DRAFT Design Document: Estimating non-growing season ET

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Design document description and purpose

The U.S. Geological Survey (USGS), in collaboration with the Idaho Department of Water Resources (IDWR) is constructing a numerical groundwater-flow model of the Wood River Valley aquifer system in order to simulate potential anthropogenic and climatic effects on groundwater and surface-water resources. This model will serve as a tool for water-rights administration and water-resource management and planning. The study will be conducted over a 3-year period from late 2012 until model and report completion in 2015. One of the goals of the modeling study is to develop the model in an open and transparent manner. To this end, a Modeling Technical Advisory Committee (MTAC) was formed to provide for transparency in model development and to serve as a vehicle for stakeholder input. Technical representation was solicited by the IDWR and includes such interested parties as water-user groups and current USGS cooperating organizations in the Wood River Valley.

The design, construction, and calibration of a groundwater-flow model requires a number of decisions such as the number of layers, model cell size, or methodologies used to represent processes such as evapotranspiration or pumpage. While these decisions will be documented in a final USGS report, intermediate decision documents will be prepared in order to facilitate technical discussion and ease preparation of the report. These decision documents should be considered preliminary status reports and not final products.

Problem statement

Winter-time evapotranspiration (ET) is one component of discharge from the Wood River Valley aquifer system. Winter-time ET is only 8% of irrigation-season ET; however, it is an important factor in calculating winter-time recharge, recharge during spring melt, and the annual water budget. Winter-time ET estimates are needed for the calibration period (1995-2010) and for the entire model domain.

Although some transpiration occurs during the winter, most of the winter-time ablation of water is due to evaporation and sublimation (Wright, 1993). Winter-time evaporation varies widely based on moisture availability, frozen soil, snow cover, the presence and volume of dead and dormant vegetation, and the amount of available energy (Allen and Robison, 2007). Few studies have been conducted that measure and document winter-time ET, and none are known of within the Wood River Valley model domain.

Options considered

The options considered for estimating precipitation are:

1) Apply an average monthly ET based on experimental data from Kimberly, Idaho, as was done in the Enhanced Snake Plain Aquifer Model versions 1.1 and 2.1 (ESPAM models).
2) Use the Allen and Robison method of calculating ET as tabulated in ET Idaho (ET Idaho, 2013).

Average monthly experimental data

Data are available from an experiment conducted in Kimberly, ID from 1985-1991 in which weighing lysimeters were used to measure the rate of winter-time ET (Wright, 1991; Wright, 1993). These data were collected using two lysimeters; one with a grass cover for the entire study period, and the other with cover that followed the cropping sequence of the area and was fallow for most of the winter-month study period. The two lysimeters were used in an attempt to compare different land cover conditions. This study developed average monthly ET rates for October, November, December, January, February, and March.

These data were used for the ESPAM models by assuming that the average ET rates determined from the experiment were applicable to most of the Eastern Snake Plain model domain during the months of November – January. The average February ET was adjusted for elevation to simulate snow cover that may differ from Kimberly. However, the scaling method relied on assumed winter-time ET rates at Twin Falls and Rexburg (Contor, 2004)

Issues

The experimental data as used in the ESPAM models were averaged over the study period, which included a combination of variable land covers over variable weather regimes. While the data may lack a bias in regards to the type of land cover and weather conditions, the data only represent the average condition, and winter-time ET is thus represented as a constant rate for the same month each year. Furthermore, it is difficult to separate the effects of land cover from climate, which makes scaling the values to match weather conditions in the Wood River Valley unworkable.

Effect

Applying the Kimberly experimental ET data to the model domain would result in constant average ET rates every winter. Furthermore, the data were developed outside of the model area at an elevation that is approximately 900 feet lower than the Picabo AgriMet weather station, which would necessitate scaling the values to the elevation range of the model domain.

The Allen and Robison method

The Allen and Robison method of calculating ET uses the ASCE standardized Penman-Monteith equation to calculate reference ET in combination with a method for calculating dual crop coefficients. Irrigation-season reference ET (ETr) represents the ET from a theoretical, standardized reference crop (fully watered, full cover, perfectly managed alfalfa crop), and incorporates net radiation, soil heat flux, air temperature, wind speed, and vapor pressure (Allen and Robison, 2007).

The crop coefficient (Kc) is the ratio of actual ET to the ETr for a specific crop or land cover. The Allen and Robison method computes a dual set of Kc values. The first coefficient is the basal Kc (Kcb) which, during the irrigation season, incorporates the non-weather factors of crop height, crop-soil resistance, and surface reflectance that cause actual ET to vary from ETr. The second coefficient is the evaporative Kc (Kce), which considers evaporation due to wetting by actual precipitation and estimated irrigation. The Kcb and Kce are added together to obtain the general Kc value. Once ETr and Kc have been developed, and the land cover has been identified, ET is calculated by Equation 1.

$$ET = Kc \times ETr \qquad \text{Equation 1}$$

Where:

ET = evapotranspiration [ft]

Kc = the crop coefficient [unitless]

ETr = the reference ET from the Picabo AgriMet weather station [ft]

Allen and Robison have performed these calculations and tabulated the ET values for various AgiMet and National Weather Service (NWS) weather stations and vegetation types on the ET Idaho website (USBR, 2013; NOAA, 2013; ET Idaho, 2013). If done correctly, the method can estimate irrigation-season ET within ±10-15% of true ET (Allen, 2013); however, land-cover distribution must be known in order to use this method. Unreliable land-cover data make this method difficult to employ during the irrigation season because for a given date, ET at any location is greatly dependent upon the type of vegetation. Despite unreliable ET estimates during the irrigation season, the Allen and Robison method can provide robust estimates of ET during the winter.

The Allen and Robison method provides better ET estimates for winter months because the majority of ET occurs as evaporation (and sublimation) during the winter (Wright, 1993). Since only minor transpiration takes place, the type of vegetated land cover is much less relevant, and the amount of mulch (dead or dormant vegetation) provides the vegetative control of ET. Lands with full or partial mulch cover will experience less ET than bare soil due to the higher albedo and insulating properties of the mulch (Allen and Robison, 2007). This makes crop mix identification is less crucial because many vegetation types have similar winter vegetative-cover percentages. Additionally, less energy is available to support evaporation, resulting in much less winter-time evaporation. Because winter-time ET rates are small, and differences in winter-time ET rates between land-cover types are also small, mistakes in land-cover identification do not represent as significant an error as during the irrigation season (Table 1).

Table 1. Average monthly ET (mm/day) at Picabo, as calculated by the Allen and Robison method.

Land Cover	Nov	Dec	Jan	Feb	Mar	Jul
100% impervious	0.00	0.00	0.00	0.00	0.00	0.00
Grass turf (lawns) - Irrigated	0.21	0.11	0.14	0.23	0.45	6.36
Alfalfa - Less Frequent Cuttings	0.47	0.29	0.36	0.58	0.88	5.44
Bare Soil	0.40	0.28	0.36	0.57	0.81	0.21
Cottonwoods	0.32	0.20	0.25	0.39	0.71	6.56
Grass Pasture - High management	0.21	0.11	0.14	0.23	0.45	6.58
Mulched Soil, incl grain stubble	0.30	0.20	0.25	0.39	0.67	0.22
Open Water - Shallow systems	0.68	0.29	0.34	0.63	1.32	4.60
Range Grass - Early short season	0.30	0.20	0.25	0.39	0.70	0.31
Sage Brush	0.30	0.20	0.25	0.39	0.70	1.10
Spring Grain - Irrigated	0.30	0.20	0.25	0.39	0.69	7.84
Sweet Corn - Late Plant	0.42	0.29	0.36	0.58	0.88	3.80
Wetlands - Narrow stands	0.32	0.20	0.25	0.39	0.71	9.70
Willows	0.33	0.20	0.25	0.39	0.72	5.82
Winter Grain	0.44	0.28	0.35	0.57	1.07	0.74
Range (not including impervious)	0.47	0.18	0.22	0.4	0.87	9.49

During the irrigation season, the terms in Equation 1 represent vegetative growth; ETr represents weather-based influences on a hypothetical alfalfa crop, Kcb incorporates the factors that adjust ETr for non-alfalfa crops, and Ke incorporates evaporation according to precipitation and estimated irrigation. During the winter months, the terms in Equation 1 represent evaporation and sublimation. ETr still incorporates net radiation, soil heat flux, air temperature, wind speed, and vapor pressure; however, it is reparameterized to represent snow cover instead of alfalfa. Kcb is set to an arbitrarily low value during the winter, and Ke incorporates the evaporative influences of mulch cover. The low Kcb value allows the total Kc to be controlled by evaporation according to mulch cover and precipitation events (Allen and Robison, 2007). Therefore, the Allen and Robison method calculates actual ET for winter months by employing a reference ET for a snow covered surface, which primarily represents ablation due to temperature and wind, and is adjusted by the amount of snow cover, mulch cover, and precipitation.

Because winter-time ET is relatively insensitive to the vegetation type, GIS crop data have been used to define the land cover (Table 2). This assumes that the crop data give reasonable representations of mulch cover despite inaccuracies in vegetation type. GIS data sources include the National Land Cover Database (MRLC, 2013) and the Cropland Data Layer (NASS, 2013).

Table 2. Land cover data source for each year in the calibration period.

Year	Land Cover Source	Year	Land Cover Source
1995	2001 nlcd[1]	2003	2005 cdl[2]
1996	2001 nlcd	2004	2005 cdl
1997	2001 nlcd	2005	2005 cdl
1998	2001 nlcd	2006	2006 nlcd
1999	2001 nlcd	2007	2007 cdl
2001	2001 nlcd	2008	2008 cdl
2001	2001 nlcd	2009	2009 cdl
2002	2001 nlcd	2010	2010 cdl

[1] National Land Cover Database
[2] Cropland Data Layer

Issues

Data are available at the Picabo weather station for the entire calibration period; however, data are not available for the Hailey and Ketchum stations during the calibration period. Although weather data are available at Hailey for the years 2005-2010, ET Idaho does not have ET data at Hailey available for these years. Because winter-time ET is largely a function of temperature and snow cover, values tabulated in ET Idaho for Picabo are not directly applicable to the Hailey and Ketchum precipitation zones. Therefore, different methods for estimating winter-time ET are needed to generate values at both Hailey and Ketchum.

Process

To develop winter-time ET data at Hailey, correlations have been made between the long-term, average monthly ET at Hailey (1894-1988) and Picabo (1994-2011), expressed as ratios of Picabo monthly ET (Table 3). The ratios are then multiplied by monthly ET values at Picabo to generate monthly winter-time ET at Hailey.

Table 3. Ratios of Hailey to Picabo monthly crop ET (mm/day) as calculated by the Allen and Robison method. Ratios based on average Hailey (1894-1988) and average Picabo (1994-2011) monthly ET rates.

Difference Hailey/Picabo	Nov	Dec	Jan	Feb	Mar
Grass turf (lawns) - Irrigated	0.95	1.09	1.00	0.91	0.71
Alfalfa - Less Frequent Cuttings	1.02	0.97	0.97	0.90	0.78
Bare Soil	1.03	0.93	1.00	0.91	0.77
Cottonwoods	1.03	1.00	0.92	0.92	0.73
Grass Pasture - High management	0.95	1.09	1.00	0.91	0.71
Mulched Soil, including grain stubble	1.00	0.90	0.96	0.92	0.72
Open Water - Shallow systems	0.99	1.14	1.24	1.11	0.94
Range Grass - Early short season	1.10	1.05	0.92	0.92	0.74
Sage Brush	1.03	1.00	0.92	0.92	0.71
Spring Grain - Irrigated	1.03	1.00	0.92	0.92	0.72
Sweet Corn - Late Plant	1.05	1.00	0.94	0.88	0.77
Wetlands - Narrow stands	1.03	1.00	0.96	0.90	0.73
Willows	1.06	1.00	0.92	0.92	0.72
Winter Grain	1.02	0.93	1.00	0.91	0.72

The Allen and Robison method has not been applied to Ketchum weather station data, and another method of estimating ET for Ketchum is required. Although the conditions are not identical, the Mackay, ID NWS weather station has Allen and Robison ET data tabulated in ET Idaho. Because the Mackay weather station is at a similar elevation (5,910 feet) as the Ketchum weather station (5,890 feet), and both sites are located in south-central Idaho mountain valleys, Mackay is used as a proxy for Ketchum. Therefore, winter-time ET data from Mackay have been substituted for ET at Ketchum.

Effect

The Allen and Robison method is undesirable for estimating irrigation-season ET; however, many of the issues that make it undesirable are absent during the winter. Therefore, the Allen and Robison method likely results in the best estimates of winter-time ET. There are few studies quantifying winter-time ET, and none are known to have been conducted within the model area. Furthermore, the only known study of winter-time ET conducted in southern Idaho (Kimberly, ID) has been incorporated into the method (Allen and Robison, 2007).

ET Idaho data are not available for the Hailey and Ketchum sites during the calibration period. However, winter-time ET rates are low, and errors associated with estimates of winter-time ET are small in terms of the overall water budget. Therefore, the use of a correlation between Hailey and Picabo, and the use of Mackay as a proxy for Ketchum, likely result in reasonable estimates of winter-time ET at Hailey and Ketchum. Figure 1 illustrates winter-time ET in comparison to irrigation-season ET.

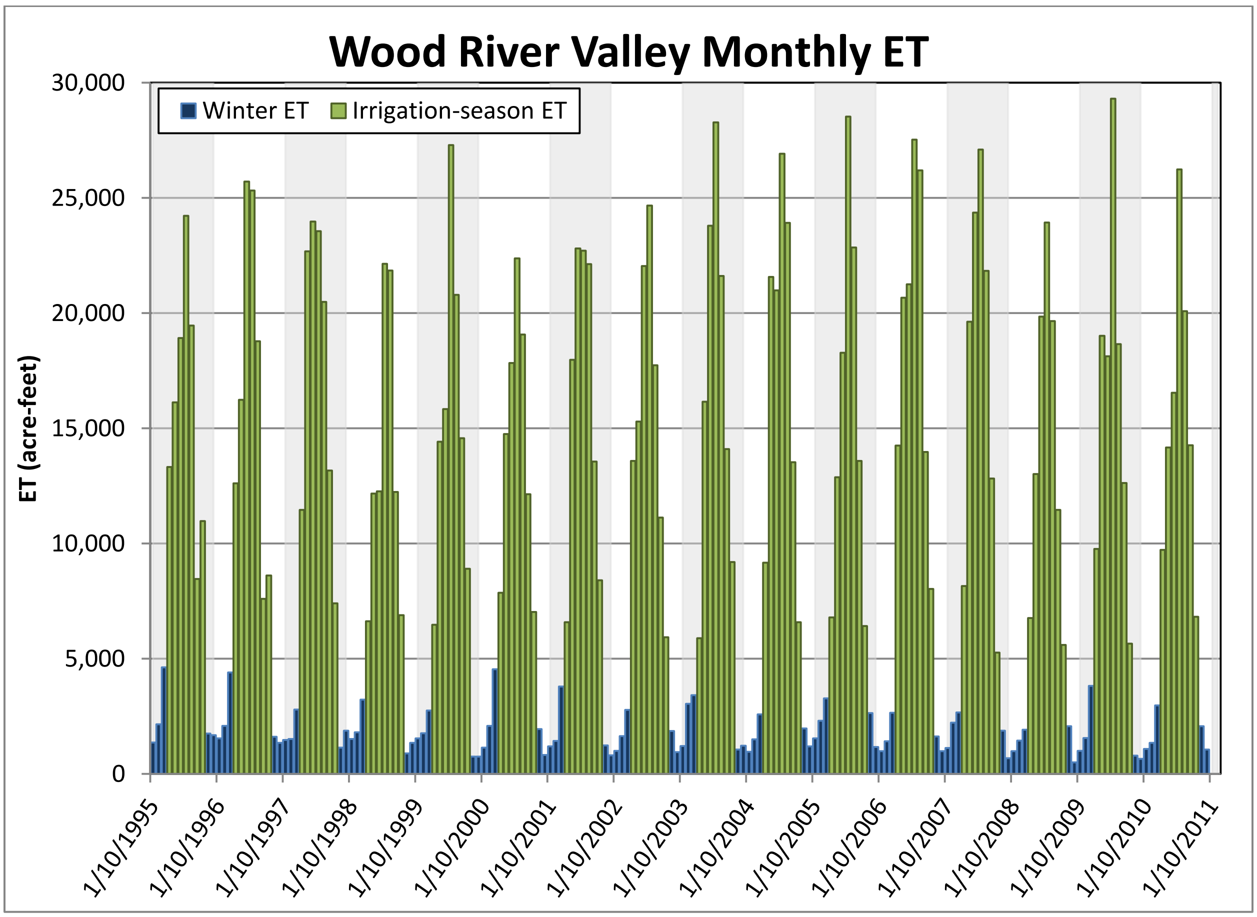

Figure 1. Monthly ET estimates for the Wood River Valley. Winter-time ET (blue) is approximately 8% of irrigation-season (green) ET, on average.

Design decision

The recommended design decision is use the Allen and Robison method to estimate winter-time ET, as tabulated in ET Idaho, for Picabo. The values tabulated in ET Idaho are likely the best values of winter-time ET available. ET Idaho data are not available for Hailey or Ketchum during the calibration period. Therefore, it is recommended to use a correlation between Hailey and Picabo to generate ET estimates at Hailey, and to use Mackay estimates of winter-time ET as a proxy for Ketchum.

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