Oregon
Statewide Long-Term Water Demand Forecast

Appendix E: Adjustments to Cuenca Irrigation Water Requirements to Reflect Climate Changes

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Projection of Future Evapotranspiration, Effective Precipitation and Net Irrigation Water Requirements for Six OWRD Administrative River Basin Regions of Oregon.

"West Wide Climate Risk Assessment" (WWCRA) (Huntington, et al., 2015) estimates of future evapotranspiration (ET), effective precipitation (Pe) and net irrigation water requirement (NIWR) under projected climate change scenarios were produced for the Columbia River and Klamath River basins of Oregon under this MWH study. The baseline period used in the WWCRA study is 1950–1999 and is based on the Maurer (2002) weather data time series bias corrected to NWS COOP weather stations. Three future periods were defined in the WWCRA computations as (1) 2010–2039; (2) 2040–2069; and (3) 2070–2099. These three future periods are labeled here as the 2020's, 2050's, and 2080's, respectively. Annual ET, Pe and NIWR were computed in the WWCRA computations for the baseline and 2020's, 2050's and 2080's periods.

The five climate change scenarios used in WWCRA are defined as:

- Warm Dry (S1) – climate change scenario is informed by projections that show precipitation change less than P50 and temperature change less than T50
- Warm Wet (S2) – climate change scenario is informed by projections that show precipitation change greater than or equal to P50 and temperature change less than T50
- Hot Dry (HD) – climate change scenario is informed by projections that show precipitation change less than P50 and temperature change greater than or equal to T50
- Hot Wet (HW) – climate change scenario is informed by projections that show precipitation change greater than or equal to P50 and temperature change greater than equal to T50
- Central Tendency (CT) – climate change scenario is informed by projections defined by the boundaries - (P75, T75); (P25, T75); (P25, T25); and (P75, T25).

Six major river basin regions besides the Columbia and Klamath River basins that are of administrative importance to OWRD are the following:

- Tilamook, Lincoln Counties – North Coast Region
- Coos, Curry Counties - South Coast Region
- Douglas County – Umqua Basin
- Jackson, Josephine Counties - Rogue River Basin
- Lake County - Goose, Summer Lakes Region
- Harney County - Harney Region

These six regions have estimates of ET, Pe and NIWR that are based on Cuenca (1992) and that represent long-term historical averages. These Cuenca (1992) values were brought up to both improved baseline estimates and to projected estimates based on WWCRA simulations in the Columbia and Klamath basins by 1) deriving ratios of WWCRA simulated values for ET, Pe and NIWR to those of Cuenca (1992) for Columbia and Klamath stations; 2) applying those 'adjustment' ratios to Cuenca (1992)

values in each of the six regions, based on associations of weather stations and crop types. Following the adjustment of Cuenca (1992) values, percent changes in ET, Pe and NIWR projected by WWCRA runs for the 2020's, 2050's and 2080's periods were applied. The WWCRA simulations of ET, Pe and NIWR are considered to be more complete and to have higher accuracy than the Cuenca (1992) estimates because they are based on the more modern dual crop coefficient method of FAO-56 (Allen et al., 1998), they utilize thermal-based methods to estimate times of planting or greenup and timing of crop development, and because they estimate ET, Pe and NIWR for the entire calendar year, as opposed to Cuenca (1992) that used mean crop coefficients, static estimates for planting and harvest, and estimated for the growing period only. The WWCRA simulations include evaporation occurring from precipitation events during nongrowing periods and effects of storage of winter precipitation and carry-over into the irrigation season.

Methodology for transforming Cuenca Evapotranspiration (ET) and Net Irrigation Water Requirement (NIWR) values in non-WWCRA units using WWCRA simulations from the Columbia and Klamath (WWCRA simulated) basins

ET estimates from Cuenca (1992) were transformed to a WWCRA basis as:

$$ET_{Cuenca\ adj\ Rx} = ET_{Cuenca\ Rx} \frac{ET_{WWCRA_{a.crop}}}{ET_{Cuenca\ Ry}} \quad (1)$$

where $ET_{Cuenca\ adj\ Rx}$ is adjusted Cuenca annual ET for a particular crop in region 'x', $ET_{Cuenca\ Rx}$ is original Cuenca annual ET for the particular crop region 'x', $ET_{WWCRA\ a.crop}$ is annual ET estimated by WWCRA for a crop that is associated with the Cuenca crop and for a selected station that is in region 'y', and $ET_{Cuenca\ Ry}$ is original Cuenca growing season ET for an associated crop in Region 'y' that contains the selected WWCRA station. The WWCRA station is selected based on its proximity to the Cuenca region x, the similarity of forecast future change in ET to other WWCRA stations in the same part of the state, and the similarity of the station location to the general Cuenca region x. In equation 1, region 'x' is one of the six non-WWCRA basins listed previously and region 'y' is a HUC8 unit within the Columbia or Klamath River basins as simulated by the WWCRA methodology.

The adjustment equation transforms the Cuenca ET for region x into an equivalent WWCRA ET according to ratios of WWCRA to Cuenca estimates in region y. This assumes that WWCRA estimates are more accurate than Cuenca estimates due to the use of the dual crop coefficient method by WWCRA, the dynamic timing of start and stops of growing season, and the use of more modern crop coefficient and reference ET methodology. The transformation also makes forecast ET under climate change scenarios equivalent to those made for the Columbia and Klamath basins where WWCRA was applied.

Effective Precipitation (Pe) from Cuenca is back-calculated by differencing Cuenca ET and Cuenca NIWR:

$$P_{e\ Cuenca} = ET_{Cuenca} - NIWR_{Cuenca} \quad (2)$$

The $P_{e\ Cuenca}$ was not transformed to the WWCRA station, since it is not based on an estimate, like ET, but is traceable to actual measurements. However, WWCRA estimates for Pe may differ from those of Cuenca (1992) since the WWCRA estimates include effects of discounting total precipitation for surface runoff, deep percolation from the effective rooting zone, and evaporation of precipitation from the soil surface, whereas Cuenca (1992) estimates for Pe were based on the USDA-SCS (1967) equation that has a generalized and empirical nature. Evaporation of precipitation from the soil surface prevents the

use of the precipitation for supporting transpiration requirements of a crop and thus the NIWR. If $P_{e\ Cuenca}$ is transformed, it can be done similar to ET:

$$P_{e\ Cuenca\ adj\ Rx} = P_{e\ Cuenca\ Rx} \frac{P_{e\ WWCRA_{a.crop}}}{P_{e\ Cuenca\ Ry}} \quad (3)$$

where $P_{e\ Cuenca\ adj\ Rx}$ is adjusted Cuenca annual P_e for Region 'x', $P_{e\ Cuenca\ Rx}$ is original Cuenca growing season P_e for Region 'x', $P_{e\ WWCRA\ a.crop}$ is annual P_e estimated by WWCRA for a crop that is associated with the Cuenca crop and for a selected station that is in Region 'y', and $P_{e\ Cuenca\ Ry}$ is original Cuenca growing season P_e for Region 'y' that contains the selected WWCRA station.

Because NIWR is the difference between two physical variables, ET and P_e, it is better to difference the adjusted values for ET and P_e rather than to ratio NIWR itself. Therefore, adjusted NIWR is calculated as:

$$NIWR_{Cuenca\ adj\ Rx} = ET_{Cuenca\ adj\ Rx} - P_{e\ Cuenca\ adj\ Rx} \quad (4)$$

The estimates for ET and NIWR under future climate scenario forecasts are made as:

$$ET_{Cuenca\ adj\ forecast\ Rx} = ET_{Cuenca\ adj\ Rx}\ \ PCET_{WWCRA_{a.crop}} \quad (5)$$

where $ET_{Cuenca\ adj\ forecast\ Rx}$ is forecast adjusted Cuenca annual ET for Region 'x' for a particular crop under a particular climate change scenario, and $PCET_{WWCRA\ forecast\ a.crop}$ is the percent change forecast for annual ET for the WWCRA station and crop associated with the Cuenca ET estimate. Forecast P_e is:

$$P_{e\ Cuenca\ adj\ forecast\ Rx} = P_{e\ Cuenca\ Rx}\ \ PCP_{WWCRA_{a.crop}} \quad (6)$$

where $P_{e\ Cuenca\ adj\ forecast\ Rx}$ is forecast adjusted Cuenca growing season P_e for Region 'x', and $PCP_{\ WWCRA\ a.crop}$ is forecast change in annual P_e estimated by WWCRA for a crop that is associated with the Cuenca crop and for a selected station that is in Region 'y'.

Associations between USDA crop statistics a Cuenca (1992) crops.

In the Cuenca (1992) and USDA summary spreadsheet produced by MWH (named cuencaTEMP), the primary crops in the six regions, according to significant acreage, are:

USDA Crop	Cuenca Association	Comments
Forage – land used for all hay and all haylage, grass silage, and greenchop (see text) (acres)	Alfalfa Hay	
Noncitrus, all	Orchards	Combine with Cuenca Orchard class
Pears, all	Orchards	Combine with other pears and orchard class
Pears, other than b]Bartlett	Orchards	Combine with other pears and orchard class
Grapes	Berries	
Cranberries	Pasture	
Corn for silage or greenchop (acres)	Corn silage or field corn when corn silage is not present	
Pears, Bartlett	Orchards	Combine with other pears and orchard class
Wheat for grain, all	Spring Grain	For Harney County

For the table above:

- Cranberries – can be associated with pasture or grass hay of Cuenca (1992), since Cuenca (1992) does not contain cranberries for the regions of interest. The cranberry and pasture cropping systems tend to have similar greenup and diedown times and have similar heights.
    - The Agrimet Kc curve for cranberries is about 0.15 higher than for pasture
    - The Agrimet Kc curve for cranberries is more similar to that for grass hay.
- Corn for silage or greenchop - associate with field corn. Often corn for silage is almost turning brown when harvested, to maximize the amount of grain on the stalk. Therefore, its seasonal ET is nearly as much as for field corn grown for grain. If there is no field corn, then associate with sweet corn since both have shorter growing seasons than field corn.
- Grapes – Associate with berries, and other wise with orchards. Grapes can have a range of row architecture and plant densities that influence water use. Vegetation densities for wine grapes may be lower than that for berries, although some berry crops can be planted with wide row spacing for ease of harvest.
- Other noncitrus fruit – can be associated with orchards of WCCRA and orchard types of Cuenca

- Pears, all – can be combined with the other Pears class. Can be associated with orchards of WCCRA and orchard types of Cuenca
- Noncitrus, all – probably refers to the USDA "Noncitrus Fruits and Nuts" category
    - This category can be combined with 'orchards' of WCCRA and the various orchard types of Cuenca that all contain the same values for ET and NIWR.

County areas / Cuenca Regions / WWCRA station Associations:

The WWCRA stations associated with nonWWCRA regions and with Cuenca (1992) regions were selected on the basis of:

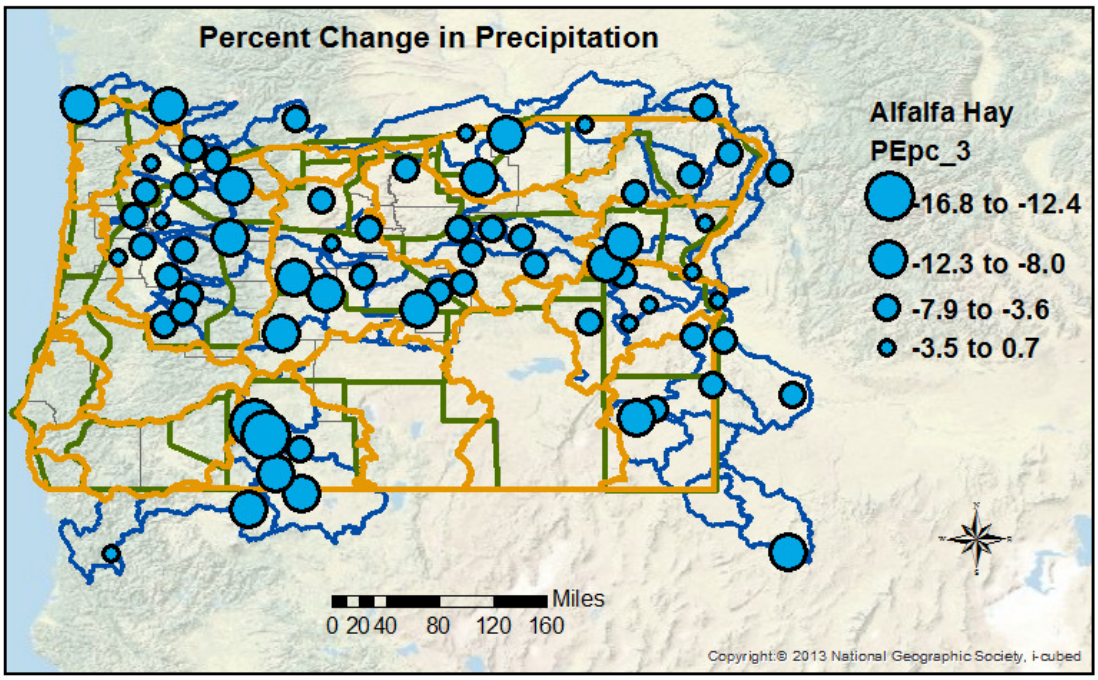
a. Having the crop needed

b. Having percentage changes in precipitation and ET that were

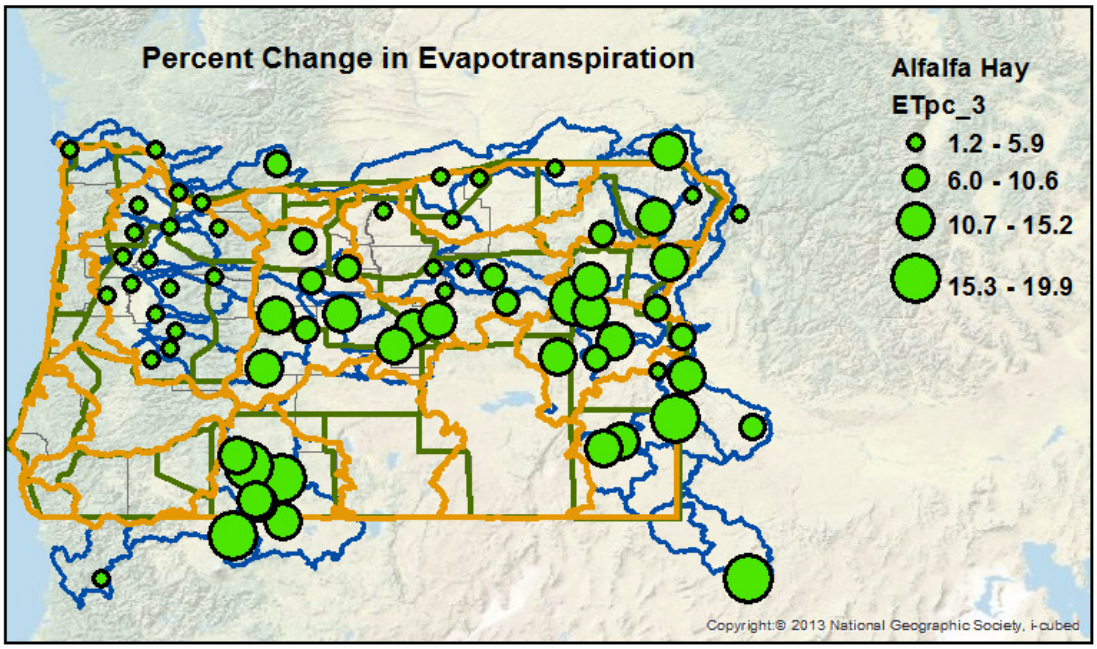
    a. Representative of other WWCRA stations in the region

    b. Have a climate that is expected to be closest to that of the OWRC Adm. Area

The selection of the representative WWCRA stations was guided using maps of percent change in ET, Pe and NIWR produced for the 2050's period and hotter, drier scenario in an ArcMAP database. WWCRA stations that followed guidelines in item b above were selected for association with non-WWCRA regions. An example of a map for alfalfa-hay is given below:



OWRD_admin_basins Cuenca_Regions HUC8_OR County boundary



Percent changes in annual ET shown in the above figure for alfalfa hay in the Willamette valley region were smaller than those for the rest of the Columbia basin and for the Klamath River basin. The reason for this is the impact of longer growing seasons projected for the rest of the Columbia and Klamath basins, relative to current growing season lengths. Relative increases in growing season lengths were less for the Willamette basin that already has relatively long growing seasons for alfalfa hay due to later freeze down and earlier green up for forage crops. In addition, winter precipitation in the Willamette basin

is higher than elsewhere in the Columbia basin, so that total annual ET did not change as much when evaporation from dormant alfalfa was, in essence, converted to ET when growing season length was extended under projected climate change. This was because nongrowing season evaporation amounts were already high.

The following six tables summarize the associations among regions and crops.

Tilamook, Lincoln counties – OWRD Mid Coast and North Coast regions / Cuenca Region 1 / Common WWCRA sta = OR2112 Dallas 2NE

Crop	Prominent Crop for OWRD region	Cuenca Region associated to OWRD region	Assoc. Crop in Cuenca	Assoc. Crop in WWCRA sta	Cuenca Region containing WCCRA station
Forage - land used for all hay and all haylage, grass silage, and greenchop (see text) (acres)	Yes	R1	Pasture (no alfalfa hay)	OR2112 Dallas 2NE – Pasture --Note: also used alfalfa as a second transformation to convert to alfalfa hay. Considered OR0328 Astoria Airport, but OR2112 used to be consistent with corn	R5
Corn for silage or greenchop (acres)	Yes	R1	Corn Silage	OR2112 Dallas 2NE – Field Corn	R5

Coos, Curry Counties – OWRD South Coast Region / Cuenca Region 2 / WCCRA station --- OR1862 Corvallis State Univ

Crop	Prominent Crop for OWRD region	Cuenca Region associated to OWRD region	Assoc. Crop in Cuenca	Assoc. Crop in WWCRA sta	Cuenca Region containing WCCRA station
Forage - land used for all hay and all haylage, grass silage, and greenchop (see text) (acres)	Yes	R2	Pasture (no alfalfa hay)	OR1862 Corvallis State Univ – Pasture --also used alfalfa in a second calculation to transform to alfalfa hay	R5
Cranberries	Yes	R2	Pasture	OR1862 Corvallis State Univ – Grass Pasture	R5
Corn for silage or greenchop (acres)					

Douglas – OWRD Umqua Region / Cuenca Region 6 / WCCRA station --- OR4506 - KLAMATH FALLS 2 SSW

Crop	Prominent for OWRD region	Cuenca Region associated to OWRD region	Assoc. Crop in Cuenca	Assoc. Crop in WWCRA sta	Cuenca Region containing WCCRA station
Forage - land used for all hay and all haylage, grass silage, and greenchop (see text) (acres)	Yes	R6	Alfalfa Hay	OR4506 - KLAMATH FALLS 2 SSW Alfalfa Hay	R8
Noncitrus, all	Yes	R6	Orchard (Cherries)	OR4506 - KLAMATH FALLS 2 SSW Blueberries	R8
Grapes	Yes	R6	No Berries – use Orchard (Cherries)	OR4506 - KLAMATH FALLS 2 SSW Blueberries	R8

Jackson, Josephine – OWRD Rogue River Region / Cuenca Region 7 / WCCRA station --- OR4506 - KLAMATH FALLS 2 SSW

Crop	Prominent for OWRD region	Cuenca Region associated to OWRD region	Assoc. Crop in Cuenca	Assoc. Crop in WWCRA sta	Cuenca Region containing WCCRA station
Forage - land used for all hay and all haylage, grass silage, and greenchop (see text) (acres)	Yes	R7	Alfalfa Hay	OR4506 - KLAMATH FALLS 2 SSW Alfalfa Hay	R8
Noncitrus, all	Yes	R7	Orchard (Cherries)	OR4506 - KLAMATH FALLS 2 SSW Blueberries	R8
Pears, all	Yes	R7	Orchard (Cherries)	“	R8
Pears, other than Bartlett	Yes	R7	Orchard (Cherries)	“	R8
Grapes	Yes	R7	Orchard (Cherries)	OR4506 - KLAMATH FALLS 2 SSW Blueberries	R8

Lake County – OWRD Goose and Summer Lakes Region / Cuenca Region 19 / WCCRA station --- OR8007 - SPRAGUE RIVER 2 SE

Crop	Prominent for OWRD region	Cuenca Region associated to OWRD region	Assoc. Crop in Cuenca	Assoc. Crop in WWCRA sta	Cuenca Region containing WCCRA station
Forage - land used for all hay and all haylage, grass silage, and greenchop (see text) (acres)	Yes	R19	Alfalfa Hay	OR8007 - SPRAGUE RIVER 2 SE Alfalfa Hay	R18

Harney County – OWRD Malheur Lake Region / Cuenca Region 20 / WCCRA station --- OR2415 DREWSEY

Crop	Prominent for OWRD region	Cuenca Region associated to OWRD region	Assoc. Crop in Cuenca	Assoc. Crop in WWCRA sta	Cuenca Region containing WCCRA station
Forage - land used for all hay and all haylage, grass silage, and greenchop (see text) (acres)	Yes	R20	Alfalfa Hay	OR2415 DREWSEY -Alfalfa Hay	R20
Wheat for grain, all	Yes	R20	Spring Wheat	OR4357 - JUNTURA 9 ENE – Spring Grain	R26

Application of Transformation Calculations and General Results

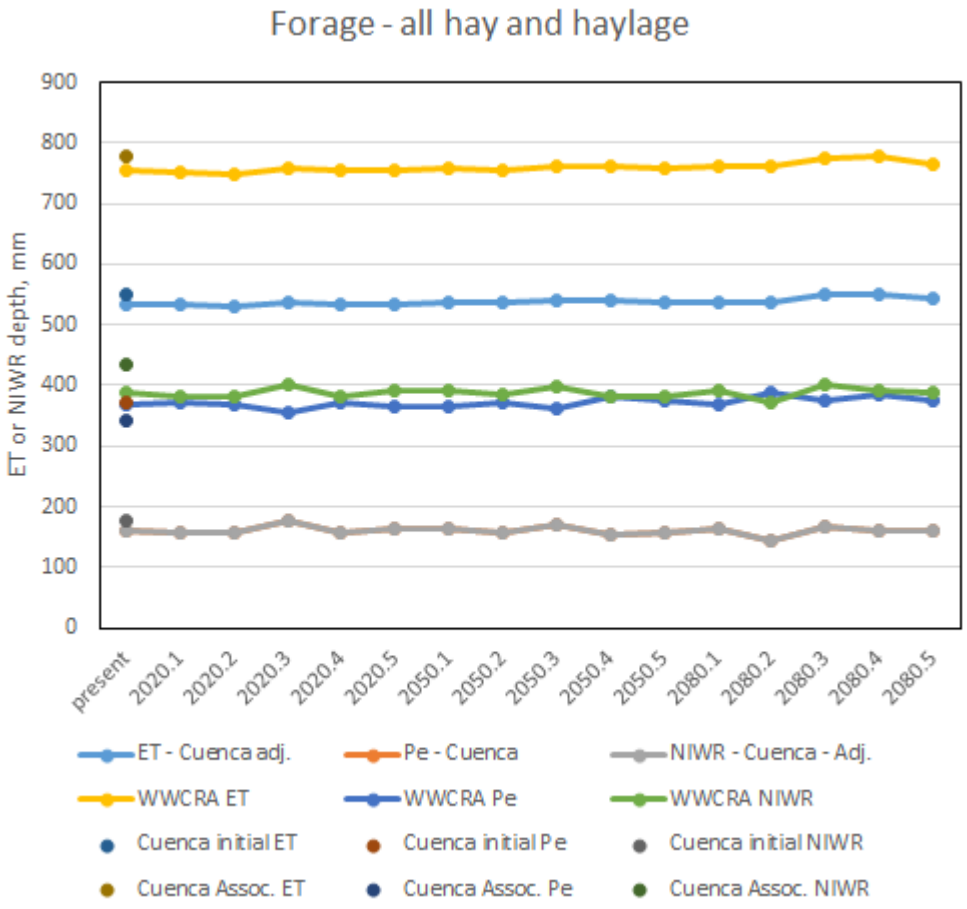
Equations 1, 2, 4, 5 and 6 were applied to the six non-WWCRA regions using associations listed in the previous tables. The spreadsheet named *ET_transformations8.xlsx* was created to make the calculations. All estimates are contained in the "Transformed_ET" sheet of the xlsx file. Sixteen entries were produced representing the three future 'dates' of 2020's, 2050's and 2080's interacted with the five climate change scenarios. A baseline entry, representing historical conditions for Cuenca (1992) and WWCRA runs was also produced. That entry was labeled 'present.' The ET_transformations8.xlsx spreadsheet file is self-contained in regard to input data, with member sheets containing WWCRA_stats_by_crop simulations by Huntington (2015), names and associated crop numbers for WWCRA crops, the Cuenca (1992) data for all regions of Oregon as produced by Charles Hillyard of Oregon State University (unpublished communication via R. Cuenca), and names and assigned crop numbers for Cuenca (1992) crops. The Cuenca (1992) dataset from Hillyard was corrected for misspelled or inconsistent crop names prior to its ingestion to the current study.

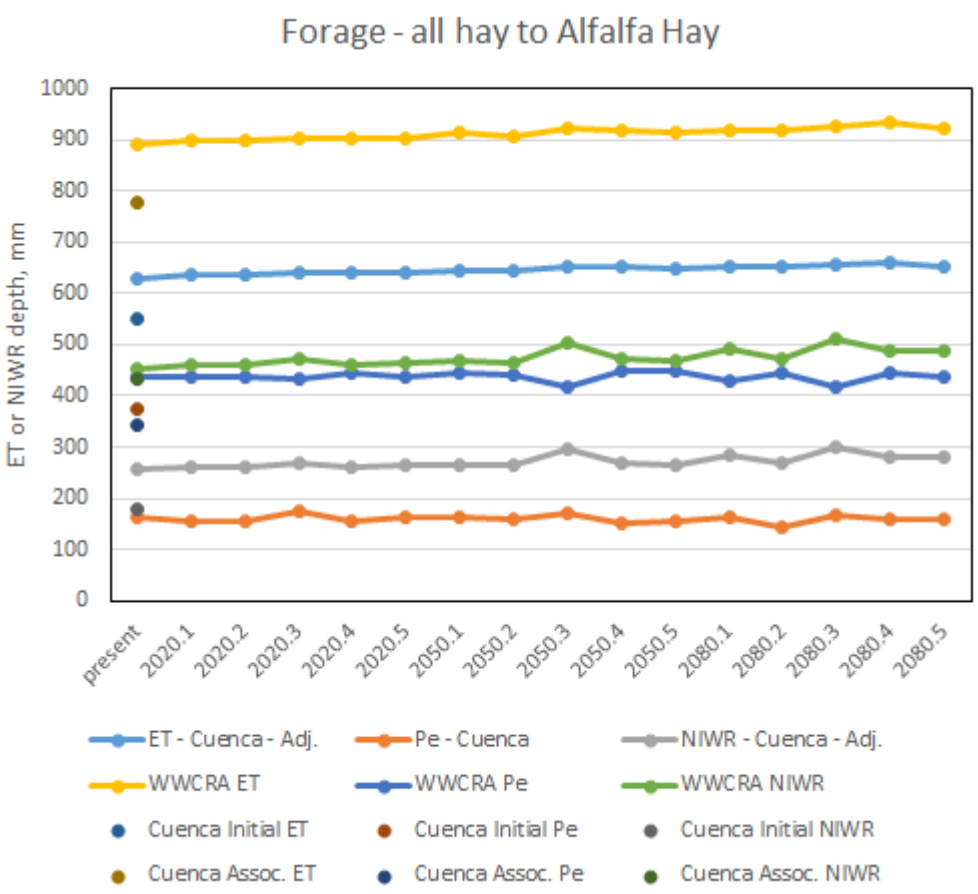
In general, Cuenca ET and NIWR estimates, following transformation to equivalent WWCRA estimates, increased, with the exception of the USDA forage – all hay category, which stayed relatively the same, or even decreased, when adjusted using pasture categories of Cuenca and WWCRA. However, when adjusted in a second set of adjustments using the pasture category, but the WWCRA category for alfalfa hay, the ET for the forage – all hay category increased. The other exception was the noncitrus and grape categories of USDA, which decreased by nearly 200 mm. Some of that decrease was due to the use of blueberries as the WWCRA proxy crop. However, the reductions are considered to be reasonable, especially for grapes grown for wine.

Projected change in crop NIWR for the six non-WWCRA regions varied substantially with climate change scenario, as expected, and had percent change values that are similar to those estimated by WWCRA simulations for the associated WWCRA crops. This outcome was also expected.

Example plots of expected change in ET, Pe and NIWR are shown in the following graphics for the Tilamook-Lincoln County – Central and North Coastal regions for the 'forage – all hay and haylage' USDA class, when transformed using the WWCRA grass pasture entry (first graph) and using the WWCRA alfalfa hay entry (second graph). The scenarios are numbered 1 – 5 for the three time periods. As indicated earlier, the use of the WWCRA alfalfa hay category caused the adjustment to Cuenca (1992)

ET and NIWR to increase due to the higher values for WWCRA alfalfa hay as compared to WWCRA pasture.




Forage - all hay to Alfalfa Hay
ET or NIWR depth, mm
1000
900
800
700
600
500
400
300
200
100
0
present
2020.1
2020.2
2020.3
2020.4
2020.5
2050.1
2050.2
2050.3
2050.4
2050.5
2080.1
2080.2
2080.3
2080.4
2080.5
ET - Cuenca - Adj.
Pe - Cuenca
NIWR - Cuenca - Adj.
WWCRA ET
WWCRA Pe
WWCRA NIWR
Cuenca Initial ET
Cuenca Initial Pe
Cuenca Initial NIWR
Cuenca Assoc. ET
Cuenca Assoc. Pe
Cuenca Assoc. NIWR