Evapotranspiration Methodology for the Raft River Water Budget

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Introduction

This paper details the methodology and procedure for calculating monthly evapotranspiration (ET) for the Raft River Basin water budget. The Department of Water Resources (IDWR) commonly utilizes ET derived from the Mapping Evapotranspiration at high Resolution with Internal Calibration (METRIC) model for basin-scale water studies (https://idwr.idaho.gov/gis/mapping-evapotranspiration/). The decision to use an alternative ET product for the Raft River water budget was due to the lack of spatial and temporal coverage of METRIC ET in the study boundary. The Raft River study boundary (Figure 1) spans from south of Lake Walcott to the northern part of Utah's Box Elder County. For earlier years of METRIC data, the southern Utah portion of the Raft River study boundary is not covered. Several years of METRIC are also missing for the temporal extent of the water budget (2000-2021). The alternative ET product, hereafter known as Raft ET, was calculated from monthly maps of gridded reference ET and crop coefficients specific to Idaho. Raft ET was created by IDWR staff and provided to the Idaho Geological Survey (IGS) under contract to IDWR. IGS was responsible for the main body of the project. Please refer to the IGS project

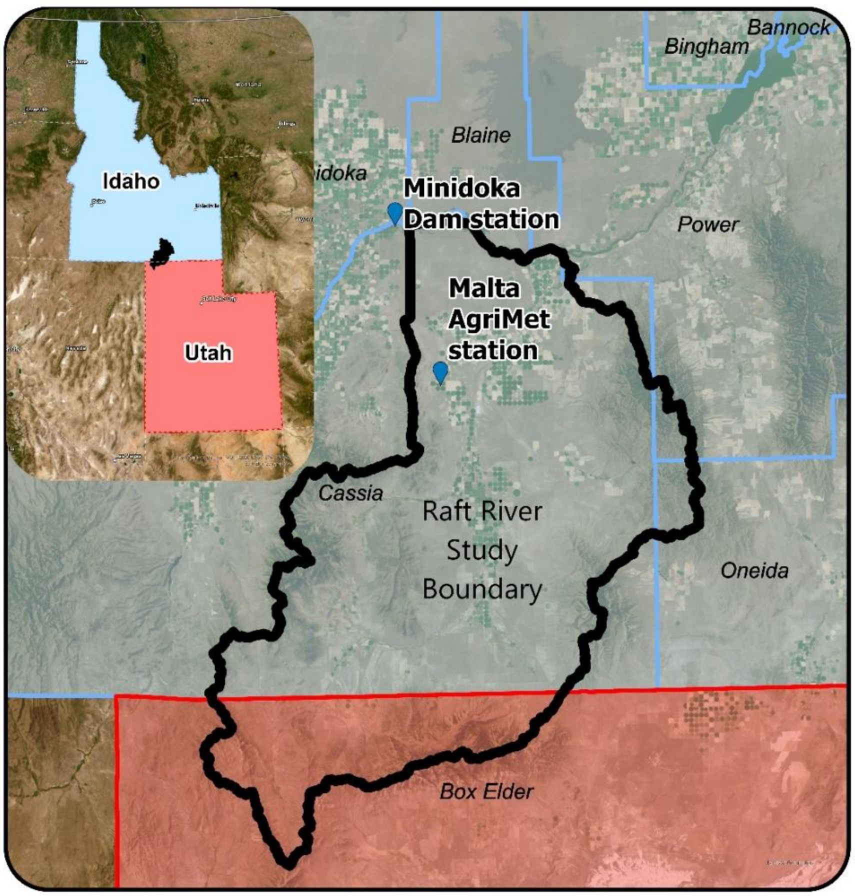

Figure 1. Raft River study boundary. Counties are delineated and italicized on map.

report (Clark, 2024) for the extent of how Raft ET was used. The following outlines the data sources used, general methodology, preprocessing, and comparative analysis and validation of the final product.

Data Sources

The method for calculating Raft ET is largely possible thanks to Utah Department of Natural Resources (DNR) and their provision of gridded, daily reference ET maps from Lewis and Allen (2016). This product covers the Raft River study boundary from 2000-2021 except for an approximately 9-mile-wide section due south of Lake Walcott. ET in this area will be handled separately (Clark, 2024). ET-IDWR (formally known as ETIdaho) is an IDWR web-based platform used for serving irrigation requirement data. These data were relied on to determine crop coefficients for the Raft River. ET-IDWR was recently updated in 2022 to include later years of data (2017-2021) and adjust the background code. The updated data were provided to IDWR staff by the University of Idaho before being made available on the public website (https://et-idwr.idaho.gov/).

Other data sources include the Cropland Data Layer (CDL) provided by US Department of Agriculture, and METRIC ET maps, which data are all available on the IDWR Raft River Basin project page (https://idwr.idaho.gov/water-data/projects/raft-river/data/). The IDWR 2017 Irrigated Lands dataset describing irrigated field polygons was also used and available at the department's online Data Hub (IDWR, 2021). The spatiotemporal coverage of these products is provided in Attachment 1. The Python code used to process these data is provided in Attachment 2.

Methodology

The calculation of Raft ET was based on the commonly used crop coefficient approach as given by Allen et al. (1998) (Eq 1). This approach uses the reference ET, which describes an ideal crop reference surface where climatic variables are the only factors affecting reference ET. In all mentions of reference ET in this documentation, the "tall" or alfalfa crop reference ET is used (hereafter ETr). The crop coefficient (Kc) is the ratio of crop ET (ETc) to ETr (Eq 2), which represents how characteristics such as crop height and albedo distinguish the crop from the reference crop.

$$ETc = ETr \times Kc \qquad \text{Eq 1.}$$

$$Kc = \frac{ETc}{ETr} \qquad \text{Eq 2.}$$

In following the approach in Eq 1, Raft ET was calculated from Utah DNR maps of gridded ETr and ET-IDWR derived crop coefficients for crops found in the Raft River. The gridded ETr was provided to IDWR in daily files which were summed to monthly totals for use in the water budget. Kc values are not directly given in ET-IDWR dataset; ETc and ETr are available on a daily timestep and were used to derive the Kc by summing to monthly totals and dividing (Eq 2).

Kc values from ET-IDWR are point-based estimates utilizing weather station data in southern Idaho. As such, monthly Kc values needed to be spatially mapped to the appropriate crops in the Raft River. This was done by using the Cropland Data Layer (CDL) which is a product of U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS). These gridded maps are produced annually for the entirety of the continental U.S. and describe land cover type at a 30-meter resolution (USDA-NASS, 2024).

Table

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OID	Value	Count	Irrigated	CDL	ETIDAHO_KC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	1	39747	1	Corn	(Kc) Silage Corn (same as field corn but with truncated season)	0.54	0.37	0.24	0.11	0.12	0.43	0.85	0.97	0.73	0.08	0.29	0.17
1	4	246	1	Sorghum	(Kc) Grass Pasture - high management	0.24	0.2	0.18	0.22	0.8	0.87	0.86	0.84	0.81	0.6	0.17	0.12
2	21	27060	1	Barley	(Kc) Spring Grain - Irrigated	0.39	0.3	0.24	0.35	0.64	1.03	0.96	0.22	0.04	0.08	0.22	0.15
3	22	9	1	Durum Wheat	(Kc) Spring Grain - Irrigated	0.39	0.3	0.24	0.35	0.64	1.03	0.96	0.22	0.04	0.08	0.22	0.15
4	23	35598	1	Spring Wheat	(Kc) Spring Grain - Irrigated	0.39	0.3	0.24	0.35	0.64	1.03	0.96	0.22	0.04	0.08	0.22	0.15
5	24	82923	1	Winter Wheat	(Kc) Winter Grain - Irrigated	0.57	0.46	0.38	0.39	0.76	1.04	0.83	0.11	0.04	0.12	0.33	0.2
6	25	6	1	Other Small Grains	(Kc) Spring Grain - Irrigated	0.39	0.3	0.24	0.35	0.64	1.03	0.96	0.22	0.04	0.08	0.22	0.15
7	28	2066	1	Oats	(Kc) Spring Grain - Irrigated	0.39	0.3	0.24	0.35	0.64	1.03	0.96	0.22	0.04	0.08	0.22	0.15
8	32	3	1	Flaxseed	(Kc) Spring Grain - Irrigated	0.39	0.3	0.24	0.35	0.64	1.03	0.96	0.22	0.04	0.08	0.22	0.15
9	33	11603	1	Safflower	(Kc) Safflower - Rainfed	0.39	0.3	0.22	0.12	0.12	0.22	0.1	0.01	0.03	0.08	0.22	0.15
10	35	3629	1	Mustard	(Kc) Mustard	0.39	0.3	0.22	0.16	0.58	0.99	0.74	0.13	0.04	0.08	0.22	0.15
11	36	209794	1	Alfalfa	(Kc) Alfalfa Hay - beef cattle style ~3 cuttings	0.55	0.37	0.24	0.55	0.95	0.8	0.95	0.64	0.79	0.37	0.3	0.17
12	37	73261	1	Other Hay/Non Alfalfa	(Kc) Spring Grain - Irrigated	0.39	0.3	0.24	0.35	0.64	1.03	0.96	0.22	0.04	0.08	0.22	0.15
13	41	30208	1	Sugarbeets	(Kc) Sugar beets	0.54	0.37	0.24	0.11	0.16	0.61	1.02	0.95	0.76	0.11	0.29	0.17
14	42	2259	1	Dry Beans	(Kc) Spring Grain - Irrigated	0.39	0.3	0.24	0.35	0.64	1.03	0.96	0.22	0.04	0.08	0.22	0.15
15	43	18802	1	Potatoes	(Kc) Potatoes--cold pack (late harvest)	0.54	0.37	0.24	0.11	0.2	0.55	0.85	0.79	0.37	0.09	0.29	0.16

0 (0 out of 39 Selected)

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Figure 2. Example of ArcMap attribute table joining the CDL raster with ET-IDWR monthly Kc values (called ETIDAHO_KC in the field heading). The CDL for the year 2020 is shown.

The CDL was 'linked' to the ET-IDWR Kc by using a key created by IDWR and IGS staff (Attachment 6). This key allowed for tabulated monthly Kc values to be joined with the CDL raster within an ArcMap attribute table (ESRI, 2011) (Figure 2). When a CDL land cover type did not have a comparable ET-IDWR category, a separate Kc was derived based on existing literature and best judgement. Additionally, there is limited coverage of the CDL in earlier water budget years (Attachment 1). How these data gap issues were resolved for calculation of Raft ET are explained in the following section.

Joined attribute tables relating the CDL to the monthly Kc values were multiplied by the monthly gridded ETr for each water budget year using the Raster Calculator tool in ArcMap. This step implements the simple equation in Eq 1 and results in the final Raft ET product. As shown, Raft ET is a combination of at least two different ET datasets. The user is encouraged to review nuances in the individual datasets by referencing Utah DNR reference ET document (Lewis and Allen 2016) and ET-IDWR methodology (Allen and Robison 2007) as the main contributing sources in the creation of Raft ET.

Preprocessing

Cropland Data Layer

Several preprocessing steps were required before use of the CDL due to data gaps and the coarseness of the data. The CDL is a product of remote sensing imagery, ground-truth datasets, and machine learning (Boryan et al. 2011). Specifically, the CDL was produced using a See5 decision tree classifier model to classify each pixel to a certain land cover type. As is common to these products, pixel-to-pixel accuracy is variable and can result in an irrigated field with multiple crop types. Fields are typically planted in one crop type, or perhaps two if a producer splits the field between two crops or sequentially plants two crops within one growing season (i.e., double cropping).

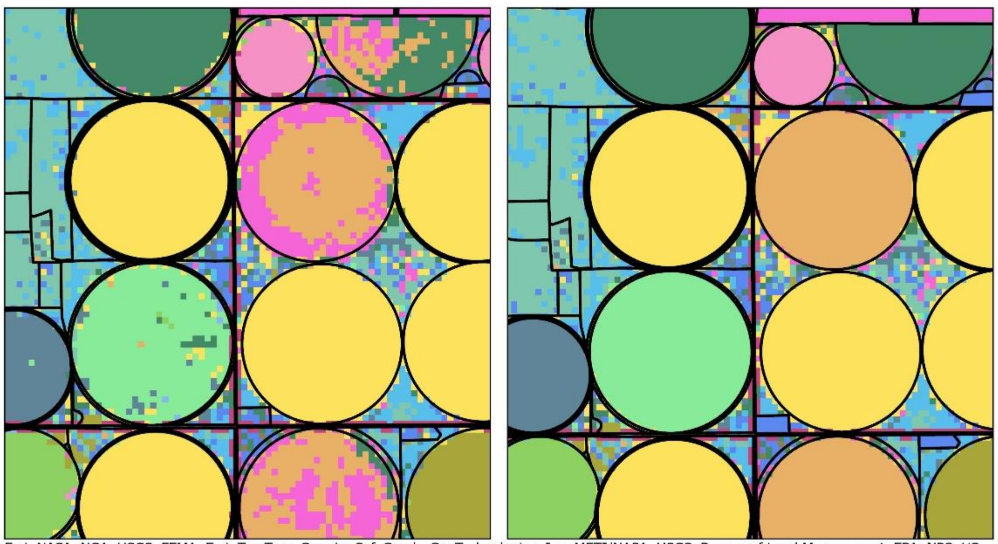


Figure 3. 2019 CDL raster before smoothing (left) and after smoothing filter applied (right). Polygons shown in black are from the IDWR Irrigated Lands dataset for 2017 (IDWR, 2021). Some fields shown here include alfalfa (yellow), barley (brown), spring wheat (pink), winter wheat (dark green), and triticale (turquoise).

To improve the accuracy of the CDL, IDWR's 2017 Irrigated Lands dataset was used exclusively to 'smooth' the CDL raster using ArcMap Zonal Statistics tool and selecting the majority pixel per irrigated polygon (Figure 3). Non-irrigated land cover types were not smoothed using this process. These data were extracted using a non-irrigated mask and joined with the smoothed irrigated polygons.

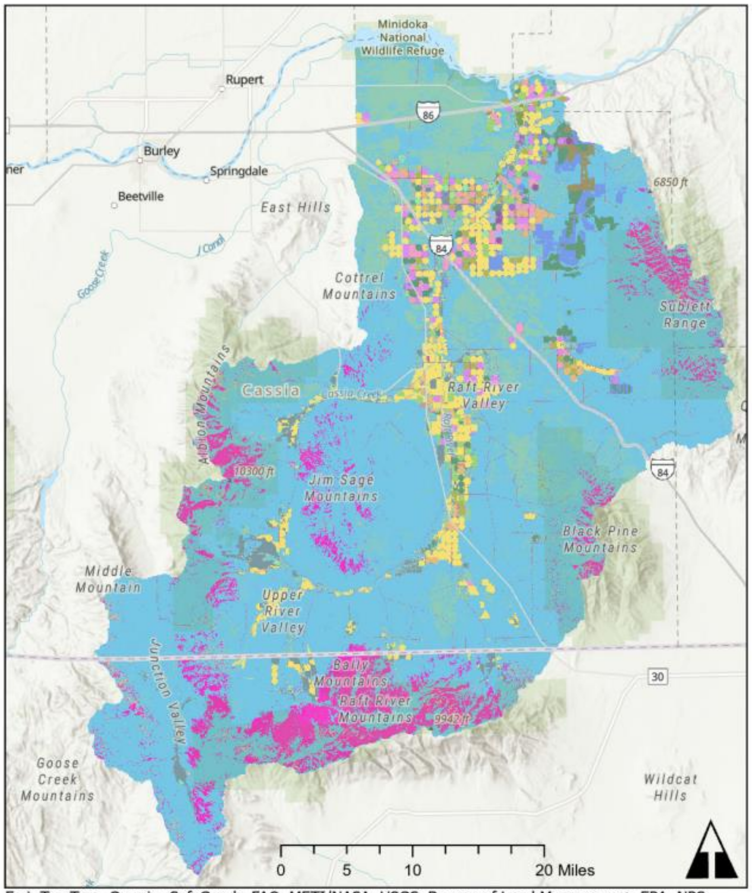
Early years of CDL development had limited coverage for some U.S states. No coverage is available for Idaho and Utah in 2000-2004, 2006, with only Idaho coverage in 2005 and 2007 (Attachment 1). To resolve this data gap, a proxy dataset was used by combining 2007 (Idaho coverage only) with 2008 (Utah coverage only) raster maps. This proxy dataset served as the map for early years of missing CDL coverage. The Idaho CDL coverage for 2005 was excluded given the large differences in irrigated acreage and land cover type between 2005 and later years. The differences are likely due to a major change in the software and data inputs that took place for the CDL program at the beginning of 2006 (Boryan et al. 2011).

ET-IDWR Crop Coefficients

The smoothing of CDL maps eliminated several erroneous land cover types and allowed for a unique list of irrigated and non-irrigated lands in Raft River from 2000-2021. This list was compared with available crop categories in ET-IDWR to generate a key (Attachment 1) by which Kc values could be linked to gridded CDL data. ET-IDWR categories and CDL land cover types are not always easily comparable or available; for example, the ET-IDWR crop type *Spring Grain – Irrigated* was used for CDL land cover types of *Oats, Flaxseed, Millet* and *Other Small Grains*.

For CDL land cover types including *Christmas Trees, Evergreen Forest*, and *Mixed Forest*, no comparable ET-IDWR category exists. In this case, a manual Kc called "Evergreen Forest" was derived with supporting evidence from ground-truthed information and literature. A large portion of these CDL land cover types exist on the Utah side of the Raft study boundary (Figure 4). Nearing the Utah border, pinyon-juniper woodlands largely predominate. For Sublett Range, Black Pine and Jim Sage Mountains, sagebrush steppe covers the mountains with pockets of Douglas Fir. Since sagebrush and juniper are largely found in similar environments and likely have similar water usage strategies designed to conserve water in semi-arid environments, the monthly Kc curve for sagebrush (from ET-IDWR) was used as baseline values for the manually derived evergreen forest Kc.

Recent research has been seeking to understand the ecological effects of juniper growth and transition on prominently sagebrush dominated systems (Kormos et al. 2016). This includes juniper's effects on snow distribution and water budgets, specifically in snow-dominated rangelands. In looking at these systems along the Idaho-Oregon border, Kormos et al. modeled ET as a residual of a yearly water balance for both juniper and sagebrush dominated scenarios (2016). Table 1 shows the results of their modeling, where "ET ratio" is a column that was calculated for Raft ET. This ratio was averaged over the course of available data and used to adjust the amount of monthly sagebrush Kc to serve as the Evergreen Forest Kc (Figure 5).



Esri, TomTom, Garmin, SafeGraph, FAO, METI/NASA, USGS, Bureau of Land Management, EPA, NPS, USFWS, Esri, CGIAR, USGS

Figure 4. 2019 CDL showing land cover types for *Evergreen Forest*, *Mixed Forest*, and *Christmas Trees* in dark pink. *Evergreen Forest* has the largest coverage among these three types for

Table 1. Modeled results of ET for juniper and sagebrush-dominated scenarios. See Kormos et al. (2016), Table 1, for more information and inclusion of sagebrush modeled p-values (not included). 'ET ratio' was calculated outside of the paper for use in deriving Raft ET. Average ET ratio was rounded to 1.6 for use in deriving evergreen forest Kc.

Water Year	Juniper-dominated Scenario (residual ET, mm)	Sagebrush-dominated Scenario (modeled ET, mm)	ET ratio (Juniper/Sagebrush)
2008	508	288	1.76
2009	578	367	1.57
2010	490	423	1.16
2011	686	450	1.52
2012	431	231	1.87
2013	492	331	1.49
		Average ET ratio:	**1.56**

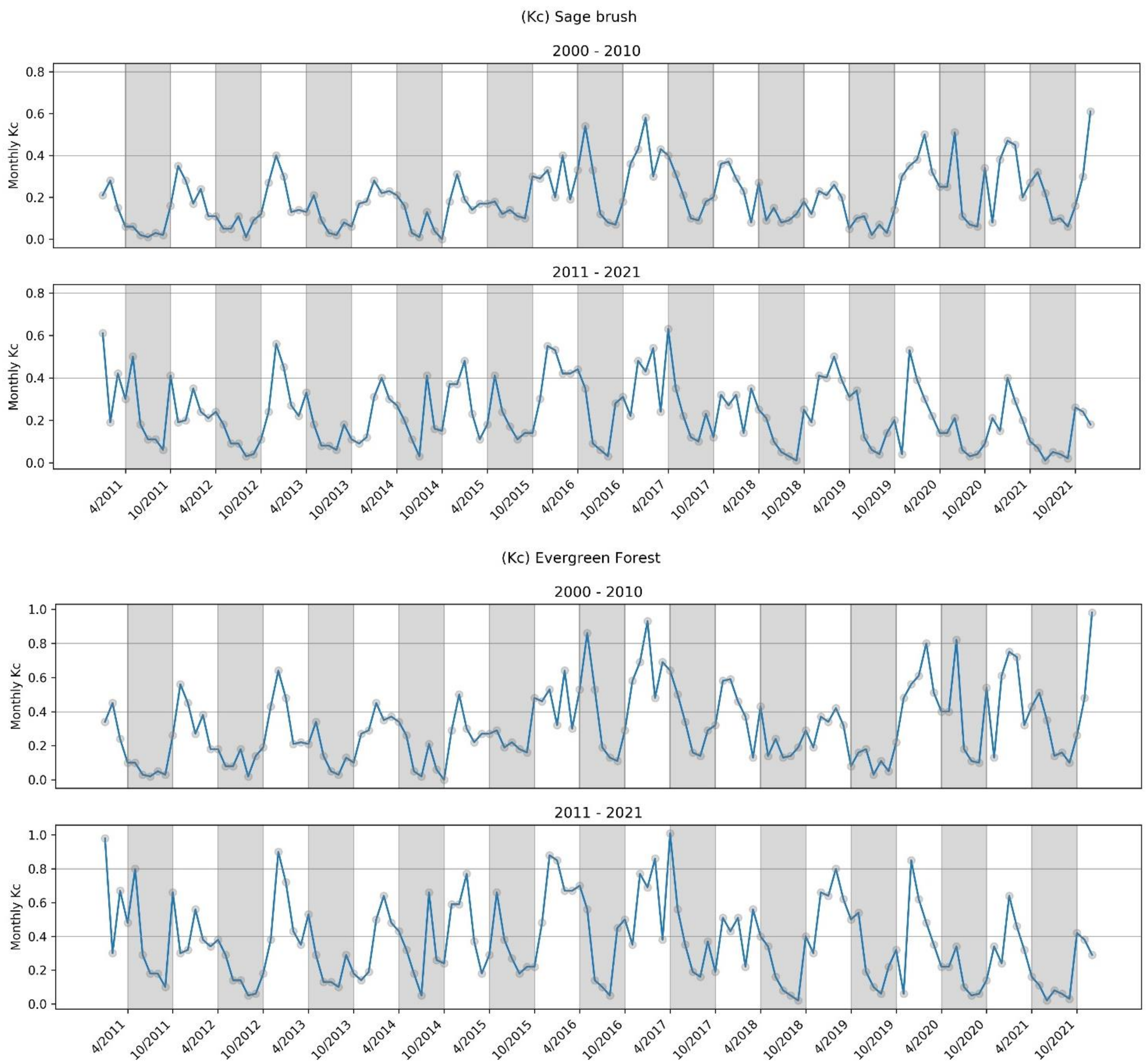


Figure 5. Crop coefficient curves for *Sage brush* (top two graphs) and the manually derived Evergreen Forest (bottom two graphs). Evergreen Forest Kc was created by multiplying monthly *Sage brush* Kc by a factor of 1.6. Dark vertical shading indicates the approximate growing season period.

CDL Double Crop Assignments

The cropland data layer distinguishes fields that harvest two crops within the same year. These crop rotations, otherwise known as double-cropping, are planted and harvested sequentially rather than grown simultaneously within the same field. ET-IDWR does not contain a double crop category, so comparable categories were substituted and an approximate planting/harvest schedule for each crop was determined based on local production practices (L. Schott with UI Twin Falls Extension, personal communication on 1/16/24) (Marshall et al., 2020). In Table 2, the following assignments were made to essentially merge two separate Kc curves into one year. Planting harvest schedule helps assign an appropriate Kc to each month, in which a scripted process extracts the associated monthly Kc and merges these values into one continuous Kc curve for a given year.

One caveat in how these monthly values were applied is our assumption that double crops were planted/harvested within the same year. It is possible certain crops like winter wheat were planted in the previous year and harvested early spring the following year. USDA NASS website notes, "…a winter wheat field planted in the Fall of 2009 will be identified in the 2010 CDL" (USDA - National Agricultural Statistics Service - Research and Science - Cropland Data Layers). Chances for inaccuracy are possible but have minimal impact on overall ET given the extent of double crop acreage as well as low ET occurring over winter months.

CDL Double Crop Name	Dbl Crop Barley/Sorghum	Dbl Crop Barley/Corn	Dbl Crop Triticale/Corn	Dbl Crop WinWht/Sorghum
CDL Coverage	2014	2018	2019-2021	2019
Acreage (approx.)	250	<1	400-2,500	90
ET-IDWR Category	Spring grain irrigated/Grass pasture high mgmt.	Spring grain irrigated/Corn silage	Spring grain irrigated/Corn silage	Winter grain irrigated/Grass pasture high mgmt.
Planting harvest schedule	Sorghum: June-October Winter wheat: Nov-July	Corn: June-October Barley: Nov-May	Corn: June-October Triticale: Nov-May	Sorghum: Aug-October Winter wheat: Nov-July

Table 2. Assignments for CDL double crop categories.

Tabulating Monthly Kcs

Before calculating the monthly Kc values for ET-IDWR crop categories, the data was checked for gaps in weather station data and filled by linear interpolation. Two ET-IDWR AgriMet station data were used, namely Minidoka Dam and Malta (Figure 1). Minidoka Dam had a total of 40 interpolated days for data gaps found in 2015, with the longest consecutive interpolation of 5 days. Crops impacted by interpolation include carrots, onions, peas (seed), mint and sunflower (irrigated). Malta station did not show any data gaps for the entirety of the study period (2000-2021). As described in more detail in the methodology, daily reference ET and crop-specific actual ET were individually summed to monthly totals, then divided as shown in Eq 2 to calculate monthly Kc values. Each resulting crop Kc curve was inspected visually for the entirety of the study period to scan for outlying data. All Kc curve plots are available in Attachment 3.

Review and Validation

The final gridded monthly Raft ET from 2000-2021 were reviewed by IDWR and IGS staff to ensure the resulting ET was within an expected range and was comparable to METRIC ET for available years. Raft ET was first summed on a volumetric basis (in acre-feet) for the entire Raft River study boundary as well as for each irrigation district boundary by water source (i.e., surface water only, groundwater only, and mixed). The summed values were compared with other water budget terms and compared interannually against PRISM gridded precipitation (OSU, 2024) and METRIC ET datasets.

Secondly, monthly Raft ET was totaled for the growing season (April-October) and an average seasonal ET per crop type was determined using the CDL layer and the Zonal Statistics tool in ArcMap. Zonal Statistics was also run on seasonal METRIC maps for available years, and the resulting values were compared with average Raft ET per crop type. One example of these comparisons is shown in Figure 6 for alfalfa hay. The CDL alfalfa acreage per year is shown in grey vertical bars. Certain years are missing bars on the graph, indicating METRIC data was unavailable for that year. The blue line shows the mean difference (METRIC minus Raft ET), where positive values indicate Raft ET underestimated ET compared to METRIC and negative values showing Raft ET overestimated ET. Each yearly difference shows vertical brackets of standard deviation.

These plots were used to tailor our assignments of ET-IDWR categories to CDL land cover types. For example, three separate ET-IDWR categories for alfalfa exist: no cutting effects, 3 cuttings, and 4 cuttings. Each Kc time series for this category is slightly different and will alter the final Raft ET for alfalfa. A few iterations of Raft ET maps were generated after considering these comparisons with METRIC. Alfalfa was a topic of concern given its wide areal coverage in the Raft River and uncertainty in alfalfa practices in the region. The alfalfa hay – beef cattle style ~ 3 cuttings" ET-IDWR category resulted in the closest agreement with METRIC ET. The results in

Figure 6 show large deviation brackets indicating that alfalfa ET, and likely management styles, vary widely within the Raft River basin.

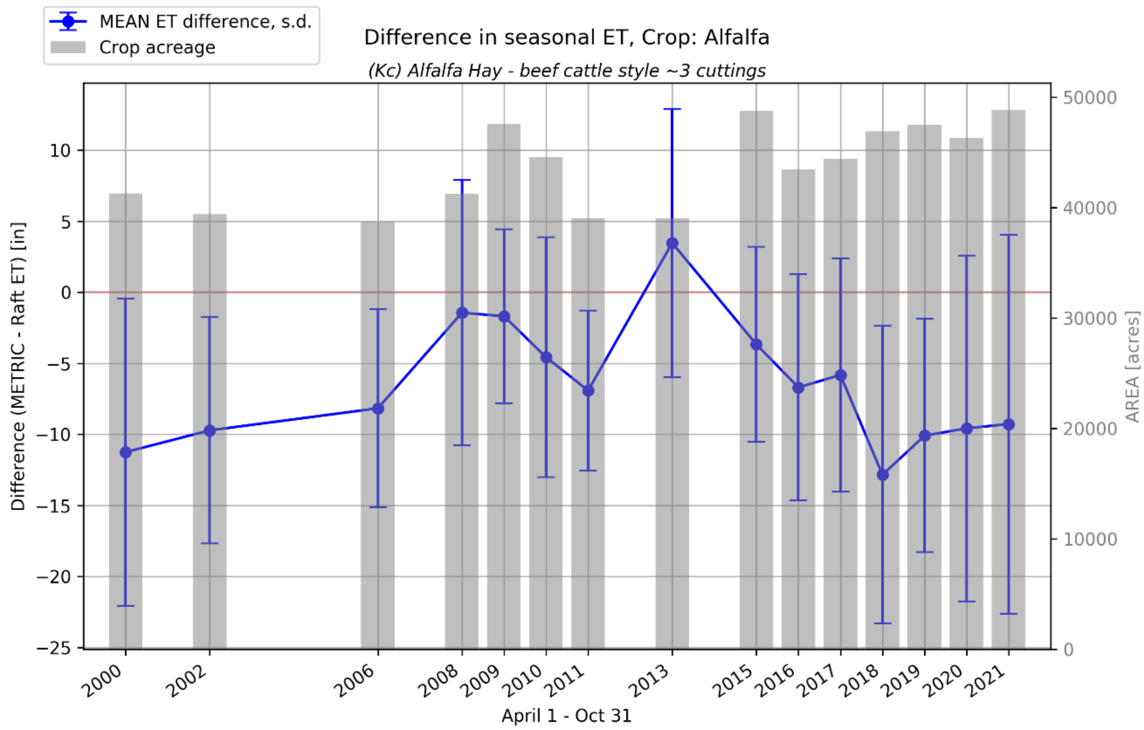


Figure 6. Comparison of average seasonal alfalfa Raft ET and alfalfa METRIC ET for all water budget years where METRIC is available (excludes 2001, 2003-2005, 2007, 2012, and 2014). Crop acreage for alfalfa (vertical grey bars) was calculated from the CDL for the year of interest.

Crops or land cover types considered irrigated were the primary focus of this comparison, given that ET-IDWR and METRIC ET estimated for non-irrigated land use types usually have uncertain accuracy. Although, the "grass/pasture" CDL category stood out in this comparison as values were drastically different from METRIC ET. It was determined the "grass/pasture" CDL category was not the correct classification for the Raft River, supported by documentation on the USDA NASS cropland data layer website, which states, "Unfortunately, the pasture and grass-related land cover categories have traditionally had very low classification accuracy in the CDL" (https://www.nass.usda.gov/Research_and_Science /Cropland/sarsfaqs2.php). For these reasons, the ET-IDWR category was changed to "range grasses – long season (bunch/wheatgrass)" for the grass/pasture CDL classification. This category fits better with personal experience in the area and demonstrates comparable values with METRIC ET.

Lastly, the average monthly Raft ET for all crop types per year were graphed and compared with the annual total PRISM precipitation (Figure 7). Monthly Raft ET was summed for the entire calendar year. This provides a way of visualizing which crops make up the bulk of ET for the Raft

River and to what extent non-irrigated crops contribute to this part of the water budget. One observation from viewing these graphs was that non-irrigated CDL types, such as range grasses and sagebrush, generally do not exceed the annual PRISM precipitation. Additionally, non-irrigated CDL types with access to sub-surface water like wetlands often surpass the annual precipitation. Another observation was irrigated crops typically associated with high consumptive use, like alfalfa, ranked among the highest average Raft ET for each year. These simple metrics help ensure realistic values for each year of ET used in the water budget. Other instances of Raft ET review may be available in the IGS project report (Clark, 2024). See Attachment 4 for a compilation of METRIC difference plots (as shown in Figure 6), and Attachment 5 for Raft ET bar graphs (as shown in Figure 7).

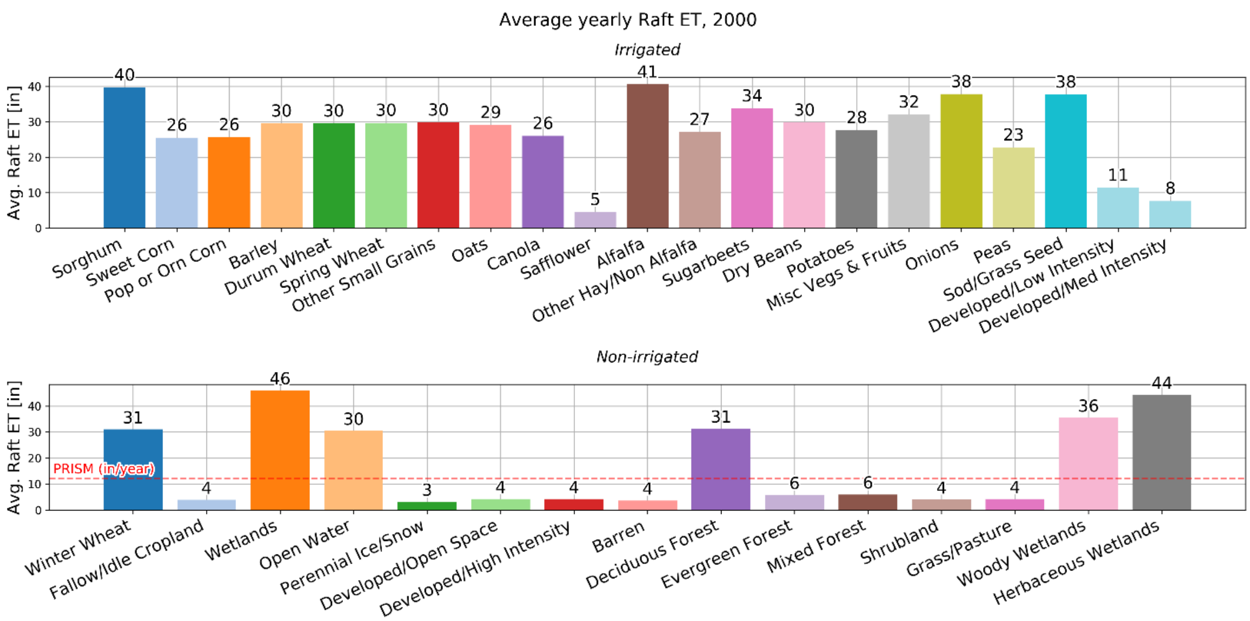


Figure 7. Average yearly Raft ET for 2000. Crops listed on the x-axis are CDL land cover types. The annual average Raft ET was determined using Zonal Statistics tool (ArcMap) and a proxy CDL coverage map for 2000.

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Attachment List

File Name	File Type	Description
Attachment 1	PDF	Table showing availability of datasets used in Raft ET, 2000-2021
Attachment 2	Zipped Folder	IGS and IDWR Scripts used for Utah ETr and Raft ET
Attachment 3	PDF	Crop coefficient curve graphs for all crops identified in the Raft River, 2000-2021
Attachment 4	PDF	Difference in seasonal ET, METRIC – Raft ET bar graphs
Attachment 5	PDF	Average yearly Raft ET for all crops and all years
Attachment 6	Excel	CDL & ETIdaho (ET-IDWR) crop coefficient key list