Canadian Water Resources Journal / Revue canadienne des ressources hydriques

ISSN: 0701-1784 (Print) 1918-1817 (Online) Journal homepage: http://www.tandfonline.com/loi/tcwr20

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To cite this article: B. Grace & B. Quick (1988) A Comparison of Methods for the Calculation of Potential Evapotranspiration Under the Windy Semi-arid Conditions of Southern Alberta , Canadian Water Resources Journal / Revue canadienne des ressources hydriques, 13:1, 9-19, DOI: 10.4296/cwrj1301009

To link to this article: http://dx.doi.org/10.4296/cwrj1301009

A Comparison of Methods for the Calculation of Potential Evapotranspiration Under the Windy Semi-arid Conditions of Southern Alberta

B. Grace[1] and B. Quick[1]

Abstract:
Eight different, commonly used methods of calculating potential evapotranspiration (PE) were compared under different climatic conditions at the Agriculture Canada Research Station in Lethbridge, Alta. Under conditions of low wind speed and moderate humidity the methods produced similar results. However, under dry windy conditions estimates of PE differed widely. Equations that require the use of wind and especially humidity data as well as temperature and radiation data are recommended for estimates of PE in the chinook-dominated semi-arid climate of southern Alberta. Examination of two soil moisture models (SPAW and DBSW) demonstrated that simulation models often have specific requirements for type of PE estimate.

Résumé:
Huit (8) méthodes différentes, couramment utilisées pour le calcul de l'évapotranspiration potentielle (EP), ont été comparées dans diverses conditions climatiques, à la station de recherche d'Agriculture Canada, à Lethbridge, en Alberta. Dans des conditions de vent à faible vitesse et d'humidité modérée, les méthodes ont produit des résultats similaires. Toutefois, dans des conditions venteuses et de temps sec, les estimations d'EP ont varié considérablement. Pour évaluer l'EP dans le climat semi-aride dominé par le chinook du sud de l'Alberta, on recommande d'utiliser des équations avec des données sur les vents et spécialement l'humidité, ainsi que des données de température et de radiation. L'étude de deux modèles d'humidité des sols (SPAW et DBSW) a prouvé que les modèles de simulation requièrent souvent des conditions particulières pour ces estimations d'EP.

Introduction

The use of computer models in agriculture to simulate field conditions is widespread. Most of the models currently used on an operational basis in southern Alberta for soil moisture evaluation, crop yield prediction, irrigation scheduling, hydrological studies, etc., employ the widely accepted concept of potential evapotranspiration (PE) as the driving function for the calculation of field evaporation.

PE may be defined as the evaporation from an extended surface of short green crop that fully shades the ground, exerts little or negligible resistance to the flow of water, and is always well supplied with water (Rosenberg, 1974). There are several methods of calculating PE and the methods generally yield similar although not identical results. The more common methods in use in western Canada include some adaptation of the Priestly-Taylor formula, Baier-Robertson formulae, and the Jensen-Haise equation. Real evapotranspiration cannot exceed and is usually less than PE. Evaporation from a Class A Evaporation Pan is always greater than PE. The reasons for these differences are best explained by reference to the conditions imposed by the definition of PE and an analysis of the reality of these conditions.

Direct and indirect methods of measuring evapotranspiration, which are costly and time consuming, are reviewed in detail by Brutsaert (1982). However, estimates of evapotranspiration based on readily available climatological data are possible by employing the concept of PE. This concept is widely accepted and was first proposed by Thornthwaite (1944, 1948). He suggested that transpiration from vegetation plentifully supplied with water would proceed at a rate governed by the characteristics of the atmosphere. Indeed, Thornthwaite's original

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[1] Agriculture Canada Research Station, Lethbridge, Alberta, Canada, T1J 4B1.

concept was that PE would be equal to consumptive use in irrigated agriculture. From the definition of PE, the variation in evaporation resulting from the vegetation component was minimized by specifying an actively growing and complete canopy closure of low height. The effects of soil-water content on evaporation were standardized by requiring that the soil be plentifully supplied with water. The problems in utilizing the PE concept are related to the imprecise nature of the definition. The PE concept is an abstraction; PE rates need not, and indeed, seldom do prevail in nature.

The availability of water at the evaporating surface and the concentration of water vapour in the atmosphere dictate the rate of evaporation. If water is added to surfaces by irrigation or precipitation, essentially all variability associated with the availability of water is eliminated. Since the effects of vegetation on the evaporation rate from well-watered surfaces appear to be essentially similar (Gay, 1981), many studies have sought to estimate evaporation solely from properties of the atmosphere.

A variety of models exists for the calculation of PE based almost entirely upon atmospheric variables. The ability of these models to produce consistent and meaningful PE estimates depends on their treatment of atmospheric factors. However, a comparison of the various methods of calculating PE has not been made for the agriculturally important and climatically unique area of southern Alberta (Grace and Hobbs, 1986). Here the climate is dominated by chinook winds. It is the intent of this paper to review and compare the most common methods of calculating PE currently in use in southern Alberta. The wide variety of models proposed for estimating PE are not reviewed in detail here. Doorenbos and Pruitt (1975), for example, identified 40 formulae for estimating potential and actual evapotranspiration from irrigated crops. No new methods or formulations for the calculation of PE are presented here.

PE Models

The problems associated with the concept of PE are related to the imprecise nature of the definition. Since the concept of PE is an abstraction, there is no reference standard to determine true PE values. The lack of a suitable reference makes it difficult to test the various approaches to estimating PE. Nearly all formulations for estimating PE are empirical and depend on the establishment of a known correlation between evapotranspiration and one or more climatic variables such as temperature, humidity, windspeed and radiation. Some formulae relate evapotranspiration to direct observations from porous plate atmometers or pan evaporation. Almost all equations contain empirical coefficients that must be used to calibrate the models for local conditions. Each model for the estimation of PE has advantages and disadvantages.[1]

Thornthwaite

Thornthwaite (1944, 1948), using the strong correlation between radiation and mean air temperature, first proposed a model for estimating PE. He related PE (g cm^{-2} day^{-1}) to air temperature:

$$PE = (d/360)1.6(10T/I)^a \qquad (1)$$

where T is the monthly mean air temperature (°C), I is the heat index for the site, derived from long-term monthly air temperature, a is a function of I and d is the day length (h). The heat index, I, is the sum of twelve monthly indices, $i = (T/5)\ 1.514$. The coefficient $a = C1I^3 + C2I^2 + C3I + C4$ where $C1 = 6.75 \times 10^{-7}$, $C2 = -7.17 \times 10^{-5}$, $C3 = 0.01792$, and $C4 = 0.49239$.

Certain shortcomings are inherent in the method. Only day length and temperature are used as climatic inputs. Application of this method to short-time periods leads to significant errors. For example, Pelton et al. (1960) found that PE estimations based on short-term mean temperatures by this method are unreliable owing to the often excessive variation in mean temperatures. The failure of the Thornthwaite method over short time periods is attributed to the fact that short-term mean temperature is not a suitable measure of net radiation. Both PE and mean temperature are, however, correlated with net radiation over relatively long periods of time and hence, the Thornthwaite model has success on a long-term basis (Rosenberg, 1974). The use of the empirical method of Thornthwaite has declined in recent years as the availability of meteorological data required for more physically based methods (i.e. Penman, Priestly-Taylor) has increased. Certainly, for computer simulation models of soil moisture, irrigation scheduling, etc., which require PE estimations on a short-term basis, the Thornthwaite method is not recommended.

Pan Evaporation Model of Doorenbos and Pruitt (1975)

Gay (1981) suggests that a possible standard for PE is the evaporation rate, which is measured directly with an evaporation pan (Epan). The basic model:

$$PE = K_p(Epan) \qquad (2)$$

where K_p is a constant determined empirically, is a simple one. As PE rates differ from those of pan evaporation owing to oasis and clothesline effects, Doorenbos and Pruitt (1975) give guidelines for the appropriate reduction coefficients for a variety of climatic and site conditions.

Considering the accuracy, simplicity and the cost, Stanhill (1965) recommended the class A pan evaporation as the best method of estimating PE. Usually crop water use is 60–90% of pan evaporation in regions where advection of sensible heat is unimportant (Rosenberg, 1974). Thus, the relation between adjusted evaporation rates and PE from irrigated crops is quite good in temperate regions (Gay, 1981). The ratio of real evaportranspiration from well-watered crops to pan evaporation for class A pans over a range of sites is about 0.8 for grass and 1.0 for alfalfa (Pruitt, 1966).

The Jensen-Haise Model

Jensen and Haise (1963) developed a model to predict PE by combining the effect of temperature on evaporation rate with that of solar radiation.

$$PE = C_t(T_d - T_x)K_s/L \qquad (3)$$

where T is the average daily temperature (°C), T_x is a constant for a given location (see Jensen and Haise, 1963), K_s is daily solar radiation (cal cm^{-2} day^{-1}), L is latent heat of vaporization (585 cal/g), and C_t is a temperature coefficient that is approximately equal to the reciprocal of the mean temperature. C_t can be estimated by

$$C_t = 1/(27 + 7.3C_h) \qquad (4)$$

with

$$C_h = 50\ mb/e_2 - e_1) \qquad (5)$$

where e_2 and e_1 are the saturation vapour pressures (mb) at the mean monthly maximum and minimum air temperatures (°C) for the warmest month. For actual calculations, refer to Jensen and Haise (1963). The coefficients for C_t and C_h vary with elevation and atmospheric moisture content, as well as with temperature. The adjustments are presented by Jensen (1966). The Jensen-Haise method produces good results when applied to conditions where advection is minor.

The Statistical Method of Baier-Robertson

In a statistical study of six Canadian sites, Baier and Robertson (1965) presented the results of a correlation of eight climatic variables (maximum temperature, temperature range, wind, duration of bright sunshine, vapour pressure deficit, solar energy at the top of the atmosphere, day length, and total sky and solar energy on a horizontal surface) with latent evaporation as measured with black porous disk atmometers. Based on the equation of Holmes and Robertson (1958) for the conversion of latent evaporation to PE (eqn. 6), simple empirical estimates of PE are possible from readily available climatic data.

$$PE = 0.08636(LE) \qquad (6)$$

where LE is latent evaporation (Holmes and Robertson, 1958).

Baier and Robertson (1965) provide eight different equations for the estimation of LE from different combinations of climatic parameters with the appropriate regression coefficients ranging from R = 0.68 for three meteorological variables (Baier-Robertson equation I) to R = 0.84 for six meteorological variables (Baier-Robertson equation VIII). Baier-Robertson I and VIII are presented here in equations 7 and 8.

$$\begin{aligned} LE = {} & -87.02 + 0.928T_{max} + 0.933(T_{max}\text{-}T_{min}) \\ & + 0.0486K_a \qquad (7) \end{aligned}$$

and

$$\begin{aligned} LE = {} & -53.39 + 0.337T_{max} + 0.531(T_{max}\text{-}T_{min}) \\ & + 0.0107K_a + 0.0512K_s + 0.0977U \\ & + 1.77(e_a^* - e_a) \qquad (8) \end{aligned}$$

where LE is latent evaporation, T_{max} is maximum daily air temperature (°F), T_{min} is daily minimum air temperature (°F), K_s is the solar radiation measured at ground level (cal/cm²), U is wind run (miles), e_a^* is the mean daily saturation vapour pressure (mb), e_a is the mean daily vapour pressure (mb) and K_a is the solar radiation at the top of the atmosphere (cal/cm²) as given in the Smithsonian Meteorological Tables (Baier and Robertson, 1965).

The Penman Combination Equation

The model of Penman (1948) is probably the most widely known PE estimator. Penman's equation has a sound physical basis. In contrast to the pan observations and the empirical models, the Penman model is based on a simplified radiation budget. The formula requires observations of net radiation, wind, temperature, and humidity. In the manner of Doorenbos and Pruitt (1975), Penman's model may be written as

$$PE = S/(S + \gamma)[Q^* + f(u)\,(e_a^* - e_a)] \qquad (9)$$

where S is the slope of the saturation vapour pressure-temperature curve, γ is the psychrometric constant, e_a^* is saturation vapour pressure of the air (mb), Q^* is net radiation (cal/cm^2) and f(u) is a wind function that approximates the diffusivity of the atmosphere near the ground and is given by

$$f(u) = 0.27\,(1 + u/100) \qquad (10)$$

were u is the 24-hr wind run in km (Doorenbos and Pruitt, 1975). The weighting factor $(S/(S+\gamma))$ is the same as in the Priestly and Taylor formula (see eqn. 12) and expresses the relative importance of the radiation and aerodynamic processes.

One of the major problems with the Penman model is the requirement for net radiation data. Unfortunately, net radiation data are not readily available for most locations. Net radiation has been measured at only six stations in the Canadian climatological network since 1965 (Selirio et al., 1971). For models that require estimates of net radiation such as the Penman model or the Priestly-Taylor model (see eqn. 12), daily net radiation (Q^*) can be calculated with Equation (11) (Jensen et al., 1970 as adapted by Doorenbos and Pruitt (1975) and Jury and Tanner (1975)).

$$Q^* = (1\text{-}r)K_S - \sigma T_a^4\,(0.34 - 0.44\,e_a^{1/4})\,(1 + 0.9\,K_S/K_a) \qquad (11)$$

where K_S is solar radiation, T_a is absolute air temperature, e_a is the water vapour pressure of the air, σ is the Stefan-Boltzman constant, K_a is maximum possible solar radiation, and r is the albedo, assumed to be 0.25 for a crop surface and 0.1 for a bare soil surface (Doorenbos and Pruitt, 1975). The actual vapour pressure e_a was calculated from the mean relative humidity and mean air temperature.

The Priestly-Taylor Correlation

The focus of the Priestly and Taylor (1972) model is the available energy (Q^*) or net radiation, the primary factor controlling PE from well-watered crops in most regions. If measurements of net radiation are unavailable, estimates may be made using equation 11. An empirical constant (a) and a temperature-dependent weighting factor $[S/(S + \gamma]$ are also required.

$$PE = a[S/(S + \gamma)]Q^* \qquad (12)$$

where a is a constant which must be obtained by local calibration (Priestly and Taylor, 1972).

The Selirio Adaptation of the Priestly-Taylor Correlation

Often measurements of global solar radiation are not available. Selirio et al. (1971) employed a regression equation utilizing solar radiation at the top of the atmosphere, duration of bright sunshine and daylength to provide an estimate of global solar radiation from which they calculate net radiation. Substituting this value in the Priestly-Taylor formula results in a functional equation:

$$PE = \frac{f(vp) \quad f(rdn)}{59} \qquad (13)$$

where (f(vp) and f(rdn) are the vapour pressure and radiation functions, respectively. The vapour pressure function is expressed in terms of the daytime mean temperature according to equation 14:

$$f(vp) = 0.516 + 0.02\,T_{dm} - 0.000152\,T_{dm}^2 \qquad (14)$$

where T_{dm} is the daytime mean temperature (°C). The radiation function is an estimation of net radiation based on the approximations of global solar radiation (Selirio et al., 1971):

$$f(rdn) = 0.52\,(0.23 + 0.57\,n/N)\,Q_a + 7.3 \qquad (15)$$

where N is daylength, n is bright sunshine hours, and Q_a is solar radiation at the top of the atmosphere (cal/cm^2).

The Advection-Modified Jury-Tanner Adaptation of the Priestly-Taylor Correlation

To account for the effects of high local advection on PE, Jury and Tanner (1975) proposed an advection-modified form of the Priestly-Taylor equation employing a vapour pressure deficit term and local calibration coefficient

$$PE = [1 + (a - 1)/(e_a^* - e_a)\,D_e]\,[S/(S + \gamma)]Q^* \qquad (16)$$

where D_e is the average vapour pressure deficit for the crop cycle. The quantities a and D_e must be obtained by local calibration (Jury and Tanner, 1975; Shouse et al., 1980).

Comparison of PE Models

Climatic data collected at the Lethbridge Research Station for 1983, 1984, and 1985 were used to calculate PE for each day of the growing season by eight different methods. The equations chosen for comparison included the methods of Penman, Jensen-Haise, Doorenbos-Pruitt, Priestly-Taylor, the Selirio adaptation of the Priestly-Taylor equation, the Jury-Tanner adaptation of the Priestly-Taylor equation, and two Baier-Robertson equations (I and VIII). Climatic data from a 21-day period in June 1984 were arbitrarily selected for the comparison of PE methods. In addition, 10 calm or light wind days and 10 windy days were selected from the 3-year period for PE estimations.

Class A pan evaporation is the only measurement of evaporation made on a regular basis. Other parameters such as temperature, radiation, wind speed, and relative humidity all affect the magnitude of pan evaporation. Analysis of daily PE values from 1983, 1984, and 1985 indicated that formulae based on only radiation and temperature, i.e., Jensen-Haise, Selirio adaptation of the Priestly-Taylor formula, and Baier-Robertson (I), were the most poorly correlated to pan evaporation (R^2 of 0.43 to 0.67). These models also produced the lowest estimates of seasonal PE for 1983, 1984, and 1985 (Table 1). Equations that required humidity and/or wind data were better correlated to pan evaporation with R^2 values ranging from 0.67 for the Penman formula to 0.96 for the Doorenbos-Pruitt equation. These latter models tended to yield higher estimates of seasonal PE.

Daily values of PE for a 20-day June period (1984) at Lethbridge indicate the disparity of the estimates of PE for eight different methods of calculation (Figure 1). Temperature, wind, humidity, radiation and class A pan evaporation data for this period are displayed in Figure 2. Under conditions of low wind (<500 km/day, wind run) and moderate relative humidities (45 to 85 percent RH), calculated values of PE ranged from 50 to

FIGURE 1: A comparison of class A pan evaporation and calculated values of potential evapotranspiration for June 10 to 30, 1984 for Lethbridge, Alberta. Pan evaporation ------; the different models of PE ________.

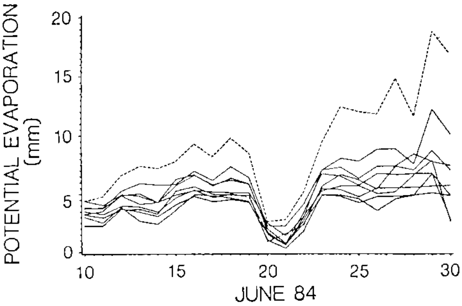
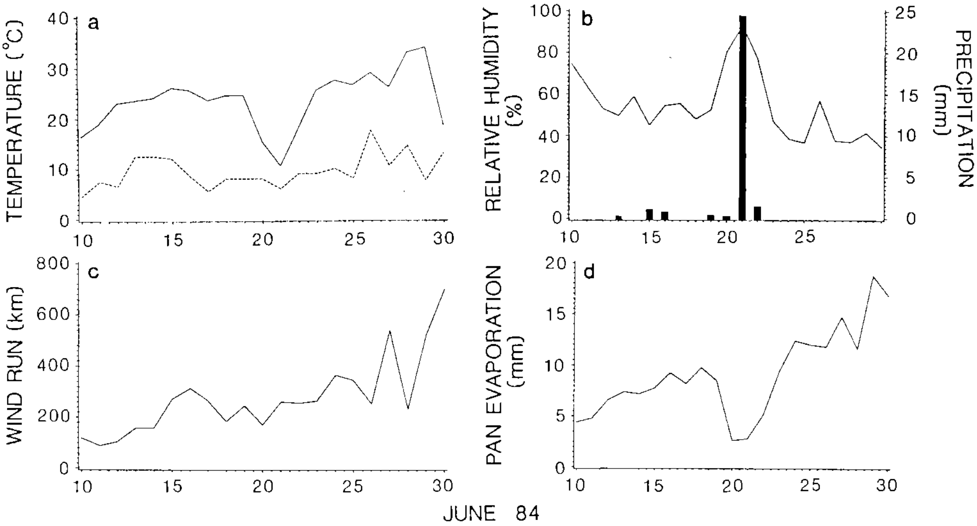
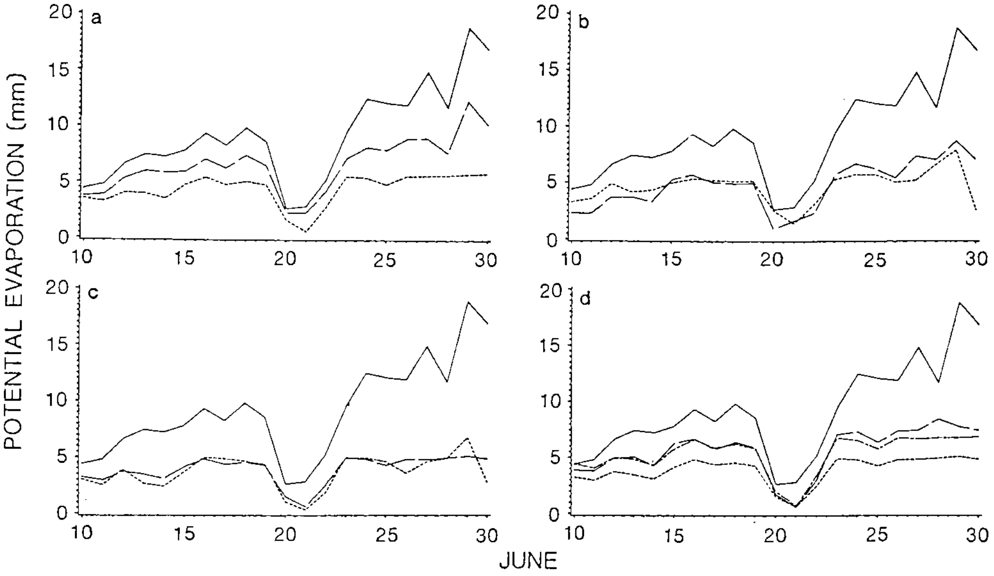


FIGURE 2: Maximum and minimum temperature, wind run, relative humidity, precipitation, and pan evaporation for June 10 to 30, 1984 for Lethbridge, Alberta.



80 percent of pan evaporation. This is illustrated in Figure 1 for the time period of June 10 to June 20, 1984. Cool temperatures, high humidities, and precipitation (24.4 mm on June 21) had the effect of depressing pan evaporation and calculated PE values on the 20, 21, and 22 of June. However, under conditions of high wind (>500 km/day, wind run) and lower humidities (<40 percent RH), estimated values of PE varied widely, ranging from 15 to 60 percent of pan evaporation. For example, the dry (35 percent RH) and windy (1126 km.day, wind run) conditions of June 30 resulted in calculated PE of 2.6 mm to 10.8 mm (Figure 3). Indeed, the increased variability of PE estimations under windy conditions at Lethbridge appears consistent.

FIGURE 3: A Comparison of Class A Pan Evaporation Measurements and Calculated Values of Potential Evapotranspiration for June 10 to June 30, 1984:
a. Pan ________, Penman Method . . . . . ., Doorenbos and Pruitt Method -----;
b. Pan ________, Baier and Robertson I . . . . ., Baier and Robertson VIII -----;
c. Pan ________, Seliro Adaptation of Priestly Taylor Method . . . . ., Jensen-Haise Method -----;
d. Pan ________, Priestly Taylor Method . . . . ., Selirio Adaptation of Priestly Taylor Method . . . . ., Jury Tanner Adaptation of the Priestly Taylor Method -----.



Estimations of PE for an arbitrary selection of 10 windy days compared with 10 days with low wind (<100 km/day, wind run) indicated that the values for days with little wind ranged from 0 to 4.8 mm per day, whereas the values for the windy days ranged from 0 to 7.9 mm per day (Figures 4 and 5). It should be noted that days with little wind also tended to be more humid with relative humidities of 60 to 76 percent, whereas windy days at Lethbridge typically are also dry days. The relative humidity for the 10 windy days selected here ranged from 27 to 50 percent.

Employing the pan evaporation method of Doorenbos and Pruitt (1975), a reduction of 55 to 85 percent was applied to pan evaluation data for Lethbridge according to these guidelines. Under most conditions (Figures 3a, 4a, 5a) the highest estimates of PE were calculated using this method. Thus, seasonal totals (Table 1) are also the highest of the models examined. Doorenbos and Pruitt (1975) suggest that pan exposure errors increase in arid climates, especially in windy regions. Undoubtedly, such is the case in the chinook-dominated semi-arid environment of southern Alberta.

FIGURE 4: A Comparison of Class A Pan Evaporation Measurements and Calculated Values of Potential Evapotranspiration for 10 Selected Windy Days:
a. Pan ________, Penman Method . . . . . ., Doorenbos and Pruitt Method -----;
b. Pan ________, Baier and Robertson I . . . . ., Baier and Robertson VIII -----;
c. Pan ________, Seliro Adaptation of Priestly Taylor Method . . . . ., Jensen-Haise Method -----;
d. Pan ________, Priestly Taylor Method . . . . ., Selirio Adaptation of Priestly Taylor Method . . . . ., Jury Tanner Adaptation of the Priestly Taylor Method -----.

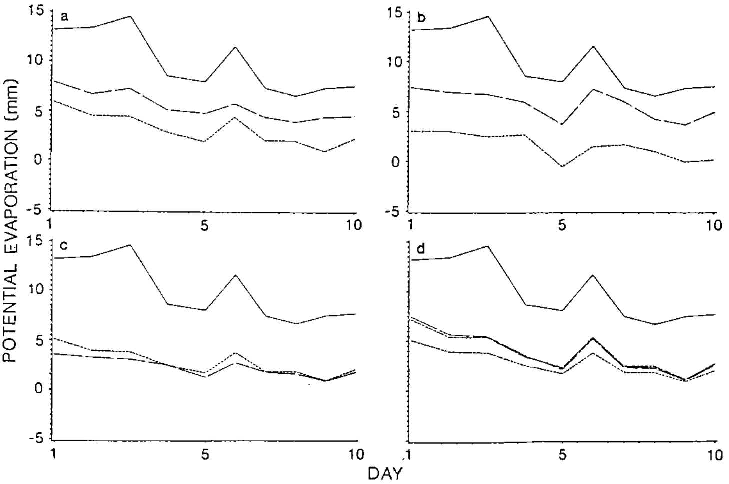
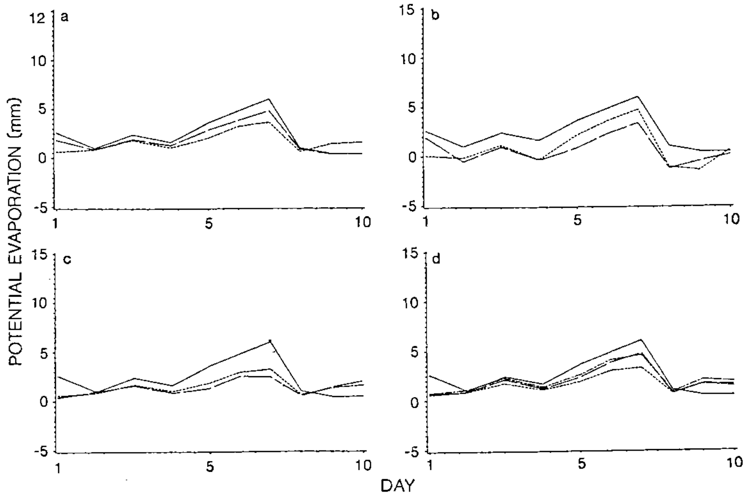


FIGURE 5: A Comparison of Class A Pan Evaporation Measurements and Calculated Values of Potential Evapotranspiration for 10 Selected Days with Little Wind:
a. Pan ________, Penman Method . . . . . ., Doorenbos and Pruitt Method -----;
b. Pan ________, Baier and Robertson I . . . . ., Baier and Robertson VIII -----;
c. Pan ________, Seliro Adaptation of Priestly Taylor Method . . . . ., Jensen-Haise Method -----;
d. Pan ________, Priestly Taylor Method . . . . ., Selirio Adaptation of Priestly Taylor Method . . . . ., Jury Tanner Adaptation of the Priestly Taylor Method -----.



The Jensen-Haise method for estimation of PE consistently gave lower values than other methods tested (Figures 3c, 4c, 5c) and thus the lowest estimation of seasonal PE with values ranging from 540 to 587 mm (Table 1). As atmospheric humidity and mixing processes affect the diffusion of vapour it is understandable that this method might underestimate PE under the dry windy conditions common in southern Alberta.

The Baier-Robertson equations utilized were the most simple, Baier-Robertson I with only three meteorological variables (eqn. 6) and the most complex, Baier-Robertson VIII with six meteorological variables (eqn. 6). Equation I yields lower estimates of PE than does Baier-Robertson VIII. The discrepancies are most apparent under windy conditions (Figures 3b and 5b) where values of PE with equation I are often less than half of those estimated with equation VIII. Under calm or low wind conditions, Baier-Robertson I estimates of PE exceeded those of Baier-Robertson VIII (Figure 4b). On a seasonal basis the simplest Baier-Robertson equation yielded low estimates of PE similar to the other temperature-radiation based models of Jensen and Haise, and the Selirio adaptation (Table 1). The Baier-Robertson VIII, however, produced seasonal estimates comparable to the Penman and Priestly-Taylor models.

TABLE 1: Accumulated Pan Evaporation and Potential Evapotranspiration (mm) for the 1983, 1984, and 1985 Growing Season.

	Year		
	1983	1984	1985
Pan Evaporation	1320	1334	1287
Doorenbos-Pruitt	964	937	896
Jury-Tanner Adaptation	831	779	773
Priestly-Taylor	817	746	745
Baier-Robertson VIII	711	702	738
Penman	665	610	610
Baier-Robertson I	639	619	589
Selirio Adaptation	600	549	548
Jensen-Haise	587	540	543

Although the regression coefficients suggested by Baier and Robertson (1965) have been uniformly applied to a wide variety of sites in Alberta (Lewis et al., 1987), the coefficients should be locally calibrated.

The PE estimations by the Penman method tended to be midway between the low values of the Jensen-Haise and Selirio adaptations of the Priestly-Taylor model, and the high values of the Jury-Tanner adaptation of the Priestly-Taylor formula and the Doorenbos-Pruitt method. Penman's model does not appear to be as sensitive to changes in humidity and wind as the advection-modified Jury-Tanner adaptation of the Priestly-Taylor formula.

The seasonal estimates of PE with the Priestly-Taylor model ranged from 745 mm in 1985 to 817 mm in 1983. These values were higher than the estimates from models that employed temperature and global radiation, i.e. Jensen-Haise, Baier-Robertson I. The Priestly-Taylor formula, however, does not react to changes in humidity and wind. For example, the increased wind and decreased humidity on June 29 and 30 (Figure 2) do not affect the PE estimates for these days (Figure 3d).

Values of PE estimated with the Selirio adaptation of the Priestly-Taylor formula were comparatively low (Table 1) and most closely approximated the values of the temperature-radiation model of Jensen-Haise (Figures 4c and 5c). Again, the effects of wind and low humidity are not accounted for by this method (Figure 3c). Estimates of PE with the Jury-Tanner adaptation, however, were consistently higher than those of the Priestly-Taylor equation alone (Table 1, Figures 3d, 4d, 5d) and indeed with the exception of the Doorenbos-Pruitt estimations, higher than the other models tested. The increases in estimated PE on June 29 and 30 (Figure 3d) are in response to a decrease in humidity.

The Use of PE in Simulation Models

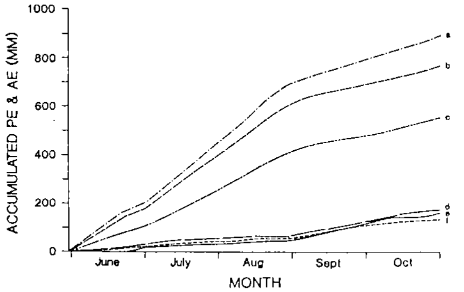
The concept of PE is widely used in simulation models for crop yield models, soil moisture models, hydrological studies, irrigation scheduling, etc. Many of these models have differing requirements for PE estimations. Although it is not possible to review all such models in this presentation, two soil moisture models are briefly discussed here as examples.

In prairie agricultural systems the practice of summer fallow is widespread as a management strategy for soil moisture conservation. Any attempt to estimate the time distribution of soil water within the upper soil profile under fallow must include consideration of surface evaporation rates and redistribution of soil moisture within the profile.

Many different approaches have evolved to describe the fate of water in the soil-atmosphere and the soil-plant-atmosphere systems. Most of these approaches have utilized the concept of PE as the driving function to estimate surface evaporation. Two such models are the diffusion-based soil water simulation model (DBSW) of Hayhoe and De Jong (1982) and the soil-plant-atmosphere-water model (SPAW) of Saxton et al. (1974). Different formulations of PE were used in the development of these models. PE as calculated by the Baier-Robertson is utilized in the DBSW whereas modified pan evaporation similar to the Doorenbos and Pruitt method is used in the SPAW model.

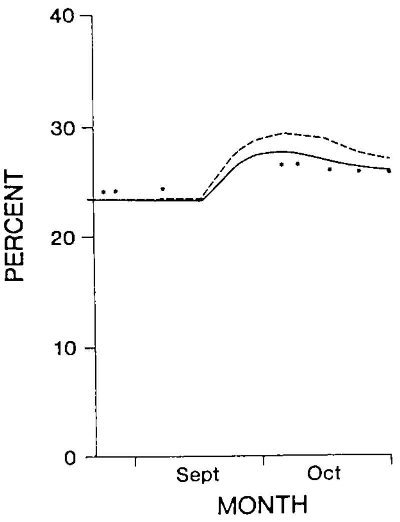
By altering the DBSW and SPAW models to remove the effects of a crop, it is possible to estimate soil water content and evaporation rates from a fallow field. Figure 6 depicts the accumulated PE values required for the two models and pan evaporation for June to October 1986 for Lethbridge as well as the observed and the simulated evaporation from a fallow field at Lethbridge. Although the Baier-Robertson and the adjusted pan methods yield very different estimates of accumulated PE, the models successfully simulate observed actual evaporation owing to the manner in which each model calculates surface evaporation (see Hayhoe and De Jong, 1982 and Saxton et al., 1984).

FIGURE 6: Accumulated Potential and Actual Evaporation from a Fallow Field for June to October 1986 where a is Pan Evaporation, b is PE (Doorenbos and Pruitt Adjusted Pan Method), c is PE (Baier-Robertson VIII Method), d is Calculated Evaporation (SPAW Model), e is Calculated PE (DBSW Model) and f is Actual Observed Evaporation (Determined by Mass Balance Method).



If, however, differing formulations of PE are used as the driving function for a specific model, different estimations of soil water content and surface evaporation are to be expected. For example, simulation of soil water content in a fallow field at the 30 to 60 cm depth for the month of September and October 1986 using the DBSW model and Baier-Robertson equations I and VIII yielded different estimates of percent soil water. The Baier-Robertson I equation (eqn. 7) does not respond to changes in atmospheric humidity and wind and as a result the low estimates of PE are reflected in a higher than observed soil water content. Under the conditions imposed by the DBSW model for the field under consideration, the model more successfully simulated observed conditions when Baier-Robertson VIII (eqn. 8) was used for PE estimation (Figure 7).

FIGURE 7: Observed and Calculated Soil Moisture (Percent) at the 30 to 60 cm Depth for a Clay-Loam Soil at Lethbridge, Alta. Under Fallow Conditions for September and October 1986. DBSW Model Employed for Prediction of Soil Moisture Utilized Precipitation and PE (Baier-Robertson I -----, Baier Robertson VIII ________) as the Driving Functions.



Summary

Many of the simulation models currently in use in Alberta accumulate PE totals to estimate the total evaporation from a site during a given period of time. This information is then used to make management decisions. The accumulated PE for the 21 days examined here ranged from a low of 75.0 mm as calculated with the Jensen-Haise method to a high of 138.1 mm with the Doorenbos-Pruitt formula. Discrepancies this large could have serious consequences for such applications as irrigation scheduling.

Examination of two soil moisture models (SPAW and DBSW) demonstrated that simulation models often have specific requirements for type of PE estimate. Some of the computer simulation models currently in use on an operational basis in the semi-arid windy environment of southern Alberta may be considerably underestimating evaporation by employing equations that do not account for advective energy input. PE equations that require wind and especially humidity data more correctly simulate real conditions in the chinook-dominated climate of southern Alberta.

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Footnotes

[1] Empirical coefficients required for the different methods of calculating Pe have been derived for specific units. For appropriate coefficients and units of calculation for each of the described PE models, the original authors should be consulted. Values of PE reported here for southern Alberta have all been converted to units of mm/day for presentation and comparison.