Appendix C

Modified Blaney-Criddle

August 13, 2021

Results memo for the Blaney-Criddle portion of the ET estimation methods comparison for the Phase III, Year 4 (2020) study.

The purpose of this memo is three-fold: 1) to explain the settings and parameters used in the estimation of Upper Colorado irrigated agricultural ET/consumptive use by the modified Blaney-Criddle method, 2) to outline methods used for input data preparation, primarily meteorological data, and 3) to briefly present a summary of the results found.

Blaney-Criddle method

The model used in this effort is the same that has been used by Reclamation since the early 2000's. It is based on the XCONS model originally written in Fortran and follows the modified Blaney-Criddle formulation as outlined in TR-21 (USDA, 1967). The original XCONS model, produced and used in Reclamation from the early 1980's, used text files to provide input data to and retrieve output data from the model. The formatting was specific and very difficult to produce and debug. As a result, the model was transformed in form, but not function, in the early 2000's. The system was rewritten in the VB.net environment. This allows input and output data to be read from and written to Excel® workbooks, eliminating the formatting difficulties of the previous version. Additionally, a comprehensive and logical graphical interface was developed and included in the software package (figure 1).

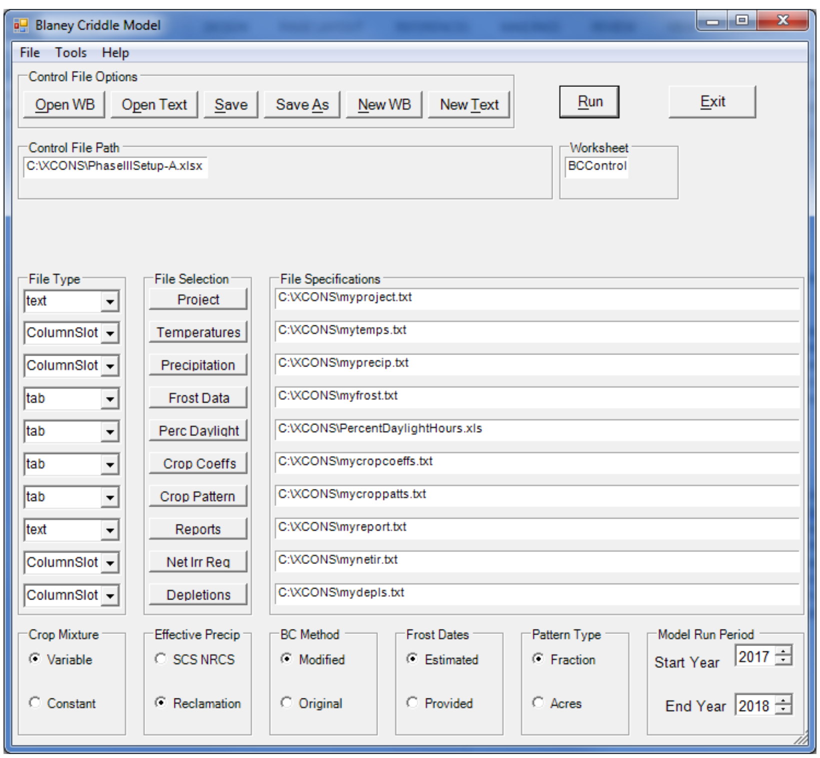

Figure 1: modified Blaney-Criddle graphical user interface

The interface allows the user to specify input data, model parameters and output variables. The model can be applied to any number of computational units, each of which can have unique meteorology and cropping information. The consumptive uses and losses work in the Upper Colorado River Basin historically has used county/HUC combinations as computational units. For this study, a gridded data set using the grid placement of the gridMET weather dataset was created for both cropping and meteorology. This will be discussed in greater detail in the next section. Specific constant inputs used in all XCONS model runs related to this study (as well as Upper Colorado Consumptive Uses and Losses calculations executed by the author) are listed below (table 1). More information on the Blanney-Criddle model used can be found in the Blanney-Criddle Users Manual (Reclamation, 2014).

Table 1: Blaney-Criddle model universal parameters

Parameter	Value	Description
Crop Mix	0	Variable crop mix (all cells have their own cropping)
Effective Precipitation	1	SCS method as outlined in TR-21
Blaney-Criddle method	1	Modified formulation
Frost Data Source	0	Estimated by the model from mean monthly temperatures
Cropping Pattern	1	Data provided in acres
Application Depth	3	3 inch depth of application[1]
Mean Elevation	0	This item indicates an early attempt to add an elevation adjustment. This feature has never been used because it is applied as a regional variable that cannot be varied by county/HUC8 or gridMET cell computation units.

The model can start and stop crop simulations based upon one of two available methods: temperatures or user provided dates. The temperature method is used for lands which receive a full water supply. The model starts and stops the calculation of plant water consumption when interpolated average monthly temperatures reach the specified start and stop values. Average monthly temperatures are linearly interpolated in time between the 15th of each month (the 14th for February) to determine the date at which consumptive use calculations begin and end. Table 2 lists the start and stop temperature values for the crops simulated in this study. No documentation has been found that specifies the source of these start and stop temperatures. If a full water supply is not available for the crops being modeled the user specifies dates at which irrigation is stopped. In this case, the model simulates plant growth and water consumption up to and including the identified date, then assumes zero plant water consumption for the remainder of the growing season. Shortage is estimated by subtracting consumptive use estimates calculated with specified water cutoff dates from those calculated assuming a full water supply. For this project, the percentage of irrigated lands subject to shortage and the stop dates for irrigation to those lands were estimated using the Indicator Gage Method described in the main body of the report and in Appendix E.

[1] Application Depth refers to an estimate of the average net irrigation application, which is used in the calculation of monthly effective precipitation (see equation below). In a monthly timestep, such as the Blanney-Criddle model, it is impossible to estimate the rate of individual precipitation events from a monthly total precipitation value. Additionally, the Blanney-Criddle model represented here is unaware of rooting depths, soil water condition and soil types. As such, it is advised in TR-21 that, unless specific local conditions are understood, an application depth value of 3 inches can be used to approximate effective precipitation.

Table 2: Cropping Start and Stop Temperatures

Crop	Temperature (°F).	
	Start	Stop
Alfalfa	50	32
Pasture	45	45
Orchard without Cover	50	45
Orchard with Cover	50	45
Barley	45	45
Grapes	50	50
Dry Beans	60	50
Spring Grain	45	45
Grain Corn	55	56
Sweet Corn	55	45
Silage Corn	55	56
Potatoes	55	45
Winter Wheat (Planting)	45	45
Winter Wheat (Harvest)	45	45
Sorghum	55	56
Strawberry	50	50
Turfgrass	55	45
Vegetable	55	45

The model calculates the actual ET based on the parameters outlined above and reports net values back to the user in the form of application (inches) and depletion (acre-feet).

Historically, Reclamation has run the modified Blaney Criddle model without an elevation adjustment, which increases crop ET by 10% for every 1000 meters of elevation above sea level. However, to facilitate comparison of results to those produced by the State of Colorado, Reclamation applied the elevation adjustment to its modified Blaney-Criddle results. Since the methods used to estimate an elevation adjustment in Reclamation's version of the model were not well understood, a manual method was developed. Because the elevation adjustment is applied to the potential ET of the crops before effective precipitation estimates are included, and because effective precipitation (the SCS method) is a function of ET, the model was run first assuming zero precipitation. This produced the potential ET values that were then used to calculate both the elevation adjustment and effective precipitation.

The elevation adjustment was applied by: 1) running the model with zero precipitation, 2) increasing calculated potential ET by 10% for each 1000 meters of elevation, and 3) calculating and applying effective precipitation estimates based on the SCS formula (presented below). This procedure generated elevation adjusted, modified Blaney-Criddle net ET estimates for the study.

The effective precipitation calculation is based on the formula presented in TR-21:

$$r_e = (0.70917\, {r_t}^{0.82416} - 0.11556)\,(10^{0.02426\, u})(f)$$

Where: r_e = Effective Rainfall

R_t = Mean Monthly Rainfall
u = Monthly Consumptive Use (ET)
f = Application Depth Factor, which is calculated as a function of application depth (D) as: $0.531747 + 0.295164*D - 0.057697*D^2 + 0.003804*D^{3.}$ Since the Application Depth used in this study is always 3 in, f=1.0.

Input Data

The data required to estimate ET using the modified Blaney-Criddle model are, as designed, relatively few: crop types and acreages, average monthly temperature and monthly precipitation. Since most meteorological data are collected on a daily (or more frequent) basis, monthly average temperature and monthly total precipitation data must be calculated. The Upper Colorado Consumptive Uses and Losses work traditionally performed by Reclamation relies on meteorological data provided by the National Weather Service COOP network of observations. These data are made available as easily downloadable monthly average temperature and total precipitation files. For this project however, GridMET temperature and precipitation data were used as inputs to the model.

GridMET temperature data are generated from North American Land Data Assimilation System Phase 2 (NLDAS-2, Mitchell et al., 2004) and Parameter-elevation Regression on Independent Slopes Model (PRISM, Daly et al., 2008) data. GridMET defines the daily maximum and minimum temperatures as the daily maximum or minimum temperature from NLDAS-2 (TX_N) plus the difference between the monthly average maximum or minimum temperature from PRISM (TX_P) and the monthly average maximum or minimum temperature from NLDAS-2(TX_N). GridMET precipitation data are derived by combining the temporally rich data from NLDAS-2, with spatially rich data from PRISM. See Abatzoglou, 2013 for a complete description of the GridMET dataset. Although the possibility existed to use precipitation, maximum air temperature (Tx), and minimum air temperature (Tn) measured at agricultural weather stations across the UCRB to bias-correct the GridMET data, the Remote Sensing Team concluded that it was best to use the uncorrected GridMET data (aggregated to monthly values) as input to the model that was applied basin-wide. This was because the physical settings of the weather stations used to generate the GridMET temperature dataset (e.g., airports, other non-agricultural land) were thought to be more similar to those used to develop the modified Blaney-Criddle model than the agricultural settings in which the agricultural weather stations were located. Also, the Remote Sensing Team thought that bias-correcting a gridded precipitation dataset with locally-measured values would reduce rather than improve accuracy, due to the patchy rainfall patterns that result from the convective precipitation that is common across the UCRB during the growing season.

Results

Results were calculated for the entire UCRB using inputs derived from GridMET data. To estimate shortage, the model was executed twice: the first using estimates of cut off dates for selected crops, and the second assuming all crops had full water supplies. ET estimates were generated using both the traditional (non-elevation adjusted) and elevation adjusted models. The results of each evaluation are presented below.

Full Basin Gridded Evaluation

The entire upper Colorado River Basin was divided into a 4km grid with cropping and meteorological data provided for each cell. The modified Blaney-Criddle model was applied to only the 3,621 cells where irrigated agriculture was present in 2020. A total of elevation adjusted net irrigation water requirement (NIWR) for the entire basin is estimated to be 3,403,289 acre-feet, with a shortage of 459,551 acre-feet. Non-elevation adjusted NIWR is 2,818,594 acre-feet with a shortage of 380,926 acre-feet.

Four grid cells near Eddy Covariance Towers

The GridMET grid cell IDs and crop type(s) that best represent the irrigated area around the four eddy covariance towers are: 387089 (Bloomfield, New Mexico; Alfalfa and Pasture), 467476 (Palisade, Colorado; Orchard with and without Cover), 511799 (Vernal, Utah; Alfalfa) and 581084 (Big Piney, Wyoming; Pasture). The weather data used in the simulation was the same used for these individual cells in the calculation of ET estimates of the entire basin. Results for these areas is summarized in tables 3 & 4 below (all units in inches).

Table 3: Eddy Covariance Station NIWR using Blaney-Criddle Method Adjusted for Elevation								
	Alfalfa		Pasture		Orchard with Cover		Orchard w/o Cover	
Station	Use	Shortage	Use	Shortage	Use	Shortage	Use	Shortage
Bloomfield, NM	44.6	0	37.5	0	0	0	0	0
Palisade, CO	0	0	0	0	34.0	0	46.0	0
Vernal, UT	35.6	5.2	0	0	0	0	0	0
Big Piney, WY	0	0	17.5	3.7	0	0	0	0

Table 4: Eddy Covariance Station NIWR using Blaney-Criddle Method Un-Adjusted for Elevation								
	Alfalfa		Pasture		Orchard with Cover		Orchard w/o Cover	
Station	Use	Shortage	Use	Shortage	Use	Shortage	Use	Shortage
Bloomfield, NM	37.9	0	31.8	0	0	0	0	0
Palisade, CO	0	0	0	0	29.5	0	40.0	0
Vernal, UT	30.3	4.5	0	0	0	0	0	0
Big Piney, WY	0	0	14.3	3.0	0	0	0	0

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