DRAFT

EVAPOTRANSPIRATION ADJUSTMENT FACTORS

Idaho Water Resources
Research Institute

University of Idaho

Bryce A. Contor
May 19, 2003

Eastern Snake Plain Aquifer Model Enhancement Project
Design Document Number DDW-021

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.

INTRODUCTION

In the Eastern Snake Plain Model Enhancement Project, the basic equation for calculating net recharge from irrigated agriculture is:

Net Recharge = (Field Delivery + Precipitation) – Evapotranspiration (ET) (1)

Where Field Delivery =
(Surface Water Diversions – Returns – Canal Leakage) (2)

The base ET in equation (1) will be calculated as described in Design Document DDW-010. When the water source is ground water, surface water diversions are zero and the calculated net recharge is negative (net withdrawal). 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 previous Snake Plain modeling efforts.

In the recharge tools of the model enhancement project, ET is expressed first as a depth, then multiplied by irrigated area within each model cell to obtain a volume of ET. Various conditions have the potential to alter the actual field ET depth from the well-watered-disease-free condition represented by typical planning ET calculations and tables. The actual consumptive use depth may also be different than calculated ET if there are consumptive fates for diverted water other than those contemplated by equations (1) and (2). Finally, the actual volume of ET calculated can be affected by bias in the data used for irrigated area within each model cell. If these differences can be identified and quantified, an ET adjustment factor may be applied to correct the calculation of net recharge:

$$\text{Net Recharge} = (\text{Field Delivery} + \text{Precipitation}) - (\text{ET} \times \text{Adjustment}) \qquad (3)$$

The recharge tools allow for two ET adjustment factors per ground-water entity or surface-water polygon, one for sprinkler application and one for gravity application. These potentially could be adjusted by the PEST software during parameter estimation. This Design Document explores the conceptual basis for ET adjustment factors and describes the proposed approach to calculate these factors.

CONCEPTUAL BASIS FOR ET ADJUSTMENTS

<u>Non-Optimum Crop Production.</u> The most obvious production limitation that affects actual ET is reduced water supply. Reduced frequency of irrigation reduces the evaporation component of evapotranspiration, and any deficit in soil moisture reduces the transpiration component. The relationship between applied water and yield is referred to as a production function, and is often illustrated as a curve showing declining response to additional applied water (Hexem and Heady 1978), as shown in Figure 1. It is important to remember that this is the response to ***applied*** water. At the upper end of the curve, less and less of the applied water actually goes to meeting crop requirements and more is devoted to runoff and percolation. The actual relationship between yield and evapotranspiration is generally linear, as illustrated in Figure 2 (Sammis 1980, Wright 2003). This linear relationship has been quantified for various crops by "extensive experimental data covering a wide range of climatic conditions" and allows calculation of yield responses to water availability (Doorenbos et al 1979). The short-term response to acute moisture deficit is for the plant to close its leaf stomates (USDA 1955), reducing circulation of air within the leaf and limiting the ability of water vapor to escape. The long-term response to chronic moisture deficit is a limitation on the growth and size of the plant.

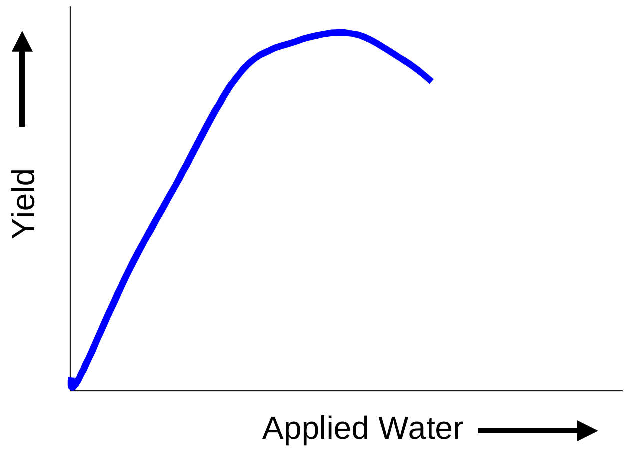

Figure 1. Hypothetical Water Production Function

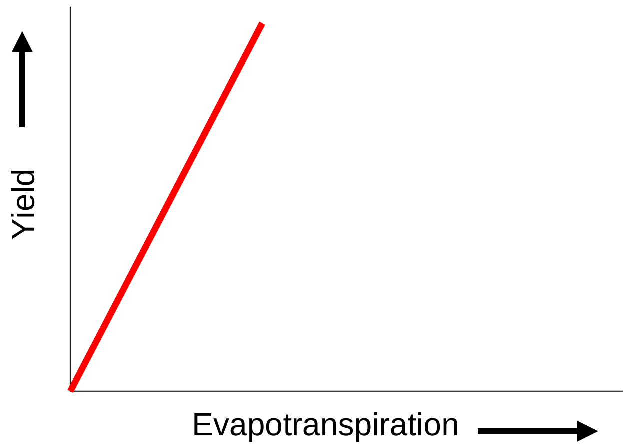

Figure 2. Yield Response to Evapotranspiration

Other factors (insects, disease, salinity, lack of soil nutrients) can also limit the size, growth, and vigor of a plant and therefore limit yield. Because the plant is a passive transport mechanism (Allen 2003) responding to the evaporative power of the atmosphere and available soil moisture, limitations in these other factors also reduce ET by reducing the size and vigor of the transport mechanism.

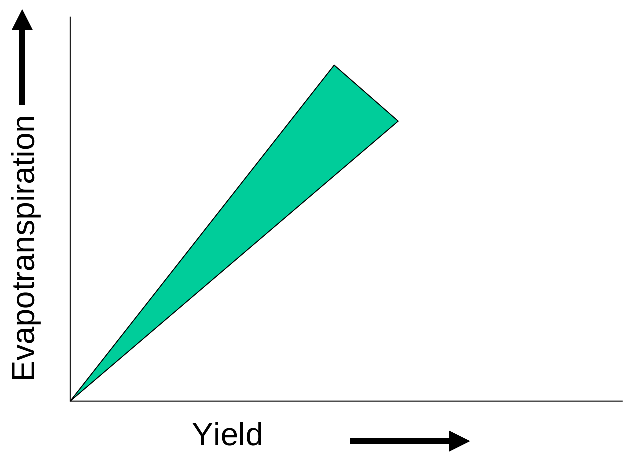

Figure 3. Evapotranspiration Response to Yield

Since these other limitations reduce both yield and ET, the yield/ET relationship works "in reverse." However, because these other factors typically do not control the stomates, the relationship is less responsive in the short term. Figure 3 illustrates a conceptual relationship of ET as a function of yield. Non-optimum crop production causes less-than-expected ET and implies a downward adjustment of ET. Johnson and Brockway (1983) proposed that "alfalfa reference ET" be "multiplied by the ratio of typical alfalfa yields to potential yield, resulting in the actual alfalfa ET. Typical and potential yield may be assumed to be the average and maximum yields in the area."

<u>Irrigation System Limitations.</u> Theoretically "an irrigation system is designed to deliver [water] at a rate sufficient to meet peak irrigation requirements" (IDWR et al 1991), but anecdotal evidence and examination of water rights indicates that many sprinkler systems actually have application capacities less than peak irrigation demand.[1] If the deficit period is not entered with adequate moisture stored in the soil profile, moisture stress and

[1] Diversion rates of 0.013 to 0.015 cfs (5 to 6.5 gallons per minute) per acre are not uncommon. At typical application efficiencies of 60 to 80% this provides the ability to replace 0.19 to 0.28 inches of water per day. Peak ET can be 0.30 to 0.33 inches per day.

reduced ET will occur. This effect would tend to push adjustment factors downward on sprinkler systems.

Gravity irrigation systems can suffer from an inability to apply frequent, light applications early in the season. Some gravity systems also suffer from lack of uniformity. These factors can limit crop vigor and ET, suggesting downward pressure on adjustment factors for gravity systems.

Other Fates for Applied Water. Besides the destinations for diverted water identified in equations (1) and (2), water can evaporate directly before reaching the crop canopy, especially with sprinkler irrigation on windy days (IDWR et al 1991). Water may move off the field to non-irrigated lands where it is evapotranspired before returning to the source. While these effects do not actually increase crop ET, they may increase net consumptive use and should be compensated by scaling the adjustment factor upward.

Improved Varieties and Methods. Traditional ET calculations multiply a reference ET value (which describes the evaporative power of the atmosphere) by a crop coefficient or Kc (which describes the genetic and growth-stage determined response of the crop to evaporative power). Many planning crop coefficients were developed a number of years ago, using then-current best management practices and crop varieties on experimental plots. Actual daily field ET values observed on intensely managed center pivots with modern varieties often exceed “well-watered-disease-free” planning values (Allen 2003). Center-pivot and linear sprinkler systems can wet the soil more frequently than the methods used in developing crop coefficients, increasing the evaporation component of ET. These effects tend to push adjustment factors upwards.

Adjustments to Base Area. As outlined in Design Document DDW-015, the GIS maps for identifying irrigated lands for the calibration period vary in data source and methodology. To adjust these maps to a common basis so that apparent changes over time represent actual changes in irrigated acreage, a reduction factor is applied in the recharge calculation to account for non-irrigated inclusions (roads, buildings, haystacks) within nominal irrigated parcels. This reduction factor is based upon the ratio of nominal acreage to the actual irrigated acreage indicated by hand-digitized polygons from aerial photographs, within statistically-selected public land survey sections. While this adjusts the irrigated area represented by all the GIS data sets to a common basis, it is possible that this method could introduce a bias to the ET calculation if the hand-digitized polygons over- or under-estimate actual irrigated area. Further, because of the potential of irrigation water moving outside field boundaries, and the potential of increased ET from heat energy advected into irrigated fields from adjacent dry areas (Allen 2003), the “correct” area for ET calculation may be different than the actual area of the physical farm field.

Adjustments due to Early- and Late-season ET. Typical ET estimation methods were generated for irrigation planning and operation. When applied to water-balance calculations, a “basic weakness” is that they “only include estimates of ET during the crop-growing season, and ignore ET during the rest of the year" (Burt et al 2001). Many growers apply an unneeded final irrigation to small grains (Hopkins 2002), and anecdotal evidence suggests fall irrigation for tillage convenience is a common practice. Weeds and late-emerging crops continue to transpire after the date that traditional estimates stop recording crop water requirements. Including early- and late-season ET could tend to push the adjustment factor upwards. Because the current recharge calculations include year-round precipitation, it is also appropriate to consider year-round ET.

PREVIOUS ESTIMATES OF ADJUSTMENT FACTORS

Idaho practitioners familiar with traditional ET estimates and actual crop irrigation practices have suggested adjustment factors ranging from about 0.85 to 0.95 (Wright 2003, Wells 2002, King 2002). A comparison of water-balance ET estimates and ET determined by reference ET and crop coefficients found that the calculated ET exceeded the water-balance ET by about eight percent (Allen 1999),[2] implying an adjustment factor of 1.00/1.08, or 0.93. Luke et al (1998) found that measured pumpage for groundwater irrigation north of the Snake River in the central Eastern Snake Plain was about 35% less than pumpage predicted using AgriMet ET.[3] This implies an ET adjustment factor less than one (or a higher irrigation efficiency than assumed). Data presented by Water District One (1998) for pumpage volume by crop near Mud Lake, Idaho suggest ET adjustment factors less than one when compared with AgriMet ET and precipitation. As mentioned above, Johnson and Brockway (1983) proposed adjustments based on the ratio of average to maximum alfalfa yields in an area. These estimates all compare ***growing season*** ET, not full-year ET.

PROPOSED CALCULATION OF ADJUSTMENT FACTORS

<u>Data for Comparison.</u> Idaho Department of Water Resources and University of Idaho have participated in the study and adaptation of a remote-sensing based method of estimating ET called the Surface Energy Balance Algorithm for Land, or SEBAL (Morse et al 2000). Based on comparisons with lysimeter data and other ET estimates, reported season-long SEBAL estimates are very accurate. It is proposed that SEBAL-estimated ET be used as the "true" ET value in the calculation:

$$\text{Adjustment Factor} = \text{True ET} / \text{Traditional ET} \qquad (4)$$

The "traditional" ET in equation (4) will be the ET calculated according to methods in Design Document DDW-010. Allen et al (2002) have prepared GIS raster maps of SEBAL

---

[2] For privacy reasons, the location of this study was not reported. The crops reported suggest it was outside of Idaho.

[3] Luke et al assumed 70% application efficiency and considered precipitation events exceeding 0.20 inches as effectively reducing irrigation demand.

ET estimates for the entire study area for crop year 2000. Maps of daily 24-hour ET are available for selected LANDSAT overflight dates, along with full-season composite maps. Because these are energy-balance based estimates, "other fates" consumptive use should be adequately represented as well as crop evapotranspiration.

Objectives. The primary goal of applying an ET adjustment factor is that the overall volume of ET be unbiased. A secondary goal is that the spatial distribution of ET across the study area be correct. Because cropland ET is a large component of the water budget, it is important to assure that calculated adjustment factors are reasonable in light of the conceptual relationships described above. This includes a requirement that adjustment factors be consistent with previous estimates, or that discrepancies be reasonably explained.

Proposed Methods. It is proposed that the primary goal be met by calculating a global adjustment factor that reflects the difference between traditional and SEBAL ET for the full year-2000 water year, over county-wide areas. The basis for comparison will be GIS polygons that include all lands shown as irrigated, plus a 300-meter buffer.[4] The buffer is intended to include sites that may have off-site ET from field runoff that does not return to the source, to compensate for inaccuracies caused by the use of hand-drawn GIS polygons to represent non-irrigated inclusions, and to compensate for pixel "bleed" effects (Tasumi 2002) at irrigated/non-irrigated junctions in the SEBAL analysis. The "true" ET within these polygons will be the March-October SEBAL ET calculated by Allen et al (2002), plus the winter-time ET (Wright 1993) calculated according to DDW-010 (SEBAL estimates are not available for winter months). The "traditional" ET will be the irrigated ET calculated according to DDW-010 on the irrigated parts of the polygons, plus the difference between precipitation[5] and non-irrigated recharge[6] on non-irrigated areas within the larger buffered polygons.

The secondary goal of spatially assigning unique ET adjustment factors to individual surface-water irrigation entities or ground-water irrigation polygons will be approached by investigating regression equations to predict ET adjustment factor according to various available data, including crop type, water application method, water source, depth to water, adequacy of supply, and interaction terms. Regression equations will be explored using a backward elimination procedure (Draper and Smith 1967). The final regression equation chosen will be statistically significant and will have all its individual coefficients statistically significant.[7] If two or more equations meet these criteria, preference will be given to simpler equations with nearly as high R^2 values. If a

[4] The buffering process adjusts for overlapping buffers of adjacent farm fields, so there will be no double-counting of areas.
[5] See Design Document DDW-011
[6] See Design Document DDW-003
[7] If a statistically-significant interaction term is retained, the terms that interact will also be retained, even if not significant (Dakins 2003).

regression equation is not found to meet these criteria, only the global adjustment factor will be used. To allow identification of individual crops and application methods, and to avoid edge-effect contamination, the regression analyses will be based upon hand-drawn polygons buffered to show only the interior of irrigated fields, on statistically-selected public land survey sections. The spatial calculation must recognize limitations in knowledge of spatial distribution of such factors as application method[8], crop planting,[9] and water source[10] (the smallest spatial areas for which these data have been compiled are irrigation entity or ground-water polygon, county, and 40-acre tract, respectively).

To reconcile the regression equation with theoretical considerations and previous estimates, relationships will be examined with season-long ET and individual image dates. Individual coefficients in the regression equations will be examined and compared with theoretical expectations.

Because the regression calculation and the global calculation treat non-irrigated inclusions and irrigated/non-irrigated junctions differently, it is expected that the regression equation factor when applied to large areas will not exactly predict the global adjustment. To incorporate the spatial knowledge gained from the regressions with the global knowledge gained from the wide-area calculations, the ET volume of irrigated lands within individual surface-water irrigation entities and ground-water polygons will be calculated using the traditional ET methods and the regression-derived adjustment factors. These volumes will be used to calculate an overall volume-weighted ET adjustment factor based on the regression equation, which will be compared with the global ET adjustment factor calculated as described above. The ratio between these two overall adjustment factors will be used to scale individual surface-water-entity or ground-water-polygon adjustment factors, so that the volume-weighted average by entity and polygon equals the calculated global adjustment factor

If no statistically significant regression equation is developed, or if a developed equation cannot be explained conceptually, the global ET adjustment factor will be applied uniformly to all surface-water entities and ground-water polygons. If the regression is statistically significant, its individual terms are statistically significant, and the relationships can be explained conceptually, individual entities and polygons will have unique adjustment factors. If application method is a statistically-significant predictor of adjustment factor, a unique "sprinkler" and "gravity" adjustment factor will be assigned to each entity and polygon. Otherwise, the "sprinkler" and "gravity" adjustment factors will be equal for each entity or polygon.

The calculation assumes that water-year 2000 is a "typical" year. Excluding two outliers that appear to represent changes in irrigated lands within an entity, preliminary diversion volume data indicate the year-2000 water supply ranged from 89% to 135% of entities' average supply over the calibration period. These data may provide an indication

[8] See Design Document DDW-022
[9] See Design Document DDW-001
[10] See Design Document DDW-017

of the effect of water supply on adjustment factor, and if so, the global factor may be adjusted to reflect the difference between the overall year-2000 water supply and average supplies.

DESIGN DECISION

ET adjustment factors may allow compensation for field conditions that depart from the assumed conditions upon which traditional ET calculations are based. Adjustment factors may also correct for bias in the hand-drawn irrigated field polygons that were used to define the reduction for non-irrigated inclusions within irrigated fields. These reductions were necessary to place the three different irrigated-lands maps (made using different methods and different data sources) on an equal basis. The ET adjustment factor will be multiplied by traditional ET to calculate ET for use in water-budget calculations. The recharge tools allow for two ET adjustment factors per ground-water entity or surface-water polygon, one for sprinkler application and one for gravity application.

Calculation of adjustment factors will be based on a global adjustment factor and upon individual regression calculations. The global factor will be based upon wide-area comparison of traditional and SEBAL ET estimates and will scale gross ET over the entire study area. Regression equations will be tested in an effort to generate prediction equations to assign unique adjustment factors to each surface-water irrigation entity or ground-water polygon. The equation will be used to spatially distribute ET adjustment factors within the study area. The regression must be statistically significant, have statistically significant terms, and be conceptually reasonable in order to be accepted. If these criteria are not met, only the global factor will be used.

REFERENCES

Allen, R.A. 2002, 2003. University of Idaho. Personal communication.

Allen, R.A., M. Tasumi and R. Trezza. 2002. Crop-year 2000 SEBAL Estimates of Evapotranspriation, Snake River Plain, Idaho. Electronic data. University of Idaho.

Allen, R.A. 1999. ***Accuracy of Predictions of Project-wide Evapotranspiration Using Crop Coefficients and Reference Evapotranspiration.*** Proceedings: Benchmarking Irrigation System Performance Using Water Measurement and Water Balances. U.S. Committee on Irrigation and Drainage. Denver, Colorado.

Burt, C.M., D.J. Howes, A. Mutziger, 2001. Evaporation Estimates for Irrigated Agriculture in California. ITRC Paper no. P 01-002. Irrigation Training and Research Center, California Polytechnic State University.

Burt, C.M. 1999. ***Irrigation Water Balance Fundamentals,*** in Water Balance Short Course printed lecture notes, Irrigation Training and Research Center, California Polytechnic State University.

Dakins, M.E. 2003. University of Idaho. Personal communication.

Draper, N.R. and H. Smith. 1967. Applied Regression Analysis. Wiley and Sons, New York.

Garabedian, S.P., 1992. Hydrology and Digital Simulation of the Regional Aquifer System, Eastern Snake River Plain, Idaho. USGS Professional Paper 1408-F.

Hexem, R.W. and E.O. Heady, 1978. Water Production Functions for Irrigated Agriculture. Iowa State University Press.

Hopkins, I. 2002. University of Idaho Cereal Grains Specialist (retired). Personal communication.

Idaho Department of Water Resources, 1997. Upper Snake River Basin Study. Boise, Idaho.

Idaho Department of Water Resources, University of Idaho, and a consortium of electric utilities, 1991. Irrigation Technologies in the '90s: Energy-Efficient Irrigation Practices Handbook.

Johnson, G.S. and C.E. Brockway. 1983. Users Manual for The University of Idaho Ground-water Flow Model and Recharge Program. University of Idaho and Idaho Department of Water Resources.

King, B. 2002. University of Idaho. Personal communication.

Luke, T.J., S.N. King, B.H. Scholer, C.J. Hodges. 1998. Eastern Snake Plain Aquifer Water Measurement Program. Idaho Department of Water Resources.

Morse, A. M., M. Tasumi, R.G. Allen, W.J. Kramber. 2000. Final Report : Application of the SEBAL Methodology for Estimating Consumptive Use of Water and Streamflow Depletion in the Bear River Basin of Idaho through Remote Sensing. Idaho Department of Water Resources and University of Idaho.

Sammis, T.W., 1980. ***Yield of Alfalfa and Cotton as Influenced by Irrigation,*** Journal Article No. 754 of the New Mexico Agricultural Experiment Station. Los Cruces, New Mexico.

Tasumi, M. 2002. University of Idaho Ph.D. Student. Personal communication.

USDA. 1955. Water: The Yearbook of Agriculture 1955

Water District One. 1998. Final 1997 Hydrographer's Report, North Water Measurement District. Idaho Falls, Idaho.

Wells, R. 2002. Snake River Consulting. Personal communication.

Wright, J.L. 2003. University of Idaho. Personal communication.

Wright, J.L. 1993. ***Nongrowing Season ET from Irrigated Fields,*** in Management of Irrigation and Drainage Systems. Conference proceedings, Irrigation and Drainage Division, American Society of Civil Engineers.