COMPARISON OF POTENTIAL EVAPOTRANSPIRATION MODELS AND SOME APPLICATIONS IN SOIL WATER MODELING

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Potential evapotranspiration (PET) estimates from adjusted Class A pan data, from three physically based combination models and from several versions of an empirical model were compared for selected regions in Canada. Both the Penman and the Monteith model provided reasonable PET estimates at all stations when compared to the adjusted Class A pan data. The size of the convective term at stations with large vapor pressure deficits and high windspeeds suggests that a constant proportionality factor of 1.26 in the Priestley-Taylor model is inappropriate. The empirical Baier-Robertson model appears to require regional calibration for improved PET estimates. Actual evapotranspiration (AET), as calculated with a diffusion based soil-water model and with a soil-water budget model, was insensitive to PET input, suggesting that the imposed soil and crop characteristics played a larger role in controlling AET than the PET regime.

INTRODUCTION

The concept of potential evapotranspiration (PET), defined by Penman (1956) as “the amount of water transpired in unit time by a short green crop, completely shading the ground, of uniform height and never short of water” has proven to be a useful one in agriculture and hydrology. Irrigation scheduling procedures, soil-water models and crop growth models generally first estimate PET from meteorological factors and then compute the amount of the potential that is utilized by the actual evapotranspiration (AET) process, given the current status of the plant, and soil-water related characteristics. Hydrologic models, concerned with stream flow forecasting, also require PET data. The effects of different PET estimates as input to crop growth models and hydrologic models have been addressed by Parmele (1977) and Dugas and Ainsworth (1985).

Direct measurements of PET from a full-cover, well-watered green crop can be made with either lysimeters (Harrold 1966) or with micro-meteorological techniques (Fritschen 1966; Goddard and Pruitt 1966). However, because these methods are time consuming and/or expensive, PET is generally estimated from standard meteorological data.

Measured evaporation from a standard Class A pan is one of the most common methods for estimating PET. Because evaporation from a pan is generally higher than that from a well-watered surface (Pruitt 1966), empirically derived coefficients (Kp) are required to adjust pan evaporation to PET. Although specific Kp values for application to any given situation or pan may have to be found by calibration, representative values from other studies can provide satisfactory results (Doorenbos and Pruitt 1977).

Physically based evapotranspiration models which incorporate both energy balance and aerodynamic principles are generally known as combination methods. Penman (1948, 1956) developed the first combination equation to calculate potential evaporation from an open water surface. With suitable refinements his model now represents one of the most reliable techniques for estimating PET from climatic data (Baier 1968; Shouse et al. 1980; Saxton and McGuinness 1982). Monteith (1965) generalized the Penman equation by specifying two resistances: (i) an aerodynamic resistance through the air to a reference height and (ii) a physiological resistance from evaporating surfaces (stomates) to the air. The aerodynamic resistance is related to windspeed and surface roughness parameters (Szeicz et al. 1969; Rittema 1970) while the physiological resistance depends on factors such as crop species, soil moisture availability, irradiance, humidity, etc. (Ziemer 1979).

Priestley and Taylor (1972) presented a simplified combination model by assuming that the radiant energy term of the original Penman formula is, by itself, equivalent to an equilibrium rate of evaporation and proportional to PET. Experimental evidence (Davies and Allen 1973; Clotier et al. 1982) has shown that the average proportionality constant in non-advective, potential conditions is 1.26.

Meteorological data required for physically based evapotranspiration models is often incomplete. Therefore, Baier and Robertson (1965) and Baier (1971) proposed a model for estimating daily PET from standard climatological observations using multiple-regression type equations. The regression coefficients in the model were derived from six stations located in central and western Canada. Although no maritime stations were included in the derivation of the coefficients, the model is extensively used throughout Canada, especially formula 1.

The objective of this paper is to present a comparison among computed PET values from (i) Class A pan data, (ii) the physically based combination models and (iii) the empirical Baier-Robertson equations. Long-term climatic data from selected regions in Canada will be used to analyze differences in the models. The effect of the PET model upon the estimation of actual evapotranspiration (AET), i.e. under soil water stress conditions, will be evaluated using a physically based soil-water diffusion model (Hayhoe and de Jong 1982) and a more empirical based soil-water budget model (Baier et al. 1979).

METHODOLOGY

Eight meteorological stations representing the main climatic regions as well as the agricultural areas of Canada (Fig. 1) were selected for this study. For each station mean daily Class A pan evaporation values were extracted from the Monthly Record of Meteorological Observations in Canada for the period 1962–1980. Monthly averages were multiplied by pan coefficients, selected following guidelines presented by Doorenbos and Pruitt (1977). Seasonal totals were then calculated for May through September.

Complete climatological records as required to calculate PET according to various models were not available for
many stations. Therefore, monthly climatic normals (1951–1980) of solar radiation, maximum and minimum air temperature, vapor pressure and windspeed were obtained from the Land Potential Data Base (LPDB) (Kirkwood et al. 1983). Since all records in the LPDB are identified by the soil map unit designations as found on the Soils Map of Canada (Clayton et al. 1977), only the data from those map units whose geographical center was within 50 km of the meteorological station were considered (Table I). Daily values of global solar radiation, air temperature, vapor pressure and windspeed were generated from the monthly normals using the Brooks (1943) sine wave interpolation technique for use in the models described below.

The net radiation flux, which is a required input for the physically based evapotranspiration models, was calculated from the radiation balance equation

\[ R_n = (1 - r) \times R_s - R_{in} \]  \hspace{1cm} (1)

where \( R_s \) is the incoming global solar radiation flux (obtained from the LPDB), \( R_{in} \) is the effective outgoing longwave radiation flux and \( r \) is the surface reflection coefficient (albedo). The latter was estimated to be 0.23, based on observed normal global solar and normal reflected solar radiation data (Environment Canada 1982).

The net longwave radiation flux was estimated using the empirical relationship (Jensen 1973)

\[ R_{in} = \epsilon \sigma T_e^4 \left( 1.1 \frac{R_s}{R_{so}} - 0.1 \right) \]  \hspace{1cm} (2)

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**TABLE I. SEASONAL CLIMATOLOGICAL CHARACTERISTICS AT THE STATIONS**

<table>
<thead>
<tr>
<th>Climatological characteristic</th>
<th>Vancouver UBC</th>
<th>Beaverlodge</th>
<th>Swift Current</th>
<th>Winnipeg</th>
<th>Harrow</th>
<th>Ottawa</th>
<th>Cookshire</th>
<th>Truro</th>
</tr>
</thead>
<tbody>
<tr>
<td>Map unit</td>
<td>G1017</td>
<td>B2011</td>
<td>A1098</td>
<td>A3107</td>
<td>G1007</td>
<td>G1002</td>
<td>D3137</td>
<td>C2114</td>
</tr>
<tr>
<td>Class A pan evaporation (mm day(^{-1}))</td>
<td>3.9</td>
<td>5.2</td>
<td>7.4</td>
<td>6.3</td>
<td>5.7</td>
<td>4.8</td>
<td>3.7</td>
<td>3.8</td>
</tr>
<tr>
<td>Global solar radiation (W m(^{-2}))</td>
<td>227.6</td>
<td>211.6</td>
<td>237.6</td>
<td>228.7</td>
<td>219.6</td>
<td>220.8</td>
<td>210.3</td>
<td>212.0</td>
</tr>
<tr>
<td>Mean air temperature (°C)</td>
<td>14.7</td>
<td>12.3</td>
<td>15.5</td>
<td>15.4</td>
<td>18.7</td>
<td>16.9</td>
<td>14.6</td>
<td>14.5</td>
</tr>
<tr>
<td>Vapor pressure deficit (Pa)</td>
<td>260</td>
<td>390</td>
<td>600</td>
<td>480</td>
<td>500</td>
<td>490</td>
<td>280</td>
<td>290</td>
</tr>
<tr>
<td>Windspeed at 2 m height (km.day(^{-1}))</td>
<td>188.8</td>
<td>239.0</td>
<td>377.9</td>
<td>299.9</td>
<td>224.6</td>
<td>192.9</td>
<td>206.6</td>
<td>212.5</td>
</tr>
<tr>
<td>Net radiation, Eq. 1 (W m(^{-2}))</td>
<td>127.9</td>
<td>119.0</td>
<td>133.9</td>
<td>129.3</td>
<td>126.7</td>
<td>125.7</td>
<td>118.6</td>
<td>119.4</td>
</tr>
</tbody>
</table>

Figure 1. Map showing sites selected for this study.
where \( \sigma \) is the Stefan-Boltzmann constant and \( T_s \), the air temperature in degrees Kelvin. Assuming that the emittance of a vegetated surface is 0.98 (Fuchs and Tanner 1966), then the difference in emittance between surface and atmosphere, \( \varepsilon' \), was calculated using Brutsaert's (1975) equation for atmospheric emissivity

\[
\varepsilon' = 0.98 - 1.24 (e/T_s)^{1/7}
\]  
(3)

where \( e \) is the vapor pressure, obtained from the LPDB.

The global solar radiation flux expected on a perfectly clear day, \( R_{so} \), was computed as

\[
R_{so} \approx 221.2 + 162.1 \sin(0.017 J + 4.956) \]  
(4)

where \( J \) is the Julian date and the argument of the function is in radians. Equation 4 was derived from data collected by Driedger (1969) at Winnipeg.

**Potential Evapotranspiration Models**

**Penman Model**

Penman (1948) combined the energy balance and the aerodynamic equations into a combination model

\[
\text{PET} = \frac{1}{L} \left[ \frac{\Delta (R_n - G) + \gamma E_a}{\Delta + \gamma} \right]
\]  
(5)

where \( L \) is the latent heat of vaporization, \( \gamma \) is the psychrometric constant, \( R_n \) is the net radiation flux (Eq. 1), and \( G \) is the soil heat flux. The latter was assumed to be negligible over the course of the growing season and was ignored in the calculation of PET.

The aerodynamic term, \( E_a \), was calculated according to

\[
E_a = 0.26 (u^2 + 0.0062 U^2) (e^* - e)
\]  
(6)

where \( u/2m \) is the windspeed at 2 m height. Windspeeds at 2 m were approximated from recorded ones at 10 m in the LPDB, using \( u/2m = 0.725 U/10m \).

Teten’s equation (Murray 1967) was used to calculate the saturated vapor pressure, \( e^* \), and its derivative, the slope of the saturation vapor pressures – mean air temperature curve, \( \Delta \).

**Monteith model**

Monteith (1965) modified Penman’s model by including an aerodynamic and a physiological resistance

\[
\text{PET} = \frac{1}{L} \left[ \frac{\Delta (R_n - G) + \rho_c (e^* - e)/r_a}{\Delta + \gamma (1 + r_s/r_a)} \right]
\]  
(7)

where \( \rho_c \) is the volumetric heat capacity of dry air, \( r_a \) is the aerodynamic diffusion resistance and \( r_s \) is the physiological resistance assumed to be 40 s m\(^{-1}\). The aerodynamic resistance was calculated using the method proposed by Thom and Oliver (1977)

\[
r_a = \frac{[4.72 \ln (200/z_0^2)] / (1.0 + 0.54 U)}{r_s}
\]  
(8)

where \( z_0 \), the surface roughness, was set at 1.0 cm and \( U \) is the windspeed expressed in m s\(^{-1}\).

**Priestley-Taylor model**

The Priestley and Taylor model (1972) was employed as a third method to compute potential evapotranspiration from combination theory

\[
\text{PET} = \frac{1}{L} \left[ \frac{\alpha \Delta}{\Delta + \gamma} (R_n - G) \right]
\]  
(9)

where the constant \( \alpha \) was assigned a value of 1.26.

**Baier and Robertson model**

Baier and Robertson’s (1965) multiple regression equations were used to calculate latent evaporation. Eight formulas provided the estimates which were based on extraterrestrial radiation, maximum air temperature and air temperature range (formula I) and also on wind, vapor pressure and solar radiation, if data for any one, two or three of these latter variables were available (formulas II–VIII). In this way, efficient use was made of all available meteorological data. A factor of 0.0094 cm cm\(^{-3}\), suggested by Baier (1971), was used to convert the results to PET.

**Calculation of Actual Evapotranspiration**

Daily potential evapotranspiration rates, calculated from the various PET models, were used as input to a diffusion-based soil-water model (Hayhoe and de Jong 1982) and a soil-water budget model (Baier et al. 1979). Daily precipitation data from 1 May till 30 Sept, for 1975 at Swift Current, for 1976 at Harrow and for 1952 at Tnro, obtained from the Monthly Record of Meteorological Observations in Canada, were also used as input.

In the diffusion-based model a 100-cm homogeneous soil profile was assumed to have the soil characteristics of a clay loam as described by Clapp and Hornberger (1978). A unit hydraulic gradient (free drainage) was applied across the basal boundary. Crop cover was assumed to be 95% throughout the season, and the root density function, RDF, was described by

\[
\text{RDF} = 6.0051 \exp (-0.02 Z)
\]  
(10)

where \( Z \) is the depth in centimetres below the soil surface. The initial volumetric water content of the profile was 40%, which corresponded to a soil water suction head of 16 kPa.

The Versatile Soil Moisture Budget (VSMB) was run with six standard zones and a total available soil-water-holding capacity of 165 mm. Empirical crop coefficients for brome grass were used. In the VSMB available soil water and the ratio of actual to potential evapotranspiration (AET/PET) were related by standard empirical curves. In this study curve G was selected, which assumed that the ratio AET/PET remained at unity from 100 to 70% available water, and reduced linearly for drying below this point to the permanent wilting condition. The soil profile was assumed to be at field capacity on 1 May, the date the runs were started.

**RESULTS AND DISCUSSION**

The climatological conditions at the stations, averaged over the period 1 May to 30 Sept., are presented in Table 1. Class A pan evaporation varied from 3.7 mm day\(^{-1}\) at Cookshire to 7.4 mm day\(^{-1}\) at Swift Current. Variations in the radiation data (global solar and net radiation flux, as calculated per Eq. 1) were relatively small among the stations, but larger variations occurred in mean air temperature, vapor pressure deficit and windspeed data. The stations on the prairies are characterized by high evaporation rates, large vapor pressure deficits and high windspeeds, whereas the maritime stations are characterized by low evaporation rates and small vapor pressure deficits.

In the Penman and Priestley-Taylor models, PET is solely determined by meteorological features, whereas in the Monteith model surface factors or crop characteristics also play a role. As the surface roughness, which is considered to be proportional to crop height (Tanner and Pelton 1960), increases, the aerodynamic resistance, \( r_a \), decreases and consequently the potential evapotranspiration rate increases. Influencing this relationship are the meteorological conditions themselves, as exemplified in Fig. 2 by the data from the stations at Vancouver UBC and Winnipeg, as well as the physiological resistance \( r_s \). For wet canopies \( r_s \) is thought to be negligible, but for a dry canopy, even when the crop is well supplied with water, a minimum physiological resistance should be introduced to avoid overestimations in PET (Bailey and Davies 1981). Apart from the soil moisture conditions, \( r_s \) is dependent upon crop species, stage of development and numerous environmental factors (Ziemer 1979). For grass well supplied with water, \( r_s \) values range from 26 to 60 sec m\(^{-1}\) (Szeicz and Long 1969; Russell 1980; De Bruin and Holtslag 1982). For this study an \( r_s \) value of 40 sec m\(^{-1}\) was selected. At this resistance the
TABLE II. ACCUMULATED POTENTIAL EVAPOTRANSPIRATION (IN MILLIMETRES FROM 1 MAY TO 30 SEPTEMBER)

<table>
<thead>
<tr>
<th>Model</th>
<th>Vancouver UBC</th>
<th>Beaverlodge</th>
<th>Swift Current</th>
<th>Winnipeg</th>
<th>Harrow</th>
<th>Ottawa</th>
<th>Cookshire</th>
<th>Truro</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted Class A pan</td>
<td>443</td>
<td>578</td>
<td>790</td>
<td>696</td>
<td>649</td>
<td>552</td>
<td>422</td>
<td>437</td>
</tr>
<tr>
<td>Penman</td>
<td>525</td>
<td>550</td>
<td>777</td>
<td>661</td>
<td>644</td>
<td>598</td>
<td>493</td>
<td>525</td>
</tr>
<tr>
<td>Monteith</td>
<td>510</td>
<td>549</td>
<td>801</td>
<td>661</td>
<td>660</td>
<td>604</td>
<td>474</td>
<td>501</td>
</tr>
<tr>
<td>Priestley-Taylor</td>
<td>537</td>
<td>488</td>
<td>590</td>
<td>559</td>
<td>578</td>
<td>555</td>
<td>503</td>
<td>496</td>
</tr>
<tr>
<td>Baier-Robertson I</td>
<td>516</td>
<td>513</td>
<td>687</td>
<td>624</td>
<td>633</td>
<td>629</td>
<td>572</td>
<td>586</td>
</tr>
<tr>
<td>Baier-Robertson II</td>
<td>504</td>
<td>477</td>
<td>626</td>
<td>579</td>
<td>582</td>
<td>572</td>
<td>509</td>
<td>518</td>
</tr>
<tr>
<td>Baier-Robertson III</td>
<td>437</td>
<td>510</td>
<td>703</td>
<td>602</td>
<td>581</td>
<td>597</td>
<td>492</td>
<td>516</td>
</tr>
<tr>
<td>Baier-Robertson IV</td>
<td>455</td>
<td>509</td>
<td>863</td>
<td>693</td>
<td>602</td>
<td>573</td>
<td>532</td>
<td>598</td>
</tr>
<tr>
<td>Baier-Robertson V</td>
<td>523</td>
<td>532</td>
<td>702</td>
<td>619</td>
<td>630</td>
<td>608</td>
<td>505</td>
<td>524</td>
</tr>
<tr>
<td>Baier-Robertson VI</td>
<td>465</td>
<td>475</td>
<td>788</td>
<td>643</td>
<td>582</td>
<td>525</td>
<td>477</td>
<td>523</td>
</tr>
<tr>
<td>Baier-Robertson VII</td>
<td>407</td>
<td>510</td>
<td>832</td>
<td>658</td>
<td>589</td>
<td>559</td>
<td>477</td>
<td>531</td>
</tr>
<tr>
<td>Baier-Robertson VIII</td>
<td>428</td>
<td>483</td>
<td>780</td>
<td>647</td>
<td>560</td>
<td>524</td>
<td>445</td>
<td>497</td>
</tr>
</tbody>
</table>

**Figure 2.** Potential evapotranspiration calculated with the Monteith model as a function of roughness length and physiological resistance ($r_p$).

Accumulated PET increased at a rate of 23 mm per centimetre increase in roughness length at Vancouver and at 65 mm per centimetre at Winnipeg (Fig. 2).

At all stations the monthly variation in pan coefficient ($Kp$), which was selected according to guidelines (Doorenbos and Pruitt 1977), was small. Seasonal mean $Kp$ values varied from 0.70 at Swift Current, 0.73 at Beaverlodge and Winnipeg to 0.75 at the remaining stations. Consequently the adjusted PET values from the Class A pan data varied less among the stations than the Class A pan data themselves.

Seasonal accumulated PET data calculated from the models are presented in Table II. Compared to the adjusted Class A pan, Penman's model estimated PET to within 5% at the drier stations where the daily average Class A pan evaporation exceeded 5.0 mm day$^{-1}$. Overestimations of approximately 20% were found at the maritime stations. The results from the Monteith model were similar to those from the Penman model, although the overestimates at Vancouver UBC, Cookshire and Truro were not as large. The differences in accumulated PET between Penman's and Monteith's model were small, varying from 24 mm at Truro to −24 mm at Swift Current.

The Priestley-Taylor model predicted accumulated PET values which were at least 15% below adjusted Class A pan evaporation data at Beaverlodge, Swift Current and Winnipeg and 15% above the adjusted Class A pan data from Vancouver UBC and Cookshire. The Priestley-Taylor model is a simplified combination model with a proportionality constant $\alpha = 1.26$. It assumes that the radiant energy term

$$\frac{1}{L} \left( \frac{\Delta}{\Delta + \gamma} (Rn - G) \right)$$

accounts for 79% of the potential evapotranspiration, while the convective energy term accounts for only 21%. In contrast, in the Penman formulation the convective energy term

$$\frac{1}{L} \left( \frac{\gamma}{\Delta + \gamma} (LEa) \right)$$

is not a constant proportion of PET, but dependent upon temperature, vapor pressure and wind speed. At Vancouver, Cookshire and Truro the convective
TABLE III. ESTIMATED ACTUAL EVAPOTRANSPIRATION FROM 1 MAY TO 30 SEPTEMBER WITH DIFFERENT PET MODELS AT SWIFT CURRENT, HARROW AND TRURO

<table>
<thead>
<tr>
<th>Station</th>
<th>Rainfall (mm)</th>
<th>Model</th>
<th>PET (mm)</th>
<th>Diffusion model VSMB (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Swift Current</td>
<td>239</td>
<td>Penman</td>
<td>777</td>
<td>355</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Priestley-Taylor</td>
<td>590</td>
<td>348</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Baier-Robertson 1</td>
<td>687</td>
<td>353</td>
</tr>
<tr>
<td>Harrow</td>
<td>339</td>
<td>Penman</td>
<td>644</td>
<td>407</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Priestley-Taylor</td>
<td>578</td>
<td>394</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Baier-Robertson 1</td>
<td>633</td>
<td>406</td>
</tr>
<tr>
<td>Truro</td>
<td>395</td>
<td>Penman</td>
<td>525</td>
<td>459</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Priestley-Taylor</td>
<td>496</td>
<td>454</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Baier-Robertson 1</td>
<td>586</td>
<td>468</td>
</tr>
</tbody>
</table>

energy term in the Penman model accounted for, respectively, 20, 22 and 24% of the potential evapotranspiration, or approximately a similar percentage as in the Priestley-Taylor model. On the other hand, at Beaverlodge, Swift Current, Winnipeg, Harrow and Ottawa, all stations with relatively large vapor pressure deficits and high windspeeds, the convective term accounted for, respectively, 30, 34, 33, 29 and 28% of PET. This caused significant differences in accumulated PET between the Penman and Priestley-Taylor models and supports evidence by Jury and Tanner (1975) and Shouse et al. (1980) that a constant proportionality factor of 1.26 in Eq. 11 is inappropriate at stations where large-scale advection can be anticipated.

The results from the Baier-Robertson model were highly variable. The difference in largest and smallest estimated accumulated PET from the eight formulas exceeded 100 mm at all stations, except at Beaverlodge and Harrow. Compared to adjusted Class A pan evaporation both under- and overestimations of PET occurred at Vancouver UBC, Swift Current and Ottawa. All eight formulas underestimated PET at Beaverlodge, Winnipeg and Harrow, while they overestimated at Cookshire and Truro.

Formula I of the Baier-Robertson model, which uses only air temperature data as a meteorological variable, predicted the largest or second largest PET at all stations, except at Swift Current and Winnipeg where formula IV produced considerably larger PET values. The differences in accumulated PET between the Penman model and formula I varied from 90 mm at Swift Current to -66 mm at Cookshire.

Formula V, which uses air temperature, global solar radiation and vapor pressure deficit data, gave the best agreement with the Penman model, except at Swift Current and Winnipeg where the higher windspeeds (see Table I) play an important role in the potential evapotranspiration process. The average difference with the Penman model, when Swift Current and Winnipeg were excluded, was less than 7 mm.

Formula VIII, which uses the same meteorological variables as the Penman model, was in good agreement with Penman's result at Swift Current, Winnipeg and Truro. However at the remaining stations the accumulated PET was at least 60 mm lower than the one calculated with the Penman model.

While PET is largely controlled by meteorological conditions, actual evapotranspiration (AET) is subject to the same meteorological conditions plus soil and crop conditions. Therefore, models which estimate AET generally use PET input as calculated by the various models.

As was shown in Table II, PET estimates varied largely among the different models. However, similar large variations did not show up in AET estimates (Table III). For example, at Swift Current where the PET estimate from the Priestley-Taylor model was 24% below Penman's estimate, the diffusion model predicted an accumulated AET which was only 2.0% lower than the Priestley-Taylor PET input as compared to the Penman PET input. Similar small differences in AET among PET input models are noted for Harrow and Truro. The differences in AET predicted by the VSMB were also small at any of the three stations, although they were somewhat larger than the relative differences predicted by the diffusion-based model.

In both soil water models, actual evapotranspiration was controlled to a large degree by the imposed soil and crop conditions and to a much smaller extent by PET conditions. In the diffusion-based model, AET was governed by a sink term specified as

\[ S = K(\theta) (\Psi_s - \Psi(\theta)) \text{ RDF (11)} \]

where \( K(\theta) \) is the hydraulic conductivity function, \( \Psi_s \) is the suction head at the root-soil interface (= 1500 kPa) and \( \Psi(\theta) \) is the soil water suction head function. The model assumed that the crop will attempt to meet the evaporative demand (PET). When water was available both near the surface and deep in the profile, the model assumptions implied that the crop would first use the readily available water near the surface. As water was depleted, uptake from the surface zones decreased rapidly due to the rapid decrease in hydraulic conductivity.

In the VSMB water was withdrawn simultaneously from different depths of the soil profile in relation to the rate of PET, the rooting pattern of the crop, the drying characteristic of the soil and the available water in each of the zones of specified water-holding capacities. The drying characteristic of the soil, which is a function of available soil water, limited evapotranspiration in the VSMB in the same way as the hydraulic conductivity function, \( K(\theta) \), limited evapotranspiration in the diffusion-based model.

CONCLUSIONS

Long-term measurements of PET, as defined by Penman (1956), are not available in Canada. Measured evaporation from a Class A pan must be multiplied by an empirical coefficient, thereby making the adjusted Class A pan data themselves an estimate of PET. Only an intercomparison of PET models was attempted in this paper.

The results from the PET models varied widely at any one station. None of the models estimated consistently either high or low PET values. The Penman and the Monteith model produced similar results and in comparison with the adjusted Class A pan data provided reasonable estimates of PET at all stations. The results from the Priestley-Taylor model were similar to Penman's at Vancouver, Cookshire and Truro, but significantly lower at the other stations, suggesting that \( \alpha \) (Eq. 11) is not a universal constant. Formula I of the Baier-Robertson model predicted larger PET values than the other formulas of the model, except at Swift Current and Winnipeg. If air temperature, global solar radiation and vapor pressure deficits were included (formula V) good agreement with the Penman model was obtained, except at Swift Current and Winnipeg where windspeed should be included as well. It is thought that derivation of regional coefficients instead of country-wide ones would improve PET estimates from the Baier-Robertson model.
Actual evapotranspiration, as calculated with a diffusion-based model and a soil-water budget model, was insensitive to PET input. The imposed soil and crop characteristics played a much larger role in controlling AET than did the PET regime. Dugas and Ainsworth (1985) also reported cumulative seasonal AET values when the Priestley-Taylor model was substituted by the Penman model in three crop-growth/soil-water models in the southern U.S. With the Penman model as input, they found that the simulated yields were significantly reduced; other water-related model outputs, except phenology, were also affected by the change in PET model. The climate, soil and crop conditions in the southern U.S. are different from the ones reported in this study. Further investigations should be undertaken to elucidate the effects of changing the PET model in crop-growth and/or soil-water models for a variety of soil and crop conditions.

REFERENCES


