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Crop and Wetland Consumptive Use and Open Water Surface Evaporation for Utah

Prepared by Robert W. Hill, J. Burdette Barker and Clayton S. Lewis

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Prepared by

Robert W. Hill, J. Burdette Barker and Clayton S. Lewis

Professor and Extension Irrigation Specialist, Graduate and Undergraduate Student Assistants
Civil and Environmental Engineering
Utah State University
Logan, Utah 84322-4110

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ABSTRACT

Crop water use and open water surface evaporation were estimated for a thirty eight year period, 1971-2008, at 150 National Weather Service Cooperative Observation Network (NWS) stations throughout Utah and another 96 stations in adjacent states, within one degree latitude or longitude of Utah's borders. The ASCE Standardized Reference Evapotranspiration Equation (Penman-Monteith) was used to calculate tall crop reference evapotranspiration. Daily weather data (maximum and minimum air temperature and precipitation) from the 246 NWS stations were provided by the Utah Climate Center. Missing daily temperature and precipitation values were estimated to complete individual NWS station datasets. Additionally, hourly and/or daily weather data (air temperature, solar radiation, humidity, wind and/or precipitation) were available at 92 electronic weather stations from a variety of meteorological networks. Solar radiation, wind run and dew point temperature estimates at the NWS stations were interpolated from electronic weather station sites to provide characteristic values for each NWS site. Air temperature from selected pairs of EWS sites and close by NWS stations were used to derive a temperature difference, denoted "aridity adjustment". This helped account for the effect on ET calculation from warmer temperatures at NWS locations than in an irrigated environment.

Net irrigation water requirement was calculated as growing season ET less the effective summer precipitation (80% of total rainfall). Generally, estimates of ET were made for principle irrigated agricultural crops (i.e., alfalfa, pasture, other hay, spring grain, corn, etc.), garden and turf, selected wetland vegetation, and also for open water surface evaporation. Daily NWS weather station temperature and precipitation data were used to develop monthly average values of ET, net irrigation and evaporation for 1971-2008.

Alfalfa ET was used as a "bellwether" or indicator of reasonableness of calculated crop ET. The validation methodology consisted of obtaining a range of field alfalfa hay yields by county and then developing associated alfalfa ET values for better than average high alfalfa yield (representing growing conditions in three years out of five) and near perfect condition (one year out of ten) high yields for each county. Corresponding alfalfa ET values were inferred from a yield versus ET relationship.

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KEYWORDS — crop water use / evapotranspiration / irrigated crops / water resource planning and management

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PREFACE

Four previous reports (Utah State Engineer, Technical Publication #8, #8 revised, #75 and UAES Research Report # 145) have presented consumptive use estimates for Utah. In the almost 17 years since the publication of Research Report # 145, technological advances have continued in irrigated crop research, irrigation management programs and weather data collection equipment. Recently, the development of the ASCE Standardized Reference ET Equation (Penman-Monteith) has provided a new state-of-the-science method for estimating evapotranspiration.

The funding agencies of this present study, Utah's Divisions of Water Resources and Water Rights, specified that the ASCE Standardized Reference ET Equation be used in updating Report # 145 ET values. Further, with consideration of utilization of GIS techniques for interpolating site specific ET estimates to a broader geographical area, they requested the inclusion of sites from adjacent states.

This report was intended to be an update of the consumptive use (ET) values contained in UAES Research Report # 145, not an exhaustive replacement. Thus, the discussion of depletion, irrigation efficiency and water quality effects on crop water use in the previous report are not included herein. The reader is referred to report #145 for these and other similar topics.

The main emphasis in the text of this report is to describe the methodology used in applying the ASCE Standardized Reference ET Equation. NWS daily air temperatures were used as the basis for long term estimates of average monthly ET. This required the adaptation of similar techniques, as applied in Idaho and Nevada, to Utah and nearby in adjacent states.

Considerable effort was required in developing reasonable estimates of solar radiation, wind travel and dew point temperatures at the NWS sites to complete the requisite daily calculation datasets.

CROP AND WETLAND CONSUMPTIVE USE AND OPEN WATER SURFACE EVAPORATION FOR UTAH

INTRODUCTION

The continued competition for water in Utah and management requirements for legal water allocation as well as hydrologic considerations necessitates accurate estimates of water use. Competition for water is due to increased urban and rural development as well as declining ground water levels and recurring drought conditions. This highlights the importance of careful water management. Accurate estimates of consumptive water use (CU) or evapotranspiration (ET) and open water surface evaporation are necessary for informed water management.

Objectives

The primary purpose of this work was to develop estimates of crop and wetland vegetation (phreatophyte) consumptive use and open water surface evaporation throughout the state of Utah. The resultant Crop-ET (ET_c), Phreatophyte-ET and evaporation estimates were to be provided for selected National Weather Service Cooperative Observation Network (NWS) stations in Utah. This was expanded to include NWS stations in adjacent states within one degree latitude or longitude of Utah's borders. Monthly and annual total ET_c (including alfalfa reference ET) and open water surface evaporation estimates were prepared for NWS sites for which reasonable datasets could be obtained for the 1971-2008 period.

Evapotranspiration Estimation

Evapotranspiration (ET) is a relatively complex and nonlinear phenomenon, depending on the interaction of air temperature, solar radiation, wind, vapor pressure (relative humidity), as well as on the crop type and growth stage (leaf area). ET or CU can be estimated or measured by many different techniques depending on study objectives and financial and data resources. These techniques range from equations that use only monthly average temperatures to thoroughly instrumented field research sites with weighing lysimeters. Additional data on crop water use are available from irrigation scheduling, experimental plot, and field research studies.

Typically, ET is estimated for a reference crop, such as full growth alfalfa or clipped grass, based on available weather data (Wright 1982; Jensen 1990; Allen et al. 1998; ASCE-EWRI 2005). ET for specific crops or land covers is then estimated by multiplying the reference ET (ET_r) by a coefficient representing crop conditions including growth stage.

The general form of the reference ET - crop coefficient approach for CU estimations is:

$$ET = K_c ET_r + E_{ws} \qquad (1)$$

where ET is the estimated crop evapotranspiration; K_c is an empirically determined crop coefficient relating crop ET to reference crop ET_r; ET_r is calculated ET for an alfalfa reference crop; and E_{ws} is estimated wet soil surface evaporation adjustment to account for conditions occurring following an irrigation or significant rain. This adjustment is made when the K_c value is less than 1.0, e.g., in the early growth stages of a row crop or following a cutting of alfalfa. Implied in Eq. 1 is a K_c value representing the "basal" condition (K_{cb}) since E_{ws} is explicitly shown. This is known as the "dual crop coefficient" approach.

An alternate form of the crop water use equation is:

$$ET = K_{cm} ET_r \qquad (2)$$

where K_{cm} is a "mean" crop coefficient (Wright, 1982) that includes the effect of evaporation from a wet soil surface from a typical irrigation schedule for the given crop.

The value of a crop coefficient (K_c or K_{cm}) at a particular growth stage depends on plant transpiration as well as evaporation from the soil surface. Care must be exercised in applying K_{cm} values from one research site to other sites with different irrigation practices and environmental conditions.

Comparison of Dual and Mean Crop Coefficient Approaches

The literature suggests that the dual crop coefficient approach more accurately represents crop systems than the mean crop coefficient approach (Allen et al. 1998; Jensen et al. 1990; Wright 1982). This, however, is dependent on accurate assumptions relating to the calculation of E_{ws} (see Allen et al. 1998 and Jensen et al. 1990). In a study in Curlew Valley, northern Box Elder County, Utah, Barker (2011) found that the K_{cm} method performed comparably to the dual K_c method for center pivot irrigated alfalfa. In some cases the K_{cm} performed better than a dual K_c as compared to ET measurements from eddy covariance and surface renewal analyses.

Mean crop coefficients were used in all ET estimates in the current report. This is because of the uncertainty of assumptions required for implementing dual crop coefficients. Applying dual crop coefficients also requires simulating irrigation events, which may not necessarily yield better results than applying a mean K_{cm}. Dual crop coefficients, however, have been used in similar studies (Allen and Robison 2007; Huntington and Allen 2010). Mean crop coefficients were further assumed to be adequate, as we are reporting only monthly ET estimates, rather than shorter periods, such as daily.

Reference Crop Evapotranspiration

ET_r is reference ET for a tall reference crop. A tall reference crop is similar to alfalfa at least 14 inches (35 cm) tall and adequately irrigated so that transpiration is not limited by available soil moisture. Another common reference is a short reference crop similar to clipped grass (denoted ET_0), water not limiting. The availability of electronic weather station (EWS) data has allowed routine use of Penman-type equations for estimating ET_r (Penman 1948; Monteith 1965; ASCE-EWRI 2005).

Many reference evapotranspiration equations have been used historically. The American Society of Civil Engineers (ASCE) and the Irrigation Association adopted a "standardized" form of the Penman-Monteith ET_r equation in 2005 (ASCE-EWRI 2005). This equation is now a generally accepted method of calculating ET_r. The ASCE Standardized Reference ET Equation overestimates ET_r in the spring and fall at Kimberly, Idaho (Wright et al., 2000), where the 1982 Kimberly modified Penman combination equation was calibrated, thus necessitating the use of "corrected" crop coefficients (Allen and Wright, 2002).

Herein, ET_r was calculated using the ASCE Standardized Reference Evapotranspiration Equation (ASCE Std. Eq.) to be consistent with current practice. ET_r calculated using the ASCE Std. Eq. is denoted ET_{rs}.

The ASCE Standardized Reference ET Equation

The ASCE Std. Eq. can be used for both a "tall" (alfalfa) or "short" (grass) reference crop calculation mode:

$$ET_{rs} = \frac{0.408\ \Delta(R_n - G) + \gamma \frac{C_n}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)} \quad (3)$$

where ET_{rs} is the standardized reference evapotranspiration (mm/d or mm/hr) for a "tall" crop (denoted by the subscript "rs"), Δ is the slope of the saturation vapor pressure vs. temperature curve (kPa/°C), R_n is the calculated net radiation at the crop surface (MJ/ m^2/d or MJ/ m^2/hr), G is soil heat flux (MJ/ m^2/d or MJ/ m^2/hr) assumed to be zero for daily calculation time steps herein, γ is the psychrometric constant (kPa/°C), C_n is the numerator constant (changes with time step and reference crop type) (K mm s^3/Mg/d or K mm s^3/Mg/hr), T is mean temperature for the calculation interval (daily or hourly) (°C), u_2 is mean wind speed for the calculation interval at a height of 2 m above the ground (m/s), e_s is the saturation vapor pressure at 2 m above the ground (kPa), e_a is the mean actual vapor pressure at 2 m above the ground (kPa), C_d is the denominator constant which changes with time step and reference type (s/m).

The units for the coefficient 0.408 are m^2 mm/MJ. In this study a "tall" crop (alfalfa) was used as the reference type. Calculations were performed on an hourly and daily time step basis for adapting parameters to the requisite daily time step with the NWS datasets.

Application of the ASCE Std. Eq. for Statewide ET Estimates

Statewide estimates of ET require spatial resolution and data record lengths not commonly available from EWS units. Therefore statewide estimates of ET have typically been estimated from air temperature and precipitation data from NWS stations (Hill 1994; Allen and Brockway 1983; Allen and Robison 2007; Huntington and Allen 2010). The NWS datasets compiled for this study contain data from 246 locations for 38 years. This is valuable when determining typical or mean estimates of CU and ET. The disadvantage of using the NWS datasets for ET estimates is that the datasets do not include solar radiation, humidity, or wind speed data, all of which are necessary for calculating ET using a Penman-Monteith type method.

Past studies have estimated ET using methods which only require temperature data, such as the Blaney-Criddle Eq. (Hill 1994; Allen and Brockway 1983). The difficulty with using the Blaney-Criddle or other temperature only based ET equations is that these often require a comparison against a more accurate model (such as a Penman equation) to produce accurate results. This is the method that was used in UAES Research Report 145 by Hill (1994), herein referred to as UAES#145, to estimate ET for Utah. Allen and Robison (2007) employed the ASCE Std. Eq. to estimate ET in Idaho from NWS datasets. They estimated solar radiation, humidity, and wind speed using models and available EWS data. Their methodology was applied, with some adaptation, in Nevada by Huntington and Allen (2010).

Allen and Robison (2007) and Huntington and Allen (2010) suggest that their methodology may have produced better estimates of ET than would be found by using a temperature only ET estimate, such as the Blaney-Criddle or Hargreaves and Samani (1982), with adjustments from comparisons with Penman type ET using available EWS data. The approach, originally employed by Allen and Robison (2007) was adapted for use in Utah (and in adjacent states within one degree latitude and longitude). Adjustments were made to estimates of weather parameters to match available data.

Crop ET Estimates

ET was estimated for 18 crop types, two wetland vegetation types, as well as evaporation for shallow and deep water systems for all 246 NWS observation stations included in the study. The included crop and wetland types are listed in Table 1. Selected crops were determined by reviewing the 2007 Update of the Utah Irrigated Acreage Survey by the USU Extension (Hill 2008) and the 2007 Census of Agriculture (USDA-NASS 2009). Crops were included in this study if there were more than 300 acres of the crop cultivated in Utah.

Open Water Surface Evaporation

Evaporation from water bodies is difficult to estimate, because of the scarcity of representative data and the difficulty of estimating certain properties, such as heat storage in the lake. UAES#145 contains a good review and comparison of methods commonly used for lake evaporation estimates (see Appendix C of that report). An adaptation of the Penman Eq. was used to estimate monthly k factors for use with the SCS-Blaney-Criddle Eq. (USDA-SCS 1970) to estimate lake evaporation. It was noted, however, that without measurements of inflow and outflow volumes and temperatures, advective energy transport in a lake would not be accounted for and that reported estimates of lake evaporation could be off by as much as 100% in the winter months.

Table 1. Crop and Land Covers Included in the Study.

Crop or Land Cover	Comments
Alfalfa (Beef)	Follows a longer interval between cuttings
Alfalfa (Dairy)	Follows a shorter interval between cuttings
Apples / Cherries	With cover crop such as grass
Barley	
Corn	Grain corn
Garden Vegetables	
Melons	
Onion	
Other Hay	Meadow and Grass Hay
Other Orchard	Includes almonds, apricots, peaches, and pecans
Pasture	
Potato	
Safflower	
Small Fruit	Includes raspberries, blackberries, blueberries, and grapes
Sorghum	Forage sorghum or sorghum - sudangrass
Spring Grain	Includes wheat and oats
Turfgrass	
Winter Wheat	
Open Water - Deep	More than 13 ft. deep
Open Water - Shallow	Less than 13 ft. deep
Wetlands - Large	Large areas of wetland vegetation (cattails and bulrushes)
Wetlands - Narrow	Narrow stands such as near canals (cattails and bulrushes)

The methods used to estimate evaporation from open water surfaces, in the current study, were adapted from Allen and Robison (2007) for deep water and from UAES #145 for shallow water.

Deep Water

Deep water was defined as being deeper than 4 m (13 ft.) following Allen and Robison (2007). They used an adaptation of the aerodynamic method for estimating lake evaporation of Kondo (1975) from NWS data in Idaho. In this method lake evaporation (E_{lake}) is found by:

$$E_{lake} = \frac{LE}{\lambda} = \rho_a C_E u(q_{satTs} - q_a) \quad (4)$$

where LE is the latent heat flux in W/m^2, u is the average daily wind speed in m/s at the measurement height, z, q_{satTs} is the saturated vapor density (kg/kg) at the surface temperature of the lake, q_a is the actual vapor pressure density at z, in this case 2 m, C_E is the aerodynamic expression:

$$C_E = \frac{k^2}{\left(ln\left(\frac{z}{z_{om}}\right)ln\left(\frac{z}{z_{ov}}\right)\right)} = \frac{1}{u_{10} r_{av}} \quad (5)$$

where k is the von Karman constant, z_{om} and z_{ov} are the roughness lengths for momentum and vapor transfer, and r_{av} is the bulk aerodynamic resistance for vapor transfer between the lake surface and height z. Allen and Robison (2007) used C_E = 0.0012, which they cited as being recommended by Kondo (1975) for neutral conditions and other studies "… for many applications to water." This is valid if u is measured at 10 m above the lake surface (Kondo 1975). Herein, the value of C_E was adjusted such that the deep water evaporation at Lifton NWS station better matched measured evaporation from Bear Lake by Amayreh (1995).

The difficulty with the Kondo method is that it requires the measurement of lake surface temperature (T_s) for calculating q_{satTs}. Allen and Tasumi (2005) studied water surface temperatures and evaporation from American Falls Reservoir in Idaho. Allen and Robison (2007) used the results from the study by Allen and Tasumi to estimate T_s from mean daily air temperature, T, as follows:

$$T_s = T + D_{month} \quad (6)$$

where D_{month} is the mean difference between running averages of T_s and T measured by Allen and Tasumi. Table 2 is a list of D_{month} values determined by Allen and Robison from the study of Allen and Tasumi. They suggested that lake evaporation estimates made using EWS data and using the D_{month} values in Table 2 should result in estimates that are ± 15 to 20% of actual based on the data of Allen and Tasumi.

The method of Allen and Robison (2007), described above was used to calculate open water evaporation from deep (> 13.1 ft.) systems from the 246 NWS datasets included in the study. The characteristic monthly wind values were adjusted following ASCE-EWRI (2005) to be representative of a 10 m measurement height. Actual vapor density was calculated from T_{dew} estimated from the monthly characteristic K_o values.

Table 2. Monthly D_{month} Values for Calculating Lake Surface Temperature from Mean Daily Air Temperature.[a]

D_{month} (degrees F)											
Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
7.2	5.4	1.8	0	0	0	0	1.8	1.8	5.4	7.2	7.2

[a]Source: Allen and Robison (2007).

Shallow Water

Evaporation estimates for shallow systems (< 13 ft.) were estimated by Allen and Robison (2007) from a coefficient applied to ET_{rs}. Evaporation from shallow systems or deep systems with high turbidity was estimated by multiplying ET_{rs} by 0.6 and evaporation from "small stock ponds" was estimated by multiplying ET_{rs} by 0.7. This method may overestimate evaporation in the winter because evaporation is near zero when ice cover is present (Huntington and Allen 2010). Preliminary calculations with the Allen and Robison (2007) approach gave shallow water evaporation values that were higher than expected. Thus, the Penman Lake evaporation equation from UAES #145 was applied herein.

Net Irrigation Requirements

Net crop irrigation requirements (NIR) were calculated following UAES#145 as:

$$NIR = ET_c - P_{eff} \tag{7}$$

where P_{eff} is effective precipitation and ET_c is crop ET. P_{eff} was defined as 80% of recorded precipitation during the growing season. This method for estimating NIR is more realistic than only using ET_c because there typically is some precipitation during the growing season. Further discussion of the application of NIR and the implications of average long term estimates of NIR on irrigation requirements is on pp. 18-20 of UAES#145.

Depletion Estimates

Depletion represents the net water demand from a water source. Depletion can be calculated as the sum of growing season evapotranspiration (ET) less the cumulative precipitation during the growing season and the soil moisture that was carried over from the winter (wet) months. The annual depletion equation used in this study, available as a runtime option, is the same as was used in UAES Research Report 125 by Hill et al. (1989), i.e.:

$$D_{pl} = ET - SM_{co} - P_{eff} \tag{8}$$

Where D_{pl} is depletion, ET is for the growing season, SM_{co} is the carry over winter soil moisture, and P_{eff} is the effective precipitation during the growing season. SM_{co} is given as the minimum between 67% of the adjusted precipitation (P_{wa}) during the winter and 75% of the available soil water holding capacity in the crop root zone. The adjusted precipitation, P_{wa}, is defined as:

$$P_{wa} = P_{win} - 1.25(ET_{win}) \tag{9}$$

where P_{win} is the total winter precipitation and ET_{win} is the total ET during the winter months (October – April). Depletion estimates are not presented herein; however, they were included in a separate report for the Bear River Commission. The software, UtahET, which was used herein to produce the NWS station output tables allows depletion estimates to be made for any selected site through changing a parameter in the input file. The UtahET software will be provided to both Water Resources and Water Rights.

PROCEDURES

Study Area

Consumptive water use estimates were calculated using weather data from Utah and surrounding areas within one degree latitude or longitude of the Utah border. The areas surrounding Utah were included for interpolation. Locations of NWS weather stations are shown in the map depicted in Fig. 1. The study area included a large variety of environmental conditions from cool, high elevation, mountain valleys to lower elevation desert. This was a challenge in applying data adjustments to obtain reasonable estimates of CU.

Available Weather Data

Estimating ET using ET_{rs} requires local weather data including air temperature, wind speed, humidity, and solar radiation for daily or even hourly time steps. Electronic weather stations are capable of measuring and recording many weather parameters. However, the spatial resolution of EWS sites located in irrigated environments is limited in Utah and surrounding areas. The period of record of most EWS sites is also limited, with the earliest dating back to the mid to late 1980's. Such data, although useful and becoming increasingly available, do not provide adequate periods of record or spatial frequency to provide long term estimates of CU.

Studies of CU have relied on manually recorded weather data, such as maximum and minimum daily air temperatures and precipitation from NWS stations (NOAA 2011a) for providing historical estimates of CU and ET. In the current study, air temperatures from NWS datasets for the period 1971 - 2008 were used. Data from EWS sites were also used, where available.

NWS Data

Most of the NWS stations in the study area have an extensive period of record. However, many have only a few years. NWS datasets were assembled to include data from the 38 year period from 1971 to 2008. An NWS station was included if the period of record was at least 20 years and ended no earlier than 1985. There were 314 NWS stations that met these criteria in the study area. Of these, five were dismissed because they were at elevations above 8000 ft.

Dataset Preparation

NWS datasets were prepared by the Utah Climate Center (UCC) at Utah State University, Logan, UT. The UCC estimated temperature and precipitation data for missing time periods so that each dataset had a complete daily record from 1971 through 2008. The methods used by the UCC are described in Appendix A. These NWS datasets were further scrutinized by comparing estimated temperature and precipitation data from each NWS station with data from the nearest three NWS stations. If estimated data were suspect, then revisions were requested until satisfactory results were obtained from the UCC.

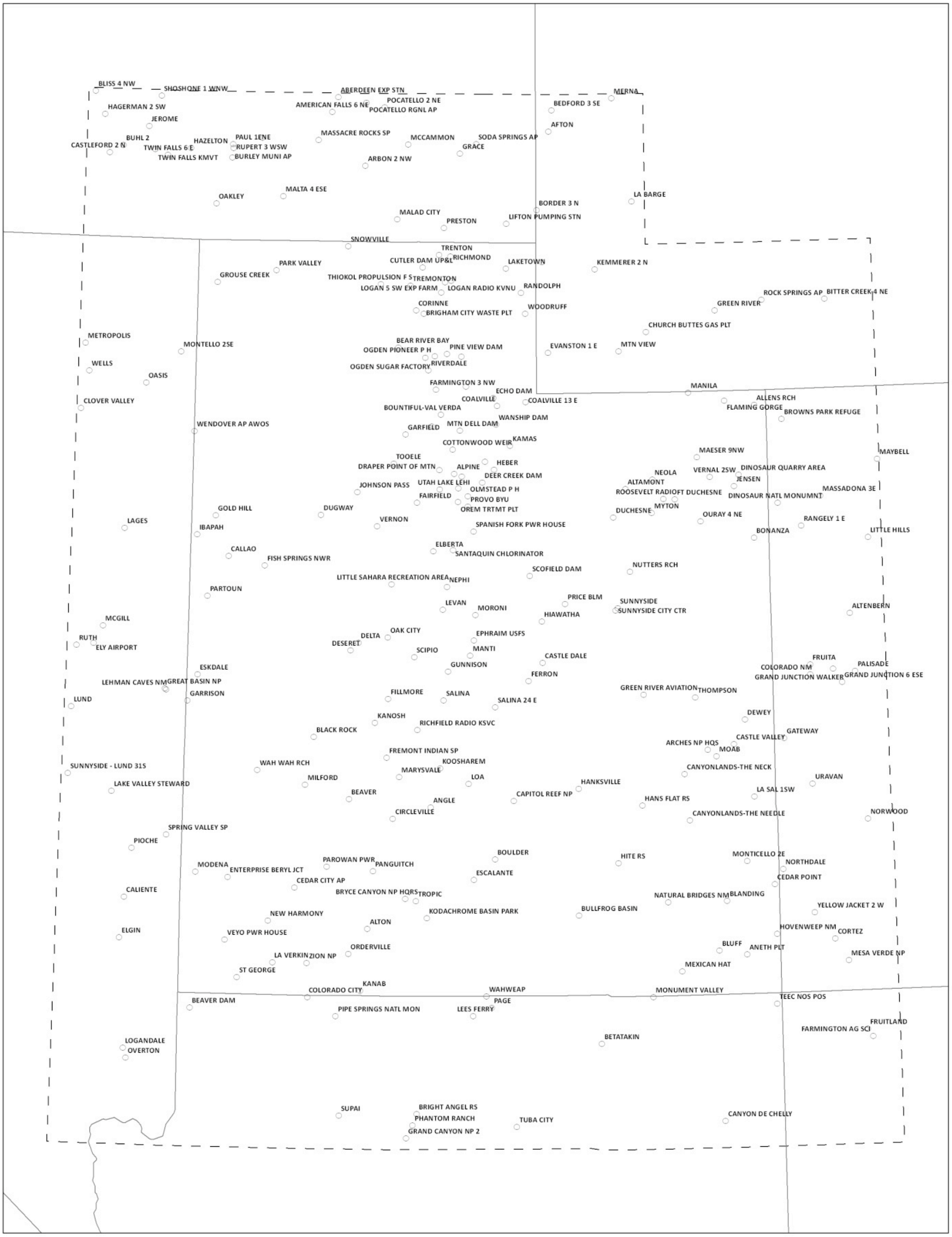


Figure 1. Locations of 246 NWS stations in Utah and in adjacent states within one degree latitude and longitude.

The NWS datasets were screened to eliminate stations with excessive amounts of estimated data. Datasets were rejected if they did not meet the criteria of having at least 12 years between 1971 and 2008 with each of those years having no more than 30 days of estimated data. Of the 309 NWS stations in the study area with adequate periods of record and site elevations below 8000 ft., 246 did not have excessive amounts of estimated data (see Appendix B for list).

Bias Adjustment for Estimated Precipitation

Examination of NWS datasets revealed that where precipitation was estimated for extended time periods (such as several continuous months or years), typically the number of events were significantly higher than for the reported occurrences. The magnitude of estimated precipitation values was often relatively greater than at surrounding stations with measured data. Thus, estimated precipitation as provided by the UCC required a bias adjustment to give reasonable estimates of net irrigation and depletion.

The precipitation bias correction was developed by comparing precipitation data from each NWS station with that of three nearby NWS stations through linear regression. Only stations with no more than 20% of their precipitation data having been estimated were used as comparison stations.

The monthly total precipitation from a target station for each month with “good” data (no more than one day with estimated data in the month) was compared with the average monthly total precipitation for the same month from the three comparison stations. This was done for months when all of the three had “good” data. Precipitation for months with more than one day of estimated data, for the target station, was then compared with precipitation estimated from the regression relationship records for corresponding “good” months at the three comparison stations. The bias adjustment was derived from the ratio of the target station estimated precipitation and that from the regression relationship with the three comparison stations. Estimated precipitation at the target station was corrected by multiplying it by the bias adjustment.

Electronic Weather Station Data

Several automated weather station networks exist in the study area. However, each network has been designed for specific purposes, including: agricultural, climate change, air quality monitoring, transportation and aviation, and wild land management. Because of the variety of weather station networks, not all available EWS data were useful for estimating CU in irrigated environments.

Weather data were obtained and considered for inclusion in the study from 18 EWS networks in Utah and adjacent states (Appendix C). Data from 11 of the 18 networks were used in the study. Reasons for excluding datasets included: lack of information on sensor positions (i.e. height above the ground), poor data quality, short or intermittent periods of record, and data that were unrepresentative for the intended application. Of the 11 included networks, eight were, at least in part, designed to be representative of irrigated areas. There were 168 stations in the study area from the eleven included networks. Of these, data from 92 were utilized herein (Fig. 2). A list of EWS sites included in the study along with information about each station is in Appendix C.

Data Quality Control

Daily and hourly datasets from the EWS sites were processed to eliminate problematic data. Software was developed to process the EWS data and flag inconsistent or missing data. Flagged data were estimated to provide complete datasets for entire calendar years. Descriptions of the processes used to flag and replace data are described in Appendix C. Datasets were visually inspected to identify obvious data issues such as trends related to instrument malfunction.

Wind Speed Adjustments

Wind speed measurements were taken using a variety of anemometers. The most common anemometers were 014A Wind Speed Sensors (Met One, Grants Pass, OR), and 05103 Wind Monitors and 03101 Wind Sentry from R. M. Young (Traverse City, MI). An unpublished internal study in 2007 found that the Met One 014A cup anemometer reported wind speeds about 1 mph greater than those measured by either R. M. Young Sensor when the manufacturer's calibration constants were used.

The Met One 014A was found to over measure wind speeds in comparison with a sonic anemometer in the same study. Subsequently all wind speed measurements from stations equipped with Met One 014A anemometers were adjusted by subtracting 1 mph for each hour, or 24 mpd for each day from the recorded wind speeds. An exception was made for the USCRN Baker, NV data, because the 014A anemometers used in the USCRN network are independently calibrated in a wind tunnel (NOAA 2011b).

Input Data Estimations and Adjustments

Effect of Local Aridity on ET Estimates

Many of the NWS stations are not located in areas that meet the "reference" conditions as described by ASCE-EWRI (2005). NWS stations are often located near parking lots, buildings, and other dry or otherwise arid surroundings. The air temperatures measured at these locations may be greater than if they had been located in an area with irrigated agriculture or "reference" surroundings (see ASCE-EWRI 2005; Allen 1996; Ley and Elliot 1993; ASAE 2009).

Aridity Rating

Allen and Brockway (1983) and later Allen and Pruitt (1986) suggested a method for adjusting NWS temperatures for local aridity. Their method involved determining the average temperature difference, by month, between arid and nearby irrigated locations. This average

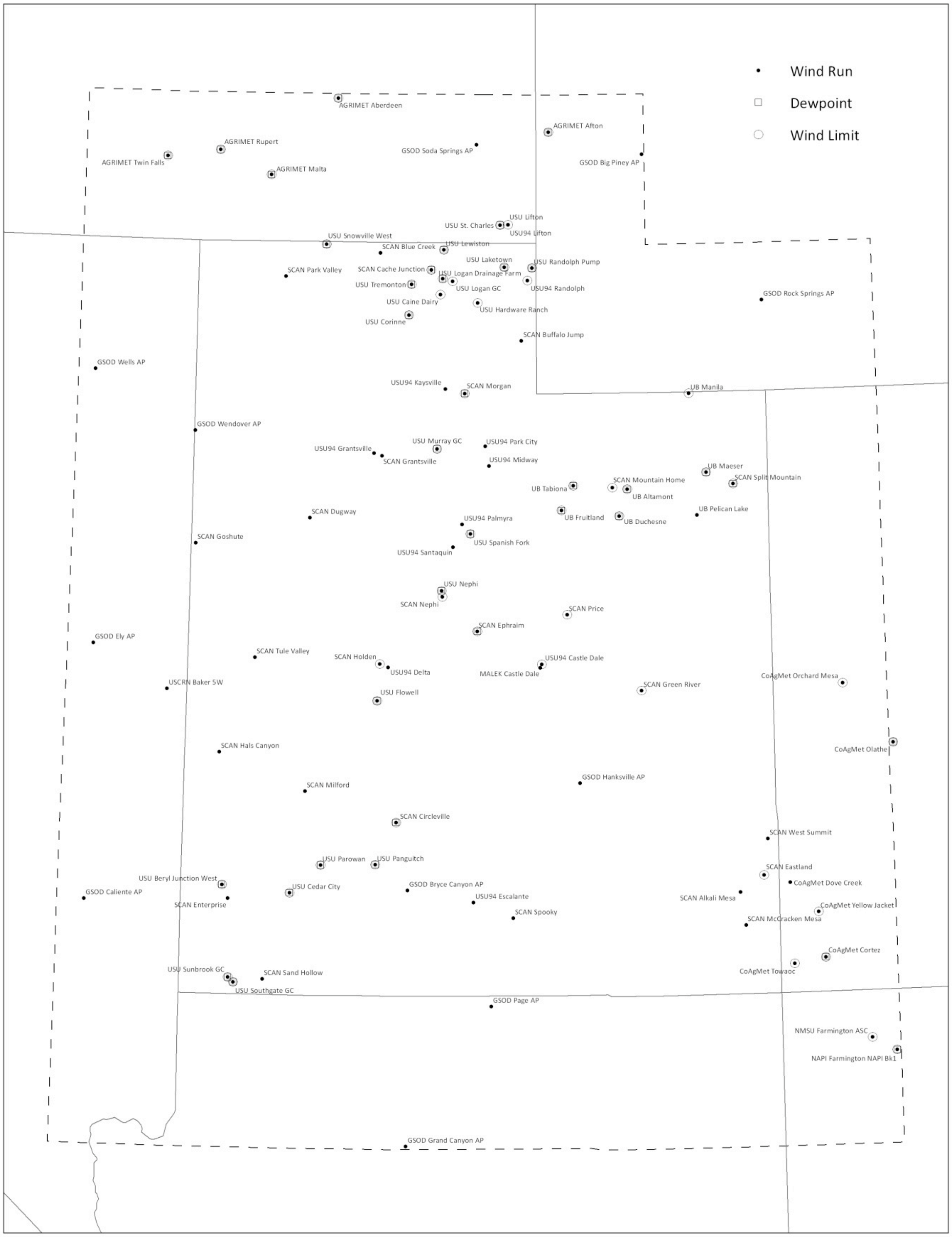


Figure 2. Locations of electronic weather stations used in the study. All stations were used for wind speed. Those marked as "Wind Speed" were only used for this purpose, those marked "Dewpoint" were also used for dew point temperature estimation, and those marked "Wind Limit" had hourly data for wind limit calculations.

temperature difference could then be subtracted from NWS temperatures to make them similar to temperatures measured in non-arid conditions. They further suggested that since the degree of aridity varies from location to location, a site aridity rating (AR) could be assigned to NWS sites, and that the aridity adjustment could be prorated accordingly. The AR would have a value of 0 to 100%, with 0% meaning well irrigated surroundings and 100% meaning fully arid. An AR of 50% would mean that only half of the magnitude of the aridity adjustment would be subtracted from the NWS temperatures at that site.

In the current study, AR's for each NWS station were determined from land cover imagery from the USGS Gap Analysis Program (GAP) (USGS 2011). The GAP dataset included land cover classifications at a resolution of a 30 by 30 m (98 by 98 ft.) grid. Aridity ratings were assigned to different land cover groups in the study area (see Appendix D). All cultivated land was grouped into one category in the GAP dataset. Therefore additional imagery, defining "Water Related Land Use," including irrigated land, was obtained from the Utah Division of Water Resources (Utah GIS Portal 2011). Irrigated land in Utah was assigned an AR of 0% and non-irrigated agricultural land was assigned a value of 20%. Cultivated land in the surrounding states was assigned an AR of 10%, because no differentiation between irrigated and non-irrigated land could be made.

The AR's for each station were determined by taking the weighted average of the average AR for the area within a 150 m (490 ft.) radius of station and a 90 degree wedge of radius 1500 m (0.93 mi.) from the station centered in the SSW direction, corresponding to the predominant wind direction in much of the study region (from the NASA wind dataset). The 150 m radius area was weighted as 80% of the station AR and the 1500 m wedge area was weighted as 20%.

Aridity Adjustment

The station AR's were used to prorate an aridity adjustment for each month at each station. An aridity adjustment curve was developed for the study area based on the difference between daily average air temperatures measured at select NWS stations, located in areas with known local aridity effects, and nearby EWS sites, located in irrigated environments. The selection of station pairs was made by pairing 66 EWS sites, which were determined as being representative of irrigated environments, with the nearest NWS station. The difference in the mean monthly air temperatures was calculated for each month and station pair. Station pairs were rejected if the distance between the two stations was more than 12 miles, the elevation difference between the two stations was more than 200 ft., the EWS air temperature was greater, on average, for any month between April and September, or if the AR for the NWS station minus the AR for the EWS was less than 50%. There were six station pairs that remained after eliminating pairs that did not meet the above criteria.

The monthly average temperature differences between the NWS station and EWS in the remaining six pairs were then divided by the difference between the AR's for the NWS and the EWS. This was done to provide an "equivalent" temperature difference as though the difference in AR's between the paired stations was 100%. The mean temperature differences from the six station pairs were calculated for each month. These monthly averages, rounded to the nearest 0.1 °F, were used as the basis for monthly aridity adjustments in conjunction with the aridity rating (AR).

Dew Point Temperature

Estimation of Dew Point Temperature

When humidity data are not available, the authors of ASCE-EWRI (2005) recommend that dew point temperature (T_{dew}) be estimated from the minimum daily air temperature (T_{min}) as follows:

$$T_{dew} = T_{min} - K_o \tag{10}$$

where K_o is the typical difference between T_{dew} and T_{min} for the region in question.

Huntington and Allen (2010) used spatial interpolation to estimate K_o for various hydrologic basins in Nevada from limited EWS humidity data. A similar approach was used herein. K_o was determined from EWS data for 41 sites in study area. K_o values for each NWS station were then found by spatial interpolation. The EWS data were used to characterize K_o by month for each site. For most of the sites T_{dew} was calculated from daily RH_{max} paired with T_{min} and RH_{min} paired with T_{max} (see ASCE-EWRI 2005). Only the datasets from AgriMet stations in Idaho and Wyoming contained daily mean T_{dew} values.

Inverse Distance Interpolation

Monthly average K_o values for each of the 246 NWS Stations used in this study were determined through spatial interpolation using the inverse distance squared weighting method (IDW) (Vieux 2004). In this method the value of a desired parameter (in this case K_o) at a given point is determined by taking a weighted average of the parameter from surrounding locations where the value of the parameter is known. The known values are weighted by the inverse of their distance from the point of interest. Thus, the nearby values are weighted heavier than those that are farther away as:

$$X_i = \frac{\sum_{j=1}^{n} x_{ij}\left(d_{ij}\right)^{-p}}{\sum_{j=1}^{n}\left(d_{ij}\right)^{-p}} \tag{11}$$

where X_i is the estimated parameter for time period (i.e. month) i, j is the index of the known values of that parameter at locations j = 1 through j = n, d is the distance between the locations with known values and the location for which the estimation is being made, and p is a power, in this study p = 2, which determines the effect of nearby values versus those from farther locations.

The monthly characteristic K_o values for each NWS Station were estimated by IDW from the average K_o for each month from the 41 dew point stations. Only dew point stations within 50 miles of each NWS Station were included unless there were less than three dew point stations in this radius of influence. In this case the radius was increased to include the nearest three dew point stations.

Wind Run

Characteristic Wind Run

ASCE-EWRI (2005) and Allen et al. (1998) suggest that, when missing, wind speed or wind run may be estimated by using monthly mean wind speeds for the area. Wind speed data were obtained for 92 sites in the study area. Wind speed measurement heights at the 92 sites ranged from 4.9 ft. (1.5 m) above the ground, at the USCRN Baker, NV site to 33 ft. (10 m), at many of the airport sites. For most of the sites the wind speed measurement height was between 6.6 ft. (2 m) and 9.8 ft. (3 m). The ASCE Std. Eq. requires wind speed data to be measured at 2 m above the ground (Equation 2). ASCE-EWRI (2005) provides a logarithmic method for scaling wind speed data measured at heights other than 2 m to be equivalent to wind speeds measured at 2 m.

All wind speed data from the 92 sites were adjusted as necessary for anemometer type and scaled to be representative of a 2 m measurement height. The mean daily wind run (WR, mpd) was then calculated for each month for the included years of record for each wind station. A list of the 92 wind sites with 2 m equivalent monthly mean WR is in Appendix E.

The monthly characteristic daily wind run (mpd) for each of the 246 NWS Stations was determined through spatial interpolation (IDW as described above) from the average daily wind run for the wind stations. Similar spatial and number of station limits, as used in the dew point temperature section above, were implemented for the wind interpolations.

Wind Limit

Recent studies have suggested that the ASCE Std. Eq. may over estimate ET_{rs} in areas with high wind speeds or variable diurnal wind conditions (Irmak et al. 2005; Fillmore 2007; Barker 2011). Irmak et al. (2005) found that the ASCE Std. Eq. tends to overestimate ET_{rs}, if a daily calculation time step is used, in areas with fluctuating diurnal wind. They suggested that hourly time steps may be more accurate in high wind environments.

The NWS data are only available on a daily time scale. Therefore it was not possible to calculate ET_{rs} from hourly data as suggested by Irmak et al. (2005). Instead, recognizing that wind was a primary cause for over estimations of ET_{rs}, a comparison of calculated ET_{rs} using hourly and daily time steps was performed. Hourly data from 48 EWS sites were used in the comparison. A calculation limit, or “wind limit,” was enforced on the daily wind run values at each of these sites to force daily time step calculated ET_{rs} to be equal to hourly time step calculated ET_{rs}. Calculation wind limits were determined for each month and averaged over the calculation period of record. Calculated monthly wind limits for the 48 wind limit stations are found in Appendix E. Spatial interpolation, using IDW with the previously discussed limits, was used to determine wind limits for each NWS site. Results from preliminary calculations led to our constraining the wind limits to be between 132 and 96 mpd.

Incident Solar Radiation

Incident solar radiation (R_s) can be used to estimate the net radiation (R_n) term in the ASCE Std. Eq. (ASCE-EWRI 2005) if R_n is not measured directly. Three models for estimating R_s were examined for estimating R_s from temperature data. These models include those published by: Hargreaves and Samani(1982), Thornton and Running (1999), and Allen and Robison (2007). The model of Allen and Robison is a modification of Thornton and Running's model. The Hargreaves and Samani, hereafter referred to as H-S, approach is recommended for filling in missing R_s data by both Allen et al. (1998) and ASCE-EWRI (2005).

Allen and Robison (2007) found that a modification of the model proposed by Thornton and Running (1999), hereafter referred to as T-R, estimated R_s better than H-S for locations in Idaho. The T-R model is an adaptation of a model published by Bristow and Campbell (1984). The T-R method is more complicated than H-S and requires humidity and precipitation data, in addition to T_{max} and T_{min}, as input. Allen and Robison modified the T-R method to simplify calculations and to be more accurate for a study in Idaho.

The three previously mentioned models were examined and attempts were made to calibrate each to solar radiation measurements from the EWS datasets in the study area. It was determined that a modification of the H-S model provided the best estimate of R_s for the available EWS data. A summary of the R_s model comparison is in Appendix E.

The H-S approach, following the notation of ASCE-EWRI (2005) is:

$$R_s = K_{RS}(T_{max} - T_{min})^{0.5} R_a \tag{12}$$

where K_{RS} is a coefficient related to humidity. Allen et al. (1998) and ASCE-EWRI (2005) suggest a value of 0.16 for K_{RS} for non-coastal regions if T_{max} and T_{min} are in °C. R_a is calculated extraterrestrial radiation. ASCE-EWRI (2005) provides thorough procedures for calculating R_a.

To provide better estimates of R_s, monthly average K_{RS} values were calculated for each NWS site. This was done by pairing the NWS stations with the nearest EWS with good solar radiation data. K_{RS} was then found by comparing the NWS station T_{max} - T_{min} with the EWS measured R_s. Monthly values of K_{RS} for each of the 246 NWS locations are given in Appendix F.

Crop Selection and Crop Coefficients

Crop Selection

Crops were selected for ET calculations for counties in Utah if at least 40 acres were cultivated in the county as reported by either Hill (2008) or USDA-NASS (2009). Crop lists for each NWS observation site in Utah were further evaluated to include only reasonable crops for the region around the station. This included imposing elevation limits on certain crops. Lists of crops at each NWS station site, by county, were sent to the respective County Extension Agricultural Agents to help finalize the crop lists. Crops at NWS sites outside of Utah were determined by pairing the stations outside of Utah with the nearest station in Utah within a similar elevation range. The elevation ranges used were < 3500 ft., 3500 – 6000 ft., and > 6000 ft. above MSL. A sample list of crops included at ten example NWS sites is in Table 3. A complete list of crops included at each NWS observation site is in Appendix F.

Development of Crop Coefficient Curves

Mean crop coefficient (K_{cm}) curves were developed for 18 crop types and two wetland types. K_{cm} curves were obtained or derived from a number of sources. The K_{cm} curves were represented as tabular K_{cm} values corresponding to crop growth stages. The K_{cm} curves, along with a description of the source and development of each K_{cm} curve are provided in Appendix G.

Table 3. Crop and Land Cover Types Included in Consumptive Use Estimates at Ten Example NWS Sites in Utah[a].

NWS Site	County	Alfalfa (Beef)	Alfalfa (Dairy)	Apples / Cherries	Barley	Corn	Garden Vegetables	Melon	Onion	Other Hay	Other Orchard	Pasture	Potato	Safflower	Small Fruit	Sorghum	Spring Grain	Turfgrass	Winter Wheat	Open Water - Deep	Open Water - Shallow	Wetlands - Large	Wetlands - Narrow	ETr	Total Crops
ENTERPRISE BERYL JCT	Iron	1	1		1	1	1			1		1	1				1	1		1	1	1	1	1	15
FILLMORE	Millard	1	1		1	1	1			1		1				1	1	1	1	1	1	1	1	1	16
MONTICELLO 2E	San Juan	1	1				1			1		1						1		1	1	1	1	1	11
MYTON	Duchesne	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	15
PANGUITCH	Garfield	1	1				1			1		1					1	1		1	1	1	1	1	12
RICHMOND	Cache	1	1		1	1	1	1		1		1	1	1	1	1	1	1	1	1	1	1	1	1	20
SANTAQUIN CHLORINATOR	Utah	1	1	1	1		1			1	1	1	1	1		1	1	1	1	1	1	1	1	1	18
SNOWVILLE	Box Elder	1	1		1		1			1		1		1			1	1	1	1	1	1	1	1	15
ST GEORGE	Washington	1	1		1	1	1	1	1	1	1	1	1			1	1	1		1	1	1	1	1	20
WOODRUFF	Rich	1	1				1			1		1					1	1		1	1	1	1	1	12

[a]1 means the crop or land cover was included.

Crop Growth Timing Controls

Controls were used to determine the timing of crop growth initiation (planting or spring emergence), effective full cover (typically when crop reaches maximum water consumption), and termination (harvest or fall kill). Several types of crop controls were used depending on the crop coefficient curve type.

Initiation

A number of models were explored to control crop growth initiation and allow reasonable variation between stations. The examined models included running average air temperatures, cumulative growing degree days (CGDD), and simple soil temperature models. It was discovered that accumulated Hargreaves ET_r (Hargreaves and Samani 1982), since January 1 yielded the best results. This may be because $ET_{rHargreaves}$ is related to both temperature and solar radiation, and not directly affected by humidity and wind. The monthly characteristic coefficient of temperature difference, KT in Hargreaves and Samani 1982 and K_{RS} herein, was used in the $ET_{rHargreaves}$ calculations. Thus, accumulated $ET_{rHargreaves}$ from January 1 of each year was used as the initiation control for all crops and wetland covers. A threshold value of $ET_{rHargreaves}$ was set for each crop, which, when reached or exceeded would initiate crop growth.

The initiation dates for all crops was further constrained by a specified cold temperature limit. This limit was related to the sensitivity of each crop to cold temperatures and was used as an early limit on crop growth initiation.

Effective Full Cover

Two methods were used to determine effective full cover (EFC) for each crop. The first was the number of days from initiation to EFC, held constant for all locations. The second was CGDD (Fahrenheit) from initiation to EFC. The second was used for crops that used CGDD based K_{cm} curves.

Termination

Three methods were used to determine termination of crop growth. The first was the number of days from EFC to harvest, used for crops that had K_{cm} curves defined by days. The second was CGDD from beginning growth to harvest, used for crops that had CGDD based K_{cm} curves. The third was an imposed killing frost temperature. This final method was used to terminate perennial crops and as a late limit for annual crops to prevent crop growth to continue too far into the winter months. Killing frost temperatures were determined for each crop based on local information and general rules regarding frost hardiness of crops.

Simulated cropping dates were compared with typical cropping dates reported in UAES#145 and more recent information provided by county agents in Utah. Typical planting dates for spring grain and corn for counties in Utah along with typical dates of the first cut of alfalfa are given in Table 4 as obtained from surveys sent to County Extension Agents.

Table 4. Cropping Date Information by County in Utah. Dates are for Spring Planting, except First Cutting for Alfalfa.

County	Crop	Early	Avg	Late	Notes
Beaver	Sp Grain	20-Feb	15-Mar	30-Apr	
Beaver	Alfalfa	20-May	10-Jun	30-Jun	
Beaver	Corn	24-Apr	10-May	30-May	
Box Elder	Sp Grain	25-Feb	20-Mar	15-Apr	
Box Elder	Alfalfa	15-May	5-Jun	25-Jun	
Box Elder	Corn	5-Apr	1-May	25-May	
Cache	Sp Grain	15-Mar	15-Apr	15-May	Sp Grain after Apr 15 will decrease yield 1 bu/acre/day
Cache	Alfalfa	27-May	12-Jun	27-Jun	Soil type may affect planting date of corn and grain
Cache	Corn	27-Apr	16-May	3-Jun	Corn by May 20 at latest
Carbon	Sp Grain	15-Apr	1-May	10-Jun	
Carbon	Alfalfa	1-Jun	15-Jun	25-Jun	
Carbon	Corn	15-May	25-May	10-Jun	
Daggett					Assume later than Uintah County
Davis	Sp Grain	1-Mar	1-Apr	15-Apr	
Davis	Alfalfa	15-May	1-Jun	10-Jun	
Davis	Corn	15-Apr	1-May	25-May	
Duchesne	Sp Grain	20-Mar	25-Apr	30-May	
Duchesne	Alfalfa	25-May	5-Jun	15-Jun	
Duchesne	Corn	15-May	23-May	30-May	
Emery	Sp Grain	5-Apr	4-May	1-Jun	Water not available until 15 Apr
Emery	Alfalfa	10-Jun	21-Jun	1-Jul	
Emery	Corn	1-May	24-May	15-Jun	
Garfield	Sp Grain	1-Mar	20-Apr	1-Jul	
Garfield	Alfalfa	15-Jun	25-Jun	5-Jul	
Grand	Sp Grain	10-Mar	15-Apr	20-May	Apr 15 approximately last Sp frost
Grand	Alfalfa	20-May	31-May	10-Jun	
Grand	Corn	15-Mar	23-Apr	1-Jun	
Iron	Sp Grain	15-Mar	25-Mar	15-Apr	
Iron	Alfalfa	25-May	5-Jun	20-Jun	Cubed is 7 days after baled
Iron	Alfalfa	20-May	15-Jun	25-Jun	Beryl Junction
Iron	Corn	10-May	10-May	20-May	Before 10 May potential Frost Danger
Juab	Sp Grain	1-Mar	15-Mar	5-Apr	
Juab	Alfalfa	2-May	5-Jun	15-Jun	
Juab	Corn	20-Apr	5-May	20-May	
Kane					See Garfield
Millard	Sp Grain	28-Feb	20-Mar	15-Apr	
Millard	Alfalfa	1-May	1-Jun	20-Jun	
Millard	Corn	10-Apr	25-Apr	10-May	
Morgan	Sp Grain	15-Mar	15-Apr	15-May	
Morgan	Alfalfa	7-Jun	16-Jun	25-Jun	
Morgan	Corn	7-May	16-May	25-May	
Piute	Sp Grain	5-Apr	13-May	20-Jun	Early Date is at Marysville, Late is at Greenwich (7000 ft.)
Piute	Alfalfa	24-Jun	7-Jul	20-Jul	Early Date is at Marysville, Late is at Greenwich (7000 ft.)
Piute					Last Sp frost at Greenwich is Jul 10
Rich	Sp Grain			1-May	
Rich	Alfalfa	25-Jun	30-Jun	4-Jul	
Salt Lake	Alfalfa	25-May	1-Jun	7-Jun	
Salt Lake	Corn		1-May		

Table 4, continued. Cropping Date Information by County in Utah. Dates are for Spring Planting, except First Cutting for Alfalfa.

County	Crop	Early	Avg	Late	Notes
San Juan	Alfalfa	1-Jun	15-Jun	25-Jun	One week earlier in Blanding
Sanpete	Sp Grain	15-Mar	15-Apr	15-May	Gunnison and Axtell are 1 - 2 weeks earlier
Sanpete	Alfalfa	1-Jun	15-Jun	15-Jul	Mt. Pleasant and Fairview are 1 - 2 weeks later
Sanpete	Corn	15-May	1-Jun	15-Jun	
Sevier	Sp Grain	25-Feb	29-Mar	30-Apr	
Sevier	Alfalfa	15-May	2-Jun	20-Jun	
Sevier	Corn	1-May	21-May	10-Jun	
Summit	Sp Grain	10-Apr	25-Apr	20-May	
Summit	Alfalfa	25-May	7-Jun	30-Jun	
Tooele	Sp Grain	1-Mar	27-Mar	18-Apr	
Tooele	Alfalfa	20-May	11-Jun	22-Jun	
Tooele	Corn	15-Apr	10-May	1-Jun	
Uintah	Sp Grain	1-Apr	1-May	31-May	Wheat and Barley before 15 May
Uintah	Alfalfa	25-May	10-Jun	25-Jun	Pelican Lake is about 2 wks ahead of Ashley Valley
Uintah	Corn	25-Apr	13-May	31-May	Jensen about 1 wk ahead of Ashley Valley
Utah	Sp Grain	20-Feb	5-Mar	1-May	
Utah	Alfalfa	25-May	1-Jun	20-Jun	
Utah	Corn	25-Apr	5-May	5-Jun	
Wasatch	Sp Grain	15-Apr	15-May	15-Jun	
Wasatch	Alfalfa	27-May	10-Jun	25-Jun	
Washington	Sp Grain	15-Feb	15-Mar	11-May	Enterprise and New Harmony abt 1 month behind rest of Cnty
Washington	Alfalfa	27-Mar	15-Apr	1-May	Herbs could get 2 seasons in County
Washington	Corn	15-Mar	3-Apr	1-May	
Wayne	Sp Grain	15-Apr	3-May	27-May	For Loa area
Wayne	Alfalfa	15-Jun	30-Jun	10-Jul	
Weber	Sp Grain	10-Mar	11-Apr	13-May	Sp Grain as soon as ground can be worked after Feb.
Weber	Alfalfa	28-Apr	27-May	25-Jun	Plant Alfalfa after 15 Mar
Weber	Corn	15-Apr	9-May	1-Jun	Plant Corn after 25 Apr
Weber					Ogden Valley about 2 weeks behind lower parts of County

Note: Information provided by USU Extension county agents and farmers.

A list of the general crop growth timing controls used in the study is in Table 5. Growth timing controls included cumulative growing degree days (CGDD), accumulated ETr from the Hargreaves equation and frost temperatures. Site specific adjustments of the control values in Table 5 were imposed as necessary to provide reasonable results.

Validation of Calculated Crop ET and Open Water Evaporation

Preferably, validation of the reasonableness of calculated crop ET and open water surface evaporation would rely on measured data for some crop or water body in the vicinity. In a few areas, the water necessary to grow particular crops has been empirically determined by measurements — through instrumented field research sites with weighing lysimeters or other soil water depletion field studies, such as line-source sprinkler experiments. Lysimeter data are

Table 5. General Crop Growth Controls Used in ET Calculations.

Crop	Root	GDD	Init. Type[a]	EFC	Term.	Ini.	EFC	Term.	Spring	Killing

	Dpth (ft.)	Base Temp.		Type[b]	Type[c]	Thshld[d]	Thshld[d]	Thshld[d]	Frost Temp. (°F)	Frost Temp. (°F)
Alfalfa (Beef)	4.5	32°F	ETr(Hargreaves)	CGDD	CGDD PtoT	6.5	1040	1460	17	28
Alfalfa (Dairy)	4.5	32°F	ETr(Hargreaves)	CGDD	CGDD PtoT	6.5	1040	1460	17	28
Apples / Cherries	3.5	None	ETr(Hargreaves)	Days	Days EtoT	7.5	55	260	24	24
Barley	3	32°F	ETr(Hargreaves)	CGDD	CGDD PtoT	6	1330	3190	17	28
Corn	3	86-50°F	ETr(Hargreaves)	CGDD	CGDD PtoT	12	960	2220	26	28
Garden	2	None	ETr(Hargreaves)	Days	Days EtoT	10	80	60	26	32
Melon	5	None	ETr(Hargreaves)	Days	Days EtoT	12	70	70	26	32
Onion	2.5	None	ETr(Hargreaves)	Days	Days EtoT	10	70	70	26	32
Other Hay	2	None	ETr(Hargreaves)	Days	Days EtoT	6.5	80	90	17	24
Other Orchard	3.5	None	ETr(Hargreaves)	Days	Days EtoT	7.5	55	260	24	24
Pasture	3.25	None	ETr(Hargreaves)	Days	Days EtoT	5.5	50	220	17	24
Potato	2.5	41°F	ETr(Hargreaves)	CGDD	CGDD PtoT	11	1390	3190	26	28
Safflower	3	None	ETr(Hargreaves)	Days	Days EtoT	12	40	120	26	24
Small Fruit	3	None	ETr(Hargreaves)	Days	Days EtoT	11	80	60	26	32
Sorghum	3	None	ETr(Hargreaves)	Days	Days EtoT	12	65	60	26	28
Spring Grain	3	32°F	ETr(Hargreaves)	CGDD	CGDD PtoT	6	1330	3190	17	28
Turfgrass	2	None	ETr(Hargreaves)	Days	Days EtoT	5.5	50	270	17	24
Turfgrass Dixie	2	None	ETr(Hargreaves)	Days	Days EtoT	5.5	60	270	17	24
Winter Wheat	3	32°F	ETr(Hargreaves)	CGDD	CGDD PtoT	3	1575	3150	12	28
Wetlands Large	6.5	None	ETr(Hargreaves)	Days	Days EtoT	15	45	200	28	28
Wetlands Narrow	6.5	None	ETr(Hargreaves)	Days	Days EtoT	15	45	200	28	28

[a]Intiation type: ET_r(Hargreaves) = Cumulative Hargreaves ET_r from Jan 1.
[b]EFC type: CGDD = CGDD from initiation to EFC, Days = No. Days from initiation to EFC.
[c]Termination type: CGDD PtoT = CGDD from initiation to Term., CGDD EtoT = CGDD EFC to Term., Days PtoT = No. Days from initiation to Term., Days EtoT = No. Days from EFC to Term.
[d]Crop control threshold.

not, however, readily available in Utah except in USU studies in Cache Valley and elsewhere in the Bear River Basin. Additional field estimates of ET are available from crop water use experiments with the line-source sprinkler technique from several USU studies in various locations in Utah and neighboring states. Some studies of open water surface evaporation have been done in Canada and in the Upper mid-western and eastern U.S. and on Bear Lake and Utah Lake. Results of various studies of crop ET and open water evaporation are summarized in Appendix H. Since equation calculated ET that differs from field expected estimates of crop ET was a concern in this study, a methodology was developed to validate the reasonableness of calculated ET values for the various NWS sites in Utah. Alfalfa ET was used as a “bellwether” or indicator of reasonableness of calculated crop ET because the Utah Division of Water Rights intends to use alfalfa ET (beef) for administering water right quantification. Thus, more particular notice was given to alfalfa water use as a means of validating the calculated values.

The notion that crop yield is linearly related to crop water use, ET, is well established. Higher yields are generally associated with higher amounts of crop available soil water and, consequently, greater ET (for example, Figures H1 and H2, herein). Associated with this yield ET relationship is the concept of crop water use per unit yield, i.e. expressed as inches per ton/acre, which is the reciprocal of water use efficiency (WUE). For alfalfa the value of ET per unit yield varies from about 4 to 6 inches per ton/acre and is generally greater at lower elevations and lower latitudes than at higher elevation and higher latitude sites (see discussion in Appendix H).

The validation methodology consisted of obtaining a range of field alfalfa hay yields from county extension agents and farmers throughout Utah (see Table H4) and then developing associated alfalfa ET values for each county. Alfalfa ET values were inferred from the yield versus ET relationship mentioned above through the following:

$$\text{Alfalfa ET inches per ton/acre} = 12.49 - 2.978\text{E-4 Elev} - 0.1604 \text{ Lat} \qquad (13)$$

where Elev is the site elevation, ft abv. msl and Lat is the site latitude, decimal degrees.

County better than average high alfalfa yield (representing growing conditions in three years out of five and above average management) and near perfect condition (one year out of ten) high yields are shown in Table 6 along with the associated ET inferred from the yield versus ET relationship above. County better than average (BTA) high yields varied from 4.5 ton/acre, Rich, San Juan (LaSal), Summit and Wayne, to 8 ton/acre, Washington. Whereas, near perfect condition (NPC), one year out of ten, yields varied from 5 ton/acre, Summit to 9 ton/acre, Washington. The statewide BTA average high alfalfa yield was 6.1 ton/acre and the corresponding NPC average high yield was 6.9 ton/acre for those counties with a reported value.

Inferred alfalfa ET values corresponding to BTA high yields varied from 17.8 inches, Rich and 18.7 inches, Summit, to 45.6 inches, Washington. Similarly, inferred ET for NPC high yields varied from 20.2 inches, Rich and 20.8 inches, Summit, to 51.4 inches, Washington. Calculated ET and evaporation values contained herein for the NWS stations were also compared in a more general way with corresponding values shown in Appendix H, Table H5.

Table 6. Alfalfa Hay Yields and Inferred ET by County in Utah.

County	Area	Elev.	Latitude	Better than Average High Yield	Near Perfect Condition High Yield	Inferred ET Better than Average High	Inferred ET Near Perfect Condition High
		feet	degree	ton/acre	ton/acre	inch	inch
Beaver	Beaver	5280	38.4	5.0	6.0	23.80	28.56
	Milford Flat	5010	38.4	6.0	7.0	29.04	33.88
Box Elder	Tremonton	4580	41.7	6.5	7.5	28.86	33.31
	Snowville	4560	41.7	5.5	6.5	24.46	28.90
Cache		4580	41.8	6.5	7.5	28.75	33.17
Carbon		6750	39.6	6.0	6.5	24.77	26.83
Daggett		6070	40.9	5.0	5.5	20.58	22.64
Davis		4460	40.9	7.0	8.5	32.17	39.06
Duchesne		5740	40.2	6.0	7.0	26.01	30.34
Emery	Castledale	5210	39.1	6.0	6.5	28.01	30.34
	Green River	4070	39.1	6.5	7.0	32.55	35.05
Garfield		6660	37.8	5.5	6.3*	24.66	28.04
Grand	Moab	4430	38.7	6.0	7.0	29.76	34.72
	Castle Valley	4725	38.7	6.5	7.8	31.66	37.75
Iron		5550	37.8	6.0	7.5	28.66	35.83
Juab		4850	39.7	6.5	7.0	30.38	32.71
Kane		5410	37.4	7.3	8.3*	35.53	40.56
Millard		4980	39.1	7.5	8.6*	35.53	40.74
Morgan		5090	41.0	5.5	6.5	24.15	28.54
Piute	Circleville	6120	38.3	5.0	5.5	22.63	24.89
Rich		6190	41.7	4.5	5.1*	17.83	20.21
Salt Lake	Riverton	4690	40.7	7.0	8.0	31.99	36.56
San Juan	La Sal	5510	37.7	4.5	5.5	21.59	26.39
	Blanding	6085	37.7	6.5	6.8	30.08	31.23
Sanpete	Manti	5490	39.3	6.3	7.1*	28.42	32.29
	Gunnison	5146	39.3	6.8	7.7*	31.39	35.81
Sevier		6170	38.7	6.5	7.5	28.85	33.28
Summit	Kamas	5990	40.9	4.5	5.0	18.69	20.77
Tooele		5040	40.3	7.0	8.0*	31.68	36.20
Uintah		5210	40.3	7.0	7.8	31.30	34.66
Utah		4850	40.2	6.0	7.0	27.54	32.13
Wasatch		5640	40.5	5.1	5.8	22.15	24.82
Washington	Wash. Fields	2700	37.3	8.0	9.0	45.66	51.37
	Hurricane	2900	37.3	7.0	7.5	39.54	42.36
Wayne	Bicknell	5870	38.3	4.5	5.5	20.67	25.27
Weber		4620	41.2	7.0	8.0	31.51	36.01
Max				8.0	9.0	45.66	51.37
Min				4.5	5.0	17.83	20.21
Average				6.11	6.91[a]	28.36	32.37
St Dev				0.91	1.03	5.76	6.41

Note: Adapted from Table H4 and equation 13 (eq. H1). County reported BTA and NPC high yields are from farmers, USU Extension county agents and Utah Technology College's Farm/Ranch Management Program. [a] Average for reported values only. * Estimated by multiplying BTA high yield by 1.142.

RESULTS AND DISCUSSION

Ten representative NWS stations from throughout Utah, which were also included in UAES#145, were selected for illustrating the results of the procedures described above. Most of these example NWS stations (Table 7) were also close to an EWS. Elevations of the ten stations vary from 2,770, St. George, to 6,820 ft. abv msl, Monticello.

NWS Data

Precipitation bias-adjustment factors are given in Table 8 for the ten example NWS stations. The adjustment factors in Table 8 are all less than one and vary from 0.56 (Myton) to 0.96 (Snowville). This suggests that the estimated precipitation, for missing values, is greater than if precipitation had been recorded. The R^2 values are reasonable, with all being greater than 0.65, but none were greater than 0.86. Precipitation bias-adjustment factors for all 246 stations are in Appendix B.

Table 7. Ten Example NWS Sites. A nearby EWS Located in an Irrigated Environment is shown, where applicable.

NWS Station Name	Station Index No.	Lat	Lon	Elev. (ft.)	Nearby EWS	Dist. Btwn. (mi.)
ENTERPRISE BERYL JCT	422561	37.770	-113.656	5150	USU Beryl Junction West	4.3
FILLMORE	422828	38.966	-112.328	5120	USU Flowell	5.0
MONTICELLO 2E	425805	37.874	-109.308	6818	NA	
MYTON	425969	40.194	-110.062	5080	UB Altamont	15.8
PANGUITCH	426601	37.824	-112.442	6630	USU Panguitch	3.3
RICHMOND	427271	41.906	-111.810	4680	USU Lewiston	4.4
SANTAQUIN CHLORINATOR	427686	39.958	-111.779	5160	USU Spanish Fork	11.0
SNOWVILLE	427931	41.967	-112.717	4560	USU Snowville West	10.1
ST GEORGE	427516	37.107	-113.561	2770	USU Southgate Golf Course	2.8
WOODRUFF	429595	41.525	-111.149	6315	USU Randolph Pump	21.5

Table 8. Estimated Precipitation Bias Adjustment Factors for Ten Example NWS Sites in Utah.

NWS Station Name	R^2	Adj. Factor
ENTERPRISE BERYL JCT	0.66	0.77
FILLMORE	0.78	0.95
MONTICELLO 2E	0.80	0.78
MYTON	0.71	0.56
PANGUITCH	0.65	0.84
RICHMOND	0.86	0.83
SANTAQUIN CHLORINATOR	0.80	0.64
SNOWVILLE	0.72	0.96
ST GEORGE	0.68	0.62
WOODRUFF	0.66	0.77

Note: Adjustment factor applied only to estimated values for missing data in the NWS dataset.

Input Data Estimations and Adjustments

Adjustments were made to the NWS data for local aridity effects on air temperature, and estimations were made for dew point temperature, wind run and solar radiation. These adjustments and estimation methods are discussed below.

Adjustment for Local Aridity

Aridity Rating

The Aridity Rating (AR) for each of the ten example stations in Utah is given in Table 9. The lower the AR, the more irrigated the environment is. The AR value varied from 11%, Woodruff, to 80%, St. George. AR values for all 246 NWS stations are found in Appendix B.

The coordinates for the NWS stations as reported result in an accuracy of about ± 40 ft. at the northern edge of the study area and about ± 45 ft. at the southern edge. Since the GAP land cover raster images had a resolution of 30 by 30 m (98.4 by 98.4 ft.) the accuracy of the coordinates was within the resolution of the imagery used to classify the AR for each site.

Aridity Adjustment

A summary of the aridity adjustment temperatures by site pair and the final average tabular values are found in Table 10. These varied from 1.9 (Feb) to 6.8 °F (Jun) and were applied statewide. The aridity adjustment for individual stations was determined by multiplying the adjustment for each month by the station AR/100. For example, for an AR value of 80% the temperature adjustment for June would be 5.4 °F (5.4 = 6.8 x 80/100). Thus, 5.4 °F would be subtracted from the NWS temperatures for the month of June for all years. Preliminary results indicated that calculated alfalfa ET for the SE portion of Utah was unreasonably high. This was apparently due to the arid surroundings of the NWS sites in general and correspondingly higher

Table 9. Aridity Indices for Ten Example NWS Stations in Utah.

NWS Station Name	AR (%)
ENTERPRISE BERYL JCT	60
FILLMORE	49
MONTICELLO 2E	51
MYTON	39
PANGUITCH	48
RICHMOND	36
SANTAQUIN CHLORINATOR	67
SNOWVILLE	16
ST GEORGE	80
WOODRUFF	11

Table 10. Summary Monthly Aridity Adjustment Values.

Electronic Station	NWS Coop Station	Dist. Btwn (mi.)	AR Diff.[a]	Elev. Diff. (ft)[b]	No. Yrs	Monthly Average Temperature Difference NWS - EWS											
						Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Unadjusted Average Difference																	
USU Logan Drng Frm	LOGAN RADIO KVNU	2.3	65	35	8	0.3	-1.1	-0.5	0.5	2.4	3.0	2.0	1.7	2.9	3.1	3.0	0.8
USU Panguitch	PANGUITCH	3.3	50	80	2	7.1	1.8	3.6	3.7	5.2	5.5	2.7	2.7	4.1	5.0	3.8	3.2
USU Sunbrook GC	ST GEORGE	4.0	50	105	7	-0.1	0.0	1.4	2.1	2.6	5.0	4.8	4.3	3.6	1.8	1.5	0.7
USU-94 Palmyra	SPANISH FORK PWR HOUSE	6.2	50	200	5	4.1	3.8	1.1	2.5	3.2	2.7	2.4	2.4	2.7	3.1	1.4	1.8
USU Murray GC	SALT LAKE TRIAD CTR	9.7	75	-10	9	4.8	2.8	3.6	3.1	4.1	4.5	4.7	5.8	4.5	4.3	3.2	2.6
USU Murray GC	SALT LAKE CITY INTL AP	10.5	75	-65	9	-1.9	-1.3	0.3	0.6	1.5	2.8	3.9	3.1	2.3	1.0	-0.2	-1.0
Normalized[c]																	
USU Logan Drng Frm	LOGAN RADIO KVNU	2.3	65	35	8	0.4	-1.7	-0.8	0.8	3.7	4.6	3.1	2.6	4.4	4.8	4.5	1.2
USU Panguitch	PANGUITCH	3.3	50	80	2	14.2	3.6	7.1	7.5	10.4	11.0	5.4	5.5	8.2	10.0	7.5	6.4
USU Sunbrook GC	ST GEORGE	4.0	50	105	7	-0.2	-0.1	2.7	4.3	5.3	9.9	9.6	8.5	7.1	3.5	2.9	1.5
USU-94 Palmyra	SPANISH FORK PWR HOUSE	6.2	50	200	5	8.2	7.5	2.3	5.0	6.5	5.4	4.9	4.8	5.5	6.1	2.8	3.5
USU Murray GC	SALT LAKE TRIAD CTR	9.7	75	-10	9	6.4	3.7	4.7	4.1	5.4	6.1	6.3	7.8	6.0	5.8	4.3	3.4
USU Murray GC	SALT LAKE CITY INTL AP	10.5	75	-65	9	-2.6	-1.7	0.4	0.8	2.0	3.7	5.1	4.1	3.0	1.3	-0.2	-1.3
					Average	4.4	1.9	2.7	3.7	5.5	6.8	5.7	5.6	5.7	5.2	3.6	2.4
					St Dev	6.3	3.7	2.9	2.6	2.8	3.0	2.2	2.2	1.9	2.9	2.6	2.6
					Final Aridity Adjustment	2.0[d]	1.9	2.7	3.7	5.5	6.8	5.7	5.6	5.7	5.2	3.6	2.4

[a]Difference between NWS Coop station Aridity Rating and paired electronic weather station Aridity Rating.
[b]Difference between NWS Coop station site elevation and site elevation for the paired electronic weather station.
[c]Normalized by Aridity Rating difference, (Monthly Average Temperature Difference between NWS and EWS)/(AR Difference/100%).
[d]Approximated value.

temperatures than accounted for in the statewide aridity adjustment values of Table 10. In order to achieve more reasonable, lower, alfalfa ET values, an additional temperature increment was applied to the aridity adjustment. This was subtracted from the NWS temperatures and generally varied from 1.5 to 6 °F, depending on the site. However, dew point temperature was not further adjusted.

Dew Point Temperature K_O

The NWS and EWS weather station pairs used for K_o determination and the resulting monthly average K_o values are found in Appendix E. The monthly average K_o values in midsummer ranged from less than 1 °F in Afton, Wyo., in the north to more than 22 °F at Southgate GC in St. George, in the south. The St. George weather stations (Southgate GC and Sunbrook GC) were known to be in well irrigated areas. However, there was a paved road about 200 ft. to the south of the Southgate GC station with turfgrass in between the road and the station and residential areas beyond the road. Irrigated turfgrass extended for at least 300 ft. in all other directions. The Sunbrook GC station was surrounded on all sides by irrigated turfgrass for about 490 ft. with the exception of a maintenance shed 320 ft. to the north.

Monthly characteristic K_o values for ten example NWS sites in Utah are presented in Table 11. Values of K_o for all 246 NWS stations are found in Appendix F. The K_o values peaked in mid-summer and dropped negative at nine of the ten example sites (all but St. George) in December and January. St. George had the greatest magnitude of K_o consistently and Panguitch, and Woodruff (6630 ft. and 6315 ft. abv. msl, respectively) had the smallest.

Characteristic Wind

The monthly characteristic daily wind run values, and corresponding calculation wind limits, for ten example NWS stations in Utah are presented in Table 12. The wind limit had greater influence at high wind locations, for example, Enterprise Beryl Jct, Panguitch, and Monticello than at low wind locations, Richmond and St. George. The wind at St. George did not reach the lower bound on the wind limit (96 mpd) for any month, because of low wind speeds in that region.

Table 11. Monthly Characteristic K_o Values for Ten Example NWS Sites in Utah.

NWS Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ENTERPRISE BERYL JCT	-4.2	-2.1	2	5.6	7.1	11.4	9.2	7.3	6.4	2.5	-0.5	-3.9
FILLMORE	-4.6	-1.3	3.8	6.6	7.5	10.3	11.1	10.7	8.9	4	-0.5	-5.2
MONTICELLO 2E	-0.4	2.8	6.5	9	9.3	12.9	9.8	6.9	6.1	4.7	2.3	-0.1
MYTON	-3.5	-0.6	5.8	9	10	11.5	13	9.9	8.1	4.3	2.8	-2
PANGUITCH	-8.4	-3.5	2.3	5.7	6.5	7.6	6.9	4.9	4.8	1.6	-0.4	-5.1
RICHMOND	-7	-6.6	-0.8	4.2	4.6	5.2	8	7.6	5	1.4	-1.4	-4.6
SANTAQUIN CHLORINATOR	-2.4	0.8	5.7	7.3	8.8	11.7	14.5	13.5	11.3	5	3	-1.7
SNOWVILLE	-5.9	-4.4	2.3	6.3	7.6	9.1	12.7	12.3	8.3	2.7	-0.3	-3.2
ST GEORGE	3.1	5.8	10.9	14.6	18.7	21.6	19.3	17.6	17.5	10.8	7	2.6
WOODRUFF	-6.9	-6.6	-1	3.5	4.2	4.9	7.5	7.2	4.8	1.9	-1.3	-4.8

Table 12. Characteristic Wind Run and Calculation Wind Limit for Ten Example NWS Stations in Utah.

NWS Station		Wind Run or Wind Limit (mpd)											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ENTERPRISE BERYL	WR[a]	107	107	143	168	140	143	120	122	116	114	107	101
JCT	Limit[b]	106	97	132	132	132	132	100	121	115	104	96	96
FILLMORE	WR	68	75	119	132	110	102	79	78	69	71	70	67
	Limit	96	96	113	132	99	97	96	96	96	96	96	96
MONTICELLO 2E	WR	155	154	191	219	193	166	131	137	140	157	154	157
	Limit	114	132	132	132	132	132	132	132	132	132	132	124
MYTON	WR	72	81	116	135	124	110	95	88	89	91	84	70
	Limit	96	96	108	131	121	111	96	96	96	96	96	96
PANGUITCH	WR	125	137	168	189	161	135	108	108	119	134	127	130
	Limit	96	96	132	132	132	128	96	96	96	96	96	96
RICHMOND	WR	77	71	101	118	103	94	90	98	92	89	83	79
	Limit	96	96	96	103	96	96	96	96	96	96	96	96
SANTAQUIN	WR	60	57	90	89	77	68	59	56	53	45	51	50
CHLORNTR	Limit	96	96	101	109	96	96	96	96	96	96	96	96
SNOWVILLE	WR	100	103	139	163	136	130	121	127	116	120	110	100
	Limit	96	96	114	132	113	105	103	106	96	96	96	96
ST GEORGE	WR	44	45	62	72	69	66	60	56	51	49	46	42
	Limit	96	96	96	96	96	96	96	96	96	96	96	96
WOODRUFF	WR	84	80	106	127	124	113	106	113	108	94	107	88
	Limit	96	96	102	113	109	96	96	96	96	96	96	96

[a] Characteristic wind run. [b] Calculation wind limit with a cap of 132 mpd.

ET_{rs} calculated using hourly time steps was often similar or greater than if calculated using a daily time step in the St. George area. Monthly characteristic wind run values with the monthly wind limits imposed were used as input into the software. Corresponding site values are included in the output tables. The calculation wind run limit was capped at a maximum of 132 mpd.

Monthly Solar Radiation K_{RS}

Monthly K_{RS} values for ten example sites in Utah varied from 0.119 in July at Panguitch to 0.192 in September at Fillmore (Table 13). The average K_{RS} over all the stations and months was 0.155, which is very similar to the 0.16 suggested by ASCE-EWRI (2005). However, the variation from station to station and month to month, reaffirmed that a constant value of K_{RS} would not have provided accurate results. Values of K_{RS} for all 246 NWS stations are included in Appendix F.

Validation of Calculated Crop ET and Open Water Evaporation

Calculated alfalfa (beef) ET values for all 150 NWS stations in Utah included herein were compared with the respective county range between BTA high and NPC high inferred ET(defined previously and in Appendix H) from Table 6. The initial calculation was based on

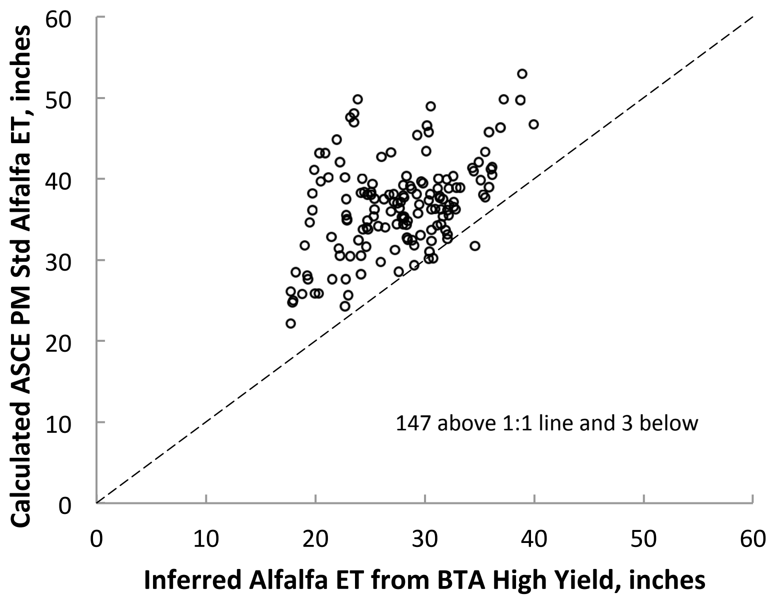
Table 13. Monthly K_{RS} for Ten NWS Sites in Utah.

NWS Station	Paired EWS	No. Yrs	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
MONTICELLO 2E	SCAN Eastland	1	0.173	0.182	0.189	0.174	0.156	0.165	0.155	0.164	0.161	0.164	0.169	0.170
MYTON	UB Altamont	20	0.157	0.165	0.157	0.146	0.145	0.145	0.142	0.142	0.148	0.153	0.158	0.157
ENTERPRISE BERYL JCT	USU Beryl Junction West	9	0.161	0.153	0.150	0.150	0.142	0.145	0.131	0.137	0.139	0.144	0.152	0.149
FILLMORE	USU Flowell	1	0.150	0.171	0.163	0.160	0.159	0.178	0.172	0.190	0.192	0.169	0.164	0.175
RICHMOND	USU Lewiston	2	0.155	0.167	0.167	0.154	0.153	0.159	0.160	0.163	0.159	0.157	0.159	0.122
PANGUITCH	USU Panguitch	2	0.157	0.160	0.160	0.150	0.138	0.151	0.119	0.132	0.136	0.146	0.143	0.136
SNOWVILLE	USU Snowville West	3	0.148	0.143	0.141	0.136	0.144	0.141	0.130	0.141	0.135	0.146	0.145	0.130
ST GEORGE	USU Southgate Golf Course	4	0.171	0.174	0.156	0.161	0.168	0.166	0.166	0.170	0.165	0.164	0.169	0.174
WOODRUFF	USU94 Randolph	2	0.142	0.175	0.161	0.144	0.146	0.145	0.145	0.140	0.137	0.139	0.145	0.150
SANTAQUIN CHLORINATOR	USU94 Santaquin	5	0.152	0.160	0.150	0.149	0.154	0.163	0.162	0.157	0.162	0.157	0.148	0.145

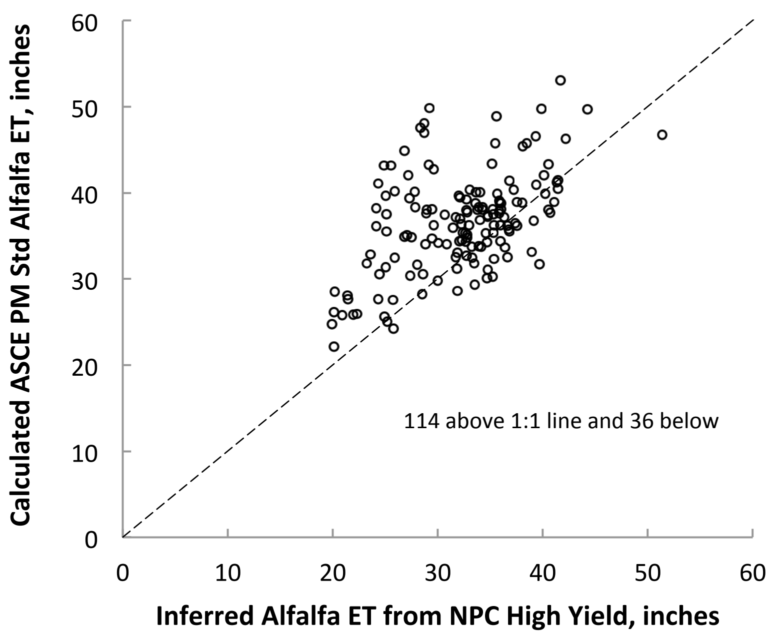
parameters for each NWS station as described previously, i.e.: aridity adjustment from the statewide values of Table 10, characteristic dew point, K_o, values and calculation wind run limit as determined from interpolation. The results for the initial calculation parameter set are shown in Figure 3. Calculated alfalfa ET values would be acceptable if they were greater than ET inferred from BTA high yields and less than ET inferred from NPC high yields.

It is clear from Figure 3b that calculated alfalfa ET for the initial calculation is unacceptably high for the majority of the 150 NWS sites in Utah, wherein calculated ET for 114 sites is higher than the 1:1 line with inferred ET from NPC high yields. Calculated ET for 36 sites is below the NPC 1:1 line, which indicates alfalfa ET for these sites may be acceptable if none of them are also below the BTA ET 1:1 line. Calculated alfalfa ET values at only three sites, Figure 3a, were lower than what may be expected for BTA high conditions. Thus, calculated alfalfa ET values at 33 sites are within the acceptable range depicted in Figure 3. Incidentally, the three sites were Mountain Dell Dam, Pineview Dam and Scipio. Calculated alfalfa (beef) ET at Scipio was the farthest below the 1:1 line in Figure 3a.

Reduction in alfalfa (beef) ET for the 114 sites of Figure 3b was accomplished through further reduction in NWS temperatures used for calculation of ASCE Std. Eq. (PM ET_r). This was done via additional temperature reduction increments of 1.5 °F in succession for those stations which remain above the 1:1 line in Figure 3b. When the station position dropped below the NPC 1:1 line, no further temperature adjustment was made unless it also dropped below the BTA 1:1 line. The progression of this process is shown in the table below. The initial run, 0 Temp. Adj,



a) Alfalfa ET Inferred from Better than Average High Yield



b) Alfalfa ET Inferred from Near Perfect Conditions High Yield

Figure 3. Calculated ASCE Std. Eq. Alfalfa ET from Initial Parameter Set and Inferred Alfalfa ET from County Better than Average (a) and Near Perfect Condition (b) High Yields.

	Number of NWS Stations			
Temp	BTA High 1:1 Line		NPC High 1:1 Line	
Adj. (°F)	Below	Above	Below	Above
0	3	147	36	114
-1.5	4	146	60	90
-3	4	146	87	63
-4.5	7	143	110	40
-6	8	142	125	25
-7.5	8	142	134	16

line corresponds to Figure 3. With each successive incremental reduction in NWS temperatures used in calculating ET_{rs}, and alfalfa ET, the relative position of the stations shift from 114 being higher than the 1:1 line with inferred ET from NPC high yields to 25 being higher with a -6 °F adjustment and 16 with -7.5 °F. However, alfalfa ET at five other sites dropped below the BTA 1:1 line. The average standard deviation of the monthly aridity adjustment values, Table 10, is 3 °F. Thus, with temperature adjustments equivalent to no more than one standard deviation, alfalfa ET at 51 NWS sites was lessened sufficiently to drop below the NPC 1:1 line of Figure 3b.

Further site specific temperature and other adjustments were made to bring the outlying stations into the acceptable area of inferred ET in Figure 3. For example, alfalfa (beef) ET at Woodruff was above the NPC 1:1 line with -3.0 °F temperature reduction. However, it became one of the sites for which calculated alfalfa (beef) ET dropped below the BTA 1:1 line in Figure 3a with a -4.5 °F adjustment. Thus, a lesser temperature adjustment of -3.5 °F was used, which placed alfalfa ET at Woodruff in the acceptable zone of Figures 3a and 3b. Similar adjustments were made to temperatures to lessen the impact at the four other sites which dropped below the BTA 1:1 line.

A positive, warmer, adjustment was made to temperatures at the three sites with alfalfa ET below the BTA 1:1 line with initial parameter conditions. This adjustment was +2.5 °F for NWS temperatures at Scipio (+0.5 °F was used for Pineview Dam and Mountain Dell Dam) in order to bring calculated alfalfa ET above the BTA inferred ET 1:1 line in Figure 3a.

The sixteen sites at which alfalfa ET remained above the NPC 1:1 line with a -7.5 F temperature adjustment were, with one exception, all from South Eastern Utah. The exception was La Verkin in Washington County. Two, Price BLM and Sunnyside City Ctr, were from Carbon County; Moab from Grand; three, Capitol Reef NP, Hanksville and Hans Flat RS, from Wayne and the remaining nine were from San Juan County. This predominance of NWS stations with high values of calculated ET from the drier areas of Utah suggests that a secondary aridity adjustment zone could have been appropriate for Southern and South Eastern Utah. This would have reduced the need for additional temperature adjustments.

The high alfalfa ET values at the sixteen sites were addressed by: 1) limiting dew point temperatures to be no more than 10 °F below the minimum daily air temperature, thus overriding the interpolated K_o values; 2) imposing a calculation wind limit cap of 120 mpd; and 3) additional temperature adjustments, as needed, beyond the -7.5 °F described above.

A comparable process was employed for evaluating calculated alfalfa ET for other states. County average yields for Arizona, Colorado, Idaho, Nevada, New Mexico and Wyoming were obtained from the respective agricultural statistics internet sites. Estimated county BTA high and NPC high alfalfa yields were obtained using the average ratios from Table H4 for Utah, since direct contact with county agents and farmers in other states was infeasible. Estimated BTA high and NPC high alfalfa yields for each of NWS stations in other states came from regression equations derived from the county alfalfa yields as a function of elevation and latitude. Some adjustment was made for known high alfalfa yields in Twin Falls County, ID (Wright 1988).

Calculated ET and evaporation values contained herein for the NWS stations were also compared in a more general way with values shown in Table H5. For example, measured evaporation on Bear Lake was 18.9 inches for Mar-Oct 1994 (Amayreh 1995). The multiplier, C_E in Equation 5 herein was adjusted such that calculated deep lake evaporation for 1994 at Lifton, ID NWS better matched measured evaporation from Bear Lake by Amayreh (1995).

Example ET and Net Irrigation Estimates

Thirty-eight year average crop and wetland ET and net irrigation requirements, along with open water surface evaporation were calculated for the 246 NWS sites included in the study. Tables 14 through 23 are illustrative results for the ten example NWS sites in Utah: Enterprise Beryl Jct, Fillmore, Monticello 2E, Myton, Panguitch, Richmond, Santaquin Chlorinator, Snowville, St George, and Woodruff. Thirty-eight year average annual air temperature varied from 39.35 °F, Woodruff, to 63.19 °F, St George. Annual total precipitation varied from 7.33 inches, Myton, to 20.29 inches, Richmond. The NWS station aridity index, AR, varied from 11%, Woodruff, to 80% at St. George and the additional temperature adjustment varied from 0 °F (Enterprise Beryl Jct, Fillmore and St George) to -7.5 F at Monticello. ET of alfalfa (beef) was lowest at Woodruff, 19.33 inches, and highest at St George, 46.75 inches. Equivalent output tables of average monthly air temperature, precipitation, crop ET, net irrigation and open water surface evaporation for all 246 NWS sites are found in Appendix I (bound separately) and for the EWS sites in Appendix J (also bound separately).

Comparison of Example Site Crop ET with Previous Estimates

Estimated crop ET for four crops, open water surface evaporation and ET_r from the present study and UAES#145 are given in Table 24 for the ten example stations. The four crops are: alfalfa (beef cutting practices), pasture, spring grain, and turfgrass. Alfalfa (Beef) ET was 5%

lower on average in the current study than alfalfa in UAES#145 and varied from 18% lower at Woodruff to 14% higher at Richmond. Pasture ET was 3% higher on average than in UAES#145 and spring grain ET 2% higher. The differences may be a result of a variable growing season in the current model and increased reference ET as well as the additional temperature adjustments which were imposed.

Evaporation from shallow open water surfaces averaged 5% higher in the current study (Table 24) than in UAES#145 and varied from 0% difference at Richmond to 22% higher at Snowville. Evaporation from deep open water surfaces was generally significantly less than from shallow except at Beryl Jct. High wind travel may have attributed to this.

Spring grain ET, while 2% higher on average, was similar to UAES#145 at some sites, more than 8% less than in #145 at Woodruff and Santaquin Chlorinator, and about 3 inches greater at Enterprise Beryl Jct. Turfgrass ET averaged 4% higher and was greater at all locations, except Monticello, Woodruff and Snowville, in this study than in UAES#145. The increase is due to using a crop coefficient of 0.6 (0.65 in the south) instead of the 0.56 used previously, and to increased reference ET.

Reference ET (ET_{rs}) calculated in the current study was greater than the ET_r reported in UAES#145 at all ten locations. This caused crop ET to be generally greater as well. However, crop ET was 5% lower to 4% greater on average than in UAES#145, while ET_{rs} was 16% greater than ET_r. This may be partly due to the ASCE Std. Eq. overestimating ET_r in the winter months relative to the Kimberly Penman Eq. (see Wright et al. 2000).

Table 14. Estimated Consumptive Use for NWS Station: ENTERPRISE BERYL JCT

Aridity Index: 60%, Temp. Adj. (F): 0, Period: 1971-2008, Lat: 37.77, Long: -113.66, Elev: 5150 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Temp (F)	27.84	32.82	39.74	45.84	54.68	63.46	70.51	69.00	60.12	49.10	36.61	27.96	48.14
St Dev	5.11	3.67	2.81	2.91	2.61	2.40	1.98	1.88	1.99	2.44	2.86	4.11	1.14
Precip (in)	0.78	0.94	1.28	0.83	0.75	0.48	1.02	1.03	0.85	1.15	0.76	0.72	10.61
St Dev	0.74	0.73	1.12	0.67	0.60	0.60	0.91	0.71	0.90	0.84	0.61	0.63	2.45
Aridity Adj. (F)	1.20	1.14	1.62	2.22	3.30	4.08	3.42	3.36	3.42	3.12	2.16	1.44	2.54
Est. Dewpoint (F)	16.63	19.38	19.46	19.73	24.93	26.84	37.16	38.52	29.56	23.87	18.08	14.90	24.09
Rs (langleys/day)	248	310	431	563	623	695	607	561	483	372	272	220	449
Wind (mpd)	107	107	143	168	140	143	120	122	116	114	107	101	124
Calc. Wind Limit (mpd)	106	97	132	132	132	132	100	121	115	104	96	96	114
	. . . . Inches												
Alfalfa (Beef)				0.78	6.90	8.23	8.69	8.26	2.80	0.10			35.76
St Dev				0.15	0.84	0.44	0.70	0.91	1.39	0.40			1.88
Net Irr				0.12	6.30	7.85	7.87	7.43	2.12				31.68
Alfalfa (Dairy)				0.78	6.90	8.11	7.49	7.13	3.07	0.08			33.56
St Dev				0.15	0.84	0.55	0.38	0.66	1.54	0.35			2.30
Net Irr				0.12	6.30	7.72	6.67	6.30	2.39				29.50
Barley				0.35	3.68	10.24	8.91	1.02					24.21
St Dev				0.06	0.69	0.99	0.94	0.76					0.77
Net Irr					3.08	9.85	8.09	0.20					21.23
Corn					0.08	2.63	7.63	9.54	3.71	0.06			23.65
St Dev					0.03	0.32	0.72	0.42	1.69	0.21			2.02
Net Irr						2.25	6.81	8.71	3.03				20.80
Other Hay				0.77	7.34	11.07	6.72	3.64	1.63	0.08			31.25
St Dev				0.15	0.71	0.71	0.38	0.15	0.51	0.15			1.44
Net Irr				0.11	6.74	10.68	5.90	2.81	0.95				27.19
Pasture				0.50	4.62	7.25	6.85	6.65	3.50	0.24			29.61
St Dev				0.09	0.45	0.46	0.35	0.29	1.36	0.49			1.83
Net Irr					4.02	6.86	6.03	5.82	2.82				25.56
Potato					0.08	2.81	6.74	7.49	3.13	0.07			20.32
St Dev					0.03	0.39	0.58	0.35	1.46	0.25			1.79
Net Irr						2.43	5.92	6.66	2.45				17.46
Spring Grain				0.35	3.51	10.01	9.55	2.11					25.52
St Dev				0.06	0.64	1.02	0.70	1.06					0.81
Net Irr					2.91	9.62	8.73	1.28					22.54

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 14. Continued. Estimated Consumptive Use for NWS Station: ENTERPRISE BERYL JCT

Aridity Index: 60%, Temp. Adj. (F): 0, Period: 1971-2008, Lat: 37.77, Long: -113.66, Elev: 5150 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
	Inches												
Garden					0.10	2.84	4.53	7.22	2.22	0.01			16.92
St Dev					0.04	0.18	0.23	0.68	1.69	0.06			2.11
Net Irr						2.46	3.71	6.39	1.54				14.10
Turfgrass				0.79	4.15	6.29	6.04	5.92	3.54	0.29			27.03
St Dev				0.14	0.39	0.40	0.31	0.25	1.21	0.57			1.62
Net Irr				0.13	3.55	5.90	5.23	5.10	2.86				22.76
Open Water Deep	1.37	1.31	2.37	2.88	4.09	5.73	5.37	6.43	4.52	3.33	1.98	1.33	40.72
St Dev	0.31	0.23	0.40	0.37	0.46	0.49	0.37	0.35	0.32	0.35	0.29	0.23	1.89
Net Evap	0.75	0.55	1.34	2.22	3.49	5.34	4.55	5.60	3.84	2.42	1.37	0.75	32.23
Open Water Shallow	1.22	1.66	3.16	4.31	5.39	6.22	6.03	5.81	4.51	3.07	1.70	1.11	44.18
St Dev	0.22	0.23	0.37	0.34	0.37	0.28	0.22	0.17	0.23	0.24	0.21	0.16	1.39
Net Evap	0.60	0.90	2.13	3.65	4.79	5.83	5.21	4.98	3.83	2.15	1.09	0.53	35.69
Wetlands Large						3.51	9.21	10.31	4.81	0.12			27.96
St Dev						0.22	0.47	0.52	2.27	0.44			2.57
Net ET						3.12	8.39	9.48	4.13				25.12
Wetlands Narrow						4.55	13.05	14.73	6.87	0.17			39.36
St Dev						0.29	0.67	0.74	3.24	0.63			3.68
Net ET						4.16	12.23	13.90	6.19				36.48
ETr	1.89	2.37	4.91	6.61	8.67	10.67	10.07	9.87	7.75	5.28	2.88	1.90	72.85
St Dev	0.52	0.49	0.86	0.71	0.80	0.68	0.52	0.41	0.59	0.63	0.54	0.41	3.30

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 15. Estimated Consumptive Use for NWS Station: FILLMORE

Aridity Index: 49%, Temp. Adj. (F): 0, Period: 1971-2008, Lat: 38.97, Long: -112.33, Elev: 5120 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Temp (F)	29.44	34.41	42.83	49.68	58.57	68.27	75.67	73.76	64.67	52.63	39.44	30.03	51.62
St Dev	5.15	3.92	3.61	3.61	3.07	3.00	2.29	1.84	2.34	3.07	3.78	4.12	1.50
Precip (in)	1.38	1.43	1.94	1.79	1.60	0.75	0.76	0.84	1.09	1.77	1.46	1.40	16.21
St Dev	0.77	0.87	0.93	1.01	1.00	0.74	0.51	0.62	0.99	1.24	0.98	0.88	3.64
Aridity Adj. (F)	0.98	0.93	1.32	1.81	2.70	3.33	2.79	2.74	2.79	2.55	1.76	1.18	2.07
Est. Dewpoint (F)	22.89	23.64	25.09	27.44	33.55	38.59	46.03	45.16	37.68	31.79	26.60	23.68	31.84
Rs (langleys/day)	189	297	404	520	609	731	690	653	540	363	234	201	453
Wind (mpd)	68	75	119	132	110	102	79	78	69	71	70	67	87
Calc. Wind Limit (mpd)	96	96	113	132	99	97	96	96	96	96	96	96	101
							Inches						
Alfalfa (Beef)			0.09	3.84	6.38	8.00	7.20	6.84	4.77	0.94	0.01		38.07
St Dev			0.19	0.78	0.42	0.95	0.43	0.50	1.00	1.05	0.04		2.19
Net Irr				2.41	5.10	7.41	6.60	6.17	3.90				31.58
Alfalfa (Dairy)			0.09	3.84	5.84	6.98	7.21	6.55	4.21	0.95	0.01		35.68
St Dev			0.19	0.78	0.34	0.37	0.33	0.24	0.80	0.98	0.04		1.94
Net Irr				2.41	4.56	6.38	6.60	5.87	3.34				29.17
Barley			0.11	1.99	6.23	9.21	2.81						20.34
St Dev			0.12	0.56	0.97	0.51	1.74						0.77
Net Irr				0.55	4.95	8.61	2.20						16.31
Corn				0.02	1.39	4.93	9.12	6.28	0.85				22.59
St Dev				0.07	0.26	1.23	0.45	1.14	0.83				1.12
Net Irr					0.11	4.33	8.52	5.61					18.56
Other Hay			0.09	4.10	7.67	7.58	3.82	2.58	0.84				26.68
St Dev			0.20	0.81	0.51	0.73	0.26	0.15	0.21				1.05
Net Irr				2.67	6.38	6.98	3.21	1.91					21.16
Pasture			0.32	3.18	5.04	6.31	6.48	5.88	3.90	1.69	0.11		32.92
St Dev			0.23	0.45	0.34	0.36	0.29	0.21	0.43	0.84	0.23		1.98
Net Irr				1.75	3.76	5.71	5.87	5.21	3.03	0.27			25.61
Sorghum				0.03	1.81	6.04	8.52	7.77	1.42				25.59
St Dev				0.08	0.39	0.82	0.39	0.31	0.81				0.92
Net Irr					0.53	5.44	7.92	7.10	0.55				21.54
Spring Grain			0.11	1.90	5.98	9.40	4.05	0.03					21.47
St Dev			0.12	0.53	1.01	0.52	1.87	0.10					0.79
Net Irr				0.47	4.70	8.80	3.44						17.41
Winter Wheat		0.04	1.04	2.53	6.51	8.36	1.63						20.11
St Dev		0.05	0.19	0.67	1.06	1.01	1.35						0.84
Net Irr				1.10	5.23	7.76	1.02						15.11

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 15. Continued. Estimated Consumptive Use for NWS Station: FILLMORE

Aridity Index: 49%, Temp. Adj. (F): 0, Period: 1971-2008, Lat: 38.97, Long: -112.33, Elev: 5120 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
	. . . .	. . . .	. . . .	. . . .	. . . .	. . . .	Inches	. . . .	. . . .	. . . .	. . . .	. . . .	
Garden				0.37	2.13	4.73	7.51	5.78	0.82				21.35
St Dev				0.20	0.19	0.50	0.42	0.43	0.33				0.77
Net Irr					0.85	4.13	6.90	5.11					16.99
Turfgrass			0.49	2.91	4.35	5.57	5.72	5.20	3.59	1.77	0.13		29.73
St Dev			0.31	0.30	0.30	0.32	0.26	0.19	0.28	0.82	0.25		1.69
Net Irr				1.48	3.07	4.97	5.11	4.52	2.72	0.35			22.23
Open Water Deep	0.76	0.98	2.13	3.03	3.19	4.42	4.76	4.79	2.99	2.40	1.39	0.75	31.58
St Dev	0.15	0.17	0.30	0.40	0.34	0.44	0.35	0.25	0.24	0.26	0.24	0.13	1.42
Net Evap			0.58	1.59	1.91	3.82	4.15	4.11	2.13	0.98	0.22		19.49
Open Water Shallow	0.89	1.56	3.06	4.27	5.31	6.44	6.74	6.44	4.78	2.95	1.44	0.86	44.74
St Dev	0.14	0.20	0.26	0.31	0.29	0.30	0.25	0.17	0.20	0.22	0.19	0.13	1.16
Net Evap		0.42	1.51	2.84	4.03	5.84	6.14	5.77	3.91	1.53	0.27		32.25
Wetlands Large					1.10	7.00	9.97	9.10	6.00	1.70	0.03		34.89
St Dev					0.51	0.98	0.45	0.33	0.86	1.48	0.13		2.79
Net ET						6.40	9.36	8.42	5.13	0.28			29.60
Wetlands Narrow					1.37	9.77	14.24	12.99	8.57	2.43	0.04		49.40
St Dev					0.67	1.44	0.64	0.47	1.23	2.11	0.18		4.00
Net ET					0.09	9.17	13.63	12.32	7.70	1.01			43.92
ETr	1.07	1.87	4.24	6.14	7.44	9.28	9.53	8.66	6.07	3.88	1.88	0.96	61.03
St Dev	0.23	0.31	0.45	0.55	0.50	0.54	0.43	0.31	0.32	0.33	0.30	0.19	2.14

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 16. Estimated Consumptive Use for NWS Station: MONTICELLO 2E

Aridity Index: 51%, Temp. Adj. (F): -7.5, Period: 1971-2008, Lat: 37.87, Long: -109.31, Elev: 6818 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Temp (F)	24.37	28.92	36.85	44.52	53.14	62.75	68.88	66.69	58.65	47.33	34.68	25.83	46.05
St Dev	4.48	3.85	3.17	2.89	2.49	2.49	1.88	1.72	2.07	2.40	2.95	3.40	1.25
Precip (in)	1.78	1.37	1.19	0.93	0.95	0.59	1.33	1.87	1.64	1.81	1.42	1.49	16.38
St Dev	1.80	1.10	0.97	0.80	0.76	0.57	0.91	0.96	1.09	1.54	1.06	1.44	3.89
Aridity Adj. (F)	1.02	0.97	1.38	1.89	2.81	3.47	2.91	2.86	2.91	2.65	1.84	1.22	2.16
Est. Dewpoint (F)	13.05	14.25	16.94	19.56	25.88	29.49	40.32	42.03	34.56	25.94	18.96	14.05	24.59
Rs (langleys/day)	231	319	460	573	606	706	628	581	477	357	250	206	450
Wind (mpd)	155	154	191	219	193	166	131	137	140	157	154	157	163
Calc. Wind Limit (mpd)	114	132	132	132	132	132	132	132	132	132	132	124	130
							Inches						
Alfalfa (Beef)					2.62	7.38	6.30	5.19	1.57				23.07
St Dev					0.34	0.57	0.32	0.58	1.27				1.69
Net Irr					1.86	6.91	5.24	3.69	0.26				17.96
Alfalfa (Dairy)					2.62	7.14	6.26	4.88	1.20				22.10
St Dev					0.34	0.43	0.36	0.82	0.84				1.53
Net Irr					1.86	6.66	5.20	3.38					17.11
Other Hay					2.85	8.18	7.81	3.10	1.23	0.03			23.20
St Dev					0.31	0.47	0.45	0.18	0.40	0.08			1.05
Net Irr					2.09	7.70	6.75	1.60					18.15
Pasture					1.73	5.30	5.61	4.72	2.18	0.05			19.60
St Dev					0.19	0.31	0.31	0.28	0.84	0.15			1.24
Net Irr					0.98	4.83	4.55	3.22	0.86				14.44

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 16. Continued. Estimated Consumptive Use for NWS Station: MONTICELLO 2E

Aridity Index: 51%, Temp. Adj. (F): -7.5, Period: 1971-2008, Lat: 37.87, Long: -109.31, Elev: 6818 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
	. . . .						Inches					. . . .	
Garden						1.57	3.08	4.54	0.88				10.07
St Dev						0.09	0.17	0.38	0.97				1.18
Net Irr						1.10	2.02	3.04					6.16
Turfgrass					2.06	4.38	4.95	4.19	2.21	0.07			17.86
St Dev					0.21	0.25	0.28	0.25	0.77	0.19			1.10
Net Irr					1.30	3.91	3.89	2.69	0.90				12.69
Open Water Deep	0.64	0.86	1.20	1.62	2.30	3.57	3.87	3.54	2.60	2.27	1.35	0.76	24.58
St Dev	0.14	0.16	0.22	0.21	0.27	0.32	0.28	0.24	0.26	0.31	0.25	0.16	1.10
Net Evap			0.25	0.88	1.54	3.09	2.81	2.04	1.28	0.82	0.21		12.92
Open Water Shallow	0.73	1.25	2.56	3.64	4.48	5.57	5.57	5.05	3.73	2.41	1.17	0.67	36.82
St Dev	0.13	0.17	0.29	0.29	0.30	0.25	0.22	0.21	0.23	0.26	0.18	0.13	1.01
Net Evap		0.15	1.60	2.90	3.72	5.09	4.51	3.55	2.42	0.96	0.03		24.94
Wetlands Large						1.82	6.87	7.12	2.55	0.01			18.37
St Dev						0.18	0.41	0.76	1.58	0.05			2.09
Net ET						1.35	5.81	5.62	1.23				14.01
Wetlands Narrow						2.31	9.65	10.17	3.64	0.01			25.79
St Dev						0.23	0.58	1.09	2.25	0.07			2.98
Net ET						1.83	8.59	8.68	2.33				21.43
ETr	0.78	1.41	3.01	4.58	6.09	8.13	8.25	6.99	5.19	3.40	1.56	0.79	50.16
St Dev	0.23	0.28	0.45	0.46	0.54	0.48	0.46	0.42	0.45	0.52	0.37	0.27	1.92

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 17. Estimated Consumptive Use for NWS Station: MYTON

Aridity Index: 39%, Temp. Adj. (F): -4.5, Period: 1971-2008, Lat: 40.19, Long: -110.06, Elev: 5080 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Temp (F)	17.23	24.25	38.24	47.52	56.70	65.71	72.53	70.17	60.86	48.53	33.78	20.92	46.37
St Dev	7.74	7.16	3.99	3.37	2.32	2.65	2.17	1.78	2.21	2.41	3.11	5.27	1.93
Precip (in)	0.43	0.36	0.49	0.70	0.86	0.55	0.54	0.65	0.88	0.92	0.48	0.48	7.33
St Dev	0.50	0.28	0.44	0.62	0.70	0.56	0.51	0.48	0.77	0.93	0.41	0.83	2.32
Aridity Adj. (F)	0.78	0.74	1.05	1.44	2.15	2.65	2.22	2.18	2.22	2.03	1.40	0.94	1.65
Est. Dewpoint (F)	6.57	10.38	16.53	20.84	28.22	33.76	39.54	40.69	33.08	25.91	15.92	9.17	23.38
Rs (langleys/day)	217	309	415	510	583	640	609	539	459	342	235	190	421
Wind (mpd)	72	81	116	135	124	110	95	88	89	91	84	70	96
Calc. Wind Limit (mpd)	96	96	108	131	121	111	96	96	96	96	96	96	103
	. . . . Inches												
Alfalfa (Beef)				1.32	5.94	6.70	7.80	6.40	2.64	0.17			30.97
St Dev				0.68	0.84	0.40	0.60	0.71	1.01	0.35			2.09
Net Irr				0.76	5.25	6.26	7.37	5.88	1.94				27.46
Alfalfa (Dairy)				1.32	5.91	6.52	6.78	5.65	2.92	0.15			29.26
St Dev				0.68	0.80	0.49	0.28	0.24	0.96	0.32			2.05
Net Irr				0.76	5.23	6.08	6.35	5.13	2.22				25.76
Barley				0.60	3.39	8.26	8.10	1.02					21.38
St Dev				0.24	0.81	0.93	0.78	0.88					0.57
Net Irr				0.04	2.71	7.82	7.67	0.50					18.74
Corn					0.43	2.28	6.90	7.47	3.57	0.16			20.82
St Dev					0.16	0.43	0.97	0.23	1.06	0.33			1.85
Net Irr						1.84	6.47	6.95	2.87				18.13
Other Hay				1.40	6.57	8.64	5.32	2.70	1.29	0.06			25.98
St Dev				0.73	0.89	0.61	1.01	0.18	0.23	0.13			1.25
Net Irr				0.84	5.89	8.20	4.89	2.17	0.59				22.57
Pasture				1.05	4.42	5.83	6.19	5.17	3.06	0.36			26.08
St Dev				0.33	0.42	0.41	0.27	0.19	0.74	0.48			1.67
Net Irr				0.49	3.73	5.39	5.76	4.65	2.36				22.38
Sorghum					0.54	3.10	7.26	6.88	3.56	0.02			21.36
St Dev					0.20	0.36	0.50	0.25	0.98	0.08			1.47
Net Irr						2.66	6.83	6.36	2.86				18.71
Spring Grain				0.60	3.22	8.08	8.65	1.96	0.01				22.51
St Dev				0.24	0.76	0.97	0.56	1.12	0.03				0.62
Net Irr				0.04	2.54	7.64	8.22	1.44					19.87

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 17. Continued. Estimated Consumptive Use for NWS Station: MYTON

Aridity Index: 39%, Temp. Adj. (F): -4.5, Period: 1971-2008, Lat: 40.19, Long: -110.06, Elev: 5080 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
	. . . .						Inches					. . . .	
Garden					0.64	2.56	4.87	6.01	2.13	0.01			16.22
St Dev					0.08	0.18	0.23	0.63	1.15	0.04			1.67
Net Irr						2.12	4.44	5.49	1.43				13.48
Turfgrass				1.39	3.71	5.13	5.46	4.59	3.02	0.44			23.74
St Dev				0.41	0.30	0.37	0.24	0.17	0.56	0.54			1.49
Net Irr				0.83	3.03	4.68	5.03	4.07	2.32				19.96
Open Water Deep	0.45	0.61	1.50	2.46	3.20	4.01	4.57	3.97	2.82	2.21	1.21	0.52	27.52
St Dev	0.14	0.15	0.27	0.34	0.33	0.41	0.34	0.21	0.21	0.26	0.18	0.13	1.41
Net Evap	0.11	0.32	1.11	1.90	2.52	3.56	4.14	3.45	2.12	1.48	0.83	0.14	21.66
Open Water Shallow	0.62	1.13	2.62	3.81	4.87	5.52	5.86	5.16	3.90	2.49	1.20	0.60	37.77
St Dev	0.16	0.21	0.31	0.31	0.29	0.30	0.21	0.15	0.17	0.21	0.15	0.12	1.21
Net Evap	0.28	0.84	2.23	3.25	4.19	5.07	5.43	4.64	3.20	1.76	0.81	0.22	31.90
Wetlands Large					0.07	3.66	8.67	8.03	4.40	0.24			25.06
St Dev					0.09	1.12	0.78	0.29	1.36	0.47			2.69
Net ET						3.21	8.24	7.51	3.70				22.66
Wetlands Narrow					0.07	4.84	12.32	11.47	6.29	0.34			35.33
St Dev					0.10	1.56	1.16	0.42	1.94	0.67			3.85
Net ET						4.40	11.89	10.95	5.59				32.82
ETr	0.79	1.39	3.63	5.66	7.27	8.58	9.10	7.65	5.74	3.72	1.77	0.81	56.11
St Dev	0.25	0.29	0.55	0.58	0.57	0.61	0.40	0.28	0.32	0.43	0.31	0.21	2.24

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 18. Estimated Consumptive Use for NWS Station: PANGUITCH

Aridity Index: 48%, Temp. Adj. (F): -1.5, Period: 1971-2008, Lat: 37.82, Long: -112.44, Elev: 6630 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Temp (F)	25.15	29.72	36.95	43.52	52.13	60.60	66.88	64.70	57.04	46.49	34.69	25.93	45.32
St Dev	4.21	3.33	3.21	3.22	3.03	2.86	2.38	2.05	2.17	2.54	3.33	3.56	1.52
Precip (in)	0.63	0.68	0.65	0.58	0.70	0.49	1.07	1.67	0.92	1.00	0.68	0.52	9.58
St Dev	0.64	0.60	0.56	0.50	0.59	0.54	0.65	1.26	1.00	0.86	0.65	0.47	2.52
Aridity Adj. (F)	0.96	0.91	1.30	1.78	2.64	3.26	2.74	2.69	2.74	2.50	1.73	1.15	2.03
Est. Dewpoint (F)	17.29	17.19	17.35	18.29	23.93	28.68	36.98	37.77	29.24	23.05	16.70	14.23	23.39
Rs (langleys/day)	253	333	453	556	601	722	545	534	467	375	255	201	441
Wind (mpd)	125	137	168	189	161	135	108	108	119	134	127	130	137
Calc. Wind Limit (mpd)	96	96	132	132	132	128	96	96	96	96	96	96	108
						Inches							
Alfalfa (Beef)					4.90	8.48	7.12	5.08	1.78	0.01			27.37
St Dev					0.66	0.48	1.06	1.25	1.53	0.08			3.37
Net Irr					4.34	8.09	6.27	3.75	1.04				23.49
Alfalfa (Dairy)					4.90	7.60	6.57	5.47	1.66	0.01			26.21
St Dev					0.66	0.47	0.35	1.08	1.57	0.08			2.72
Net Irr					4.34	7.21	5.72	4.13	0.92				22.32
Other Hay					5.21	10.04	7.26	3.07	1.18	0.04			26.80
St Dev					0.53	0.70	0.40	0.18	0.58	0.10			1.44
Net Irr					4.66	9.65	6.41	1.73	0.44				22.89
Pasture					3.25	6.50	5.89	5.18	2.18	0.07			23.07
St Dev					0.33	0.45	0.31	0.39	1.25	0.20			1.85
Net Irr					2.69	6.11	5.03	3.85	1.44				19.13
Spring Grain					2.12	7.49	8.84	4.76	0.25				23.45
St Dev					0.46	1.23	0.42	1.52	0.31				1.07
Net Irr					1.56	7.09	7.99	3.43					20.07

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 18. Continued. Estimated Consumptive Use for NWS Station: PANGUITCH

Aridity Index: 48%, Temp. Adj. (F): -1.5, Period: 1971-2008, Lat: 37.82, Long: -112.44, Elev: 6630 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
	. . . .						Inches						
Garden						1.95	3.30	5.13	1.10				11.48
St Dev						0.14	0.18	0.46	1.14				1.51
Net Irr						1.56	2.45	3.80	0.36				8.16
Turfgrass					3.42	5.49	5.19	4.65	2.26	0.10			21.10
St Dev					0.34	0.38	0.28	0.29	1.17	0.26			1.66
Net Irr					2.86	5.10	4.34	3.31	1.52				17.13
Open Water Deep	0.83	1.00	1.95	2.44	3.46	4.48	4.09	3.95	3.08	2.57	1.71	1.05	30.62
St Dev	0.17	0.18	0.33	0.34	0.44	0.47	0.35	0.28	0.25	0.30	0.28	0.19	1.82
Net Evap	0.33	0.46	1.42	1.97	2.90	4.09	3.24	2.61	2.34	1.78	1.17	0.64	22.96
Open Water Shallow	1.00	1.56	3.03	4.06	5.01	6.03	5.27	5.05	4.03	2.84	1.52	0.93	40.34
St Dev	0.15	0.20	0.33	0.34	0.34	0.30	0.21	0.19	0.21	0.24	0.20	0.14	1.27
Net Evap	0.49	1.02	2.51	3.59	4.45	5.64	4.42	3.72	3.29	2.05	0.98	0.52	32.68
Wetlands Large						2.39	7.40	7.77	2.66	0.04			20.26
St Dev						0.17	0.41	1.42	2.12	0.26			3.17
Net ET						2.00	6.54	6.44	1.92				16.90
Wetlands Narrow						3.04	10.42	11.10	3.80	0.06			28.43
St Dev						0.21	0.59	2.02	3.02	0.38			4.52
Net ET						2.65	9.57	9.77	3.07				25.05
ETr	1.34	2.07	4.32	5.98	7.85	9.69	8.66	7.82	6.34	4.54	2.57	1.58	62.77
St Dev	0.31	0.38	0.67	0.66	0.71	0.67	0.46	0.42	0.46	0.55	0.47	0.34	2.59

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 19. Estimated Consumptive Use for NWS Station: RICHMOND

Aridity Index: 36%, Temp. Adj. (F): -1.5, Period: 1971-2008, Lat: 41.91, Long: -111.81, Elev: 4680 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Temp (F)	23.18	27.73	38.06	46.45	54.80	64.07	72.53	71.15	61.17	49.08	35.55	25.17	47.41
St Dev	5.92	5.28	4.19	3.44	2.69	2.89	2.93	2.24	3.01	2.66	3.74	4.52	1.76
Precip (in)	1.73	1.70	2.12	2.32	2.45	1.28	0.86	0.94	1.46	2.04	1.68	1.73	20.29
St Dev	1.05	0.90	0.99	1.38	1.37	0.97	0.82	0.98	1.23	1.30	0.94	1.12	5.46
Aridity Adj. (F)	0.72	0.68	0.97	1.33	1.98	2.45	2.05	2.02	2.05	1.87	1.30	0.86	1.52
Est. Dewpoint (F)	20.88	23.72	26.56	27.56	33.25	39.45	43.86	43.50	37.30	31.50	25.55	20.27	31.12
Rs (langleys/day)	159	252	373	479	584	682	696	617	470	313	190	111	411
Wind (mpd)	77	71	101	118	103	94	90	98	92	89	83	79	91
Calc. Wind Limit (mpd)	96	96	96	103	96	96	96	96	96	96	96	96	97
							Inches						
Alfalfa (Beef)				1.29	5.50	6.27	8.10	7.61	3.31	0.37			32.46
St Dev				0.68	0.71	0.55	0.63	0.76	1.13	0.63			2.67
Net Irr					3.54	5.25	7.42	6.86	2.14				25.20
Alfalfa (Dairy)				1.29	5.37	6.18	7.26	6.67	3.54	0.35			30.65
St Dev				0.68	0.59	0.54	0.41	0.30	0.94	0.54			2.42
Net Irr					3.41	5.16	6.57	5.92	2.37				23.43
Barley				0.70	3.61	8.06	7.29	0.41					20.06
St Dev				0.32	0.99	0.90	1.53	0.56					0.64
Net Irr					1.65	7.04	6.60						15.29
Corn					0.59	2.50	8.01	8.40	3.59	0.16			23.25
St Dev					0.26	0.77	1.18	0.42	0.87	0.24			1.68
Net Irr						1.48	7.32	7.65	2.42				18.88
Melon					0.56	3.54	6.32	5.75	2.44	0.06			18.66
St Dev					0.29	0.76	0.36	0.34	1.14	0.23			1.87
Net Irr						2.52	5.63	5.00	1.27				14.42
Other Hay				1.35	6.01	8.06	5.41	3.10	1.40	0.09			25.41
St Dev				0.72	0.73	0.63	0.85	0.16	0.23	0.11			1.31
Net Irr					4.05	7.04	4.72	2.35	0.23				18.39
Pasture				1.40	4.16	5.51	6.63	6.07	3.70	0.96	0.02		28.45
St Dev				0.54	0.43	0.46	0.36	0.26	0.65	0.74	0.08		2.15
Net Irr					2.20	4.48	5.95	5.32	2.53				20.48
Potato					0.82	3.23	7.24	6.42	2.79	0.12			20.61
St Dev					0.27	0.92	0.58	0.33	0.87	0.19			1.31
Net Irr						2.20	6.55	5.67	1.62				16.04
Safflower					1.09	7.56	9.76	8.76	4.15	0.66			31.98
St Dev					0.81	1.01	0.53	0.40	1.06	0.52			2.78
Net Irr						6.54	9.07	8.01	2.98				26.60
Sorghum					0.74	3.49	8.14	8.05	3.71				24.12
St Dev					0.32	0.80	0.68	0.34	0.79				1.54
Net Irr						2.46	7.45	7.30	2.54				19.75
Spring Grain				0.68	3.41	7.93	8.26	1.07					21.36
St Dev				0.31	0.94	0.96	1.18	0.97					0.76
Net Irr					1.45	6.91	7.57	0.32					16.26
Winter Wheat			0.39	1.35	3.77	8.01	5.83	0.28					19.62
St Dev			0.18	0.27	1.10	0.93	1.89	0.39					0.60
Net Irr					1.81	6.98	5.14						13.94

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 19. Continued. Estimated Consumptive Use for NWS Station: RICHMOND

Aridity Index: 36%, Temp. Adj. (F): -1.5, Period: 1971-2008, Lat: 41.91, Long: -111.81, Elev: 4680 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
	. . . .						Inches					. . . .	
Garden					1.26	3.10	6.53	7.06	1.82				19.77
St Dev					0.29	0.45	0.68	0.38	0.76				1.44
Net Irr						2.08	5.84	6.31	0.65				14.88
Small Fruit					0.77	3.97	8.80	8.52	3.17	0.05			25.28
St Dev					0.31	0.86	0.78	0.52	1.48	0.19			2.58
Net Irr						2.95	8.12	7.77	2.00				20.83
Turfgrass				1.63	3.47	4.86	5.85	5.36	3.47	1.07	0.03		25.74
St Dev				0.49	0.37	0.41	0.32	0.23	0.48	0.74	0.10		1.92
Net Irr					1.51	3.83	5.17	4.61	2.30				17.43
Open Water Deep	0.40	0.37	0.99	1.73	2.33	3.17	4.59	5.10	3.18	2.30	1.16	0.58	25.90
St Dev	0.06	0.07	0.21	0.30	0.29	0.39	0.43	0.34	0.36	0.31	0.20	0.09	1.61
Net Evap					0.37	2.15	3.90	4.35	2.01	0.67			13.46
Open Water Shallow	0.44	0.90	2.27	3.50	4.70	5.66	6.57	6.03	4.13	2.41	1.00	0.40	38.01
St Dev	0.06	0.11	0.29	0.35	0.35	0.38	0.28	0.19	0.28	0.24	0.15	0.07	1.47
Net Evap			0.58	1.64	2.74	4.64	5.88	5.28	2.96	0.78			24.51
Wetlands Large					0.10	3.79	9.47	9.39	5.53	0.59			28.87
St Dev					0.20	1.14	0.82	0.40	1.10	0.87			3.19
Net ET						2.77	8.78	8.64	4.36				24.55
Wetlands Narrow					0.12	5.05	13.48	13.41	7.90	0.85			40.81
St Dev					0.24	1.63	1.21	0.56	1.57	1.24			4.56
Net ET						4.03	12.79	12.66	6.73				36.21
ETr	0.37	0.85	2.73	4.70	6.45	8.10	9.76	8.94	6.00	3.50	1.35	0.56	53.29
St Dev	0.10	0.15	0.44	0.59	0.59	0.67	0.53	0.38	0.52	0.46	0.27	0.13	2.61

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 20. Estimated Consumptive Use for NWS Station: SANTAQUIN CHLORINATOR

Aridity Index: 67%, Temp. Adj. (F): 0, Period: 1971-2008, Lat: 39.96, Long: -111.78, Elev: 5160 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Temp (F)	28.13	32.78	40.96	48.11	57.55	67.31	75.88	73.69	63.37	51.35	38.18	29.07	50.53
St Dev	5.38	4.05	3.29	3.53	3.03	3.67	3.28	2.49	3.44	3.20	3.80	3.72	1.67
Precip (in)	1.56	1.68	1.99	1.99	2.01	0.85	0.67	0.90	1.36	2.22	1.78	1.55	18.56
St Dev	1.13	0.97	0.94	1.08	1.41	0.83	0.52	0.82	1.83	1.69	0.95	0.98	4.97
Aridity Adj. (F)	1.34	1.27	1.81	2.48	3.69	4.56	3.82	3.75	3.82	3.48	2.41	1.61	2.84
Est. Dewpoint (F)	18.94	19.71	21.65	25.49	31.35	36.13	42.31	40.95	32.84	28.90	21.44	19.00	28.23
Rs (langleys/day)	185	269	354	462	566	657	643	563	472	326	202	158	405
Wind (mpd)	60	57	90	89	77	68	59	56	53	45	51	50	63
Calc. Wind Limit (mpd)	96	96	101	109	96	96	96	96	96	96	96	96	97
							Inches						
Alfalfa (Beef)				2.11	5.75	6.06	6.53	6.14	3.90	0.71	0.02		31.22
St Dev				0.61	0.44	0.59	0.37	0.30	1.11	0.67	0.09		2.03
Net Irr				0.52	4.14	5.38	5.99	5.42	2.81				24.26
Alfalfa (Dairy)				2.11	5.32	5.89	6.29	5.46	3.51	0.73	0.01		29.32
St Dev				0.61	0.33	0.34	0.30	0.21	0.80	0.75	0.04		1.84
Net Irr				0.52	3.71	5.20	5.76	4.74	2.42				22.35
Apples / Cherries				1.03	4.96	7.91	8.71	7.46	4.51	1.59	0.01		36.19
St Dev				0.33	0.50	0.49	0.33	0.19	0.35	0.55	0.03		1.70
Net Irr					3.35	7.22	8.18	6.73	3.42				28.91
Barley			0.01	1.08	4.50	7.78	4.21	0.07					17.64
St Dev			0.03	0.35	0.99	0.49	1.71	0.16					0.64
Net Irr					2.89	7.09	3.67						13.65
Corn					0.79	2.84	7.51	6.16	1.97	0.09			19.36
St Dev					0.22	0.81	0.80	0.63	1.19	0.19			0.91
Net Irr						2.16	6.97	5.43	0.88				15.44
Other Hay				2.23	6.41	7.17	3.87	2.35	1.03	0.01			23.07
St Dev				0.65	0.52	0.55	0.39	0.10	0.17	0.04			0.99
Net Irr				0.63	4.80	6.49	3.33	1.63					16.87
Other Orchard				0.97	4.74	7.33	8.04	6.86	4.06	1.56	0.01		33.58
St Dev				0.29	0.50	0.44	0.31	0.17	0.32	0.54	0.03		1.60
Net Irr					3.13	6.65	7.51	6.14	2.97				26.40
Pasture			0.06	2.04	4.31	5.20	5.70	4.92	3.39	1.34	0.07		27.03
St Dev			0.10	0.43	0.31	0.31	0.22	0.13	0.33	0.55	0.15		1.51
Net Irr				0.45	2.69	4.52	5.16	4.20	2.30				19.33
Potato					1.06	3.76	6.37	4.68	1.35	0.04			17.26
St Dev					0.27	0.91	0.29	0.54	1.02	0.13			0.76
Net Irr						3.08	5.84	3.95	0.26				13.13
Safflower					1.80	7.46	8.38	7.15	3.90	0.74			29.42
St Dev					0.86	0.60	0.32	0.20	0.57	0.33			1.69
Net Irr					0.19	6.78	7.84	6.43	2.81				24.04
Sorghum					0.99	3.80	7.25	6.52	2.66				21.23
St Dev					0.28	0.68	0.40	0.18	0.72				0.87
Net Irr						3.12	6.72	5.80	1.57				17.20
Spring Grain			0.01	1.05	4.28	7.77	5.27	0.22					18.59
St Dev			0.03	0.33	0.97	0.55	1.55	0.39					0.66
Net Irr					2.67	7.08	4.73						14.48
Winter Wheat			0.77	1.66	4.85	7.53	2.76	0.04					17.62
St Dev			0.18	0.36	1.13	0.43	1.74	0.10					0.61
Net Irr				0.07	3.24	6.84	2.23						12.38

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 20. Continued. Estimated Consumptive Use for NWS Station: SANTAQUIN CHLORINATOR

Aridity Index: 67%, Temp. Adj. (F): 0, Period: 1971-2008, Lat: 39.96, Long: -111.78, Elev: 5160 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
	. . . . Inches												
Garden				0.03	1.56	3.28	6.07	5.50	1.38				17.81
St Dev				0.08	0.26	0.39	0.46	0.19	0.46				0.81
Net Irr						2.60	5.53	4.78	0.29				13.19
Turfgrass			0.10	2.11	3.64	4.59	5.03	4.35	3.08	1.42	0.09		24.41
St Dev			0.16	0.32	0.28	0.27	0.19	0.12	0.24	0.51	0.18		1.32
Net Irr				0.52	2.03	3.91	4.49	3.62	1.99				16.57
Open Water Deep	0.71	0.75	1.64	1.90	2.38	2.98	3.70	3.53	2.32	1.44	1.06	0.64	23.06
St Dev	0.12	0.12	0.24	0.27	0.27	0.35	0.34	0.23	0.25	0.17	0.16	0.10	1.39
Net Evap			0.05	0.31	0.77	2.29	3.17	2.81	1.23				10.63
Open Water Shallow	0.88	1.39	2.63	3.61	4.79	5.62	6.21	5.55	4.14	2.52	1.28	0.77	39.39
St Dev	0.10	0.16	0.24	0.30	0.30	0.29	0.22	0.14	0.23	0.20	0.14	0.10	1.20
Net Evap		0.05	1.04	2.02	3.18	4.94	5.67	4.83	3.05	0.75			25.53
Wetlands Large					0.24	4.29	8.46	7.60	5.14	1.29	0.02		27.05
St Dev					0.24	0.83	0.47	0.20	0.84	1.11	0.10		2.51
Net ET						3.60	7.93	6.88	4.05				22.46
Wetlands Narrow					0.28	5.81	12.08	10.86	7.34	1.85	0.03		38.24
St Dev					0.29	1.22	0.67	0.29	1.21	1.58	0.14		3.58
Net ET						5.12	11.54	10.14	6.25	0.07			33.13
ETr	1.08	1.65	3.61	4.89	6.43	7.65	8.38	7.24	5.17	2.96	1.63	0.95	51.64
St Dev	0.13	0.21	0.39	0.47	0.46	0.45	0.32	0.20	0.30	0.25	0.20	0.15	1.75

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 21. Estimated Consumptive Use for NWS Station: SNOWVILLE

Aridity Index: 16%, Temp. Adj. (F): -1.5, Period: 1971-2008, Lat: 41.97, Long: -112.72, Elev: 4560 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Temp (F)	16.60	21.40	31.77	40.74	50.82	60.27	70.08	68.47	56.52	44.33	30.48	19.16	42.56
St Dev	6.28	6.22	4.61	3.34	2.93	3.58	3.64	2.53	3.40	2.40	4.20	4.95	1.67
Precip (in)	1.14	0.94	1.16	1.26	1.80	0.91	0.79	0.73	0.90	1.13	1.04	1.22	13.03
St Dev	0.82	0.62	0.75	0.82	1.16	0.68	0.82	0.59	0.76	0.82	0.70	0.92	3.83
Aridity Adj. (F)	0.32	0.30	0.43	0.59	0.88	1.09	0.91	0.90	0.91	0.83	0.58	0.38	0.68
Est. Dewpoint (F)	4.76	7.79	11.74	15.35	23.35	29.99	35.63	34.64	25.76	20.64	13.08	4.88	18.97
Rs (langleys/day)	216	287	390	500	620	660	601	575	453	345	226	167	420
Wind (mpd)	100	103	139	163	136	130	121	127	116	120	110	100	122
Calc. Wind Limit (mpd)	96	96	114	132	113	105	103	106	96	96	96	96	104
							. . . . . . Inches						
Alfalfa (Beef)					3.32	7.81	8.60	6.08	2.06	0.01			27.88
St Dev					0.48	0.48	1.04	1.74	1.82	0.05			3.68
Net Irr					1.87	7.08	7.97	5.50	1.34				23.76
Alfalfa (Dairy)					3.32	6.99	7.79	6.65	1.34	0.01			26.10
St Dev					0.48	0.38	0.91	1.87	1.36	0.04			3.24
Net Irr					1.87	6.26	7.16	6.07	0.63				21.99
Barley					1.42	6.72	10.41	2.75					21.30
St Dev					0.30	1.01	0.84	1.39					1.81
Net Irr						5.99	9.78	2.16					17.93
Other Hay					3.34	8.91	9.98	4.32	1.10	0.01			27.67
St Dev					0.41	0.68	0.70	0.52	0.69	0.05			1.55
Net Irr					1.90	8.18	9.35	3.74	0.39				23.55
Pasture					2.02	5.77	7.10	6.31	1.83	0.02			23.05
St Dev					0.25	0.44	0.49	0.97	1.29	0.07			2.04
Net Irr					0.58	5.04	6.47	5.72	1.11				18.93
Safflower						3.14	10.37	8.74	1.69	0.01			23.94
St Dev						0.28	0.72	1.58	1.38	0.04			2.67
Net Irr						2.41	9.74	8.15	0.97				21.27
Spring Grain					1.38	6.42	10.57	4.08	0.02				22.47
St Dev					0.28	1.01	0.81	1.67	0.07				2.10
Net Irr						5.69	9.94	3.50					19.13
Winter Wheat				0.73	2.44	7.02	9.67	1.48					21.33
St Dev				0.11	0.41	1.31	1.09	0.97					1.64
Net Irr					1.00	6.29	9.03	0.89					17.21

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 21. Continued. Estimated Consumptive Use for NWS Station: SNOWVILLE

Aridity Index: 16%, Temp. Adj. (F): -1.5, Period: 1971-2008, Lat: 41.97, Long: -112.72, Elev: 4560 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
							Inches						
Garden						1.57	3.76	6.40	1.24	0.01			12.98
St Dev						0.13	0.27	0.36	1.32	0.07			1.39
Net Irr						0.84	3.13	5.82	0.52				10.31
Turfgrass					2.45	4.77	6.26	5.68	1.93	0.03			21.11
St Dev					0.29	0.36	0.44	0.79	1.24	0.10			1.81
Net Irr					1.01	4.04	5.63	5.09	1.21				16.98
Open Water Deep	0.79	0.81	1.51	2.41	3.09	3.99	5.89	6.21	3.61	2.67	1.56	0.96	33.51
St Dev	0.14	0.15	0.27	0.34	0.37	0.48	0.60	0.44	0.36	0.26	0.22	0.14	1.70
Net Evap		0.06	0.58	1.40	1.65	3.26	5.26	5.63	2.90	1.76	0.72		23.23
Open Water Shallow	0.73	1.11	2.37	3.60	4.97	5.57	6.07	5.84	4.01	2.60	1.23	0.70	38.81
St Dev	0.09	0.15	0.28	0.31	0.36	0.32	0.30	0.22	0.20	0.18	0.13	0.07	1.24
Net Evap		0.36	1.45	2.59	3.52	4.85	5.44	5.26	3.29	1.69	0.40		28.84
Wetlands Large						1.86	8.57	9.54	2.45	0.02			22.44
St Dev						0.21	0.63	2.00	2.19	0.10			3.62
Net ET						1.13	7.94	8.96	1.74				19.76
Wetlands Narrow						2.35	12.04	13.63	3.51	0.02			31.54
St Dev						0.27	0.90	2.86	3.12	0.15			5.17
Net ET						1.62	11.40	13.05	2.79				28.86
ETr	1.31	1.74	3.67	5.75	7.61	8.92	10.44	9.85	6.84	4.53	2.27	1.47	64.39
St Dev	0.21	0.27	0.56	0.68	0.74	0.68	0.73	0.55	0.49	0.50	0.36	0.23	2.90

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 22. Estimated Consumptive Use for NWS Station: ST GEORGE

Aridity Index: 80%, Temp. Adj. (F): 0, Period: 1971-2008, Lat: 37.11, Long: -113.56, Elev: 2770 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Temp (F)	41.76	47.07	54.19	61.45	70.91	80.34	86.58	84.60	76.31	63.68	49.92	41.48	63.19
St Dev	3.25	2.83	3.44	3.55	3.46	2.76	2.26	2.50	2.48	2.76	2.64	2.67	1.56
Precip (in)	1.16	1.12	1.19	0.59	0.36	0.21	0.52	0.68	0.58	0.81	0.73	0.69	8.64
St Dev	1.25	0.89	1.17	0.63	0.46	0.31	0.47	0.59	0.66	0.79	0.66	0.68	3.02
Aridity Adj. (F)	1.60	1.52	2.16	2.96	4.40	5.44	4.56	4.48	4.56	4.16	2.88	1.92	3.39
Est. Dewpoint (F)	24.30	26.18	26.53	28.44	31.84	36.40	46.74	47.02	37.84	32.35	25.69	24.24	32.30
Rs (langleys/day)	258	347	428	559	666	708	671	612	511	392	286	239	473
Wind (mpd)	44	45	62	72	69	66	60	56	51	49	46	42	55
Calc. Wind Limit (mpd)	96	96	96	96	96	96	96	96	96	96	96	96	96
							Inches						
Alfalfa (Beef)			2.03	5.68	7.39	7.28	7.76	7.43	5.16	3.02	0.95	0.01	46.72
St Dev			0.70	0.41	0.78	0.50	0.58	0.53	0.56	0.55	0.80	0.05	1.66
Net Irr			1.08	5.21	7.11	7.11	7.34	6.88	4.69	2.38	0.37		42.18
Alfalfa (Dairy)			2.03	5.22	6.51	7.23	7.38	6.48	4.88	3.05	0.69	0.01	43.50
St Dev			0.70	0.35	0.39	0.29	0.26	0.22	0.24	0.61	0.67	0.06	1.57
Net Irr			1.08	4.76	6.22	7.06	6.96	5.94	4.42	2.41	0.11		38.95
Barley			1.21	5.58	8.33	2.24							17.36
St Dev			0.49	0.99	0.58	1.67							0.90
Net Irr			0.25	5.11	8.04	2.07							15.48
Corn				0.86	4.13	9.09	6.51	0.35					20.94
St Dev				0.27	1.12	0.57	1.57	0.51					1.03
Net Irr				0.39	3.85	8.92	6.09						19.25
Melon				0.85	4.31	6.23	6.35	5.26	0.34				23.33
St Dev				0.32	0.63	0.24	0.21	0.42	0.47				0.64
Net Irr				0.38	4.03	6.06	5.93	4.72					21.11
Onion			0.07	2.92	6.25	9.53	9.55	4.13					32.45
St Dev			0.15	0.52	0.82	0.39	0.36	1.14					0.86
Net Irr				2.45	5.97	9.36	9.13	3.58					30.50
Other Hay			1.98	6.60	8.29	4.54	3.23	1.80	0.04				26.48
St Dev			0.66	0.59	0.56	0.49	0.17	0.25	0.09				0.98
Net Irr			1.02	6.13	8.01	4.38	2.81	1.26					23.60
Other Orchard			0.97	4.90	8.29	9.20	9.26	6.77	4.10	0.15			43.64
St Dev			0.42	0.65	0.50	0.35	0.31	0.29	0.42	0.27			1.19
Net Irr			0.02	4.43	8.01	9.04	8.84	6.22	3.64				40.19
Pasture		0.01	1.82	4.46	5.89	6.52	6.64	5.83	4.34	2.75	0.89	0.01	39.16
St Dev		0.03	0.46	0.36	0.35	0.25	0.22	0.18	0.19	0.25	0.44	0.03	1.34
Net Irr			0.87	3.99	5.60	6.35	6.22	5.28	3.87	2.10	0.31		34.60
Potato				1.21	5.07	7.26	4.29	0.05					17.88
St Dev				0.40	0.92	0.24	1.43	0.13					0.73
Net Irr				0.74	4.78	7.09	3.87						16.49
Sorghum				1.06	4.36	8.34	8.79	4.18					26.72
St Dev				0.32	0.79	0.45	0.29	1.19					0.69
Net Irr				0.59	4.07	8.18	8.37	3.63					24.83
Spring Grain			1.16	5.37	8.62	3.36	0.01						18.52
St Dev			0.46	1.00	0.47	1.86	0.07						0.90
Net Irr			0.20	4.91	8.33	3.19							16.63

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 22. Continued. Estimated Consumptive Use for NWS Station: ST GEORGE

Aridity Index: 80%, Temp. Adj. (F): 0, Period: 1971-2008, Lat: 37.11, Long: -113.56, Elev: 2770 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
	. . . . . .						Inches					. . . . . .	
Garden			0.05	1.60	3.70	6.96	7.44	2.46					22.22
St Dev			0.10	0.30	0.49	0.55	0.44	0.78					0.58
Net Irr				1.13	3.41	6.80	7.02	1.92					20.29
Turgrass Dixie		0.03	2.14	3.64	5.61	6.23	6.35	5.57	4.18	2.85	1.16	0.12	37.86
St Dev		0.06	0.39	0.33	0.34	0.24	0.21	0.17	0.18	0.20	0.56	0.25	1.35
Net Irr			1.18	3.17	5.32	6.06	5.93	5.03	3.71	2.20	0.58		33.19
Open Water Deep	1.10	1.22	2.12	2.92	4.04	5.03	5.51	5.11	3.62	2.67	1.59	1.02	35.96
St Dev	0.14	0.15	0.30	0.36	0.45	0.40	0.32	0.31	0.25	0.24	0.16	0.12	1.68
Net Evap	0.17	0.33	1.17	2.45	3.76	4.86	5.09	4.57	3.16	2.02	1.01	0.47	29.05
Open Water Shallow	1.62	2.27	3.67	4.95	6.31	6.73	7.04	6.56	5.11	3.57	2.06	1.44	51.32
St Dev	0.17	0.22	0.34	0.32	0.34	0.22	0.21	0.18	0.21	0.21	0.15	0.14	1.23
Net Evap	0.69	1.37	2.71	4.48	6.02	6.57	6.62	6.02	4.65	2.93	1.48	0.89	44.41
Wetlands Large				0.31	5.03	9.77	10.25	9.00	6.75	4.45	1.22	0.03	46.80
St Dev				0.30	0.99	0.53	0.34	0.28	0.29	0.61	0.96	0.13	2.07
Net ET					4.74	9.61	9.83	8.46	6.28	3.80	0.64		43.36
Wetlands Narrow				0.36	6.84	13.95	14.64	12.86	9.64	6.35	1.75	0.04	66.43
St Dev				0.36	1.46	0.77	0.49	0.40	0.42	0.87	1.38	0.19	2.96
Net ET					6.56	13.78	14.22	12.31	9.17	5.71	1.17		62.92
ETr	1.85	2.59	4.80	6.70	8.66	9.59	9.76	8.57	6.42	4.41	2.45	1.61	67.41
St Dev	0.21	0.28	0.49	0.49	0.52	0.36	0.32	0.27	0.28	0.28	0.20	0.18	1.81

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 23. Estimated Consumptive Use for NWS Station: WOODRUFF

Aridity Index: 11%, Temp. Adj. (F): -3.5, Period: 1971-2008, Lat: 41.52, Long: -111.15, Elev: 6315 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
Temp (F)	15.37	18.33	30.22	39.57	48.12	56.46	63.24	61.32	52.18	41.58	28.14	17.59	39.35
St Dev	6.17	6.19	4.50	3.14	2.03	2.36	2.38	2.21	2.23	1.99	4.15	5.18	1.65
Precip (in)	0.54	0.53	0.61	0.90	1.18	0.96	0.72	0.83	1.17	1.09	0.69	0.49	9.72
St Dev	0.45	0.36	0.39	0.63	0.64	0.94	0.65	0.70	1.05	0.72	0.38	0.33	2.69
Aridity Adj. (F)	0.22	0.21	0.30	0.41	0.61	0.75	0.63	0.62	0.63	0.57	0.40	0.26	0.47
Est. Dewpoint (F)	9.42	11.44	18.00	20.48	27.11	33.14	36.07	33.95	27.36	21.29	15.44	9.65	21.95
Rs (langleys/day)	180	305	385	478	579	635	641	557	437	311	203	168	407
Wind (mpd)	84	80	106	127	124	113	106	113	108	94	107	88	104
Calc. Wind Limit (mpd)	96	96	102	113	109	96	96	96	96	96	96	96	99
	. . . .						Inches					. . . .	
Alfalfa (Beef)					2.76	6.47	6.04	3.81	0.25				19.33
St Dev					0.41	0.72	1.08	1.99	0.53				3.18
Net Irr					1.82	5.70	5.46	3.15					16.13
Alfalfa (Dairy)					2.76	6.10	6.19	3.05	0.22				18.31
St Dev					0.41	0.51	0.98	2.07	0.49				2.99
Net Irr					1.82	5.33	5.61	2.38					15.14
Other Hay					3.01	7.12	7.79	3.07	0.56	0.01			21.57
St Dev					0.41	0.73	0.51	0.50	0.56	0.03			1.65
Net Irr					2.07	6.36	7.22	2.40					18.05
Pasture					1.89	4.63	5.73	4.63	0.94	0.01			17.84
St Dev					0.22	0.46	0.38	0.92	1.04	0.04			1.97
Net Irr					0.94	3.87	5.16	3.97					13.94
Spring Grain					1.10	4.20	8.43	5.06	0.26				19.05
St Dev					0.19	0.82	0.79	2.54	0.52				3.24
Net Irr					0.15	3.44	7.85	4.40					15.84

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 23. Continued. Estimated Consumptive Use for NWS Station: WOODRUFF

Aridity Index: 11%, Temp. Adj. (F): -3.5, Period: 1971-2008, Lat: 41.52, Long: -111.15, Elev: 6315 ft, 8/9/2011

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
	. . . .						Inches					. . . .	
Garden						1.42	3.22	4.83	0.21				9.68
St Dev						0.15	0.22	0.54	0.41				0.97
Net Irr						0.65	2.65	4.17					7.46
Turfgrass					2.16	3.85	5.06	4.25	1.00	0.01			16.33
St Dev					0.24	0.38	0.34	0.75	1.03	0.06			1.77
Net Irr					1.22	3.08	4.48	3.59	0.06				12.43
Open Water Deep	0.38	0.31	0.72	1.38	1.97	2.38	3.42	3.60	2.45	1.95	1.07	0.52	20.16
St Dev	0.08	0.07	0.18	0.26	0.23	0.32	0.34	0.27	0.24	0.22	0.23	0.11	1.36
Net Evap			0.24	0.66	1.02	1.61	2.84	2.94	1.51	1.08	0.52	0.12	12.55
Open Water Shallow	0.45	0.86	1.97	3.11	4.28	4.90	5.60	4.97	3.48	2.16	0.94	0.48	33.20
St Dev	0.07	0.13	0.27	0.36	0.30	0.37	0.28	0.21	0.22	0.20	0.17	0.08	1.46
Net Evap	0.02	0.43	1.48	2.39	3.34	4.13	5.02	4.31	2.54	1.29	0.39	0.08	25.42
Wetlands Large						1.02	6.22	5.78	0.49				13.51
St Dev						0.46	0.99	2.50	1.02				3.06
Net ET						0.25	5.64	5.12					11.01
Wetlands Narrow						1.26	8.66	8.26	0.70				18.88
St Dev						0.60	1.47	3.57	1.45				4.38
Net ET						0.49	8.08	7.59					16.17
ETr	0.54	0.87	2.34	4.24	5.93	7.02	8.43	7.62	5.46	3.54	1.49	0.66	48.15
St Dev	0.14	0.19	0.43	0.65	0.57	0.70	0.56	0.44	0.51	0.48	0.40	0.18	2.87

All values are 38 year averages. Effective precipitation is 80% of total during growing season.

Table 24. Crop ET, Evaporation and ET_r from this Report and UAES#145 for Four Selected Crops at Ten Example NWS Sites.

NWS Station		Crop ET (in)				Evaporation(in)		ET_r (in)
		Alfalfa (Beef)[a]	Pasture	Spring Grain	Turfgrass	Open - Water		
						Deep	Shallow	
ENTERPRISE BERYL JCT	New	35.76	29.61	25.52	27.03	40.72	44.18	72.85
	UAES#145	34.81	27.6	22.5	25.17		41.63	55.83
	Difference	0.95	2.01	3.02	1.86		2.55	
	New/145, %	103	107	113	107		106	
FILLMORE	New	38.07	32.92	21.47	29.73	31.58	44.74	61.03
	UAES#145	35.25	28.43	20.08	25.08		40.43	53.39
	Difference	2.82	4.49	1.39	4.65		4.31	
	New/145, %	108	116	107	119		111	
MONTICELLO 2E	New	23.07	19.6		17.86	24.58	36.82	50.16
	UAES#145	28.57	23.19	19.66	20.28		38.78	46.89
	Difference	-5.5	-3.59		-2.42		-1.96	
	New/145, %	81	85		88		95	
MYTON	New	30.97	26.08	22.51	23.74	27.52	37.77	56.11
	UAES#145	31.96	23.46	20.9	22.79		37.39	49.87
	Difference	-0.99	2.62	1.61	0.95		0.38	
	New/145, %	97	111	108	104		101	
PANGUITCH	New	27.37	23.07	23.45	21.1	30.62	40.34	62.77
	UAES#145	29.41	21.97	21.43	20.43		38.02	52.72
	Difference	-2.04	1.1	2.02	0.67		2.32	
	New/145, %	93	105	109	103		106	
RICHMOND	New	32.46	28.45	21.36	25.74	25.9	38.01	53.29
	UAES#145	28.46	23.08	19.66	21.16		38.11	47.07
	Difference	4	5.37	1.7	4.58		-0.1	
	New/145, %	114	123	109	122		100	
SANTAQUIN CHLORINATOR	New	31.22	27.03	18.59	24.41	23.06	39.39	51.64
	UAES#145	33.8	27.1	20.33	24.1		38.76	50.22
	Difference	-2.58	-0.07	-1.74	0.31		0.63	
	New/145, %	92	100	91	101		102	
SNOWVILLE	New	27.88	23.05	22.47	21.11	33.51	38.81	64.39
	UAES#145	32.78	25.33	22.75	22.58		31.84	43.88
	Difference	-4.9	-2.28	-0.28	-1.47		6.97	
	New/145, %	85	91	99	93		122	
ST GEORGE	New	46.72	39.16	18.52	37.86	35.96	51.32	67.41
	UAES#145	47.06	38.89	19.65	33.79		50.65	66.5
	Difference	-0.34	0.27	-1.13	4.07		0.67	
	New/145, %	99	101	94	112		101	
WOODRUFF	New	19.33	17.84	19.05	16.33	20.16	33.2	48.15
	UAES#145	23.56	20.12	22.65	17.75		31.38	43.25
	Difference	-4.23	-2.28	-3.6	-1.42		1.82	
	New/145, %	82	89	84	92		106	
Ten Site	Average	95	103	102	104		105	116

[a] Alfalfa (Beef) has a longer interval between cuttings than for dairy hay.

SUMMARY

Consumptive water use for crops and wetland vegetation, along with evaporation from open water was estimated for Utah and surrounding areas within one degree latitude and longitude. Estimates were made using the ASCE Std. Eq. with data from NWS temperature and precipitation datasets. Solar radiation was estimated from the daily temperatures using an adaptation of the Hargreaves and Samani (1982) approach. Spatial interpolation was used to characterize humidity and wind at each NWS site using data from electronic weather stations located throughout the study area.

Net irrigation was calculated by subtracting effective summer precipitation from growing season ET. Effective summer precipitation was assumed to be 80% of any precipitation during months in which ET occurred. An optional procedure was included for calculating estimated depletion similar to that of the Bear River Commission approved procedure.

A methodology was developed to validate the reasonableness of calculated ET values for the various NWS sites. Alfalfa ET was used as a “bellwether” or indicator of reasonableness of calculated crop ET. The validation methodology consisted of obtaining a range of field alfalfa hay yields by county and then developing associated alfalfa ET values for better than average high alfalfa yield (representing growing conditions in three years out of five) and near perfect condition (one year out of ten) high yields for each county. Alfalfa ET values were inferred from the yield versus ET relationship.

Software was developed for future calculations and adaptations of CU estimates throughout Utah and the surrounding areas.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. The methods used in this study could be used to update CU estimates on an ongoing basis as additional weather data becomes available.

2. Crop ET estimates were generally between 3% lower and 7% greater, on average, than those published in UAES#145 (ten example NWS sites of Table 24).

3. Reasons for the differences in ET in the current study over UAES#145 include increased reference ET and variable length crop growth seasons.

4. A more conclusive study on the effect and subsequent adjustment for local aridity in the area could improve ET estimates.

Recommendations

1. The database developed for this report should be maintained and updated for future CU estimates. Such action would greatly reduce the effort required to update CU estimates in the future. This can be accomplished by assembling the requisite NWS datasets with daily maximum and minimum air temperatures and precipitation. Header information could be adapted from the input files used herein to complete the updated input file. A similar process could be used for entirely new sites not included herein.

2. Improved methodology for estimating missing NWS temperature and, particularly, precipitation data is needed.

3. Including observed snow depth at NWS sites could improve the accuracy of a crop growth initiation timing model.

GLOSSARY AND LIST OF SYMBOLS

GLOSSARY

Adiabatic Process. – A reversible thermodynamic change of state of a system without the addition or removal of heat or mass.

Advection. – Horizontal transfer of heat energy by large-scale movement of the atmosphere.

Albedo. – The ratio of electromagnetic radiation reflected from a soil and crop surface to the amount incident upon it. The value commonly is about 0.23 for a green growing crop.

Aridity Rating. – Percentage representing an irrigated environment around a weather station site, 0% = irrigated and 100% = dry, not irrigated.

ASCE Standardized Reference Evapotranspiration Equation (ASCE Std. Eq.). – An adaptation of the Penman-Monteith ET equation by the American Society of Civil Engineers (2005) to be used as a benchmark equation for estimating short and tall reference evapotranspiration.

Available Soil Moisture. – See Moisture (available).

Beginning Growth. – Planting, green up, emergence, or initiation of plant water use.

Better Than Average Evapotranspiration. – Alfalfa ET inferred from BTA yields using Equation 13 (Eq. H1).

Better Than Average Yield. – Alfalfa yields attainable three out of five years with better than average management.

Bulk Density. – The ratio of the mass of a given volume of dry soil, including air space, to the given volume. Expressed as grams per cubic centimeter.

Carryover Soil Moisture. – Non-growing season precipitation stored in the soil that may be used in meeting the crop's evapotranspiration requirement in the subsequent growing season. For example it could be 2/3 of the winter (October-April) precipitation after subtracting ET but not to exceed 75% of the available soil moisture storage capacity for root zone.

Consumptive Use. – The amount of water used by plants in transpiration, retained in plant tissue, and the evaporation of water from plant and adjacent soil surfaces during a specified time period. Synonymous with evapotranspiration.

Crop Coefficient. – Relates ET of a given crop at a specific time in its growth stage to a reference ET condition. Incorporates effects of crop growth state, plant density, and other cultural factors affecting ET, usually expressed or exhibited as tabular values or as a curve or polynomial. The reference condition has been termed "potential" or "reference crop" and relates to ET of alfalfa or grass, depending upon the research that resulted in the crop coefficient.

Crop Irrigation Requirement. – The quantity of water, exclusive of effective growing season precipitation, winter precipitation stored in the root zone, or (perhaps) upward water movement from shallow water table, that is required as an irrigation application to meet the evapotranspiration needs of the crop. It also may include water requirements for germination, frost protection, prevention of wind erosion, leaching of salts and plant cooling.

Depletion (Irrigation). – The amount of water lost from a river basin or other hydrologic system resulting from irrigation withdrawals from surface or subsurface sources. It is calculated as consumptive use (ET) less the sum of effective precipitation and carryover soil moisture. It is intended to represent the net loss to the basin after return flows and/or excess irrigation water has returned to the stream or groundwater system.

Depletion; Crop Acreage Weighted. – Depletion estimated as an average for several crops for a large area such as a sub-basin of a river system. Calculated herein as the sum for all crops of the product of consumptive use for each crop times the crop's respective fraction of total area, less the sum of carry over soil moisture and effective precipitation.

Dew Point. – The temperature to which a given parcel of air must be cooled at constant pressure and at constant water vapor content until saturation occurs, or the temperature at which saturation vapor pressure of the parcel is equal to the actual vapor pressure of the contained water vapor.

Duty of Water. – The total volume of irrigation water required to mature a particular type of crop. It includes that portion of consumptive use not satisfied by precipitation, evaporation and seepage from ditches and canals and the water eventually returned to streams by percolation and surface runoff.

Effective Full Cover. – Flowering, leafing, or intermediate growth stage of a plant representing a shift to a maximum crop coefficient or consumptive use.

Effective Precipitation. – Precipitation occurring during the growing season that is available to meet the evapotranspiration requirements of crops. It does not include precipitation lost through deep percolation below the root zone or through surface runoff. Estimated in this report as 80% of May-April precipitation.

Empirical Equation. – An equation whose derivation and/or accuracy (calibration) is based upon observation.

Evaporation. – The physical process by which a liquid or solid is transformed to the gaseous state which in irrigation usually is restricted to the change of water from liquid to gas.

Evapotranspiration (ET). – Synonymous with consumptive use.

Evapotranspiration (ET_r). – The reference condition has been termed "potential" or "reference crop" and relates to ET of alfalfa or grass at specified growth conditions, soil water not limiting, depending upon the research that resulted in the crop coefficient.

Field Capacity. – The moisture content of a soil following an application of water and after the downward movement of excess water (from gravitational forces) has essentially ended. Usually it is assumed that this condition is reached about two days after a full irrigation or heavy rain.

Global Radiation. – See Radiation.

Growing Season. – The period that is warm enough for plants to transpire and grow. In the case of annual plants, it approximates the time interval between planting and crop maturity; for perennial crops, it is the period between certain temperature conditions that establish growth and dormancy. This growing season is sometimes restricted to the period between killing frosts.

Irrigation Efficiency. – The ratio of the volume of water required for a specific beneficial use as compared to the volume of water delivered for this purpose. It is commonly interpreted as the volume of water stored in the soil for evapotranspiration compared to the volume of water diverted for this purpose, but may be defined and used in different ways.

Langley. – A unit of energy per unit area commonly used in radiation measurements which is equal to gram calorie per square centimeter.

Lysimeter. – A device such as a tank or large barrel that contains a mass of soil and vegetation similar to that in the immediate vicinity, which is isolated hydrologically from its surroundings. It is commonly used in research to determine the water use of various crops in field conditions.

Near Perfect Condition Evapotranspiration. – Alfalfa ET inferred from NPC yield using Equation 13 (Eq. H1).

Near Perfect Condition Yield. – Alfalfa yields attainable one year out of ten, second year stand with near perfect weather, pest control, fertility and water supply.

Net Irrigation Requirement. – See crop irrigation requirement.

Pan Evaporation. – Evaporation from a class A or similar pan. The U.S. Weather Bureau class A pan is a cylindrical container fabricated of galvanized iron or monel metal with a depth of ten inches and a diameter of forty-eight inches. The pan is accurately leveled at a site which is nearly flat, well sodded, and free from obstructions. The pan is filled with water to a depth of eight inches, and periodic measurements are made of the changes of the water level with the aid of a hook gage set in the stilling well. When the water level drops to seven inches, the pan is refilled.

Peak Irrigation Period. – The period of highest consumptive use that is used in irrigation design to size on-farm or project facilities such as pumping plants, pipelines, canals, distribution systems, etc. Peak period consumptive use is the average daily ET rate of a crop at its maximum during the period between normal irrigations.

Potential Evapotranspiration. – The rate at which water, if available would be removed from the soil and plant surfaces. Expressed as the rate of latent heat transfer per square centimeter or depth of water. In this report potential evapotranspiration is the same as "reference crop ET" and refers to ET of a well-watered crop like alfalfa with 30 to 50 cm of top growth and about 100 m of fetch under given climatic conditions.

Pyranometer. – A general name for instruments which measure the combined intensity of incoming direct solar radiation and diffuse sky radiation.

Radiation. – Process by which electromagnetic radiation is propagated through space. Classified for agricultural purposes as:

> Clear day radiation. – Theoretical incoming radiation at Earth's surface assuming complete absence of clouds (R_{so}).
>
> Extraterrestrial radiation. – Incoming solar radiation above Earth's atmosphere (R_a).
>
> Global Radiation. – Total of direct solar radiation and diffuse sky radiation received at Earth's surface by a unit horizontal surface (R_s).
>
> Net back radiation. – The thermal or long wave radiation that is outgoing from Earth's surface (R_b).
>
> Net clear day outgoing long wave radiation. – Theoretical outgoing long wave radiation at Earth's surface assuming complete absence of clouds (R_{bo}).
>
> Net Radiation. – The difference of the downward and upward solar and long wave radiation flux passing through a horizontal plane just above the ground surface (R_n).

Reference Crop ET. – See potential evapotranspiration.

Relative Humidity. – The dimensionless ratio of actual vapor pressure of the air to saturation vapor pressure, commonly expressed in percent.

Root Zone. – The depth to which plant roots invade the soil and where water extraction occurs.

Saturation Deficit. – (also called vapor pressure deficit) The difference between the actual vapor pressure and the saturation vapor pressure at the existing temperature.

Soil Moisture (available). – Water in the root zone that can be extracted by plants. The available soil moisture is the difference between field capacity and wilting point.

Soil Moisture (unavailable). – Water in the root zone that is held so firmly by various forces that it usually cannot be absorbed by plants.

Soil Water. – Water present in the soil pores (also called soil moisture which includes water vapor).

Solar Radiation. - Synonymous with global radiation (see radiation) in this report.

Specific Yield. – The ratio of the volume of water which will drain freely from a saturated soil under a water table condition to the total volume of soil dewatered with a given drop in the water table surface.

Transpiration. – The process by which water in plants in transferred as water vapor to the atmosphere.

Wet Bulb Depression. – The difference in degrees between the dry bulb temperature and the psychrometric wet bulb temperature.

Wet Bulb Temperature. – The temperature an air parcel would have if cooled adiabatically to saturation at constant pressure by evaporation of water in it with all latent heat being supplied by the parcel.

Wilting Point. – The soil moisture content at which a plant can no longer obtain sufficient moisture to satisfy its requirements and, therefore, will wilt permanently.

Wind Run. – Accumulated wind travel past a given point during a 24-hour period. For use in the Penman Equation, the wind run data is for 2 meters above the ground.

LIST OF SYMBOLS

AR	Aridity Rating
BG	Beginning Growth
BTA ET	Better Than Average Evapotranspiration
BTA Yield	Better Than Average Yield
CU	Consumptive Use
D_{month}	Monthly Average Air and Lake Surface Daily Temperature Difference
D_{pl}	Depletion
e_a	Actual Vapor Pressure
EFC	Effective Full Cover
E_{lake}	Lake Evaporation
Elev	Elevation
e_s	Saturation Vapor Pressure
ET	Evapotranspiration
ET_c	Crop Evapotranspiration
ET_o	Short Crop Reference Evapotranspiration
ET_{os}	ASCE Standardized Short Crop Reference Evapotranspiration
ET_r	Tall Crop (Alfalfa) Reference Evapotranspiration
$ETr_{Hargreaves}$	Hargreaves Tall Crop Reference Evapotranspiration
ET_{rs}	ASCE Standardized Tall Crop Reference Evapotranspiration
ET_{win}	Winter Evapotranspiration
E_{ws}	Wet Soil Evaporation
EWS	Electronic Weather Station
G	Soil Surface Heat Flux
H-S	Hargreaves and Samani 1982 Incident Solar Radiation Model
IDW	Inverse Distance Weighting
K_c	Crop Coefficient
K_{cb}	Basal Crop Coefficient
K_{cm}	Mean Crop Coefficient
K_o	Dewpoint Depression
K_{RS}	Leading Coefficient in Hargreaves and Samani 1982 Incident Solar Radiation Model
Lat	Latitude
NIR	Net Irrigation Requirement
NPC ET	Near Perfect Condition Evapotranspiration
NPC Yield	Near Perfect Condition Yield
NWS	National Weather Service
P_{eff}	Effective Precipitation
P_{wa}	Adjusted Winter Precipitation
P_{win}	Winter Precipitation
R_a	Extraterrestrial Solar Radiation
RH_{max}	Maximum Daily Relative Humidity
RH_{maxhr}	Maximum Hourly Relative Humidity

RH_{min}	Minimum Daily Relative Humidity
RH_{minhr}	Minimum Hourly Relative Humidity
R_n	Net Solar Radiation
R_s	Incident Solar Radiation
R_{shr}	Net Solar Radiation
SM_{co}	Soil Moisture Carry Over
T	Mean Daily Temperature
T_{base}	Growing Degree Day Base Temperature
T_{dew}	Dewpoint Temperature
T_{hr}	Mean Hourly Temperature
T_{max}	Maximum Daily Temperature
T_{maxhr}	Maximum Hourly Temperature
T_{min}	Minimum Daily Temperature
T_{minhr}	Minimum Hourly Temperature
T-R	Thornton-Running 1999 Incident Solar Radiation Model
T-R-Mod	Thornton-Running Incident Solar Radiation Modified by Allen and Robison, 2007.
T_s	Lake Surface Temperature
u_2	Wind Speed at 2 meter Height
UCC	Utah Climate Center
u_{day}	Daily Wind Run
u_{hr}	Hourly Wind Run
WR	Wind Run
WUE	Water Use Efficiency
γ	Psychrometric Constant
Δ	Slope of the Saturation Vapor Pressure vs. Temperature Curve

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APPENDICES

APPENDIX A: METHODS USED TO ESTIMATE MISSING NWS DATA

The information in this appendix was derived from progress reports provided by the Utah Climate Center (UCC).

Two sets of gridded data were obtained for the replacement of missing data:

1. 1971-2003: Daily 1/8-degree gridded meteorological data from the Dept. of Civil & Environmental Engineering, U of Washington [Hamlet A.F. and Lettenmaier D.P., 2005: Production of temporally consistent gridded precipitation and temperature fields for the continental U.S., J. Hydrometeorology, 6, 330-336.] This gridded dataset was developed from adjustments for daily precipitation and temperature maxima and minima based on COOP station data archived at the National Climatic Data Center from the early 1900s on. The intent of this dataset was to produce gridded meteorological variables that can be used in hydrologic modeling and long-term trend analysis.

2. 2003-2008: 3 hourly, 32 km-resolution North American Regional Reanalysis (NARR) [Mesinger, F. et al., 2006: North American Regional Reanalysis. Bull. Amer. Meteor. Soc., 87, 343–360.] The NARR project is an extension of the NCEP Global Reanalysis which is run over the North American Region. The NARR model uses the very high resolution NCEP Eta Model (32 km/45 layer) together with the Regional Data Assimilation System, significantly assimilating precipitation along with other variables. The improvements in the model/assimilation have resulted in a dataset with substantial improvements in the accuracy of temperature, winds and precipitation compared to the NCEP-DOE Global Reanalysis 2. The UCC obtained variables which include surface data recorded 8 times a day.

Bias correction methods included the following:

1. Climatological method: All gridded data to estimate the missing COOP records are compared with the original COOP station observations during their overlapping periods. Any differences in the monthly mean between the two datasets are eliminated.

2. Spatial method: For data that reveal large rms errors (i.e. larger than their climatological MSE), a Cressman weighting scheme was used to interpolate the bias values of Tmax, Tmin, and precipitation obtained from all available COOP stations to the COOP station locations. These bias values were then added to the numerical model values which are bilinearly interpolated to this same specified location. Ref.: [Yussouf, N., and D.J. Stensrud, 2006: Prediction of Near-Surface Variables at Independent Locations from a Bias-Corrected Ensemble Forecasting System. Mon. Wea. Rev., 134, 3415–3424.]

APPENDIX B: NWS STATIONS INCLUDED IN THE STUDY WITH SITE INFORMATION

The 246 NWS stations included in the study with site information (WRCC 2010) are given below. The station period of record along with other information, including aridity rating, and precipitation bias adjustment factor are shown.

Table B1. NWS Stations Included in the Study.

NWS Station	Index No.	Lat	Lon	Elev	St.	County	Station Period of Record[a]	AR (%)[b]	Pcp Adj[c]
ABERDEEN EXP STN	100010	42.9536	-112.825	4405	ID	Bingham	Aug 1948 - Present	37	0.85
AFTON	480027	42.7314	-110.934	6210	WY	Lincoln	May 1957 - Present	39	0.96
ALLENS RCH	420050	40.8997	-109.153	5490	UT	Daggett	Aug 1962 - Nov 2001	40	0.86
ALPINE	420061	40.4644	-111.771	5070	UT	Utah	Jan 1894 - Present	48	0.88
ALTAMONT	420074	40.3561	-110.288	6370	UT	Duchesne	Jun 1953 - Present	18	0.92
ALTENBERN	50214	39.5008	-108.379	5678	CO	Garfield	Nov 1942 - Present	29	0.94
ALTON	420086	37.4403	-112.482	7040	UT	Kane	Jul 1948 - Present	49	0.70
AMERICAN FALLS 6 NE	100227	42.8572	-112.880	4405	ID	Power	Aug 1948 - Jan 2009	17	1.13
ANETH PLT	420157	37.2558	-109.329	4576	UT	San Juan	Aug 1959 - Feb 2008	100	0.61
ANGLE	420168	38.2486	-111.961	6400	UT	Piute	Jun 1981 - Present	55	0.78
ARBON 2 NW	100347	42.5031	-112.576	5210	ID	Power	Jul 1962 - Feb 2003	14	0.96
ARCHES NP HQS	420336	38.6164	-109.619	4130	UT	Grand	May 1980 - Present	92	0.77
BEAR RIVER BAY	420490	41.3000	-112.267	4210	UT	Box Elder	May 1969 - Mar 1997	64	0.84
BEAVER	420519	38.3000	-112.650	5940	UT	Beaver	Jul 1948 - Jun 1990	54	0.82
BEAVER DAM	20672	36.8969	-113.942	1875	AZ	Mohave	Aug 1956 - Present	100	0.56
BEDFORD 3 SE	480603	42.8733	-110.908	6425	WY	Lincoln	Jun 1975 - Present	18	0.96
BETATAKIN	20750	36.6778	-110.541	7286	AZ	Navajo	Jul 1948 - Present	44	1.01
BITTER CREEK 4 NE	480761	41.5894	-108.509	6720	WY	Sweetwater	Sep 1962 - Present	98	0.75
BLACK ROCK	420730	38.7086	-112.953	4895	UT	Millard	Apr 1951 - Present	30	1.20
BLANDING	420738	37.6131	-109.485	6085	UT	San Juan	Jul 1948 - Present	86	1.30
BLISS 4 NW	101002	42.9544	-115.013	3275	ID	Gooding	Aug 1948 - May 2004	14	0.78
BLUFF	420788	37.2828	-109.558	4320	UT	San Juan	Jul 1948 - Present	86	0.64
BONANZA	420802	40.0167	-109.183	5450	UT	Uintah	Jul 1948 - Jun 1993	100	0.90
BORDER 3 N	480915	42.2128	-111.046	6069	WY	Lincoln	Aug 1948 - Present	12	0.92
BOULDER	420849	37.9050	-111.420	6680	UT	Garfield	Jun 1954 - Present	29	0.89
BOUNTIFUL-VAL VERDA	420820	40.8547	-111.890	4540	UT	Davis	Apr 1981 - Present	100	0.91
BRIGHAM CITY WASTE PLT	420928	41.5239	-112.044	4230	UT	Box Elder	Jun 1974 - Present	35	0.83
BRIGHT ANGEL RS	21001	36.2147	-112.062	8000	AZ	Coconino	Jul 1948 - Present	74	1.65
BROWNS PARK REFUGE	51017	40.8008	-108.917	5354	CO	Moffat	Apr 1966 - Present	43	0.97
BRYCE CANYON NP HQRS	421008	37.6411	-112.169	7915	UT	Garfield	Jun 1959 - Present	69	0.87
BUHL 2	101220	42.6006	-114.745	3800	ID	Twin Falls	Jul 1963 - Present	15	0.78
BULLFROG BASIN	421020	37.5300	-110.720	3822	UT	Kane	Mar 1967 - Present	97	0.69
BURLEY MUNI AP	101303	42.5417	-113.766	4142	ID	Cassia	Jan 1948 - Present	34	1.44
CALIENTE	261358	37.6169	-114.516	4400	NV	Lincoln	Jul 1948 - Present	55	0.56
CALLAO	421144	39.8997	-113.713	4330	UT	Juab	Jul 1948 - Present	38	0.99
CANYON DE CHELLY	21248	36.1533	-109.539	5610	AZ	Apache	Sep 1969 - Present	71	0.88
CANYONLANDS-THE NECK	421163	38.4600	-109.821	5930	UT	San Juan	Jun 1965 - Present	82	0.54
CANYONLANDS-THE NEEDLE	421168	38.1506	-109.782	4998	UT	San Juan	Jun 1965 - Present	98	0.49
CAPITOL REEF NP	421171	38.2917	-111.262	5500	UT	Wayne	Apr 1967 - Present	93	1.15
CASTLE DALE	421214	39.2078	-111.012	5620	UT	Emery	Dec 1948 - Present	38	0.77
CASTLE VALLEY	421241	38.6514	-109.399	4725	UT	Grand	Jul 1978 - Present	46	0.94

[a] Source: WRCC (2010)
[b] Aridity Rating
[c] Estimated Precipitation Bias Adjustment

Table B1 continued. NWS Stations Included in the Study.

NWS Station	Index No.	Lat	Lon	Elev	St.	County	Station Period of Record[a]			AR (%)[b]	Pcp Adj[c]
CASTLEFORD 2 N	101551	42.5503	-114.866	3825	ID	Twin Falls	Jun 1963	-	Present	12	0.92
CEDAR CITY AP	421267	37.7086	-113.094	5586	UT	Iron	Jul 1948	-	Present	57	1.00
CEDAR POINT	421308	37.7158	-109.083	6760	UT	San Juan	Jan 1957	-	Present	53	0.80
CHURCH BUTTES GAS PLT	481736	41.3975	-110.086	7075	WY	Uinta	Nov 1955	-	Present	95	0.88
CIRCLEVILLE	421432	38.1706	-112.279	6050	UT	Piute	Jul 1948	-	Present	44	0.71
CLOVER VALLEY	261740	40.8492	-115.032	5750	NV	Elko	Jan 1931	-	Mar 2010	79	1.02
COALVILLE	421588	40.9139	-111.398	5550	UT	Summit	Jan 1948	-	Present	47	0.66
COALVILLE 13 E	421590	40.9383	-111.149	6510	UT	Summit	Oct 1974	-	Present	58	0.78
COLORADO CITY	21920	36.9817	-112.973	5010	AZ	Mohave	Jul 1963	-	Present	96	1.18
COLORADO NM	51772	39.1014	-108.734	5780	CO	Mesa	Mar 1940	-	Present	53	0.89
CORINNE	421731	41.5481	-112.111	4230	UT	Box Elder	Jul 1948	-	Mar 2007	41	0.96
CORTEZ	51886	37.3444	-108.593	6153	CO	Montezuma	Aug 1948	-	Present	67	0.88
COTTONWOOD WEIR	421759	40.6242	-111.787	4960	UT	Salt Lake	Jul 1948	-	Present	66	0.68
CUTLER DAM UP&L	421918	41.8328	-112.056	4290	UT	Box Elder	Jan 1980	-	Present	11	0.95
DEER CREEK DAM	422057	40.4047	-111.529	5270	UT	Wasatch	Jul 1948	-	Present	79	1.17
DELTA	422090	39.3375	-112.586	4623	UT	Millard	Jul 1948	-	Present	20	0.68
DESERET	422101	39.2872	-112.652	4590	UT	Millard	Jul 1948	-	Present	42	0.82
DEWEY	422150	38.8128	-109.300	4120	UT	Grand	Sep 1967	-	Jun 2004	62	0.78
DINOSAUR NATL MONUMNT	52286	40.2442	-108.972	5920	CO	Moffat	Jun 1965	-	Present	83	1.18
DINOSAUR QUARRY AREA	422173	40.4378	-109.304	4800	UT	Uintah	Apr 1958	-	Present	45	0.88
DRAPER POINT OF MTN	422235	40.4878	-111.900	4500	UT	Salt Lake	Sep 1985	-	Mar 2009	36	0.70
DUCHESNE	422253	40.1678	-110.395	5520	UT	Duchesne	Jul 1948	-	Present	49	0.98
DUGWAY	422257	40.1839	-112.922	4340	UT	Tooele	Sep 1950	-	Present	50	0.77
ECHO DAM	422385	40.9675	-111.431	5470	UT	Summit	Jul 1948	-	Present	68	0.69
ELBERTA	422418	39.9500	-111.950	4690	UT	Utah	Jul 1948	-	Dec 1992	51	0.82
ELGIN	262557	37.3478	-114.543	3420	NV	Lincoln	Mar 1951	-	Present	70	0.80
ELY AIRPORT	262631	39.2953	-114.847	6262	NV	White Pine	Jan 1888	-	Present	99	0.94
ENTERPRISE BERYL JCT	422561	37.7697	-113.656	5150	UT	Iron	Jul 1948	-	Dec 2008	60	0.77
EPHRAIM USFS	422578	39.3583	-111.599	5510	UT	Sanpete	Oct 1949	-	Present	37	0.70
ESCALANTE	422592	37.7686	-111.598	5810	UT	Garfield	Jul 1948	-	Present	43	5.94
ESKDALE	422607	39.1078	-113.953	4980	UT	Millard	Mar 1966	-	Present	77	0.75
EVANSTON 1 E	483100	41.2650	-110.951	6825	WY	Uinta	Aug 1948	-	Present	37	0.67
FAIRFIELD	422696	40.2703	-112.094	4880	UT	Utah	Sep 1950	-	Present	33	0.85
FARMINGTON 3 NW	422726	41.0222	-111.935	4380	UT	Davis	Jan 1940	-	Present	38	0.73
FARMINGTON AG SCI	293142	36.6897	-108.309	5625	NM	San Juan	Mar 1976	-	Present	15	0.75
FERRON	422798	39.0872	-111.132	5930	UT	Emery	Jul 1948	-	Present	32	1.01
FILLMORE	422828	38.9664	-112.328	5120	UT	Millard	Jul 1948	-	Present	49	0.95
FISH SPRINGS NWR	422852	39.8400	-113.398	4335	UT	Juab	Jun 1960	-	Present	77	0.88
FLAMING GORGE	422864	40.9317	-109.412	6270	UT	Daggett	Nov 1957	-	Present	79	0.69
FREMONT INDIAN SP	423012	38.5778	-112.335	5920	UT	Sevier	Jun 1988	-	Present	59	0.87
FRUITA	53146	39.1653	-108.733	4504	CO	Mesa	Aug 1948	-	Present	94	0.85
FRUITLAND	293340	36.7381	-108.348	5130	NM	San Juan	Jul 1946	-	Present	34	0.80
FT DUCHESNE	422996	40.2842	-109.861	5050	UT	Uintah	Jul 1948	-	Present	60	0.70
GARFIELD	423097	40.7236	-112.198	4330	UT	Salt Lake	Jan 1951	-	Present	94	0.77
GARRISON	423138	38.9333	-114.033	5260	UT	Millard	May 1951	-	Aug 1990	51	0.86
GATEWAY	53246	38.6825	-108.972	4550	CO	Mesa	Aug 1948	-	Present	37	0.84
GOLD HILL	423260	40.1667	-113.833	5250	UT	Tooele	Apr 1966	-	Aug 1990	100	1.21
GRACE	103732	42.5872	-111.728	5550	ID	Caribou	Aug 1948	-	Present	12	0.56
GRAND CANYON NP 2	23596	36.0528	-112.150	6785	AZ	Coconino	May 1976	-	Present	49	1.36
GRAND JUNCTION 6 ESE	53489	39.0422	-108.466	4760	CO	Mesa	Mar 1962	-	Present	10	1.11

[a] Source: WRCC (2010)
[b] Aridity Rating
[c] Estimated Precipitation Bias Adjustment

Table B1 continued. NWS Stations Included in the Study.

NWS Station	Index No.	Lat	Lon	Elev	St.	County	Station Period of Record[a]	AR (%)[b]	Pcp Adj[c]
GRAND JUNCTION WALKER	53488	39.1342	-108.540	4858	CO	Mesa	Dec 1947 - Present	99	1.00
GREAT BASIN NP	263340	39.0092	-114.227	6830	NV	White Pine	Apr 1987 - Present	40	1.22
GREEN RIVER	484065	41.5314	-109.477	6077	WY	Sweetwater	Aug 1948 - Present	35	0.78
GREEN RIVER AVIATION	423418	38.9906	-110.154	4070	UT	Emery	Jul 1948 - May 2009	43	0.38
GROUSE CREEK	423486	41.7139	-113.869	5320	UT	Box Elder	Apr 1959 - Present	60	0.69
GUNNISON	423514	39.1500	-111.817	5146	UT	Sanpete	Mar 1956 - Dec 1990	37	1.04
HAGERMAN 2 SW	103932	42.8036	-114.919	2875	ID	Gooding	May 1982 - Present	21	0.83
HANKSVILLE	423611	38.3706	-110.715	4308	UT	Wayne	Jul 1948 - Present	56	0.68
HANS FLAT RS	423600	38.2553	-110.180	6600	UT	Wayne	Oct 1980 - Present	94	1.11
HAZELTON	104140	42.5972	-114.138	4060	ID	Jerome	Aug 1948 - Present	33	0.90
HEBER	423809	40.4917	-111.426	5630	UT	Wasatch	Jul 1948 - Present	26	0.78
HIAWATHA	423896	39.4833	-111.017	7284	UT	Carbon	Jul 1948 - Nov 1992	56	1.08
HITE RS	423980	37.8750	-110.388	4000	UT	San Juan	Aug 1977 - Present	97	0.72
HOVENWEEP NM	424100	37.3858	-109.075	5210	UT	San Juan	Dec 1955 - Present	98	0.96
HUNTSVILLE MONASTERY	424135	41.2403	-111.713	5140	UT	Weber	Oct 1976 - Present	44	0.87
IBAPAH	424174	40.0378	-113.988	5280	UT	Tooele	Jul 1948 - Present	24	0.88
JENSEN	424342	40.3642	-109.345	4750	UT	Uintah	Jul 1948 - Present	26	0.57
JEROME	104670	42.7325	-114.519	3740	ID	Jerome	Aug 1948 - Present	50	0.77
JOHNSON PASS	424362	40.3375	-112.611	5630	UT	Tooele	Aug 1964 - Present	37	1.02
KAMAS	424467	40.6492	-111.285	6475	UT	Summit	Oct 1948 - Present	44	0.65
KANAB	424508	37.0286	-112.537	4940	UT	Kane	Jul 1948 - Present	48	1.00
KANOSH	424527	38.8067	-112.437	4990	UT	Millard	Jul 1948 - Present	49	0.95
KEMMERER 2 N	485105	41.8167	-110.533	6926	WY	Lincoln	Aug 1948 - Present	45	0.87
KODACHROME BASIN PARK	424755	37.5142	-111.988	5810	UT	Kane	Apr 1979 - Present	63	0.83
KOOSHAREM	424764	38.5086	-111.884	6930	UT	Sevier	Oct 1948 - Apr 2009	54	0.74
LA BARGE	485252	42.2625	-110.199	6595	WY	Lincoln	Jun 1958 - Present	53	0.73
LA SAL 1SW	424947	38.3011	-109.234	6785	UT	San Juan	Mar 1978 - Present	89	0.93
LA VERKIN	424968	37.2100	-113.267	3220	UT	Washington	Apr 1950 - Apr 2010	55	0.48
LAGES	264341	40.0633	-114.615	5960	NV	White Pine	Nov 1983 - Present	100	0.84
LAKE VALLEY STEWARD	264384	38.3167	-114.650	6350	NV	Lincoln	Nov 1970 - Feb 1999	41	1.22
LAKETOWN	424856	41.8250	-111.321	5980	UT	Rich	Jul 1948 - Present	20	0.69
LEES FERRY	24849	36.8644	-111.602	3210	AZ	Coconino	Jul 1948 - Present	93	0.66
LEHMAN CAVES NM	264514	39.0000	-114.217	6826	NV	White Pine	Jul 1948 - Apr 1987	40	1.18
LEVAN	425065	39.5608	-111.865	5290	UT	Juab	Jul 1948 - Present	34	0.82
LIFTON PUMPING STN	105275	42.1231	-111.314	5926	ID	Bear Lake	Aug 1948 - Present	0	0.36
LITTLE HILLS	55048	40.0000	-108.200	6140	CO	Rio Blanco	Aug 1948 - Jan 1992	43	0.95
LITTLE SAHARA RECREATION AREA	425138	39.7269	-112.307	5240	UT	Juab	May 1979 - Present	89	0.82
LOA	425148	38.4058	-111.643	7070	UT	Wayne	Jul 1948 - Present	30	0.76
LOGAN 5 SW EXP FARM	425194	41.6661	-111.891	4490	UT	Cache	Oct 1967 - Present	32	0.76
LOGAN RADIO KVNU	425182	41.7353	-111.856	4470	UT	Cache	Nov 1956 - Present	65	0.85
LOGAN UTAH ST UNIV	425186	41.7456	-111.803	4790	UT	Cache	Jul 1948 - Present	57	0.85
LOGANDALE	264651	36.6167	-114.483	1410	NV	Clark	Jan 1968 - Dec 1991	22	0.69
LUND	264745	38.8678	-115.016	5560	NV	White Pine	Aug 1957 - Present	13	0.73
MAESER 9NW	425268	40.5603	-109.664	6440	UT	Uintah	May 1983 - Dec 2009	17	1.17
MALAD CITY	105559	42.1492	-112.287	4470	ID	Oneida	Jan 1948 - Present	14	0.64
MALTA 4 ESE	105563	42.2917	-113.304	4590	ID	Cassia	Sep 1963 - Nov 2002	17	0.99
MANILA	425377	40.9900	-109.726	6450	UT	Daggett	Jun 1952 - Present	70	0.81
MANTI	425402	39.2583	-111.631	5740	UT	Sanpete	Jul 1948 - Present	50	0.67
MARYSVALE	425477	38.4500	-112.229	5910	UT	Piute	Jul 1948 - Present	43	0.61
MASSACRE ROCKS SP	105678	42.6681	-112.998	4195	ID	Power	Apr 1973 - Present	63	0.83
MASSADONA 3E	55422	40.2844	-108.602	6190	CO	Moffat	Oct 1985 - Jul 2009	59	1.01

[a] Source: WRCC (2010)
[b] Aridity Rating
[c] Estimated Precipitation Bias Adjustment

Table B1 continued. NWS Stations Included in the Study.

NWS Station	Index No.	Lat	Lon	Elev	St.	County	Station Period of Record[a]			AR (%)[b]	Pcp Adj[c]
MAYBELL	55446	40.5158	-108.095	5908	CO	Moffat	Jun 1958	-	Present	78	1.19
MCCAMMON	105716	42.6447	-112.192	4776	ID	Bannock	Aug 1949	-	Present	34	1.03
MCGILL	264950	39.4136	-114.773	6270	NV	White Pine	Jul 1948	-	Present	71	0.72
MERNA	486165	42.9500	-110.367	7698	WY	Sublette	Oct 1963	-	Jul 1988	15	0.79
MESA VERDE NP	55531	37.1986	-108.488	7115	CO	Montezuma	Aug 1948	-	Present	45	1.06
METROPOLIS	265092	41.2833	-115.017	5800	NV	Elko	Jul 1965	-	Jan 1996	26	0.92
MEXICAN HAT	425582	37.1497	-109.868	4115	UT	San Juan	Jul 1948	-	Present	91	1.27
MILFORD	425654	38.3900	-113.021	5010	UT	Beaver	Jul 1948	-	Present	69	0.96
MINIDOKA DAM	105980	42.6767	-113.500	4164	ID	Minidoka	Aug 1948	-	Present	65	1.28
MOAB	425733	38.5744	-109.546	4073	UT	Grand	Jul 1948	-	Present	94	0.96
MODENA	425752	37.7981	-113.926	5460	UT	Iron	Jan 1948	-	Jul 2004	78	0.73
MONTELLO 2SE	265352	41.2458	-114.174	4890	NV	Elko	Jul 1948	-	Present	89	0.65
MONTICELLO 2E	425805	37.8736	-109.308	6818	UT	San Juan	Jul 1948	-	Present	51	0.78
MONUMENT VALLEY	25665	36.9819	-110.111	5564	AZ	Navajo	Sep 1980	-	Present	99	0.59
MORGAN POWER & LIGHT	425826	41.0428	-111.672	5090	UT	Morgan	Jul 1948	-	Present	68	0.60
MORONI	425837	39.5267	-111.587	5560	UT	Sanpete	Jul 1948	-	Present	43	0.53
MTN DELL DAM	425892	40.7497	-111.722	5420	UT	Salt Lake	Jul 1948	-	Present	74	0.89
MTN VIEW	486555	41.2708	-110.331	6800	WY	Uinta	Mar 1966	-	Present	41	1.03
MYTON	425969	40.1942	-110.062	5080	UT	Duchesne	Jul 1948	-	Present	39	0.56
NATURAL BRIDGES NM	426053	37.6094	-109.977	6500	UT	San Juan	Jun 1965	-	Present	51	0.80
NEOLA	426123	40.4178	-110.051	5950	UT	Duchesne	Apr 1956	-	Present	11	0.80
NEPHI	426135	39.7122	-111.832	5125	UT	Juab	Jul 1948	-	Present	50	0.73
NEW HARMONY	426181	37.4844	-113.313	5265	UT	Washington	Jul 1948	-	Present	52	1.10
NORTHDALE	55970	37.8139	-109.011	6680	CO	Dolores	Aug 1948	-	Dec 2002	47	0.83
NORWOOD	56012	38.1317	-108.286	7020	CO	San Miguel	Aug 1948	-	Aug 2008	19	1.06
NUTTERS RCH	426340	39.8081	-110.257	5790	UT	Duchesne	Jul 1963	-	Present	35	0.84
OAK CITY	426357	39.3758	-112.334	5081	UT	Millard	Jul 1948	-	Present	52	0.87
OAKLEY	106542	42.2342	-113.898	4559	ID	Cassia	Aug 1948	-	Present	13	0.79
OASIS	265722	41.0333	-114.471	5830	NV	Elko	May 1987	-	Present	99	0.98
OGDEN PIONEER P H	426404	41.2442	-111.946	4350	UT	Weber	Jul 1948	-	Present	54	0.69
OGDEN SUGAR FACTORY	426414	41.2319	-112.028	4280	UT	Weber	Jul 1948	-	Present	75	0.52
OLMSTEAD P H	426455	40.3161	-111.654	4820	UT	Utah	Feb 1977	-	Present	55	0.98
ORDERVILLE	426534	37.2722	-112.639	5460	UT	Kane	Jul 1948	-	Present	42	0.74
OREM TRTMT PLT	426538	40.2767	-111.737	4510	UT	Utah	Jul 1982	-	Present	41	0.78
OURAY 4 NE	426568	40.1342	-109.642	4670	UT	Uintah	Aug 1955	-	Present	37	0.62
OVERTON	265846	36.5508	-114.458	1250	NV	Clark	Jul 1948	-	Present	68	0.64
PAGE	26180	36.9208	-111.448	4270	AZ	Coconino	Oct 1957	-	Present	100	0.65
PALISADE	56266	39.1136	-108.351	4810	CO	Mesa	Aug 1948	-	Present	37	1.53
PANGUITCH	426601	37.8239	-112.442	6630	UT	Garfield	Jul 1948	-	Present	48	0.84
PARK VALLEY	426658	41.8000	-113.350	5440	UT	Box Elder	Jul 1948	-	Apr 1990	16	1.07
PAROWAN PWR	426686	37.8497	-112.828	6000	UT	Iron	Jul 1948	-	May 2009	50	0.85
PARTOUN	426708	39.6308	-113.886	4780	UT	Juab	Mar 1950	-	Present	98	1.15
PAUL 1ENE	106877	42.6283	-113.762	4150	ID	Minidoka	Aug 1948	-	Present	10	0.86
PHANTOM RANCH	26471	36.1383	-112.096	2530	AZ	Coconino	Aug 1966	-	Present	99	0.89
PINE VIEW DAM	426869	41.2578	-111.838	4940	UT	Weber	Jul 1948	-	Present	37	1.04
PIOCHE	266252	37.9444	-114.466	6180	NV	Lincoln	Jul 1948	-	Present	44	0.99
PIPE SPRINGS NATL MON	26616	36.8586	-112.739	4920	AZ	Mohave	Jun 1963	-	Present	98	0.65
PLEASANT GROVE	426919	40.3675	-111.734	4714	UT	Utah	Jul 1948	-	Present	51	1.04
POCATELLO 2 NE	107208	42.8917	-112.409	4832	ID	Bannock	Feb 1956	-	Present	80	0.96
POCATELLO RGNL AP	107211	42.9203	-112.571	4440	ID	Power	Jan 1948	-	Present	62	1.00
PRESTON	107346	42.0933	-111.868	4800	ID	Franklin	Sep 1964	-	Present	41	0.85
PRICE BLM	427026	39.5989	-110.819	5545	UT	Carbon	Jul 1968	-	Present	48	0.64

[a] Source: WRCC (2010)

[b] Aridity Rating

[c] Estimated Precipitation Bias Adjustment

Table B1 continued. NWS Stations Included in the Study.

NWS Station	Index No.	Lat	Lon	Elev	St.	County	Station Period of Record[a]			AR (%)[b]	Pcp Adj[c]
PROVO BYU	427064	40.2458	-111.651	4570	UT	Utah	Sep 1980	-	Present	50	1.09
RANDOLPH	427165	41.6628	-111.186	6270	UT	Rich	May 1982	-	Present	19	0.96
RANGELY 1 E	56832	40.0894	-108.772	5290	CO	Rio Blanco	Jun 1950	-	Present	84	1.08
RICHFIELD RADIO KSVC	427260	38.7619	-112.077	5300	UT	Sevier	Jul 1948	-	Present	32	0.72
RICHMOND	427271	41.9064	-111.810	4680	UT	Cache	Jul 1948	-	Present	36	0.83
RIVERDALE	427318	41.1500	-112.000	4400	UT	Weber	Jul 1948	-	Mar 1991	100	0.79
ROCK SPRINGS AP	487845	41.5942	-109.065	6742	WY	Sweetwater	Dec 1947	-	Present	69	0.68
ROOSEVELT RADIO	427395	40.2878	-109.959	5050	UT	Uintah	Jul 1948	-	Present	47	0.72
RUPERT 3 WSW	107968	42.6042	-113.757	4200	ID	Minidoka	Aug 1948	-	Jun 2002	19	0.89
RUTH	267175	39.2764	-114.991	6850	NV	White Pine	Jun 1958	-	Present	56	0.90
SAGE 4 NNW	487955	41.8667	-111.000	6210	WY	Lincoln	Aug 1948	-	Aug 2001	20	0.65
SALINA	427557	38.9594	-111.855	5131	UT	Sevier	Sep 1949	-	Present	49	0.80
SALINA 24 E	427559	38.9139	-111.416	7560	UT	Sevier	Jul 1986	-	Present	47	0.93
SALT LAKE CITY INTL AP	427598	40.7781	-111.969	4225	UT	Salt Lake	Jan 1948	-	Present	93	1.00
SANTAQUIN CHLORINATOR	427686	39.9578	-111.779	5160	UT	Utah	Jul 1948	-	Present	67	0.64
SCIPIO	427714	39.2453	-112.107	5315	UT	Millard	Jul 1948	-	Present	44	0.92
SCOFIELD DAM	427724	39.7858	-111.119	7630	UT	Carbon	Jul 1948	-	Present	38	0.92
SHOSHONE 1 WNW	108380	42.9383	-114.417	3950	ID	Lincoln	Aug 1948	-	Present	54	0.88
SNAKE CREEK POWERHOUSE	427909	40.5453	-111.504	6010	UT	Wasatch	Jul 1948	-	Present	42	1.05
SNOWVILLE	427931	41.9667	-112.717	4560	UT	Box Elder	Jul 1948	-	Oct 1991	16	0.96
SODA SPRINGS AP	108535	42.6514	-111.583	5842	ID	Caribou	Dec 1967	-	Present	65	0.88
SPANISH FORK PWR HOUSE	428119	40.0797	-111.604	4720	UT	Utah	Jul 1948	-	Present	57	1.18
SPRING VALLEY SP	267750	38.0406	-114.180	5950	NV	Lincoln	Aug 1974	-	Present	63	0.61
ST GEORGE	427516	37.1069	-113.561	2770	UT	Washington	Oct 1892	-	Present	80	0.62
SUNNYSIDE	428474	39.5667	-110.367	6785	UT	Carbon	Apr 1958	-	Jul 1988	46	0.97
SUNNYSIDE - LUND 31S	267908	38.4236	-115.023	5300	NV	Nye	Jul 1948	-	Present	72	0.75
SUNNYSIDE CITY CTR	428478	39.5517	-110.385	6530	UT	Carbon	Oct 1988	-	Apr 2008	54	1.00
SUPAI	28343	36.2000	-112.700	3204	AZ	Coconino	Jun 1956	-	Jun 1987	99	0.71
TEEC NOS POS	28468	36.9233	-109.090	5290	AZ	Apache	Jun 1962	-	Present	83	0.68
THIOKOL PROPULSION F S	428668	41.7197	-112.426	4600	UT	Box Elder	Jun 1962	-	Present	99	0.77
THOMPSON	428705	38.9667	-109.717	5099	UT	Grand	Jul 1948	-	Jan 1995	58	1.00
TIMPANOGOS CAVE	428733	40.4447	-111.707	5740	UT	Utah	Jul 1948	-	Present	71	0.77
TOOELE	428771	40.5278	-112.298	5070	UT	Tooele	Jul 1948	-	Present	52	1.00
TREMONTON	428817	41.7108	-112.164	4310	UT	Box Elder	Jan 1931	-	Present	43	0.92
TRENTON	428828	41.9153	-111.913	4455	UT	Cache	Jul 1948	-	Present	13	0.95
TROPIC	428847	37.6258	-112.081	6280	UT	Garfield	Jul 1948	-	Nov 1999	32	0.93
TUBA CITY	28792	36.1306	-111.244	4988	AZ	Coconino	Jul 1948	-	Present	51	0.65
TWIN FALLS 6 E	109303	42.5458	-114.346	3960	ID	Twin Falls	Apr 1962	-	Present	15	0.97
TWIN FALLS KMVT	109293	42.5808	-114.457	3670	ID	Twin Falls	Jul 1960	-	Present	53	0.87
URAVAN	58560	38.3761	-108.742	5010	CO	Montrose	Nov 1960	-	Present	91	0.88
UTAH LAKE LEHI	428973	40.3597	-111.897	4497	UT	Utah	Jul 1948	-	Present	5	0.71
VERNAL 2SW	429111	40.4269	-109.553	5470	UT	Uintah	Jul 1948	-	Present	20	0.80
VERNON	429133	40.1125	-112.435	5485	UT	Tooele	Aug 1953	-	Present	22	0.82
VEYO PWR HOUSE	429136	37.3522	-113.667	4600	UT	Washington	Aug 1957	-	Present	40	1.32
WAH WAH RCH	429152	38.4831	-113.426	4880	UT	Beaver	Aug 1955	-	Jul 2009	84	0.73
WAHWEAP	29114	36.9953	-111.491	3730	AZ	Coconino	Apr 1961	-	Present	51	0.58
WANSHIP DAM	429165	40.7908	-111.408	5940	UT	Summit	Aug 1955	-	Present	65	0.70
WELLS	268988	41.1006	-114.974	5700	NV	Elko	Jul 1948	-	Jul 2004	44	0.80
WENDOVER AP AWOS	429382	40.7206	-114.036	4237	UT	Tooele	Jul 1948	-	Present	51	0.69
WOODRUFF	429595	41.5250	-111.149	6315	UT	Rich	Jul 1948	-	Present	11	0.77
YELLOW JACKET 2 W	59275	37.5206	-108.756	6860	CO	Montezuma	May 1962	-	Dec 2002	11	0.86
ZION NP	429717	37.2083	-112.984	4050	UT	Washington	Jul 1948	-	Present	60	1.00

[a] Source: WRCC (2010)
[b] Aridity Rating
[c] Estimated Precipitation Bias Adjustment

APPENDIX C: ELECTRONIC WEATHER STATION INFORMATION

Weather Station Networks in the Study Area

AgriMet
The Pacific Northwest Cooperative Agricultural Weather Network
http://www.usbr.gov/pn/agrimet/
Organization: United States Bureau of Reclamation
Stations: 74
Used: 5/5
Agriculturally Representative: High

ASC
NMSU State Climate Network, Agricultural Science Center
http://monsoon.nmsu.edu/nmcombined
Organization: New Mexico State University
Stations: 5
Used: 1/1
Agriculturally Representative: Medium-High

CEMP
Community Environmental Monitoring Program
http://www.cemp.dri.edu/
Organization: United States Department of Energy, Desert Research Institute
Stations: 29
Used: 0/9
Agriculturally Representative: Low

CoAgMet
Colorado Agricultural Weather Network
http://climate.colostate.edu/~coagmet/
Organization: Colorado State University
Stations: 69
Used: 6/10
Agriculturally Representative: Medium-High

CSI
Campbell's Scientific, Inc., Instrument Research
http://weather.campbellsci.com/
Organization: Campbell's Scientific, Inc.
Stations: Manufacturer
Used: 0/4
Agriculturally Representative: Low-High

UET-Net
Utah EvapoTranspiration Network
http://www.conservewater.utah.gov/ET/ETSite/default.asp?Summary.htm
Organization: Utah Department of Water Resources
Stations: 17
Used: 0/17
Agriculturally Representative: Low-High

EWCD
Emery Water Conservancy District
http://www.ewcd.org/
Organization: Emery Water Conservancy District
Stations: 8
Used: 0/8
Agriculturally Representative: Low-High

GSOD
Global Surface Summary of the Day
http://climate.usurf.usu.edu/products/data.php?tab=gsod
Organization: United States Federal Aviation Administration
Stations: 1000+
Used: 13/42
Agriculturally Representative: Low

MALEK
Huntington PacifiCorp Power Plant
http://www.pacificorp.com/index.html
Organization: Huntington PacifiCorp Power Plant
Stations: 1
Used: 1/1
Agriculturally Representative: High

NAPI
Navajo Agricultural Products Industry
http://monsoon.nmsu.edu/nmcombined
Organization: Navajo Agricultural Products Industry
Stations: 2
Used: 1/2
Agriculturally Representative: Low-Medium

RAWS
Remote Automated Weather Stations
http://raws.fam.nwcg.gov/
Organization: United States Interagency
Stations: 1000+
Used: 0/113
Agriculturally Representative: Low-Medium

SCAN
Soil Climate Analysis Network
http://www.wcc.nrcs.usda.gov/scan/
Organization: United States Natural Resources Conservation Service
Stations: 184
Used: 26/35
Agriculturally Representative: Low-High

SNOTEL
SNOwpack TELemetry
http://www.wcc.nrcs.usda.gov/snow/
Organization: United States Natural Resources Conservation Service
Stations: 796
Used: 0/91
Agriculturally Representative: Low

SRWUA
Sevier River Water Users Authority
http://www.sevierriver.org/
Organization: Sevier River Water Users Authority
Stations: 3
Used: 0/3
Agriculturally Representative: Medium-High

UB
Uintah Basin
http://www.wrcc.dri.edu/uintabasin/
Organization: United States Natural Resources Conservation Service
Stations: 10
Used: 7/10
Agriculturally Representative: Low-High

USCRN
United States Climate Reference Network
http://www.ncdc.noaa.gov/crn/
Organization: United States National Oceanic and Atmospheric Administration
Stations: 114
Used: 1/5
Agriculturally Representative: Low-High

USU
Utah State University Agricultural Network
http://extension.usu.edu/agweather/
Organization: Utah State University
Stations: 27
Used: 22/27
Agriculturally Representative: Medium-High

USU 94
Utah State University 1994 Study Data
Utah Agricultural Experiment Station Research Report 145
Organization: Utah State University
Stations: 27
Used: 11/27
Agriculturally Representative: Medium-High

Electronic Weather Stations Included in the Study

Table C1. Electronic Weather Stations Used for Characterizing Weather Parameters at NWS Sites in Utah and Surrounding Areas.

Station Name	Network[a]	Lat.	Lon.	Elev. (ft.)	Wnd Hgt[b] (m)	Anmt Type[c]	Data Use[d]		
							Wind	Wind Limit	Tdew
Aberdeen	AGRIMET	42.953	-112.827	4400	2	1	1	1	1
Afton	AGRIMET	42.733	-110.936	6210	2	1	1	1	1
Malta	AGRIMET	42.438	-113.414	4410	2	1	1	1	1
Rupert	AGRIMET	42.596	-113.874	4155	2	1	1	1	1
Twin Falls	AGRIMET	42.546	-114.345	3920	2	1	1	1	1
Cortez	CoAgMet	37.225	-108.673	6015	2	3	1	1	1
Dove Creek	CoAgMet	37.727	-108.954	6595	2	3	1		
Olathe	CoAgMet	38.635	-108.050	5324	2	3	1	1	1
Orchard Mesa	CoAgMet	39.042	-108.460	4600	2	3	1	1	
Towaoc	CoAgMet	37.189	-108.935	5319	2	3	1	1	
Yellow Jacket	CoAgMet	37.529	-108.724	6900	2	3	1	1	
Big Piney AP	GSOD	42.580	-110.100	6969	10	4	1		
Bryce Canyon AP	GSOD	37.700	-112.150	7585	10	4	1		
Caliente AP	GSOD	37.600	-114.850	4380	9	4	1		
Ely AP	GSOD	39.300	-114.850	6260	10	4	1		
Grand Canyon AP	GSOD	36.000	-112.150	6608	10	4	1		
Hanksville AP	GSOD	38.410	-110.700	4308	9	4	1		
Page AP	GSOD	36.930	-111.450	4278	8	4	1		
Rock Springs AP	GSOD	41.600	-109.060	6739	10	4	1		
Soda Springs AP	GSOD	42.650	-111.580	5840	9	4	1		
Wells AP	GSOD	41.120	-114.920	5679	9	4	1		
Wendover AP	GSOD	40.730	-114.030	4236	9	4	1		
Castle Dale	MALEK	39.179	-111.031	5660	3	1	1		
Farmington NAPI Bk1	NAPI	36.595	-108.111	5790	3	1	1	1	1
Farmington ASC	NMSU	36.683	-108.310	5650	3	1	1	1	
Alkali Mesa	SCAN	37.670	-109.370	6451	3.25	2	1		
Blue Creek	SCAN	41.930	-112.430	5189	3.28	2	1		
Buffalo Jump	SCAN	41.350	-111.183	6686	2.95	2	1		
Cache Junction	SCAN	41.820	-111.980	4431	2.95	2	1	1	1
Circleville	SCAN	38.150	-112.250	6120	3.2	2	1	1	1
Dugway	SCAN	40.167	-113.017	4318	2.95	2	1		
Eastland	SCAN	37.780	-109.170	6845	3.07	2	1	1	
Enterprise	SCAN	37.630	-113.650	5249	3.05	2	1		
Ephraim	SCAN	39.420	-111.570	5504	3.2	2	1	1	1
Goshute	SCAN	39.983	-114.000	5470	3	2	1		
Grantsville	SCAN	40.583	-112.400	4339	2.95	2	1		

[a]AgriMet = USBR AgriMet, CoAgMet = Colorado St. Univ. CoAgMet, GSOD = Global Summary of the Day (airports), Malek = Private Research Station, NAPI = Navajo Agricultural Products Industry, NMSU = New Mexico St. Univ., SCAN = NRCS SCAN, UB = NRCS Uintah Basin, USU = Utah St. Univ. Agweather, USU94 = from Hill (1994).
[b]Wind measurement height.
[c]Wind anemometer type: 1 = MetOne 014A, 2 = R.M. Young 05103, 3 = R.M. Young 03101, and 4 = Other or Wind Tunnel Calibrated.
[d]Wind = characterization of wind speeds, wind limit = hourly data used to determine wind limits, T_{dew} = characterization of dew point offset temperatures.

Table C1 continued. Electronic Weather Stations Used for Characterizing Weather Parameters at NWS Sites in Utah and Surrounding Areas.

Station Name	Network[a]	Lat.	Lon.	Elev. (ft.)	Wnd Hgt[b] (m)	Anmt Type[c]	Data Use[d] Wind	Wind Limit	Tdew
Green River	SCAN	39.020	-110.170	4107	3.12	2	1	1	
Hals Canyon	SCAN	38.600	-113.750	5250	3	2	1		
Holden	SCAN	39.200	-112.400	4741	3.2	2	1	1	
McCracken Mesa	SCAN	37.450	-109.330	5319	3.28	2	1		
Milford	SCAN	38.350	-113.020	4997	3.23	2	1		
Morgan	SCAN	41.000	-111.680	5149	3.28	2	1	1	1
Mountain Home	SCAN	40.370	-110.400	6950	3.4	2	1	1	
Nephi	SCAN	39.650	-111.870	5255	3.25	2	1	1	
Park Valley	SCAN	41.767	-113.267	5100	3	2	1		
Price	SCAN	39.530	-110.800	5647	3.15	2	1	1	
Sand Hollow	SCAN	37.100	-113.350	3180	3	2	1		
Split Mountain	SCAN	40.383	-109.350	4839	3	2	1	1	1
Spooky	SCAN	37.517	-111.267	5338	3	2	1		
Tule Valley	SCAN	39.233	-113.467	4583	3	2	1		
West Summit	SCAN	38.020	-109.130	7004	3.48	2	1		
Altamont	UB	40.359	-110.269	6279	2.8	1	1	1	1
Duchesne	UB	40.181	-110.342	5448	3	1	1	1	1
Fruitland	UB	40.222	-110.840	6591	3	1	1	1	1
Maeser	UB	40.463	-109.582	5342	3	1	1	1	1
Manila	UB	40.989	-109.720	6348	10	1	1	1	
Pelican Lake	UB	40.181	-109.668	4801	3	1	1		
Tabiona	UB	40.386	-110.738	6597	2.9	1	1	1	1
Baker 5W	USCRN	39.012	-114.209	6617	1.5	4	1		
Beryl Junction West	USU	37.720	-113.702	5187	3	1	1	1	1
Caine Dairy	USU	41.657	-111.899	4499	3	1	1		1
Cedar City	USU	37.673	-113.137	5529	3	1	1	1	1
Corinne	USU	41.519	-112.174	4238	3	4	1	1	1
Flowell	USU	38.957	-112.421	4735	3	1	1	1	1
Hardware Ranch	USU	41.601	-111.567	5564	3	1	1		1
Laketown	USU	41.838	-111.334	5959	3	1	1	1	1
Lewiston	USU	41.952	-111.869	4514	3	2	1	1	1
Lifton	USU	42.120	-111.300	5920	3	1	1		
Logan Drainage Farm	USU	41.763	-111.879	4435	3	1	1	1	1
Logan GC	USU	41.745	-111.789	4808	4	1	1	1	
Murray GC	USU	40.631	-111.920	4290	4	1	1	1	1
Nephi	USU	39.689	-111.877	5002	3	1	1	1	1
Panguitch	USU	37.869	-112.422	6550	3	2	1	1	1
Parowan	USU	37.862	-112.881	5770	3	1	1	1	1
Randolph Pump	USU	41.833	-111.088	6264	3	1	1	1	1

[a]AgriMet = USBR AgriMet, CoAgMet = Colorado St. Univ. CoAgMet, GSOD = Global Summary of the Day (airports), Malek = Private Research Station, NAPI = Navajo Agricultural Products Industry, NMSU = New Mexico St. Univ., SCAN = NRCS SCAN, UB = NRCS Uintah Basin, USU = Utah St. Univ. Agweather, USU94 = from Hill (1994).

[b]Wind measurement height.

[c]Wind anemometer type: 1 = MetOne 014A, 2 = R.M. Young 05103, 3 = R.M. Young 03101, and 4 = Other or Wind Tunnel Calibrated.

[d]Wind = characterization of wind speeds, wind limit = hourly data used to determine wind limits, T_{dew} = characterization of dew point offset temperatures.

Table C1 continued. Electronic Weather Stations Used for Characterizing Weather Parameters at NWS Sites in Utah and Surrounding Areas.

Station Name	Network[a]	Lat.	Lon.	Elev. (ft.)	Wnd Hgt[b] (m)	Anmt Type[c]	Data Use[d] Wind	Wind Limit	Tdew
Snowville West	USU	41.984	-112.912	4443	3	2	1	1	1
Southgate GC	USU	37.074	-113.590	2559	3	2	1	1	1
Spanish Fork	USU	40.067	-111.629	4721	3	1	1	1	1
St. Charles	USU	42.117	-111.368	5951	3	1	1	1	1
Sunbrook GC	USU	37.108	-113.634	2665	3	2	1	1	1
Tremonton	USU	41.723	-112.154	4331	3	1	1	1	1
Castle Dale	USU94	39.200	-111.020	5619	3	1	1		1
Delta	USU94	39.180	-112.330	4623	3	1	1		
Escalante	USU94	37.620	-111.600	5790	3	1	1		
Grantsville	USU94	40.600	-112.470	4290	3	1	1		
Kaysville	USU94	41.030	-111.850	4340	2	1	1		
Lifton	USU94	42.120	-111.300	5920	3	1	1		1
Midway	USU94	40.520	-111.470	5550	3	1	1		
Palmyra	USU94	40.130	-111.700	4520	3	1	1		
Park City	USU94	40.650	-111.500	7140	3	1	1		
Randolph	USU94	41.750	-111.130	6240	3	1	1		1
Santaquin	USU94	39.980	-111.780	4850	3	1	1		

[a]AgriMet = USBR AgriMet, CoAgMet = Colorado St. Univ. CoAgMet, GSOD = Global Summary of the Day (airports), Malek = Private Research Station, NAPI = Navajo Agricultural Products Industry, NMSU = New Mexico St. Univ., SCAN = NRCS SCAN, UB = NRCS Uintah Basin, USU = Utah St. Univ. Agweather, USU94 = from Hill (1994).
[b]Wind measurement height.
[c]Wind anemometer type: 1 = MetOne 014A, 2 = R.M. Young 05103, 3 = R.M. Young 03101, and 4 = Other or Wind Tunnel Calibrated.
[d]Wind = characterization of wind speeds, wind limit = hourly data used to determine wind limits, T_{dew} = characterization of dew point offset temperatures.

Daily Data Quality Control

Daily datasets from the EWS sites were processed to eliminate poor data and, where necessary, estimate small gaps in the datasets. Software was developed to process the EWS data and flag poor or missing data. Bad or missing data was estimated to provide complete datasets for entire calendar years. Duplicate data records were removed from the datasets. Data records were flagged if data records for all weather parameters were identical for two consecutive days. Individual weather parameters were flagged if identical measurements were recorded for four consecutive days. Descriptions of the processes used to flag and replace data for daily maximum and minimum air temperatures and humidity, daily wind run, and daily total solar radiation, are found below. If the total number of flagged, missing, or rejected weather values (including all parameters) exceeded 500 data points for a given year, then that entire year was excluded from further consideration in the study. Datasets were visually inspected further for any obvious trends related to instrument malfunction.

Air Temperature

Daily maximum and minimum air temperatures, T_{max} and T_{min}, respectively, were flagged if they exceeded 120 °F or dropped below -70 °F. If $T_{max} < T_{min}$ then both were flagged. If a temperature record was missing, or exceeded the mentioned limits, then it was estimated using the following hierarchy of methods, i.e. if the data necessary for the first method in the list were not available then the second was used and so on in succession:

1. If T_{max} needed to be estimated and T_{min} was available and the dataset had more than one year, then the average difference between T_{max} and T_{min} over all the years for that day was used to find T_{max}, T_{min} was estimated similarly if T_{max} was good.
2. T_{max} and/or T_{min} were estimated using the average of the values from the preceding two days and following two days.
3. T_{max} and/or T_{min} were estimated using the average of the values from the preceding day and following two days.
4. T_{max} and/or T_{min} were estimated using the average of the values from the preceding two days and following day.
5. T_{max} and/or T_{min} were estimated using the average of the values from the preceding day and following day.
6. T_{max} and/or T_{min} were estimated using the average of the value from the preceding day and the historical average for the day in question, if the dataset included more than one year.
7. T_{max} and/or T_{min} were estimated using the historical average for the day in question, if the dataset included more than one year.
8. T_{max} and/or T_{min} were estimated using the value from the following day.
9. T_{max} and/or T_{min} were estimated using the value from the previous day.

If the necessary data were not available to estimate a data gap using the above listed criteria, then the data line was flagged for manual inspection. Typically if a value could not be estimated, the data year would have also been rejected for other reasons.

Humidity

Most of the included EWS datasets included daily maximum and minimum relative humidity, RH_{max} and RH_{min}, respectively. Some datasets, however, included the average daily dew point temperature, T_{dew}, as the measurement of humidity. In the case of RH, RH_{max} and RH_{min} records were rejected if they exceeded 120% or dropped below 0%. If they did not exceed 120% they were limited to 100%. If $RH_{max} < RH_{min}$, then both were rejected for that day. RH_{max} and RH_{min} were estimated using a similar process as was used to estimate T_{max} and T_{min} data. T_{dew} was only reported at 5 included stations. T_{dew} values were flagged if they exceeded similar bounds as described for the air temperatures. T_{dew} was estimated similar to T_{max} and T_{min} with the exception that for the No. 1 priority T_{dew} was estimated using T_{min} and the average difference between T_{dew} and T_{min} for that day.

Wind

Daily wind run, u_{day}, is the daily average wind speed reported in miles per day (mpd). Wind run values were rejected if they exceeded 1000 mpd or were below 24 mpd. Gaps in the WR data were estimated similar to those in the temperature data with the exclusion of the No. 1 priority method (i.e. priorities 2 through 9 only).

Solar Radiation

Daily total incident solar radiation, R_s, values were rejected if they exceeded 1000 Langleys (Ly) per day or dropped below 20 Ly/day. A Langley is 1 cal/cm^2. If R_s values fell outside these bounds then they were estimated using a method described by Allen and Robison (2007) for estimating R_s from temperature and humidity data. This method is referred to herein as the modified Thornton and Running Method (T-R-Mod). This method has a theoretical asymptote at clear day solar radiation and, although it performs well on average, it typically does not produce in the same range of R_s values from day to day as is observed in measured R_s datasets. Therefore estimated values of R_s were alternately multiplied by 1.1 or 0.9 to better approximate the observed range. See Appendix E for a summary comparison of R_s estimation methods.

Hourly Data Quality Control

Although daily data was available for all included EWS datasets, hourly data was only available for 48 stations. Often, the hourly records did not extend as far back in time as the daily records did. However, hourly data was useful in evaluating ET estimates calculated using daily time steps because of wind effects (see Irmak et al. 2005). This helped identify further data adjustments, which are discussed later. Hourly datasets were processed similarly to the daily datasets.

Methods for filling in missing data (gaps) are described below. Software was developed to process the hourly EWS datasets similar to that used to process the daily EWS datasets. Bad or missing data were estimated to provide complete datasets for entire calendar years. Duplicate data records were removed from the datasets. Data records were flagged if all weather parameters were identical for two consecutive hours. Individual weather parameters were flagged if identical measurements were recorded for four consecutive hours. Descriptions of the processes used to flag and replace data for hourly average, maximum, and minimum air temperatures and humidity, hourly average wind speed, and hourly total solar radiation, are found below. If the total number of flagged, missing, or rejected weather values (including all parameters) exceeded 15000 data points for a given year, then that entire year was excluded from further consideration in the study.

Air Temperature

Hourly maximum and minimum air temperatures, T_{maxhr}, and T_{minhr}, respectively, were rejected and estimated using the same criteria and hierarchy as described for daily T_{max} and T_{min}. However, hourly values were estimated using values from the preceding and following hours, and historical averages were calculated from the same day and hour for all the years in the record. Hourly average air temperature, T_{hr}, records were flagged using the same limits as were used for T_{maxhr}, and T_{minhr}. Missing or rejected T_{hr} values were estimated similarly to T_{maxhr}, and T_{minhr} with the exclusion of the first priority T_{hr}.

Humidity

Hourly relative humidity, RH_{maxhr} and RH_{minhr}, respectively, were rejected and estimated using the same criteria and hierarchy as described for daily RH_{max} and RH_{min}. However, hourly values were estimated using values from the preceding and following hours, and historical averages were calculated from the same day and hour for all the years in the record. Hourly average relative humidity, RH_{hr}, records were flagged using the same limits as were used for RH_{maxhr}, and RH_{minhr}. Missing or rejected RH_{hr} values were estimated similarly to RH_{maxhr}, and RH_{minhr} with the exclusion of the first priority.

Wind Speed

Hourly average wind speed, u_{hr}, values, were rejected if they exceeded 80 mph or dropped below 0 mph. Missing or rejected u_{hr} values were estimated using the same procedures described for daily wind run. However, hourly values were estimated using values from the preceding and following hours, and historical averages were calculated from the same day and hour for all the years in the record.

Solar Radiation

Hourly average incident solar radiation values, R_{shr}, were rejected if they exceeded 200 cal/cm^2/hr or if they dropped below -20 cal/cm^2/hr. Missing or rejected R_{shr} values were estimated using a process similar to that used to estimate the daily R_s. R_{shr} were estimated by estimating R_s for the day as was described for filling in daily R_s. The ratio of estimated daily R_s to calculated theoretical daily extra terrestrial solar radiation, R_a, was used to approximate R_{shr} by multiplying hourly R_a, by that ratio. The estimated R_{shr} values were alternately multiplied by 1.1 or 0.9 to simulate the range observed in measured datasets, as was explained for estimated daily R_s.

APPENDIX D: ARIDITY RATINGS ASSIGNED TO GAP LAND COVERS

D1. Aridity Ratings Assigned to GAP Land Covers.

NRCS Curve Number	Description	Aridity Rating
CN Level 1	No Data	0
CN Level 3	Developed, Open Space	30
CN Level 3	Developed, Low Intensity	50
CN Level 3	Developed, Medium Intensity	80
CN Level 3	Developed, High Intensity	100
CN Level 3	Quarries, Mines, Gravel Pits and Oil Wells	90
CN Level 3	Orchards Vineyards and Other High Structure Agriculture	0
CN Level 3	Cultivated Cropland	10
CN Level 3	Pasture/Hay	20
CN Level 1	Aquatic	0
CN Level 2	Beach, shore and sand	100
CN Level 2	Cliff, canyon and talus	100
CN Level 2	Bluff and badland	100
CN Level 3	Temperate Pacific Intertidal Mudflat	10
CN Level 3	Temperate Pacific Freshwater Mudflat	10
CN Level 3	Inter-Mountain Basins Wash	100
CN Level 3	North Pacific Serpentine Barren	100
CN Level 3	North American Warm Desert Playa	100
CN Level 3	Mediterranean California Serpentine Barrens	100
CN Level 3	Inter-Mountain Basins Playa	100
CN Level 2	Alpine sparse and barren	100
CN Level 3	Geysers and Hot Springs	0
CN Level 3	Inter-Mountain Basins Volcanic Rock and Cinder Land	100
CN Level 3	North Pacific Volcanic Rock and Cinder Land	100
CN Level 3	North American Warm Desert Pavement	100
CN Level 3	North American Warm Desert Volcanic Rockland	100
CN Level 2	Deciduous dominated forest and woodland (xeric-mesic)	20
CN Level 2	Mixed deciduous/coniferous forest and woodland (xeric-mesic)	30
CN Level 3	Northern Rocky Mountain Western Larch Savanna	40
CN Level 3	Central and Southern California Mixed Evergreen Woodland	40
CN Level 3	Colorado Plateau Pinyon-Juniper Woodland	40
CN Level 3	Columbia Plateau Western Juniper Woodland and Savanna	40
CN Level 3	Great Basin Pinyon-Juniper Woodland	40
CN Level 3	Inter-Mountain Basins Subalpine Limber-Bristlecone Pine Woodland	40
CN Level 3	Klamath-Siskiyou Lower Montane Serpentine Mixed Conifer Woodland	40
CN Level 3	Klamath-Siskiyou Upper Montane Serpentine Mixed Conifer Woodland	40
CN Level 3	Madrean Pinyon-Juniper Woodland	40
CN Level 3	Mediterranean California Dry-Mesic Mixed Conifer Forest and Woodland	40
CN Level 3	California Montane Jeffrey Pine-(Ponderosa Pine) Woodland	40
CN Level 3	Mediterranean California Subalpine Woodland	40
CN Level 3	North Pacific Maritime Dry-Mesic Douglas-fir-Western Hemlock Forest	40
CN Level 3	North Pacific Mountain Hemlock Forest	40
CN Level 3	Northern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest	40
CN Level 3	Northern Rocky Mountain Subalpine Woodland and Parkland	40
CN Level 3	Rocky Mountain Foothill Limber Pine-Juniper Woodland	75
CN Level 3	Rocky Mountain Lodgepole Pine Forest	40
CN Level 3	Southern Rocky Mountain Dry-Mesic Montane Mixed Conifer Forest and Woodland	90
CN Level 3	Northern Rocky Mountain Ponderosa Pine Woodland and Savanna	75
CN Level 3	Southern Rocky Mountain Ponderosa Pine Woodland	75
CN Level 3	Rocky Mountain Subalpine Dry-Mesic Spruce-Fir Forest and Woodland	55
CN Level 3	Rocky Mountain Subalpine-Montane Limber-Bristlecone Pine Woodland	55
CN Level 3	Sierra Nevada Subalpine Lodgepole Pine Forest and Woodland	40
CN Level 3	Southern Rocky Mountain Pinyon-Juniper Woodland	75
CN Level 3	Middle Rocky Mountain Montane Douglas-fir Forest and Woodland	40
CN Level 3	Rocky Mountain Poor-Site Lodgepole Pine Forest	40
CN Level 3	California Coastal Closed-Cone Conifer Forest and Woodland	40
CN Level 3	Sierran-Intermontane Desert Western White Pine-White Fir Woodland	80
CN Level 3	North Pacific Dry-Mesic Silver Fir-Western Hemlock-Douglas-fir Forest	80
CN Level 3	Northwestern Great Plains - Black Hills Ponderosa Pine Woodland and Savanna	90
CN Level 3	East Cascades Oak-Ponderosa Pine Forest and Woodland	75
CN Level 3	North Pacific Wooded Volcanic Flowage	65
CN Level 2	Conifer dominated forest and woodland (mesic-wet)	35

Table D1 continued. Aridity Ratings Assigned to GAP Land Covers.

NRCS Curve Number	Description	Aridity Rating
CN Level 2	Alpine and avalanche chute shrubland	55
CN Level 2	Scrub shrubland	100
CN Level 2	Steppe	80
CN Level 2	Chaparral	90
CN Level 2	Deciduous dominated savanna and glade	60
CN Level 2	Conifer dominated savanna	95
CN Level 2	Sagebrush dominated shrubland	100
CN Level 2	Deciduous dominated shrubland	100
CN Level 2	Alpine grassland	50
CN Level 2	Montane grassland	60
CN Level 2	Lowland grassland and prairie (xeric-mesic)	80
CN Level 2	Sand prairie, coastal grasslands and lomas	50
CN Level 2	Harvested forest	65
CN Level 2	Recently burned	75
CN Level 3	Introduced Upland Vegetation - Treed	50
CN Level 3	Introduced Upland Vegetation - Shrub	50
CN Level 3	Introduced Upland Vegetation - Annual Grassland	50
CN Level 3	Introduced Riparian and Wetland Vegetation	0
CN Level 3	Introduced Upland Vegetation - Perennial Grassland and Forbland	35
CN Level 3	Disturbed, Non-specific	75
CN Level 3	Disturbed/Successional - Recently Chained Pinyon-Juniper	100
CN Level 1	Riparian and wetland systems	0

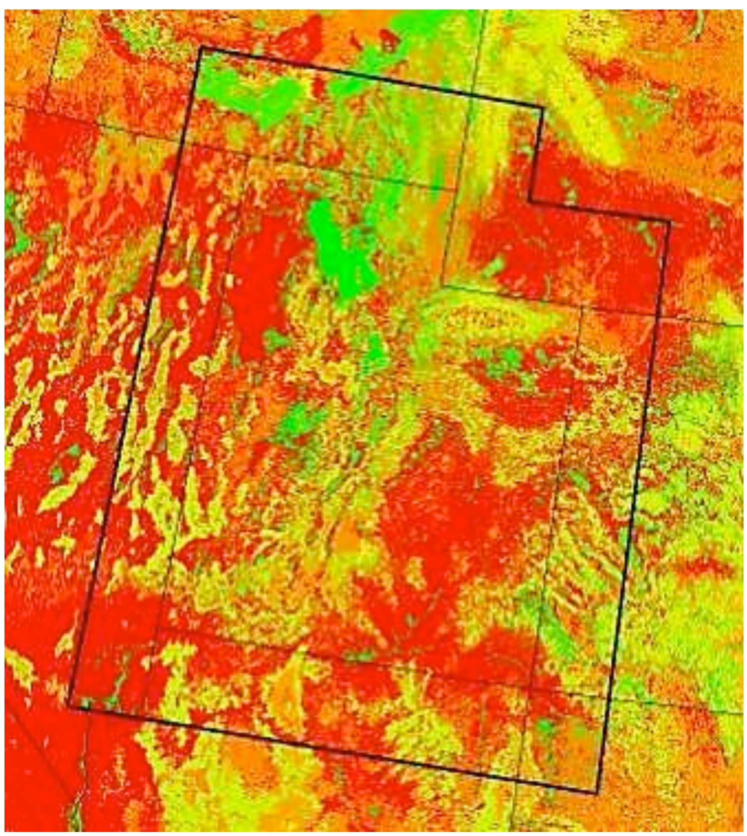


Figure D1. Map of aridity ratings corresponding to GAP land cover data in the area one degree latitude and longitude of Utah. Red is AR = 100%, green is AR = 0%.

APPENDIX E: MONTHLY CHARACTERISTIC WEATHER DATA FROM EWS DATASETS

Table E1. Monthly Mean Wind Run (mpd) at EWS sites adjusted to Equivalent Anemometer Height of 2 m.

STATION	LAT	LONG	ELEV	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
AGRIMET Aberdeen	42.953	-112.827	4400	139	134	151	166	151	131	102	99	102	116	123	129
AGRIMET Afton	42.733	-110.936	6210	42	41	55	74	75	63	56	56	52	50	43	43
AGRIMET Malta	42.438	-113.414	4410	174	160	185	204	153	134	109	105	122	141	151	162
AGRIMET Rupert	42.596	-113.874	4155	177	176	190	205	175	143	103	102	114	145	157	174
AGRIMET Twin Falls	42.546	-114.345	3920	136	141	143	148	128	115	94	89	99	114	118	128
ASC Farmington	36.683	-108.310	5650	100	118	140	160	141	121	104	97	98	98	101	102
CoAgMet Cortez	37.225	-108.673	6015	93	104	114	121	92	86	77	74	76	87	89	90
CoAgMet Dove Creek	37.726	-108.954	6595	147	157	176	199	179	168	132	127	138	146	147	149
CoAgMet Olathe	38.635	-108.050	5324	68	84	109	128	112	98	66	56	63	71	74	69
CoAgMet Orchard Mesa	39.042	-108.460	4600	87	100	126	139	125	121	116	107	111	100	98	83
CoAgMet Towaoc	37.189	-108.935	5319	122	141	170	171	149	145	132	116	125	126	120	124
CoAgMet Yellow Jacket	37.529	-108.724	6900	95	105	123	142	120	109	94	88	97	102	99	98
GSOD BIG PINEY (AMOS)	42.560	-110.100	6969	83	81	107	128	130	128	119	110	105	103	90	78
GSOD BRYCE CANYON	37.700	-112.150	7585	127	133	145	164	154	150	126	123	134	132	127	120
GSOD CALIENTE (AMOS)	37.610	-114.510	4380	55	57	69	81	82	86	83	76	70	57	57	47
GSOD ELY YELLAND FIELD	39.300	-114.850	6260	141	138	148	157	144	152	145	150	147	143	137	140
GSOD GRAND CANYON PARK	36.000	-112.150	6608	97	102	105	123	117	117	88	79	90	94	93	92
GSOD HANKSVILLE	38.360	-110.710	4308	61	68	83	99	88	81	61	63	67	67	70	62
GSOD PAGE MUNI (AMOS)	36.930	-111.450	4278	55	65	86	107	102	99	90	84	80	71	59	53
GSOD ROCK SPRINGS ARPT	41.600	-109.060	6739	194	183	193	196	181	170	147	142	151	176	174	182
GSOD SODA SPRINGS-TIGERT	42.650	-111.580	5840	151	158	150	159	153	157	139	143	136	136	137	141
GSOD WELLS	41.110	-114.960	5679	152	134	129	128	136	108	108	93	84	110	112	122
GSOD WENDOVER (AUT)	40.730	-114.030	4236	82	87	118	142	134	131	128	116	102	96	85	78
MALEK CAST	39.179	-111.031	5660	39	62	110	140	126	114	100	91	95	79	77	44
NAPI Farmington Block 1	36.595	-108.111	5790	94	119	137	155	143	132	99	99	99	95	81	86
SCAN Alkali Mesa	37.670	-109.370	6451	89	97	134	161	148	134	108	113	105	111	96	99
SCAN Blue Creek	41.930	-112.430	5189	119	119	148	181	149	137	142	149	141	133	131	108
SCAN Buffalo Jump	41.350	-111.183	6686	110	101	125	158	155	155	152	162	150	120	159	128
SCAN Cache Junction	41.820	-111.980	4431	86	69	110	132	107	96	95	93	91	89	87	82
SCAN Circleville	38.150	-112.250	6120	109	111	161	188	157	141	111	113	108	123	117	120
SCAN Dugway	40.167	-113.017	4318	82	93	153	167	155	123	124	169	128	101	132	89
SCAN Eastland	37.780	-109.170	6845	203	193	237	264	233	190	147	156	164	195	195	198
SCAN Enterprise	37.630	-113.650	5249	134	115	167	178	151	148	133	138	128	136	128	122
SCAN Ephraim	39.420	-111.570	5504	70	72	104	128	110	92	79	89	73	73	68	67
SCAN Goshute	39.983	-114.000	5470	89	126	105	133	128	118	125	137	131	104	109	87
SCAN Grantsville	40.583	-112.400	4339	94	91	152	175	144	137	143	186	156	132	161	96
SCAN Green River	39.020	-110.170	4107	50	61	112	145	129	99	71	61	56	62	61	56
SCAN Hals Canyon	38.600	-113.750	5250	68	147	158	175	189	177	147	180	145	111	133	109
SCAN Holden	39.200	-112.400	4741	86	95	137	147	125	120	113	123	109	103	91	88
SCAN McCracken Mesa	37.450	-109.330	5319	86	100	139	163	152	141	123	120	118	118	102	97
SCAN Milford	38.350	-113.020	4997	139	138	193	198	177	162	140	159	143	153	150	142
SCAN Morgan	41.000	-111.680	5149	36	37	58	86	78	65	54	57	57	59	57	48
SCAN Mountain Home	40.370	-110.400	6950	79	85	104	126	125	114	119	111	114	103	91	76
SCAN Nephi	39.650	-111.870	5255	123	106	143	155	129	109	107	125	116	106	107	114
SCAN Park Valley	41.767	-113.267	5100	97	77	109	162	146	126	134	129	123	111	117	79
SCAN Price	39.530	-110.800	5647	79	92	162	190	170	148	139	129	121	119	112	87
SCAN Sand Hollow	37.100	-113.350	3180	74	69	116	107	122	111	101	108	82	83	89	55
SCAN Split Mountain	40.383	-109.350	4839	50	49	99	130	131	116	100	94	76	67	68	56

Table E1. Continued. Monthly Mean Wind Run (mpd) at EWS sites adjusted to Equivalent Anemometer Height of 2 m.

SCAN Spooky	37.517	-111.267	5338	93	150	155	186	196	165	135	130	137	125	124	110
SCAN Tule Valley	39.233	-113.467	4583	60	139	133	160	158	159	137	191	141	109	123	98
SCAN West Summit	38.020	-109.130	7004	149	146	179	212	180	159	127	134	134	145	146	152
UB Altamont	40.359	-110.269	6279	76	85	120	142	139	128	109	103	105	104	89	73
UB Duchesne	40.181	-110.342	5448	78	91	131	144	121	103	81	70	73	88	90	74
UB Fruitland	40.222	-110.840	6591	120	115	132	140	134	116	103	91	98	108	102	107
UB Maeser	40.463	-109.582	5342	43	52	79	91	81	74	71	66	63	63	57	48
UB Manila	40.989	-109.720	6348	63	61	90	100	81	69	56	52	57	63	63	55
UB Pelican Lake	40.181	-109.668	4801	36	45	91	115	101	92	70	65	62	58	50	38
UB Tabiona	40.386	-110.738	6597	138	145	169	182	167	151	145	137	154	157	147	128
USCRN Baker 5 W	39.012	-114.209	6617	94	89	111	120	115	116	111	118	117	100	100	87
USU Beryl Junction West	37.720	-113.702	5187	104	107	140	169	140	144	119	121	116	112	104	99
USU Caine Dairy	41.657	-111.899	4499	35	42	62	92	85	66	75	72	63	64	43	45
USU Cedar City	37.673	-113.137	5529	112	113	145	166	125	126	95	105	106	104	106	120
USU Corinne	41.519	-112.174	4238	103	124	147	151	135	126	96	98	91	111	98	100
USU Flowell	38.957	-112.421	4735	67	74	116	132	108	100	75	73	65	69	69	66
USU Hardware Ranch	41.601	-111.567	5564	37	38	51	56	56	51	48	51	51	46	36	32
USU Laketown	41.838	-111.334	5959	105	85	116	125	124	113	107	114	104	105	107	106
USU Lewiston	41.952	-111.869	4514	81	69	102	117	97	87	80	94	86	88	84	84
USU Lifton	42.120	-111.300	5920	61	71	70	102	99	86	77	68	75	78	68	64
USU Logan Drainage Farm	41.763	-111.879	4435	56	53	80	101	89	76	71	76	67	64	55	53
USU Logan Golf and Country Club	41.745	-111.789	4808	65	87	116	143	143	149	167	170	167	130	113	82
USU Murray Golf Course	40.631	-111.920	4290	77	85	103	115	94	90	82	90	79	77	73	82
USU Nephi	39.689	-111.877	5002	94	84	114	131	113	117	91	99	88	83	87	83
USU Panguitch	37.869	-112.422	6550	126	139	170	191	162	134	107	107	119	135	128	132
USU Parowan	37.862	-112.881	5770	82	83	119	155	130	128	95	106	109	105	93	79
USU Randolph Pump	41.833	-111.088	6264	87	89	118	141	134	123	110	106	103	105	95	88
USU Snowville West	41.984	-112.912	4443	93	99	145	166	136	136	119	129	112	123	106	101
USU Southgate Golf Course	37.074	-113.590	2559	41	39	55	65	63	60	55	50	46	45	42	40
USU Spanish Fork	40.067	-111.629	4721	51	57	76	87	70	69	60	72	61	65	55	57
USU St. Charles	42.117	-111.368	5951	65	55	70	99	101	85	67	78	73	71	82	82
USU Sunbrook Golf Course	37.108	-113.634	2665	45	54	67	79	74	71	64	60	57	52	46	44
USU Tremonton	41.723	-112.154	4331	122	157	139	140	136	144	134	131	131	125	114	111
USU94 Castle Dale	39.200	-111.020	5619	51	52	81	140	106	135	111	91	97	73	63	54
USU94 Delta	39.180	-112.330	4623	60	67	126	119	115	100	91	88	67	64	66	58
USU94 Escalante	37.620	-111.600	5790	125	138	152	144	121	123	103	102	97	109	114	114
USU94 Grantsville	40.600	-112.470	4290	85	88	112	113	116	115	114	83	69	76	50	31
USU94 Kaysville	41.030	-111.850	4340	67	72	104	101	115	96	89	96	89	83	79	63
USU94 Lifton	42.120	-111.300	5920	49	33	59	87	88	83	74	57	56	48	58	56
USU94 Midway	40.520	-111.470	5550	43	48	72	82	100	84	69	72	61	73	63	42
USU94 Palmyra	40.130	-111.700	4520	76	73	132	132	132	112	99	94	90	82	90	82
USU94 Park City	40.650	-111.500	7140	56	49	70	75	71	58	56	64	52	60	60	50
USU94 Randolph	41.750	-111.130	6240	87	87	121	133	131	99	81	97	102	87	109	72
USU94 Santaquin	39.980	-111.780	4850	59	56	89	88	76	67	58	54	52	43	50	49

Table E2. Monthly Calculation Wind Limit Values (mpd) derived from EWS Data

STATION	LAT	LONG	ELEV	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
AGRIMET Aberdeen	42.953	-112.827	4400	94	133	125	171	141	138	115	113	100	97	101	116
AGRIMET Afton	42.733	-110.936	6210	34	41	66	73	74	56	49	56	52	44	39	16
AGRIMET Malta	42.438	-113.414	4410	140	140	178	220	160	116	99	98	101	114	141	89
AGRIMET Rupert	42.596	-113.874	4155	116	162	164	239	198	160	121	118	125	146	116	121
AGRIMET Twin Falls	42.546	-114.345	3920	102	136	131	160	134	112	97	89	92	100	99	82
ASC Farmington	36.683	-108.31	5650	74	101	119	150	135	127	96	86	94	94	84	79
CoAgMet Cortez	37.225	-108.673	6015	74	86	95	117	90	86	71	69	71	78	72	70
CoAgMet Olathe	38.635	-108.05	5324	55	71	101	120	109	98	59	49	58	62	56	56
CoAgMet Orchard Mesa	39.042	-108.46	4600	62	71	102	129	120	115	92	84	88	76	71	49
CoAgMet Towaoc	37.189	-108.935	5319	71	92	117	147	130	125	100	90	91	96	79	76
CoAgMet Yellow Jacket	37.529	-108.724	6900	77	90	123	140	113	109	85	82	90	94	89	76
NAPI Farmington Block 25	36.595	-108.111	5790	63	89	121	144	121	117	84	79	89	87	69	63
SCAN Cache Junction	41.82	-111.98	4431	86	69	110	132	107	91	95	93	83	75	76	80
SCAN Circleville	38.15	-112.25	6120	109	106	161	188	157	141	109	113	105	111	100	103
SCAN Eastland	37.78	-109.17	6845	118	144	214	264	233	190	145	146	156	162	157	129
SCAN Ephraim	39.42	-111.57	5504	70	61	104	123	110	92	79	89	72	59	45	55
SCAN Green River	39.02	-110.17	4107	50	61	112	145	129	99	71	61	56	62	61	56
SCAN Holden	39.2	-112.4	4741	81	90	137	147	124	116	113	123	101	89	69	61
SCAN Morgan	41	-111.68	5149	36	37	58	86	78	65	54	57	57	58	56	48
SCAN Mountain Home	40.37	-110.4	6950	79	85	104	126	125	114	111	110	112	103	91	76
SCAN Nephi	39.65	-111.87	5255	102	77	126	139	129	109	107	125	116	99	82	77
SCAN Price	39.53	-110.8	5647	79	92	162	190	170	148	139	127	117	119	107	87
SCAN Split Mountain	40.383	-109.35	4839	50	49	99	130	131	116	100	94	76	67	68	56
UB Altamont	40.359	-110.269	6279	86	90	110	144	136	129	97	96	98	94	94	77
UB Duchesne	40.181	-110.342	5448	57	93	116	127	113	101	67	58	58	66	91	73
UB Fruitland	40.222	-110.84	6591	81	115	130	145	131	125	94	82	88	83	80	78
UB Maeser	40.463	-109.582	5342	36	56	57	89	76	61	61	63	53	59	58	27
UB Manila	40.989	-109.72	6348	57	69	82	102	84	77	54	54	54	59	67	58
UB Tabiona	40.386	-110.738	6597	75	104	113	142	121	118	103	93	99	98	94	72
USU Beryl Junction West	37.72	-113.702	5187	108	98	142	165	137	142	101	122	116	105	95	95
USU Cedar City	37.673	-113.137	5529	101	107	144	166	125	126	93	105	101	108	106	106
USU Corinne	41.519	-112.174	4238	99	98	108	120	110	98	89	94	76	78	75	96
USU Flowell	38.957	-112.421	4735	52	61	111	132	96	95	71	70	65	66	63	60
USU Laketown	41.838	-111.334	5959	89	52	118	110	114	92	106	105	89	78	102	80
USU Lewiston	41.952	-111.869	4514	54	49	83	99	81	69	80	85	71	60	68	67
USU Logan Drainage Farm	41.763	-111.879	4435	48	47	75	90	72	62	57	69	57	44	46	42
USU Logan Golf and Country Club	41.745	-111.789	4808	59	75	99	107	103	95	104	99	89	74	71	67
USU Murray Golf Course	40.631	-111.92	4290	69	75	105	114	92	86	73	85	78	76	74	80
USU Nephi	39.689	-111.877	5002	69	75	109	123	104	103	96	108	92	82	63	55
USU Panguitch	37.869	-112.422	6550	87	75	133	174	153	128	90	85	67	95	77	70
USU Parowan	37.862	-112.881	5770	69	79	119	148	131	131	79	104	108	99	93	80
USU Randolph Pump	41.833	-111.088	6264	87	86	119	132	134	118	106	95	94	85	70	79
USU Snowville West	41.984	-112.912	4443	86	91	116	148	116	111	109	111	88	91	78	96
USU Southgate Golf Course	37.074	-113.59	2559	40	40	58	67	65	62	58	53	49	46	35	34
USU Spanish Fork	40.067	-111.629	4721	51	52	91	95	70	67	62	78	58	63	46	37
USU St. Charles	42.117	-111.368	5951	61	62	68	98	95	85	62	71	60	61	68	80
USU Sunbrook Golf Course	37.108	-113.634	2665	42	50	64	77	73	71	64	60	56	44	40	39
USU Tremonton	41.723	-112.154	4331	91	126	101	106	98	99	99	102	89	70	70	84

Comparison of R_s Models

Several empirical methods of estimating R_s were evaluated to determine the best model for use in ET calculations. Summaries of the performance of four models are found below for entire years and for April to September time periods.

Comparison of R_s Models Over Entire Years at 17 Locations in Utah.

Station	No. Yrs	H-S, K_{RS} = 0.15[a]			T-R[b,c]			T-R-Mod[b,d]			H-S, Monthly K_{RS}[e]		
		Est/ Obs	RMSE- Day[f]	RMSE- Mon[f]	Est/ Obs	RMSE- Day[f]	RMSE- Mon[f]	Est/ Obs	RMSE- Day[f]	RMSE- Mon[f]	Est/ Obs	RMSE- Day[f]	RMSE- Mon[f]
Beryl Junct. West	11	1.00	3.38	1.06	1.03	3.45	1.43	1.00	3.24	1.09	1.00	3.31	0.79
Cedar City	6	1.01	3.73	1.47	1.05	3.80	1.86	1.02	3.72	1.61	1.00	3.63	1.21
Corinne	5	0.94	3.78	1.46	1.04	3.46	1.47	0.98	3.55	1.14	1.00	3.57	0.79
Flowell	3	1.13	4.46	2.97	1.14	4.82	3.42	1.13	4.53	3.09	1.00	3.63	1.39
Lewiston	4	1.03	3.55	1.05	1.08	3.65	1.83	1.05	3.55	1.33	1.00	3.48	0.73
Logan Drain. Farm	8	1.04	3.66	1.24	1.06	4.10	1.68	1.05	3.50	1.22	1.00	3.55	0.82
Logan GC	8	0.92	4.42	2.31	1.07	4.05	1.81	0.99	3.85	1.59	1.00	3.90	1.23
Murray GC	9	0.92	4.20	1.86	1.03	3.41	0.93	0.96	3.90	1.21	1.00	3.85	0.76
Panguitch	4	1.07	4.03	2.12	1.09	4.28	2.55	1.07	4.10	2.22	1.00	3.59	1.02
Parowan	5	1.10	4.16	2.34	1.15	4.60	2.98	1.12	4.30	2.60	1.00	3.72	1.33
Randolph Pump	10	1.02	3.53	1.26	1.08	3.74	1.98	1.04	3.51	1.31	1.00	3.41	0.80
Snowville West	5	1.03	3.68	1.40	1.07	3.95	2.12	1.04	3.68	1.54	1.00	3.49	0.76
Southgate GC	4	0.96	3.19	1.11	1.00	3.31	1.08	0.97	2.99	0.98	1.00	3.09	0.77
Spanish Fork	8	0.98	3.77	1.11	1.07	3.69	1.69	1.03	3.66	1.16	1.00	3.71	0.89
St. Charles	5	1.00	3.73	1.61	1.05	3.71	1.79	1.03	3.69	1.58	1.00	3.62	1.30
Sunbrook GC	7	1.03	3.02	1.20	1.04	3.10	1.20	1.02	2.80	0.91	1.00	2.86	0.72
Tremonton	7	0.97	4.16	2.10	1.07	3.96	2.29	1.01	3.87	1.94	1.00	3.96	1.68
Average		1.01	3.79	1.63	1.07	3.83	1.89	1.03	3.67	1.56	1.00	3.55	1.00
Wgt'd Avg.[g]		1.00	3.77	1.56	1.06	3.77	1.79	1.02	3.63	1.46	1.00	3.55	0.97
St. Dev.		0.06	0.41	0.56	0.04	0.45	0.65	0.05	0.43	0.60	0.00	0.28	0.30

[a]Hargreaves and Samani (1982) with K_{RS} = 0.15.
[b]T_{dew} was calculated for T-R and T-R-Mod using the monthly dew point depression (K_0) for each station.
[c]Thornton and Running (1999).
[d]Thornton and Running (1999) as modified by Allen and Robison (2007) with no adjustment on days with precipitation.
[e]RHargreaves and Samani (1982) with K_{RS} determined for each month by comparison with actual R_s.
[f]Root Mean Squared Error, Day is for daily calculations, Mon. is for monthly average R_s.
[g]Weighted average using the number of years for each station.

Comparison of R_s Models from April to September at 17 Locations in Utah.

Station	No. Yrs	H-S, K_{RS} = 0.15[a]			T-R[b,c]			T-R-Mod[b,d]			H-S, Monthly K_{RS}[e]		
		Est/ Obs	RMSE-Day[f]	RMSE-Mon[f]	Est/ Obs	RMSE-Day[f]	RMSE-Mon[f]	Est/ Obs	RMSE-Day[f]	RMSE-Mon[f]	Est/ Obs	RMSE-Day[f]	RMSE-Mon[f]
Beryl Junct. West	11	1.02	3.90	1.30	1.06	4.06	1.87	1.02	3.73	1.33	1.00	3.79	0.93
Cedar City	6	1.02	4.45	1.94	1.07	4.61	2.56	1.04	4.45	2.17	1.00	4.30	1.58
Corinne	5	0.94	4.41	1.77	1.04	4.09	1.91	0.98	4.04	1.38	1.00	4.11	0.92
Flowell	3	1.13	5.50	3.95	1.15	6.04	4.55	1.13	5.60	4.12	1.00	4.28	1.84
Lewiston	4	1.02	3.92	1.00	1.07	4.20	2.29	1.03	3.88	1.44	1.00	3.88	0.66
Logan Drain. Farm	8	1.04	4.32	1.42	1.06	4.97	2.15	1.04	4.09	1.43	1.00	4.21	0.96
Logan GC	8	0.89	5.32	3.05	1.05	4.79	2.14	0.96	4.46	1.96	1.00	4.53	1.52
Murray GC	9	0.91	5.00	2.36	1.03	3.94	1.06	0.95	4.57	1.44	1.00	4.50	0.79
Panguitch	4	1.10	4.96	2.85	1.13	5.39	3.52	1.11	5.07	3.04	1.00	4.25	1.24
Parowan	5	1.07	4.73	2.34	1.12	5.43	3.52	1.09	4.96	2.83	1.00	4.45	1.65
Randolph Pump	10	1.03	4.24	1.30	1.10	4.63	2.63	1.06	4.24	1.61	1.00	4.13	0.86
Snowville West	5	1.06	4.26	1.79	1.11	4.78	2.83	1.07	4.25	2.00	1.01	3.95	0.86
Southgate GC	4	0.97	3.47	1.22	1.02	3.72	1.22	0.98	3.19	0.94	1.00	3.35	0.72
Spanish Fork	8	0.97	4.40	1.39	1.07	4.38	2.13	1.02	4.26	1.42	1.00	4.31	1.12
St. Charles	5	1.00	4.18	1.51	1.07	4.16	1.96	1.03	4.05	1.40	1.00	4.03	0.99
Sunbrook GC	7	1.01	3.44	1.27	1.04	3.66	1.46	1.01	3.23	0.98	1.00	3.30	0.81
Tremonton	7	0.94	4.97	2.30	1.06	4.55	2.19	0.99	4.50	1.94	1.00	4.68	1.56
Average		1.01	4.44	1.93	1.07	4.55	2.35	1.03	4.27	1.85	1.00	4.12	1.12
Wgt'd Avg.[g]		1.00	4.42	1.85	1.07	4.48	2.22	1.02	4.22	1.72	1.00	4.14	1.09
St. Dev.		0.06	0.59	0.79	0.04	0.64	0.88	0.05	0.61	0.82	0.00	0.38	0.37

[a]Hargreaves and Samani (1982) with K_{RS} = 0.15.
[b]T_{dew} was calculated for T-R and T-R-Mod using the monthly dew point depression (K_0) for each station.
[c]Thornton and Running (1999).
[d]Thornton and Running (1999) as modified by Allen and Robison (2007) with no adjustment on days with precipitation.
[e]RHargreaves and Samani (1982) with K_{RS} determined for each month by comparison with actual R_s.
[f]Root Mean Squared Error, Day is for daily calculations, Mon. is for monthly average R_s.
[g]Weighted average using the number of years for each station.

While the Hargreaves and Samani (1982) approach with variable monthly K_{RS} did perform slightly better than the other three methods in terms of precision (RMSE), the major advantage of the variable K_{RS} was that it greatly improved the accuracy of the model to match monthly average R_s.

Table E3. Monthly Values of Dew Point Depression Factor, K_O, derived at 41 EWS Sites.

STATION NAME	LAT	LONG	ELEV	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
AgriMet Aberdeen	42.953	-112.827	4400	-4.55	-4.05	-0.59	2.57	3.37	2.01	1.67	4.06	2.75	0.64	-2.48	-4.37
AgriMet Afton	42.733	-110.936	6210	-5.13	-4.96	-2.62	0.98	1.53	0.98	3.38	4.19	2.42	0.87	-2.07	-4.56
AgriMet Malta	42.438	-113.414	4410	-3.15	-2.70	0.12	1.61	1.22	2.30	5.05	5.65	2.59	0.75	-2.47	-3.54
AgriMet Rupert	42.596	-113.874	4155	-2.62	-1.89	0.67	2.74	2.94	1.98	2.16	3.71	2.29	1.35	-1.37	-2.68
AgriMet Twin Falls	42.546	-114.345	3920	-1.24	-0.67	2.24	3.56	4.21	5.03	6.00	5.57	4.84	3.20	-0.05	-1.51
CoAgMet Cortez	37.225	-108.673	6015	0.18	3.68	7.37	9.71	9.32	13.69	10.53	7.65	6.52	5.54	2.92	0.60
CoAgMet Olathe	38.635	-108.050	5324	-1.66	1.12	4.52	7.54	8.91	11.25	8.55	5.10	4.50	2.55	0.60	-1.81
NAPI Farmington Block 1	36.595	-108.111	5790	-0.45	2.40	6.52	8.91	9.93	12.89	9.41	6.77	7.22	4.82	2.74	0.26
UB Altamont	40.359	-110.269	6279	-3.47	-1.22	5.14	8.77	10.45	11.28	12.54	9.29	7.87	3.18	2.23	-2.01
UB Duchesne	40.181	-110.342	5448	-3.41	0.57	7.43	9.54	10.04	11.61	13.20	9.85	7.55	5.25	3.06	-2.27
UB Fruitland	40.222	-110.840	6591	-3.83	-1.50	3.20	6.22	7.81	9.47	12.65	9.33	8.35	3.88	2.04	-1.98
UB Maeser	40.463	-109.582	5342	-4.32	-1.15	4.25	8.43	8.53	11.78	14.21	11.73	7.59	3.74	2.89	-2.85
UB Tabiona	40.386	-110.738	6597	-0.41	2.03	7.00	9.71	11.07	11.83	13.71	10.20	10.22	6.66	6.03	0.51
SCAN Cache Junction	41.820	-111.980	4431	-6.20	-5.77	0.27	6.09	5.49	5.20	10.90	13.15	9.60	3.40	-0.47	-4.01
SCAN Circleville	38.150	-112.250	6120	-5.24	-2.08	4.81	8.58	8.51	11.21	10.58	9.93	7.23	4.21	0.80	-2.75
SCAN Ephraim	39.420	-111.570	5504	-9.37	-5.55	2.18	6.06	5.32	6.11	8.84	8.56	6.56	2.31	-0.79	-6.19
SCAN Morgan	41.000	-111.680	5149	-5.41	-4.25	1.09	4.89	5.19	4.24	6.05	6.08	5.03	2.73	-0.07	-3.53
SCAN Split Mountain	40.383	-109.350	4839	-5.34	-7.03	1.04	9.80	9.72	13.63	12.79	10.80	12.37	3.66	1.37	-0.60
USU Beryl Junction West	37.720	-113.702	5187	-4.25	-2.23	1.81	5.37	6.86	11.22	8.99	7.10	6.23	2.37	-0.65	-4.02
USU Caine Dairy	41.657	-111.899	4499	-8.86	-8.40	-1.75	2.58	5.13	7.26	8.57	10.62	3.36	2.05	-3.70	-6.99
USU Cedar City	37.673	-113.137	5529	-5.15	-1.68	3.15	7.14	8.23	12.88	11.30	8.83	7.90	3.04	1.62	-4.03
USU Corinne	41.519	-112.174	4238	-3.86	-1.84	4.09	7.62	10.67	11.67	14.11	12.70	9.19	3.54	0.88	-2.14
USU Flowell	38.957	-112.421	4735	-4.57	-1.24	3.82	6.59	7.48	10.38	11.07	10.74	8.94	4.03	-0.52	-5.19
USU Hardware Ranch	41.601	-111.567	5564	-8.38	-8.74	-2.35	0.78	1.42	1.64	5.37	5.28	2.56	0.05	-4.55	-7.11
USU Laketown	41.838	-111.334	5959	-3.29	-2.61	1.03	4.66	6.44	6.81	10.25	9.24	8.82	4.57	1.26	-0.09
USU Lewiston	41.952	-111.869	4514	-7.22	-6.82	-1.04	4.17	4.36	4.90	7.13	6.40	4.23	0.90	-1.46	-4.92
USU Logan Drainage Farm	41.763	-111.879	4435	-6.94	-7.14	-0.96	3.22	4.19	4.82	7.72	6.91	3.63	0.55	-1.52	-3.29
USU Murray Golf Course	40.631	-111.920	4290	-0.89	0.51	4.26	7.38	8.99	11.99	14.53	12.68	8.83	3.82	0.67	-1.38
USU Nephi	39.689	-111.877	5002	-8.40	-3.51	4.01	4.13	7.50	9.59	11.60	11.11	9.46	3.23	1.89	-4.63
USU Panguitch	37.869	-112.422	6550	-8.53	-3.53	2.21	5.59	6.39	7.46	6.78	4.71	4.73	1.52	-0.48	-5.21
USU Parowan	37.862	-112.881	5770	-6.73	-2.61	3.02	6.55	7.41	10.25	9.08	8.02	7.92	3.23	1.88	-3.74
USU Randolph Pump	41.833	-111.088	6264	-7.58	-8.49	-2.71	2.73	4.10	5.77	9.27	7.86	4.96	1.73	-2.83	-6.86
USU Snowville West	41.984	-112.912	4443	-6.00	-4.30	2.90	6.92	8.32	9.88	13.50	13.09	8.94	2.76	-0.04	-2.99
USU Southgate Golf Course	37.074	-113.590	2559	3.69	5.97	11.54	15.35	19.42	22.52	20.39	18.81	18.92	11.81	7.92	3.04
USU Spanish Fork	40.067	-111.629	4721	0.09	2.69	6.62	8.46	9.42	12.76	15.90	14.74	12.42	5.89	3.72	-0.40
USU St. Charles	42.117	-111.368	5951	-7.67	-8.04	-4.01	1.33	3.26	3.85	4.93	3.68	1.94	-1.06	-1.81	-4.77
USU Sunbrook Golf Course	37.108	-113.634	2665	2.11	5.46	9.57	13.14	17.29	19.89	17.30	15.37	14.69	8.82	5.18	1.83
USU Tremonton	41.723	-112.154	4331	-4.80	-2.37	3.08	6.16	7.86	10.62	15.43	13.55	10.26	4.73	0.47	-2.82
USU94 Castle Dale	39.200	-111.020	5619	-3.38	-2.61	-1.84	10.18	7.75	14.94	14.50	10.47	10.50	3.19	4.55	0.92
USU94 Lifton	42.120	-111.300	5920	-6.21	-7.49	-1.53	5.71	6.68	8.04	9.11	10.93	8.80	3.74	0.63	-3.95
USU94 Randolph	41.750	-111.130	6240	-7.23	-5.94	0.03	4.42	3.96	4.48	6.28	5.89	3.80	2.01	-0.11	-4.93

APPENDIX F: NWS SITE SOLAR RADIATION K_{RS} FACTORS AND CROP LISTS

TABLE F1. MONTHLY VALUES OF SOLAR RADIATION FACTOR, K_{RS}, AT EACH OF THE 246 NWS SITES

NWS Site	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
ABERDEEN EXP STN	0.151	0.165	0.161	0.145	0.15	0.151	0.147	0.143	0.145	0.145	0.142	0.138
AFTON	0.124	0.148	0.162	0.146	0.134	0.142	0.143	0.139	0.138	0.136	0.132	0.127
ALLENS RCH	0.147	0.155	0.142	0.142	0.138	0.127	0.126	0.12	0.134	0.141	0.143	0.16
ALPINE	0.149	0.165	0.17	0.158	0.161	0.164	0.161	0.16	0.164	0.159	0.162	0.154
ALTAMONT	0.172	0.18	0.172	0.16	0.156	0.159	0.153	0.153	0.162	0.168	0.173	0.17
ALTENBERN	0.142	0.143	0.145	0.143	0.142	0.147	0.137	0.134	0.138	0.137	0.139	0.141
ALTON	0.172	0.176	0.165	0.155	0.147	0.152	0.131	0.14	0.149	0.158	0.152	0.161
AMERICAN FALLS 6 NE	0.17	0.185	0.171	0.152	0.157	0.161	0.16	0.157	0.16	0.164	0.163	0.163
ANETH PLT	0.174	0.168	0.181	0.175	0.159	0.18	0.159	0.163	0.18	0.17	0.158	0.152
ANGLE	0.146	0.168	0.155	0.156	0.139	0.147	0.129	0.133	0.135	0.15	0.129	0.14
ARBON 2 NW	0.165	0.178	0.167	0.15	0.148	0.151	0.148	0.149	0.152	0.154	0.155	0.152
ARCHES NP HQS	0.159	0.184	0.168	0.175	0.162	0.167	0.153	0.15	0.144	0.16	0.163	0.18
BEAR RIVER BAY	0.208	0.209	0.193	0.189	0.196	0.193	0.175	0.191	0.179	0.19	0.187	0.168
BEAVER CANYON PH	0.177	0.181	0.176	0.175	0.157	0.154	0.143	0.162	0.166	0.165	0.178	0.161
BEAVER DAM	0.149	0.146	0.16	0.162	0.162	0.162	0.152	0.155	0.153	0.148	0.143	0.138
BEDFORD 3 SE	0.129	0.147	0.16	0.149	0.139	0.144	0.144	0.14	0.14	0.141	0.136	0.131
BETATAKIN	0.183	0.191	0.189	0.165	0.169	0.171	0.158	0.175	0.171	0.185	0.182	0.173
BITTER CREEK 4 NE	0.164	0.17	0.158	0.147	0.143	0.133	0.133	0.132	0.144	0.152	0.149	0.163
BLACK ROCK	0.129	0.149	0.144	0.141	0.132	0.145	0.14	0.154	0.153	0.148	0.137	0.152
BLANDING	0.183	0.179	0.185	0.177	0.165	0.173	0.158	0.168	0.179	0.175	0.175	0.169
BLISS 4 NW	0.166	0.171	0.152	0.146	0.147	0.151	0.149	0.144	0.148	0.15	0.15	0.157
BLUFF	0.182	0.165	0.16	0.159	0.151	0.156	0.16	0.156	0.16	0.155	0.151	0.172
BONANZA	0.164	0.183	0.175	0.162	0.159	0.157	0.153	0.148	0.152	0.159	0.166	0.165
BORDER 3 N	0.137	0.138	0.154	0.15	0.147	0.152	0.145	0.127	0.144	0.144	0.147	0.129
BOULDER	0.177	0.191	0.189	0.172	0.169	0.178	0.161	0.179	0.174	0.184	0.175	0.173
BOUNTIFUL-VAL VERDA	0.163	0.202	0.174	0.173	0.177	0.187	0.192	0.182	0.182	0.192	0.183	0.195
BRIGHAM CITY WASTE PLT	0.156	0.174	0.164	0.159	0.161	0.16	0.164	0.164	0.155	0.153	0.151	0.155
BRIGHT ANGEL RS	0.172	0.182	0.188	0.173	0.17	0.166	0.152	0.171	0.165	0.178	0.171	0.164
BROWNS PARK REFUGE	0.13	0.142	0.143	0.139	0.138	0.138	0.134	0.13	0.133	0.135	0.135	0.125
BRYCE CANYON NP HQRS	0.175	0.182	0.166	0.162	0.155	0.165	0.136	0.155	0.16	0.172	0.176	0.171
BUHL 2	0.176	0.182	0.168	0.163	0.171	0.171	0.17	0.166	0.167	0.168	0.164	0.165
BULLFROG BASIN	0.18	0.18	0.176	0.155	0.164	0.163	0.149	0.169	0.159	0.164	0.172	0.17
BURLEY MUNI AP	0.168	0.175	0.165	0.161	0.163	0.165	0.161	0.155	0.159	0.165	0.158	0.158
CALIENTE	0.158	0.155	0.16	0.16	0.154	0.153	0.142	0.146	0.151	0.15	0.154	0.161
CALLAO	0.168	0.154	0.159	0.158	0.144	0.153	0.14	0.153	0.152	0.154	0.162	0.16
CANYON DE CHELLY	0.161	0.162	0.156	0.152	0.156	0.159	0.16	0.159	0.16	0.157	0.156	0.161
CANYONLANDS-THE NECK	0.196	0.221	0.194	0.194	0.184	0.203	0.194	0.196	0.193	0.2	0.208	0.202
CANYONLANDS-THE NEEDLE	0.163	0.171	0.179	0.174	0.161	0.17	0.153	0.156	0.164	0.161	0.161	0.157
CAPITOL REEF NP	0.18	0.191	0.184	0.165	0.166	0.169	0.158	0.173	0.167	0.185	0.182	0.187
CASTLE DALE	0.122	0.15	0.152	0.152	0.142	0.147	0.143	0.136	0.157	0.152	0.167	0.148
CASTLE VALLEY	0.187	0.202	0.183	0.179	0.161	0.165	0.144	0.161	0.159	0.171	0.177	0.189
CASTLEFORD 2 N	0.174	0.176	0.157	0.153	0.155	0.158	0.158	0.154	0.159	0.163	0.162	0.162
CEDAR CITY AP	0.16	0.161	0.162	0.158	0.148	0.15	0.139	0.154	0.154	0.156	0.15	0.153
CEDAR POINT	0.172	0.198	0.198	0.177	0.16	0.164	0.148	0.157	0.165	0.171	0.17	0.167
CHURCH BUTTES GAS PLT	0.19	0.197	0.187	0.161	0.156	0.149	0.149	0.146	0.16	0.163	0.181	0.18
CIRCLEVILLE	0.148	0.17	0.159	0.159	0.136	0.149	0.131	0.141	0.144	0.153	0.143	0.152
CLOVER VALLEY	0.137	0.155	0.152	0.154	0.158	0.16	0.161	0.152	0.149	0.146	0.134	0.127
COALVILLE	0.142	0.142	0.148	0.145	0.139	0.132	0.134	0.138	0.148	0.139	0.146	0.141
COALVILLE 13 E	0.135	0.138	0.151	0.158	0.151	0.141	0.142	0.138	0.155	0.147	0.148	0.139

Table F1. Continued. Monthly values of Solar Radiation Factor, K_{RS}, at each of the 246 NWS Sites

COLORADO CITY	0.17	0.166	0.159	0.157	0.164	0.163	0.156	0.158	0.158	0.163	0.163	0.162
COLORADO NM	0.17	0.166	0.167	0.171	0.171	0.178	0.16	0.157	0.168	0.157	0.167	0.169
CORINNE	0.169	0.181	0.176	0.16	0.163	0.166	0.161	0.167	0.158	0.156	0.158	0.156
CORTEZ	0.157	0.16	0.161	0.156	0.155	0.157	0.153	0.151	0.158	0.157	0.16	0.155
COTTONWOOD WEIR	0.163	0.173	0.183	0.174	0.179	0.186	0.185	0.181	0.188	0.179	0.175	0.167
CUTLER DAM UP&L	0.17	0.209	0.184	0.159	0.157	0.17	0.172	0.173	0.176	0.173	0.156	0.152
DEER CREEK DAM	0.139	0.148	0.146	0.14	0.145	0.145	0.14	0.145	0.146	0.142	0.162	0.145
DELTA	0.129	0.156	0.143	0.139	0.135	0.144	0.135	0.143	0.15	0.145	0.135	0.146
DESERET	0.144	0.167	0.145	0.148	0.142	0.153	0.146	0.153	0.159	0.154	0.144	0.16
DEWEY	0.18	0.195	0.156	0.155	0.145	0.142	0.124	0.135	0.137	0.141	0.148	0.202
DINOSAUR NATL MONUMNT	0.157	0.167	0.164	0.154	0.15	0.155	0.154	0.155	0.159	0.161	0.161	0.151
DINOSAUR QUARRY AREA	0.14	0.15	0.146	0.14	0.139	0.142	0.14	0.14	0.143	0.143	0.143	0.135
DRAPER POINT OF MTN	0.151	0.159	0.167	0.158	0.158	0.162	0.161	0.156	0.158	0.158	0.154	0.15
DUCHESNE	0.165	0.173	0.167	0.158	0.153	0.15	0.139	0.136	0.145	0.158	0.171	0.166
DUGWAY	0.13	0.137	0.14	0.145	0.149	0.152	0.147	0.146	0.146	0.151	0.141	0.136
ECHO DAM	0.124	0.166	0.174	0.147	0.136	0.147	0.148	0.145	0.149	0.144	0.136	0.119
ELBERTA	0.146	0.156	0.142	0.139	0.139	0.148	0.152	0.149	0.155	0.15	0.141	0.142
ELGIN 3 SE	0.164	0.157	0.17	0.167	0.164	0.161	0.147	0.15	0.153	0.148	0.148	0.148
ELY AIRPORT	0.159	0.154	0.162	0.157	0.137	0.142	0.131	0.143	0.147	0.149	0.156	0.148
ENTERPRISE	0.157	0.164	0.155	0.156	0.146	0.148	0.152	0.171	0.164	0.152	0.148	0.139
EPHRAIM USFS	0.133	0.165	0.17	0.152	0.139	0.153	0.144	0.148	0.146	0.137	0.125	0.132
ESCALANTE	0.16	0.174	0.172	0.151	0.149	0.149	0.136	0.15	0.15	0.16	0.156	0.157
ESKDALE	0.165	0.153	0.157	0.151	0.138	0.147	0.138	0.151	0.15	0.151	0.153	0.152
EVANSTON 1 E	0.161	0.187	0.17	0.158	0.15	0.152	0.148	0.147	0.147	0.152	0.156	0.167
FAIRFIELD	0.122	0.139	0.147	0.14	0.142	0.145	0.143	0.139	0.139	0.135	0.131	0.123
FARMINGTON 3 NW	0.148	0.174	0.152	0.15	0.151	0.159	0.166	0.161	0.159	0.166	0.161	0.169
FARMINGTON AG SCI	0.163	0.16	0.158	0.155	0.158	0.154	0.156	0.154	0.16	0.161	0.16	0.164
FERRON	0.121	0.16	0.163	0.165	0.157	0.157	0.153	0.143	0.173	0.157	0.171	0.156
FILLMORE	0.15	0.171	0.163	0.16	0.159	0.178	0.172	0.19	0.192	0.169	0.164	0.175
FISH SPRINGS NWR	0.184	0.164	0.17	0.168	0.154	0.164	0.144	0.161	0.161	0.164	0.172	0.169
FLAMING GORGE	0.154	0.159	0.158	0.147	0.137	0.132	0.132	0.134	0.144	0.149	0.15	0.148
FREMONT INDIAN SP	0.113	0.146	0.144	0.149	0.142	0.146	0.139	0.154	0.154	0.141	0.134	0.137
FRUITA	0.144	0.152	0.136	0.143	0.146	0.153	0.147	0.138	0.138	0.131	0.132	0.137
FRUITLAND	0.158	0.153	0.15	0.145	0.148	0.146	0.15	0.149	0.152	0.151	0.153	0.157
FT DUCHESNE	0.156	0.169	0.162	0.15	0.148	0.147	0.145	0.144	0.147	0.151	0.159	0.152
GARFIELD	0.168	0.185	0.191	0.182	0.185	0.187	0.187	0.183	0.188	0.188	0.183	0.173
GARRISON	0.19	0.175	0.157	0.153	0.139	0.154	0.144	0.155	0.152	0.156	0.158	0.15
GATEWAY	0.143	0.14	0.142	0.145	0.147	0.154	0.149	0.146	0.148	0.136	0.137	0.143
GOLD HILL	0.245	0.221	0.199	0.202	0.172	0.181	0.155	0.179	0.18	0.191	0.206	0.206
GRACE	0.146	0.144	0.162	0.153	0.14	0.147	0.14	0.135	0.141	0.149	0.153	0.136
GRAND CANYON NP 2	0.154	0.167	0.167	0.152	0.153	0.151	0.14	0.156	0.152	0.159	0.151	0.149
GRAND JUNCTION 6 ESE	0.15	0.153	0.155	0.16	0.161	0.173	0.159	0.154	0.159	0.15	0.15	0.151
GRAND JUNCTION WALKER	0.157	0.159	0.153	0.156	0.155	0.165	0.157	0.153	0.155	0.15	0.147	0.153
GREAT BASIN NP	0.179	0.173	0.183	0.181	0.167	0.171	0.159	0.174	0.18	0.182	0.184	0.175
GREEN RIVER	0.145	0.148	0.145	0.134	0.129	0.126	0.122	0.122	0.14	0.138	0.141	0.143
GREEN RIVER AVIATION	0.189	0.173	0.14	0.184	0.165	0.165	0.154	0.143	0.158	0.161	0.132	0.156
GROUSE CREEK	0.143	0.158	0.156	0.151	0.148	0.15	0.144	0.141	0.144	0.142	0.142	0.137
GUNNISON	0.138	0.16	0.141	0.152	0.136	0.15	0.141	0.146	0.146	0.147	0.129	0.136
HAGERMAN 2 SW	0.157	0.157	0.148	0.144	0.148	0.148	0.145	0.141	0.142	0.144	0.145	0.149
HANKSVILLE	0.145	0.154	0.146	0.151	0.148	0.15	0.152	0.147	0.137	0.136	0.135	0.14
HANS FLAT RS	0.2	0.234	0.21	0.205	0.2	0.209	0.191	0.195	0.201	0.213	0.2	0.206
HAZELTON	0.167	0.176	0.165	0.156	0.16	0.161	0.158	0.154	0.155	0.157	0.156	0.157
HEBER	0.14	0.149	0.146	0.141	0.143	0.144	0.141	0.147	0.146	0.138	0.157	0.141
HIAWATHA	0.18	0.187	0.176	0.176	0.161	0.183	0.156	0.167	0.174	0.179	0.179	0.147
HITE RS	0.199	0.197	0.191	0.198	0.168	0.188	0.174	0.179	0.188	0.184	0.188	0.186
HOVENWEEP NM	0.161	0.161	0.158	0.152	0.156	0.157	0.154	0.154	0.157	0.156	0.159	0.162
HUNTSVILLE MONASTERY	0.124	0.139	0.154	0.152	0.133	0.145	0.144	0.14	0.143	0.142	0.131	0.118
IBAPAH	0.143	0.14	0.15	0.15	0.133	0.133	0.119	0.125	0.132	0.139	0.143	0.139

Table F1. Continued. Monthly values of Solar Radiation Factor, K_{RS}, at each of the 246 NWS Sites

JENSEN	0.14	0.151	0.144	0.138	0.139	0.144	0.141	0.142	0.144	0.143	0.141	0.133
JEROME	0.161	0.167	0.158	0.15	0.154	0.155	0.154	0.151	0.154	0.155	0.152	0.153
JOHNSON PASS	0.152	0.157	0.154	0.159	0.157	0.159	0.159	0.16	0.164	0.173	0.161	0.16
KAMAS	0.159	0.157	0.168	0.165	0.156	0.144	0.15	0.153	0.165	0.162	0.164	0.155
KANAB	0.171	0.161	0.153	0.152	0.145	0.151	0.133	0.143	0.15	0.153	0.152	0.163
KANOSH	0.146	0.176	0.167	0.162	0.153	0.163	0.166	0.177	0.187	0.171	0.156	0.165
KEMMERER 2 N	0.13	0.136	0.152	0.135	0.133	0.136	0.131	0.125	0.13	0.127	0.127	0.121
KODACHROME BASIN PARK	0.148	0.172	0.168	0.147	0.152	0.148	0.137	0.15	0.144	0.152	0.149	0.15
KOOSHAREM	0.158	0.171	0.171	0.165	0.14	0.154	0.134	0.153	0.148	0.156	0.156	0.162
LA BARGE	0.101	0.125	0.149	0.136	0.13	0.139	0.141	0.137	0.133	0.127	0.113	0.103
LA SAL 1SW	0.203	0.201	0.172	0.195	0.17	0.17	0.147	0.165	0.176	0.174	0.185	0.191
LA VERKIN	0.17	0.167	0.16	0.157	0.161	0.161	0.157	0.159	0.156	0.16	0.162	0.172
LAGES	0.171	0.162	0.165	0.157	0.141	0.147	0.133	0.144	0.15	0.154	0.163	0.162
LAKE VALLEY STEWARD	0.233	0.21	0.184	0.187	0.17	0.189	0.16	0.178	0.17	0.182	0.185	0.191
LAKETOWN	0.137	0.152	0.159	0.153	0.136	0.154	0.161	0.156	0.155	0.148	0.146	0.134
LEES FERRY	0.171	0.162	0.164	0.147	0.153	0.152	0.14	0.152	0.15	0.159	0.157	0.154
LEHMAN CAVES NM	0.2	0.197	0.184	0.189	0.165	0.18	0.165	0.188	0.179	0.191	0.183	0.177
LEVAN	0.148	0.16	0.141	0.146	0.143	0.164	0.155	0.16	0.165	0.157	0.131	0.138
LIFTON PUMPING STN	0.149	0.145	0.166	0.162	0.162	0.165	0.159	0.136	0.152	0.156	0.167	0.147
LITTLE HILLS	0.136	0.139	0.129	0.14	0.144	0.14	0.132	0.122	0.121	0.119	0.123	0.128
LITTLE SAHARA RECREATION AREA	0.16	0.16	0.152	0.138	0.14	0.139	0.129	0.128	0.118	0.172	0.169	0.172
LOA	0.147	0.168	0.162	0.167	0.155	0.159	0.14	0.147	0.147	0.151	0.139	0.147
LOGAN 5 SW EXP FARM	0.134	0.154	0.166	0.147	0.152	0.155	0.151	0.143	0.145	0.146	0.155	0.136
LOGAN RADIO KVNU	0.156	0.165	0.163	0.151	0.16	0.159	0.157	0.153	0.15	0.144	0.14	0.138
LOGAN UTAH ST UNIV	0.153	0.174	0.173	0.164	0.17	0.173	0.171	0.17	0.166	0.161	0.146	0.133
LOGANDALE	0.146	0.145	0.153	0.155	0.154	0.155	0.141	0.145	0.143	0.142	0.136	0.128
LUND	0.158	0.149	0.156	0.155	0.138	0.142	0.132	0.142	0.146	0.145	0.15	0.15
MAESER 9NW	0.15	0.165	0.167	0.159	0.158	0.164	0.163	0.164	0.168	0.169	0.161	0.145
MALAD CITY	0.156	0.168	0.188	0.146	0.141	0.141	0.142	0.145	0.145	0.143	0.148	0.164
MALTA 4 ESE	0.163	0.17	0.154	0.147	0.144	0.144	0.139	0.137	0.141	0.144	0.152	0.152
MANILA	0.158	0.162	0.156	0.149	0.148	0.139	0.142	0.14	0.151	0.153	0.153	0.153
MANTI	0.169	0.181	0.174	0.164	0.153	0.165	0.16	0.159	0.163	0.157	0.15	0.149
MARYSVALE	0.164	0.175	0.165	0.164	0.139	0.147	0.129	0.139	0.139	0.147	0.146	0.145
MASSACRE ROCKS SP	0.158	0.169	0.163	0.149	0.152	0.152	0.148	0.149	0.151	0.153	0.148	0.151
MASSADONA 3E	0.152	0.164	0.167	0.158	0.158	0.162	0.161	0.16	0.163	0.161	0.158	0.144
MAYBELL	0.13	0.145	0.151	0.141	0.14	0.143	0.141	0.141	0.142	0.14	0.137	0.124
MCCAMMON	0.161	0.178	0.168	0.15	0.15	0.152	0.149	0.151	0.152	0.152	0.152	0.153
MCGILL	0.166	0.156	0.161	0.164	0.148	0.154	0.142	0.155	0.156	0.153	0.166	0.16
MERNA	0.132	0.161	0.161	0.151	0.137	0.15	0.152	0.15	0.147	0.143	0.138	0.129
MESA VERDE NP	0.176	0.177	0.182	0.171	0.17	0.173	0.165	0.163	0.174	0.175	0.178	0.172
METROPOLIS	0.159	0.172	0.162	0.164	0.166	0.168	0.162	0.159	0.158	0.155	0.149	0.147
MEXICAN HAT	0.174	0.168	0.163	0.163	0.158	0.159	0.164	0.156	0.159	0.155	0.153	0.162
MILFORD	0.144	0.152	0.142	0.147	0.146	0.161	0.135	0.144	0.14	0.129	0.122	0.116
MINIDOKA DAM	0.17	0.173	0.16	0.151	0.15	0.155	0.151	0.146	0.151	0.15	0.155	0.159
MOAB	0.186	0.183	0.169	0.165	0.15	0.155	0.142	0.153	0.151	0.155	0.161	0.175
MODENA	0.163	0.158	0.15	0.152	0.145	0.152	0.136	0.14	0.156	0.15	0.156	0.156
MONTELLO 2SE	0.123	0.14	0.138	0.137	0.142	0.141	0.139	0.136	0.135	0.132	0.123	0.113
MONTICELLO 2E	0.173	0.182	0.189	0.174	0.156	0.165	0.155	0.164	0.161	0.164	0.169	0.17
MONUMENT VALLEY	0.19	0.206	0.198	0.185	0.166	0.192	0.173	0.181	0.208	0.191	0.184	0.173
MORGAN POWER & LIGHT	0.134	0.154	0.167	0.151	0.14	0.151	0.145	0.148	0.148	0.144	0.133	0.119
MORONI	0.154	0.169	0.157	0.156	0.142	0.155	0.15	0.15	0.159	0.156	0.132	0.135
MTN DELL DAM	0.138	0.152	0.163	0.16	0.156	0.156	0.152	0.15	0.156	0.157	0.155	0.146
MTN VIEW	0.176	0.181	0.174	0.147	0.144	0.14	0.142	0.14	0.151	0.155	0.164	0.169
MYTON	0.157	0.165	0.157	0.146	0.145	0.145	0.142	0.142	0.148	0.153	0.158	0.157
NATURAL BRIDGES NM	0.172	0.19	0.193	0.176	0.171	0.173	0.16	0.169	0.183	0.193	0.186	0.175
NEOLA	0.176	0.184	0.174	0.159	0.155	0.158	0.154	0.153	0.161	0.169	0.178	0.173
NEPHI	0.197	0.182	0.166	0.146	0.152	0.151	0.146	0.147	0.136	0.195	0.193	0.212
NEW HARMONY	0.166	0.168	0.17	0.168	0.157	0.156	0.146	0.161	0.161	0.162	0.16	0.164

Table F1. Continued. Monthly values of Solar Radiation Factor, K_{RS}, at each of the 246 NWS Sites

NORTHDALE	0.158	0.162	0.154	0.144	0.141	0.139	0.135	0.138	0.139	0.144	0.151	0.16
NORWOOD	0.148	0.156	0.159	0.15	0.146	0.145	0.143	0.143	0.15	0.157	0.152	0.151
NUTTERS RCH	0.158	0.163	0.158	0.155	0.149	0.15	0.135	0.133	0.139	0.151	0.161	0.156
OAK CITY	0.162	0.192	0.163	0.168	0.158	0.17	0.165	0.175	0.18	0.18	0.173	0.174
OAKLEY	0.16	0.173	0.163	0.158	0.163	0.166	0.169	0.165	0.164	0.163	0.157	0.153
OASIS	0.127	0.146	0.146	0.147	0.151	0.151	0.149	0.145	0.145	0.143	0.131	0.117
OGDEN PIONEER P H	0.158	0.188	0.161	0.16	0.162	0.174	0.176	0.177	0.178	0.181	0.18	0.183
OGDEN SUGAR FACTORY	0.139	0.169	0.149	0.148	0.148	0.158	0.16	0.157	0.155	0.161	0.158	0.163
OLMSTEAD P H	0.15	0.163	0.153	0.153	0.151	0.154	0.152	0.14	0.148	0.156	0.151	0.151
ORDERVILLE	0.163	0.158	0.153	0.151	0.144	0.15	0.124	0.139	0.151	0.151	0.14	0.153
OREM TRTMT PLT	0.156	0.174	0.16	0.157	0.159	0.162	0.16	0.145	0.156	0.162	0.165	0.168
OURAY 4 NE	0.154	0.164	0.158	0.15	0.146	0.146	0.143	0.142	0.147	0.148	0.157	0.15
OVERTON	0.134	0.136	0.149	0.153	0.153	0.15	0.141	0.143	0.142	0.134	0.129	0.126
PAGE	0.194	0.186	0.188	0.167	0.174	0.173	0.156	0.176	0.171	0.183	0.187	0.181
PALISADE	0.158	0.155	0.159	0.162	0.165	0.178	0.165	0.16	0.165	0.158	0.155	0.158
PANGUITCH	0.157	0.16	0.16	0.15	0.138	0.151	0.119	0.132	0.136	0.146	0.143	0.136
PARK VALLEY	0.177	0.174	0.17	0.162	0.16	0.161	0.144	0.152	0.15	0.159	0.164	0.156
PAROWAN PWR	0.133	0.144	0.142	0.145	0.148	0.157	0.13	0.141	0.136	0.129	0.124	0.113
PARTOUN	0.168	0.158	0.159	0.152	0.139	0.145	0.134	0.147	0.148	0.152	0.156	0.154
PAUL 1ENE	0.164	0.173	0.163	0.155	0.159	0.164	0.158	0.153	0.156	0.157	0.155	0.157
PHANTOM RANCH	0.173	0.173	0.17	0.155	0.162	0.163	0.147	0.162	0.16	0.175	0.167	0.176
PINE VIEW DAM	0.128	0.159	0.153	0.148	0.152	0.152	0.154	0.149	0.147	0.158	0.157	0.164
PIOCHE	0.171	0.166	0.175	0.175	0.18	0.194	0.161	0.165	0.195	0.183	0.173	0.171
PIPE SPRINGS NATL MON	0.163	0.166	0.153	0.151	0.158	0.155	0.157	0.161	0.153	0.16	0.155	0.161
PLEASANT GROVE	0.153	0.165	0.157	0.155	0.157	0.161	0.159	0.145	0.153	0.16	0.157	0.156
POCATELLO 2 NE	0.169	0.182	0.174	0.159	0.161	0.16	0.161	0.161	0.166	0.169	0.163	0.161
POCATELLO RGNL AP	0.168	0.182	0.17	0.154	0.153	0.153	0.149	0.149	0.154	0.158	0.155	0.158
PRESTON	0.146	0.148	0.157	0.147	0.15	0.152	0.155	0.153	0.154	0.154	0.152	0.122
PRICE BLM	0.183	0.195	0.175	0.169	0.152	0.17	0.15	0.157	0.168	0.178	0.176	0.142
PROVO BYU	0.16	0.169	0.156	0.155	0.153	0.154	0.152	0.138	0.147	0.157	0.158	0.159
RANDOLPH	0.142	0.176	0.163	0.147	0.142	0.144	0.145	0.137	0.133	0.138	0.144	0.149
RANGELY 1 E	0.141	0.155	0.158	0.151	0.151	0.155	0.153	0.152	0.154	0.15	0.148	0.135
RICHFIELD RADIO KSVC	0.131	0.165	0.151	0.151	0.14	0.146	0.139	0.153	0.152	0.14	0.135	0.149
RICHMOND	0.155	0.167	0.167	0.154	0.153	0.159	0.16	0.163	0.159	0.157	0.159	0.122
RIVERDALE	0.145	0.17	0.153	0.151	0.153	0.16	0.165	0.159	0.158	0.163	0.159	0.159
ROCK SPRINGS AP	0.192	0.196	0.181	0.156	0.15	0.145	0.144	0.145	0.163	0.169	0.177	0.182
ROOSEVELT RADIO	0.149	0.162	0.154	0.144	0.143	0.142	0.139	0.138	0.144	0.145	0.152	0.144
RUPERT 3 WSW	0.149	0.167	0.155	0.147	0.149	0.154	0.15	0.145	0.145	0.144	0.144	0.14
RUTH	0.151	0.147	0.153	0.167	0.144	0.149	0.135	0.151	0.147	0.145	0.154	0.148
SAGE 4 NNW	0.12	0.138	0.145	0.13	0.126	0.13	0.123	0.12	0.121	0.118	0.117	0.112
SALINA	0.111	0.115	0.115	0.11	0.11	0.117	0.115	0.113	0.112	0.107	0.112	0.109
SALINA 24 E	0.153	0.203	0.208	0.195	0.18	0.175	0.177	0.165	0.192	0.189	0.209	0.19
SALT LAKE CITY INTL AP	0.161	0.173	0.18	0.172	0.17	0.173	0.169	0.166	0.172	0.171	0.169	0.164
SANTAQUIN CHLORINATOR	0.152	0.16	0.15	0.149	0.154	0.163	0.162	0.157	0.162	0.157	0.148	0.145
SCIPIO	0.115	0.12	0.12	0.115	0.113	0.119	0.12	0.118	0.114	0.112	0.119	0.114
SCOFIELD DAM	0.156	0.168	0.167	0.17	0.154	0.164	0.139	0.15	0.157	0.165	0.181	0.14
SHOSHONE 1 WNW	0.17	0.178	0.159	0.151	0.156	0.155	0.157	0.154	0.157	0.161	0.163	0.163
SNAKE CREEK POWERHOUSE	0.138	0.148	0.145	0.14	0.141	0.141	0.136	0.143	0.145	0.139	0.161	0.138
SNOWVILLE	0.148	0.143	0.141	0.136	0.144	0.141	0.13	0.141	0.135	0.146	0.145	0.13
SODA SPRINGS AP	0.155	0.154	0.174	0.161	0.143	0.151	0.144	0.137	0.143	0.155	0.156	0.137
SPANISH FORK PWR HOUSE	0.162	0.169	0.16	0.152	0.151	0.156	0.159	0.159	0.158	0.157	0.151	0.157
SPRING VALLEY SP	0.148	0.152	0.156	0.151	0.141	0.142	0.129	0.132	0.14	0.142	0.148	0.146
ST GEORGE	0.171	0.174	0.156	0.161	0.168	0.166	0.166	0.17	0.165	0.164	0.169	0.174
SUNNYSIDE	0.209	0.209	0.176	0.179	0.158	0.172	0.151	0.163	0.176	0.184	0.182	0.149
SUNNYSIDE - LUND 31S	0.15	0.142	0.151	0.151	0.133	0.142	0.133	0.143	0.144	0.14	0.142	0.15
SUNNYSIDE CITY CTR	0.208	0.212	0.189	0.197	0.172	0.182	0.165	0.174	0.182	0.192	0.193	0.158
SUPAI	0.17	0.165	0.145	0.145	0.148	0.155	0.152	0.156	0.146	0.153	0.155	0.147
TEEC NOS POS	0.175	0.173	0.164	0.162	0.166	0.17	0.168	0.169	0.168	0.167	0.167	0.16

Table F1. Continued. Monthly values of Solar Radiation Factor, K_{RS}, at each of the 246 NWS Sites

THIOKOL PROPULSION F S	0.173	0.191	0.18	0.149	0.148	0.155	0.152	0.155	0.16	0.161	0.149	0.132
THOMPSON	0.181	0.218	0.171	0.181	0.165	0.178	0.172	0.168	0.165	0.171	0.161	0.19
TIMPANOGOS CAVE	0.197	0.186	0.167	0.154	0.153	0.155	0.149	0.154	0.164	0.171	0.227	0.209
TOOELE	0.162	0.162	0.156	0.165	0.163	0.175	0.168	0.164	0.166	0.173	0.169	0.168
TREMONTON	0.13	0.133	0.129	0.133	0.154	0.163	0.17	0.158	0.155	0.142	0.126	0.118
TRENTON	0.154	0.142	0.153	0.139	0.148	0.152	0.145	0.146	0.145	0.14	0.143	0.111
TROPIC	0.182	0.183	0.174	0.161	0.151	0.165	0.135	0.146	0.15	0.163	0.157	0.152
TUBA CITY	0.162	0.169	0.167	0.152	0.159	0.158	0.147	0.159	0.154	0.159	0.151	0.15
TWIN FALLS 6 E	0.168	0.179	0.164	0.159	0.165	0.166	0.162	0.158	0.161	0.161	0.158	0.159
TWIN FALLS KMVT	0.165	0.169	0.161	0.16	0.161	0.163	0.161	0.157	0.16	0.16	0.157	0.156
URAVAN	0.162	0.175	0.164	0.161	0.152	0.151	0.135	0.15	0.149	0.15	0.152	0.159
UTAH LAKE LEHI	0.141	0.158	0.169	0.151	0.158	0.157	0.155	0.153	0.155	0.153	0.151	0.142
VERNAL 2SW	0.151	0.163	0.157	0.15	0.149	0.152	0.148	0.15	0.153	0.156	0.153	0.144
VERNON	0.135	0.142	0.145	0.146	0.149	0.157	0.153	0.152	0.15	0.155	0.142	0.141
VEYO PWR HOUSE	0.167	0.169	0.179	0.176	0.175	0.169	0.159	0.159	0.164	0.161	0.158	0.158
WAH WAH RCH	0.156	0.159	0.162	0.163	0.149	0.16	0.146	0.15	0.152	0.147	0.153	0.154
WAHWEAP	0.142	0.163	0.159	0.151	0.161	0.164	0.158	0.164	0.158	0.173	0.166	0.158
WANSHIP DAM	0.148	0.149	0.161	0.148	0.14	0.134	0.138	0.136	0.147	0.14	0.15	0.148
WELLS	0.134	0.156	0.153	0.153	0.155	0.155	0.151	0.146	0.146	0.143	0.133	0.125
WENDOVER AP AWOS	0.179	0.181	0.171	0.18	0.192	0.195	0.187	0.185	0.186	0.196	0.185	0.18
WOODRUFF	0.142	0.175	0.161	0.144	0.146	0.145	0.145	0.14	0.137	0.139	0.145	0.15
YELLOW JACKET 2 W	0.172	0.176	0.167	0.158	0.16	0.163	0.147	0.15	0.158	0.165	0.168	0.166
ZION NP	0.168	0.158	0.161	0.159	0.151	0.151	0.143	0.159	0.165	0.16	0.154	0.16

Table F2. Crop and Land Cover Types Included in Consumptive Use Estimates at each of the 246 NWS Sites

NWS Site	Alfalfa (Beef)	Alfalfa (Dairy)	Apples / Cherries	Barley	Corn	Garden	Melon	Onion	Other Hay	Other Orchard	Pasture	Potato	Safflower	Small Fruit	Sorghum	Spring Grain	Turfgrass	Turfgrass Dixie	Winter Wheat	Open Water Deep	Open Water Shallow	Wetlands Large	Wetlands Narrow	ETr
ABERDEEN EXP STN	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
AFTON	1	1		1		1			1		1					1	1			1	1	1	1	1
ALLENS RCH	1	1				1			1		1					1	1			1	1	1	1	1
ALPINE	1	1	1	1	1	1			1	1	1	1	1		1	1	1		1	1	1	1	1	1
ALTAMONT	1	1				1			1		1					1	1			1	1	1	1	1
ALTENBERN	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
ALTON	1	1				1			1		1						1			1	1	1	1	1
AMERICAN FALLS 6 NE	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
ANETH PLT	1	1	1			1			1	1	1				1	1	1		1	1	1	1	1	1
ANGLE	1	1		1		1			1		1					1	1			1	1	1	1	1
ARBON 2 NW	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
ARCHES NP HQS	1	1			1	1	1		1		1			1		1	1		1	1	1	1	1	1
BEAR RIVER BAY	1	1	1	1	1	1		1	1	1	1		1		1	1	1		1	1	1	1	1	1
BEAVER CANYON PH	1	1				1			1		1						1			1	1	1	1	1
BEAVER DAM	1	1		1	1	1	1	1	1	1	1	1			1	1		1		1	1	1	1	1
BEDFORD 3 SE	1	1		1		1			1		1					1	1			1	1	1	1	1
BETATAKIN	1	1				1			1		1				1	1	1		1	1	1	1	1	1
BITTER CREEK 4 NE	1	1				1			1		1					1	1			1	1	1	1	1
BLACK ROCK	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
BLANDING	1	1				1			1		1					1	1			1	1	1	1	1
BLISS 4 NW	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
BLUFF	1	1	1			1			1	1	1				1	1	1		1	1	1	1	1	1
BONANZA	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
BORDER 3 N	1	1		1		1			1		1					1	1			1	1	1	1	1
BOULDER	1	1				1			1		1					1	1			1	1	1	1	1
BOUNTIFUL-VAL VERDA	1	1	1	1	1	1	1	1	1	1	1	1		1		1	1		1	1	1	1	1	1
BRIGHAM CITY WASTE PLT	1	1	1	1	1	1		1	1	1	1		1		1	1	1		1	1	1	1	1	1
BRIGHT ANGEL RS	1	1	1	1		1			1	1	1	1				1	1			1	1	1	1	1
BROWNS PARK REFUGE	1	1				1			1		1					1	1			1	1	1	1	1
BRYCE CANYON NP HQRS	1	1							1		1						1			1	1	1	1	1
BUHL 2	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
BULLFROG BASIN	1	1		1		1			1		1	1				1	1			1	1	1	1	1
BURLEY MUNI AP	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
CALIENTE	1	1		1	1	1			1		1	1				1	1			1	1	1	1	1
CALLAO	1	1	1	1	1	1			1	1	1					1	1			1	1	1	1	1
CANYON DE CHELLY	1	1	1			1			1	1	1				1	1	1		1	1	1	1	1	1
CANYONLANDS-THE NECK	1	1				1			1		1				1	1	1		1	1	1	1	1	1
CANYONLANDS-THE NEEDLE	1	1				1			1		1				1	1	1		1	1	1	1	1	1
CAPITOL REEF NP	1	1	1	1		1			1	1	1					1	1			1	1	1	1	1
CASTLE DALE	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
CASTLE VALLEY	1	1			1	1	1		1		1			1		1	1		1	1	1	1	1	1
CASTLEFORD 2 N	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
CEDAR CITY AP	1	1		1	1	1			1		1					1	1			1	1	1	1	1
CEDAR POINT	1	1				1			1		1					1	1			1	1	1	1	1
CHURCH BUTTES GAS PLT	1	1				1			1		1					1	1			1	1	1	1	1

Table F2. Continued. Crop and Land Cover Types Included in Consumptive Use Estimates at Each of the 246 NWS Sites

CIRCLEVILLE	1	1		1		1			1		1	1				1	1			1	1	1	1	1
CLOVER VALLEY	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
COALVILLE	1	1		1		1			1		1					1	1			1	1	1	1	1
COALVILLE 13 E	1	1				1			1		1					1	1			1	1	1	1	1
COLORADO CITY	1	1	1	1	1	1	1	1	1	1	1	1				1	1			1	1	1	1	1
COLORADO NM	1	1			1	1	1		1		1			1		1	1		1	1	1	1	1	1
CORINNE	1	1	1	1	1	1		1	1	1	1		1		1	1	1		1	1	1	1	1	1
CORTEZ	1	1	1			1			1	1	1				1	1	1		1	1	1	1	1	1
COTTONWOOD WEIR	1	1	1	1	1	1			1	1	1					1	1			1	1	1	1	1
CUTLER DAM UP&L	1	1	1	1	1	1		1	1	1	1		1		1	1	1		1	1	1	1	1	1
DEER CREEK DAM	1	1		1		1			1		1					1	1			1	1	1	1	1
DELTA	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
DESERET	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
DEWEY	1	1			1	1	1		1		1			1		1	1		1	1	1	1	1	1
DINOSAUR NATL MONUMNT	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
DINOSAUR QUARRY AREA	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
DRAPER POINT OF MTN	1	1	1	1	1	1			1	1	1					1	1			1	1	1	1	1
DUCHESNE	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
DUGWAY	1	1	1	1	1	1			1	1	1				1	1	1		1	1	1	1	1	1
ECHO DAM	1	1		1		1			1		1					1	1			1	1	1	1	1
ELBERTA	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1		1	1	1	1	1	1
ELGIN 3 SE	1	1		1	1	1	1	1	1	1	1	1			1	1		1		1	1	1	1	1
ELY AIRPORT	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
ENTERPRISE	1	1	1	1	1	1	1		1	1	1	1				1	1			1	1	1	1	1
EPHRAIM USFS	1	1		1	1	1			1		1		1		1	1	1		1	1	1	1	1	1
ESCALANTE	1	1			1	1			1		1					1	1			1	1	1	1	1
ESKDALE	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
EVANSTON 1 E	1	1				1			1		1					1	1			1	1	1	1	1
FAIRFIELD	1	1		1		1			1		1	1	1	1	1	1	1		1	1	1	1	1	1
FARMINGTON 3 NW	1	1	1	1	1	1	1	1	1	1	1	1		1		1	1		1	1	1	1	1	1
FARMINGTON AG SCI	1	1	1			1			1	1	1				1	1	1		1	1	1	1	1	1
FERRON	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
FILLMORE	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
FISH SPRINGS NWR	1	1				1			1		1					1	1			1	1	1	1	1
FLAMING GORGE	1	1				1			1		1					1	1			1	1	1	1	1
FREMONT INDIAN SP	1	1		1		1	1		1		1					1	1			1	1	1	1	1
FRUITA	1	1			1	1	1		1		1			1		1	1		1	1	1	1	1	1
FRUITLAND	1	1	1			1			1	1	1				1	1	1		1	1	1	1	1	1
FT DUCHESNE	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
GARFIELD	1	1	1	1	1	1			1	1	1					1	1			1	1	1	1	1
GARRISON	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
GATEWAY	1	1			1	1	1		1		1			1		1	1		1	1	1	1	1	1
GOLD HILL	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
GRACE	1	1		1	1	1	1		1		1	1	1	1	1	1	1		1	1	1	1	1	1
GRAND CANYON NP 2	1	1	1	1		1			1	1	1	1				1	1			1	1	1	1	1
GRAND JUNCTION 6 ESE	1	1			1	1	1		1		1			1		1	1		1	1	1	1	1	1
GRAND JUNCTION WALKER	1	1			1	1	1		1		1			1		1	1		1	1	1	1	1	1
GREAT BASIN NP	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
GREEN RIVER	1	1				1			1		1					1	1			1	1	1	1	1
GREEN RIVER AVIATION	1	1		1	1	1	1		1		1				1	1	1			1	1	1	1	1
GROUSE CREEK	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
GUNNISON	1	1	1	1	1	1			1	1	1		1		1	1	1		1	1	1	1	1	1
HAGERMAN 2 SW	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
HANKSVILLE	1	1		1		1			1		1					1	1			1	1	1	1	1
HANS FLAT RS	1	1				1			1		1					1	1			1	1	1	1	1
HAZELTON	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1

Table F2. Continued. Crop and Land Cover Types Included in Consumptive Use Estimates at Each of the 246 NWS Sites

HEBER	1	1		1		1			1		1					1	1			1	1	1	1	1
HIAWATHA	1	1							1		1						1			1	1	1	1	1
HITE RS	1	1	1			1			1	1	1				1	1	1		1	1	1	1	1	1
HOVENWEEP NM	1	1	1			1			1	1	1				1	1	1		1	1	1	1	1	1
HUNTSVILLE MONASTERY	1	1		1		1			1		1	1		1		1	1			1	1	1	1	1
IBAPAH	1	1		1		1			1		1				1	1	1			1	1	1	1	1
JENSEN	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
JEROME	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
JOHNSON PASS	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
KAMAS	1	1				1			1		1					1	1			1	1	1	1	1
KANAB	1	1	1	1		1			1	1	1	1				1	1			1	1	1	1	1
KANOSH	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
KEMMERER 2 N	1	1				1			1		1					1	1			1	1	1	1	1
KODACHROME BASIN PARK	1	1		1		1			1		1					1	1			1	1	1	1	1
KOOSHAREM	1	1				1			1		1						1			1	1	1	1	1
LA BARGE	1	1				1			1		1					1	1			1	1	1	1	1
LA SAL 1SW	1	1				1			1		1					1	1			1	1	1	1	1
LA VERKIN	1	1		1	1	1	1	1	1	1	1	1			1	1		1		1	1	1	1	1
LAGES	1	1		1		1			1		1				1	1	1			1	1	1	1	1
LAKE VALLEY STEWARD	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
LAKETOWN	1	1		1		1			1		1					1	1			1	1	1	1	1
LEES FERRY	1	1		1		1			1	1	1	1				1		1		1	1	1	1	1
LEHMAN CAVES NM	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
LEVAN	1	1	1	1	1	1			1	1	1					1	1		1	1	1	1	1	1
LIFTON PUMPING STN	1	1		1		1			1		1					1	1			1	1	1	1	1
LITTLE HILLS	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
LITTLE SAHARA RECREATION AREA	1	1	1	1	1	1			1	1	1					1	1			1	1	1	1	1
LOA	1	1				1			1		1					1	1			1	1	1	1	1
LOGAN 5 SW EXP FARM	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1		1	1	1	1	1	1
LOGAN RADIO KVNU	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1		1	1	1	1	1	1
LOGAN UTAH ST UNIV	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1		1	1	1	1	1	1
LOGANDALE	1	1		1	1	1	1	1	1	1	1	1			1	1		1		1	1	1	1	1
LUND	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
MAESER 9NW	1	1				1			1		1					1	1			1	1	1	1	1
MALAD CITY	1	1		1	1	1		1	1		1		1		1	1	1		1	1	1	1	1	1
MALTA 4 ESE	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
MANILA	1	1				1			1		1					1	1			1	1	1	1	1
MANTI	1	1		1	1	1			1		1		1		1	1	1		1	1	1	1	1	1
MARYSVALE	1	1		1		1			1		1					1	1			1	1	1	1	1
MASSACRE ROCKS SP	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
MASSADONA 3E	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
MAYBELL	1	1				1			1		1					1	1			1	1	1	1	1
MCCAMMON	1	1		1	1	1		1	1		1		1		1	1	1		1	1	1	1	1	1
MCGILL	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
MERNA	1	1		1		1			1		1					1	1			1	1	1	1	1
MESA VERDE NP	1	1	1			1			1	1	1				1	1	1		1	1	1	1	1	1
METROPOLIS	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
MEXICAN HAT	1	1	1			1			1	1	1				1	1	1		1	1	1	1	1	1
MILFORD	1	1		1	1	1			1		1					1	1			1	1	1	1	1
MINIDOKA DAM	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
MOAB	1	1			1	1	1		1		1			1		1	1		1	1	1	1	1	1
MODENA	1	1		1	1	1			1		1	1				1	1			1	1	1	1	1
MONTELLO 2SE	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
MONTICELLO 2E	1	1				1			1		1						1			1	1	1	1	1
MONUMENT VALLEY	1	1				1			1		1				1	1	1		1	1	1	1	1	1
MORGAN POWER & LIGHT	1	1		1	1	1			1		1	1				1	1			1	1	1	1	1

Table F2. Continued. Crop and Land Cover Types Included in Consumptive Use Estimates at Each of the 246 NWS Sites

MORONI	1	1		1	1	1			1		1		1		1	1	1		1	1	1	1	1	1
MTN DELL DAM	1	1		1		1			1		1					1	1			1	1	1	1	1
MTN VIEW	1	1				1			1		1					1	1			1	1	1	1	1
MYTON	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
NATURAL BRIDGES NM	1	1				1			1		1					1	1			1	1	1	1	1
NEOLA	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
NEPHI	1	1	1	1	1	1			1	1	1					1	1		1	1	1	1	1	1
NEW HARMONY	1	1	1	1	1	1			1	1	1	1				1	1			1	1	1	1	1
NORTHDALE	1	1				1			1		1					1	1			1	1	1	1	1
NORWOOD	1	1				1			1		1					1	1			1	1	1	1	1
NUTTERS RCH	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
OAK CITY	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
OAKLEY	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
OASIS	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
OGDEN PIONEER P H	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1		1	1	1	1	1	1
OGDEN SUGAR FACTORY	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1		1	1	1	1	1	1
OLMSTEAD P H	1	1	1	1	1	1			1	1	1	1	1	1	1	1	1		1	1	1	1	1	1
ORDERVILLE	1	1		1		1			1		1	1				1	1			1	1	1	1	1
OREM TRTMT PLT	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1		1	1	1	1	1	1
OURAY 4 NE	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
OVERTON	1	1		1	1	1	1	1	1	1	1	1			1	1		1		1	1	1	1	1
PAGE	1	1	1	1		1			1	1	1	1				1	1			1	1	1	1	1
PALISADE	1	1			1	1	1		1		1			1		1	1		1	1	1	1	1	1
PANGUITCH	1	1				1			1		1					1	1			1	1	1	1	1
PARK VALLEY	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
PAROWAN PWR	1	1		1	1	1			1		1					1	1			1	1	1	1	1
PARTOUN	1	1	1	1	1	1			1	1	1					1	1			1	1	1	1	1
PAUL 1ENE	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
PHANTOM RANCH	1	1		1		1			1	1	1	1				1		1		1	1	1	1	1
PINE VIEW DAM	1	1		1		1			1		1	1		1		1	1			1	1	1	1	1
PIOCHE	1	1		1	1	1			1		1	1				1	1			1	1	1	1	1
PIPE SPRINGS NATL MON	1	1	1	1		1			1	1	1	1				1	1			1	1	1	1	1
PLEASANT GROVE	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1		1	1	1	1	1	1
POCATELLO 2 NE	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
POCATELLO RGNL AP	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
PRESTON	1	1		1	1	1	1		1		1	1	1	1	1	1	1		1	1	1	1	1	1
PRICE BLM	1	1	1	1	1	1			1	1	1				1	1	1			1	1	1	1	1
PROVO BYU	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1		1	1	1	1	1	1
RANDOLPH	1	1				1			1		1					1	1			1	1	1	1	1
RANGELY 1 E	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
RICHFIELD RADIO KSVC	1	1	1	1	1	1	1		1	1	1					1	1			1	1	1	1	1
RICHMOND	1	1		1	1	1	1		1		1	1	1	1	1	1	1		1	1	1	1	1	1
RIVERDALE	1	1	1	1	1	1	1	1	1	1	1	1		1	1	1	1		1	1	1	1	1	1
ROCK SPRINGS AP	1	1				1			1		1					1	1			1	1	1	1	1
ROOSEVELT RADIO	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
RUPERT 3 WSW	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
RUTH	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
SAGE 4 NNW	1	1				1			1		1					1	1			1	1	1	1	1
SALINA	1	1	1	1	1	1	1		1	1	1					1	1			1	1	1	1	1
SALINA 24 E	1	1							1		1						1			1	1	1	1	1
SALT LAKE CITY INTL AP	1	1	1	1	1	1			1	1	1					1	1			1	1	1	1	1
SANTAQUIN CHLORINATOR	1	1	1	1	1	1			1	1	1	1	1		1	1	1		1	1	1	1	1	1
SCIPIO	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
SCOFIELD DAM	1	1							1		1						1			1	1	1	1	1
SHOSHONE 1 WNW	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
SNAKE CREEK POWERHOUSE	1	1		1		1			1		1					1	1			1	1	1	1	1

Table F2. Continued. Crop and Land Cover Types Included in Consumptive Use Estimates at Each of the 246 NWS Sites

SNOWVILLE	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
SODA SPRINGS AP	1	1		1	1	1	1		1		1	1	1	1	1	1	1		1	1	1	1	1	1
SPANISH FORK PWR HOUSE	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1		1	1	1	1	1	1
SPRING VALLEY SP	1	1		1	1	1			1		1	1				1	1			1	1	1	1	1
ST GEORGE	1	1		1	1	1	1	1	1	1	1	1			1	1		1		1	1	1	1	1
SUNNYSIDE	1	1				1			1		1					1	1			1	1	1	1	1
SUNNYSIDE - LUND 31S	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
SUNNYSIDE CITY CTR	1	1				1			1		1					1	1			1	1	1	1	1
SUPAI	1	1		1		1			1	1	1	1				1		1		1	1	1	1	1
TEEC NOS POS	1	1	1			1			1	1	1				1	1	1		1	1	1	1	1	1
THIOKOL PROPULSION F S	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
THOMPSON	1	1				1			1		1					1	1			1	1	1	1	1
TIMPANOGOS CAVE	1	1		1	1	1			1		1	1			1	1	1		1	1	1	1	1	1
TOOELE	1	1		1	1	1			1		1	1			1	1	1			1	1	1	1	1
TREMONTON	1	1		1	1	1		1	1		1		1		1	1	1		1	1	1	1	1	1
TRENTON	1	1		1	1	1	1		1		1	1	1	1	1	1	1		1	1	1	1	1	1
TROPIC	1	1				1			1		1					1	1			1	1	1	1	1
TUBA CITY	1	1	1	1		1			1	1	1	1				1	1			1	1	1	1	1
TWIN FALLS 6 E	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
TWIN FALLS KMVT	1	1		1		1			1		1		1			1	1		1	1	1	1	1	1
URAVAN	1	1				1			1		1					1	1			1	1	1	1	1
UTAH LAKE LEHI	1	1	1	1	1	1	1		1	1	1	1	1	1	1	1	1		1	1	1	1	1	1
VERNAL 2SW	1	1		1	1	1			1		1				1	1	1			1	1	1	1	1
VERNON	1	1		1		1			1		1				1	1	1			1	1	1	1	1
VEYO PWR HOUSE	1	1	1	1	1	1	1		1	1	1	1				1	1			1	1	1	1	1
WAH WAH RCH	1	1		1	1	1			1		1					1	1			1	1	1	1	1
WAHWEAP	1	1	1	1		1			1	1	1	1				1	1			1	1	1	1	1
WANSHIP DAM	1	1		1		1			1		1					1	1			1	1	1	1	1
WELLS	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
WENDOVER AP AWOS	1	1		1	1	1			1		1				1	1	1		1	1	1	1	1	1
WOODRUFF	1	1				1			1		1					1	1			1	1	1	1	1
YELLOW JACKET 2 W	1	1	1			1			1	1	1				1	1	1		1	1	1	1	1	1
ZION NP	1	1	1	1	1	1	1	1	1	1	1	1				1	1			1	1	1	1	1

TABLE F3. Monthly Values of Dew Point Depression Factor, K_o, at each of the 246 NWS Sites

NWS STATION NAME	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
ABERDEEN EXP STN	-4.6	-4.1	-0.6	2.6	3.4	2	1.7	4.1	2.8	0.6	-2.5	-4.4
AFTON	-5.1	-5	-2.6	1	1.5	1	3.4	4.2	2.4	0.9	-2.1	-4.6
ALLENS RCH	-4.7	-3.8	2.9	9.1	9.3	12.5	13.4	11	9.7	3.6	2.1	-1.7
ALPINE	-1.2	0.4	4.3	7.3	8.7	11.3	13.9	12.4	9.1	4.1	1.1	-1.4
ALTAMONT	-3.5	-1.2	5.2	8.8	10.4	11.3	12.5	9.3	7.9	3.2	2.2	-2
ALTENBERN	-3.3	-1.8	3.4	8.4	9.1	12.1	11.1	8.3	7.5	3.1	1.3	-1.7
ALTON	-7.1	-2.8	2.7	6.3	7.2	9.7	8.6	6.8	6.5	2.4	0.8	-4.5
AMERICAN FALLS 6 NE	-4.5	-4	-0.6	2.5	3.3	2	1.8	4.1	2.7	0.7	-2.5	-4.3
ANETH PLT	0	3.3	7	9.4	9.4	13.4	10.2	7.3	6.5	5.2	2.7	0.4
ANGLE	-5.7	-2.3	4.3	7.9	8.1	10.5	10	9.1	6.9	3.7	0.5	-3.3
ARBON 2 NW	-4.6	-3.8	0.7	3.7	4.3	4.5	6.2	7.2	4.6	1.3	-1.7	-3.7
ARCHES NP HQS	-1.9	0.3	2.8	9	8.6	13.2	11.3	7.7	7.3	3.5	2.6	-0.2
BEAR RIVER BAY	-5.3	-4	1.9	5.7	7.6	8.7	11.6	11	7.4	2.9	-0.4	-3.4
BEAVER DAM	2.4	5.2	9.9	13.6	17.5	20.5	18.1	16.4	16	9.7	6	2
BEAVER	-6.3	-2.4	3.7	7.2	7.6	10	9.4	8.4	7	3.3	0.6	-3.8
BEDFORD 3 SE	-5.2	-5.1	-2.6	1.1	1.7	1.3	3.6	4.4	2.6	0.9	-2	-4.5
BETATAKIN	-2.6	1.2	5.6	8.3	8.6	11.6	9.1	6.5	6.2	4.2	1.9	-1.2
BITTER CREEK 4 NE	-4.5	-3.5	3.2	9	9.4	12.4	13.3	10.8	9.5	3.6	2.1	-1.8
BLACK ROCK	-5.1	-1.7	3.9	7	7.7	10.5	10.6	10	8.4	3.9	0.2	-4.4
BLANDING	-0.2	3	6.8	9.2	9.4	13.2	10	7.1	6.3	4.9	2.5	0.1
BLISS 4 NW	-1.9	-1.3	1.5	3	3.4	3.8	4.8	5.1	3.8	2.3	-0.8	-2.1
BLUFF	-0.1	3.2	6.9	9.3	9.4	13.3	10.1	7.2	6.4	5.1	2.6	0.3
BONANZA	-4.8	-4.6	2.5	9.3	9.4	12.8	13.2	10.9	10.4	3.6	1.9	-1.4
BORDER 3 N	-6.5	-7	-2	3.7	4.9	5.8	7.6	7.7	5.7	2	-0.6	-4.3
BOULDER	-6.7	-2.7	3.6	7.1	7.6	9.7	8.9	7.7	6.4	3.1	0.5	-3.8
BOUNTIFUL-VAL VERDA	-3.3	-2	2.7	6.2	7.2	8.1	10.3	9.4	7	3.3	0.3	-2.5
BRIGHAM CITY WASTE PLT	-5.4	-4	2	5.8	8.1	9.3	12	11.5	7.5	3	-0.4	-3.5
BRIGHT ANGEL RS	-0.4	3	8.1	11.8	14.9	17.2	15.4	13.5	13.3	7.8	4.5	0.2
BROWNS PARK REFUGE	-4.7	-4.1	2.7	9.2	9.3	12.7	13.3	11	10	3.6	2.1	-1.6
BRYCE CANYON NP HQRS	-7.5	-3.1	2.9	6.4	7	8.7	8	6.4	5.8	2.4	0.2	-4.4
BUHL 2	-1.6	-1	1.8	3.3	3.8	4.3	5.3	5.3	4.3	2.7	-0.4	-1.8
BULLFROG BASIN	-5	-1.1	4.5	7.8	7.9	10.5	9.2	7.4	6.1	3.6	0.9	-2.8
BURLEY MUNI AP	-2.6	-1.9	0.7	2.7	2.8	2.1	2.6	4	2.4	1.4	-1.4	-2.7
CALIENTE	-0.6	1.9	6.3	9.9	12.8	16.4	14.1	12.2	11.7	6.4	3	-0.7
CALLAO	-4.8	-1.5	4	6	7.9	10.6	12.3	11.4	9.1	3.7	0.6	-3.9
CANYON DE CHELLY	-0.3	2.8	6.7	9.1	9.6	13.1	9.8	7	6.7	4.9	2.6	0.2
CANYONLANDS-THE NECK	-1.9	0.2	2.5	9.2	8.5	13.5	11.6	8.1	7.6	3.6	2.9	0
CANYONLANDS-THE NEEDLE	-1.5	1	3.7	9.2	8.7	13.3	11.2	7.7	7.1	3.9	2.7	0
CAPITOL REEF NP	-5.5	-2.6	2.1	8.3	7.7	11.4	10.8	8.7	7.6	3.2	1.6	-2.3
CASTLE DALE	-3.4	-2.6	-1.8	10.2	7.7	14.9	14.5	10.5	10.5	3.2	4.5	0.9
CASTLE VALLEY	-1.7	0.6	3.4	8.8	8.7	12.9	10.7	7.2	6.7	3.4	2.3	-0.5
CASTLEFORD 2 N	-1.7	-1.1	1.7	3.2	3.7	4.2	5.2	5.2	4.1	2.6	-0.5	-1.9
CEDAR CITY AP	-5.2	-1.7	3.1	7.1	8.2	12.7	11.1	8.7	7.9	3	1.6	-4
CEDAR POINT	-0.2	3.1	6.8	9.3	9.3	13.2	10.1	7.1	6.3	5	2.5	0.2
CHURCH BUTTES GAS PLT	-6.6	-5.6	0.2	4.9	5.2	6.9	9.5	8.2	5.2	2.4	-0.3	-5.1
CIRCLEVILLE	-5.3	-2.1	4.8	8.5	8.5	11.2	10.5	9.9	7.2	4.2	0.8	-2.8
CLOVER VALLEY	-3.2	-2.2	2	4.3	5.1	5.6	7.1	7.3	5.3	2.5	-0.5	-2.3
COALVILLE 13 E	-3.3	-1.8	3.1	6.5	7.3	7.6	9.6	8.4	7	3.9	1.5	-2.2
COALVILLE	-4.9	-3.8	1.3	5	5.5	5.3	7.4	7.1	5.5	2.7	-0.3	-3.5

Table F3. Continued. Monthly values of dew point depression Factor, K_O, at each of the 246 NWS Sites

COLORADO CITY	1.2	4.1	9	12.8	16.2	19.5	17.3	15.4	15	8.8	5.6	1.1
COLORADO NM	-2.7	-0.7	3.9	8.1	9	11.8	10.2	7.1	6.4	2.9	1.1	-1.7
CORINNE	-4.5	-2.7	3.2	6.8	9.5	10.6	13.3	12.2	8.6	3.4	0.3	-2.7
CORTEZ	0.1	3.6	7.3	9.7	9.3	13.6	10.5	7.6	6.5	5.5	2.9	0.6
COTTONWOOD WEIR	-1.1	0.3	4.1	7.3	8.8	11.5	14	12.3	8.7	3.8	0.7	-1.5
CUTLER DAM UP&L	-6.3	-5.6	0.3	5.5	5.6	6	10.7	11.8	8.3	3	-0.7	-4
DEER CREEK DAM	-1.4	0.6	4.9	7.6	8.8	11	13.7	11.9	9.7	4.7	2.4	-1.1
DELTA	-6.2	-2.4	3.6	5.9	7.1	9.5	10.8	10.5	8.7	3.6	0	-5.2
DESERET	-5.9	-2.2	3.6	6.1	7.2	9.7	10.9	10.5	8.7	3.7	-0.1	-5.2
DEWEY	-2.9	-1.6	2.1	8.7	8.8	12.7	11	7.7	7.7	3	1.8	-0.8
DINOSAUR NATL MONUMNT	-4.9	-5.1	2.2	9.4	9.5	13	13.1	10.9	10.8	3.6	1.8	-1.3
DINOSAUR QUARRY AREA	-5.2	-6.5	1.3	9.7	9.6	13.5	12.9	10.9	11.9	3.7	1.5	-0.8
DRAPER POINT OF MTN	-1.1	0.4	4.3	7.3	8.8	11.6	14.1	12.4	8.9	3.9	0.9	-1.4
DUCHESNE	-3.4	0.5	7.3	9.5	10	11.6	13.2	9.8	7.6	5.2	3.1	-2.2
DUGWAY	-3.1	-0.2	4.9	6.6	8.6	11.4	14	12.8	10.1	4.2	2	-2.2
ECHO DAM	-5.1	-4	1.2	4.9	5.4	5	7	6.8	5.3	2.7	-0.3	-3.5
ELBERTA	-4.5	-0.8	5	6.3	8.2	10.8	13.3	12.5	10.4	4.3	2.3	-2.8
ELGIN	0.4	3	7.5	11.1	14.4	17.7	15.4	13.6	13.1	7.5	4	0.2
ELY AIRPORT	-5.1	-2	2.8	6.1	7.2	10.7	9.7	8.6	7.6	3.2	0.1	-4.3
ENTERPRISE BERYL JCT	-4.2	-2.1	2	5.6	7.1	11.4	9.2	7.3	6.4	2.5	-0.5	-3.9
EPHRAIM USFS	-9.2	-5.4	2.2	6.1	5.5	6.4	9.1	8.7	6.8	2.4	-0.6	-6
ESCALANTE	-6.8	-2.8	3.5	7	7.5	9.5	8.8	7.5	6.3	3	0.5	-3.9
ESKDALE	-5.1	-1.9	3	6.2	7.3	10.6	9.9	8.9	7.8	3.3	0.1	-4.4
EVANSTON 1 E	-6.6	-6.2	-0.6	3.5	4.1	4.5	7.3	6.7	4.8	2.1	-1.3	-4.7
FAIRFIELD	-1.8	0.6	5.1	7.2	8.9	11.9	14.5	13.2	10.3	4.5	2.1	-1.6
FARMINGTON 3 NW	-4.9	-3.7	1.5	5.2	6.1	6.3	8.5	8.2	5.9	2.9	-0.3	-3.5
FARMINGTON AG SCI	-0.4	2.5	6.6	9	9.9	12.9	9.5	6.8	7.1	4.9	2.7	0.3
FERRON	-4	-2.9	-1.4	9.7	7.5	14.1	14	10.3	10.2	3.1	4.1	0.2
FILLMORE	-4.6	-1.3	3.8	6.6	7.5	10.3	11.1	10.7	8.9	4	-0.5	-5.2
FISH SPRINGS NWR	-4.7	-1	4.6	6.2	8	10.7	12.5	11.9	10.1	4.2	1.5	-3.7
FLAMING GORGE	-4.6	-3.3	3.2	9	9.3	12.4	13.4	11	9.4	3.6	2.2	-1.9
FREMONT INDIAN SP	-5.4	-1.9	4	7.2	7.7	10.3	10.3	9.6	7.7	3.7	0	-4.3
FRUITA	-2.9	-0.9	3.8	8.2	9	11.8	10.4	7.4	6.6	3	1.1	-1.7
FRUITLAND	-0.4	2.6	6.6	9	9.8	13	9.6	6.9	7.1	4.9	2.7	0.3
FT DUCHESNE	-3.9	-1.6	4.7	9	9.6	11.9	13.3	10.5	8.6	4	2.7	-2
GARFIELD	-1.6	-0.2	3.9	7	8.4	10.7	13.1	11.7	8.4	3.8	0.7	-1.7
GARRISON	-5.1	-2	2.9	6.1	7.2	10.6	9.8	8.7	7.7	3.2	0.1	-4.4
GATEWAY	-1.6	1.1	4.2	8.2	8.8	12.1	9.7	6.2	5.6	3.1	1.5	-1.1
GOLD HILL	-4.5	-1.4	4	6	8	10.7	12.5	11.5	9.1	3.7	0.7	-3.7
GRACE	-6.6	-6.9	-2.4	3	4	4.5	6.1	6.3	4.4	1.1	-1.1	-4.5
GRAND CANYON NP 2	0.7	3.7	8.5	12.3	15.6	19	16.8	14.9	14.4	8.4	5.2	0.7
GRAND JUNCTION 6 ESE	-2.2	0.1	4.2	7.8	9	11.5	9.4	6.2	5.5	2.8	0.9	-1.8
GRAND JUNCTION WALKER	-2.5	-0.4	4	8	9	11.7	9.9	6.7	6	2.9	1	-1.8
GREAT BASIN NP	-5.1	-2	2.8	6.1	7.2	10.7	9.7	8.6	7.6	3.2	0.1	-4.3
GREEN RIVER AVIATION	-4.6	-2.6	0.9	9.2	7.7	12.4	13	9.9	9.1	3.4	3.1	-1.2
GREEN RIVER	-5.6	-5.2	1.2	7.3	7.7	10.7	12.3	10.3	8.4	3.1	0.8	-3.3
GROUSE CREEK	-4.1	-3.1	1.3	3.9	4.4	5.1	7.4	7.9	4.9	1.7	-1.2	-3.1
GUNNISON	-7.4	-3.9	2.3	6.4	6.5	8.8	10.6	9.7	8.1	2.9	0.5	-4.7
HAGERMAN 2 SW	-1.8	-1.2	1.6	3.1	3.6	4	4.9	5.1	4	2.5	-0.7	-2
HANKSVILLE	-5.3	-3.2	0.8	8.8	7.3	11.9	12.1	9.9	8.7	3.2	2.3	-1.7
HANS FLAT RS	-4	-1.7	1.6	9	7.5	12.4	12	9.3	8.5	3.6	2.8	-1
HAZELTON	-1.9	-1.2	1.5	3.1	3.6	3.7	4.5	4.8	3.7	2.4	-0.7	-2.1
HEBER	-1.8	0.2	4.6	7.4	8.6	10.5	13.1	11.1	9.2	4.6	2.3	-1.3

Table F3. Continued. Monthly values of dew point depression Factor, K_O, at each of the 246 NWS Sites

HIAWATHA	-5.5	-3.5	-0.1	8.4	7.1	12	12.7	10	9.3	3	2.8	-1.6
HITE RS	-2.9	-0.4	3.2	9.5	8.5	13.3	12	9.4	8.2	4.3	2.8	-0.4
HOVENWEEP NM	0	3.4	7.2	9.5	9.4	13.5	10.3	7.4	6.5	5.3	2.8	0.4
HUNTSVILLE MONASTERY	-5.9	-5.1	0.6	4.5	5.5	5.9	8.5	8.4	5.6	2.4	-1	-4
IBAPAH	-4.7	-1.4	4	6	8	10.6	12.4	11.5	9.1	3.7	0.7	-3.8
JENSEN	-5.3	-7	1.1	9.8	9.7	13.6	12.8	10.8	12.3	3.7	1.4	-0.6
JEROME	-1.6	-1	1.9	3.3	3.8	4.4	5.3	5.3	4.3	2.8	-0.4	-1.8
JOHNSON PASS	-2.4	0.2	4.9	6.9	8.8	11.6	14.2	12.9	10	4.3	1.8	-1.9
KAMAS	-2.3	-0.4	4.2	7.2	8.3	9.7	12.1	10.2	8.6	4.4	2.3	-1.5
KANAB	-3.4	0.2	5.6	9.3	11.3	14.3	12.8	10.7	10.4	5.4	3	-2.1
KANOSH	-4.7	-1.4	3.8	6.7	7.5	10.3	11	10.6	8.8	4	-0.5	-5.1
KEMMERER 2 N	-6.6	-6.7	-1.4	3.7	4.7	5.7	8.1	7.5	5.4	2.2	-0.9	-4.7
KODACHROME BASIN PARK	-7.2	-2.9	3.1	6.6	7.2	9.1	8.3	6.8	6.1	2.6	0.4	-4.2
KOOSHAREM	-5.7	-2.1	4	7.4	7.8	10.3	10	9.2	7.3	3.7	0.2	-3.9
LA BARGE	-6.2	-6.8	-2.3	2.9	3.9	4.6	6.9	7.3	5.1	2	-1.5	-5.1
LA SAL 1SW	-1.3	1.4	4.4	8.7	8.9	12.7	10.3	6.9	6.2	3.7	2.1	-0.5
LA VERKIN	0.6	3.5	8.3	12.1	15.3	18.6	16.4	14.6	14.2	8.2	5	0.6
LAGES	-4.6	-1.4	4	6.1	8	10.6	12.4	11.5	9.1	3.7	0.6	-3.8
LAKE VALLEY STEWARD	-3.1	-0.4	3.9	7.6	9.6	13.6	11.5	9.4	8.6	4	1.2	-2.7
LAKETOWN	-3.4	-2.8	0.9	4.6	6.4	6.8	10.2	9.2	8.7	4.5	1.2	-0.3
LEES FERRY	-7	-2.8	3.2	6.8	7.3	9.4	8.6	7.3	6.4	2.8	0.6	-4
LEHMAN CAVES NM	-5.1	-2	2.8	6.1	7.2	10.7	9.7	8.6	7.6	3.2	0.1	-4.3
LEVAN	-8.2	-3.6	3.8	4.7	7.2	9.1	11.3	10.8	9.1	3.2	1.5	-4.7
LIFTON PUMPING STN	-6.3	-7.5	-1.7	5.4	6.4	7.8	8.8	10.4	8.3	3.4	0.5	-4
LITTLE HILLS	-4.2	-3.3	2.8	8.9	9.2	12.5	12.3	9.8	9.1	3.4	1.7	-1.6
LITTLE SAHARA RECREATION AREA	-7	-2.7	4.2	5.3	7.5	9.6	11.9	11.3	9.5	3.6	1.8	-4.1
LOA	-5.9	-2.2	4	7.4	7.8	10.1	9.8	8.9	7	3.5	0.2	-3.9
LOGAN 5 SW EXP FARM	-8.8	-8.3	-1.7	2.6	5.1	7.2	8.6	10.6	3.4	2	-3.6	-6.9
LOGAN RADIO KVNU	-7.1	-7.1	-0.9	3.4	4.5	5.2	8.1	7.8	4.1	1	-1.7	-3.8
LOGAN UTAH ST UNIV	-7.1	-7	-0.8	3.5	4.6	5.4	8.4	8.3	4.5	1.3	-1.7	-4.1
LOGANDALE	1.6	4.3	9	12.6	16.3	19.4	17	15.3	14.9	8.9	5.2	1.3
LUND	-5.2	-2.2	2.5	6.2	7.4	11.4	9.7	7.9	7.2	2.8	0.7	-3.9
MAESER 9NW	-4.4	-1.8	4	8.6	8.8	12	13.9	11.5	8.2	3.7	2.7	-2.5
MALAD CITY	-6.4	-5.6	0.4	5	6	7	10.4	10.2	6.7	2.3	-0.9	-4
MALTA 4 ESE	-3.5	-2.8	0.5	2.4	2.2	3.2	5.9	6.4	3.3	1	-2.1	-3.4
MANILA	-4.4	-2.9	3.5	8.9	9.3	12.2	13.4	10.9	9.1	3.6	2.3	-2
MANTI	-8.5	-4.9	2.1	6.3	5.9	7.5	9.7	9.1	7.3	2.6	0	-5.3
MARYSVALE	-5.6	-2.1	4.2	7.7	8	10.4	10.1	9.3	7.2	3.7	0.3	-3.6
MASSACRE ROCKS SP	-4	-3.4	0.1	2.7	3.1	2.9	4	5.4	3.3	1	-2.1	-3.8
MASSADONA 3E	-4.8	-4.5	2.5	9.2	9.4	12.8	13.2	10.9	10.3	3.6	2	-1.5
MAYBELL	-4.7	-4	2.8	9.1	9.4	12.6	13.2	10.9	10	3.6	2	-1.6
MCCAMMON	-6	-5.8	-1.5	2.7	3.6	3.3	4	4.6	3	0.3	-2	-4.6
MCGILL	-5.1	-2	2.9	6.1	7.2	10.6	9.8	8.7	7.7	3.2	0.1	-4.4
MERNA	-5.6	-5.7	-2.6	1.7	2.5	2.3	4.4	5.1	3.2	1	-1.7	-4.5
MESA VERDE NP	0.1	3.6	7.3	9.7	9.3	13.6	10.5	7.6	6.5	5.5	2.9	0.6
METROPOLIS	-2.2	-1.6	1.2	2.8	3	3.3	4.5	5	3.4	2	-1.1	-2.4
MEXICAN HAT	-0.2	3	6.8	9.2	9.4	13.2	10	7.1	6.4	5	2.6	0.2
MILFORD	-6.4	-2.5	3.3	7	7.6	10.4	9.4	8	7.1	3.1	1.1	-3.9
MINIDOKA DAM	-2.9	-2.4	0.4	2.2	2.2	2.4	3.8	4.8	2.7	1.1	-1.9	-3.2
MOAB	-1.8	0.5	3.1	9	8.6	13.1	11	7.5	7	3.5	2.5	-0.3
MODENA	-3.9	-1.7	2.4	6	7.6	11.9	9.7	7.7	6.9	2.8	-0.1	-3.7
MONTELLO 2SE	-3.6	-2.7	1.8	4.2	4.8	6	8.5	8.4	5.7	2.3	-0.8	-2.7

Table F3. Continued. Monthly values of dew point depression Factor, K_O, at each of the 246 NWS Sites

MONTICELLO 2E	-0.4	2.8	6.5	9	9.3	12.9	9.8	6.9	6.1	4.7	2.3	-0.1
MONUMENT VALLEY	-1.6	2	6.2	8.7	9	12.3	9.5	6.9	6.4	4.6	2.3	-0.5
MORGAN POWER & LIGHT	-5.4	-4.2	1.1	4.9	5.2	4.3	6.2	6.2	5.1	2.7	-0.1	-3.5
MORONI	-8.8	-4.9	2.4	6	5.8	7	9.6	9.1	7.2	2.6	-0.1	-5.6
MTN DELL DAM	-2.4	-1	3.3	6.6	7.7	9.3	11.6	10.5	7.7	3.5	0.6	-2.1
MTN VIEW	-6.3	-5.6	0.4	5	5.7	6.8	9	7.5	5.3	2.2	-0.4	-4.8
MYTON	-3.5	-0.6	5.8	9	10	11.5	13	9.9	8.1	4.3	2.8	-2
NATURAL BRIDGES NM	-0.7	2	5.2	9.6	9.1	13.8	11.2	8.1	7.5	4.9	3.2	0.6
NEOLA	-3.5	-1.1	5.2	8.9	10	11.5	13	9.8	8.2	3.9	2.6	-1.9
NEPHI	-8.3	-3.5	4	4.2	7.5	9.6	11.6	11.1	9.5	3.2	1.9	-4.6
NEW HARMONY	-3.2	0	4.7	8.5	10.4	14.4	12.5	10.5	9.8	4.7	2.5	-2.4
NORTHDALE	-0.3	2.9	6.6	9.1	9.3	13.1	9.9	7	6.2	4.8	2.4	0
NORWOOD	-1.2	1.8	5.3	8.1	9.1	11.9	9.1	5.8	5.2	3.4	1.3	-1.1
NUTTERS RCH	-3.1	0	6.1	8.8	9.9	11.2	13	9.7	8.1	4.8	3.1	-1.8
OAK CITY	-7	-3	3.5	5.6	7	9.2	10.8	10.4	8.6	3.4	0.3	-5.2
OAKLEY	-2.4	-1.8	0.9	2.6	2.7	2.9	4.1	4.8	3.1	1.6	-1.4	-2.6
OASIS	-3.5	-2.6	1.8	4.1	4.7	5.9	8.3	8.2	5.6	2.3	-0.8	-2.6
OGDEN PIONEER P H	-5.8	-4.8	1	4.9	6.3	7.1	9.8	9.5	6.3	2.6	-0.9	-3.9
OGDEN SUGAR FACTORY	-5.6	-4.4	1.3	5.1	6.7	7.6	10.4	10	6.6	2.7	-0.8	-3.8
OLMSTEAD P H	-1.5	0.9	5.3	7.6	8.9	11.5	14.2	12.7	10.5	4.9	2.7	-1.2
ORDERVILLE	-6.7	-2.5	2.8	6.5	7.4	10.4	9.2	7.3	6.9	2.6	1	-4.3
OREM TRTMT PLT	-1.1	1.4	5.6	7.7	9	12.1	15	13.6	11.1	5.1	2.8	-1.1
OURAY 4 NE	-4.4	-3	3.7	9.1	9.4	12.3	13.3	10.8	9.3	3.8	2.3	-1.8
OVERTON	1.6	4.3	9	12.7	16.3	19.4	17.1	15.3	14.9	8.9	5.3	1.3
PAGE	-7	-2.8	3.3	6.8	7.3	9.4	8.6	7.3	6.4	2.8	0.6	-4
PALISADE	-2.3	0.1	4.1	7.9	9	11.5	9.5	6.3	5.6	2.8	0.9	-1.8
PANGUITCH	-8.4	-3.5	2.3	5.7	6.5	7.6	6.9	4.9	4.8	1.6	-0.4	-5.1
PARK VALLEY	-5	-3.7	2	5.2	6.1	7.2	10.3	10.3	6.7	2.1	-0.7	-3.1
PAROWAN PWR	-6.7	-2.6	3	6.6	7.4	10.3	9.1	8	7.9	3.2	1.8	-3.8
PARTOUN	-4.7	-1	4.6	6.3	8	10.7	12.4	11.8	9.9	4.2	1.3	-3.9
PAUL 1ENE	-2.6	-1.9	0.7	2.7	2.9	2.1	2.5	3.9	2.4	1.4	-1.4	-2.7
PHANTOM RANCH	0.7	3.6	8.5	12.3	15.5	18.9	16.8	14.8	14.3	8.3	5.2	0.6
PINE VIEW DAM	-5.9	-4.9	0.8	4.6	5.9	6.5	9.3	9.1	6	2.5	-1	-4
PIOCHE	-3.1	-0.5	3.7	7.4	9.4	13.4	11.2	9.2	8.4	3.9	1.1	-2.8
PIPE SPRINGS NATL MON	0.8	3.8	8.7	12.4	15.8	19.1	16.9	15	14.6	8.5	5.3	0.8
PLEASANT GROVE	-1.7	0.4	4.8	7.2	8.6	11.2	13.9	12.5	9.8	4.4	1.9	-1.5
POCATELLO 2 NE	-4.5	-3.9	-0.2	2.8	3.6	2.7	3	5	3.2	0.8	-2.3	-4.2
POCATELLO RGNL AP	-4.5	-4	-0.4	2.7	3.4	2.3	2.3	4.5	3	0.7	-2.4	-4.3
PRESTON	-6.8	-6.5	-0.8	4.2	4.9	5.6	8.3	8	5.4	1.6	-1.2	-4.5
PRICE BLM	-4.7	-2.5	1.5	8.4	7.6	11.4	12.7	9.7	8.8	3.5	2.7	-1.7
PROVO BYU	-0.9	1.7	6	8	9.2	12.2	15.2	13.7	11.5	5.4	3.2	-0.9
RANDOLPH	-6.9	-6.3	-0.6	3.9	4.2	4.9	7.3	6.8	4.7	2.1	-0.8	-4.7
RANGELY 1 E	-4.8	-4.5	2.5	9.3	9.4	12.8	13.2	10.9	10.4	3.6	1.9	-1.5
RICHFIELD RADIO KSVC	-5.3	-1.9	3.8	6.9	7.4	10	10.7	10.3	8.3	3.8	-0.3	-4.9
RICHMOND	-7	-6.6	-0.8	4.2	4.6	5.2	8	7.6	5	1.4	-1.4	-4.6
RIVERDALE	-5.4	-4.3	1.3	5.1	6.3	7	9.6	9.3	6.3	2.7	-0.7	-3.7
ROCK SPRINGS AP	-5.5	-5.1	1.4	7.6	7.9	11	12.5	10.5	8.7	3.2	1	-3
ROOSEVELT RADIO	-3.6	-1.2	5.1	8.9	9.8	11.6	13.1	10.1	8.4	4.1	2.7	-1.9
RUPERT 3 WSW	-2.6	-1.9	0.7	2.7	2.9	2.1	2.5	3.9	2.4	1.4	-1.4	-2.7
RUTH	-4.6	-1.7	2.8	6.3	7.5	11.4	10.3	8.8	7.6	3.1	0	-4.4
SAGE 4 NNW	-7.2	-7.7	-2	3.2	4.2	5.6	8.6	7.6	5	1.9	-2	-6
SALINA 24 E	-5.6	-3.4	0.4	8.3	6.9	11.3	12.1	9.9	8.9	3	2	-2.4

Table F3. Continued. Monthly values of dew point depression Factor, K_O, at each of the 246 NWS Sites

SALINA	-6	-3	2.2	7.1	6.8	9.8	10.9	9.9	8.4	3.3	0.3	-4.4
SALT LAKE CITY INTL AP	-1.7	-0.3	3.7	7	8.3	10.6	13	11.5	8.2	3.7	0.6	-1.7
SANTAQUIN CHLORINATOR	-2.4	0.8	5.7	7.3	8.8	11.7	14.5	13.5	11.3	5	3	-1.7
SCIPIO	-7	-3.1	3.4	5.8	6.8	8.9	10.5	10.2	8.4	3.3	0	-5.3
SCOFIELD DAM	-4.2	-1.3	3.9	7.5	8.2	10.7	12.9	10.7	9.4	4.2	2.7	-2.2
SHOSHONE 1 WNW	-1.9	-1.3	1.5	3.1	3.5	3.7	4.7	5	3.8	2.3	-0.7	-2.1
SNAKE CREEK POWERHOUSE	-1.9	-0.1	4.3	7.2	8.5	10.3	12.9	11.1	8.9	4.3	1.9	-1.5
SNOWVILLE	-5.9	-4.4	2.3	6.3	7.6	9.1	12.7	12.3	8.3	2.7	-0.3	-3.2
SODA SPRINGS AP	-6.2	-6.6	-2.7	2.5	3.5	3.9	5.5	6	4.1	1.1	-1.2	-4.4
SPANISH FORK PWR HOUSE	0	2.7	6.6	8.4	9.4	12.7	15.9	14.7	12.4	5.9	3.7	-0.4
SPRING VALLEY SP	-3.5	-1	3.2	6.9	8.7	12.9	10.7	8.7	7.8	3.5	0.7	-3.1
ST GEORGE	3.1	5.8	10.9	14.6	18.7	21.6	19.3	17.6	17.5	10.8	7	2.6
SUNNYSIDE - LUND 31S	-2.9	-0.1	4.2	7.8	9.9	13.9	11.7	9.7	8.8	4.2	1.5	-2.5
SUNNYSIDE CITY CTR	-3.5	-1.2	2.7	9	8.6	12.4	13.6	10	8.9	4.1	3.4	-0.9
SUNNYSIDE	-3.5	-1.1	2.9	8.9	8.6	12.3	13.5	9.9	8.8	4.1	3.3	-1
SUPAI	1.1	4.1	8.9	12.7	16.1	19.4	17.2	15.3	14.9	8.7	5.5	1
TEEC NOS POS	0	3.3	7.1	9.5	9.4	13.4	10.2	7.4	6.6	5.3	2.8	0.4
THIOKOL PROPULSION F S	-5.7	-4.3	1.7	5.6	7.1	8.7	12.4	11.7	8.1	3.2	-0.4	-3.5
THOMPSON	-2.9	-0.7	2.5	9.3	8.7	13	12.5	8.9	8.1	3.6	3.1	-0.7
TIMPANOGOS CAVE	-1.4	0.3	4.4	7.3	8.6	11.1	13.8	12.2	9.2	4.2	1.4	-1.4
TOOELE	-1.4	0.1	4.1	7.2	8.5	10.9	13.5	12	8.8	3.9	1	-1.6
TREMONTON	-4.8	-2.5	3	6.1	7.8	10.5	15.3	13.5	10.2	4.7	0.4	-2.9
TRENTON	-7	-6.6	-0.7	4.4	4.7	5.2	8	7.8	5.2	1.4	-1.3	-4.6
TROPIC	-7.4	-3	3	6.5	7.1	8.9	8.1	6.6	5.9	2.5	0.2	-4.3
TUBA CITY	-1.3	2.3	7.5	11.1	14	16.2	14.4	12.6	12.4	7.1	4	-0.4
TWIN FALLS 6 E	-1.2	-0.7	2.2	3.6	4.2	5	6	5.6	4.8	3.2	-0.1	-1.5
TWIN FALLS KMVT	-1.3	-0.7	2.1	3.5	4.1	4.9	5.8	5.5	4.7	3.1	-0.1	-1.6
URAVAN	-1.2	1.7	5.2	8.1	9.1	11.9	9	5.7	5.1	3.3	1.2	-1.2
UTAH LAKE LEHI	-1.6	0.4	4.7	7.2	8.7	11.3	13.9	12.6	9.6	4.3	1.6	-1.6
VERNAL 2SW	-4.4	-1.5	4.1	8.5	8.6	11.9	14.1	11.6	7.9	3.7	2.8	-2.7
VERNON	-3.2	-0.2	5	6.6	8.6	11.4	13.9	12.8	10.3	4.3	2.1	-2.2
VEYO PWR HOUSE	0.8	3.6	8.2	11.8	15.2	18.5	16.2	14.3	13.8	8	4.6	0.6
WAH WAH RCH	-5.4	-2.2	2.7	6.3	7.5	11.4	9.7	8	7.4	2.9	1	-3.9
WAHWEAP	-7	-2.8	3.3	6.8	7.3	9.4	8.6	7.3	6.4	2.8	0.6	-4
WANSHIP DAM	-3.5	-2.1	2.8	6.2	7.1	7.6	9.7	8.6	6.9	3.6	1	-2.4
WELLS	-2.2	-1.6	1.1	2.7	2.9	3.3	4.5	5	3.4	1.9	-1.2	-2.5
WENDOVER AP AWOS	-3.7	-2	3.7	7.3	9.3	11.1	14	12.8	9	3.3	0.5	-2.2
WOODRUFF	-6.9	-6.6	-1	3.5	4.2	4.9	7.5	7.2	4.8	1.9	-1.3	-4.8
YELLOW JACKET 2 W	0	3.5	7.2	9.5	9.3	13.5	10.3	7.5	6.5	5.3	2.8	0.5
ZION NP	-1.1	2.1	7.1	10.9	13.5	16.9	15	13.1	12.7	7	4.3	-0.5

APPENDIX G: CROP CURVE DEVELOPMENT

Mean crop coefficient (K_{cm}) curves were developed for 18 crop types and three types of wetland stands. K_{cm} curves were obtained or derived from a number of sources. The K_{cm} curves were represented as tabular K_{cm} values corresponding to crop growth stages.

Three different crop curve definitions were used in ET_c calculations. These definitions included: 1) percent days from beginning growth (BG) to effective full cover (EFC), then days after EFC until harvest or season termination (Term.) similar to Wright (1982), 2) AgriMet style K_{cm} curves with percent days from BG to EFC, then percent days from EFC to Term. (USBR 2011), 3) percent cumulative growing degree days from BG to EFC also applied after EFC similar to Allen and Robison (2007). Table G1 lists the K_{cm} curves used in this study with the curve source and definition type as described above. K_{cm} curves for each crop are discussed below.

Crop Coefficient Curves with % Days BG to EFC Then Days After EFC

K_c curves have often been defined as having two portions, the first defined by the percent of cumulative days from BG to EFC and the second applied according to the cumulative days following EFC (Wright 1982; Hill 1991). Table G2 contains tabular values of K_{cm} curves for each crop for which this method was used. Details on the development of the curves in Table G2 are provided below.

Apples and Cherries

The K_{cm} curve for apples and cherries was adapted from the AgriMet K_{cm} curve for cherries with cover from USBR (2011). The original curve was compared with curves for apples and cherries with cover reported by Allen et al. (1998) and Hill (1991). The curve was adapted to use % days from beginning growth to EFC and days after EFC. The K_{cm} was maintained at 0.68 at the end of the season (similar to pasture) until a killing frost (see Table 5). Beginning growth was defined as full bloom in the spring, for cherries, and beginning leafing for apples. EFC was defined as occurring when the trees were fully leafed. The K_{cm} for apples and cherries with cover is shown in Figure G1.

Garden Vegetables

The K_{cm} curve for garden vegetables was adapted from Hill (1991). The original K_{cm} curve was defined by two third order polynomial functions: one to be applied before EFC and one to be applied after. It was developed for use with ET_r from the 1982 Kimberly Penman Equation or other alfalfa reference (Hill 1991). This curve was tabularized to maintain consistency with the other curves used in this study. The garden K_{cm} curve is a composite derived from curves for peas, carrots, sweet corn, and tomatoes. The curve was defined with beginning growth occurring after the planting of peas and carrots, but before the planting of sweet corn and tomatoes. EFC corresponds with sweet corn tasseling and crop termination occurs 55 days after EFC or following a killing frost (see Table 5).

Table G1. K_{cm} Curves Used in the Study with Curve Type and Curve Source.

K_{cm} Curve Name	Curve Type[a]	Curve Source
Alfalfa	Days	Allen and Wright (2002)
Alfalfa	NCGDD	Adapted from Allen and Wright (2002) and Allen and Robison (2007)
Apples and Cherries	Days	Adapted from USBR (2011)
Corn (Grain)	Days	Allen and Wright (2002)
Corn (Grain)	NCGDD	Adapted from Allen and Wright (2002) and Allen and Robison (2007)
Garden Vegetables	Days	Adapted from Hill (1991)
Melons	AgriMet	USBR (2011)
Onion	AgriMet	USBR (2011)
Other Hay	Days	Adapted from Hill et al. (1989)
Pasture	AgriMet	USBR (2011)
Potatoes	Days	Allen and Wright (2002)
Potatoes	NCGDD	Adapted from Allen and Wright (2002) and Allen and Robison (2007)
Safflower	AgriMet	USBR (2011)
Sorghum	Days	Adapted from Allen et al. (1998) and Howell et al. (2010)
Spring Grain	Days	Allen and Wright (2002)
Spring Grain	NCGDD	Adapted from Allen and Wright (2002) and Allen and Robison (2007)
Stone Fruit and Tree Nuts[b]	Days	Adapted from Allen et al. (1998)
Berries and Small Fruit[c]	AgriMet	USBR (2011)
Turfgrass (North)[d]	Days	Adapted from Hill and Barker (2010)
Turfgrass (South)[d]	Days	Adapted from Hill and Barker (2010)
Wetlands (Large Stand Cattails)[e]	Days	Adapted from Allen (1998)
Wetlands (Narrow Stand Bulrush)[e]	Days	Adapted from Allen (1998)
Wetlands (Narrow Stand Cattails)[e]	Days	Adapted from Allen (1998)
Winter Wheat	Days	Allen and Wright (2002)
Winter Wheat	NCGDD	Adapted from Allen and Wright (2002) and Allen and Robison (2007)

[a]Days = % Days from BG to EFC, then Days after EFC, NCGDD = normalized cumulative growing degree days, AgriMet = USBR Pacific Northwest Cooperative Agricultural Weather Network (AgriMet).

[b]Stone fruit include: peaches, apricots, and plums.
[c]Includes raspberries and blackberries.
[d]North is northern Utah (elevation > 3500 ft. above MSL), South is southern Utah (elevation ≤ 3500 ft. above MSL).
[e]Narrow stands are narrow riparian areas along river corridors, large stands are any stands larger than that.

A graph of the adapted garden vegetable K_{cm} curve used in this study is found in Figure G2.

Table G2. K_{cm} Curves Applied Using Percent of Days from Beginning Growth to Effective Full Cover then Days After Effective Full Cover (cont.).

	% Days or Days	Apples / Cherries[a]	Garden Vegetables[b]	Other Hay[c]	Other Orchard[d]	Sorghum[e]	Turfgrass (North)[f]	Turfgrass (South)[f]	Wetlands (Large Stand Cattails)[g]	Wetlands (Narrow Stand Bulrush)[g]	Wetlands (Narrow Stand Cattails)[g]
% Days from BG to EFC	0	0.40	0.25	0.35	0.42	0.25	0.45	0.50	0.30	0.30	0.30
	10	0.45	0.25	0.57	0.42	0.25	0.45	0.50	0.39	0.45	0.43
	20	0.52	0.25	0.75	0.45	0.25	0.45	0.50	0.47	0.60	0.56
	30	0.58	0.28	0.89	0.54	0.25	0.45	0.50	0.56	0.75	0.69
	40	0.66	0.33	1.00	0.63	0.37	0.45	0.50	0.64	0.90	0.82
	50	0.76	0.39	1.05	0.73	0.48	0.48	0.50	0.73	1.05	0.95
	60	0.85	0.46	1.05	0.82	0.60	0.50	0.50	0.81	1.20	1.08
	70	0.94	0.54	1.05	0.91	0.72	0.53	0.52	0.90	1.35	1.21
	80	1.00	0.63	1.02	0.96	0.83	0.55	0.56	0.98	1.50	1.34
	90	1.04	0.72	0.92	0.96	0.88	0.58	0.61	1.07	1.65	1.47
	100	1.04	0.82	0.77	0.96	0.90	0.60	0.65	1.15	1.80	1.60
Cumulative Days After EFC	0	1.04	0.83	0.44	0.96	0.90	0.60	0.65	1.15	1.80	1.60
	10	1.04	0.84	0.41	0.96	0.90	0.60	0.65	1.15	1.80	1.60
	20	1.04	0.74	0.38	0.96	0.90	0.60	0.65	1.15	1.80	1.60
	30	1.04	0.57	0.35	0.96	0.90	0.60	0.65	1.15	1.80	1.60
	40	1.04	0.39	0.32	0.96	0.90	0.60	0.65	1.15	1.53	1.60
	50	1.04	0.24	0.28	0.96	0.90	0.60	0.65	1.15	1.25	1.60
	60	1.04	0.20	0.25	0.96	0.90	0.60	0.65	1.15	0.98	1.60
	70	0.98		0.21	0.89		0.60	0.65	1.15	0.71	1.60
	80	0.91		0.17	0.82		0.60	0.65	1.15	0.44	1.60
	90	0.84		0.13	0.75		0.60	0.65	1.15	0.16	1.60
	100	0.75			0.68		0.60	0.65	1.15		1.60
	110	0.68			0.68		0.60	0.65	1.15		1.60
	120	0.68			0.68		0.60	0.65	1.15		1.60
	130						0.60	0.65	1.15		1.60
	140						0.60	0.65	1.15		1.60
	150						0.60	0.65	1.15		1.60
	160						0.60	0.65	1.15		1.60
	170						0.55	0.65	1.15		1.60
	180						0.46	0.65	1.15		1.60
	190						0.45	0.65	1.15		1.60
	200						0.45	0.65	1.15		1.60
	240						0.45	0.65			
	280						0.45	0.59			

[a]Adapted from USBR (2011).
[b]Adapted from Hill (1991).
[c]Adapted from Hill et al. (1989).
[d]Adapted from Allen et al. (1998).
[e]Adapted from Allen et al. (1998) and Howell et al. (2008).
[f]Adapted from Hill and Barker (2010).
[g]Adapted from Allen (1998).

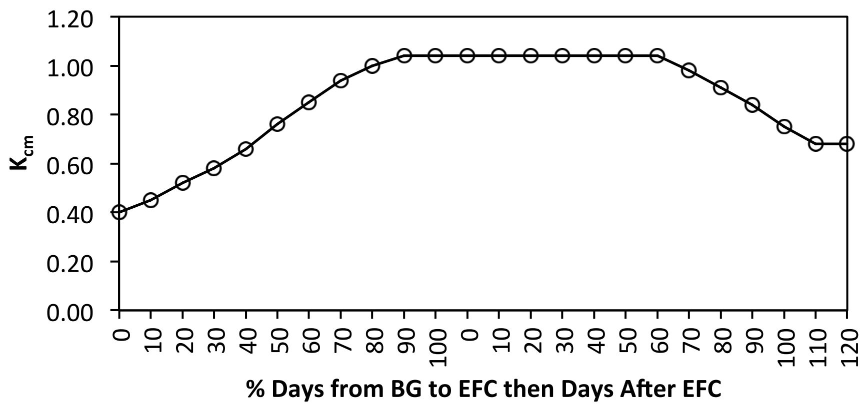


Figure G1. K_{cm} curve for apples and cherries with cover applied using % days from planting to EFC then days after EFC. Adapted from USBR (2011).

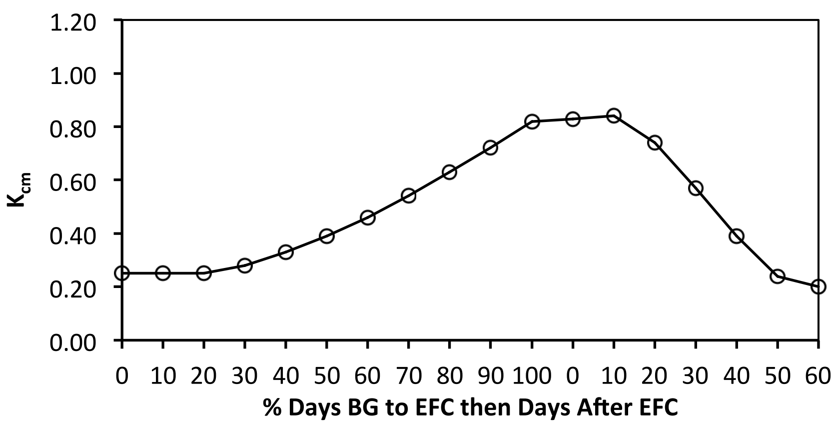


Figure G2. K_{cm} curve for garden vegetables applied using % days from planting to EFC then days after EFC. Adapted from Hill (1991).

Other (or Meadow) Hay

The other hay K_{cm} curve was adapted from the meadow hay curve of Hill et al. (1989). The original K_{cm} curve was described using two third order polynomial functions: one to be applied before EFC and one to be applied after. The original K_{cm} curve was developed for use with ET_r. calculated using the 1972 Kimberly Penman Equation. This curve was tabularized similar to the garden vegetable curve. The curve was defined with beginning growth at green up in the spring. EFC occurs when the hay is cut in mid-summer, The K_{cm} then decreases as irrigation is cut back and the grass is grazed during the fall. Crop growth was terminated 90 days after EFC or following a killing frost (see Table 5). A graph of the adapted other hay K_{cm} curve used in this study is found in Figure G3.

Other Orchard

The K_{cm} curve for other orchard was adapted from the K_{cm} curve for peaches reported by Allen et al. (1998). Other orchard includes almonds, apricots, peaches, pecans, and plums. The original curve was reported for use with short reference ET_o. The curve was divided by 1.2 and adapted to use % days from beginning growth to EFC and days after EFC. The curve was maintained at 0.68 at the end of the season (similar to pasture) until a killing frost (see Table 5). Beginning growth was defined as full bloom in the spring with EFC occurring when the trees were fully leafed. The K_{cm} for stone fruit and tree nuts is shown in Figure G4.

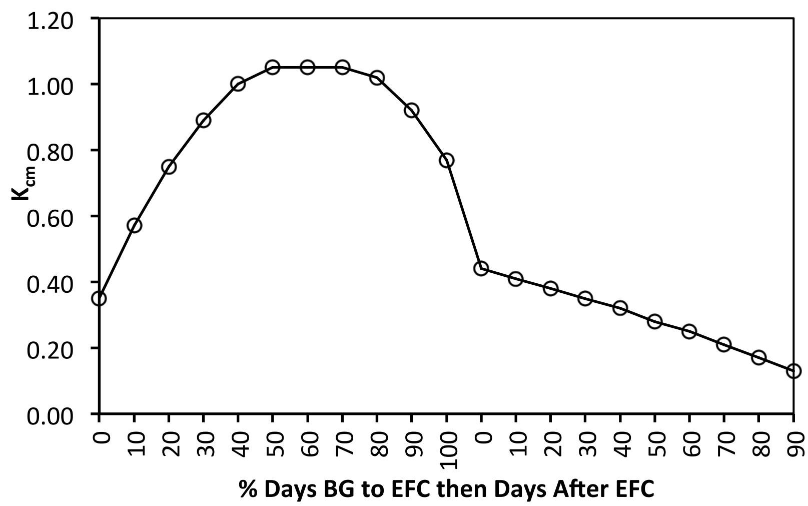


Figure G3. K_{cm} curve for field other hay applied using % days from planting to EFC then days after EFC. Adapted from Hill et al. (1989).

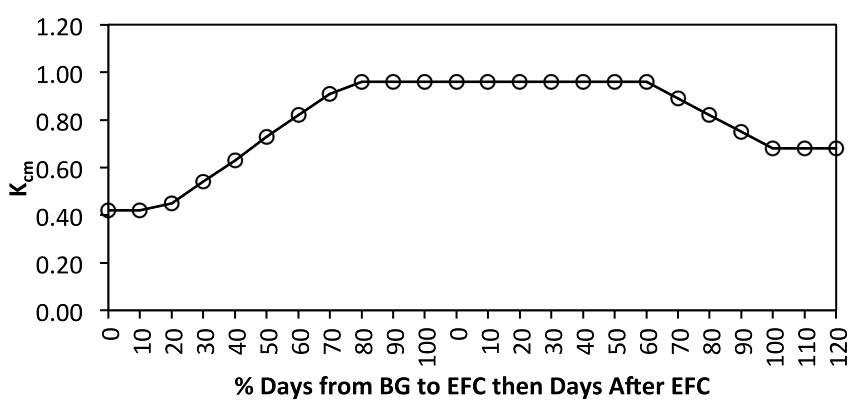


Figure G4. K_{cm} curve for other orchard and applied using % days from planting to EFC then days after EFC. Adapted from Allen et al. (1998).

Sorghum

Sorghum in this report refers to forage sorghum similar to sorghum-sudangrass or hay grazer varieties. The sorghum K_{cm} curve was adapted from forage sorghum curves reported by Allen et al. (1998) and Howell et al. (2008). The original curve reported by Allen et al. was for short reference ET_o and was divided by 1.2 to approximate a curve for use with tall reference ET_r. The curve reported by Howell et al. was developed for use with ASCE PM ET_{rs}, from measurements in Bushland, TX in 2006 and 2007. The adapted curve follows Allen et al.'s (1998) curve (divided by 1.2) for the initial and developmental stages and levels off at 0.9 following Howell et al. (2008). Beginning growth was defined as planting and with EFC occurring at heading. Crop growth was terminated 60 days after EFC or with a killing frost (see Table 5). A graph of the adapted sorghum K_{cm} curve used in this study is found in Figure G5.

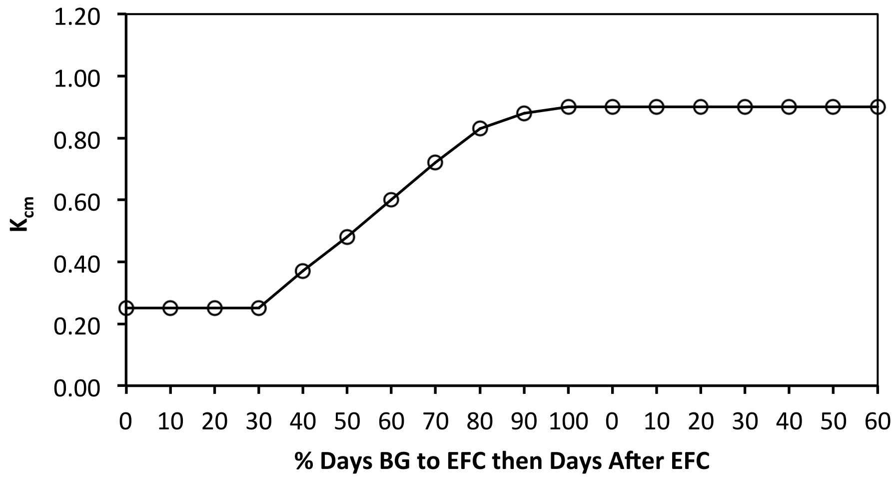


Figure G5. K_{cm} curve for forage sorghum applied using % days from planting to EFC then days after EFC. Adapted from Allen et al. (1998) and Howell et al. (2008).

Turfgrass

Two K_{cm} curves were developed for turfgrass based on the findings of Hill and Barker (2010). Hill and Barker reported separate K_{cm} curves for northern Utah and southern Utah (Dixie). Their curves were developed for use with ASCE PM ET_{rs}. Hill and Barker's K_{cm} curves were adapted to use percent days from green up in the spring to EFC (fully active growth) and days after EFC. The curves were tabularized for consistency. The north curves was applied at sites with an elevation greater than 3500 ft. abv msl and the south curve was applied at sites with an elevation of 3500 ft. or less. Note that the north curve was used for low elevations in Idaho. The curves were applied until 240 days after EFC in the north or 270 days in the south, or until a hard frost (see Table 5). Figure G6 contains turfgrass K_{cm} curves for northern (high elevation) and southern (low elevation) regions.

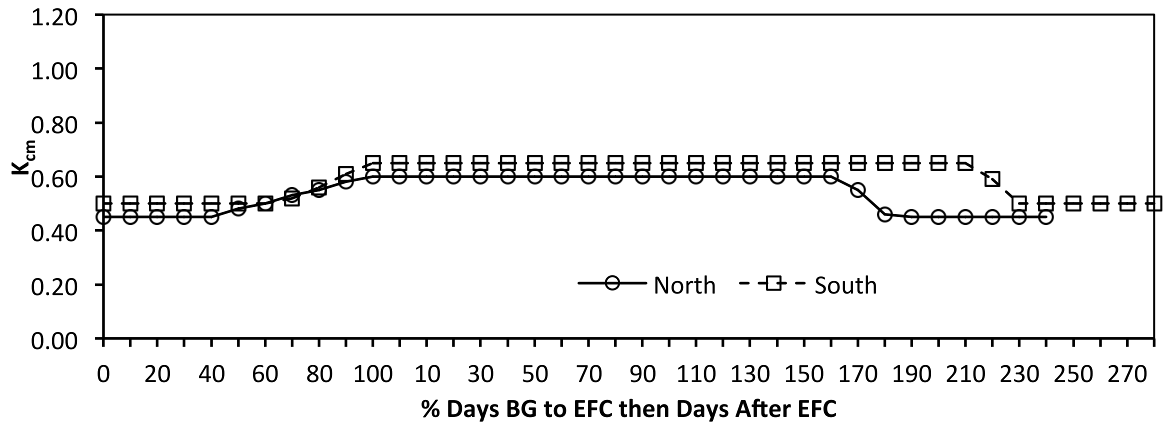


Figure G6. K_{cm} curves for turfgrass applied using % days from planting (begin growth) to EFC then days after EFC. Adapted from Hill and Barker (2010).

Wetlands

Wetlands were separated in to two categories, large cattail stands and narrow cattail stands. Narrow stands would be small riparian stands along canals, ditches, streams, and barrow pits. Large stands are stands covering larger expanses. The K_{cm} curves for wetlands were adapted from a study in Logan, UT (Allen et al. 1992; Allen 1998). Allen's(1998) curves for cattails were modified to maintain the full cover K_{cm} until a killing frost (see Table 5) similar to Allen and Robison (2007), but the full cover K_c of Allen (1998) was maintained. Beginning growth for cattails was defined as green up in the spring with EFC occurring 45 days later as described by Allen (1998). The K_{cm} curves for wetlands (cattails) are shown in Figure G7.

Allen et al. (1992) and Allen (1998) also provided a K_{cm} curve for bulrush. This curve was not used in ET calculations, but is provided in Figure 11 for comparison purposes. The curve for Bulrush was adapted for use with % Days from BG to EFC and days after EFC. BG for bulrush was defined as green up in the spring with EFC occurring 70 days after BG. Bulrush growth was terminated 90 days after EFC or with a killing frost (see Table 5). Note that the narrow stands for both cattails and bulrush have high K_{cm} values at EFC, 1.60 and 1.80, respectively. This is due to a "clothes-lining effect" created by a stand of wetlands that is relatively tall in comparison with surrounding vegetation or land surfaces (Allen 1998; Allen et al. 1992).

Crop Coefficient Curves with % Days from BG to EFC Then % Days from EFC to Term.

A number of K_{cm} curves were obtained from the United States Bureau of Reclamation's Pacific Northwest Cooperative Agricultural Weather Network, called AgriMet (USBR 2011). The AgriMet K_{cm} curves are defined as percent days from beginning growth to EFC and then percent days from EFC to Termination. Table G3 contains tabular values of K_{cm} curves for each crop using the AgriMet method. All AgriMet curves were developed for use with ET_r from the 1982

Kimberly Penman Equation (USBR 2011). Details concerning the application of the curves in Table G3 are discussed below.

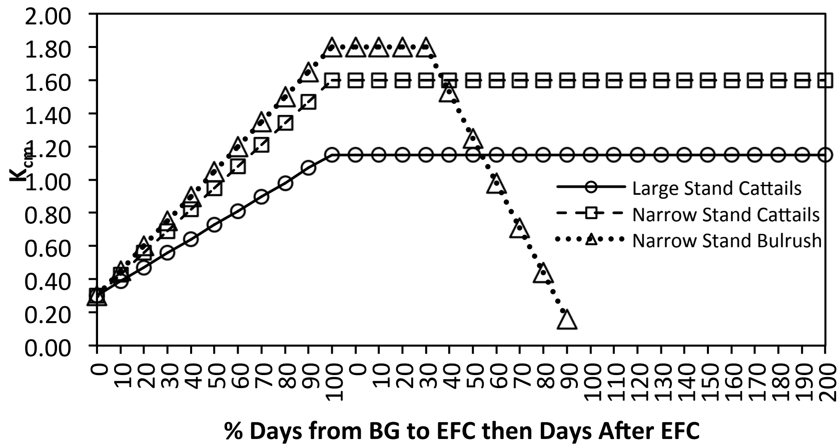


Figure G7. K_{cm} curves for wetlands applied using % days from planting to EFC then days after EFC. Adapted from Allen (1998).

Table G3. K_{cm} Curves Defined by Percent of Days from Beginning Growt Effective Cover then Percent of Days from Effective Cover to Terminati Curves from USBR (2011).

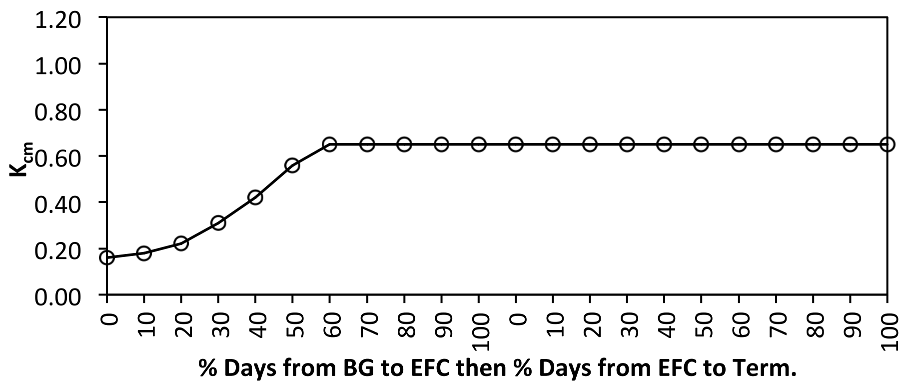
	% Days	Melons	Onion	Pasture	Safflower	Small Fruit
% Days from BG to EFC	0	0.16	0.30	0.25	0.20	0.15
	10	0.18	0.50	0.30	0.20	0.17
	20	0.22	0.50	0.36	0.30	0.23
	30	0.31	0.50	0.43	0.60	0.33
	40	0.42	0.50	0.50	0.83	0.46
	50	0.56	0.55	0.60	0.94	0.60
	60	0.65	0.69	0.63	0.98	0.73
	70	0.65	0.82	0.66	1.00	0.85
	80	0.65	0.95	0.68	1.00	0.95
	90	0.65	1.00	0.68	1.00	1.00
	100	0.65	1.00	0.68	1.00	1.01
% Days from EFC to Term.	0	0.65	1.00	0.68	1.00	1.01
	10	0.65	1.00	0.68	1.00	1.00
	20	0.65	1.00	0.68	1.00	0.99
	30	0.65	1.00	0.68	1.00	0.97
	40	0.65	1.00	0.68	1.00	0.95
	50	0.65	1.00	0.68	1.00	0.92
	60	0.65	1.00	0.68	0.94	0.90
	70	0.65	0.87	0.68	0.80	0.88
	80	0.65	0.75	0.65	0.62	0.86
	90	0.65	0.62	0.60	0.43	0.83
	100	0.65	0.50	0.40	0.20	0.80

Melons

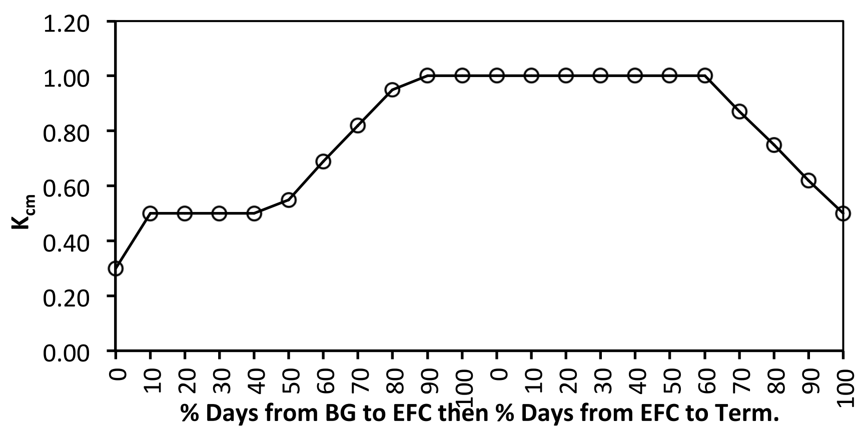
The AgriMet (USBR 2011) K_{cm} curve for melons and wine grapes was used as the curve for melons. Beginning growth was initiated at planting with EFC occurring at full canopy. Termination occurred at final harvest or a killing frost (see Table 5). The K_{cm} curve for melons is shown in Figure G8.

Onion

The AgriMet (USBR 2011) K_{cm} curve for onions and garlic was used as the curve for onions. Beginning growth was initiated at planting with EFC occurring when half of the stand had 12 or more leaves. Termination occurred at harvest or a killing frost (see Table 5). The K_{cm} curve for onions is shown in Figure G9.



FigureG8. K_{cm} curve for melons applied using % days from planting to EFC then % days from EFC to termination. Source: USBR (2011).



FigureG9. K_{cm} curve for onions applied using % days from planting to EFC then % days from EFC to termination. Source: USBR (2011).

Pasture

The AgriMet (USBR 2011) K_{cm} curve for pasture was used as the curve for pasture. Beginning growth was initiated at green up in the spring with EFC occurring when the grass was about 8 in. tall or near heading. Termination occurred after a killing frost (see Table 5). The K_{cm} curve for pasture is shown in Figure G10.

Safflower

The AgriMet (USBR 2011) K_{cm} curve for safflower was used as the curve for safflower. Beginning growth was initiated at emergence with EFC occurring at 50% heading. Termination occurred with plant senescence or a killing frost (see Table 5). The K_{cm} curve for safflower is shown in Figure G11.

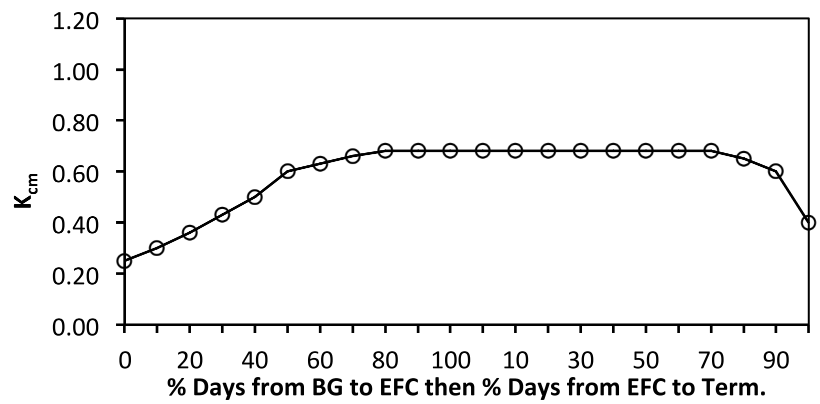


Figure G10. K_{cm} curve for pasture applied using % days from planting to EFC then % days from EFC to termination. Source: USBR (2011).

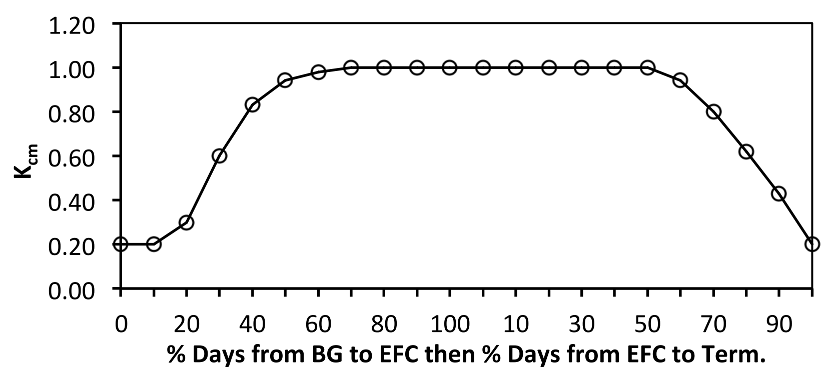


Figure G11. K_{cm} curve for safflower applied using % days from planting to EFC then % days from EFC to termination. Source: USBR (2011).

Small Fruit

Small fruit were defined as raspberries, blackberries, blueberries and grapes. The K_{cm} curve used for small fruit was the "Trailing Berries" K_c curve from AgriMet (USBR 2011). Beginning growth was defined as green up in the spring with EFC occurring at full bloom. Crop growth was terminated by a killing frost (see Table 5). The K_{cm} curve for berries and small fruit is shown in Figure G12.

Crop Coefficient Curves with % Days from BG to EFC Applied All Season

Alfalfa

The alfalfa K_{cm} curves were modified from the K_{cm} curves of Allen and Wright (2002). Alfalfa has three separate K_{cm} curves, corresponding to different stages of alfalfa growth. The first curve is for green up in the spring until the first cutting. The second curve is for all intermediate cycles, applied from cutting to cutting. The third curve is for the final cycle, or crop growth after the last cutting until a killing frost occurs. The tabular alfalfa K_{cm} values are given in Table G4. The three alfalfa K_{cm} curves are shown in Figure G13.

The alfalfa K_{cm} curves were modified to use the percent of days from beginning growth or cutting to effective cover (about 20 inches). This was done to allow for variable harvest intervals without effecting the time necessary for development. The first cycle K_{cm} was modified to start earlier than Allen and Wright 's original curve. The curves were maintained at 1 following effective cover until cutting.

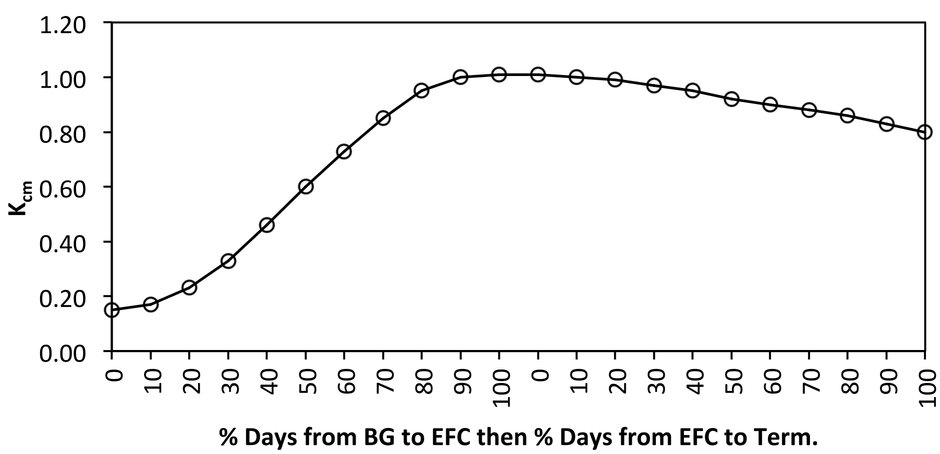


Figure G12. K_{cm} curve for berries and small fruit applied using % days from planting to EFC then % days from EFC to termination. Source: USBR (2011).

Table G4. Alfalfa K_{cm}, Defined by Percent of Days from Beginning Growth to Effective Full Cover Applied All Season. Adapted from Allen and Wright (2002).

% Days BG to EFC[a]	Alfalfa 1st[b]	Alfalfa Int[b]	Alfalfa Last[b]
0	0.38	0.30	0.30
10	0.56	0.38	0.34
20	0.71	0.47	0.39
30	0.81	0.55	0.46
40	0.86	0.69	0.56
50	0.89	0.86	0.67
60	0.92	0.92	0.78
70	0.95	0.97	0.87
80	0.98	0.98	0.93
90	0.99	0.99	0.96
100	1.00	1.00	0.98
110	1.00	1.00	0.99
120	1.00	1.00	1.00
250	1.00	1.00	1.00

[a]Percent days from beginning growth to effictive cover.
[b]1st is first crop, int is all other crops, last is the final growth period after the last cutting.

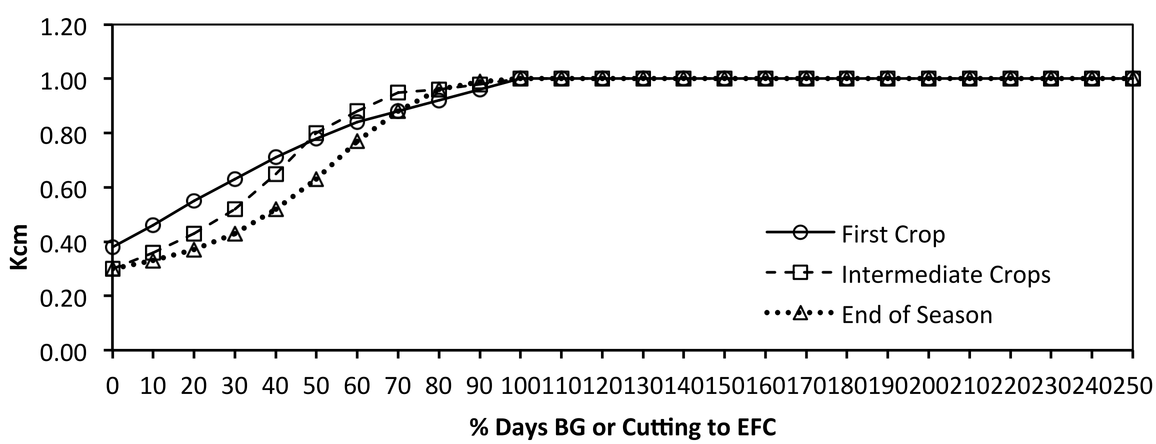


Figure G13. K_{cm} curves for alfalfa applied using % CGDD from beginning growth to cutting or cutting to cutting (until killing frost). Adapted from Allen and Robison (2007) and Allen and Wright (2002).

The final curve was applied as though the alfalfa would be cut at the same interval as was used in the intermediate cycles, but growth was terminated after a killing frost (28 °F). The final curve was adjusted further to account for the effect of light, or soft frosts (32 °F) similar to the method reported by Allen and Robison (2007). In this method once the minimum daily air temperature reached or dropped below the soft frost temperature (without reaching a killing frost), K_{cm} curve progression was stopped. The K_{cm} was then found by subtracting 0.005 from the preceding day's value each day until a killing frost occurred, beginning with the day of the soft frost. The K_{cm} was limited to be 0.30 or greater.

Crop Coefficient Curves with % CGDD from BG to EFC Applied All Season

Allen and Robison (2007) and Huntington and Allen (2010) used growing degree days (GDD) to define K_c curves following Wright (2001). The use of GDD to define K_c curves allowed for automatic variability in season lengths for different regions in Idaho and Nevada (Allen and Robison 2007; Huntington and Allen 2010). Allen and Robison (2007) developed basal crop coefficient (K_{cb}) curves for use with cumulative GDD (CGDD) based on the K_{cb} curves published by Allen and Wright (2002). Allen and Robison used the same datasets that were used to develop Allen and Wright's K_{cb} curves from Kimberley, ID to develop curves based on CGDD. Allen and Robison's K_{cb} curves were developed using what they called "normalized cumulative growing degree days" (NCGDD) which were defined as the percent of CGDD from beginning growth to EFC applied both before and after EFC.

Allen and Robison used two methods for calculating GDD. The first was the conventional method of determining GDD for corn, known as the "86/50" method. In this method GDD is

calculated from daily maximum and minimum air temperatures, T_{max} and T_{min}, in °F, with a ceiling of 86 °F and floor of 50 °F imposed on the temperatures as:

$$GDD_{86/50} = \frac{max(min(T_{max},86),50) + max(min(T_{min},86),50)}{2}, 50 \quad \text{(H1)}$$

where $GDD_{86/50}$ is GDD for corn (F° d^{-1}) using the "86/50" method and max() and min() represent the functions for finding the maximum and minimum. In their report Allen and Robison (2007) used GDD in C° d^{-1} rather than (F° d^{-1}), but that is a matter of preference.

The second method for calculating GDD used by Allen and Robison (2007) involved using the mean daily air temperature (calculated from T_{max} and T_{min}). A base or lower temperature limit temperature (T_{base}) was imposed, however, there was no maximum limit on air temperature as:

$$GDD_{Tbase} = max\left(\frac{T_{max} + T_{mini}}{2}, T_{base}\right) - T_{base} \quad \text{(H2)}$$

Allen and Robison (2007) used a base temperature of 0 °C (32 °F) for early crops like small grain and 5 °C (41 °F) for late crops like potatoes.

Several mean crop coefficient (K_{cm}) curves were developed for use in the current study based on the NCGDD K_{cb} curves reported by Allen and Robison (2007) and the K_{cm} curves published by Allen and Wright (2002). This was done by comparing Allen and Robison's NCGDD K_{cb} curves with the original day based K_{cb} curves of Allen and Wright. NCGDD K_{cm} curves were then developed from the K_{cm} curves reported by Allen and Wright (2002) and the relationship between the % Days to EFC or Days after EFC and the %CGDD from the published K_{cb} curves. The same temperature bases were used for the derived K_{cm} as were used by Allen and Robison (2007) for each respective crop. Note that GDD units have been converted in this report from C° d^{-1} to F° d^{-1}. A list of the derived NCGDD K_{cm} values for each crop is found in Table G5. Descriptions of the NCGDD K_{cm} curves used in this study are provided below.

Corn

The K_{cm} curve for corn was developed as described above from Allen and Robison's (2007) K_{cb} curve for field corn and Allen and Wright's (2002) K_{cb} and K_{cm} curves for field corn. The corn K_{cm} curve is based on GDD_{corn} calculated using the "86/50" method. Beginning growth was defined as planting with EFC corresponding to tasseling. Crop growth was terminated by killing frost (see Table 5) or after 230% CGDD from BG to EFC was achieved. The K_{cm} for field corn is shown in Figure G14.

Potatoes

The K_{cm} curve for potatoes was developed as described above from Allen and Robison's (2007) K_{cb} curve for late harvest potatoes and Allen and Wright's (2002) K_{cb} and K_{cm} curves for potatoes. GDD were calculated using a T_{base} of 41°F. Beginning growth was defined as planting with EFC occurring when distinction between rows is no longer visible. Crop growth was terminated after 230% of CGDD from planting to EFC was achieved or after a killing frost (see Table 5) The K_{cm} for potatoes is shown in Figure G15.

Spring Grain

The K_{cm} curve for spring grain was used for barley and spring grain (oats and wheat). The K_{cm} curve for spring grain was developed as described above from Allen and Robison's (2007) K_{cb} curve for spring grain and Allen and Wright's (2002) K_{cb} and K_{cm} curves for spring grain. The spring grain K_{cm} curve was developed using a T_{base} of 32°F. Beginning growth was defined as planting with EFC occurring at heading. Crop growth was terminated after 230% of CGDD from BG to EFC was achieved or following a killing frost (see Table 5). The K_{cm} for spring grain is shown in Figure G16

Table G5. K_{cm} Defined by Percent of Cumulative Growing Degree Days from Beginning Growth to Effective Full Cover Applied All Season. Adapted from Allen and Robison (2007) and Allen and Wright (2002).

% CGDD BG to EFC[a]	Corn	Potatoes	Spring Grain	Winter Wheat
0	0.20	0.20	0.20	0.25
10	0.20	0.20	0.20	0.27
20	0.20	0.20	0.27	0.32
30	0.24	0.34	0.41	0.39
40	0.31	0.44	0.54	0.48
50	0.45	0.54	0.65	0.64
60	0.59	0.66	0.73	0.85
70	0.71	0.72	0.92	0.96
80	0.85	0.76	1.02	1.00
90	0.94	0.78	1.03	1.03
100	1.00	0.80	1.03	1.03
110	1.00	0.80	1.03	1.03
120	1.00	0.78	1.03	1.03
130	1.00	0.75	1.03	1.02
140	0.97	0.74	1.03	1.01
150	0.93	0.72	1.03	0.84
160	0.89	0.70	1.01	0.59
170	0.84	0.68	0.97	0.39
180	0.79	0.65	0.89	0.26
190	0.73	0.62	0.70	0.18
200	0.66	0.58	0.51	0.14
210	0.48	0.51	0.40	0.10
220	0.27	0.32	0.31	
230	0.18	0.23	0.21	
240			0.10	
250				

[a]Percent cumulative growing degree days from beginning growth to effictive cover.

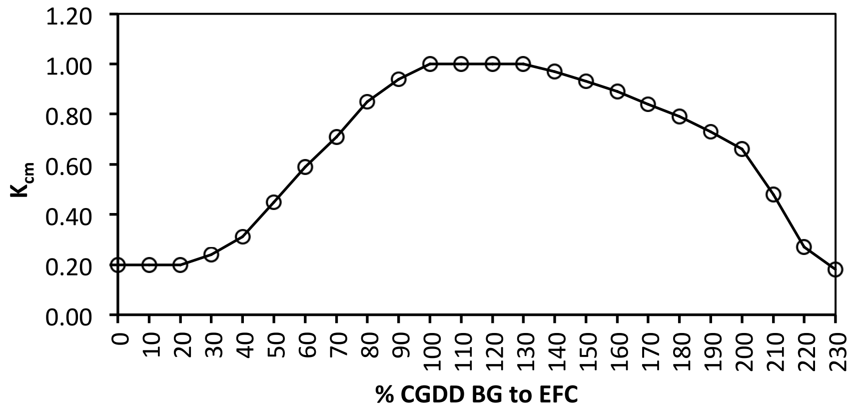


Figure G14. K_{cm} curve for field corn applied using % CGDD from planting to EFC. Adapted from Allen and Robison (2007) and Allen and Wright (2002).

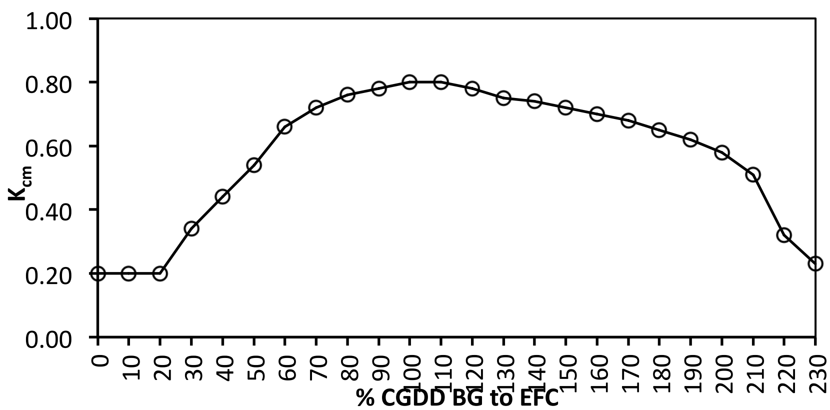


Figure G15. K_{cm} curve for potatoes applied using % CGDD from planting to EFC. Adapted from Allen and Robison (2007) and Allen and Wright (2002).

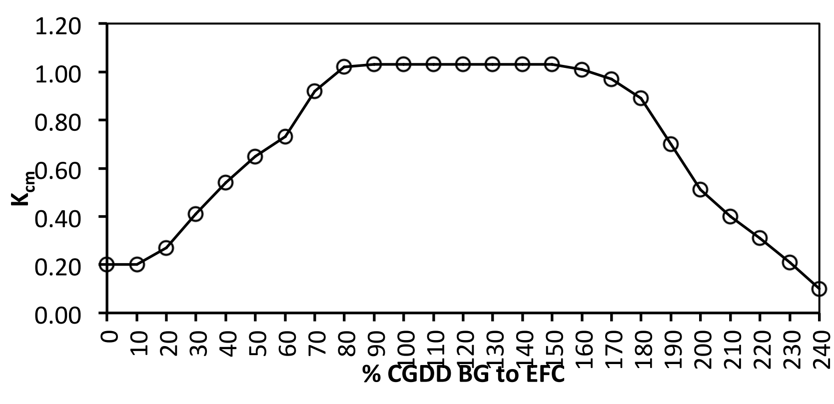


Figure G16. K_{cm} curve for spring grain applied using % CGDD from planting to EFC. Adapted from Allen and Robison (2007) and Allen and Wright (2002).

Winter Grain

The K_{cm} curve for spring grain was developed as described above from Allen and Robison's (2007) K_{cb} curve for spring grain and Allen and Wright's (2002) K_{cb} and K_{cm} curves for spring grain. A T_{base} of 32°F was used in GDD calculations for winter grain. The NCGDD were adjusted from those in Allen and Robison (2007) so that beginning growth could be defined by a "pseudo planting date" when the crop began active growth in the spring as described by Wright (1982). EFC was defined to occur at heading. Crop growth was terminated after 210% of CGDD from BG to EFC was achieved or following a killing frost (see Table 5) The K_{cm} for winter grain is shown in Figure G17.

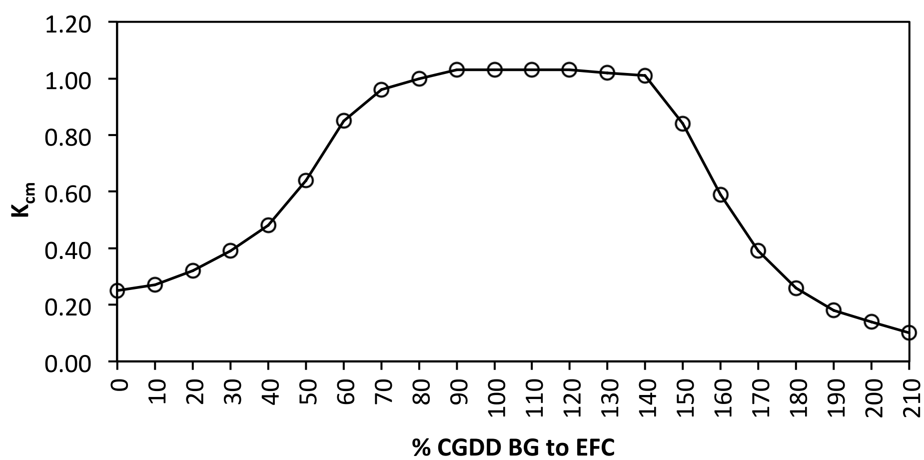


Figure G17. K_{cm} curve for winter grain applied using % CGDD from a "pseudo-planting date in the spring" to EFC. Adapted from Allen and Robison (2007) and Allen and Wright (2002).

APPENDIX H. EMPIRICAL MEASUREMENT OF CROP ET AND OPEN WATER SURFACE EVAPORATION

In evaluating the use of a theoretical ET or evaporation estimate, it is preferable to have measured data for some crop or water body in the vicinity. In a few areas, the water necessary to grow particular crops has been empirically determined by measurements — through instrumented field research sites with weighing lysimeters or other soil water depletion field studies, such as line-source sprinkler experiments. Lysimeter data are not, however, readily available in Utah except in USU studies in Cache Valley and elsewhere in the Bear River Basin. Additional field estimates of ET are available from crop water use experiments with the line-source sprinkler technique from several USU studies in various locations in Utah and neighboring states. Measurement of open water surface evaporation from water bodies is even scarcer. Some studies have been done in Canada and in the Upper mid-western and eastern U.S. and on Bear Lake and Utah Lake.

Crop ET

Equation calculated ET that differs from field measured estimates of crop ET is a concern. Consumptive use values as calculated by 10 different theoretical equations were tested by comparing each equation (or a variation) with field research measured consumptive use at selected sites in the Western United States in a USBR study (Hill, et.al. 1983). Field data on water use and yields of alfalfa (10 sites) and corn (8 sites) were included in the study. Research techniques included lysimeters, line-source sprinkler, irrigation frequency, stress plots and soil water budget accounting on farm fields.

Average alfalfa research study ET corresponding to high yields varied from 23.9 inches (Huntington, UT) to 42.5 inches (Fallon, NV) at those sites above 3,000 ft elevation and North of 36° N latitude, which excluded Bushland, TX and Las Cruces, NM (Table H1, adapted from Hill, et.al., 1983). Corresponding average research study high alfalfa yields varied from 5.9 to 9.6 ton/acre. Similarly, research study ET of corn, for those sites north of 36° N latitude, varied from 18.5 inches (Fort Collins, CO) to 28.1 inches (Grand Junction, CO) and was 22.6 inches at Logan, UT.

Considerable variation was found between calculated and field estimates of ET. This is illustrated for the USBR study (Boman, 1983) at Farmington, New Mexico (Fig. H1). The SCS-Blaney-Criddle equation (with SCS TR-21 crop coefficients, USDA-SCS, 1970) calculated ET was 19% lower than expected field crop water use, 33.7 inches, at Farmington, NM, for alfalfa yielding about 6.5 ton/acre. Whereas, the 1972 Kimberly Penman equation crop ET was 9% high (Fig. H1). Calculated alfalfa ET by the methodology used herein was 46 inches (38 year average) at Farmington, NM, which is 36% higher than the expected field ET mentioned above and 22% higher than experiment average high ET of 37.6 inches (Table H1).

Table H1. Summary of Alfalfa and Corn Yield and ET at Various Sites in Western United States.

Site and study period (in order of increasing elevation)		Elev. (ft above m.s.l)	Latitude (°N)	Experiment Average high Yield (t/acre)	ET (in)
Alfalfa[a]					
Bushland, Texas	1970-75	3840	35.2	9.6	53.8
Las Cruces, N. Mexico	1978-80	3900	32.3	8.9 11.3[b]	54.9 68.9[b]
Kimberly, Idaho	1969-75	3922	42.4	7.7	37.7
Fallon, Nevada	1973-78	3965	39.5	8.4 9.6[c]	40.5 42.5[c]
Logan, Utah	1977	4500	41.5	8.7	28.6
Grand Junction, Colorado	1979	4590	39.2	5.8	34.5
Millard and Iron Co, Utah	1979-81	4702	39.0	7.3	31.1
Farmington, New Mexico	1980-82	5652	36.7	7.7	37.6
Huntington, Utah	1979	6300	39.3	5.9	23.9
Corn[d]					
Sandhills, Nebraska	1978	3200	41.6	4.97	25.3
Bushland, Texas	1975-79	3840	35.2	4.4	29.0
Akron, Colorado	1977, -79, -80	4540	40.2	3.46 3.86[e]	22.6 23.7[e]
Logan, Utah	1974-75	4580	41.8	3.25	22.6
Grand Junction, Colorado	1977-80	4590	39.2	5.04	28.1
Fort Collins, Colorado	1974-75	5000	40.5	3.92[f]	18.5[f]

Notes: Adapted from Table 3-4 of Hill, et.al. (1983). [a] All yields at 12 percent moisture to approximate field dry conditions. [b] Average of seven highest 1978 lysimeter yields and ET values. [c] Average of 10 highest lysimeter yields and corresponding ET values. [d] All yields at 15.5 percent moisture. To convert yields to bushels per acre, multiply tons per acre by 35.71 (35.71 = 2,000/56), assuming 56 pounds corn grain per bushel. [e] Average of high yields, Treatment III four replications 1980. Two replications average high, III 1980, was 4.10 t/acre and 23.6 inches. [f] Average of three highest yields and corresponding ET from 1974 only.

Evapotranspiration Estimated from Lysimeter Studies

Alfalfa ET was determined in precision weighing lysimeters at Kimberly, ID (Wright, 1988) over a seven year period (1969-1975). Full season ET varied from 38.9 to 42.9 inches and yields varied from 6.7 to 9 ton/acre. Yield and ET on the adjacent farm field was about 5% less than in the lysimeters. The average water use was 5 inches per ton/acre of field dried alfalfa hay (12% moisture).

Water use efficiency of alfalfa grown in three drainage lysimeters from 1973-1978 at Fallon, NV was reported by Guitjens (1982) to vary from 0.78 to 1.52 tons per 6 acre-inch of annual water use (ET) with a six year average WUE of 1.12 tons per 6 acre-inch of annual ET. Average WUE for the three best years (1975, 1977 and 1978) was 1.31 tons per 6 acre-inch (0.218 tons per ac-in) the inverse of which is equivalent to 4.6 inches per ton/acre.

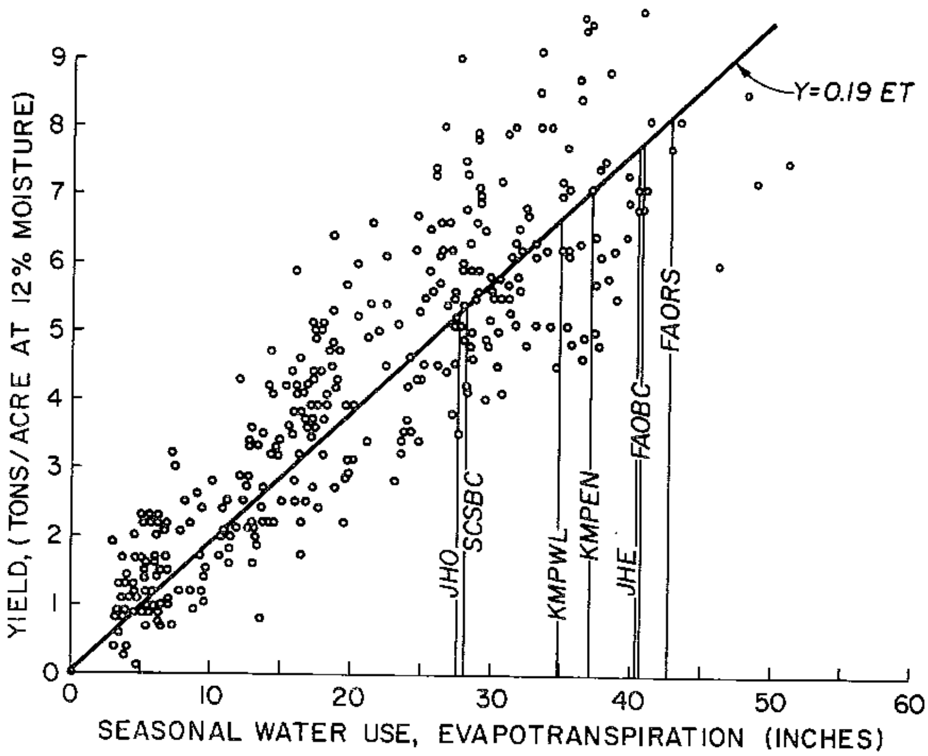


Figure H1. Alfalfa yield and ET - Farmington, New Mexico (from Hill, et al., 1983).

Tovey (1969) reported alfalfa yields varying from 6.3 to 7.4 tons/acre in a three year, 1959-61, study with water table lysimeters near Reno, NV. Seasonal evapotranspiration varied from 31.2 to 42.0 inches, 37.2 inches average, and ET per unit yield averaged 5.4 inches per ton /acre and varied from 4.9 to 5.7 inches per ton/acre. Alfalfa yields were higher in 1959 relative to ET and lower in following years, perhaps due to frosts in late June and early August in 1960 and increased cloudiness and somewhat lower temperatures in 1961 (Tovey, 1969).

Seasonal irrigated meadow water use varied from 15.8 to 27.5 inches, Table H2, during 1984-1987 under established growth conditions as reported in a study for the Bear River Commission (Hill, et.al. 1989). Water use on water table lysimeters was adjusted to represent typical irrigation season ET as if the lysimeters had been allowed to dry out after mid-July. Water use for 1987 (24.5 to 27.5 inches) was somewhat higher than in other years, possibly because the growing season was longer. The four year average meadow hay ET varied from 21.8 inches (Hilliard Flat) to 23.5 inches (Randolph) and the three site average was 22.3 inches.

Table H2. Seasonal Water Use of Irrigated Meadows at Three Sites in the Bear River Basin, 1984-1987.

Site	1984	1985	1986	1987	Site Average
	Lysimeter ET, inches[a]				
Hilliard Flat, WY	15.8	20.5	24.5	26.4	21.8
Montpelier, ID –old	20.0	20.7	20.2[b]	24.5	22.6[c]
Montpelier, ID –new				27.5	
Randolph, UT	22.5	23.2	23.2	24.9	23.5
Year average:	19.4	21.5	22.6	25.8	22.3

Notes: Adapted from Table 8 of Hill, et.al. (1989). [a] Adjusted to remove the effect of continued irrigation on the lysimeters when irrigation had ceased in the surrounding meadows after mid-July. [b] Corrected for excessive dryness in June by correlation with Randolph. [c] Montpelier new 1987 included.

Seasonal ET of cattails and bulrush, average of two lysimeters each, in Cache Valley varied from 36.5 inches, cattail 1988, to 40.7 inches, bulrush 1989 (Pruegar, 1991). The two year average ET was 38.1 and 39.0 inches, respectively, for cattail and bulrush for the June through August season. Cattail used about 60% more water than alfalfa reference ETr during the peak period, Kc =1.6, and bulrush 80%, Kc = 1.8, in isolated stands (approximately 20 ft by 20 ft plots) of these hydrophytes (Allen, Pruegar and Hill, 1992).

Verification of turfgrass consumptive use was accomplished with drainage lysimeter field studies generally during 2002-2008 in four areas of Utah (Hill and Barker, 2010): Cache Valley (Logan Golf and Country Club), Salt Lake County (Murray Parkway Golf Course), Utah County (Brigham Young University [BYU] Spanish Fork Farm 2002-06) and Washington County (Sunbrook Golf Course, 2002-06 and Southgate Golf Course, 2004-08). Observed seasonal turfgrass consumptive use varied from 11.2 inches (Logan West, 2004,) to 50.0 inches (Southgate, 2007). The range at Logan was 11.2 (West, 2004) to 35.2 inches (new, 2007); at Murray, 22.2 (East 2008) to 30.5 inches (East 2005); at Southgate, 19.7 (East 2006) to 50.0 inches (West 2007); at Spanish Fork, 14.2 (South 2002) to 30.4 inches (North 2004) and 13.0 (East 2004) to 35.5 inches (West 2002) at Sunbrook. Direct comparison of such variation in ET values across years and sites is problematic due to differing growing season lengths from year to year, site environmental conditions (average temperatures and wind patterns), and elevation (range of 2600 to 4800 ft. above msl) from south to north in Utah (latitude 37° N to 42° N).

Evapotranspiration Estimated from Line-source Sprinkler Studies

Yield response of alfalfa to varying amounts of applied irrigation water under a line-source sprinkler was reported by Retta and Hanks (1980). Alfalfa ET varied from 9.1 to 28.7 inches and yield varied from 1.3 to 7.8 ton/acre in a two year (1976-77) line-source sprinkler study in

Cache Valley, UT. Alfalfa water use averaged 3.9 inches per ton/acre (yield at 12% moisture) and was higher (4.2 inches per ton/acre) at lower yield levels.
Sammis (1981) reported alfalfa ET values varying from 21.5 to 57.4 inches, average of 40.9, under a line-source sprinkler near Las Cruces, NM. Corresponding yields averaged 6.8 ton/acre and varied from 2.1 to 11.0 ton/acre. Water use varied from 4.3 to 10.1 and averaged 6.4 inches per ton/acre.

Evapotranspiration and yield of alfalfa, corn, potatoes and spring wheat were evaluated using line-source sprinklers at Kaysville, UT; Kimberly, ID and Logan, UT in a three year study (1980-1982) as reported by Hill, Hanks and Wright (1984). Maximum site yield for corn (Table H3) varied from 2.3 ton/acre (Logan, June 9, 1980 planting) to 4.4 ton/acre (Kimberly, May 1, 1980 planting) and was higher for early planting dates than for later. Similarly, maximum spring wheat yield varied from 1.8 ton/acre (Kaysville May 15, 1980 planting) to 4.2 ton/acre (Logan, April 14, 1980 planting) and was higher for early planting dates than for later.

However, ET did not vary greatly from early to late planting dates at a given site. Seasonal corn ET varied from 26.1 to 26.9 inches at Kaysville, 17.9 to 21.6 inches at Kimberly and 18.6 to 27 inches at Logan (Table H3) with ET from later plantings being lowest at each site. Spring wheat ET did not vary as much across planting dates as for corn and was higher for the later planting at Kimberly and Logan, but not at Kaysville. Seasonal spring wheat ET varied from 21.7 to 23.5 inches at Kaysville, 19.7 to 21.4 inches at Kimberly and 20.5 to 21 inches at Logan.

Table H3. Maximum Crop ET and Yield for Corn and Spring Wheat at Kaysville, UT, Kimberly, ID and Logan, UT, 1980 Line-source Sprinkler.

Location	Corn[a]			Spring Wheat[c]		
	Planting Date	Max Yield (ton/ac)	Max ET (in)	Planting Date	Max Yield (ton/ac)	Max ET (in)
Kaysville	2-May	4.1	26.9	9-Apr	3.1	23.5
	15-May	3.8	26.4	25-Apr	2.3	21.8
	6-Jun	3.1	26.1	15-May	1.8	21.7
Kimberly	1-May	4.4	21.6	31-Mar	3.5	20.6
	14-May	3.6	19.3	17-Apr	3.0	19.7
	30-May	4.0	17.9	1-May	2.8	21.4
Logan	5-May	4.1	27.0	14-Apr	4.2	20.6
	19-May	3.8	22.5	28-Apr	3.1	20.5
	9-Jun	2.3	18.6	19-May	2.9	21.0
	Average	3.7	22.9	Average	3.0	21.2

Notes: [a] NKPX20 variety. [b]Fieldwin variety.

Generally, seasonal ET of corn would be expected to vary from about 19 inches to 27 inches, average of 23 inches, in Utah and surrounding states. Similarly, seasonal spring wheat ET would be expected to average 21 inches and range from 20 to 22 or perhaps 24 inches.

Average maximum plot ET for three varieties of potatoes, Kennebec, Lemhi, and Burbank, was 21.7 inches at Kimberly, 22.1 at Logan and 26.1 at Kaysville for the 1982 season (Hill, et.al. 1984). Similarly, maximum ET for alfalfa varied from 30.6 inches at Kimberly to 33.4 inches at Logan. Values from Kaysville are excluded due to the presence of a water table which confounded the analysis of soil water depletion. Alfalfa water use averaged 4.4 inches per ton/acre for the non establishment years of 1981 and 1982.

ET for pasture grass harvested as hay varied from 10.6 to 19.3 inches under a line-source sprinkler for the 1999 season in a high elevation, 6800 ft abv. msl, mountain valley north of Randolph, Utah (Nicholas, 2001). Yield (at 12% moisture) of eight grass pasture varieties varied from 3.1 ton/acre (Crown Blend Perennial Ryegrass) to 5.8 ton/acre (Regar Meadow Brome) and averaged 4 ton/acre in the well watered plots with recommended nitrogen fertilizer levels. Pasture grass water use averaged 4.6 inches per ton/acre and was higher (6.2 inches per ton/acre) at lower yield levels and less (3.3 inches per ton/acre) at the highest yield.

Other Evapotranspiration Studies

Consumptive use of field alfalfa was determined from soil water budget accounting in selected farm fields in Southern Utah (Keller, 1982, Hill, 1983). Estimated alfalfa water use varied from 6 to 34.5 inches and averaged 25.7 inches, excluding the lowest value. The average yield, excluding the lowest value, was 5.5 ton/acre which was slightly higher than the county average. The relationship between field alfalfa yield and ET (Yield = -0.765 + 0.243ET, rsq = 0.74) is shown in Figure H2. Estimated ET from this equation is 25.8 inches at a yield of 5.5 ton/acre, which is equivalent to 4.7 inches per ton/acre. Also shown in Fig. H2 are the Kimberly, ID lysimeter and earlier Hanks and Retta yield versus ET equations and data. A value of alfalfa water use of 4.7 inches per ton/acre generally fits in between the Kimberly and Utah farm fields yield and ET relationships for yields greater than 4 ton/acre. Whereas, the Hanks and Retta yield vs. ET equation is essentially an upper envelope line for the highest yield values relative to ET.

Recently, Lindenmayer, et.al. (2011) compiled alfalfa water use efficiency (WUE) data from a number of studies in the mid-west and intermountain areas of the U.S. They found that the regional average water-use efficiency (WUE) was 0.16 Mg/ha per cm which equivalent to 0.18 ton/acre per inch or, reciprocally, 5.5 inches of ET per ton/acre.

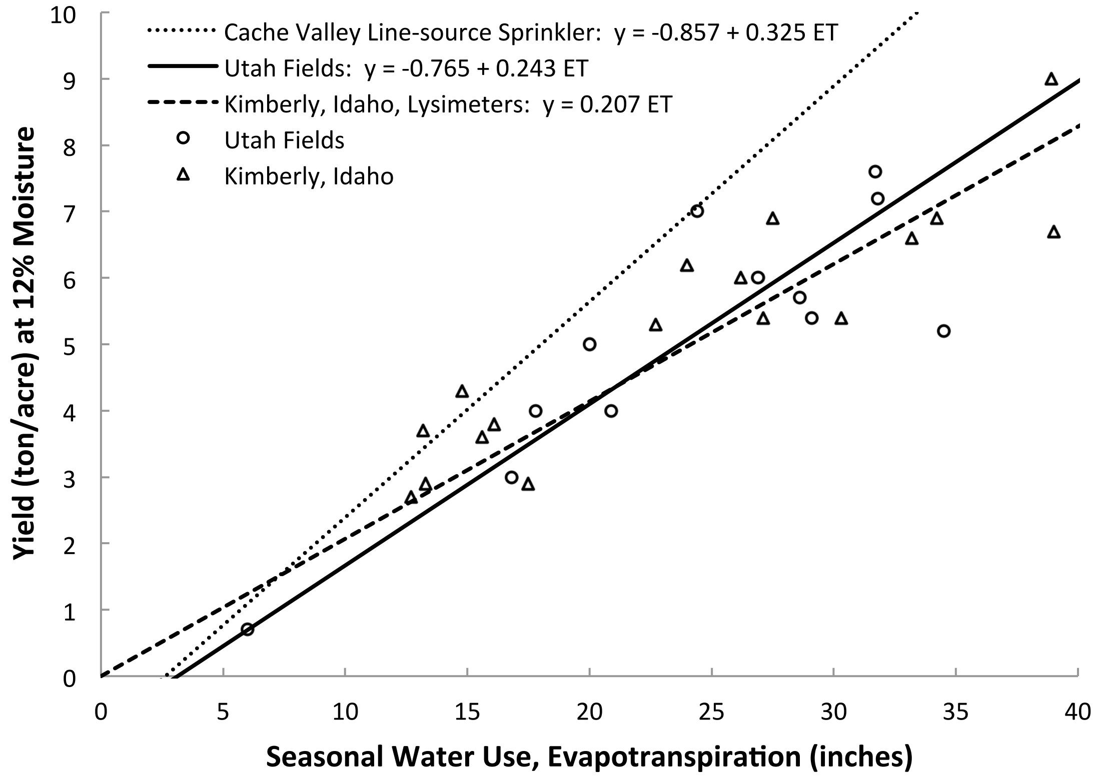


Figure H2. Alfalfa Yield related to ET for Southern Utah Farm Fields, Lysimeters in Kimberly, Idaho and Line-Source Sprinkler in Cache Valley, Utah (various years).

Alfalfa ET in Non-Ideal Conditions

The reference ET and alfalfa crop coefficients used herein were developed using data from carefully managed experiment plots. Barker (2011) measured ET over a center pivot irrigated alfalfa field in Curlew Valley, Box Elder County, Utah in 2009 and 2010. The alfalfa stand was 9 years old in 2009. Actual ET over the old stand alfalfa, which, excepting its age, had been well managed, was 13% less in 2009 and 10% less in 2010 than was estimated using ET_{rs} with a similar alfalfa K_{cm} as was used in the current study. Barker's measurements were only taken during the 2nd and 3rd cutting cycles, however his study provided evidence that crop ET under actual field conditions may differ from those on experiment plots.

The alfalfa ET - yield relationship reported by Barker (2011) for the alfalfa stand in Curlew Valley was 6.8 inches per ton/acre for combined 2nd and 3rd crops in 2009 and nearly 17.7 in 2010. This is significantly more than the 5 inches per ton/acre typical in the previously cited studies. The high ET-yield relationship was primarily due to poor yields (2.1 ton/ac for combined 2nd and 3rd crops in 2009 and 0.9 in 2010). The season total yields were 4.2 and 2.1 ton/ac in 2009 and 2010, respectively. These low yields were a result of age related stand thinning. Jia et al. (2009)

found that water use efficiency (yield/ET) decreased with alfalfa stand age for dry-land alfalfa in China. This was due to decreased yields, not increased ET.

Although the ET - yield relation reported by Barker was relatively high, total ET at 13.9 inches for combined 2^{nd} and 3^{rd} crops in 2009 and 16.0 inches in 2010 was less than would be expected if the crop had been growing in ideal conditions for the area. High yields for that area were reported to be about 6.8 ton/acre (Al Dustin, Personal Communication June 8, 2011). Assuming that 2^{nd} and 3^{rd} crops represented half of that yield, which may be a low estimate, and using the 5 inches per ton/acre rule for alfalfa in ideal conditions, expected ET for 2^{nd} and 3^{rd} crops would be about 17 inches.

Open Water Surface Evaporation

Evaporation from Bear Lake near Lifton, ID was measured through the use of energy balance techniques (Bowen Ratio and Eddy Covariance) during the 1993 and 1994 summers by Amayreh (1995). He found that evaporation averaged 1.9 mm/day from August 17 through October 22, 1993 for a total of 130 mm (5.1 inches) and 2 mm/day from March 3 through October 26, 1994 for a total of 480 mm (18.9 inches). Bear Lake is classified as a deep lake, which may explain the seemingly low values.

The USGS conducted energy budget studies in the mid 1980's of open-water evaporation in humid areas at Williams Lake, Minnesota (Winter, et. al. 1995) and Mirror Lake, New Hampshire (Winter, et.al. 2003). Both were situated in mountainous and forested sites. Williams Lake, about 1200 ft wide by 3200 ft long with an average depth of about 10 ft and area of 90 acres, was selected in part due to average annual precipitation being approximately equal to evaporation. Whereas, annual precipitation at Mirror Lake, about 1100 ft wide by 1900 ft long with an average depth of about 19 ft and area of 37 acres, was about 2.5 times evaporation.

Monthly evaporation varied from 2 inches (Sep 1982) to 4.7 inches (Jul 1983) and seasonal, May-Sep, evaporation varied from 15 (1985) to 17.6 inches (1986), average of 16.5, at Williams Lake. Evaporation computed by a Penman equation, 1963 version, with modified wind term ($0.5 + .01\ U_2$) ranked in the top three estimating methods in comparison with the energy balance method.

Seasonal, Jun-Oct, evaporation varied from 12.6 (1984) to 16.2 inches (1987) with a six year (1982-1987) average of 16.2 inches, at Mirror Lake. Monthly evaporation varied from 0.8 inches (Oct 1984) to 4.2 inches (Jul 1985). The Penman equation was in the top six estimating methods in comparison with energy balance evaporation (Rosenberry, et.al. 2007).

A water budget study of the hydrology of Utah Lake, reported by Fuhriman, et.al. (1981), indicated that annual evaporation for this 90,000 acre lake was about 45 inches. Seasonal, April-October, evaporation averaged 41 inches and was 39.3 and 43.8 inches, respectively in 1971 and 1972. The Class A pan coefficient for the Lehi, UT evaporation pan varied from 0.70

(Apr) to 0.91 (Aug) and averaged 0.80. This value is higher than the 0.70 typically assumed and may be due to the pan being at the downwind, north, end of the lake. The average depth of Utah Lake is about 9 ft, thus, it is considered to be a shallow lake.

Evaporation studies on Lake Hefner, a 2,270 acre reservoir near Oklahoma City, OK, were conducted by the USGS, Bureau of Reclamation, and other government agencies for the period May 1950-August 1951 (Harbeck, et.al. 1954). Lake Hefner's average depth was about 27 feet. The water budget method of estimating evaporation was used as the basis for comparison of other methods. Annual, 12 month, total evaporation varied from 52.2 inches, July 1950 – June 1951 to 54.3 inches, September 1950 - August 1951.

Adjustments to Wetland ET and Open Water Surface Evaporation

Estimates of evaporation from shallow water bodies and of evapotranspiration for wetlands of small (less than 1/4 acre) and large (20 acres or more) areal extent are given in Tables 14-23 herein. These wetland ET values are based on the assumption that the surrounding area is irrigated land, particularly in the prevailing upwind (or fetch) direction. If the surrounding area is dryland (rainfed only) adjacent to the wetland vegetation, then an upward adjustment (adapted from Allen, 1995) varying from 109% to 132% should be made for large and small areas, respectively. A linear interpolation may be used for in-between surrounding conditions and areal extent and intermediate vegetation height. This adjustment should be applied to the ET value prior to subtracting effective precipitation for estimating depletion.

Deep open water surface evaporation values, denoted "Open Water Deep", shown in Tables 14-23 herein apply to a large deep lake such as Bear Lake. "Open Water Shallow" evaporation applies to shallow water bodies which have a water surface area of 40 acres or larger. Utah Lake is an example of a "shallow" water body.

Adjustments to shallow open water evaporation for areas less than 40 acres should be made using the following factors:

Area, acres:	2	5	10	20	40
Area Adjustment Factor, Fea	1.35	1.23	1.15	1.07	1.00

Open water surface depletion adjusted for area is calculated as:

Open Water Depletion = Fea x Evaporation - Seasonal Precipitation

Where, Open Water Depletion is depletion from open water surface evaporation, inches; Fea is the evaporation area adjustment factor (after Lakshman, 1972); and Seasonal Precipitation is the total seasonal precipitation for the water year evaporation season (generally October plus April-September), inches.

County Alfalfa Yields

County average alfalfa yields were obtained from the Utah Agricultural Statistics and from local sources. Local reported yields were always greater than the county average values in the Utah agricultural statistics reports (Table H4). State-wide better than average high alfalfa yields (attainable three out of five years with better than average management) were 60% more than the agricultural statistics 2007-2010 mean and near perfect condition high yields (attainable one year out of ten, second year stand with near perfect weather, pest control, fertility and water supply) were about 82% greater. County better than average (BTA) high yields varied from 4.5 ton/acre, Rich, San Juan, Summit and Wayne, to 8 ton/acre, Washington. Whereas, near perfect condition (NPC), yields varied from 5 ton/acre, Summit to 9 ton/acre, Washington. The statewide BTA average high alfalfa yield was 6.1 ton/acre and the corresponding NPC average high yield was 6.9 ton/acre for those counties with a reported value.

Alfalfa ET Relative to Yield Relationship

Higher yields are generally associated with higher amounts of crop available soil water and, consequently, greater ET (for example, Figures H1 and H2, above). Associated with this yield ET relationship is the concept of crop water use per unit yield, i.e. expressed as inches per ton/acre, which is the reciprocal of water use efficiency (WUE). For alfalfa the value of ET per unit yield varies from about 4 to 6 inches per ton/acre and is generally greater at lower elevations and lower latitudes than at higher elevation and higher latitude sites. Values of alfalfa ET per unit yield from Table H1 and from the above text are shown in Figures H3 and H4. Alfalfa ET per unit yield (inches per ton/acre) with respect to elevation displayed a trend of lower values with increasing elevation (Fig H3). Alfalfa ET per unit yield was greater at lower latitudes than at higher latitudes (Fig. H4). There was a stronger correlation with latitude than with elevation.

The combined relationship of alfalfa ET per unit yield with both elevation and latitude (R^2 of 0.49) was:

$$\text{Alfalfa ET inches per ton/acre} = 12.49 - 2.978\text{E-4 Elev} - 0.1604 \text{ Lat} \qquad \text{(H1)}$$

where Elev is the site elevation, ft abv. msl and Lat is the site latitude, decimal degrees.

Table H4. Alfalfa Hay Yields from Utah Agricultural Statistics and Local Reports

County	Area	1980-2010 Mean	2007-2010 Mean	Local Reported Yields: Better than Average Range		Local Reported Yields: Near Perfect Conditions High
				Low	High	
		ton / acre				
Beaver	Beaver	4.0	4.0	4.5	5.0	6.0
	Milford Flat			5.5	6.0	7.0
Box Elder	Tremonton	3.8	3.9	5.5	6.5	7.5
	Snowville			4.5	5.5	6.5
Cache		3.5	2.9	5.5	6.5	7.5
Carbon		2.8	2.1	5.5	6.0	6.5
Daggett		4.3	4.6	4.5	5.0	5.5
Davis		3.6	3.5	6.0	7.0	8.5
Duchesne		3.4	3.2	5.0	6.0	7.0
Emery	Castledale	3.2	3.1	5.0	6.0	6.5
	Green River			5.5	6.5	7.0
Garfield		4.2	4.1	4.5	5.5	6.3*
Grand	Moab	4.7	5.1	5.0	6.0	7.0
	Castle Valley			5.5	6.5	7.8
Iron		3.8	4.3	5.5	6.0	7.5
Juab		3.5	3.2	6.0	6.5	7.0
Kane		4.6	5.0	3.8	7.3	8.3*
Millard		3.3	2.9	7.3	7.5	8.6*
Morgan		3.4	3.4	4.5	5.5	6.5
Piute	Circleville	2.8	2.6	4.5	5.0	5.5
Rich		4.2	4.2	4.2	4.5	5.1*
Salt Lake	Riverton	2.6	2.2	6.5	7.0	8.0
San Juan	La Sal	4.1	4.0	3.5	4.5	5.5
	Blanding			6.0	6.5	6.8
Sanpete	Manti	4.5	4.5	6.0	6.3	7.1*
	Gunnison			6.3	6.8	7.7*
Sevier		2.8	2.5	5.5	6.5	7.5
Summit	Kamas	3.8	3.7	3.5	4.5	5.0
Tooele		3.9	4.1	6.0	7.0	8.0*
Uintah		4.5	4.7	6.0	7.0	7.8
Utah		3.8	3.6	5.5	6.0	7.0
Wasatch		4.7	4.6	4.8	5.1	5.8

Table H4. Continued. Alfalfa Hay Yields from Utah Agricultural Statistics and Local Reports

County	Area	1980-2010 Mean	2007-2010 Mean	Local Reported Yields		
				Better than Average Range		Near Perfect Conditions High
				Low	High	
		ton / acre				
Washington	Washington Fields	3.6	4.1	7.0	8.0	9.0
	Hurricane			6.5	7.0	7.5
Wayne	Bicknell	4.4	4.2	4.3	4.5	5.5
Weber		3.8	3.8	6.0	7.0	8.0
Maximum		4.70	5.10	7.25	8.00	9.00
Minimum		2.60	2.10	3.50	4.50	5.00
Average		3.78	3.80	5.30	6.11	6.90
St Dev		0.60	0.78	0.93	0. 91	0.98
Ratio to 2007-2010 Mean		0.995	1.000	1.394	1.608	1.815
Ratio to BTA High		0.619	0.622	0.867	1.000	1.142
Ratio to Near Perfect		0.548	0.551	0.768	0.886	1.000

Notes: 1980-2010 and 2007-2010 mean yield values are from Utah Ag Statistics Reports. Local reported yields are from farmers, USU Extension county agents and Utah Technology College's Farm/Ranch Management Program. * denotes value estimated from Better than Average (BTA) High yield and ratio of Near Perfect High Yield to BTA High (1.142).

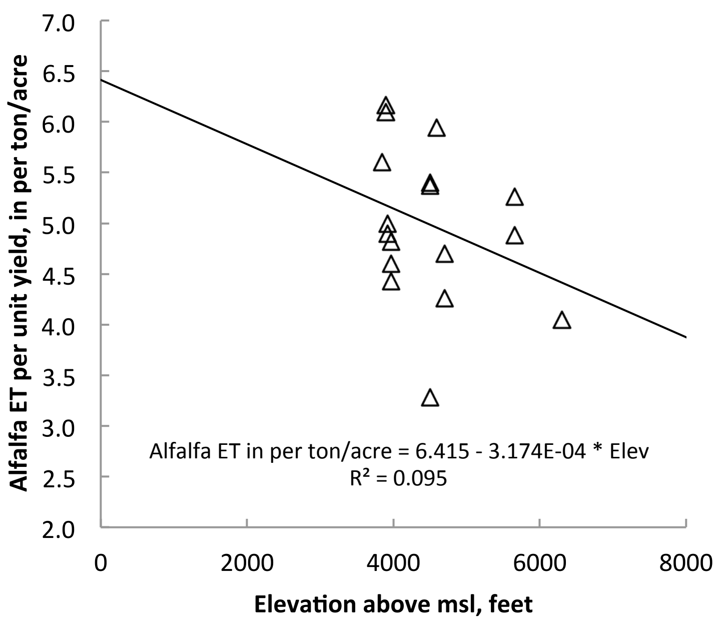


Figure H3. Variation of Alfalfa ET per Unit Yield (inches per ton/acre) with Elevation

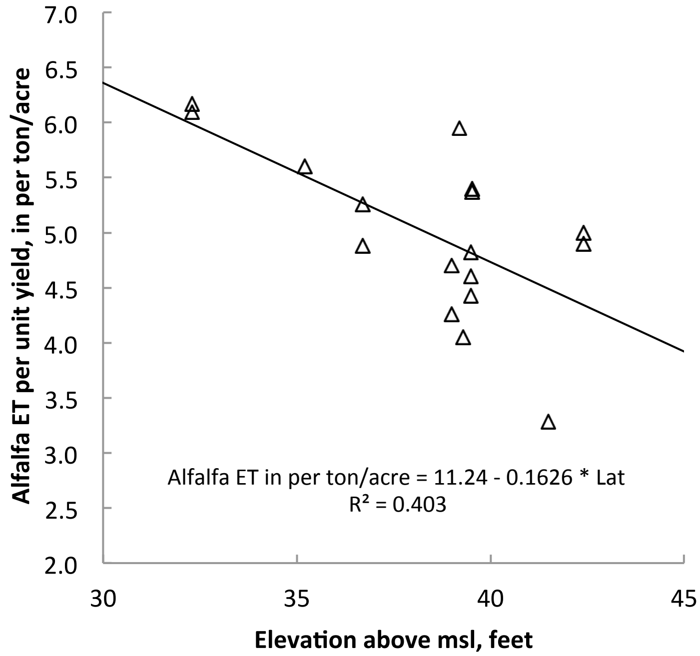


Figure H4. Variation of Alfalfa ET per Unit Yield (inches per ton/acre) with Latitude

Alfalfa water use varied from 4.5 to 6 inches per ton/acre, respectively, from high (cool mountain valleys) to lower elevation (and warmer) areas. For example, in Rich, San Juan (LaSal), Summit and Wayne Counties the reported BTA high alfalfa yields were 4.5 tons/acre (Table H4). This is equivalent to an ET of about 20.3 inches (20.3 = 4.5 x 4.5). Similarly, expected alfalfa ET in Cache, Duchesne, Juab, Tooele and Uintah Counties would be 33.6 inches (35 = 7 x 4.8), whereas, in Washington County (Hurricane area) ET could be about 45 inches (45 = 7.5 x 6). The yield value of 9 ton/acre shown in Table H4 for Washington Fields may be an overstatement.

Summary – Expected ET for Better than Average Conditions

Calculated ET and evaporation values contained herein for the NWS stations were generally compared with corresponding values shown in Table H5. Equation H1 was applied to the county BTA and NPC high yields to derive reasonable values for validating calculated alfalfa (beef) ET. Alfalfa ET was used as a “bellwether” or indicator of reasonableness of calculated crop ET. Thus, more particular notice was given to alfalfa water use (inches per ton/acre) as a means of evaluating the calculated values.

Table H5. Summary Field Measured Consumptive Use and Open Water Evaporation and ET per unit Yield for Various Crops in Utah and the Western U.S.

Crop	Condition	Consumptive Use Range, inches		ET/Yield, inches per ton/ac
		Low	High	
Alfalfa	Elev > 5500 ft			4.5
	3900 ft < Elev < = 5500 ft			4.8
	Elev < = 3900 ft			6.0
Alfalfa	Line Source Sprinkler	30.6	33.4	4.4
Corn	Line Source Sprinkler	19	27	
Other Hay	Upper Bear River	22	26	
Improved Grass Pasture Hay	Rich County, UT		19.3	4.6
Phreatophytes	Cache Valley Cattail	36.5	37.2	
	Cache Valley Bulrush	39.7	40.7	
Potato	Line Source Sprinkler	21.7	26.1	
Sp Wheat	Line Source Sprinkler	20	22 (24)	
Turfgrass	Lysimeter, N. UT	22.2	35.2	
Turfgrass	Lysimeter, St. George	35.5	50.0	
Open Water	Bear Lake 1994, Mar-Oct		18.9	
Open Water	Utah Lake 1971-72, Apr-Oct	39.3	43.8	
Open Water	Lake Hefner, OK, annual	52.2	54.3	
Open Water	Small mtn. lakes in MN and NH, seasonal, Jun-Oct and May-Sep.	12.6	17.6	

Note: There is an indication that alfalfa ET per ton/acre at the highest yield levels is less than shown. Line source sprinkler data are from Kimberly, ID and Kaysville and Logan, UT, 1980-1982.

UtahStateUniversity
UTAH AGRICULTURAL EXPERIMENT STATION