depletion Rate' listed in the table as +/- Depletion Rates. The resulting 'Subtracted' 'Depletion (af)' was subtracted from the 'Added' 'Depletion (af)' for the final 'Depletion (af) value exhibited in Table 6.

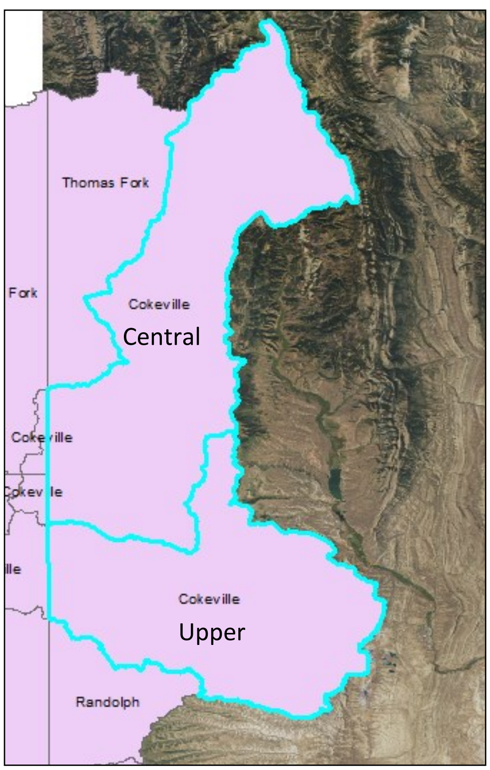

Figure 5.

Wyoming's last action item, seen in Table 6., was the need to divide lands within Cokeville Central and Upper Divisions. Cokeville Central and Upper Divisions were divided by using the Clip function to separate the appropriate division boundaries and the WY_BRC_classification_2019 gbd. files used by each state in the agreed upon methods described in the mapping effort Appendix A.

With continued growth and changes in landuse for Wyoming this process will need to continue for future depletion estimate efforts. Wyoming is committed to working with Utah and Idaho to improve upon the methods and are currently working on how innovative technology, like Open ET might be used in future estimates.

Figure 5. Is a map of Wyoming lands Cokeville Central and Upper Divisions highlighted in blue.

SUPPLEMENTAL SUPPLY IRRIGATION DEPLETION AND INTERIM EFFORTS

Wyoming reviewed water rights to determine the changes from the 2009 depletions update. A spreadsheet was created listing all of the post-1976 irrigation permits granted with a supplemental supply or an additional supply (Ground Water). Diversion records for the years 2009-2019 were reviewed and each water right was field inspected every year since the 2009 depletions update report to verify sources and the use of the supplemental supplies. The Hydrographer/Water Commissioners' and supervisor's personal knowledge, along with some questioning of the appropriator, helped to verify days of supplemental water use.

Wyoming has explored a number of different methods for calculating the supplemental depletions, and has worked with diversion records, efficiency rates, and other methods trying to come up with a common number or common method that could be duplicated by other states as directed by the Management Committee. In investigating different methods, Wyoming found that only utilizing diversion data along with a multiplier such as an efficiency number, can result in varied outcomes depending on soil types. Wyoming found that several irrigators are over watering to compensate for rocky soils that do not retain soil moisture. In exploring other methods, we also found that some water users are using sprinklers to spread water on more acres increasing depletion. After looking into several different methods, it was determined that the most important factors to consider in calculating depletion amounts are acres irrigated and the timeframe in which acres are irrigated. It is also important to consider the soil moisture carryover to know at what point crops no longer deplete water supplied by irrigation. We also re-evaluated our previous method and although the days and acres were important, the 10-year average previously used skewed the data low with only a portion of the years using supplemental. Using the Penman-Monteith method the data can also exceed the overall subbasin depletion amount.

Idaho, Wyoming and Utah have recently agreed on a common method for calculating the depletion on supplemental acres of using a standard number of 40% of the full supply based on a five-year average depletion rate. Wyoming is concerned that this method could underestimate depletion amounts on dry years. Wyoming found this to be the case in 2021 as we continued to evaluate supplemental depletions. In 2021 early regulation caused supplemental usage to be closer to 80% of the total being supplied by supplemental. As individual states get closer to their depletion allocation caps, Wyoming is concerned that using an average calculation number could allow a state to exceed the max annual depletion allowed by the compact. Moving forward as both Idaho and Wyoming above Stewart Dam are creeping up on their maximum allowed depletion allocation, yearly accounting may be necessary to ensure these caps are not exceeded.

The following is the total supplemental depletion for each sub basin for water years 2015-2019 using the 40% as adopted in this report.

Year	2015	2016	2017	2018	2019	5-Year Average
Cokeville	863	863	0	1062	1062	770
Thomas Fork	277	277	0	277	460	258
Evanston	17	17	17	17	17	17

The following table is the list of supplemental water rights monitored by Wyoming on an annual basis and the shown calculations were made using the common method adopted by all three States for the purpose of this report. The attached table depicts the supplemental water usage for water year 2019.

Sub Basin	Facility Name 2019	Stream Source / Type	Permit #	Priority Date	Status	Permitted Acres	Full Supply	Acres/in use	Depletion Factor	Actual Depletion
Cokeville	Cooper Ditch Corral Creek Diversion	Corral Creek/ Surface Water	33364	7/11/2002		49.16	1.25	49.16	0.4	25
Cokeville	Cornia PipeLine	Birch Creek / Surface Water	33627	12/22/2000		34	1.25	34	0.4	17
Cokeville	Mud Creek Diversion	Mud Creek / Surface Water	34035	1/28/2008		14	1.25	14	0.4	7
Cokeville	Thornock Pump and Pivot	Bear River / Surface Water	34396	2/12/2010		20	1.25	20	0.4	10
Cokeville	Putnam Enl. West Ditch	Bear River	6976E	9/11/1987		27	1.25	0	0.4	0
Cokeville	C-12 Pipeline and Pivot	Bear River	34100	2/27/2007		17.2	1.25	17.2	0.4	9
Cokeville	Buckley Enl. Of the Covey Canal	Smiths Fork / Surface Water	7680E	12/22/2010		52	1.25	52	0.4	26
Cokeville	A. Ryan No.1 Well	Ground Water	UW129440	7/27/2000		9.81	1.25	9.81	0.4	5
Cokeville	Cornia No. 3 Well	Ground Water	UW 42138	2/6/1977		251.08	1.25	187.5	0.4	94
Cokeville	Roberts No.1 Well	Ground Water	UW 98694	2/3/1995		215.17	1.25	170	0.4	85
Cokeville	Roberts Water Well No.2	Ground Water	UW145683	5/1/2002		77	1.25	52	0.4	26
Cokeville	BQ Well No. 1	Ground Water	UW140753	7/16/2001		300	1.25	267	0.4	134
Cokeville	M. Reed No.1 Well	Ground Water	UW193097	2/5/1987		106.35	1.25	73.4	0.4	37
Cokeville	Thornock Bros. #1 replacement Well	Ground Water	UW195332	12/22/2010		284.16	1.25	199.6	0.4	100
Cokeville	Beckwith Enl. Replacement well	Ground Water	UW195333	12/22/2010		184.1	1.25	134.8	0.4	67
Cokeville	Pine Creek South Well	Ground Water	UW201723	2/24/2014		259.1	1.25	259.1	0.4	130
Cokeville	Hufford East Well	Ground Water	UW206482	5/16/2016		56.75	1.25	56.75	0.4	28
Cokeville	Enl. Buckly # 4	Ground Water	UW742180	11/9/1984		158.62	0		0.4	0
Cokeville	Garrett Well	Ground Water	UW201724	2/24/2014	(unused)	238	0		0.4	0
Cokeville	Teichert Bros. West Side Pivot No.1 Well	Ground Water	UW203332	11/20/2014		29.5	1.25	29.5	0.4	15
Cokeville	Teichert Bros. West Side Pivot No.2 Well	Ground Water	UW204258	7/2/2015		20	1.25	20	0.4	10
Cokeville	Teichert Bros. West Side Pivot No.3 Well	Ground Water	UW203333	11/20/2014		10	1.25	10	0.4	5
Cokeville	Enl. Dana No.1 Well	Ground Water	UW101111	4/30/1993		307.37	1.25	281.8	0.4	141
Cokeville	Teichert Brothers No. 1 Well	Ground Water	UW187280	5/27/2008	(unused)	86	0		0.4	0
Cokeville	Buckley No.4 Well	Ground Water	UW60689	2/8/1982	(unused)	158.62	0		0.4	0
Cokeville	Bartek #1 Well	Ground Water	UW41237	7/16/1977	(unused)	552.74	0		0.4	0
Cokeville	Linford #1 Well	Ground Water	UW170139	9/8/2005	(unused)	15	0		0.4	0
Cokeville	4-E # 1 Well	Ground Water	UW107739	1/2/1997	(unused)	35.62	0		0.4	0
Cokeville	Teichert Spreader Dike Diversion of Thompson Slough	Thompson Slough / Surface Water	34861	4/1/2011	(unused)	163.15	1.25	163.15	0.4	82
Cokeville	Icebox Stream No.1 Ditch	Rock Creek / Surface Water	34073	6/6/2008		6.1	1.25	6.1	0.4	3
Cokeville	Icebox Stream No.2 Ditch	Rock Creek / Surface Water	34074	6/6/2008		12	1.25	12	0.4	6
Cokeville	Icebox Stream No.3 Ditch	Rock Creek / Surface Water	34075	6/6/2008		5.8	1.25	5.8	0.4	3
Cokeville	First Enl. Sulphur Springs Pipeline Rock Creek Diversion	Rock Creek / Surface Water	6999E	1/24/1991	(unused)	32.9	0		0.4	0
Cokeville	Sulphur Springs Pipeline- Rock Creek Diversion	Rock Creek / Surface Water	30703	1/26/1989	(unused)	86.9	0		0.4	0
Cokeville	Bird # 3 and Enl. Bird No.3 Well	Ground Water	UW14882/UW173544	1/6/2003	serves same acres	3.84	0		0.4	0
Thomas Fork	Chalk Creek Pipeline	Chalk Creek/ Surface Water	25316	1/26/1976		50.32	1.17	50.32	0.4	24
Thomas Fork	Alonzo F. Sights Old Channel Diversion	Old Channel Bear River/ Surface	34447	11/30/2000		650	1.17	57	0.4	27
Thomas Fork	Child Enl.Alonzo F Sights Bear River Old Channel	Old Channel Bear River/ Surface	7740E	12/5/2012		52	1.17	52	0.4	24
Thomas Fork	Groo-Bourne Enl.of Alonzo Sights Ditch	Bear River	7658E	11/30/2000		85.8	1.17	85.8	0.4	40
Thomas Fork	Roberts Land and Livestock#4 Well /Enl.Roberts Land and Livestock#4 Well	Ground Water	UW97747/UW150994	8/23/1993	serves same acres	128	1.17	47	0.4	22
Thomas Fork	Potato Hallow Well / Potato Hallow Well No.2	Ground Water	UW191651/UW201783	10/1/2009	serves same acres	219.56	1.17	219.15	0.4	103
Thomas Fork	Feuz No.2	Ground Water	UW37960	5/10/1977		80	1.17	80	0.4	37
Thomas Fork	Merril's Well/Ray's Well (Idaho Import water)	Gound Water	11-1470	4/10/1970		77.3	1.17	77.3	0.4	36
Thomas Fork	Taylor Canal (Idaho Import water)	Thomas Fork/ Surface Water	11-7678/11-7679	7/15/1893		154.5	1.17	154.5	0.4	72
Thomas Fork	Jacobs Well (Widmer)	Ground Water	UW206782	2/13/2017		160	1.17	160	0.4	75
Thomas Fork	Nate Maninfior	Ground Water	UW186878	2/1/2008	(unused)	185	0		0.4	0
Thomas Fork	Knowles Irrigation System	Six Springs	36054	8/20/2018	(unused)	11.08	0		0.4	0
Evanston	Hansen Well No. 5	Yellow Creek	UW195794	10/1/2009		206	1.24	**23**	0.4	11
Evanston	Hansen Wahsatch ditch	Yellow Creek	7667E	1/26/2010		12	1.24	12	0.4	6
	Totals:					**5950**		3142.74		Acre Ft of deletion
										1540

Appendix G
Description of OpenET Methods

MEMO

State of Idaho
Department of Water Resources
322 E Front Street, P.O. Box 83720, Boise, Idaho 83720-0098

Phone: (208) 287-4800 Fax: (208) 287-6700

Date:	October 17, 2022
To:	Bear River Commission Technical Advisory Committee
From:	Philip Blankenau, Evapotranspiration Analyst 5
cc:	Linda Davis, Water Resource Information Section Manager Sean Vincent, Hydrology Section Manager
Subject:	Actual versus potential evapotranspiration for estimating depletions in the Bear River Basin

Background

Interest in using actual evapotranspiration (ET_{act}) rather than potential ET (ET_{pot}) to estimate depletions to streamflow arose during the Bear River Commission Technical Advisory Committee (TAC) meetings for the 2019 Bear River Compact Depletion Update. Actual ET is the true amount of ET that occurred at a location over some duration. Potential ET, as defined in this context, is a hypothetical amount of ET that would occur for a particular location and duration if the crop grown there had a full water supply. Using these definitions, actual ET is less than or equal to potential ET.

This document records the methods and results of comparing depletions computed using GridET[1] potential ET to depletions computed using OpenET[2] actual ET. The comparison aimed to examine the differences in depletion volumes between the two methods and some of the underlying reasons for the differences.

At this time, the OpenET organization does not estimate depletions, so all references to OpenET depletions within this document simply refer to depletions computed using ET_{act} data from OpenET.

[1] C. S. Lewis and L. N. Allen, "Potential crop evapotranspiration and surface evaporation estimates via a gridded weather forcing dataset," Journal of Hydrology, vol. 546, pp. 450–463, Mar. 2017, doi: 10.1016/j.jhydrol.2016.11.055.
[2] F. S. Melton et al., "OpenET: Filling a Critical Data Gap in Water Management for the Western United States," J American Water Resour Assoc, pp. 1752–1688.12956, Nov. 2021, doi: 10.1111/1752-1688.12956.

Estimating potential ET using GridET

Potential ET is typically estimated using crop coefficients. The GridET model, developed by the State of Utah, and used in the 2019 depletion update, is a modernized crop coefficient model. ET_{pot} is estimated by equation 1.

$$ET_{pot} = K_c * ET_r \quad (1)$$

Where:

K_c [unitless] = The crop coefficient.

ET_r [ft]= The ASCE standardized Penman-Monteith tall reference ET[3].

K_c and ET_r are typically daily values. Within GridET, ET_r is estimated on an hourly basis and summed to a daily value. ET_r is a function of solar radiation, wind speed, humidity, and air temperature. It expresses how much ET would occur for a full cover, 0.5 meter tall alfalfa crop with a full water supply. K_c is a dimensionless factor multiplied by ET_r to adjust to different crop types and/or growth stages. For example, if an alfalfa field is cut for hay the K_c might become 0.25 because the field would transpire at a reduced rate. K_c curves show how a crop's K_c changes throughout the growing season. K_c curves have been empirically developed from field studies for a variety of crops. An example of a K_c curve taken from the Hill 2011[4] report is shown below in Figure 1.

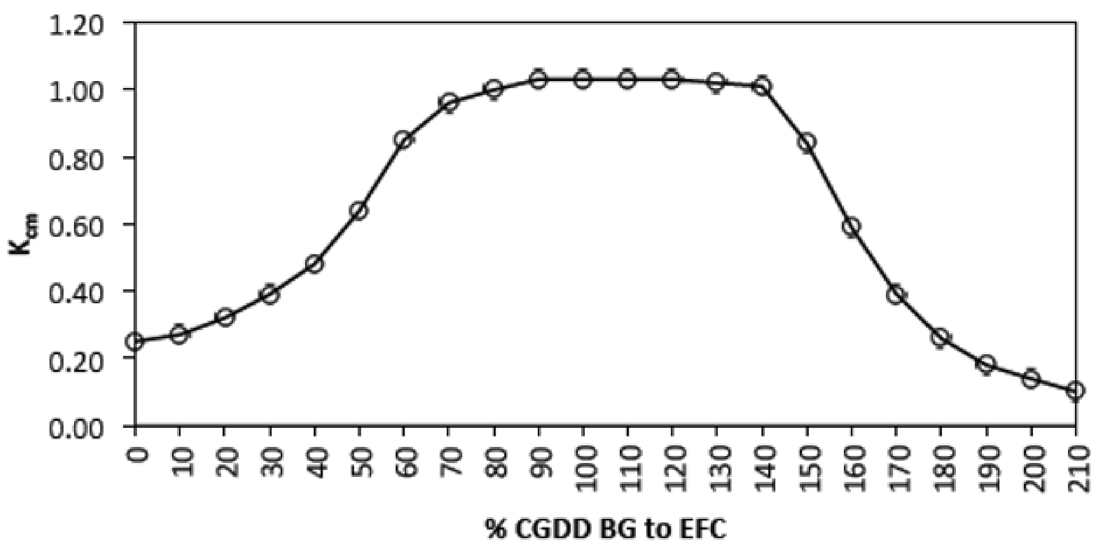

Figure 1. K_c curve for winter grain applied using the percentage of cumulative growing degree days from a "pseudo-planting date in the spring" to effective full cover.

[3] R. G. Allen et al., The ASCE Standardized Reference Evapotranspiration Equation. American Society of Civil Engineers, 2005. doi: 10.1061/9780784408056.

[4] R. W. Hill, J. B. Barker, and C. S. Lewis, "Crop and Wetland Consumptive Use and Open Water Surface Evaporation for Utah," Utah Agricultural Experiment Station Research Report, 213, Aug. 2011. Accessed: Mar. 25, 2022. [Online]. Available: https://extension.usu.edu/irrigation/ou-files/ez-plug/uploads/Crop_and_Wetland_Water_Use_Hill_Baker_Lewis.pdf

K_c curves in the GridET program have shapes defined by crop. Initiation, intermediate, and termination thresholds help define the curve and its temporal placement. The initiation date is determined by cumulative Hargreaves reference ET or days since January 1. The intermediate and termination dates are determined by cumulative growing degree days (CGDD) or days since the last stage. Curve start and end dates are also constrained by freezing air temperatures. Using reference ET and CGDD to modify the K_c curves allows the curves to track the growing season better than static calendar dates.

GridET downscales a gridded (raster) weather data product called NLDAS-2A[5] from ~12 km to ~0.54 km and generates ET_{pot} for every crop over the entire basin. The crop-specific ET_{pot} rasters can be combined with a crop map to generate a single ET_{pot} map analogous to the maps of ET_{act} produced with OpenET.

Estimating actual ET

A variety of methods exist for estimating actual ET, but thermal-based remote sensing models are the best approach for estimating ET_{act} at field-scale resolutions over large areas. The Landsat series of satellites detect thermal radiation emitted by earth's surface, which is indicative of land surface temperature. Land surface temperature is closely tied to ET_{act} by physical mechanisms. The OpenET project provides data from five thermal remote sensing models, one vegetation index-based model, and a model ensemble that averages at least four model estimates together after removing outliers. This comparison uses two thermal-based models, eeMETRIC and SSEBop, and the model ensemble. The vegetation index-based model, SIMS, was not investigated because vegetation indices will not identify water stress as readily as thermal models. The three other thermal models, geeSEBAL, PT-JPL, and DisALEXI, all tend to underestimate ET_{act} from irrigated fields in semi-arid environments. OpenET states on their website, as of October 11, 2022, that they have made corrections to DisALEXI and PT-JPL to improve estimates in semi-arid areas. geeSEBAL underestimates because it does not account for the contribution of advected sensible heat to ET. No mention of corrections to geeSEBAL to account for advection are made on OpenET's website. To keep this analysis focused, I only examined models known to perform well. The model ensemble was included because OpenET recommends it as a good default choice. The other models may warrant further analysis in the future.

Remote sensing models can only estimate ET_{act} on days a satellite captures data, so temporal interpolation is needed to obtain a full time series. Interpolating ET_{act} directly works poorly because ET_{act} changes rapidly based on weather conditions. For the eeMETRIC and SSEBop models, ET_{act} is divided by ASCE standardized grass (short) reference ET to obtain K_c and the timeseries of K_c values are interpolated. A K_c curve is developed for every satellite image pixel location. Therefore, eeMETRIC and SSEBop can be regarded as K_c models, where the K_c is defined using satellite observations rather than from curves developed from field studies.

Figure 2 illustrates the process for computing ET_{act} using remote sensing. The larger blue dots correspond to K_c values computed from satellite observations. The smaller blue dots are interpolated daily K_c values. OpenET uses linear interpolation between observations. The green dots are daily ET_r values. The values for corresponding dates in the K_c and ET_r time series are multiplied to obtain a time series of ET_{act} (the red dots).

[5] B. A. Cosgrove et al., "Real-time and retrospective forcing in the North American Land Data Assimilation System (NLDAS) project," J. Geophys. Res., vol. 108, no. D22, p. 2002JD003118, Nov. 2003, doi: 10.1029/2002JD003118.

More information on the OpenET project and models can be found on their website at https://openetdata.org/.

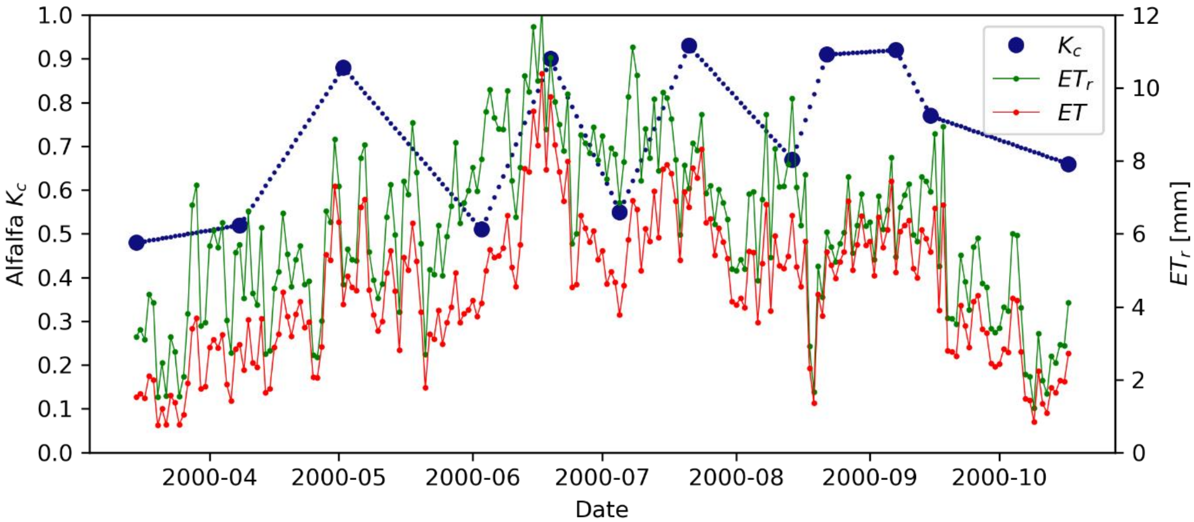

Figure 2. Estimation of a K_c curve by interpolating between satellite observations.

Depletion depth computations

Depletion depth is the depth of irrigation water applied that is consumptively used. Depletion depth is computed for GridET and OpenET using equation 2 below.

$$Dpl = ET - SM_{co} - P_{eff} \quad (2)$$

Where:

Dpl [ft] = The depletion depth.

ET [ft] = GridET ET_{pot} or OpenET ET_{act} summed for the irrigation season (May through September).

P_{eff} [ft]= The effective precipitation for the irrigation season.

SM_{co} [ft]= The winter carryover soil moisture at the start of the season.

Equation 3 was used for computing SM_{co} and comes from the Hill 2011 report.

$$SM_{co} = minimum(0.67 * (P_{win} - 1.25 * ET_{win}),\ 0.75 * RZ * AWC) \quad (3)$$

Where:

P_{win} [ft] = Winter precipitation occurring between the end of the last irrigation season and the start of the next irrigation season.

ET_{win} [ft] = Any ET occurring during the winter.

RZ [ft] = The crop rooting depth.

AWC [ft/ft] = The soil available water capacity.

Notice that winter ET reduces the winter precipitation contributing to soil moisture. How winter ET is estimated differs between GridET and OpenET and will be explained later in this section.

P_{eff} is estimated using the USDA 1970 method[6] which is packaged with the GridET software. A custom version was programmed to work with OpenET. The USDA 1970 method computes P_{eff} every month using ET and precipitation as inputs. Because ET is an input to P_{eff}, P_{eff} differs between OpenET and GridET.

Precipitation data for P_{eff} and SM_{co} come from a 1 km resolution rasterized weather dataset, Daymet v4[7]. The soil AWC map is derived from the average of the STATSGO[8] and SSURGO[9] soil map AWC values. The AWC map was then averaged with a constant AWC of 2/12 to help moderate extreme values. The root zone map was created by translating the USDA Cropland Data Layer (CDL)[10] to crops with root zones listed in Hill 2011.

GridET does not count any ET or effective precipitation occurring before the K_c curve initiation or after termination. Figure 3 helps illustrate the GridET method for calculating depletion depths. The blue line represents a contrived winter wheat K_c curve. All ET occurring outside the May-September irrigation season (the green region in the figure) is counted as winter ET in the SM_{co} calculation. Note that if the crop's termination is after September 30, then the ET occurring after that date contributes to winter ET for the next season's SM_{co} calculation. The K_c curve in the figure ends at the start of August when the winter wheat is harvested. ET and P_{eff} after termination are not considered to have an effect on depletions so they are not estimated after termination. Winter precipitation is summed from October 1 to April 31.

[6] "Part 623 National Engineering Handbook," United States Department of Agriculture Soil Conservation Service, Sep. 1993. [Online]. Available: https://www.wcc.nrcs.usda.gov/ftpref/wntsc/waterMgt/irrigation/NEH15/ch2.pdf

[7] Thornton, M.M., Shrestha, R., Wei, Y., Thornton, P.E., Kao, S., and Wilson, B.E., "Daymet: Daily Surface Weather Data on a 1-km Grid for North America, Version 4," p. 0 MB, 2020, doi: 10.3334/ORNLDAAC/1840.

[8] Natural Resources Conservation Service, "U.S. General Soil Map (STATSGO2)." United States Department of Agriculture. [Online]. Available: https://sdmdataaccess.sc.egov.usda.gov

[9] Natural Resources Conservation Service, "Soil Survey Geographic (SSURGO) Database." United States Department of Agriculture. [Online]. Available: https://sdmdataaccess.sc.egov.usda.gov

[10] "National Agricultural Statistics Service Cropland Data Layer," United States Department of Agriculture. [Online]. Available: https://nassgeodata.gmu.edu/CropScape/.

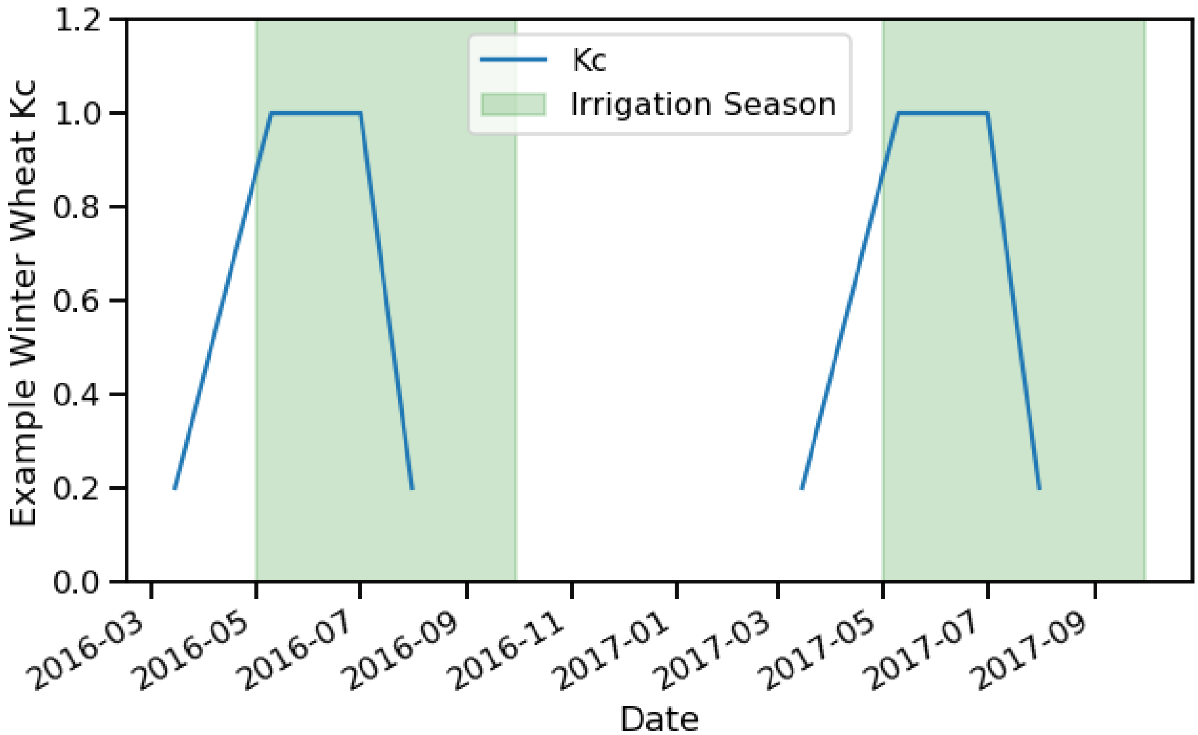

Figure 3. Hypothetical K_c curves for a winter wheat crop.

OpenET does not have initiation and termination criteria like GridET. This study computed OpenET depletions by applying equation 2 to the entire May through September irrigation period, regardless of when true initiation or termination occurs. While GridET stops summing ET and P_{eff} after crop termination, continuing to sum ET and P_{eff} for the remainder of the irrigation season is a reasonable choice when using ET_{act}. Any additional ET_{act} that occurs after termination is due either to residual soil moisture or subsequent effective precipitation. ET_{act} minus P_{eff} is attributable to residual soil moisture and can be counted as depletion. For OpenET depletions, winter ET was set equal to zero in the SM_{co} calculation. In GridET, ET outside the irrigation season reduces winter carryover. The assumption of zero winter ET for OpenET depletions was made for simplicity and to better match GridET, since winter ET in GridET is typically small. The OpenET project provides ET in the winter months, but it is less accurate and more prone to contain missing data due to cloud cover.

Because of the differences in summation periods between OpenET and GridET, we created a second estimate of OpenET depletion depths for some crops using GridET initiation and termination dates to prorate OpenET ET_{act} and precipitation. The full irrigation season OpenET depletions are likely closer to what would be operationally used in depletion studies. The prorated OpenET depletions attempt to make the depletions more comparable to GridET so we can observe the effects of actual versus potential ET rates.

Depletion volume computation

Once depletion depths have been computed for the entire basin, depletion volumes for state/division/subbasin areas can be computed with equation 4.

$$depl\_vol = added * added\_depth + (added\_not\_irr + added\_small\_fields - subtracted) * irr\_depth \quad (4)$$

There are two distinct depletion depths in equation 4: "*added_depth"* is the mean irrigated depletion depth for all added acres, and "*irr_depth"* is the depth for all irrigated acres. The mean added depletion depth is multiplied by all "*added*" acres - new acres after 1976 that are irrigated. The mean irrigated depletion depth is multiplied by any acres without good depletion estimates. Acres subtracted since 1976 are, by definition, not being irrigated, so we must estimate the depletion from those acres as if they were still being irrigated. The state/division/subbasin mean irrigated depletion depth (*irr_depth*) was chosen as a reasonable estimate. Added and unirrigated acres (*added_not_irr*) are also multiplied by the mean irrigated depletion depth. Lastly, fields that are too small for OpenET to accurately resolve ET_{act} (*added_small_fields*) are multiplied by the mean irrigated depletion depth. Satellite image resolution is not an issue for GridET so added small fields can use the mean added depletion rate.

OpenET provides ET_{act} rasters with 30-meter pixel size. Depletions are computed with the same resolution. The true resolution of the thermal sensor on Landsat 8 is 100 meters, but the USGS resamples it to 30-meter resolution. Pixels that straddle the edge of a field represent an area-weighted average of ET_{act} within and outside the field, so these mixed pixels should be excluded in depletion depth estimates. To ensure that the unirrigated area didn't influence depletion depth estimates, field polygons were buffered in by approximately 71 meters (½ the hypotenuse of a 100-meter pixel). Buffered areas were merely used to calculate depletion depths and were not used to determine the areas in equation 4. If an area had added acres but didn't have a mean added depletion depth due to buffering, we used the mean irrigated depth.

Depletion depth comparisons

OpenET is only available 2016-present, so the depletion depths were not directly comparable to the 2015-2019 depletion values generated by GridET. We recreated GridET depth and volume estimates for 2016-2019. In addition to using different years, we processed the GridET data slightly differently than Utah did for their 2015-2019 pre-final numbers. Despite the processing differences, the 2016-2019 GridET depletion depths and volumes are very similar to the 2015-2019 GridET depletion depths and volumes.

Table 1 below shows the added (*added_depth* in equation 4) and subtracted (*irr_depth* in equation 4) depletion depths estimated for subbasins. Green indicates the OpenET value is higher than the corresponding GridET value and red indicates that OpenET is lower. OpenET tends to estimate smaller depletion depths for both added and subtracted acres. The Evanston and Oneida subbasins are exceptions. SSEBop is the OpenET model that most frequently exceeds GridET. The OpenET ensemble typically has the smallest depletion depths because it's an average of at least four of the six OpenET models after outlier removal, and some of those models tend to estimate less ET than SSEBop and eeMETRIC.

Added and subtracted depletion depths are more similar for GridET than they are for OpenET. For the OpenET models, the added depletion depth is usually smaller than the subtracted depth. The effect on depletion volumes is that subtracted acres more readily offset added acres when using OpenET.

ESTIMATED DEPLETION FOR POST JANUARY 1, 1976
LANDS FOR SUBBASINS OF THE BEAR RIVER BASIN

Based on average (2016 - 2019) crop mixes, updated ET rates from Utah Division of Water Resources' GridET program (2022), and May-September OpenET actual ET

Model	Area	Units	SUBBASIN										
			Evanston	Randolph	Cokeville	Thomas Fork	Bear Lake	Soda	Oneida	Cache Valley	Malad	Tremonton	Brigham City
GridET	Added	AF/A	1.26	1.34	1.23	1.17	1.17	1.15	1.23	1.35	1.45	1.47	1.60
GridET	Subtracted	AF/A	1.32	1.32	1.28	1.23	1.21	1.15	1.22	1.42	1.51	1.42	1.51
eeMETRIC	Added	AF/A	1.46	0.89	1.06	0.99	0.75	0.98	1.24	0.85	1.07	1.10	1.24
eeMETRIC	Subtracted	AF/A	1.84	1.30	1.21	0.98	0.98	1.15	1.34	1.17	1.15	1.34	1.35
SSEBop	Added	AF/A	1.54	0.96	1.23	1.17	0.75	0.91	1.27	0.79	1.19	1.19	1.26
SSEBop	Subtracted	AF/A	1.90	1.37	1.31	0.98	0.97	1.13	1.38	1.12	1.26	1.39	1.51
Ensemble	Added	AF/A	1.19	0.82	0.97	0.94	0.70	0.78	1.06	0.82	0.97	1.06	1.32
Ensemble	Subtracted	AF/A	1.53	1.19	1.13	0.90	0.92	0.97	1.17	1.13	1.11	1.27	1.41

Table 1. Depletion depths for added and subtracted acres. Green indicates the OpenET value is higher than the corresponding GridET value and red indicates that OpenET is lower.

Table 2 shows depletion volumes by state/division/subbasin. Depletion depths were computed for each state/division/subbasin area for the 2016-2019 datasets. The 2015-2019 GridET values represent subbasin-wide depletion depths applied to all state/division areas that lay within a subbasin. Despite this difference and the different years, depletion volumes for the 2015-2019 GridET and the 2016-2019 GridET were very similar.

OpenET depletion volumes were typically lower than the GridET volumes. One exception was Cache Valley in Utah. Cache Valley had far more subtracted acres than added acres and the subtracted depletion depth for GridET was much higher than for OpenET. This caused GridET to have a negative depletion of greater magnitude.

Net Change in Full Supply Irrigation Depletion Since 1976									
Depletions (AF)									
State	**Stewart Dam**	**Subbasin**	**2009 Report**	**GridET (2015-2019)**	**GridET (2016-2019)**	**eeMETRIC (2016-2019)**	**SSEBop (2016-2019)**	**Ensemble (2016-2019)**
Idaho	Above	Bear Lake	343	482	530	395	370	341
Idaho	Above	Thomas Fork	531	315	323	271	259	237
Idaho	Below	Bear Lake	200	347	337	53	89	67
Idaho	Below	Cache Valley	281	-162	-35	-732	-674	-717
Idaho	Below	Malad	989	3846	3823	2792	3086	2438
Idaho	Below	Oneida	118	2029	2135	2124	2177	1805
Idaho	Below	Soda Springs	312	862	903	724	661	563
Idaho	Below	Tremonton	609	3234	3311	2744	3133	2654
Utah	Below	Bear Lake	-322	-624	-647	-710	-675	-621
Utah	Below	Brigham City	-289	-825	-813	-756	-858	-786
Utah	Below	Cache Valley	-7037	-16030	-16016	-13591	-13130	-13340
Utah	Below	Tremonton	-1036	-3843	-3705	-4888	-5135	-4615
Utah	Above	Cokeville	32	-116	-114	-140	-146	-131
Utah	Above	Evanston	0	9	8	12	12	9
Utah	Above	Randolph	468	-398	-401	-603	-623	-553
Wyoming	Above	Cokeville	1750	4557	4517	3826	4487	3491
Wyoming	Above	Thomas Fork	57	540	508	386	553	380
Wyoming	Above	Evanston	-681	-2693	-2742	-4001	-4099	-3345

Table 2. Depletion volumes grouped by state, division, and subbasin

The bar charts in Figure 4 show the depletion depths from Table 1 along with the proportion of the depths attributable to each crop. Crop mix varies substantially between subbasins and between added acres and all irrigated acres. GridET tends to have higher alfalfa depletion depths, resulting in higher depletion depths in some subbasins, but not all. In Oneida, small grains had smaller GridET depletion depths than eeMETRIC and SSEBop, which resulted in eeMETRIC and SSEBop exceeding GridET. In Evanston, the crop mix was mostly composed of pasture and other hay, and eeMETRIC and SSEBop had larger depletion depths for both of those crops. In other subbasins GridET had larger depletion depths for pasture and other hay. GridET may not be able to capture the diversity of pasture management that occurs throughout the basin.

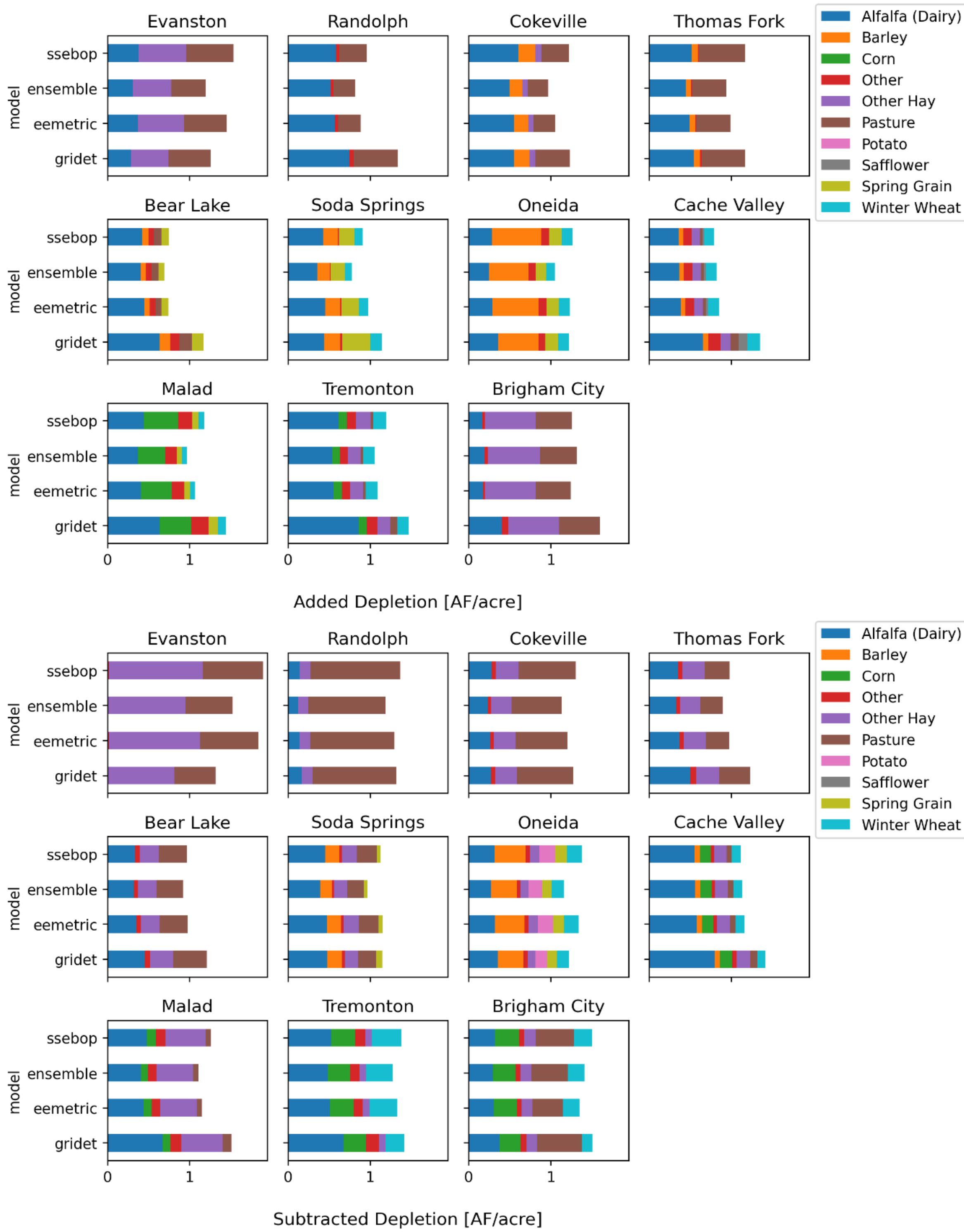

Figure 4. Depletion depths by crop and subbasin for added and subtracted acres.

Figure 5 shows average basin-wide depletion depths for some of the more common crops for 2017 through 2020. Figure 6 is similar to Figure 5 but shows the results of prorating the growing season in OpenET to mimic GridET. Data for 2017-2020 were used in Figures 5 and 6 instead of 2016-2019 because proration required ET data for the previous year to fully account for SM_{co}. Calculating 2016 depletions requires 2015 data, which is not available from OpenET. In Figure 5 whether GridET or OpenET is higher for a given crop varies from year to year, but OpenET typically has a larger depletion depth for small grains than GridET. Figure 6 shows that prorated OpenET small grain and corn depletions become consistently lower GridET, which matches our intuitions about actual versus potential depletions. This highlights the importance of how the growing season is defined. Alfalfa has a higher depletion depth for GridET than for OpenET in both Figure 5 and 6.

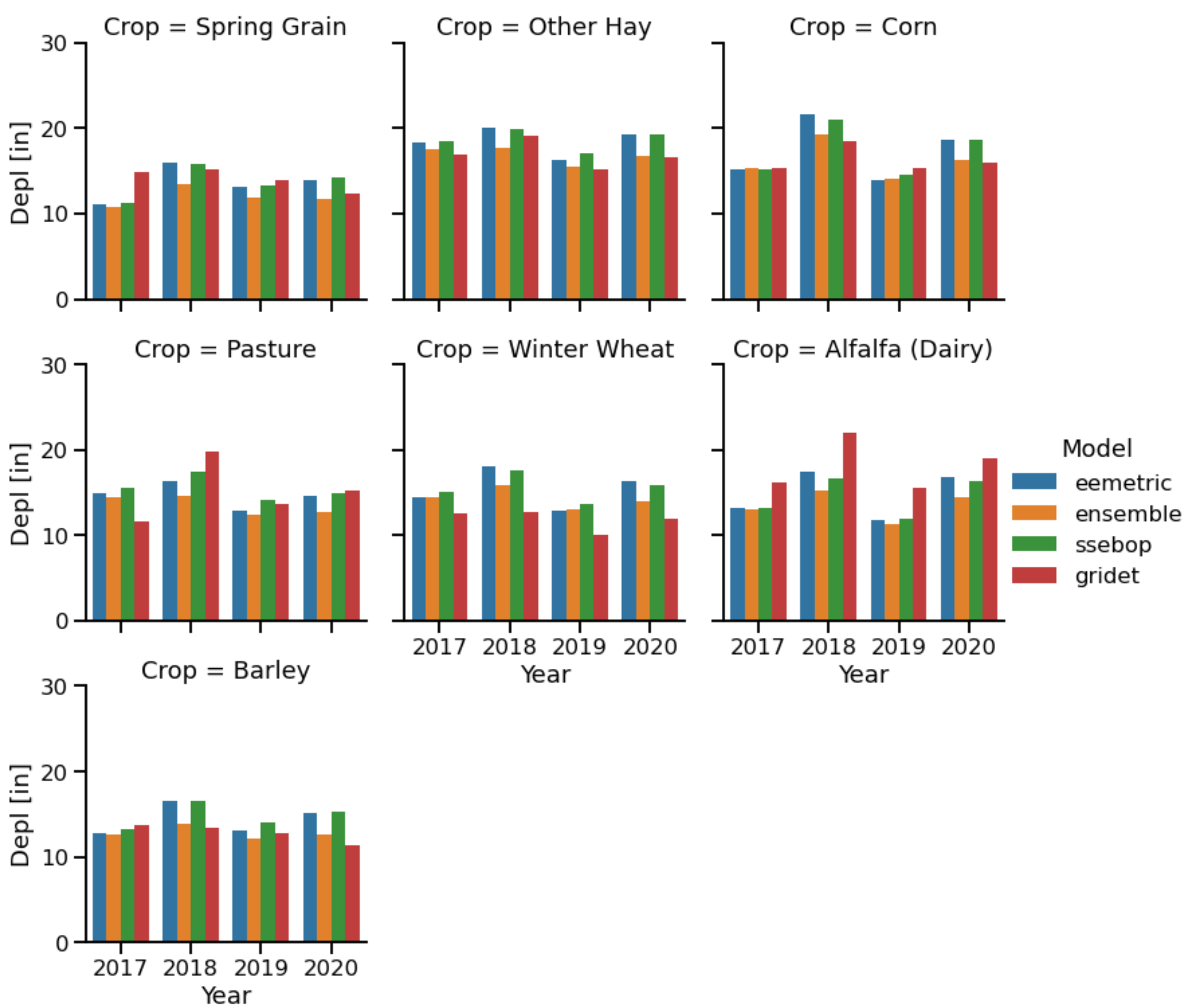

Figure 5. Crop depletion depths with the regular May-Sep season.

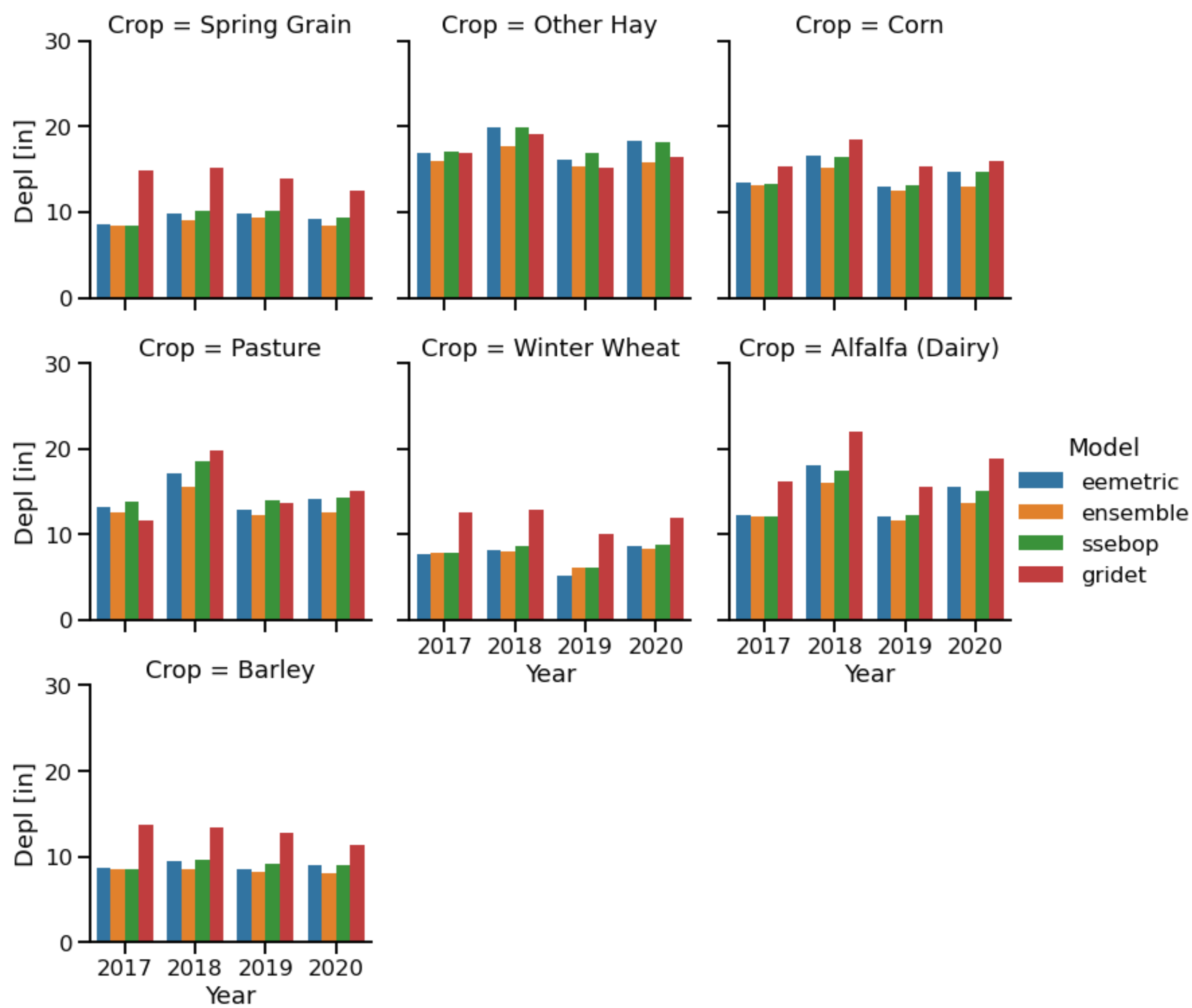

Figure 6. Crop depletion depths with OpenET prorated.

Conclusions and Recommendations

The aim of using actual ET instead of potential ET in the depletion update procedure is to know if the states have exceeded their allocations. Potential ET, by definition, exceeds actual ET and would therefore risk identifying exceedances that did not occur. Potential ET is valuable in planning contexts because it shows the upper limit of what actual ET could be. However, if the depletion update's purpose does not involve planning, actual ET should be used during the next depletion update.

If identifying exceedances is a goal, we should not average multiple years of depletions together, as presently done. Using a five-year average of actual ET suggests that the depletions update is not looking for exceeded allocations. Instead of averaging the past five years of actual ET we should examine each year's depletion for exceedance. A depletion estimate made during a cool, wet summer may be under a state's allocation, but a dry hot summer may cause the depletion to exceed the allocation, even holding irrigated area and crop mix constant.

Remote sensing is the best way to estimate the actual ET from irrigated agriculture over large areas. Thermal remote sensing models better represent water shortage than vegetation index models such as SIMS. The PT-JPL model and DisALEXI models, as implemented in OpenET, require corrections to perform well in semi-arid conditions. geeSEBAL underestimates ET because it does not account for the contribution of advected sensible heat to ET. The model ensemble removes outlier models averages a minimum of four models. This means that models that tend to underestimate ET will be included in the ensemble. Of the models included in OpenET, I believe that SSEBop and eeMETRIC are best suited for use in the depletion update procedure. This recommendation should be reevaluated at the next depletion update because the technology and models will evolve.

Presently, an irrigation map representing a single year is assumed to be sufficient for the five-year average depletions. To find actual depletion volumes, we should pair each year's actual depletion depths with an accurate irrigation map for that year. If we intend to analyze multiple years, this presents a practical challenge because the irrigation map is currently produced with a time-consuming manual process. Irrigation map creation may need to be more automated to make depletion estimates available within a reasonable amount of time.

Despite how potential and actual ET are defined, there are cases where the potential depletion depths from GridET are lower than actual depletions from OpenET, even after prorating the OpenET growing season. This may be because GridET cannot account for the diverse farming practices that impact actual ET. Nevertheless, we found that GridET estimated larger depletion depths and volumes for most subbasins.

How we estimate depletion depths for subtracted acres greatly affects depletion volumes. The method for determining depletion depths for subtracted acres should be revisited before adopting an actual ET method.

This study examined the effects of ET on depletions, but effective precipitation and winter soil moisture carryover are also important in the depletion calculation. Our estimates for these variables are perhaps more uncertain than our ET estimates. We should remain open to improved methods should they become available. For example, OpenET is exploring the use of a daily soil water balance model to improve estimates of effective precipitation. We should also keep in mind that more complex models that include additional processes will not necessarily yield additional accuracy and may, in fact, diminish accuracy[11].

[11] A. Saltelli, "A short comment on statistical versus mathematical modelling," Nat Commun, vol. 10, no. 1, p. 3870, Dec. 2019, doi: 10.1038/s41467-019-11865-8.