TRADITIONAL EVAPOTRANSPIRATION CALCULATIONS

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Eastern Snake Plain Aquifer Model Enhancement Project Scenario
Document DWS-010Final As-built

DESIGN DOCUMENT OVERVIEW

Design documents are a series of technical papers addressing specific design topics on the Eastern Snake Plain Aquifer Model Enhancement Project. Each design document will contain the following information: topic of the design document, how that topic fits into the whole project, which design alternatives were considered and which design alternative is proposed. In draft form, design documents are used to present proposed designs to reviewers. Reviewers are encouraged to submit suggested alternatives and comments to the design document. Reviewers include all members of the Eastern Snake Hydrologic Modeling (ESHM) Committee as well as selected experts outside of the committee. The design document author will consider all suggestions from reviewers, update the draft design document, and submit the design document to the Eastern Snake Plain Model Enhancement Project Model Upgrade Program Manager. The Program Manager will make a final decision regarding the technical design of the described component. The author will modify the design document and publish the document in its final form in .pdf format on the ESPAM web site.

The goal of a draft design document is to allow all of the technical groups which are interested in the design of the ESPAM Enhancement to voice opinions on the upgrade design. The final design document serves the purpose of documenting the final design decision. Once the final design document has been published for a specific topic, that topic will no longer be open for reviewer comment. Many of the topics addressed in design documents are subjective in nature. It is acknowledged that some design decisions will be controversial. The goal of the Program Manager and the modeling team is to deliver a well-documented, defensible model which is as technically representative of the physical system as possible, given the practical constraints of time, funding and manpower. Through the mechanism of design documents, complicated design decisions will be finalized and documented. Final model documentation will include all of the design documents, edited to ensure that the “as-built” condition is appropriately represented. This is the final as-built document for traditional evapotranspiration (ET) calculation.

INTRODUCTION

Calculation of net recharge from surface-water irrigation and calculation of net discharge from ground-water irrigation require estimates of crop evapotranspiration (ET). The details of the calculations proposed for the Eastern Snake Plain Aquifer Model Enhancement Project are discussed in Design Document DDW-002. The calculations involve diversion volumes that are large relative to the overall aquifer water budget. The proposed calculations are:

$$\text{Field Delivery} = \text{Diversions} - \text{Canal Leakage} - \text{Return Flows} \quad (1)$$

Net Recharge (surface)=
(Field Delivery + Precipitation) - (ET x Adjustment Factor) (2)

The calculation for net recharge from ground-water irrigation (typically a negative recharge, or net withdrawal) is:

Net Recharge (ground) = Precipitation - (ET x Adjustment Factor) (3)

These are commonly used and accepted methods (Burt 1999) and are the methods used by the US Geological Survey (Garabedian 1992) and Idaho Department of Water Resources (1997) in former Snake Plain modeling efforts. The ET adjustment factor is an innovation added in this effort to accommodate differences between potential and actual crop conditions. ET adjustment factors are discussed in Design Document DDW-021. Calculation of recharge on irrigated lands will include a consideration of antecedent soil moisture and available irrigation diversions, to allow reduction of ET when water supplies are reduced. This helps avoid under-predicting recharge on surface-water irrigated lands, and avoids over-predicting extraction on ground-water irrigated lands. This paper describes the data sources and methods proposed for determining the basic ET rate for these calculations.

Evapotranspiration is controlled by climate as well as crop and soil characteristics. Climate affects the evaporative power of the atmosphere, reflecting the capacity of air to accept evapotranspired water and the energy available to drive evapotranspiration. Soil and plant characteristics control the crop's ability to extract water from the soil, and biological characteristics of the crop that control the transpiration response to evaporative power. Soil texture, surface wetness and condition and shading by crop plants control the soil’s evaporation response to evaporative power.

DATA SOURCES

Typical evapotranspiration calculations reflect the evaporative power of the atmosphere as reference evapotranspiration, abbreviated as ETr or ETo.[1] Published formulas and procedures allow calculation of reference ET from weather data (Allen et al 1998) and calculated reference ET values are available from various sources. The crop evapotranspiration is calculated by multiplying reference ET by a crop coefficient, which incorporates the soil and crop characteristics that govern ET response to evaporative power. Crop coefficients may be calculated theoretically or determined empirically. Calculated ET values for various crops may also be found in published sources, and evapotranspiration may also be estimated using remote sensing techniques (Morse et al 2000).

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[1] ETr refers to a reference based on a hypothetical pristine alfalfa crop, while ETo refers to a referenced based on a hypothetical grass crop.

The option of calculating ET from weather-station and crop data was rejected because published values are available and recalculation represents a significant investment of effort. Available published data include Consumptive Irrigation Requirements for Crops in Idaho (Sutter and Corey 1970), Estimating Consumptive Irrigation Requirements for Crops In Idaho (Allen and Brockway 1983), Agrimet on-line electronic data (US BOR 2003), and a draft revision of Estimating Consumptive Irrigation Requirements for Crops In Idaho (Allen 2002). The Sutter and Corey source provides average crop ET values by area, and the Allen and Brockway source provides average crop ET as well as average reference ET by area. The revised data from Allen include individual ETr estimates for each date for the period of record for each NOAA weather station (typically starting before 1930) through year 2000. The Agrimet data include individual daily ETr and crop ET values from the startup of each Agrimet station (typically 1987 to 1993) through the present. The available SEBAL remote-sensing ET estimates (Allen et al 2002) are presented as a GIS raster map of ET rates that covers the year-2000 irrigation season.

Because of annual variability in climatic factors, neither of the average-value sources of data nor the single-year SEBAL estimates were selected. The revised Estimating Consumptive Irrigation Requirements for Crops In Idaho (Allen 2002) estimates were selected over Agrimet estimates because data are available through nearly all of the calibration period. Though not used to directly estimate ET, SEBAL data will be used in calculation of ET adjustment factors, as described in Design Document DDW-021. This allows knowledge gained from the SEBAL evaluation to improve ET calculations for the entire period.

CALCULATIONS

The selected data series is a series of reference ET values for each NOAA weather station. Five different calculation methods were used and data are reported for each. The Kimberly-Penman Alfalfa Reference method was chosen as most suitable for the modeling application (Allen 2003). This method was developed with Idaho empirical data and of the five methods is the most directly comparable to the original Estimating Consumptive Irrigation Requirements for Crops In Idaho data and to Agrimet estimates.

The selected data series provides only reference ET, but calculation of crop ET also requires crop coefficients (Kc values). Coefficients for individual crops were extracted from the original Estimating Consumptive Irrigation Requirements for Crops In Idaho data by dividing individual crop ET by reference ET, for each weather station each month. The original data only include typically grown crops for each location. To avoid calculating zero ET if an unusual crop is grown, Kc values for all crops were assigned to all weather stations. Missing values were supplied from nearby stations. The spatial variation of Kc is low (Allen 2003) and this substitution affects only the Kc value. Because the data include values for all typically grown crops, missing values represent rarely-grown crops. Therefore, this substitution will affect only a few acres within any stress period and has a very low potential of introducing error. The Kc used for each county is weighted by the crop percentage for each stress period. Crop data for weighting are described in Design Document DDW-001. For each county, the Kc values that were weighted came from the NOAA station selected as the “nearest neighbor” by a GIS analysis.

The Kimberly-Penman Reference Alfalfa equation requires numerous climatic data. For the calculation of the revised series, many of these data were estimated or interpolated (Allen 2003). A comparable calculation for crop year 2001 would require generating comparable estimates for all these data. The Hargreaves equation (University of Idaho 1999) requires only temperature data from the weather station, and Hargreaves estimates are one of the five data series included in the revised data. Hargreaves estimates were calculated for year 2001 using Agrimet temperature data (US BOR 2003) and calculation procedures from University of Idaho (1999). The calculated Hargreaves reference ET values were scaled to be comparable to Kimberly-Penman Alfalfa reference ET by regression equations developed for NOAA stations near to the Agrimet stations of interest. Figure 1 shows the relationship between Hargreaves and Kimberly-Penman Alfalfa reference ET for 1980 through 2000, and Figure 2 shows the relationship between the calculated Hargreaves ET and the predicted Kimberly-Penman ET for 2001. Regression parameters are listed in Table 1. The slight differences between parameters from station to station are reflected in the scatter of data in Figure 2. Figure 2 represents monthly, rather than daily, calculations. The gaps in the Figure 2 series appear to be periods of rapid transition in the spring and fall, when daily values would range between the calculation values representing average monthly conditions.

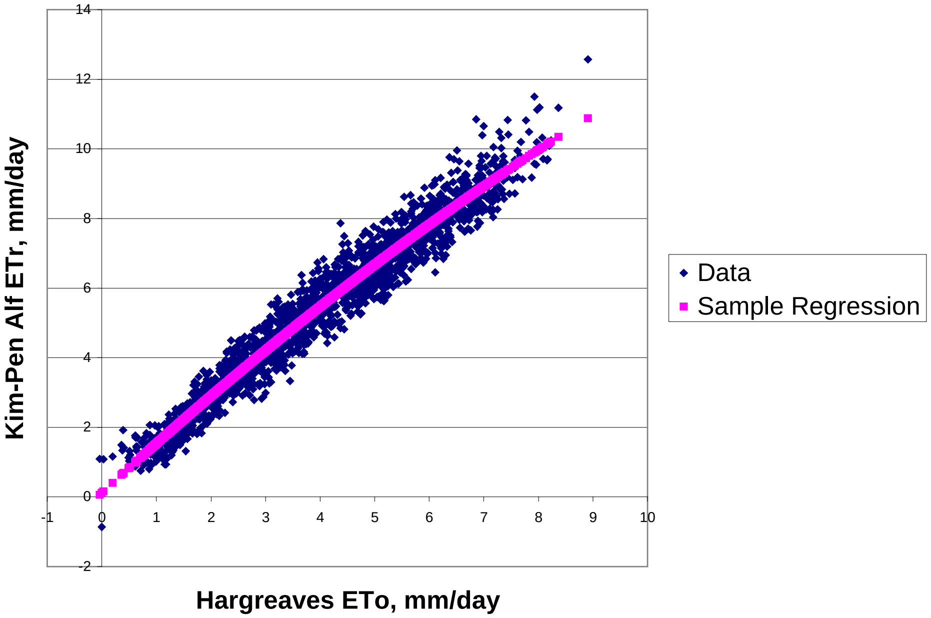

Figure 1. Kimberly-Penman and Hargreaves Reference ET, 1980-2000

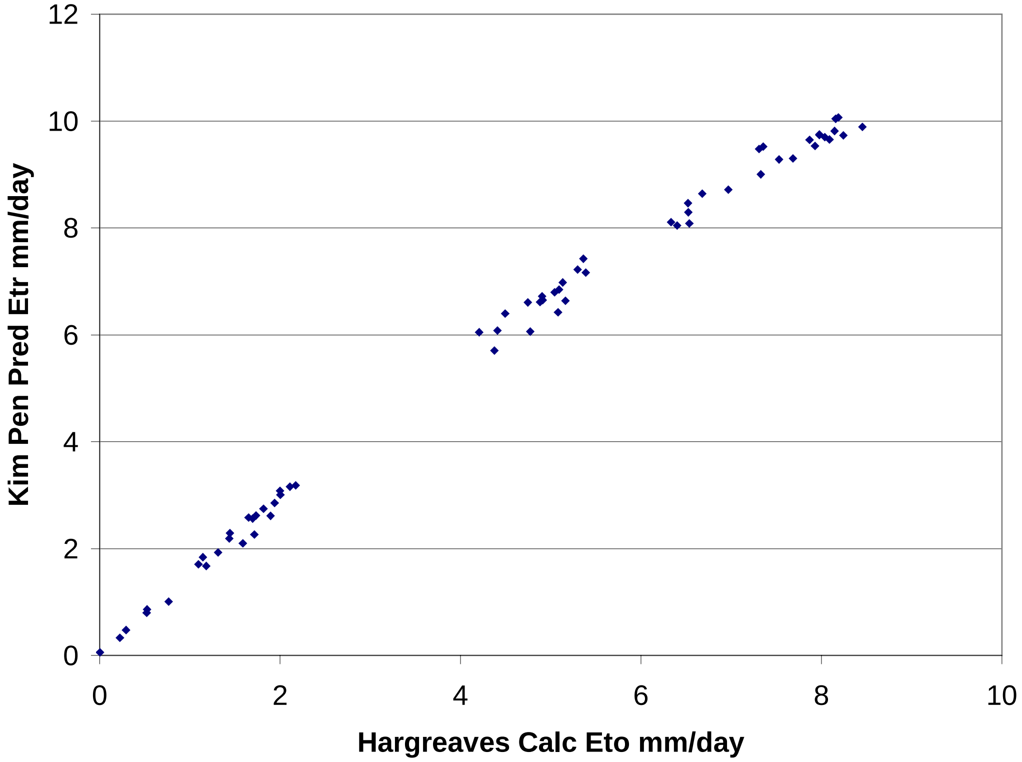

Figure 2. Calculated Hargreaves and Predicted Kimberly-Penman Reference ET, 2001.

Table 1

Prediction Parameters
for Estimation of Kimberly-Penman Alfalfa Reference ET
from Hargreaves Grass Reference ET

Kimberly-Penman = B0 + B1 x Hargreaves + B2 x Hargreaves^2 (4)

Agrimet Station	**NOAA Station used for Regression**	**B0**	**B1**	**B2**	**Adjusted R^2**
ABEI	Aberdeen 100010	0.0173	1.6364	-0.0524	0.97
AHTI	Ashton 100470	0.0495	1.6097	-0.0438	0.96
FTHI	IdFalls 104456	-0.0326	1.6203	-0.0529	0.96
KTBI	IdFalls 104456	-0.0326	1.6203	-0.0529	0.96
MNTI	Hamer 103964	0.0777	1.3766	-0.0206	0.96
PICI	Picabo 107040	-0.0302	1.3720	-0.0201	0.97
RPTI	Burley 101303	0.0316	1.5707	-0.0421	0.96
TWFI	Twin Falls 109294	-0.1375	1.6444	-0.0536	0.96

WINTER-TIME EVAPOTRANSPIRATION

Though crops do not actively transpire in the winter time, evaporation does continue. The calculation of (reference ET x Kc) is problematic because the winter-time reference ET values are theoretical values not completely applicable to colder months (Allen 2003) and winter-time Kc values are not available. Instead, winter-time ET will be based on experimental data collected over several years at Kimberly, Idaho (Wright 1993). The average winter ET from the study is reported in Table 2:

Table 2
Six-year Average ET
Lysimeter 2
Kimberly, Idaho

Month	**Average ET, mm/day**	**Average ET, ft/month**
November	0.7	0.069
December	0.4	0.041
January	0.6	0.061
February	1.0	0.093

Except for February, these values should generally be representative of the entire study area. The February value is representative of the lower-elevation portions of the study area, but February ET for higher elevation areas that are still snow covered in February is probably closer to the January average from Kimberly (Wright 2003). Snow increases the reflection of solar radiation back into the atmosphere, reducing the energy available to drive evaporation or sublimation. To adjust for differences in snow cover, February ET was scaled by elevation. February ET at Twin Falls (3770 feet) was set to 1.0 mm/day, and at Rexburg (4920 feet) to 0.6 mm/day. ET at other locations was adjusted linearly from these points according to the equation:

$$\text{ET (mm/day)} = -0.0003478 \times \text{Elevation (feet)} + 2.3112 \qquad (5)$$

For stations higher in elevation than Rexburg, December and January ET were adjusted to be no higher than the elevation-adjusted February value. November ET was adjusted to be no higher than 120% of the adjusted February value. Table 3 lists the resulting winter-time ET values for all stations, converted to feet per month:

Table 3
Calculated Winter-Time ET Rates, Feet Per Month

Station	County	ID	Elev (Ft)	Nov ET	Dec ET	Jan ET	Feb ET
Aberdeen Exp	Bingham	100010	4400	0.069	0.041	0.061	0.072
American Falls 3 NW	Power	100227	4320	0.069	0.041	0.061	0.075
Arco 3 SW	Butte	100375	5330	0.050	0.041	0.042	0.042
Ashton	Fremont	100470	5110	0.059	0.041	0.049	0.049
Blackfoot Fire Dept	Bingham	100915	4320	0.069	0.041	0.061	0.075
Bliss	Gooding	101002	3270	0.069	0.041	0.061	0.109
Burley FAA AP	Cassia	101303	4160	0.069	0.041	0.061	0.080
Dubois Exp	Clark	102707	5460	0.046	0.038	0.038	0.038
Fort Hall Indian Age	Bingham	103297	4500	0.069	0.041	0.061	0.069
Hamer 4 NW	Jefferson	103964	4800	0.069	0.041	0.060	0.060
Hazelton	Jerome	104140	3770	0.069	0.041	0.061	0.093
IF 16 SE	Bonneville	104456	5720	0.036	0.030	0.030	0.030
IF FAA AP	Bonneville	104457	4740	0.069	0.041	0.061	0.061
Jerome	Jerome	104670	3770	0.069	0.041	0.061	0.093
MacKay Ranger St	Custer	105462	5910	0.029	0.024	0.024	0.024
Minidoka Dam	Minidoka	105980	4210	0.069	0.041	0.061	0.079
Paul	Minidoka	106877	4150	0.069	0.041	0.061	0.080
Picabo	Blaine	107040	4880	0.068	0.041	0.057	0.057
Poc WB AP	Bannock	107211	4770	0.069	0.041	0.060	0.060
Richfield	Lincoln	107673	4310	0.069	0.041	0.061	0.075
Shoshone	Lincoln	108380	3970	0.069	0.041	0.061	0.086
St Anthony	Fremont	108022	4970	0.065	0.041	0.054	0.054

APPLICATION TO RECHARGE CALCULATIONS

In the GIS recharge tool, the base ET for an irrigated parcel will be multiplied by an ET adjustment factor associated with the irrigation entity and application method. The base summertime ET for the parcel is calculated as:

ET = Reference ET x
(sum over all crops of (crop fraction x crop Kc)) (6)

To calculate values for all irrigated parcels within a particular stress period, the calculation is performed using GIS. For each stress period, the reference ET values for the weather stations are interpolated to a GIS raster (grid) data set using the inverse distance weighting option of the Interpolate Grid function of ArcView 3.2. The county weighted-average Kc (crop coefficient) values for each month are also are converted to raster format, which allows raster multiplication of the reference ET and the crop coefficient. The product of this raster calculation is a raster map that covers the entire study area and shows the ET rate that applies to irrigated lands for the month.

The winter-time ET values listed in Table 3 are average values that reflect typical moisture regimes at Kimberly, Idaho. Actual winter-time ET, however, cannot exceed the moisture physically available. In this study, winter-time ET was limited to the lesser of the estimates in Table 3 or the sum of winter precipitation and an estimate of 0.083 feet (one inch) of available soil moisture that also may contribute to ET (Allen 2003, Allen et all 1998). This analysis was performed in GIS by interpolating the values of Table 3 to a raster, then summarizing the average raster value within four-mile by four-mile zones. The average precipitation[2] by stress period is also summarized by zone, and within each zone the calculation in equation seven is applied to determine ET for the zone.

ET = The lesser of (Table 3 ET) and (Precipitation + 0.083 ft) (7)

Finally, a winter-time ET raster is generated from the zone values. Figure 3 illustrates the ET raster for the winter of 1980-81:

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[2] Precipitation data are described in Design Document DDW-011

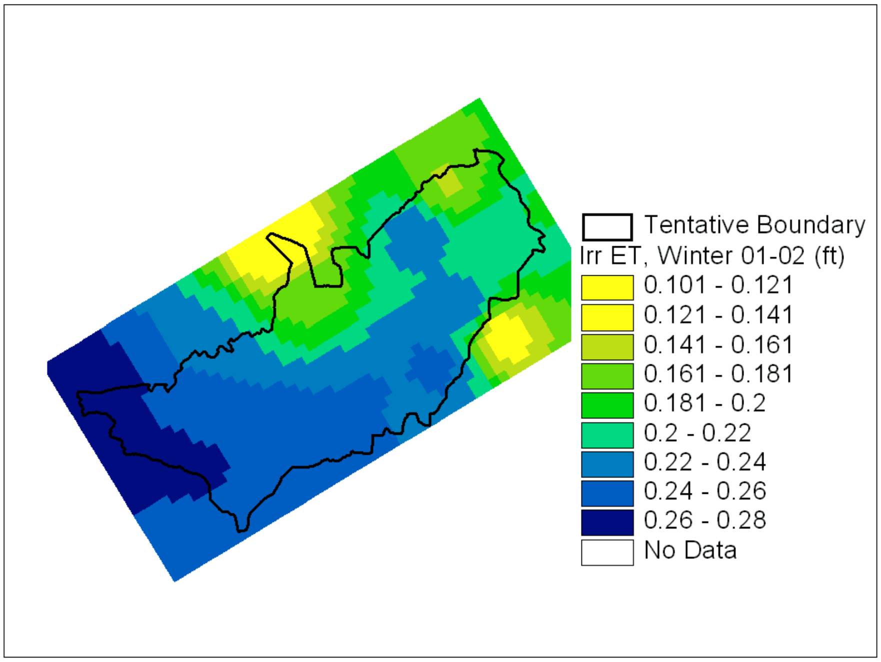

Figure 3. Sample Winter-time Irrigated-Ag Evapotranspiration Rates

From 1980 through May 2001, two stress periods per year will be used in model calibration. The winter months of November through February are included within a single stress period, so a single winter-time raster is produced. The stress periods used for the winter of 2001/2002 are each one month long. ET for that entire winter is calculated for each zone, then apportioned to the stress periods according to the precipitation rasters for the months.

Winter rasters and individual monthly summer rasters are summed by stress period to produce raster maps of irrigated agriculture ET for each stress period. In the recharge calculation, the GIS recharge tool applies the ET rate from the raster to each polygon identified as irrigated for the stress period in question. Design Document DDW-015 discusses determination of irrigated lands. Recharge on non-irrigated lands is discussed in Design Document DDW-003.

DESIGN DECISION

Evapotranspiration rates for irrigated lands for the summer months are calculated from the Kimberly-Penman Alfalfa Reference ET values in the revised <u>Estimating Consumptive Irrigation Requirements for Crops In Idaho</u> (Allen 2002), crop coefficients derived from the original <u>Estimating Consumptive Irrigation Requirements for Crops In Idaho</u> (Allen and Brockway 1983) and county-average crop mix. Design Document DDW-001 describes determination of crop mix. Winter-time evapotranspiration rates are based on data collected at Kimberly, Idaho (Wright 1993) and adjusted for snow cover (Wright 2003) and available moisture (Allen 2003). Calculations are performed in GIS to produce a raster map that identifies irrigated agriculture evapotranspiration rates for the entire plain, for each stress period. For each stress period, the GIS recharge tool applies the evapotranspiration rate to the irrigated polygons for that period. Design Document DDW-015 discusses identification of irrigated lands.

In the recharge calculation for irrigated lands, precipitation and field deliveries from surface water sources are added to potential recharge, and crop evapotranspiration is subtracted. The crop evapotranspiration is scaled by an ET adjustment factor to compensate for field conditions different than the conditions for which ET parameters were calculated. A cell-by-cell calculation of stored soil moisture will allow consideration of antecedent moisture condition. Adjustment factors are discussed in Design Document DDW-021.

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