Oregon
Statewide Long-Term Water Demand Forecast

Appendix F: Comparison of Evapotranspiration Methods for the Klamath River Basin

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Publication available electronically at:

http://www.oregon.gov/OWRD/

December 2015

Task 1.2 -- Comparison of Evapotranspiration Estimated by Three Independent Methods for the Klamath River Basin: Traditional Single Crop Coefficient – Monthly Reference ET; Dual Crop Coefficient – Daily Reference ET; and Actual ET from Satellite-based Energy Balance (METRIC)

Introduction

Task 1.2 produced and summarized comparisons among monthly estimates of evapotranspiration (ET) from three largely independent methods and approaches. Those approaches included estimates from the historical 1992 report by Cuenca et al., (1992) that estimated ET and net irrigation water requirements (NIWR) for 27 climatic-hydrologic regions of Oregon. That method applied the FAO-24 Blaney-Criddle method to estimate grass reference ET_o on a monthly basis to weather data summarized from 244 National Weather Service where periods of record ranged from 13 to 88 years. The monthly ETo from stations from within each climatic-hydrologic region were averaged and multiplied by a 'single' monthly crop coefficient (Kc) for about 20 primary crop types common to Oregon, based on the FAO-24 (Doorenbos and Pruitt, 1977) report. The single Kc incorporated approximate, average effects of evaporation from precipitation and irrigation wetting events and transpiration from the crop itself. A single Kc curve was developed for each region for each crop according to average planting or greenup dates and harvest dates typical to the region. Only periods between planting or greenup and harvest were included in the ET estimates. NIWR was calculated by differencing ET and effective precipitation (Pe) for each month of the growing season. Effective precipitation was estimated using the SCS (1967) Tech. 21 method which produces approximate estimates of Pe based on monthly precipitation, ET_o and soil type. Statistical analyses were used to produce estimates of ET and Pe for probabilities of 5 years out of 10 years, 6 out of 10, 7 out of 10, 8 out of 10, 9 out of 10 and 19 out of 20 years.

The second ET method is a more modern dual Kc – reference ET method applied using the ETDemands model of the US Bureau of Reclamation (USBR). The ETDemands model is based on computational code traceable to the ETIdaho estimating system developed for application in Idaho by Allen and Robison (2007) and applied as ETNevada in Nevada by Huntington and Allen (2010). The ETDemands model was applied recently for the West-Wide Climate Risk Assessments: Irrigation Demand and Reservoir Evaporation Projections (WWCRA) study of Huntington et al., (2014) to seven major river basins of the western United States including the Columbia and Klamath basins. The ETDemands model uses the ASCE standardized Penman-Monteith reference evapotranspiration equation that is a nationally standardized method (ASCE-EWRI 2005) and that calculates a reproducible index approximating the climatic demand for water vapor. Reference ET is the ET rate from an extensive surface of reference vegetation having a standardized uniform height and that is actively growing, completely shading the ground, has a dry but healthy and dense leaf surface, and is not short of water. The ASCE Penman-Monteith (PM) equation was standardized by ASCE-EWRI (2005) for application to both full-cover alfalfa reference and to the clipped cool season grass reference (ETo). The ETo reference is used in ETDemands.

Crop evapotranspiration, ET, is calculated on a daily timestep basis using the dual crop coefficient of FAO-56 (Allen et al., 1998). The dual Kc method produces for separate estimation of evaporation from wet soil and transpiration from vegetation. The separate calculation improves the accuracy of ET estimates because of the ability to determine impacts of specific timing and amounts of precipitation or irrigation events. ET for monthly, growing season and annual periods are summed in ETDemands from the daily calculations. In ETDemands, starts and durations of growing seasons for most crops are determined specific to each year according to mean 30-day running average air and according to accumulate growing degree days following the start of growing period. Growing periods are terminated according to accumulated growing degree days or by a killing frost. The basal Kcb curves that represent the transpiration component are expressed using relative time scales or using relative thermal unit scales to ‘stretch’ Kcb curves differently each year, according to weather conditions. The use of a thermal basis for the crop factors has the benefit of estimating year to year variation in ET caused by weather and the ability to assimilate projections of future climates on crop factors and ET. ETDemands holds crop water use information for about 80 crop types.

The evaporation component of the dual Kc is based on the FAO-56 method where a daily water balance is computed for the top 10 cm of soil, with reduction in evaporation as the soil surface dries. In irrigated regions, irrigation depths and timing are simulated using daily soil water balances of rooting zones for purposes of estimating evaporation from wet soil surfaces. Simulated irrigation schedules are typically like those practiced with surface irrigation and with hand-move or wheel-line sprinkler systems (i.e., ‘low frequency’). Available water holding capacity and texture of soil for each station was determined using information from the National StatsGo soils information data base. Precipitation runoff is estimated using the NRCS Curve Number method where antecedent moisture is computed from the daily surface soil water balance.

The advantage of using a dual crop coefficient over a ‘mean’ or single crop coefficient approach is that it allows for separate accounting of transpiration, via the basal Kcb, and evaporation, via an evaporation coefficient (Ke), to better quantify evaporation from variable precipitation, simulated irrigation events, and during freezing months of winter for dormant covers of mulch and grass as well as for bare soil, thus providing the ability to produce growing season ET and year-round ET estimates. Winter time ET estimation allows for accurate accounting of winter time soil moisture losses and gains, leading to more accurate estimation of NIWR under historical and future climate conditions.

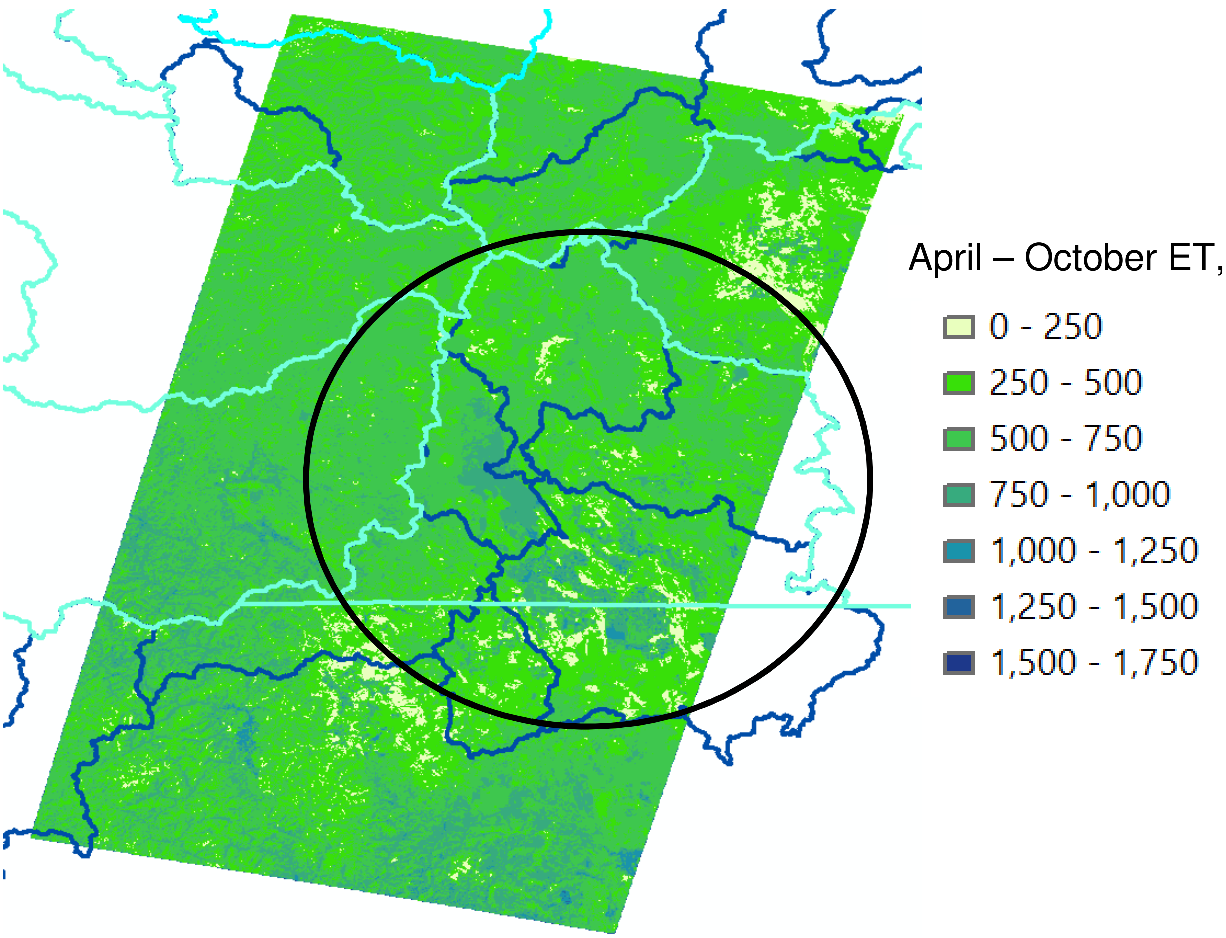
Like its ETIdaho and ETNevada predecessors, the ETDemands model is designed to produce estimates based primarily on maximum and minimum air temperature, since generally only air temperature is observed at the National Weather Service cooperative stations. The solar radiation, humidity and wind speed data parameters required in the ASCE-PM equation are estimated following recommendations in ASCE-EWRI (2005) where estimates for solar radiation (Rs) are based on differences between daily maximum and minimum air temperature and estimates for daily dewpoint temperature are based on daily minimum air temperature. Estimates for wind speed are based on long-term mean monthy summaries from AgriMet and similar stations in the local region. Additional specifics of the ETDemands and WWCRA procedures and approaches are given under Task 1.1.

The third ET estimation method produced spatial maps of actual ET using the METRIC (Mapping Evapotranspiration at high Resolution using Internalized Calibration) process where thermal and reflected spectral imagery from the Landsat satellite series are transformed into ET using a surface energy balance method. The full surface energy balance is used in METRIC where energy is partitioned into net incoming radiation (both solar and thermal), ground heat flux, sensible heat flux to the air and latent heat flux. The latent heat flux is calculated as the residual of the energy balance and represents the energy consumed by ET. The topography of the region is incorporated into METRIC via a digital elevation model (DEM), and is used to account for impacts of slope and aspect on solar radiation absorption. METRIC is calibrated for each Landsat image processed during the growing season using ground based meteorological information and identified ‘anchor’ conditions (the cold and hot pixels of METRIC) present in each image. A detailed description of METRIC can be found in Allen et al. (2007a,b).

A strong advantage of using energy balance is that actual ET rather than potential ET based on amount of vegetation is computed so that reductions in ET caused by a shortage of soil moisture are captured. Another strong advantage of METRIC is that specific crop type is not needed, nor known, so that ET maps are produced independent of crop type information. In the case of this comparison, crop type for agricultural areas was based on the USDA Cropland Data Layer (CDL) for year 2013.

The ASCE Penman-Monteith reference method (ASCE-EWRI 2005) is used in METRIC to calibrate the upper end of the population of ET. This is done using the alfalfa reference method. Daily reference ET is also used during time-integration of relative ET produced from Landsat images to produce monthly ET images. A daily surface soil water balance model uses daily precipitation daily reference ET to estimate residual evaporation associated with bare soil conditions in the image area to account for the presence of background evaporation.

The METRIC model has been applied in many western US states, including applications in the Powder River and in the Klamath Basin. Klamath Basin applications have been made for years 2004, 2006, 2010 and 2013. Evapotranspiration in the Klamath Basin was produced for year 2013 by the University of Idaho with funding provided by the USGS (Zhao et al. 2014). The 30 m ET data were produced by METRIC for the April – October 2013 period and covered a majority of the Klamath Basin residing in Oregon as shown in Figure 1.



Note: The large dark green area in the center of the image is Klamath Lake and dark green areas SE of Klamath Lake are irrigated areas in Oregon and California. The light blue lines outline OWRD administrative river basins in Oregon including the Klamath

Basin, and the dark blue lines in the lower 2/3 of the image outline HUC8 subbasins in the Klamath Basin of both Oregon and California. The black circle outlines the Klamath HUC8 subbasins residing in Oregon and evaluated during this study.
Figure 1. April – October ET in WRS-2 Path 45 Covering Most of the Klamath Basin and Areas North of the Basin

Strengths and Weaknesses of Methods

Each of the three ET estimation methods has strengths and weaknesses. These are:

- Cuenca (1992)
    - Strengths - This method has been used for more than 20 years by OWRD and other entities to plan and design irrigation systems and to estimate water depletion from irrigation. It utilizes a grass reference basis (FAO-24 Blaney-Criddle method), which is preferred over the older SCS Blaney-Criddle method (Jensen et al., 1990).
    - Weaknesses - The single Kc incorporates only approximate, average effects of evaporation from precipitation and irrigation wetting events and may underestimate ET during 'wet' years and overestimate during 'dry' years. Only one single Kc value, by month, is produced for a crop for a region of OWRD. Consequently, spatial variation in Kc is not considered, nor is year-to-year variation caused by weather. The Cuenca et al. (1992) ET estimates represent potential ET under full-water conditions, which may not be the case when estimating actual water depletions. Effective precipitation was estimated using the SCS (1967) Tech. 21 method which produces only approximate estimates.
- WCCRA/ETDemands
    - Strengths - The ETDemands model uses the ASCE standardized Penman-Monteith reference evapotranspiration equation that is a nationally standardized method (ASCE-EWRI 2005) and is considered to generally be more accurate than the FAO-24 Blaney-Criddle method (Jensen et al, 1990). The dual Kc method produces for separate estimation of evaporation from wet soil and transpiration from vegetation. The separate calculation improves the accuracy of ET estimates because of the ability to determine impacts of specific timing and amounts of precipitation or irrigation events. In ETDemands, starts and durations of growing seasons and durations of growing seasons are determined for most crops specific to each year according to mean 30-day running average air and according to accumulate growing degree days following the start of growing period. This allows for the tailoring of Kc curves differently each year, according to weather conditions and the ability to assimilate projections of future climates on crop factors and ET.
    - Weaknesses – There are few weaknesses with the WWCRA/ETDemands approach. However, as with the Cuenca ET estimates, the ETDemands model produces estimates for potential ET for irrigated crops rather than actual ET. Potential ET is valuable for planning and design and for establishing upper bounds on ET. However, it might overestimate actual ET under water short conditions or poor water and agronomic management. In addition, spatial information is not available to assess ET on a field-by-field or parcel-by-parcel basis.
- METRIC ET
    - Strengths - A strong advantage of METRIC is the use of the satellite-thermal-based energy balance so that actual ET rather than potential ET is computed. Therefore reductions in ET caused by a shortage of soil moisture due to low water supply or poor water management or

poor vegetation cover are captured. Another advantage of METRIC is that ET maps are produced independent of crop type information. METRIC utilizes the ASCE Penman-Monteith reference method (ASCE-EWRI 2005) during both calibration and time-integration of ET, so that ET estimates by METRIC tend to be fully congruent and consistent with ASCE Penman-Monteith based estimates such as used in ETDemands. METRIC has proven to have high accuracy via comparisons to measurements in Idaho (Allen et al., 2007a,b), Nevada (Huntington et al. 2014) and in an ongoing USGS-funded model intercomparison study, where METRIC produced estimates in SE California that were within 2% of ground-based meaurements.

- Weaknesses – METRIC requires relatively sophisticated software to apply and the accuracy of ET estimates are proportional to skill and experience of the applier (Allen et al, 2007a,b; Kilic et al. 2012). Production of growing season-long estimates of ET is sometimes thwarted by the occurrence of cloud cover over too many Landsat images that are available on only an 8-day revisit schedule. Often, time gaps of 30 to 60 days can occur in a year having substantial cloud cover. These gaps have to mitigated using image information from other time periods and can reduce the overall accuracy of the ET estimates.

Objectives and Intercomparisons

The objective of Task 1.2 was to intercompare monthly and growing season/annual ET among the three methods for common time periods with the intent to determine similarities in timing and magnitude of the three estimates for primary crop types. Questions to be answered were whether the ET estimates by the WWCRA/ETDemands method are compatible with the older, more approximate estimates of Cuenca (1992) and/or the amount of increase or decrease in the WWCRA estimates relative to Cuenca. The WWCRA estimates have the additional benefit of being applied with future climate forecasts to assess projected change in future ET and NIWR under future conditions. The comparison with METRIC-based ET provides information on the variation in field-to-field ET for individual crops as opposed to the single region-wide values produced by the crop coefficient methods of Cuenca (1992) and WWCRA/ETDemands. That comparison also provides opportunity to assess the congruency and agreement between the WWCRA/ETDemands estimates for potential ET and the actual ET produced by METRIC and surface energy balance methodology.

The intercomparison was conducted in two parts. The first analysis compared ET sampled from METRIC for year 2013 with longterm historical average estimates from Cuenca (1992) and longterm historical average estimates from WWCRA. The long term WWCRA data set represented 1950-1999 mean ET over the January-December period. The Cuenca (1992) data represented 50% and 90% values of nonexceedence over the historical period of record that was in place for two OWRD administrative basins/Cuenca regions: Klamath, no. 18 and Lake Creek/Little Butte Creek, no. 8.

The analysis of METRIC ET data was conducted on each of five HUC8 subbasins residing inside the Klamath basin and inside boundaries of Oregon. This spatial analysis provided an opportunity to compare WWCRA simulations against METRIC-based observations on a HUC8 basis within the Klamath Basin to observe spatial trends and variation across the basin.

The second analysis compared ET sampled from METRIC for year 2013 with ET simulated for year 2013 by WWCRA under current climate conditions on a monthly basis. That analysis was done for the HUC subbasin number 18010204, only, where weather data used in WWCRA represented the Klamath Falls COOP weather station. This station was the only one that was simulated under a special WWCRA run under Task 1.1 to produce monthly time series of crop ET. The second analysis is important in that it provides comparison of METRIC and WWCRA for the same year and months.

Statistical Summaries of METRIC ET

METRIC-based ET estimates were time integrated from the individual Landsat images over the Klamath Basin and surrounding area into monthly ET totals. The data were produced for each 30 m pixel of Landsat independent of other pixels. The CDL crop classification for 2013 by FSA was also produced on a pixel-by-pixel basis. The CDL pixels were grouped, spatially, to produce field-sized areas of the same crop type using a “despeckling” process described in Attachment A. The resulting despeckled CDL was then used to sample the monthly ET of METRIC on a crop-by-crop basis. Prior to the sampling, the Klamath Basin was divided into the seven HUC8 sub-basins outlined during the WWCRA analyses (Huntington et al., 2014). Five of those basins reside partially or completely in Oregon. Those five basins were sampled individually for ET from the METRIC results. Those samples provide indication of variation in ET by crop type with regional location.

In each of the five subbasins, METRIC results were contrasted with ET estimated from WWCRA and ET estimated by Cuenca (1992) for crops that were common to the three sources. ArcMAP was used to summarize spatial statistics from the METRIC ET.

Accuracy of the 2013 Cropland Data Layer. The accuracy of statistical summaries of ET from METRIC, sampled by crop, is impacted by the accuracy of the crop classification used to guide pixel sampling. In this analysis, the USDA Cropland Data Layer (CDL) product was utilized for year 2013 to coincide with the 2013 ET data. The CDL classification process is trained by the USDA using extensive, confidential field data provided by growers during their enlistment in FSA agricultural programs. Error statistics for all of Oregon for year 2013 was 89% for all primary agricultural crops according to the CDL metadata available at the CDL web site. Statistics are shown in Table 1 of Attachment A for primary crops in Oregon.

Crop Types in WWCRA analyses and Cuenca et al., (1992) report. The WWCRA ET calculations were made for principal crops in each HUC8 subbasin of the Klamath Basin. Principal crops were those that were identified for a subbasin from the 2009 cropland data for Reclamation’s Klamath Project portion of the Klamath BCSD Irrigation Demand and Reservoir Evaporation Projections report provided by Reclamation’s Klamath Basin Area Office (Huntington et al. 2015). Crop types represented in WWCRA and Cuenca et al., (1992) are listed in Tables B6 and B7 of Attachment B, and those identified and simulated by WWCRA runs for the Klamath Basin are listed in Tables B1 through B5 of Attachment B.

Handling of Data Layers. The Image Analysis Clipping tool of ArcMAP was used to clip both CDL2013 and seasonal ET2013 to the domains of each of five HUC8 basins of WWCRA residing in the Klamath Basin. A shape file named nrcs_huc8_or was opened as an attribute table and each of the five basins was selected within the Image Analysis tool prior to clipping. The result was a CDL and ET raster for that HUC8 only. Only portions of the HUC’s residing in Oregon were retained in clipped CDL subimages. The five HUCs had object ID’s 1, 2, 4, 5, and 7 in the NRCS_HUC8_OR shape file that were associated with HUC8 numbers 18010206, 18010204, 18010202, 18010203 and 18010201.

CDL and METRIC ET rasters were saved as TIF files and had extents equal to the domain of each HUC8. CDL tif’s were 8 bit and ET tif’s were 32 bit (floating point). A screenshot of the Image Analysis window in ArcMAP is shown in Figure C1 to show the layout of the ArcMAP tool used for clipping. The resulting clipped CDL images for the five HUC8 areas residing in Klamath Basin and Oregon appear as shown in Figure 2. Also shown in Figure 2 are the WWCRA weather stations associated with HUC8 subbasins in the Klamath area. One weather station was associated with each HUC8 unit during the WWCRA runs provided by J. Huntington under Task 1.1. Association of weather stations with HUC8 units is shown in Table 2.

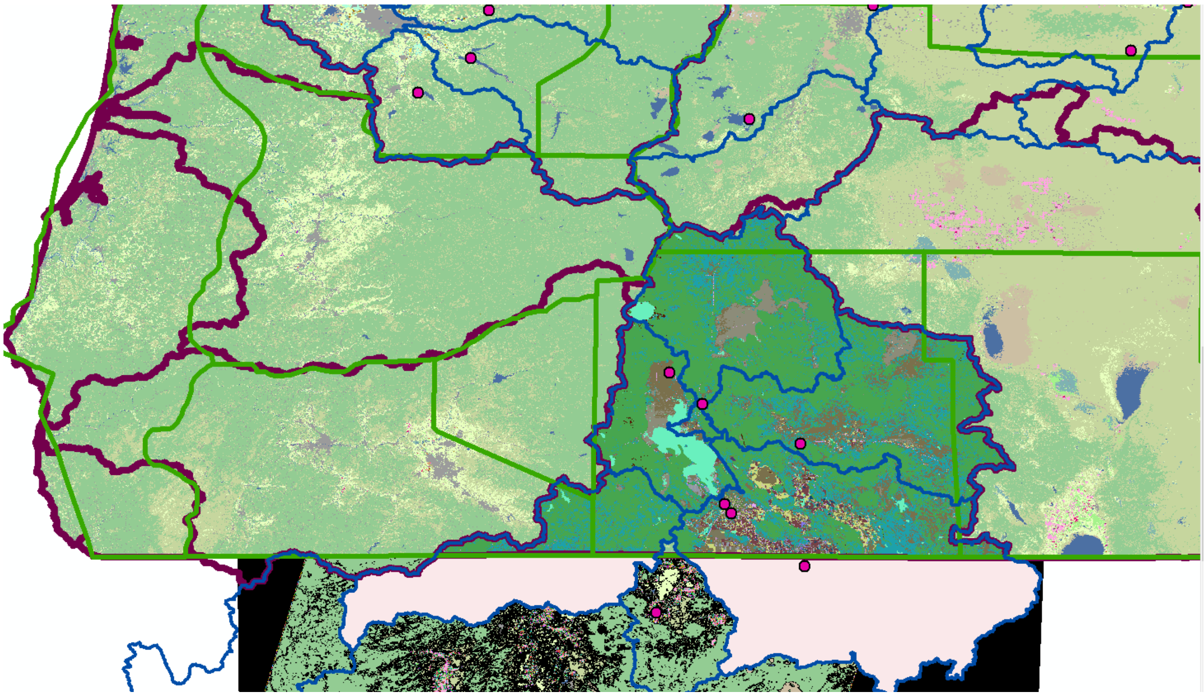


Figure 2. Clipped CDL images for the five HUC8 areas residing in Klamath Basin and Oregon.

Table 2. Weather Stations Associated with HUC 8 Units of the Klamath Basin of Oregon During WWCRA Runs

Internal Basin No.	HUC 8	WWCRA number	Desc.	Station used	WWCRA ET Cell ID	StationID
1	18010206	6	SW Klamath - lower	Mt. Hebron Ranger Sta.	Klamath_6	CA5941
3	18010204	4	SE Klamath	Klamath Falls Ag. Sta.	Klamath_4	OR4511
4	18010202	2	Sprague River	Sprague River 2E	Klamath_2	OR8007
5	18010203	3	West of Klamath Lake	Chiloquin 12NW	Klamath_3	OR1574
7	18010201	1	Northern Klamath	Chiloquin 1E	Klamath_1	OR1571

The 'Spatial Analyst Zonal Statistics as a Table' tool was used to generate statistical summaries by CDL crop type within each Klamath HUC. An example screenshot is shown in Figure C2. One statistical table was produced for each HUC8 and contained summary statistics for each crop type identified in the despeckled CDL for that HUC8. Following the creation of the zonal statistical tables, the tables were exported as '.dbf' files that were then opened using Excel.

The statistics from METRIC ET samples were associated with ET produced by WWCRA runs and Cuenca (1992) within an Excel spreadsheet named "Klamath_seas_ET_2013_METRIC_by_HUC8_summary_c.xlsx". The growing season period for METRIC ET represented the April 1 – October 31 period.

Results and Discussion

The first analysis compared ET sampled from METRIC for year 2013 with longterm historical average estimates from WWCRA and Cuenca (1992). The WWCRA data set represented 1950-1999 mean ET over the January-December period and the Cuenca (1992) data represented 50% and 90% values of nonexceedence over the historical period of record that was in place for the basins (Klamath, no. 18 and Lake Creek/Little Butte Creek, no. 8) at the time of their computations. The analysis was conducted on each of five HUC8 subbasins residing inside the boundaries of Oregon. This analysis is useful to compare the two historical data sets of WWCRA and Cuenca (1992) with each other and against METRIC-based observations in 2013. It also provides an opportunity to compare WWCRA simulations against METRIC-based observations on a HUC8 basis within the Klamath Basin to observe spatial trends and variation across the basin.

Comparisons of METRIC with Historical Averages for WWCRA and Cuenca (1992). All CDL crop types appearing in the five HUC8 areas were sampled from the METRIC ET images and were summarized in five tables. Table 3 below presents a summary of those results averaged over the five HUC8 subbasins using a weighted average according to area of the crop in each subbasin. The table includes the standard deviation of April-Season ET across the Klamath Basin portion of Oregon and the associated coefficient of variation (CV). The standard deviation and coefficient of variation represent deviation of ET among all pixels of the particular crop class. In general, the CV ranged from about 0.15 to 0.20 for the dominate crop types, indicating that 68% of areas (pixels) for a crop had growing season ET that was within 15 to 20% of the average ET value. This indicates relatively good uniformity within the crop populations as well as consistency of the METRIC application, spatially. It also reflects well on the accuracy of the CDL crop classification.

The METRIC results of Table 3 are compared in Table 4 with Cuenca (1992) results for the Klamath and Lake Creek units of the Cuenca report. The Lake Creek unit was included due to the proximity of that unit to the Klamath Basin (see map of Cuenca (1992) in Attachment D). Summary tables for each of the five HUC8 subbasins are included as Tables B1 – B5 in Attachment B.

Table 3. Sampling Results for all Five Klamath HUC8s Presented as a Weighted Average from METRIC for 2013 and from WWCRA

CDL No	CDL Crop	Pixel COUNT	AREA, acres	METRIC ET mean, mm	METRIC ET Std. Dev., mm	METRIC ET Coef. Var.	WWCRA Crop No.	Associated WWCRA Crop Name	WWCRA ET, mm	WWCRA NIWR, mm
4	Sorghum	197	44	171	102	0.60	11	Spring Grain - irrigated	684	434
14	Mint	5	1	716	7	0.01	33	Mint	905	678
21	Barley	75,171	16,718	714	136	0.19	11	Spring Grain - irrigated	693	426
23	Spring Wheat	42,578	9,469	712	114	0.16	11	Spring Grain - irrigated	712	413
24	Winter Wheat	50	11	645	90	0.14	13	Winter Grain - irrigated	895	549
27	Rye	3,756	835	481	157	0.33	11	Spring Grain - irrigated	688	435
28	Oats	8,369	1,861	670	113	0.17	11	Spring Grain - irrigated	685	434
36	Alfalfa	287,622	63,966	902	151	0.17	3	Alfalfa Hay - beef cattle style ~3 cuttings	945	679
37	Other Hay/Non Alfalfa	221,875	49,344	839	168	0.20	4	Grass Hay	965	751
43	Potatoes	25,457	5,662	697	104	0.15	30	Potatoes - cold pack (late harvest)	706	445
49	Onions	408	91	645	122	0.19	23	Onions	700	464
57	Herbs	218	48	790	156	0.20	21	Garden Vegetables - general	822	595
61	Fallow/Idle Cropland	23,627	5,255	443	207	0.47				
111	Open Water	482,454	107,295	875	155	0.18				
121	Developed/Open Space	79,595	17,702	640	236	0.37				
122	Developed/Low Intensity	59,301	13,188	497	179	0.36				
123	Developed/Med Intensity	13,277	2,953	396	175	0.44				
124	Developed/High Intensity	4,244	944	326	146	0.45				
131	Barren	41,126	9,146	326	187	0.57				
141	Deciduous Forest	1,129	251	753	156	0.21				
142	Evergreen Forest	9,184,233	2,042,526	725	454	0.63				
143	Mixed Forest	848	189	705	197	0.28				
152	Shrubland	3,332,704	741,176	776	574	0.74				
176	Grassland/Pasture	1,764,162	392,341	771	656	0.85				
190	Woody Wetlands	3,424	761	746	368	0.49				
195	Herbaceous Wetlands	561,448	124,863	594	229	0.39				
205	Triticale	3,778	840	471	200	0.42	11	Spring Grain - irrigated	688	435
208	Garlic	347	77	582	116	0.20	43	Garlic		
221	Strawberries	840	187	623	291	0.47	62	Strawberries	646	422

Table 4. Sampling Results for all Five Klamath HUC8s Presented as a Weighted Average from METRIC and Compared Against Estimates from Cuenca (1992) for the Klamath Unit and Lake Creek Unit of that Report

CDL No	CDL Crop	AREA, acres	METRIC ET mean, mm	METRIC ET Std. Dev., mm	METRIC ET Coef. Var.	Cuenca Crop no.	Cuenca ET_50 Klam, mm	Cuenca NIWR_50 Klam, mm	Cuenca ET_90 Klam, mm	Cuenca NIWR_90Klam, mm	Cuenca ET_50 LakeC, mm	Cuenca NIWR_50 LakeC, mm	Cuenca ET_90 LakeC, mm	Cuenca NIWR_90 LakeC, mm
4	Sorghum	44	171	102	0.60	11								
14	Mint	1	716	7	0.01	33								
21	Barley	16,718	714	136	0.19	11	540	484	590	573	558	484	590	573
23	Spring Wheat	9,469	712	114	0.16	11	540	484	590	573	558	484	590	573
24	Winter Wheat	11	645	90	0.14	13	488	411	546	504	538	381	590	509
27	Rye	835	481	157	0.33	11	540	484	590	573	558	484	590	573
28	Oats	1,861	670	113	0.17	11	540	484	590	573	558	484	590	573
36	Alfalfa	63,966	902	151	0.17	3	486	439	534	514	746	582	816	754
37	Other Hay/Non Alfalfa	49,344	839	168	0.20	4								
43	Potatoes	5,662	697	104	0.15	30	613	543	670	650				
49	Onions	91	645	122	0.19	23					676	539	736	675
57	Herbs	48	790	156	0.20	21								
61	Fallow/Idle Cropland	5,255	443	207	0.47									
111	Open Water	107,295	875	155	0.18									
121	Developed/Open Space	17,702	640	236	0.37									
122	Developed/Low Intensity	13,188	497	179	0.36									
123	Developed/Med Intensity	2,953	396	175	0.44									
124	Developed/High Intensity	944	326	146	0.45									
131	Barren	9,146	326	187	0.57									
141	Deciduous Forest	251	753	156	0.21									
142	Evergreen Forest	2,042,526	725	454	0.63									
143	Mixed Forest	189	705	197	0.28									
152	Shrubland	741,176	776	574	0.74									
176	Grassland/Pasture	392,341	771	656	0.85									
190	Woody Wetlands	761	746	368	0.49									
195	Herbaceous Wetlands	124,863	594	229	0.39									
205	Triticale	840	471	200	0.42									
208	Garlic	77	582	116	0.20									
221	Strawberries	187	623	291	0.47									

Figures 3 – 8 show comparisons of seasonal ET among METRIC, WWCRA and Cuenca (1992) by crop type. For METRIC and WWCRA, results are shown for each of the five HUC8 subbasins and for the total Klamath Basin-Oregon area weighted averages. Cuenca (1992) estimates are shown for the Klamath region of Cuenca (1992) and for the Lake Creek region that lies to the west of Klamath and represents the upper Rogue River area east of Medford. ET values were extracted from Cuenca (1992) for the "5 of 10 years" and "9 of 10 years" entries. The "5 of 10 years" value approximates the long term mean value. The "9 of 10 years" value represents ET that is expected to be exceeded only one year out of 10. The "9 of 10 years" value has only a 10% chance of being exceeded in any one year and might be used for design of irrigation systems for high value cash crops. The absence of an entry in the graphs for METRIC, WWCRA or Cuenca indicates that this crop was not identified by CDL for that subbasin.

The METRIC ET values represent the April 1 – October 31, 2013 period for all crops. In contrast, the WWCRA ET values represent the January 1 – December 31 period averaged from 1951 – 2013 (J. Huntington, pers. Commun. 2015). Therefore, the two data groups represent very different historical periods (only a single year for METRIC and a 63 year period for WWCRA) and different within year periods (April – October 'growing seasons' for METRIC and the entire January – December calendar year for WWCRA). However, it is still considered to be useful to compare the two data groups and estimation methods to evaluate relative differences between the groups and how those differences vary by crop type. The added time length of the WWCRA estimates includes predominately non-growing season ET occurring during January 1 – March 31 and during November 1 – December 31. The additional evaporation is expected to be less than 10% of total April – October ET, based on the proportion of reference ET distribution across a year. For example, for 2013, the proportion of alfalfa reference ET and grass reference ET occurring during the January – March period and the November – December period was 16 % of annual, where the reference crop assumes full, active vegetation cover during winter, which would typically not exist.

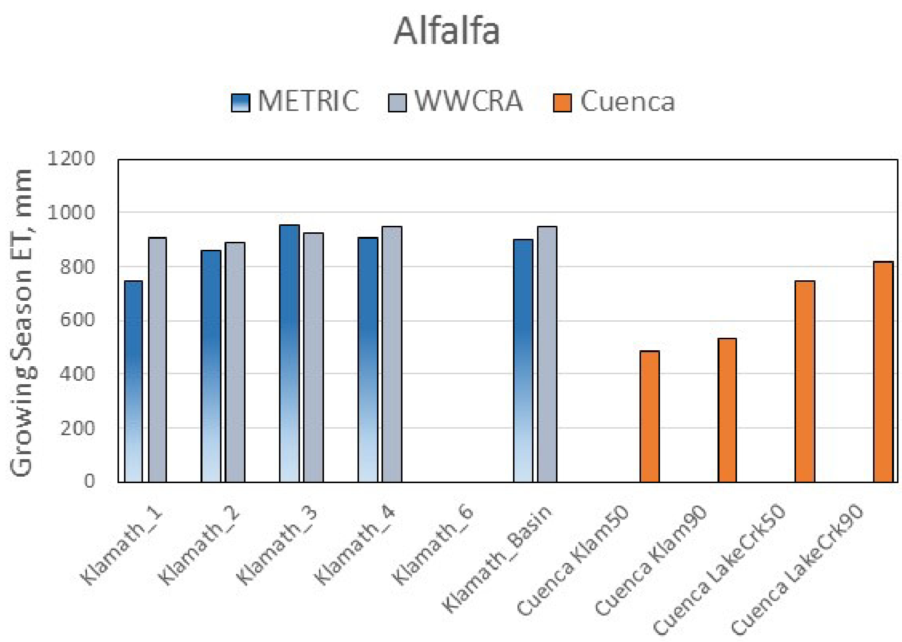


Figure 3. Seasonal ET for Alfalfa for five Klamath Basin HUC8 Subbasins and the Klamath Basin Average for METRIC and WWCRA and Four Entries from Cuenca (1992) from the Klamath and Lake Creek Units for 50% and 90% (9 of 10 years nonexceedance)

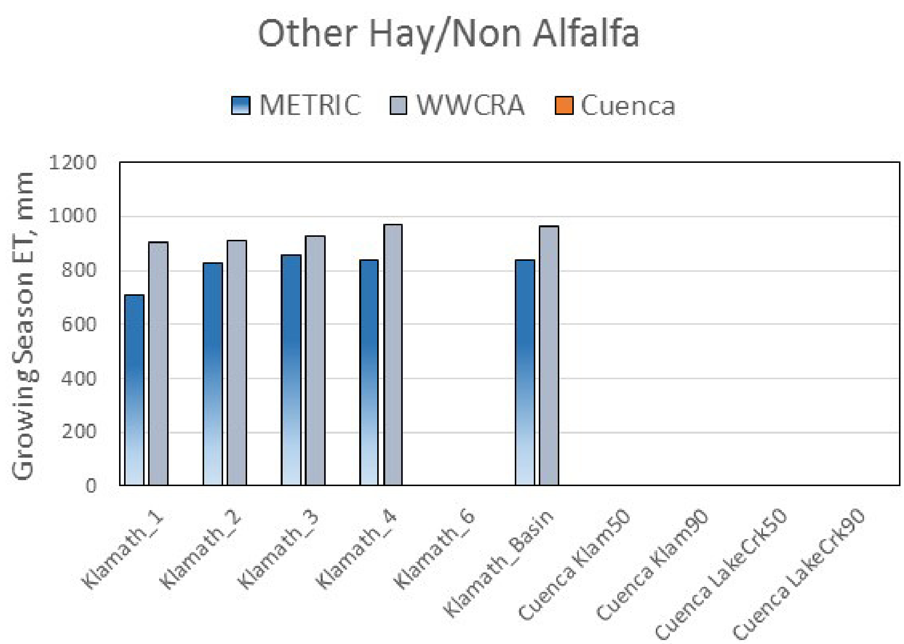


Figure 4. Seasonal ET for "other hay/non-alfalfa" for five Klamath Basin HUC8 Subbasins and the Klamath Basin Average for METRIC and WWCRA and Four Entries from Cuenca (1992) from the Klamath and Lake Creek Units for 50% and 90% (9 of 10 years nonexceedance)

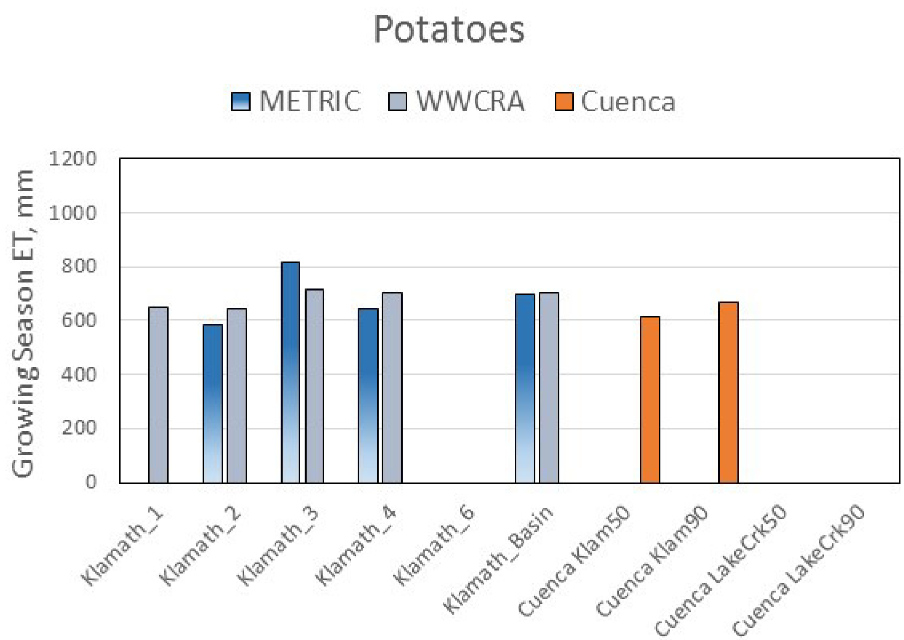


Figure 5. Seasonal ET for Potatoes for five Klamath Basin HUC8 Subbasins and the Klamath Basin Average for METRIC and WWCRA and Four Entries from Cuenca (1992) from the Klamath and Lake Creek Units for 50% and 90% (9 of 10 years nonexceedance)

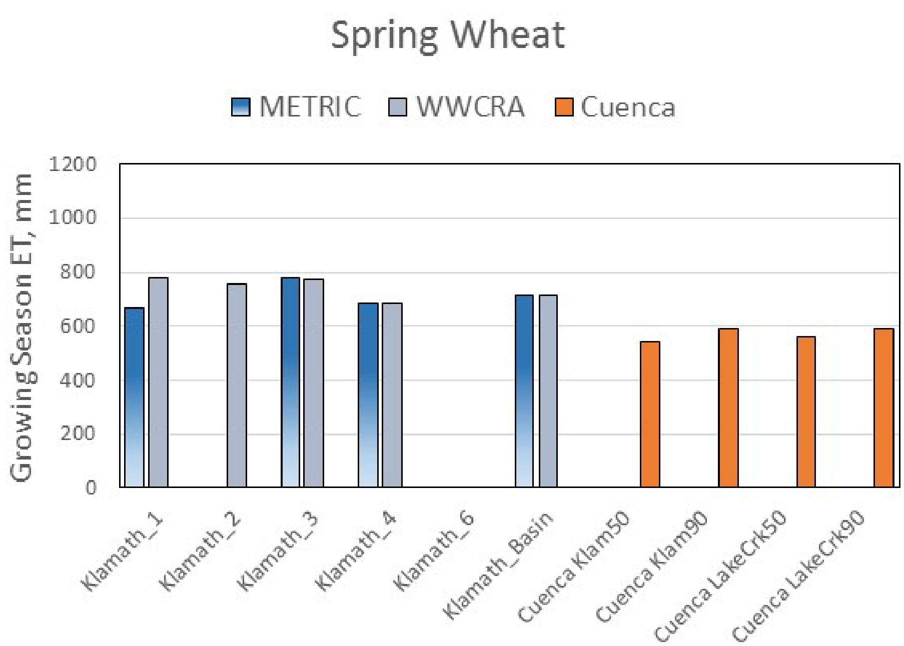


Figure 6. Seasonal ET for spring wheat for five Klamath Basin HUC8 Subbasins and the Klamath Basin Average for METRIC and WWCRA and Four Entries from Cuenca (1992) from the Klamath and Lake Creek Units for 50% and 90% (9 of 10 years nonexceedance)

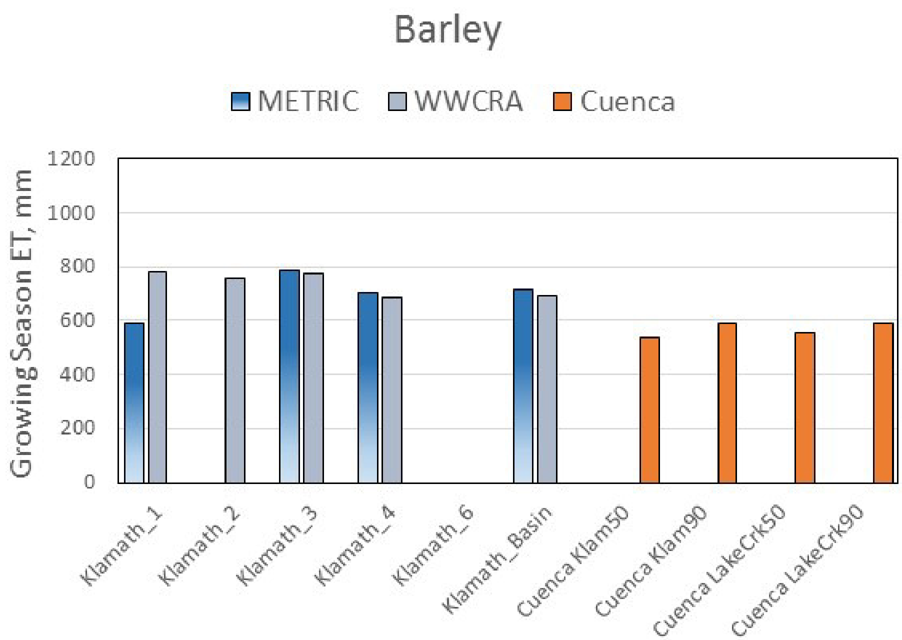


Figure 7. Seasonal ET for Barley for Five Klamath Basin HUC8 Subbasins and the Klamath Basin Average for METRIC and WWCRA and Four Entries from Cuenca (1992) from the Klamath and Lake Creek Units for 50% and 90% (9 of 10 years nonexceedance)

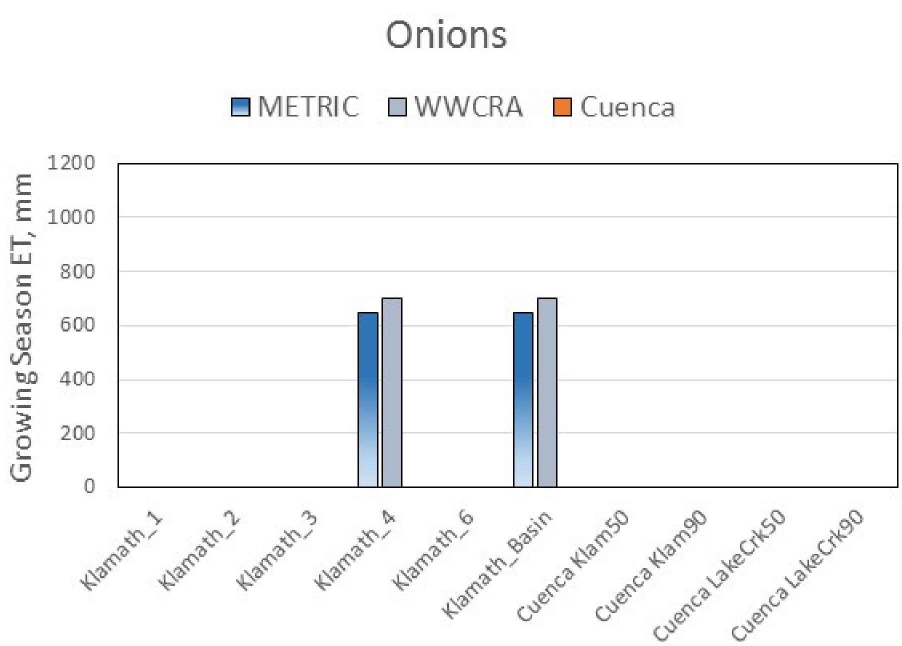


Figure 8. Seasonal ET for Onions for Five Klamath Basin HUC8 Subbasins and the Klamath Basin Average for METRIC and WWCRA and Four Entries from Cuenca (1992) from the Klamath and Lake Creek units for 50% and 90% (9 of 10 years nonexceedance)

In general, the METRIC April – October 2013 ET agreed relatively closely with the annual WWCRA-based ET estimates. This represents a relatively good indication of the good performance by both estimating systems, since they are completely independent of one another and utilize different means of ET estimation. The METRIC procedure used a Landsat-thermal-energy-balance based estimation process to determine relative ET (ETrF) on Landsat overpass dates with ET for monthly and seasonal periods calculated by multiplying daily interpolated ETrF by daily alfalfa reference ET computed from about ten Agrimet and CIMIS stations distributed over the Klamath area. The METRIC estimates were then aggregated over all pixels identified by CDL as belonging to a particular crop type. The WWCRA ET estimates were based on a dual crop coefficient method calculated daily for a single representation of a crop and soil for a HUC8 unit/weather station combination (Huntington et al., 2014). In four of the five HUC8's in the Klamath Basin, the weather station was a single National Weather Service Cooperative station, where solar radiation and humidity required to estimate reference ET were estimated from air temperature and wind speed was derived from long term monthly means obtained from the GridMET data system (Huntington et al., 2014). A grass reference basis was used in the WWCRA study.

In Figures 3 – 8, ET summaries are shown for METRIC only when the total area for the crop was greater than 20 acres. This was done to reduce the opportunity for sampling error caused by small crop area and the greater risk of miss-classification by the CDL process.

For alfalfa, METRIC and historical WWCRA estimates agreed closely in subbasins 2, 3 and 4. Estimates over the entire Klamath basin were within 5% between the two estimation methods, with WWCRA estimating about 40 mm higher than METRIC. METRIC averaged about 900 mm for the April – October period. The higher estimates by WWCRA are attributed to evaporation occurring during the nongrowing season that was accounted for in the WWCRA runs, but is not included in the METRIC April – October estimates. Both METRIC and WWCRA estimated about 90% higher than the average ET estimates (the 5 out of 10 years estimate) from Cuenca (1992) for alfalfa for the Klamath unit. The 9 of 10 year value from Cuenca (1992) for the Lake Creek unit, which is at a lower elevation than Klamath and that has a longer growing season was within 10 to 15% of METRIC. The cause of the underestimation by Cuenca (1992) for alfalfa is unknown, but may stem from the use of too short a growing season for alfalfa in the Klamath basin (May 15 to August 30) as compared to observations by METRIC of actual ET and vegetative growth and presence. This is observed later in Figure 10 and Table 6.

For 'other hay/non-alfalfa' as classified by CDL, METRIC and WWCRA produced similar estimates, with WWCRA about 15% higher, on average. The Cuenca report did not contain entries for non-alfalfa or grass hay crops. ET estimates for potatoes were similar among all three estimation approaches, averaging about 700 mm per year.

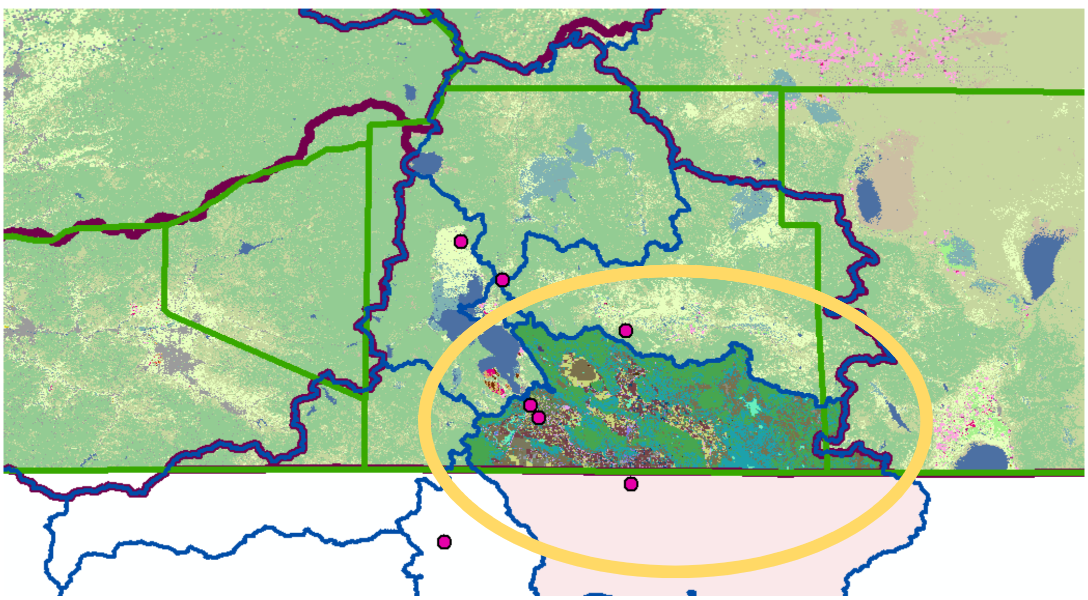
ET estimates for spring wheat were quite similar between METRIC and WWCRA and showed the same trends among the sub-basins. ET averaged about 700 mm for both methods across the Klamath basin. Cuenca (1992) estimates were about 20 to 30% lower than METRIC and WWCRA. Results were similar for barley were similar to those for spring wheat, which is expected. Cuenca (1992) estimates were about 20 to 30% lower than those by METRIC and WWCRA.

Cuenca (1992) did not contain entries for onions for Klamath and Lake Creek units. Estimates by METRIC and WWCRA were within 10% of one another, averaging 650 to 700 mm. Onions were listed by CDL for only two HUC8 subbasins.

Comparisons of METRIC with WWCRA for HUC 18010204 subbasin for year 2013 and with Historical Averages from Cuenca (1992)

The second analysis compared ET sampled from METRIC for year 2013 with ET simulated for year 2013 by WWCRA under current climate conditions, with results presented on a monthly basis. The WWCRA analysis was done for the HUC number 18010204, only (Figure 9) under Task 1.1, where weather data in WWCRA represented the Klamath Falls coop weather station. The special WWCRA application to the HUC 18010204 subbasin produced daily and monthly estimates of ET and NIWR based on a daily timestep-based computation of ET that utilized the dual crop coefficient multiplied by reference ET method as applied to the Klamath Experiment Station COOP weather station (J. Huntington, 2015, pers. comm.). ET estimates were sampled from the 2013 METRIC map on a monthly basis from April – October and by CDL crop type. Mean values were compared with monthly ET and irrigation water requirement estimates from WWCRA for 2013 and with Cuenca (1992) historical estimates. The METRIC 2013 ET estimates were based on METRIC calibrations which utilized data from the Worden Agrimet weather station, with ET for monthly periods computed using daily reference ET surfaces that were produced using about 12 Agrimet and CIMIS stations in the region (Zhao et al., 2015).

The analyses were conducted for crops in the SE Klamath HUC8 that were common to at least two of the three approaches. Comparisons were made on a monthly and seasonal basis, where the monthly comparisons provide an indication of differences or similarities in ET due to differences in simulation of crop phenologies. They also provide an opportunity to note differences in estimates of peak summer monthly ET.



Note: Also shown are WWCRA weather stations used in the historical and future analyses, with the Klamath Exp. Station Coop station located in the western part of the HUC8, just south of Klamath Lake. The other close-by symbol is the Klamath Falls Agrimet station location.

Figure 9. Area of HUC 18010204 SE Klamath HUC8 Subbasin Residing in Oregon (dark green overlay area inside the yellow circle) that was Sampled for METRIC Monthly and Growing Season ET and that was Simulated by WWCRA on a Daily Timestep

Table 5 lists crops in the Klamath SE subbasin that were identified by the USDA-NASS CDL product for 2013 for that subbasin. The primary crops were alfalfa (60,000 acres), other hay (45,000 acres), barley (15,000 acres), spring wheat (7,000 acres), winter wheat (5,000 acres) and potatoes (4,000 acres). There were minor amounts of oats and rye identified and only one or two fields of onions (91 acres).

Table 5. CDL Crop and Land-use Acreage in the Klamath Falls HUC 18010204 Klamath SE Subbasin During 2013

CDL No	Crop / Land Cover	Pixel COUNT	AREA_Acres
4	Sorghum	197	44
14	Mint	5	1
21	Barley	67,221	14,950
23	Spring Wheat	29,460	6,552
24	Winter Wheat	24,026	5,343
27	Rye	3,567	793
28	Oats	8,203	1,824
36	Alfalfa	270,142	60,078
37	Other Hay/Non Alfalfa	202,946	45,134
43	Potatoes	17,692	3,935
49	Onions	408	91
57	Herbs	217	48
61	Fallow/Idle Cropland	22,558	5,017
111	Open Water	54,514	12,124
121	Developed/Open Space	50,345	11,196
122	Developed/Low Intensity	42,349	9,418
123	Developed/Med Intensity	10,647	2,368
124	Developed/High Intensity	3,808	847
131	Barren	3,519	783
141	Deciduous Forest	43	10
142	Evergreen Forest	1,279,191	284,485
152	Shrubland	966,365	214,915
176	Grassland/Pasture	674,803	150,073
190	Woody Wetlands	138	31
195	Herbaceous Wetlands	16,927	3,764
205	Triticale	3,534	786
208	Garlic	316	70
221	Strawberries	840	187

The following sequence of tables 6 – 14 and figures 10 – 18 summarizes comparisons among ET and NIWR data sources for the primary and common crops in the SE Klamath HUC8 for year 2013 from METRIC and WWCRA and for historical means from Cuenca (1992). The growing season totals at the bottoms of the tables represents the April – October period for METRIC ET samples and for WWCRA monthly simulations, and for the tabulated monthly data of Cuenca (1992) as shown in each table.

ET estimates for alfalfa hay compared relatively closely among all methods during July and August (Figure 11) and between METRIC and WWCRA for April – June. However, with the April – June period tended to have higher estimates by WWCRA. Differences in May and June may have been caused by differences in estimation of greenup dates by WWCRA and Cuenca and estimation of first cutting dates in WWCRA. Growing season ET totals agreed closely between METRIC and WWCRA, which both averaged about nearly double the Cuenca (1992) ET estimates for the Klamath unit and about 20% higher than Cuenca (1992) ET estimates for the Lake Creek unit. Similar comparisons occurred for the NIWR. No NIWR data are shown for METRIC, since that procedure produced only ET estimates.

Table 6. Monthly Alfalfa Hay Evapotranspiration from METRIC and WWCRA for Year 2013 for the HUC 18010204 Klamath SE Subbasin and from Cuenca (1992) for the Historical Period for two Cuenca Regions

	METRIC ET	WWCRA ET	WWCRA NIWR	Klamath Cuenca ET	Klamath Cuenca NIWR	Lake Crk Cuenca ET	Lake Crk Cuenca NIWR
April	94	79	50	0	0	80	27
May	135	166	140	58	45	116	70
June	155	203	182	130	108	136	110
July	178	173	171	167	161	169	165
August	168	140	130	131	125	139	132
September	116	111	75	0	0	102	78
October	59	61	61	0	0	0	0
Growing Season	904	932	810	486	439	742	582

Note: Net irrigation water requirement (NIWR) is also listed for WWCRA and Cuenca (1992).

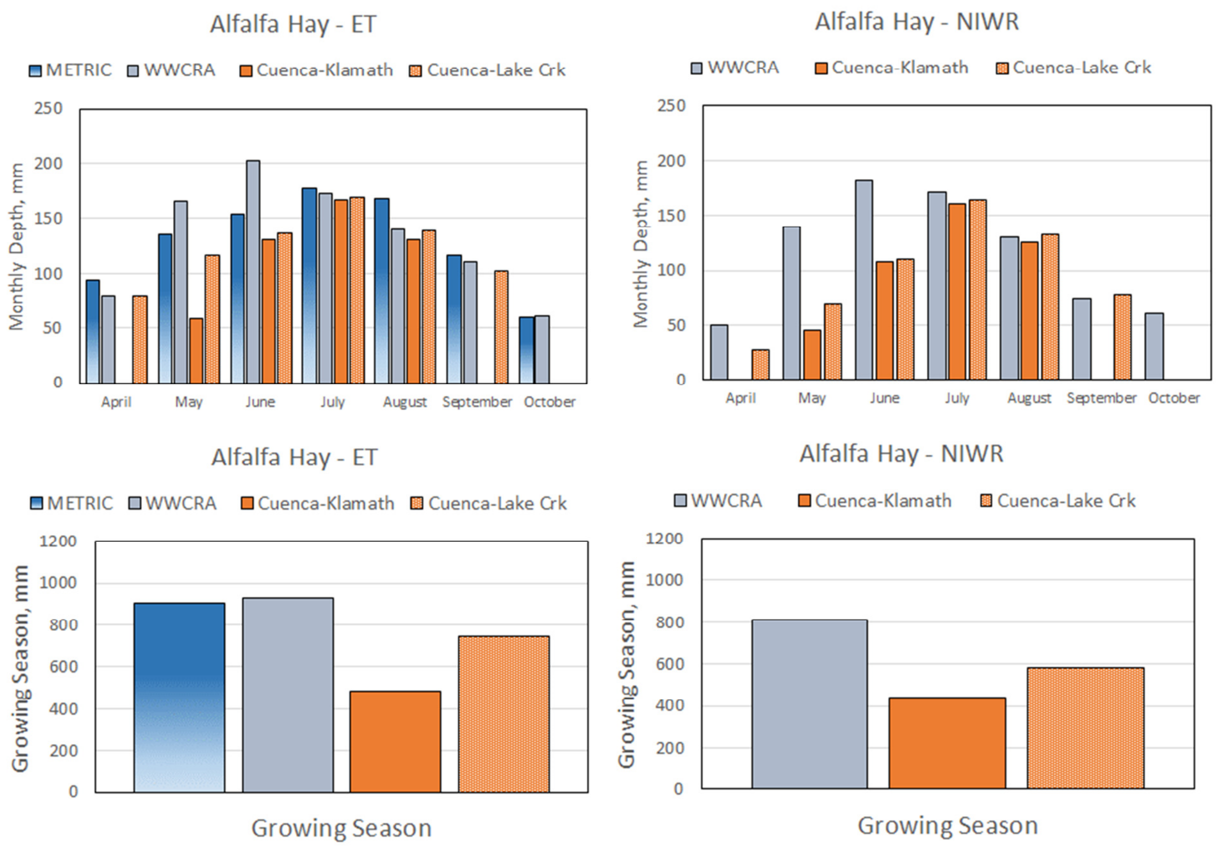


Figure 10. Comparison of Monthly ET for alfalfa hay (upper left), Monthly NIWR (upper right) and Growing Season Totals for year 2013 (METRIC and WWCRA for the HUC 18010204 Klamath SE subbasin) and for Historical Cuenca (1992) Estimates for Klamath and Lake Creek / Little Butte Creek Units of Cuenca

ET estimates for grass pasture were about 20 to 25% higher from METRIC as compared to the other two data sources, with estimates comparing relatively closely between WWCRA and Cuenca (1992) for most of the growing season. The lower estimates by WWCRA as compared to METRIC are somewhat due to the use of the “low management” crop coefficient curve type for pasture in the WWCRA simulations. The higher ET estimates from METRIC suggest that pastures in the region are relatively well managed and watered, with relatively high ET. The METRIC estimates for pasture can be considered to be better representations of actual ET for pasture, since they represent actual conditions as observed by satellite and determined by surface energy balance. This conclusion presumes that the CDL classification for pasture was accurate.

Table 7. Monthly Grass Pasture Evapotranspiration from METRIC and WWCRA for Year 2013 for the HUC 18010204 Klamath SE Subbasin and from Cuenca (1992) for the Historical Period for two Cuenca Regions

	METRIC ET	WWCRA ET	WWCRA NIWR	Klamath Cuenca ET	Klamath Cuenca NIWR	Lake Crk Cuenca ET	Lake Crk Cuenca NIWR
April	138	88	55	73	44	84	32
May	153	134	109	110	84	124	76
June	174	150	129	138	114	147	118
July	195	169	168	179	172	180	175
August	151	136	126	145	137	149	142
September	101	75	40	107	93	108	85
October	70	13	13	32	16	68	8
Growing Season	982	765	639	784	660	860	636

Net irrigation water requirement (NIWR) is also listed for WWCRA and Cuenca (1992).

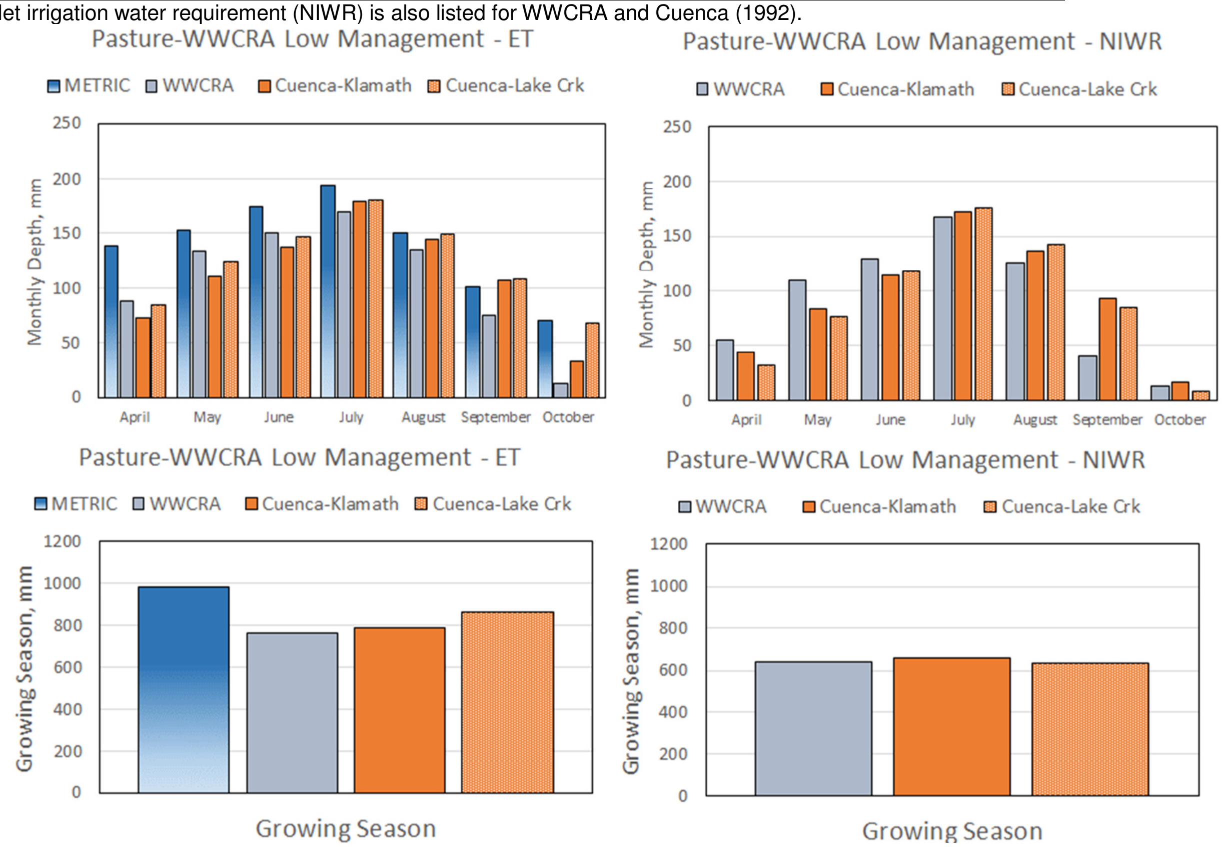


Figure 11. Comparison of Monthly ET for Grass Pasture (upper left), Monthly NIWR (upper right) and Growing Season Totals for year 2013 (METRIC and WWCRA for the HUC 18010204 Klamath SE subbasin) and for Historical Cuenca (1992) Estimates for Klamath and Lake Creek / Little Butte Creek Units of Cuenca

ET estimates for spring grain were similar between METRIC and WWCRA except for the month of June, where WWCRA estimated considerably higher from METRIC. This, coupled with lower ET estimated by

WWCRA in August suggests that the WWCRA procedure estimated earlier development for spring grain as compared to observations by METRIC. Growing season estimates were similar between METRIC and WWCRA, with those by Cuenca (1992) about 20 to 25% lower.

Table 8. Monthly Spring Grain Evapotranspiration from METRIC and WWCRA for Year 2013 for the HUC 18010204 Klamath SE Subbasin and from Cuenca (1992) for the Historical Period for two Cuenca Regions

	METRIC ET	WWCRA ET	WWCRA NIWR	Klamath Cuenca ET	Klamath Cuenca NIWR	Lake Crk Cuenca ET	Lake Crk Cuenca NIWR
April	63	53	25	0	0	64	14
May	85	106	81	41	26	138	89
June	131	216	195	117	95	168	138
July	191	223	222	205	200	160	156
August	127	22	11	153	144	12	12
September	57	14	-22	24	19	0	0
October	31	11	11	0	0	0	0
Growing Season	686	646	524	540	484	542	409

Net irrigation water requirement (NIWR) is also listed for WWCRA and Cuenca (1992).

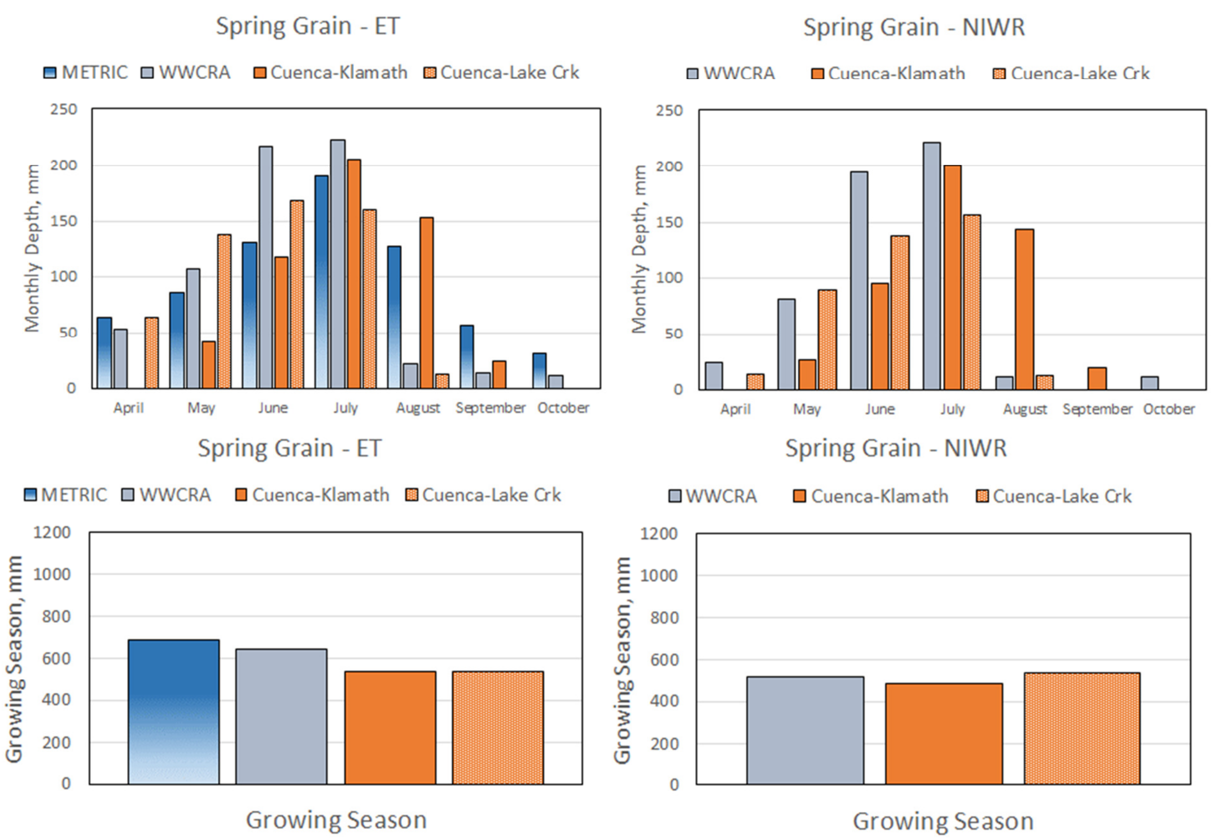


Figure 12. Comparison of Monthly ET for Spring Grain (upper left), Monthly NIWR (upper right) and Growing Season Totals for year 2013 (METRIC and WWCRA for the HUC 18010204 Klamath

SE subbasin) and for Historical Cuenca (1992) Estimates for Klamath and Lake Creek / Little Butte Creek Units of Cuenca

There were no unique estimates for barley in WWCRA and Cuenca (1992), so that the spring grain entries were compared with the CDL and METRIC based estimates for barley in Table 9 and Figure 13. Results are similar as for spring wheat, with small increases in differences between WWCRA and METRIC.

Table 9. Monthly Barley Evapotranspiration from METRIC and WWCRA (spring grain) for Year 2013 for the HUC 18010204 Klamath SE Subbasin and Spring Grain from Cuenca (1992) for the Historical Period for two Cuenca Regions

	METRIC ET	WWCRA ET	WWCRA NIWR	Klamath Cuenca ET	Klamath Cuenca NIWR	Lake Crk Cuenca ET	Lake Crk Cuenca NIWR
April	102	53	25	0	0	64	14
May	82	106	81	41	26	138	89
June	103	216	195	117	95	168	138
July	179	223	222	205	200	160	156
August	141	22	11	153	144	12	12
September	67	14	-22	24	19	0	0
October	32	11	11	0	0	0	0
Growing Season	706	646	524	540	484	542	409

Net irrigation water requirement (NIWR) is listed for WWCRA and Cuenca (1992).

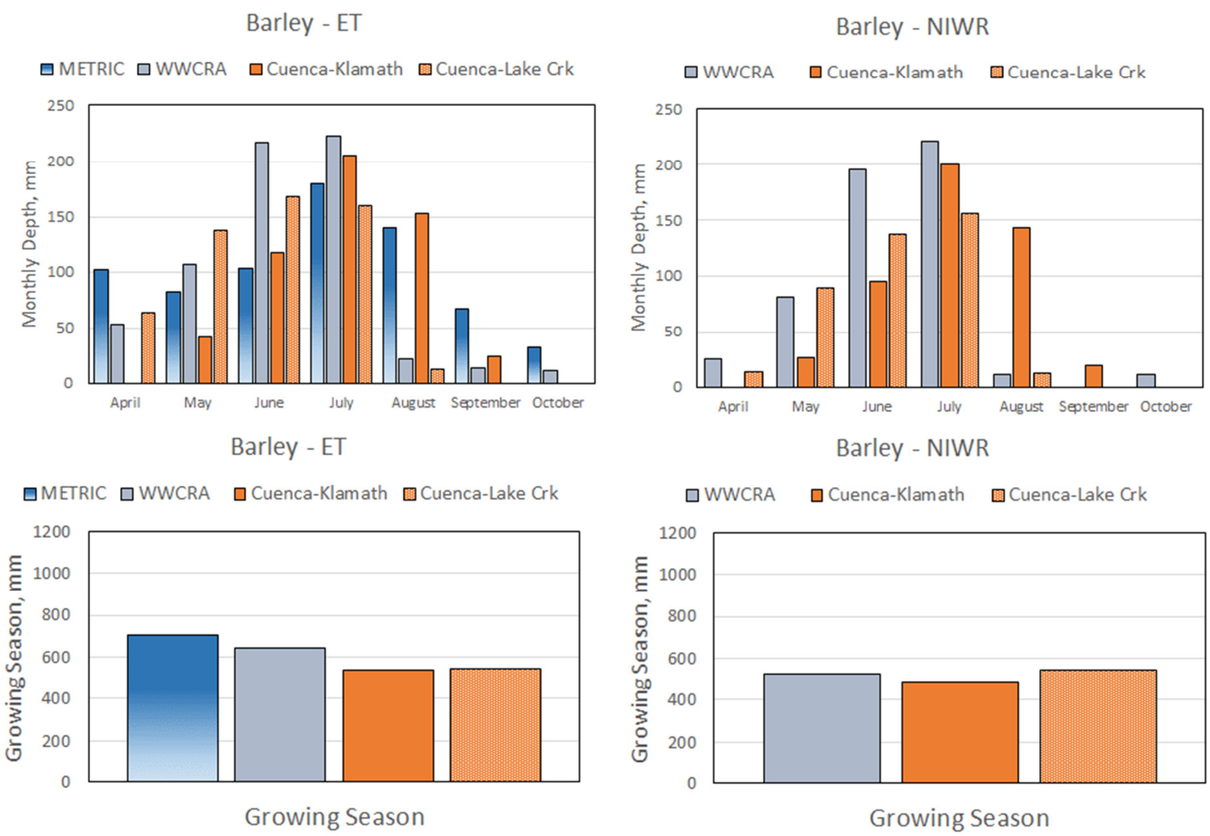


Figure 13. Comparison of Monthly ET for barley (upper left), Monthly NIWR (upper right) and Growing Season Totals for Year 2013 (METRIC and (spring grain) WWCRA for the HUC 18010204 Klamath SE subbasin) and Spring Grain for Historical Cuenca (1992) Estimates for Klamath and Lake Creek / Little Butte Creek Units of Cuenca

ET estimates for potatoes were very similar among all three data sources, including monthly trends and amounts, as shown in Table 10 and Figure 14. Growing season totals were also similar. This indicates good accuracy by WWCRA and Cuenca (1992) in estimating crop development and growing season length for potatoes. Similarities also suggest good accuracy in the CDL-based identification of potato crops and the estimation by METRIC, which does not require specific information on crop type.

Table 10. Monthly Potato Evapotranspiration from METRIC and WWCRA for Year 2013 for the HUC 18010204 Klamath SE Subbasin and from Cuenca (1992) for the Historical Period for two Cuenca Regions

	METRIC ET	WWCRA ET	WWCRA NIWR	Klamath Cuenca ET	Klamath Cuenca NIWR	Lake Crk Cuenca ET	Lake Crk Cuenca NIWR
April	43	35	1	0	0	0	0
May	55	45	20	24	14	0	0
June	92	111	90	82	64	0	0
July	192	203	201	199	192	0	0
August	166	163	153	167	160	0	0
September	73	84	49	114	100	0	0
October	24	17	17	27	13	0	0
Growing Season	644	658	531	613	543	0	0

Net irrigation water requirement (NIWR) is also listed for WWCRA and Cuenca (1992).

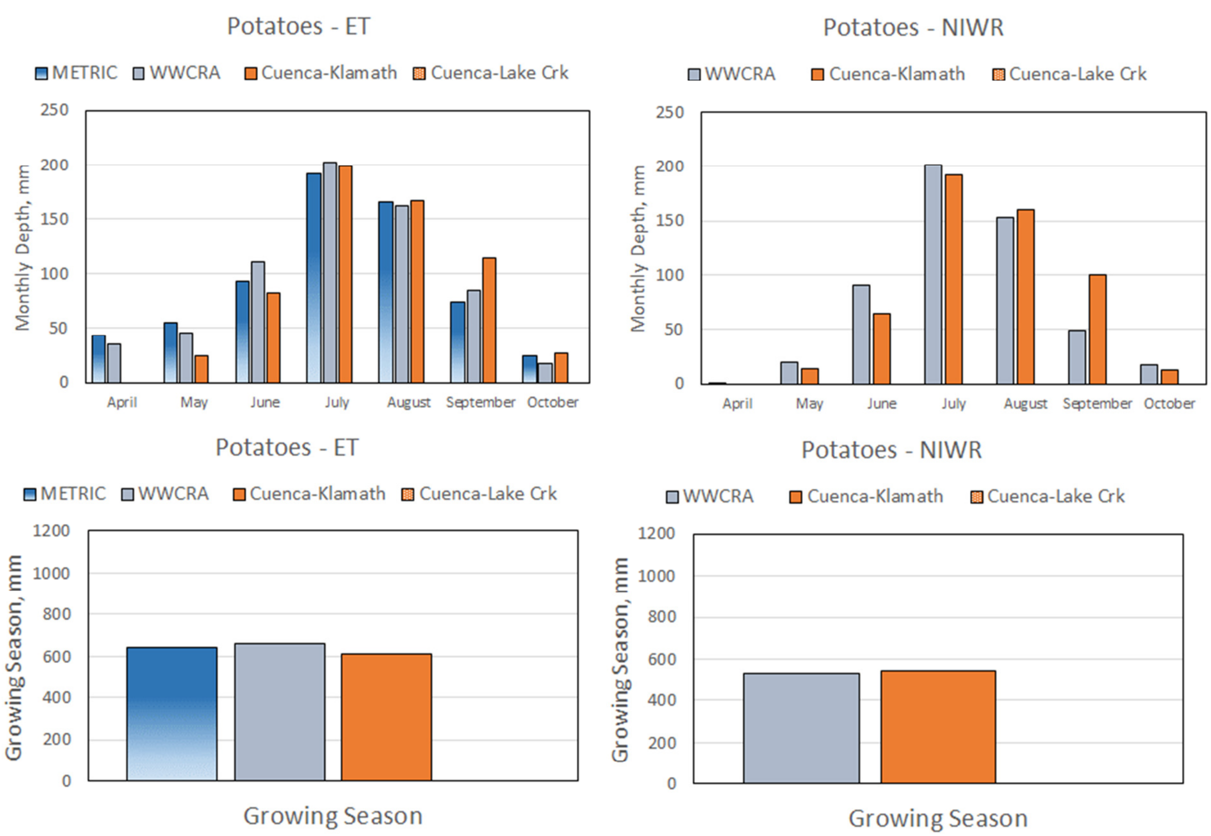


Figure 14. Comparison of Monthly ET for Potatoes (upper left), Monthly NIWR (upper right) and Growing Season Totals for year 2013 (METRIC and WWCRA for the HUC 18010204 Klamath SE subbasin) and for Historical Cuenca (1992) Estimates for Klamath and Lake Creek / Little Butte Creek Units of Cuenca.

There were only 91 acres of onions identified for the Klamath SE HUC8 in the 2013 CDL for the portion residing in Oregon. Therefore, estimates from METRIC sampling may not be representative of all onions, plus the average accuracy of the CDL identification for onions may not be high, with the small number of fields. The METRIC ET trends for onions show a later development and shorter growing season than do WWCRA and Cuenca (1992), which may be caused by the small number of fields sampled, or by specific grower practices. ET estimated for the growing seasons was similar, however among the methods. NIWR tended to be lower for Cuenca (1992) than WWCRA, apparently due to a higher estimate for effectiveness of precipitation by Cuenca, which used the more approximate SCS 1967 method.

Table 11. Monthly Onion Evapotranspiration from METRIC and WWCRA for Year 2013 for the HUC 18010204 Klamath SE Subbasin and from Cuenca (1992) for the Historical Period for two Cuenca Regions

	METRIC ET	WWCRA ET	WWCRA NIWR	Klamath Cuenca ET	Klamath Cuenca NIWR	Lake Crk Cuenca ET	Lake Crk Cuenca NIWR
April	50	66	32	0	0	68	23
May	61	137	112	0	0	128	84
June	88	184	163	0	0	151	27
July	130	179	178	0	0	182	79
August	156	24	13	0	0	131	25
September	108	14	-21	0	0	0	0
October	51	14	14	0	0	0	0
Growing Season	645	618	491	0	0	660	238

Net irrigation water requirement (NIWR) is also listed for WWCRA and Cuenca (1992).

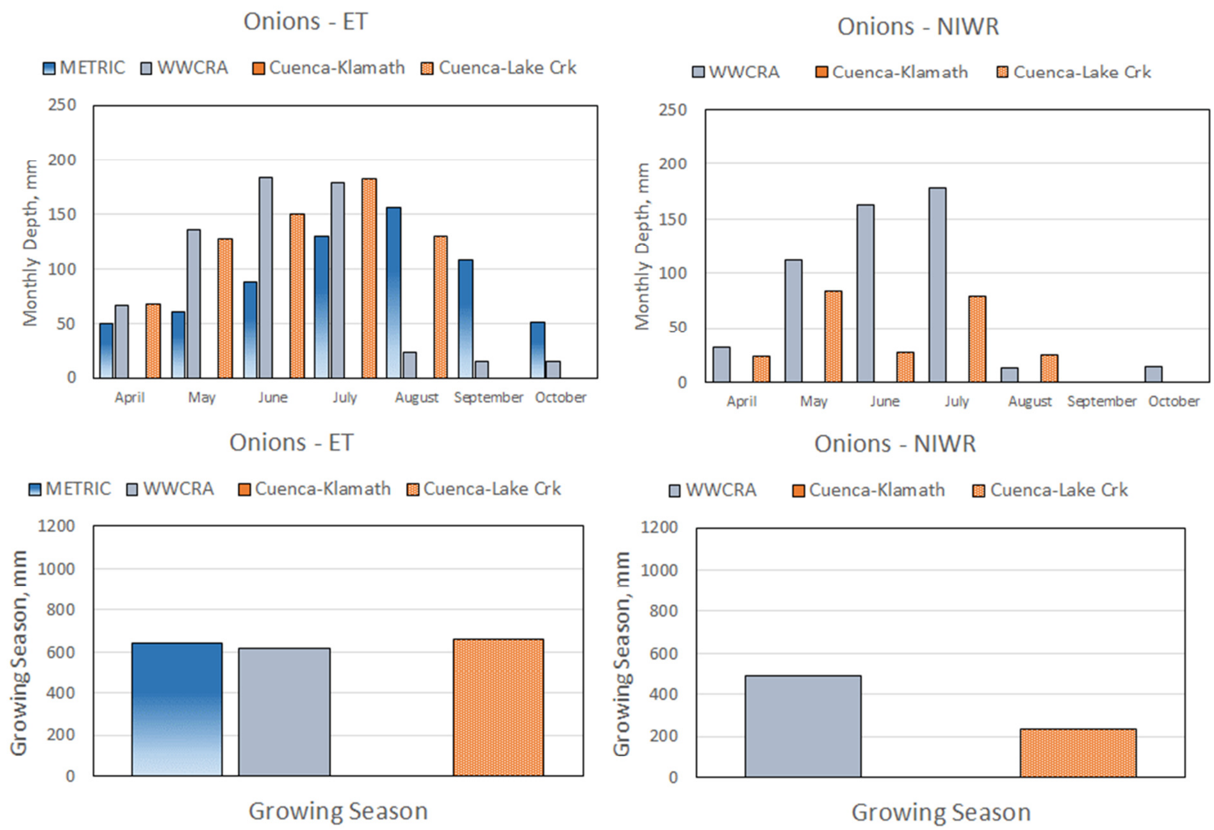


Figure 15. Comparison of Monthly ET for onions (upper left), Monthly NIWR (upper right) and Growing Season Totals for year 2013 (METRIC and WWCRA for the HUC 18010204 Klamath SE subbasin) and for Historical Cuenca (1992) Estimates for Klamath and Lake Creek / Little Butte Creek Units of Cuenca

Estimated ET for the ‘other, grass hay’ CDL category was lower from METRIC than from WWCRA, and is most likely due to the trend for many grass hay fields to be less well-managed and irrigated than for other crops. The crop coefficient curve used in WWCRA may represent a higher level of water and crop management than is practiced in the Klamath basin. No entries for ‘other hay’ exist in Cuenca (1992) for the two Cuenca units evaluated.

Table 12. Monthly Other (grass) Hay Evapotranspiration from METRIC and WWCRA for Year 2013 for the HUC 18010204 Klamath SE Subbasin (no entries in Cuenca (1992))

	METRIC ET	WWCRA ET	WWCRA NIWR	Klamath Cuenca ET	Klamath Cuenca NIWR	Lake Crk Cuenca ET	Lake Crk Cuenca NIWR
April	95	95	61	0	0	0	0
May	119	164	139	0	0	0	0
June	144	205	184	0	0	0	0
July	170	185	184	0	0	0	0
August	150	163	153	0	0	0	0
September	103	104	69	0	0	0	0
October	59	53	53	0	0	0	0
Growing Season	840	970	842	0	0	0	0

Net irrigation water requirement (NIWR) is also listed for WWCRA.

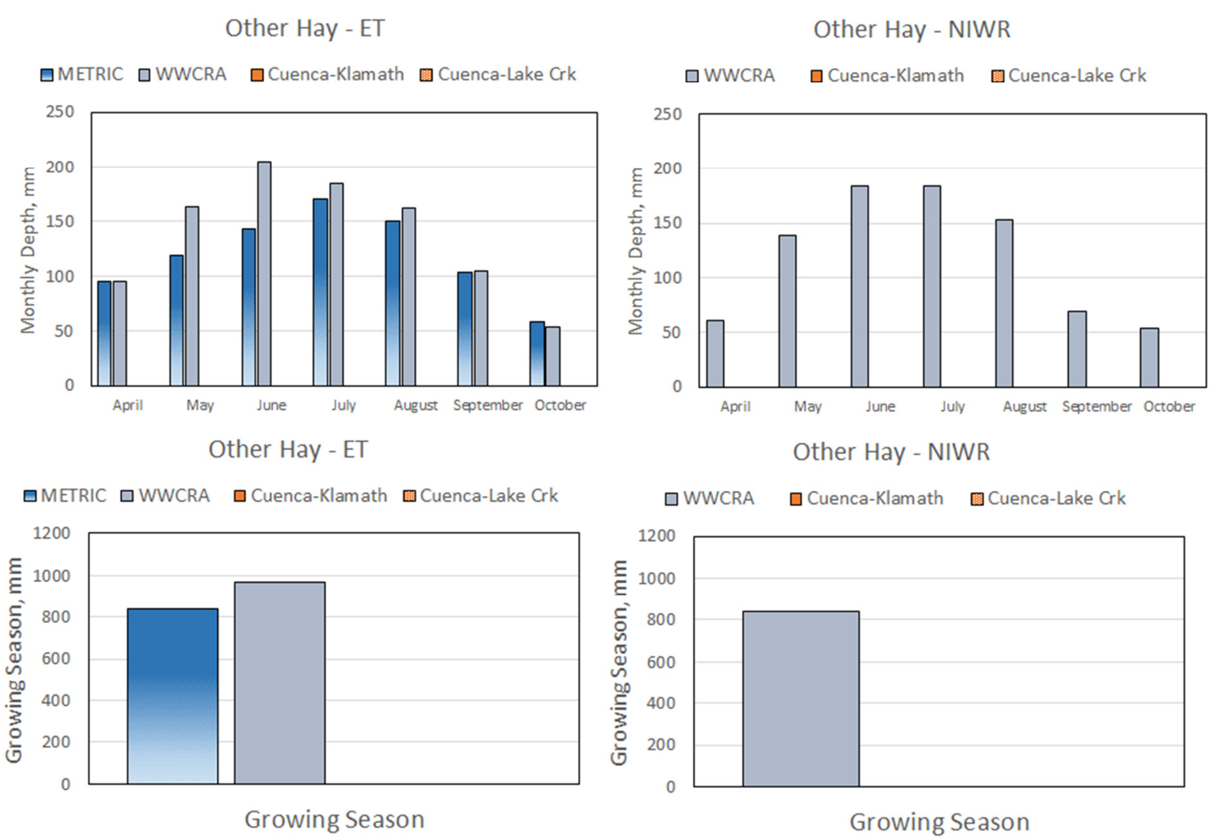


Figure 16. Comparison of Monthly ET for other (grass) hay (upper left), Monthly NIWR (upper right) and Growing Season Totals for year 2013 (METRIC and WWCRA for the HUC 18010204 Klamath SE subbasin) (no entries in Cuenca (1992))

The WWCRA simulations did not include a winter wheat or winter grain category for the Klamath SE HUC, so that only METRIC estimates and those from Cuenca (1992) are compared in Table 13 and

Figure 17. Trends are relatively similar between METRIC and Cuenca (1992), with the start and end of the growing season ET being later and earlier, respectively, with Cuenca estimates, so that total growing season ET was about 30% lower than from METRIC.

Table 13. Monthly Winter Wheat Evapotranspiration from METRIC for year 2013 for the HUC 18010204 Klamath SE Subbasin and from Cuenca (1992) for the Historical Period for two Cuenca Regions

	METRIC ET	WWCRA ET	WWCRA NIWR	Klamath Cuenca ET	Klamath Cuenca NIWR	Lake Crk Cuenca ET	Lake Crk Cuenca NIWR
April	76			39	18	0	0
May	129			111	86	0	0
June	148			157	133	0	0
July	155			165	159	0	0
August	99			16	15	0	0
September	52			0	0	0	0
October	33			0	0	0	0
Growing Season	691	0	0	488	411	0	0

Net irrigation water requirement (NIWR) is also listed for Cuenca (1992) (no entries for WWCRA).

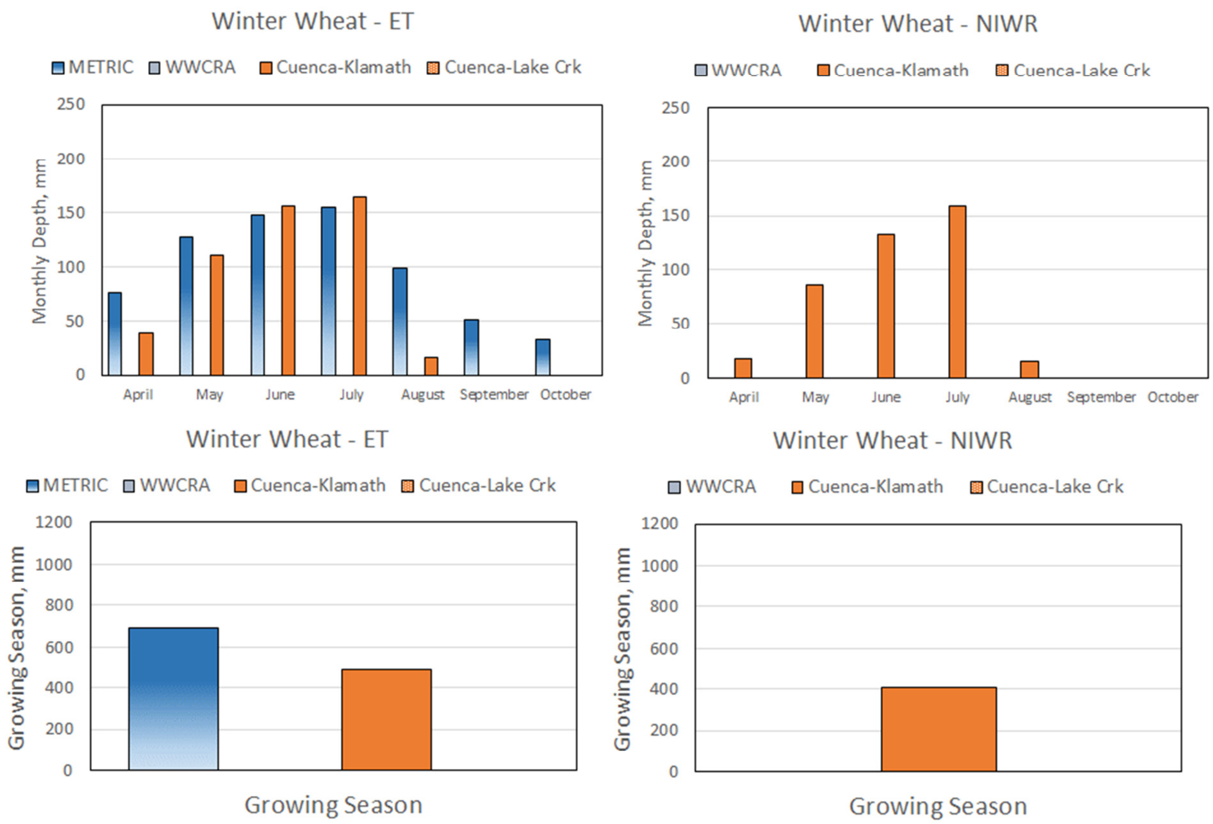


Figure 17. Comparison of Monthly ET for Winter Wheat (upper left), Monthly NIWR (upper right) and Growing Season Totals for year 2013 (METRIC and WWCRA for the HUC 18010204 Klamath SE subbasin) (no entries in Cuenca (1992)

The CDL for 2013 did not include sweet corn for the Klamath SE HUC, therefore, only WWCRA and Cuenca (1992) ET estimates are compared in Table 14 and Figure 18. Cuenca (1992) estimates reflect a later estimated start and stop for the growing season for sweet corn than in WWCRA. Variability in growing season for sweet corn is quite common and the crop is often planted in stages to meet a longer market period. Therefore, one should probably not expect the two sources to agree month to month, since they use different means to estimate start and ending dates for the growing period. The WWCRA/ETDemands model uses mean 30-day air temperature to estimate planting and cumulative growing degree-days to estimate growing season length for sweet corn. ET and NIWR estimated for the growing season were similar between the two data sources.

Table 14. Monthly Sweet Corn Evapotranspiration from WWCRA for year 2013 (no entry for METRIC) for the HUC 18010204 Klamath SE Subbasin and from Cuenca (1992) for the Historical Period for two Cuenca Regions

	METRIC ET	WWCRA ET	WWCRA NIWR	Klamath Cuenca ET	Klamath Cuenca NIWR	Lake Crk Cuenca ET	Lake Crk Cuenca NIWR
April		66	32	0	0	0	0
May		137	112	0	0	65	23
June		184	163	0	0	131	102
July		179	178	0	0	206	203
August		24	13	0	0	169	163
September		14	-21	0	0	59	48
October		14	14	0	0	0	0
Growing Season	0	618	491	0	0	630	539

Net irrigation water requirement (NIWR) is also listed for WWCRA and Cuenca (1992).

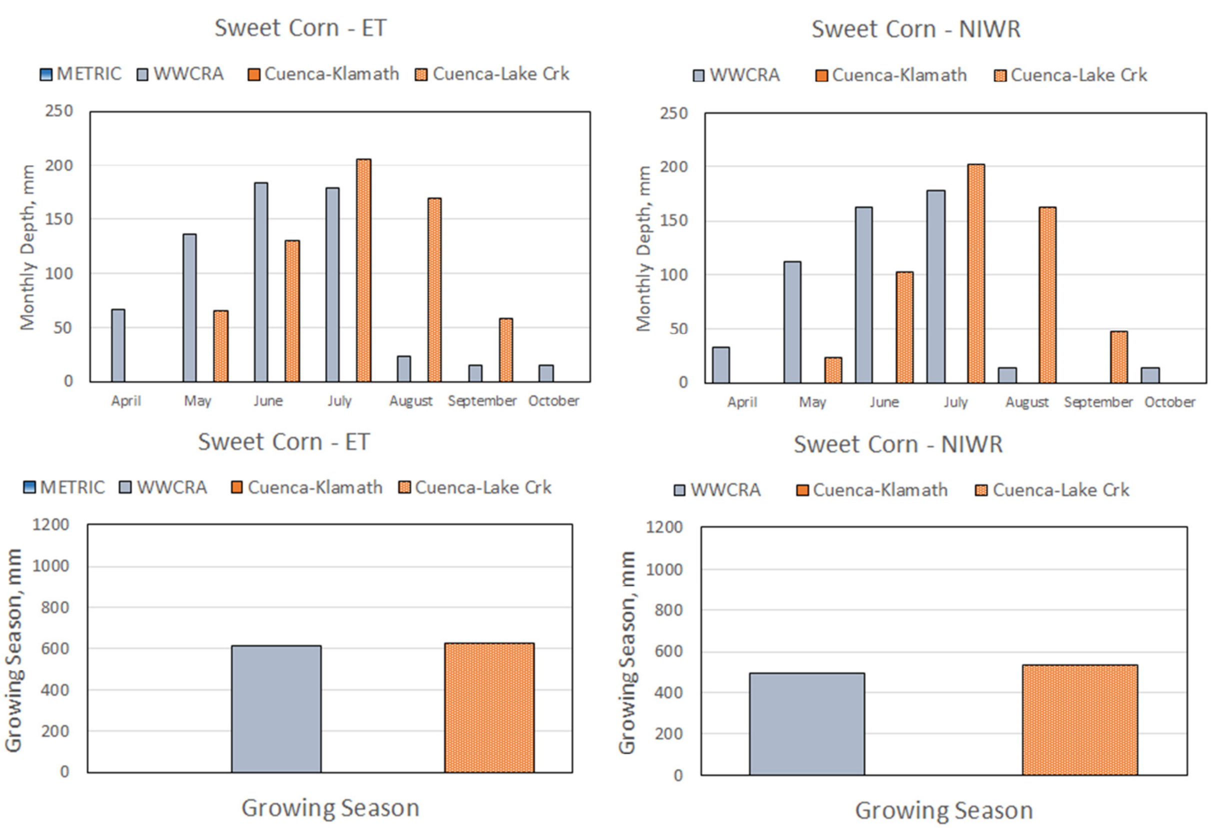


Figure 18. Comparison of Monthly ET for Sweet Corn (upper left), Monthly NIWR (upper right) and Growing Season Totals for year 2013 (METRIC and WWCRA for the HUC 18010204 Klamath SE subbasin) and for Historical Cuenca (1992) Estimates for Klamath and Lake Creek / Little Butte Creek Units of Cuenca

Conclusions and Discussion

The generally good agreement between METRIC and WWCRA ET estimates for monthly periods and for growing seasons (for METRIC) and annual periods (for WWCRA) is a good outcome and promotes confidence in the two independent estimation systems.

Growing season ET totals agreed closely between METRIC and WWCRA for alfalfa hay crops, which both averaged about nearly double the Cuenca (1992) ET estimates for the Klamath unit and about 20% higher than Cuenca (1992) ET estimates for the Lake Creek unit. Similar comparisons occurred for the NIWR.

ET estimates for potatoes were very similar among all three data sources, including monthly trends and amounts. Growing season totals were also similar. This indicates good accuracy by WWCRA and Cuenca (1992) in estimating crop development and growing season length for potatoes. Similarities also suggest good accuracy in the CDL-based identification of potato crops and the estimation by METRIC, which does not require specific information on crop type.

The close agreement between METRIC and WWCRA estimates suggests that essentially all crops sampled, with the exception of 'other grass hay' were fully or nearly fully irrigated so that actual ET as produced from METRIC approached the potential crop ET as produced by the WWCRA ET-Demands model and process for the Klamath Basin.

In general, Cuenca (1992) based estimates are lower than those observed with METRIC and estimated by WWCRA for more than half of the primary crops in the Klamath region. Some of that understatement is due to METRIC and WWCRA including impacts of evaporation from bare, wet soil prior to planting and after harvest, and also specific evaporation effects from rain and irrigation during the season. The Cuenca (1992) estimates may be lower for other reasons, including the use of crop coefficient curves that may be too small in value or use of too short of growing season lengths in some cases. Good agreement between Cuenca (1992) and METRIC and WWCRA for some crops, such as potatoes, suggests that the reference ET basis used in Cuenca (1992) performed similarly to that of WWCRA and METRIC, and that the differences among estimates is more due to the crop coefficient approach and data used in Cuenca (1992) as compared to WWCRA.

Future updates to estimates of agricultural water demands in Oregon should probably be based on a combined process where extended time series of daily, monthly, growing season and annual estimates are produced using a model such as the WWCRA/ETDemands model used in this study. That type of model is able to make calculations for historical periods dating to the late 1800's (Allen and Robison 2007) when only air temperature and precipitation were measured, but can also take advantage of modern weather data systems such as Agrimet where a full complement of weather data that impact ET and water demands are measured. Having a long time series provides information on long-term variation and evolution of both weather and ET demands. WWCRA estimates are valuable in that they can be easily produced for extended time periods spanning decades and can be projected into the future under climate change forecasts.

METRIC estimates are useful for years that have sufficient Landsat imagery, to assess spatial distribution of ET within a county, subbasin or region and to identify specific ET associated with individual land-use parcels such as agricultural fields. Parcel-based ET, which is obtained when 30 m resolution Landsat imagery are processed, is useful in water rights management, mitigation and litigation. It is also useful when calculating water balances used in ground water modeling and hydrologic studies. METRIC-based ET can be used to derive or improve crop coefficient values that are in turn used in an ETDemands type of modeling process (Allen et al., 2007b). Because METRIC ET is actual ET, it is useful to evaluate effects of actual water supply conditions on meeting water demands of irrigated crops.

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Attachment A. Documentation of Cropland Data Layer (CDL) Handling

Error statistics for the CDL crop classification for 2013 in Oregon as reported by FSA are listed in Table 1. Average classification accuracy was 89% for the state, which is considered to be a relatively high accuracy.

Table 1. Crop Classification Error Statistics for Primary Crops in Oregon as Reported by FSA

Cover Type	Attribute Code	*Correct Pixels	Producer's Accuracy	Omission Error	Kappa	User's Accuracy	Commiss Error	Cond'l Kappa
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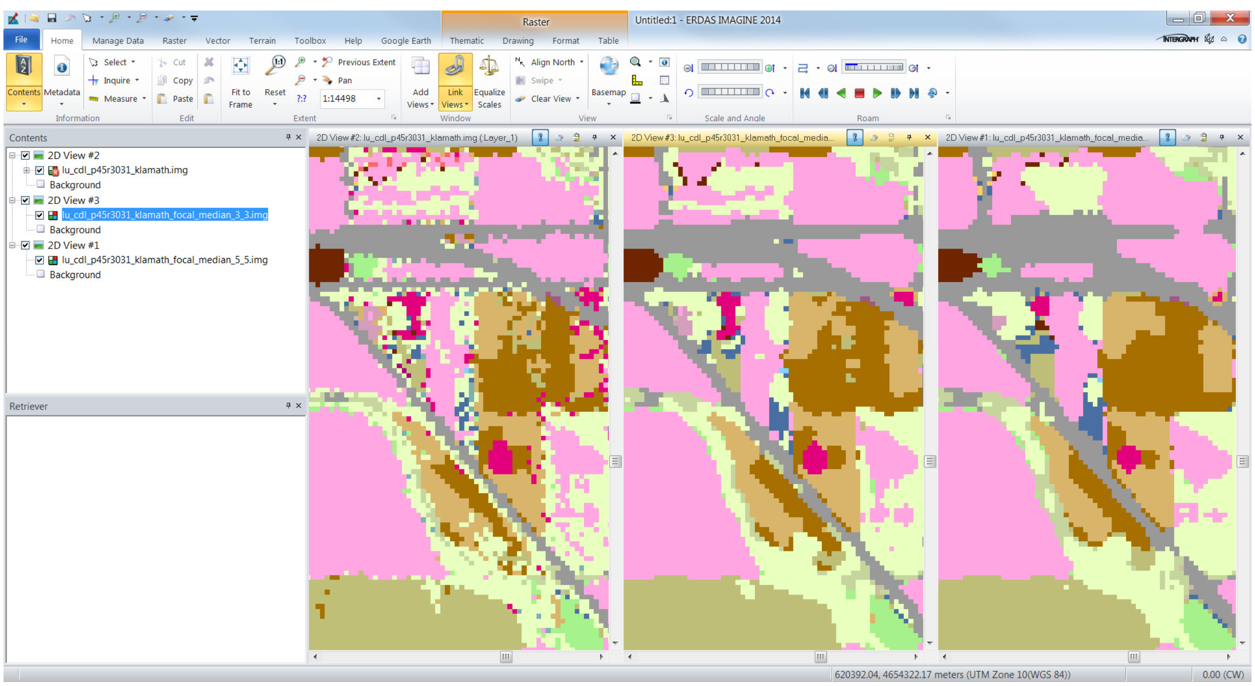
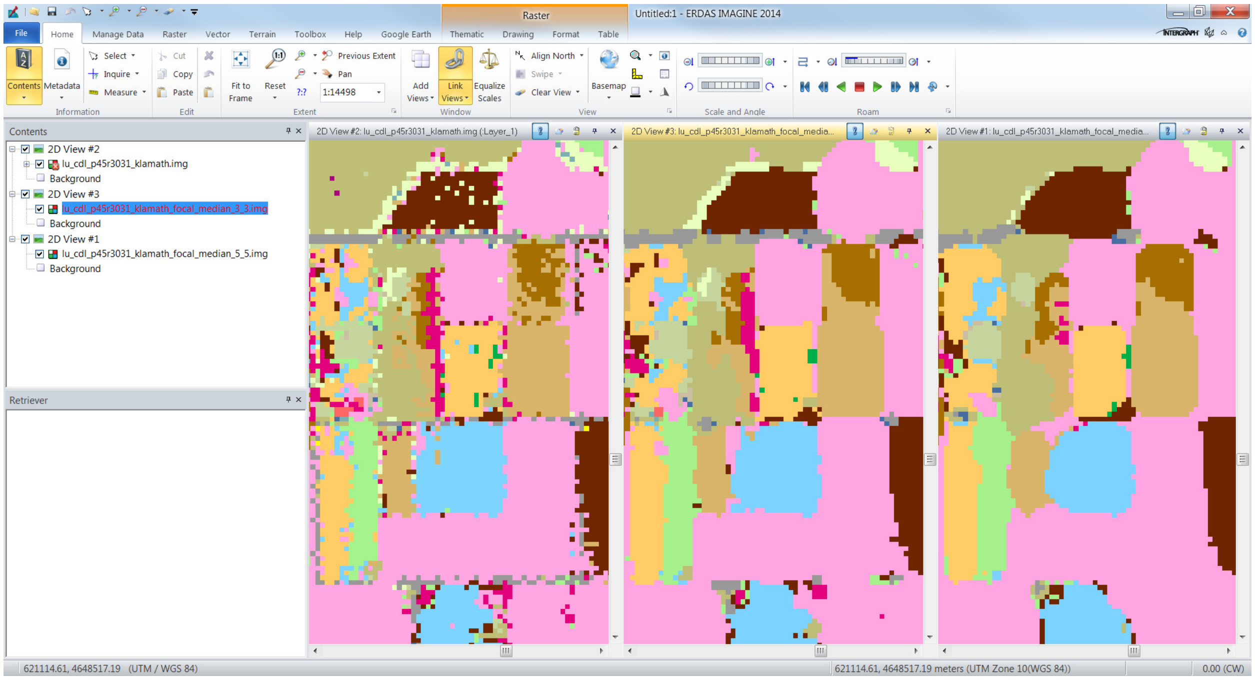
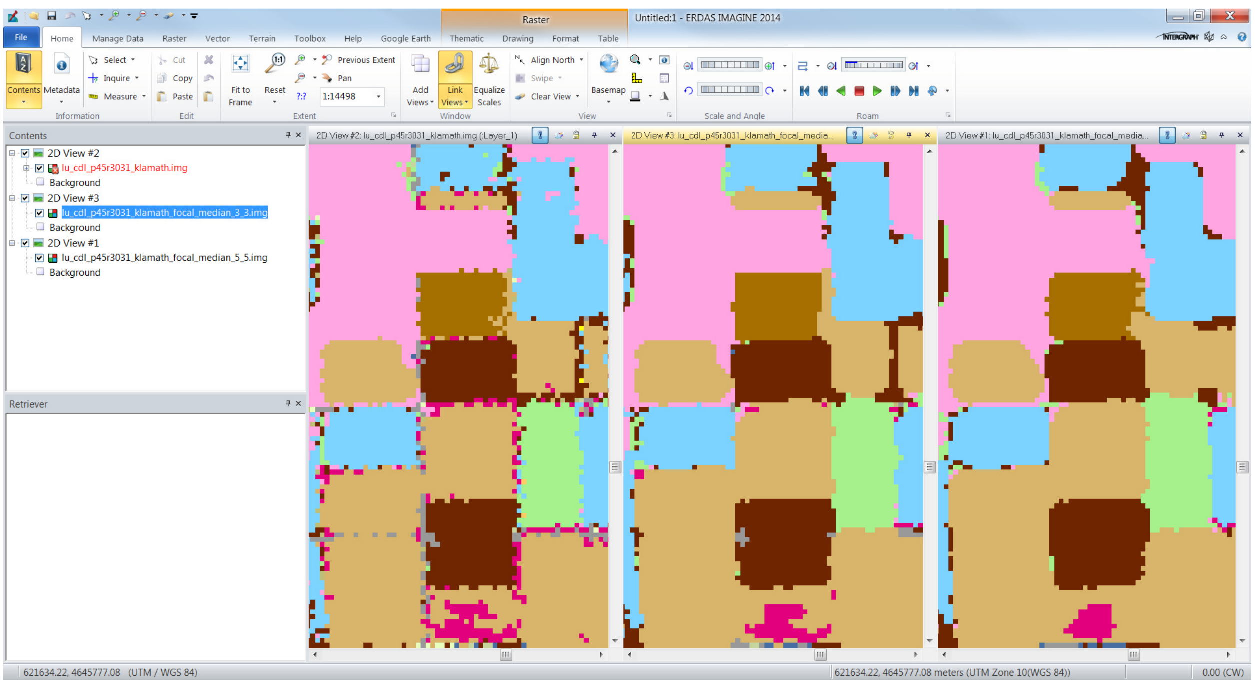
Corn	1	42856	93.85%	6.15%	0.937	87.19%	12.81%	0.87
Sweet Corn	12	6187	65.62%	34.38%	0.655	69.55%	30.45%	0.694
Mint	14	859	40.20%	59.80%	0.402	79.46%	20.54%	0.794
Spring Wheat	23	42397	74.25%	25.75%	0.737	78.57%	21.43%	0.781
Winter Wheat	24	603659	97.00%	3.00%	0.961	96.53%	3.47%	0.955
Alfalfa	36	165628	88.24%	11.76%	0.873	87.08%	12.92%	0.861
Other Hay/Non Alfalfa	37	104608	71.26%	28.74%	0.699	89.28%	10.72%	0.887
Sugarbeets	41	5561	88.88%	11.12%	0.889	93.13%	6.87%	0.931
Dry Beans	42	6997	69.46%	30.54%	0.694	81.84%	18.16%	0.818
Potatoes	43	31045	94.32%	5.68%	0.943	91.44%	8.56%	0.913
Misc Vegs & Fruits	47	47	12.47%	87.53%	0.125	85.45%	14.55%	0.855
Watermelons	48	50	43.48%	56.52%	0.435	45.87%	54.13%	0.459
Onions	49	13195	85.68%	14.32%	0.856	90.46%	9.54%	0.904
Peas	53	17845	85.44%	14.56%	0.853	93.31%	6.69%	0.933
Caneberries	55	411	34.00%	66.00%	0.34	46.81%	53.19%	0.468
Hops	56	452	49.29%	50.71%	0.493	80.14%	19.86%	0.801
Herbs	57	9164	79.34%	20.66%	0.793	87.23%	12.77%	0.872
Sod/Grass Seed	59	139298	88.25%	11.75%	0.875	91.47%	8.53%	0.909
Fallow/Idle Cropland	61	549034	96.58%	3.42%	0.957	98.19%	1.81%	0.977
Cherries	66	5424	80.80%	19.20%	0.808	90.79%	9.21%	0.908
Apples	68	1133	73.00%	27.00%	0.73	78.25%	21.75%	0.782
Grapes	69	405	41.12%	58.88%	0.411	68.18%	31.82%	0.682
Christmas Trees	70	2810	61.57%	38.43%	0.615	81.47%	18.53%	0.814
Other Tree Crops	71	5037	70.13%	29.87%	0.701	79.90%	20.10%	0.798
Carrots	206	2452	58.80%	41.20%	0.588	85.94%	14.06%	0.859
Garlic	208	497	49.85%	50.15%	0.498	89.87%	10.13%	0.899
Peppers	216	162	90.00%	10.00%	0.9	94.19%	5.81%	0.942
Strawberries	221	16	6.08%	93.92%	0.061	8.79%	91.21%	0.088
Vetch	224	123	15.91%	84.09%	0.159	34.07%	65.93%	0.341
Pumpkins	229	149	61.57%	38.43%	0.616	42.57%	57.43%	0.426
Blueberries	242	505	36.12%	63.88%	0.361	52.77%	47.23%	0.527
Radishes	246	2713	48.96%	51.04%	0.489	94.01%	5.99%	0.94
Turnips	247	27	2.82%	97.18%	0.028	93.10%	6.90%	0.931
Cranberries	250	3	20.00%	80.00%	0.2	75.00%	25.00%	0.75

*Correct Pixels represent the total number of independent validation pixels correctly identified in the error matrix.
**The Overall Accuracy represents only the FSA row crops and annual fruit and vegetables (codes 1-61,66-80 and 200-255). FSA-sampled grass and pasture, aquaculture, and all National Land Cover Dataset (NLCD)-sampled categories (codes 62-65 and 81-199) are not included in the Overall Accuracy.

Preparation of the Cropland Data Layer for 2013. A 3x3 Focus Median filter was applied to the CDL2013 image for the state of Oregon domain. The median filter removed classification speckles of 1, 2 and 3 pixels in size that were surrounded by a single CDL type. The use of the median statistic in the filter preserves the majority CDL land use type within the filter (3x3) area. The removal of speckles was considered to be desirable prior to sampling to reduce the number of false associations between ET and crop type. A 5x5 filter was experimented with to remove even larger speckle groups. The 3x3 filter tended to retain small roadways better than the 5x5. Both 3x3 and 5x5 tend to produce straight field boundaries, which is desirable. Results of both filter sizes are considered to be acceptable. The 3x3 filter appeare to be adequate to remove most unwarranted speckles and may have the least impact on change to the original CDL, and therefore was the one utilized. Some sample screenshots of the original CDL (left), the 3x3 (center) and 5x5 (right) are presented below. The filtered CDL image for Oregon was reprojected to WGS1984 UTM zone 10N, following despeckling, to coincide with Klamath ET maps produced from METRIC. That reprojection to zone 10 may not be valid for eastern Oregon, which is zone 11.







The names of the despeckled, clipped CDL images are:

Layers

- C:\Users\Rick\Documents\CO\ETPlus\MWH_OWRD\CDL_2
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  - Clip_cdl_2013_41_3x3_focal_median_utm_10n_Klam3.tif
  - Clip_cdl_2013_41_3x3_focal_median_utm_10n_Klam4.tif
  - Clip_cdl_2013_41_3x3_focal_median_utm_10n_Klam5.tif
  - Clip_cdl_2013_41_3x3_focal_median_utm_10n_Klam7.tif

Attachment B. Summary Tables of Growing Season or Annual ET from METRIC and WWCRA by HUC8 Subbasin

Tables B1 – B5 show summaries of ET for growing seasons from METRIC and for annual ET from WWCRA for the five HUC8 subbasins contained in the Oregon portion of the Klamath River Basin. Column 2 of the tables list crops as identified in the 2013 Cropland Data Layer and the ninth column lists the names of crops for which ET estimates were produced by WWCRA simulations. The WWCRA crop names are listed in the same row as the CDL crop to which they are most associated.

Table B6 lists all crops contained in the WWCRA ETDemands software and Table B7 lists all crops contained in the Cuenca et al. (1992) report.

Table B1. Sampling Results for Klamath HUC8 1 from METRIC for 2013 and from WWCRA HUC 18010201/Weather Station OR1571-Chiloquin 1E

CDL No	Crop	COUNT	AREA_m2	METRIC ET mean, mm	METRIC ET Std.Dev., mm	METRIC ET Coef.Var.	WWCRA Crop No.	WWCRA Crop Name	WWCRA ET, mm	WWCRA NIWR, mm
21	Barley	486	437,400	592	71	0.121	11	Spring Grain - irrigated	779	407
23	Spring Wheat	789	710,100	666	91	0.136	11	Spring Grain - irrigated	779	407
24	Winter Wheat	21	18,900	630	56	0.089	13	Winter Grain - irrigated	911	543
27	Rye	29	26,100	491	119	0.243	11	Spring Grain - irrigated	779	407
28	Oats	22	19,800	669	31	0.046	11	Spring Grain - irrigated	779	407
36	Alfalfa	4,238	3,814,200	744	94	0.126	3	Alfalfa Hay - beef cattle style ~3 cuttings	905	515
37	Other Hay/Non Alfalfa	1,071	963,900	711	92	0.130	4	Grass Hay	903	622
43	Potatoes	42	37,800	959	52	0.054	30	Potatoes - cold pack (late harvest)	649	328
61	Fallow/Idle Cropland	246	221,400	493	321	0.652				
111	Open Water	84,811	76,329,900	609	141	0.231				
121	Developed/Open Space	7,610	6,849,000	557	207	0.372				
122	Developed/Low Intensity	4,289	3,860,100	439	141	0.322				
123	Developed/Med Intensity	186	167,400	389	163	0.419				
124	Developed/High Intensity	29	26,100	379	154	0.406				
131	Barren	20,448	18,403,200	259	144	0.556				
141	Deciduous Forest	4	3,600	297	207	0.696				
142	Evergreen Forest	2,805,121	2,524,608,900	514	108	0.210				
152	Shrubland	781,452	703,306,800	528	114	0.216				
176	Grassland/Pasture	138,731	124,857,900	418	191	0.457				
190	Woody Wetlands	958	862,200	536	139	0.258				
195	Herbaceous Wetlands	285,588	257,029,200	493	183	0.372				
205	Triticale	20	18,000	209	49	0.234				

Table B2. Sampling Results for Klamath HUC8 2 from METRIC for 2013 and from WWCRA HUC 18010202/Weather Station OR8007- Sprague R.2E

CDL No	Crop	COUNT	AREA_m2	METRIC ET mean, mm	METRIC ET Std.Dev., mm	METRIC ET Coef.Var.	WWCRA Crop No.	WWCRA Crop Name	WWCRA ET, mm	WWCRA NIWR, mm
21	Barley	45	40,500	358	110	0.308	11	Spring Grain - irrigated	757	488
23	Spring Wheat	20	18,000	377	153	0.405	11	Spring Grain - irrigated	757	488
24	Winter Wheat	24	21,600	615	135	0.219	13	Winter Grain - irrigated	879	563
27	Rye	151	135,900	547	143	0.261	11	Spring Grain - irrigated	757	488
28	Oats	93	83,700	440	54	0.122	11	Spring Grain - irrigated	757	488
36	Alfalfa	7,973	7,175,700	858	239	0.279	3	Alfalfa Hay - beef cattle style ~3 cuttings	888	600
37	Other Hay/Non Alfalfa	16,383	14,744,700	828	301	0.363	4	Grass Hay	910	684
43	Potatoes	33	29,700	583	186	0.319	30	Potatoes - cold pack (late harvest)	647	379
61	Fallow/Idle Cropland	126	113,400	339	149	0.440	47			
111	Open Water	5,722	5,149,800	1536	830	0.540	19			
121	Developed/Open Space	7,268	6,541,200	661	452	0.683	19			
122	Developed/Low Intensity	2,464	2,217,600	466	305	0.653	19			
123	Developed/Med Intensity	184	165,600	618	741	1.200				
124	Developed/High Intensity	5	4,500	451	135	0.300				
131	Barren	2,411	2,169,900	447	491	1.097				
142	Evergreen Forest	2,705,021	2,434,518,900	1004	873	0.870				
152	Shrubland	1,044,586	940,127,400	922	827	0.898				
176	Grassland/Pasture	687,241	618,516,900	682	693	1.016				
190	Woody Wetlands	1,674	1,506,600	773	540	0.699				
195	Herbaceous Wetlands	149,966	134,969,400	571	310	0.543				
205	Triticale	222	199,800	364	94	0.258	11	Spring Grain - irrigated	757	488
208	Garlic	31	27,900	353	30	0.086	43	Garlic		

Table B3. Sampling Results for Klamath HUC8 3 from METRIC for 2013 and from WWCRA HUC 18010203/Weather Station OR1574- Chiloquin 12NW

CDL No	Crop	COUNT	AREA_m2	METRIC ET mean, mm	METRIC ET Std.Dev., mm	METRIC ET Coef.Var.	WWCRA Crop No.	WWCRA Crop Name	WWCRA ET, mm	WWCRA NIWR, mm
21	Barley	7,419	6,677,100	790	84	0.106	11	Spring Grain - irrigated	775	363
23	Spring Wheat	12,309	11,078,100	778	94	0.120	11	Spring Grain - irrigated	775	363
24	Winter Wheat	5	4,500	851	21	0.024	13	Winter Grain - irrigated	898	509
27	Rye	9	8,100	675	159	0.236	11	Spring Grain - irrigated	775	363
28	Oats	51	45,900	954	14	0.015	11	Spring Grain - irrigated	775	363
36	Alfalfa	5,269	4,742,100	956	129	0.135	3	Alfalfa Hay - beef cattle style ~3 cuttings	927	531
37	Other Hay/Non Alfalfa	1,475	1,327,500	858	157	0.183	4	Grass Hay	927	650
43	Potatoes	7,690	6,921,000	817	94	0.114	30	Potatoes - cold pack (late harvest)	714	379
57	Herbs	1	900	636	0	0.000	21	Garden Vegetables - general	811	476
61	Fallow/Idle Cropland	693	623,700	915	135	0.147				
111	Open Water	325,173	292,655,700	888	74	0.084				
121	Developed/Open Space	12,449	11,204,100	711	191	0.268				
122	Developed/Low Intensity	8,316	7,484,400	555	167	0.301				
123	Developed/Med Intensity	2,041	1,836,900	428	175	0.408				
124	Developed/High Intensity	357	321,300	417	199	0.476				
131	Barren	14,103	12,692,700	329	143	0.434				
142	Evergreen Forest	1,219,109	1,097,198,100	548	128	0.234				
143	Mixed Forest	10	9,000	889	168	0.189				
152	Shrubland	130,386	117,347,400	593	187	0.316				
176	Grassland/Pasture	228,153	205,337,700	737	141	0.191				
190	Woody Wetlands	247	222,300	750	124	0.166				
195	Herbaceous Wetlands	105,768	95,191,200	784	114	0.146				
205	Triticale	2	1,800	256	21	0.080	11	Spring Grain - irrigated	775	363

Table B4. Sampling Results for Klamath HUC8 4 from METRIC for 2013 and from WWCRA HUC 18010204/Weather Station OR4511-Klamath Falls Ag. Sta.

CDL No	Crop	COUNT	AREA_m2	METRIC ET mean, mm	METRIC ET Std.Dev., mm	METRIC ET Coef.Var.	WWCRA Crop No.	WWCRA Crop Name	WWCRA ET, mm	WWCRA NIWR, mm
4	Sorghum	197	177,300	171	102	0.596	11	Spring Grain - irrigated	684	434
14	Mint	5	4,500	716	7	0.010	33	Mint	905	678
21	Barley	67,221	60,498,900	706	142	0.202	11	Spring Grain - irrigated	684	434
23	Spring Wheat	29,460	26,514,000	686	123	0.180	11	Spring Grain - irrigated	684	434
24	Winter Wheat	24,026	21,623,400	691	208	0.301	13	Winter Grain - irrigated	0	0
27	Rye	3,567	3,210,300	478	158	0.331	11	Spring Grain - irrigated	684	434
28	Oats	8,203	7,382,700	670	115	0.171	11	Spring Grain - irrigated	684	434
36	Alfalfa	270,142	243,127,800	904	150	0.166	3	Alfalfa Hay - beef cattle style ~3 cuttings	948	686
37	Other Hay/Non Alfalfa	202,946	182,651,400	840	158	0.188	4	Grass Hay	970	757
43	Potatoes	17,692	15,922,800	644	108	0.167	30	Potatoes - cold pack (late harvest)	703	474
49	Onions	408	367,200	645	122	0.189	23	Onions	700	464
57	Herbs	217	195,300	791	157	0.199	21	Garden Vegetables - general	822	596
61	Fallow/Idle Cropland	22,558	20,302,200	428	208	0.486				
111	Open Water	54,514	49,062,600	1152	595	0.516				
121	Developed/Open Space	50,345	45,310,500	634	221	0.349				
122	Developed/Low Intensity	42,349	38,114,100	498	176	0.353				
123	Developed/Med Intensity	10,647	9,582,300	388	165	0.426				
124	Developed/High Intensity	3,808	3,427,200	317	140	0.442				
131	Barren	3,519	3,167,100	589	409	0.694				
141	Deciduous Forest	43	38,700	411	188	0.458				

Table B4. Sampling Results for Klamath HUC8 4 from METRIC for 2013 and from WWCRA HUC 18010204/Weather Station OR4511-Klamath Falls Ag. Sta. (contd.)

CDL No	Crop	COUNT	AREA_m2	METRIC ET mean, mm	METRIC ET Std.Dev., mm	METRIC ET Coef.Var.	WWCRA Crop No.	WWCRA Crop Name	WWCRA ET, mm	WWCRA NIWR, mm
142	Evergreen Forest	1,279,191	1,151,271,900	922	909	0.986				
152	Shrubland	966,365	869,728,500	922	898	0.974				
176	Grassland/Pasture	674,803	607,322,700	964	913	0.948				
190	Woody Wetlands	138	124,200	1820	951	0.522				
195	Herbaceous Wetlands	16,927	15,234,300	1305	1021	0.782				
205	Triticale	3,534	3,180,600	480	208	0.433	11	Spring Grain - irrigated	684	434
208	Garlic	316	284,400	605	124	0.206	43	Garlic		
221	Strawberries	840	756,000	623	291	0.468	62	Strawberries	646	422

Table B5. Sampling Results for Klamath HUC8 5 from METRIC for 2013 and from WWCRA HUC 18010206/Weather Station CA5941- Mt. Hebron Ranger Sta

CDL No	Crop	COUNT	AREA_m2	METRIC ET mean, mm	METRIC ET Std.Dev., mm	METRIC ET Coef.Var.	WWCRA Crop No.	WWCRA Crop Name	WWCRA ET, mm	WWCRA NIWR, mm
43	Potatoes	2	1,800	665	31	0.047	30	Potatoes - cold pack (late harvest)	709	483
61	Fallow/Idle Cropland	4	3,600	283	40	0.142	47	Range Grasses - early	0	0
111	Open Water	12,234	11,010,600	837	117	0.140				
121	Developed/Open Space	1,923	1,730,700	578	200	0.346				
122	Developed/Low Intensity	1,883	1,694,700	397	212	0.533				
123	Developed/Med Intensity	219	197,100	294	189	0.644				
124	Developed/High Intensity	45	40,500	284	209	0.736				
131	Barren	645	580,500	478	188	0.394				
141	Deciduous Forest	1,082	973,800	769	154	0.201				
142	Evergreen Forest	1,175,791	1,058,211,900	557	158	0.284				
143	Mixed Forest	838	754,200	703	197	0.280				
152	Shrubland	409,915	368,923,500	595	164	0.276				
176	Grassland/Pasture	35,234	31,710,600	420	153	0.365				
190	Woody Wetlands	407	366,300	759	154	0.202				
195	Herbaceous Wetlands	3,199	2,879,100	559	99	0.177				

Table B6. Names and Identification Numbers of crops Contained in the WWCRA ETDemands Software (from J.Huntington, 2015, personal communication)

WWCRA CROP ID	WWCRA CROP_NAME
1	Alfalfa Hay - peak (no cutting effects (i.e.
2	Alfalfa Hay - frequent dairy style ~4 cuttings
3	Alfalfa Hay - beef cattle style ~3 cuttings
4	Grass Hay
5	Snap and Dry Beans - fresh
6	Snap and Dry Beans - seed
7	Field Corn (having moderate lengthened season)
8	Silage Corn (same as field corn
9	Sweet Corn - early plant
10	Sweet Corn - late plant
11	Spring Grain - irrigated
12	Spring Grain - rainfed
13	Winter Grain - irrigated
14	Winter Grain - rainfed
15	Grass Pasture - high management
16	Grass Pasture - low management
17	Grass - turf (lawns) - irrigated
18	Grass - turf (lawns) - rainfed
19	Orchards - apples and cherries w/ground cover
20	Orchards - apples and cherries no ground cover
21	Garden Vegetables - general
22	Carrots
23	Onions
24	Melons
25	Grapes - wine
26	Alfalfa Seed
27	Peas - fresh
28	Peas - seed
29	Potatoes - processing (early harvest)
30	Potatoes - cold pack (late harvest)
31	Sugar beets
32	Hops
33	Mint
34	Poplar (third year and older)
35	Lentils
36	Sunflower - irrigated
37	Sunflower - rainfed
38	Safflower - irrigated
39	Safflower - rainfed
40	Canola
41	Mustard
42	BlueGrass Seed

Table B6. Names and Identification Numbers of crops Contained in the WWCRA ETDemands Software (from J.Huntington, 2015, personal communication) (contd.)

WWCRA CROP ID	WWCRA CROP_NAME
43	Garlic
44	Bare soil
45	Mulched soil - including wheat stubble
46	Dormant turf (winter time)
47	Range Grasses - early
48	Range Grasses - long season (bunch
49	Range Grasses - bromegrass
50	Sage brush
51	Wetlands - large stands
52	Wetlands - narrow stands
53	Cottonwoods
54	Willows
55	Open water - shallow systems (large ponds
56	Open water - deep systems (lakes
57	Open water - small stock ponds
58	Cotton
59	Peppers
60	Sorghum
61	Olives
62	Strawberries
63	Blueberries
64	Raspberries
65	Rice
66	Soybeans
67	Peanuts
68	Millet
69	Tomatoes
70	Oranges
71	Lettuce - single Crop
72	Lettuce - first Planting
73	Lettuce - second Planting
74	Nuts
75	Cranberries
76	Sugarcane
77	Field Corn after another crop
78	Sorghum after another crop
79	Cotton after another crop
80	Cabbage
81	Sudan
82	Christmas Trees
83	Melons after another crop
84	Grain after another crop

Table B7. Names and Identification Numbers of Crops Contained in the Cuenca et al. (1992) Report

Cuenca No.	Cuenca Crop Name
1	Alfalfa Hay
2	Apples
3	Beans
4	Berries
5	Cherries
6	Corn(field)
7	Corn(silage)
8	Corn(sweet)
9	Filberts
10	Grain (Spring)
11	Grain (Winter)
12	Grapes
13	Grass seed
14	Grass Seed (Fall)
15	Grass Seed(Spring)
16	Mint
17	Onions
18	Pasture
19	Pears
20	Peas
21	Plums
22	Potatoes
23	Tomatoes

Attachment C. Documentation of ArcMAP useage during statistical summary of METRIC ET for year 2013 in the Klamath Basin.

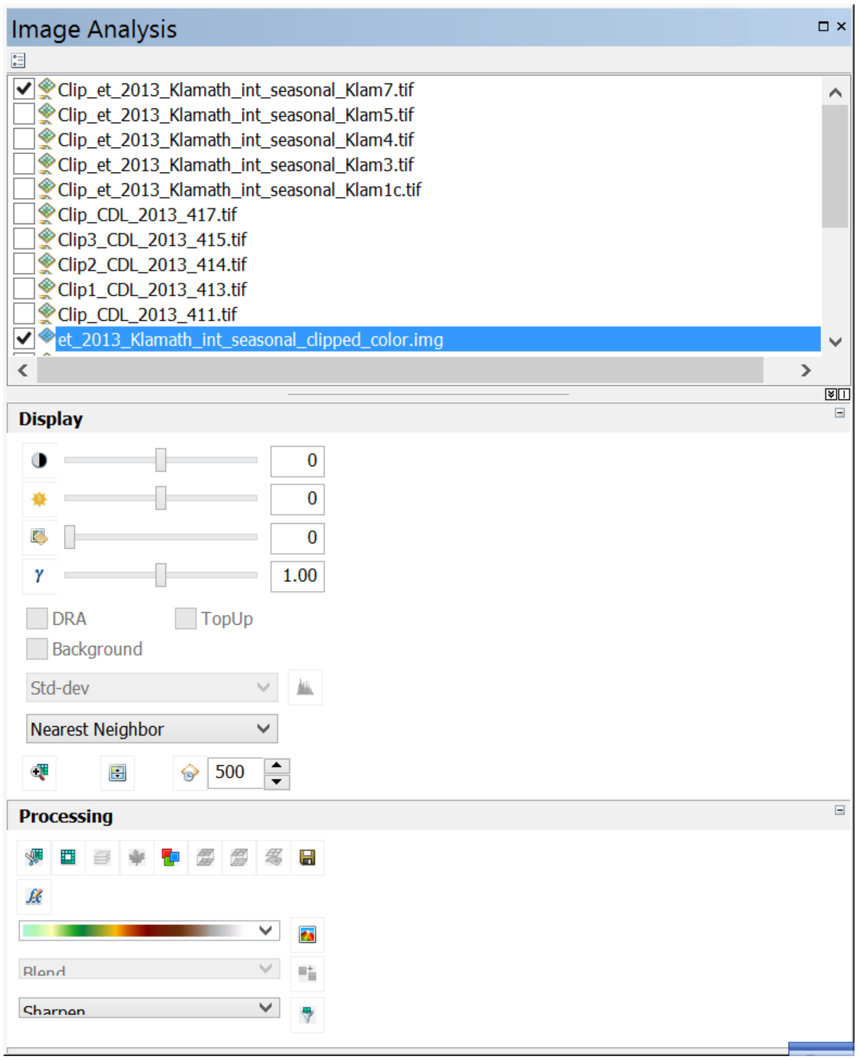


Figure C1. Image Analysis Tool Window of ArcMAP used to clip CDL and METRIC ET Images to HUC8 Domains

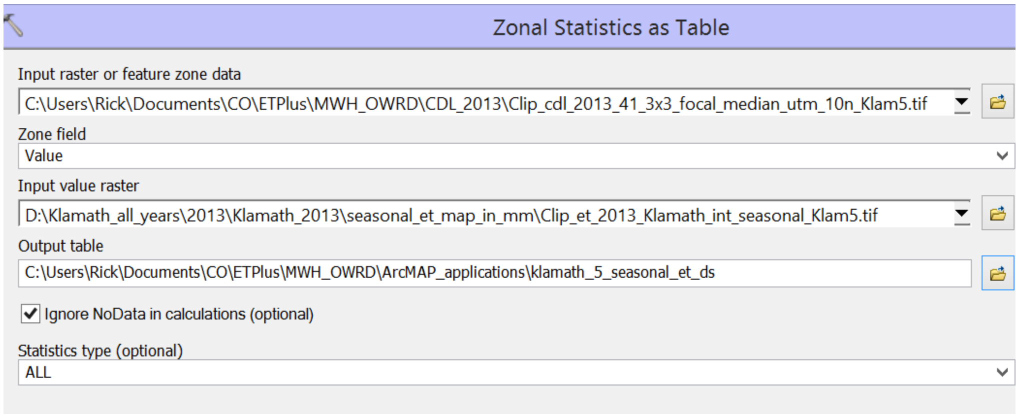
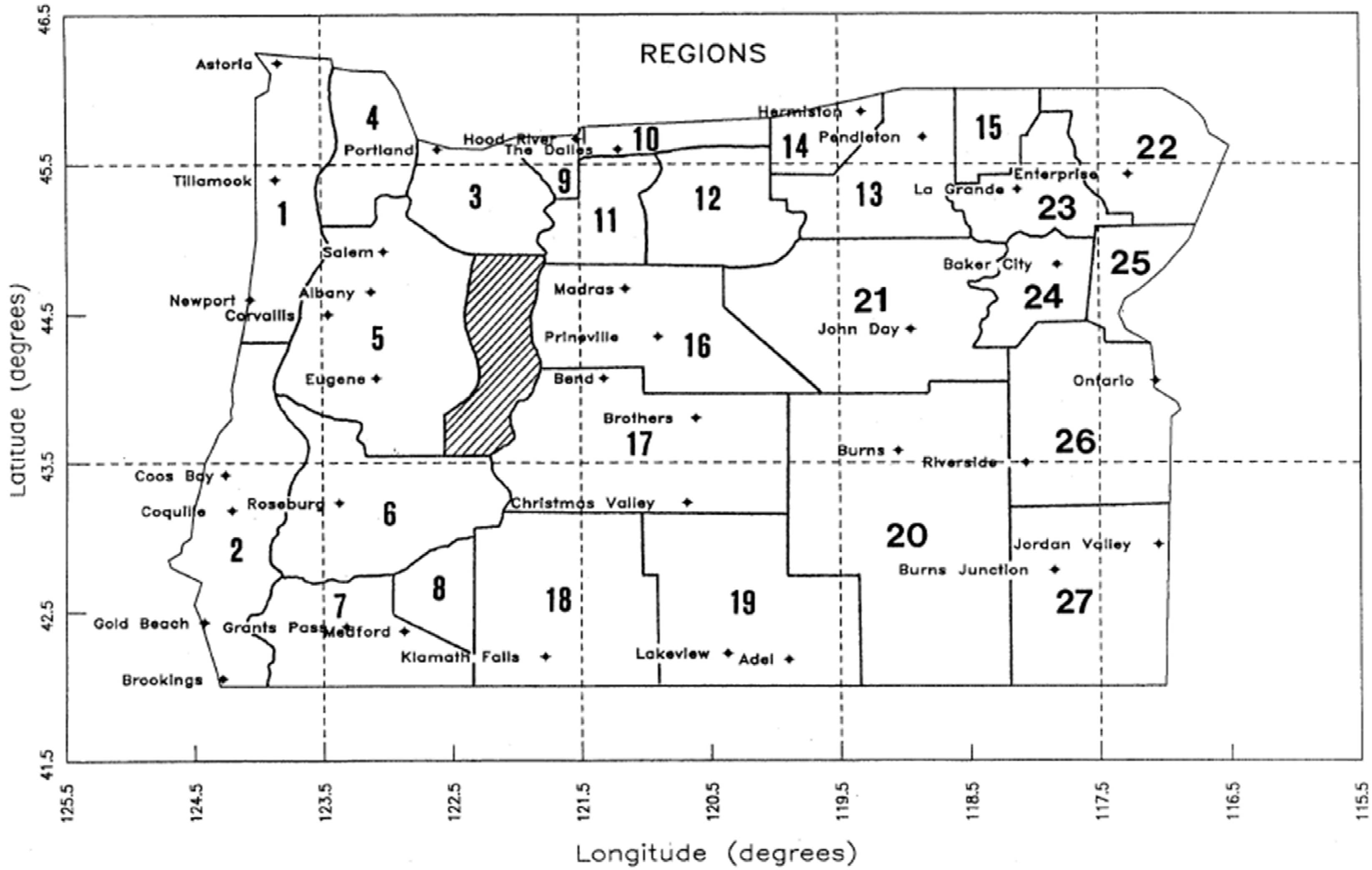


Figure C2. Data File and Image Entry Screen used in the ArcMAP Zonal Statistics as a Table Tool for Determining Statistics such as mean, Standard Deviation, and Range for Seasonal ET in a HUC8 Subbasin

Attachment D. Regions of Cuenca et al., (1992) (from the Cuenca et al., (1992) report.



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