Estimating watertable fluctuations with a daily weather-based water budget approach

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Boisvert, J.B., Dyer, J.A., Lagacé, R. and Dubé, P.A. 1992. Estimating watertable fluctuations with a daily weather-based water budget approach. Can. Agric. Eng. 34:115-124. An empirical sub-model that can be included in multi-layered soil moisture budget models was developed for predicting the watertable depth. Two years of field observations at three drained sites near St. Hyacinthe, PQ were used to calibrate the sub-model. Another year of observations from two of these sites and one year at an undrained site near Ottawa, ON were used to validate it. The required coefficients for the watertable model included the porosity of subsoil below the rooting depth, the outflow rate and the maximum watertable depth. The watertable sub-model realistically reflected watertable fluctuation observations throughout the growing season during the test years. The sub-model showed good potential to be used as a means of predicting and analyzing watertable depths throughout the St. Lawrence Lowlands, where excess soil moisture and chronically high watertables have been a major problem in agriculture. However, it can not be used at the present time to evaluate the capillary rise contributions of the watertable to the root zones and crop growth.

Une fonction empirique pouvant être incluse dans un modèle de bilan hydrique multi-couches fut développée afin de prédire les hauteurs de nappe d’eau. Deux années d’observations prises à trois sites drainés de la région de St-Hyacinthe, PQ, ont servi à calibrer cette fonction. Une année d’observations prises à deux des sites ainsi qu’une année provenant d’un site non drainé situé près d’Ottawa, ON, ont permis de la valider. Les coefficients nécessaires à la fonction de nappe d’eau incluent la porosité du sol sous la zone racinaire, le taux d’écoulement souterrain et la profondeur maximale de la nappe d’eau. La fonction de nappe d’eau reflète de façon réaliste les fluctuations observées au cours des saisons de croissance étudiées. La fonction montre un bon potentiel d’utilisation pour la prévision et l’analyse des hauteurs de nappe dans les basses terres du St-Laurent, où les excédants d’eau et les nappes d’eau élevées sont un problème important en agriculture. Cependant, elle ne peut être utilisée pour le moment dans l’évaluation des contributions de la remontée capillaire à l’approvisionnement en eau de la zone racinaire et à la croissance des cultures.

INTRODUCTION

Assessment of soil moisture reserves available for crop growth is commonly done in arid and semi-arid regions by using daily water budget models (Dyer 1988a; Mack 1988; Mapanao 1988). The main advantage of these models is the limited amount of simplified input data they require, while still providing sufficiently accurate output information. However, in humid climates, watertable fluctuations can contribute significantly to increase soil moisture in the root zones and limit the usefulness of these models. To estimate the contribution of this source of water to the overall soil water balance, the depth of the watertable below the roots must be monitored (Stuff and Dale 1978). Except in soil with unusually high bulk density, capillary rise also can contribute significantly to the water supply of the roots when watertable depth remains stable (Webster and Topp 1983).

Wheater et al. (1982) used a one-layer model to estimate groundwater recharge. They recognized the deficiency of their model for representing a dynamic soil water profile and suggested the use of a multi-layer model. Chieng et al. (1978) used a four layer model and reported satisfactory results on one site during four months. The budgeting of water in their model was done with two forms of storage: available water storage and excess water storage. The movement of the watertable was driven by the excess water storage. The bottom of a variable fourth zone, which also corresponded to the maximum watertable depth, was set below the tile drain depth. A deterministic model developed by Lagacé and St.Yves-Desilets (1979) divided the soil into two zones: a root zone and a bottom zone. Capillary rise and watertable movement were calculated from simplified physical parameters such as hydraulic conductivity, drain spacing, equivalent depth and drainable porosity. Their model predicted watertable depth and plant available water in both zones.

These three models, however, were soil mechanics oriented, rather than crop oriented. They were aimed at constraints to field trafficability and village, rather than at crop growth and crop water use analysis under varied production conditions. To keep the advantages of a multi-layer, crop oriented soil moisture model while keeping input requirements simple, the Versatile Soil Moisture Budget (Baier and Robertson 1966; Baier et al. 1979; Dyer and Mack 1984), was modified in this study, as suggested by Dyer and Boisvert (1985), to include a watertable function. The Versatile Soil Moisture Budget (VB) was used because it is suitable for regional soil moisture estimation (Dyer 1988b; Gallichand et al. 1991; Sophocleous and McAilister 1987) and is available for irrigation scheduling in a user-friendly version for desktop computers (Boisvert et al. 1990). It has also proved reliable for estimating soil moisture in the root zones for several crops (Teixeira de Faria et al. 1987; Baier et al. 1979; Dyer and Mack 1984).

This paper describes a watertable function that can be tested for use in a multi-layer crop oriented soil moisture...
budget model to predict watertable depth. It applies the concept of excess storage at the bottom of the root zone. The control parameters that must be defined by the user are related to soil characteristics easily measurable in the field. Results from the calibration and validation of the watertable function using data from three drained and one undrained site are presented and discussed.

THE WATERTABLE FUNCTION DEVELOPMENT

The Versatile Soil Moisture Budget model (VB)

The VB divides the soil profile containing the roots into several zones, where each zone is characterized by a root density distribution, a permanent wilting point, field capacity and excess water capacity (saturation). In versions three and four of the VB, these zones are grouped into two drainage layers to simulate a minimum of one day delay in the drainage of excess soil water from the surface to the watertable (Dyer and Baier 1979; Dyer and Mack 1984). A zone, as originally defined by Baier and Robertson (1966), is a thickness of soil sharing a common set of soil and plant root characteristics. The deepest zone corresponds to the maximum rooting depth. Also, the daily water balance of a zone results from only one set of computations.

A layer was distinguished from a zone in later versions of the VB models, as being a group of zones which can all be recharged or drained in the same day at the same rate. Although all the root zones were assigned to only two layers in these models, it would be feasible to simulate more than one day delay to reach deeper depths in clay soils by using more than two drainage layers in the rooting zones.

The watertable function

A new bottom (third) layer was added to version four of the VB, which was used in this study, specifically to simulate watertable levels. The bottom layer is limited by the maximum watertable depth. To predict the watertable depth, the bottom layer acts as a reservoir and accumulates the free water draining from above.

The watertable function is conceptualized in Fig.1. The bottom (third) layer is emptied by drain outflow (seq. 1) and filled to saturation with the excess water coming from the second drainage layer, which includes all those zones not recharged until one day after a rain (seq. 2). Because of the one day rate of drainage from layer one to layer two, rain water does not immediately reach the watertable. The second drainage layer is filled with free water from the first drainage layer (seq. 3) and the first drainage layer is filled by precipitation (seq. 4) according to daily weather records.

When the bottom layer reaches its saturation value, the watertable starts rising into the root zones. This process is defined here as backflooding (seq. 5). Starting with the deepest zone, each zone is filled to its field capacity, then to saturation, before backflooding of the zone above starts. This process continues until the free water available for backflooding has all been distributed upward. The height of the watertable from the bottom of the zone to where it stops rising is directly proportional to the ratio of excess water to the maximum possible excess water in the zone.

Three parameters are involved in the watertable function:

the porosity, the outflow, and the maximum watertable depth (thickness of the bottom layer). The porosity reflects the amount of pores drained when the watertable retreats downward to the next deeper zone and is related to equivalent drainable porosity (Lagace 1981). Hysteresis effects are not taken into account. The depth of water stored in the bottom layer is computed from the porosity by:

\[ Sm = P \times Hm / 100 \]  

where:

- \( P \) = soil moisture volume above field capacity (%),
- \( Sm \) = maximum storage amount of free (or gravitational) water that can be held in bottom layer between field capacity and saturation (mm), and
- \( Hm \) = thickness of bottom layer (mm).

The outflow determines the rate at which the bottom layer will be emptied, thereby simulating the loss of water through the drains and deep seepage. Some authors, such as De Jong and Shaykewich (1981) and Stoff and Dale (1978), used a constant value of outflow. Fayer and Hillel (1982) considered the outflow as a function of the height of the watertable, the slope of the bottom boundary, the conductivity at saturation and the horizontal rate of change in height of the watertable, suggesting that such flow would vary among sites and decrease with increasing watertable depth.

In the model, outflow, \( Fm \), is maximum and becomes...
constant when the watertable is at or above the top of the bottom layer. When the watertable is within the bottom layer, the outflow decreases linearly as a function of the watertable depth. The fraction of the bottom layer actually storing ground water determines the ratio of the outflow, \( F_w \), to the maximum outflow at any time:

\[
F_w = F_m \times \frac{S_w}{S_m}
\]  
\[\text{(2)}\]

where:

- \( F_w \) = actual outflow (mm/day),
- \( F_m \) = maximum outflow (mm/day), and
- \( S_w \) = actual amount of water in the bottom layer between 0 and \( S_m \) (maximum storage).

Outflow values are assumed to take into account the hydraulic conductivity of the soil, the drain spacing and the presence of a slope. The maximum outflow can be determined from the one day drop in the watertable depth, \( H_d \), when the watertable is at the top of the bottom layer. At this depth, outflow is at maximum value and is computed directly from \( H_d \) (once \( H_d \) has been determined from observations) and porosity by rearranging Eq. 1 to:

\[
F_m = H_d \times S_m / H_m
\]  
\[\text{(3)}\]

The watertable depth, \( D_w \), is calculated differently, depending on whether the watertable has risen into the root zone, or is still in the bottom layer. Once the watertable is above the bottom layer, the watertable depth is calculated from the free water in the zone being backflooded (i) and the ith zone thickness (\( Z_i \)):

\[
D_w = D_{z_i} - (S_{z_i} / S_{mi}) \times Z_i
\]  
\[\text{(4)}\]

where:

- \( S_{z_i} \) = excess water stored in zone \( i \),
- \( S_{mi} \) = maximum possible excess water in zone \( i \), and
- \( D_{z_i} \) = depth to bottom of zone \( i \).

In the bottom layer, the calculation of the watertable depth is done in two steps. The first step computes a linear rate of fall with increasing watertable depth.

\[
D_w' = D_m - (S_w / S_m) H_m
\]  
\[\text{(5)}\]

where:

- \( D_w' \) = watertable depth before correction, and
- \( D_m \) = maximum depth of watertable.

In the second step, the squared term makes the rate of change in the corrected \( D_w \) sensitive to depth. An increasing rate change with depth is assumed because of higher bulk density and decreased porosity at greater depths.

\[
D_w = D_{z_n} + H_m x \left( (D_w' - D_{z_n}) / \left( D_m - D_{z_n} \right) \right) ^2
\]  
\[\text{(6)}\]

where \( D_{z_n} \) = depth to bottom of zone \( n \) which corresponds to the top of bottom (third) layer.

The model can be easily converted back to a linear falling rate by bypassing Eq. 6. However, the non-linear version was a better fit to the observed watertable depths and was used throughout this study.

When backfloodings stops, some capillary rise occurs in the capillary fringe above the watertable. This effect could move water from the zone containing the watertable into the zone(s) above. Contributions from the capillary fringe were neglected, however, since neither the precision of the data nor the sensitivity of the model justified such computations for the amount of water involved. St-Yves-Desilets (1983) suggested that capillary rise would have very little influence on the behavior of the watertable in Quebec.

**MATERIALS AND METHODS**

The data used to develop and calibrate the watertable function were taken from an experiment carried out at St.Hyacinthe, PQ from 1984 to 1986 (Boisvert and Dubé 1985). Three tile-drained farm fields identified by owner names were chosen for this study. The characteristics of these fields are presented in Table I. These soils are quite uniform in the rooting zone, except the Leblanc site, where a layer of sandy soil was found between 0.4 and 0.8 m depth. The depth at which soil texture changed to heavy clay (marked by a sharp change in bulk density) varied among soil series and within a field from 0.8 to 1.0 m. Drain spacing was determined from the drainage installation plan. The drainage systems were in place for more than 10 years.

The crop grown at all sites was corn (Zea mays L.). Soils were fertilized at the beginning of the season and farmers applied their usual pesticide and fertilizer treatments throughout the season. Seeding time varied slightly at each farm and each year between April 26 and May 11. The rooting depths observed after silking stage varied between 0.90 and 1.10 m at all sites, with maximum rooting depths observed during 1986 and minimum depths in 1985. Crop and soil coefficients were adjusted for the VB4 based on results described by Boisvert et al. (1992).

Watertable depths at mid-spacing between drains were recorded continuously during the growing season in 1985 and 1986, but only once every two weeks in 1984. Rainfall observations were recorded at each site by the farm operators. Temperatures used for the estimation of the potential evapotranspiration were taken from the St.Hyacinthe weather station located within 10 km of these sites. Along with precipitation, daily PE estimates are required input to the VB. Soil moisture observations were also measured once every two weeks using gravimetric sampling every 200 mm down to the watertable level. These soil moisture observations were used to verify the complete range of soil moisture levels predicted by the model for the root zones, although only the watertable predictions are described in this paper. A more detailed discussion on the performance of the VB4 for estimating plant available soil moisture and actual evapotranspiration in corn from daily rainfall and temperature data is provided by Boisvert et al. (1992).

The watertable sub-model was further validated in undrained field conditions with data taken in the Ottawa area (Personal communication, G.C. Topp, CLBRR, Agriculture Canada, Ottawa, ON) during 1982. The field was a well structured Rideau clay soil cropped with grass hay. Soil characteristics were taken from the soil water desorption curves and soil texture analysis described by De Jong et al. (1989). Crop coefficients were adapted from Baier et al. (1979). Roots were mostly in the first 400 mm. Volumetric water contents were measured weekly using time domain
Table 1: Soil characteristics for each site

<table>
<thead>
<tr>
<th>Farm site</th>
<th>Palardy</th>
<th>Leblanc</th>
<th>Chollet</th>
<th>Rideau</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location</td>
<td>Ste. Madeleine, PQ</td>
<td>St. Thomas d’Aquins, PQ</td>
<td>Douville, PQ</td>
<td>Ottawa, ON</td>
</tr>
<tr>
<td>Major soil type</td>
<td>sandy clay loam</td>
<td>loam then sand (0.6 m)</td>
<td>loam</td>
<td>silty clay</td>
</tr>
<tr>
<td>Tile drain</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- depth (m)</td>
<td>0.85</td>
<td>1.20</td>
<td>1.40</td>
<td>none</td>
</tr>
<tr>
<td>- spacing (m)</td>
<td>15.30</td>
<td>48.70</td>
<td>20.00</td>
<td></td>
</tr>
<tr>
<td>Depth of heavy clay (m)</td>
<td>0.85</td>
<td>0.80</td>
<td>0.90</td>
<td>0.30</td>
</tr>
<tr>
<td>Maximum depth (m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(1982 or 1985, 1986)</td>
<td>1.38</td>
<td>1.94</td>
<td>1.51</td>
<td>1.79</td>
</tr>
<tr>
<td>(1984)</td>
<td>1.43</td>
<td>2.20</td>
<td>2.10</td>
<td></td>
</tr>
<tr>
<td>Natural drainage</td>
<td>poor</td>
<td>poor</td>
<td>poor</td>
<td>imperfect</td>
</tr>
<tr>
<td>Hydraulic conductivity (m/day)</td>
<td>1.1</td>
<td>1.3</td>
<td>4.5</td>
<td>0.1-0.3 m: 0.70^a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.8-1.2 m: 0.031</td>
</tr>
</tbody>
</table>

^a from DeJong et al. 1989, using Guelph permeameter

reflectometry at five depths and daily watertable elevations were estimated from weekly measurement (De Jong et al. 1989).

The watertable function was calibrated on the Leblanc and Palardy sites using 1985 and 1986 data and on the Chollet site using 1984 and 1986. Validation was carried out at the Leblanc and Palardy sites with 1984 observations and at Ottawa with 1982 data. In all tests the soil profile was divided into three drainage layers, as described above.

For the three corn sites, the bottom layer started at the depth where heavy clay appeared, and ended at the maximum watertable depth recorded from all observations within the calibration period (1985-86). The estimation of the maximum outflow was based on the maximum observed one day drop of the watertable when the watertable was at or above the top of the bottom layer (Eq. 3). Values for the porosity and the outflow were found empirically from the calibration observations by using an optimization procedure based on the Marquardt (1963) algorithm.

At the Ottawa site, the bottom layer started at 800 mm and stopped at the maximum watertable depth recorded through the season. The porosity was taken as the difference between saturation and field capacity at 800 mm estimated from the desorption curves. The outflow was estimated from the observed drop of the watertable depth at the top of the bottom drainage layer.

The Chollet site observations from 1986 were used in the sensitivity analysis. Accurate estimation of the watertable depth depends largely on its sensitivity to the porosity, the outflow and the maximum watertable depth. The range of each of these three parameters was tested while keeping the other two parameters constant. Sensitivity is demonstrated by the response of the estimated watertable depth. For simplicity, a whole season of watertable depth estimates was summarized to one mean for each range test.

RESULTS AND DISCUSSION

Calibration and validation

The standard error of estimation (SEE) and the coefficient of determination ($R^2$) were calculated (Table II) using watertable depths predicted from the model and observed watertable depths. Graphical comparison between the model and field observations is shown in Figs 2, 3, and 4.

The Palardy and Leblanc site statistics from 1984, which were only used as validation, showed as good a fit to the model as did the combined 1985-86 statistics, which were used for development and calibration of the watertable function. Figures 2 and 3 give the potential of the model for predicting watertable fluctuations at these two sites.

The agreement of the model with the validation data from 1984 at Chollet was initially very poor. The main reason for this was that the watertable in 1984 was much deeper than the watertable in 1986. Recalibration of all three parameters at the Chollet site was done by using both 1984 and 1986 data and a deepest maximum watertable (Fig.4), which improved the fit of the model on 1984 data. Figure 4 demonstrates that after recalibration, the model could follow the strong downward trend in the watertable depth observed in 1984.

At the Ottawa site, statistics from Table II and Fig. 5
Fig. 2. Observed 1984, observed 1985 to 1986 and predicted watertable from 1984 to 1986 for the Palardy site.

Fig. 3. Observed 1984, observed 1985 to 1986 and predicted watertable from 1984 to 1986 for Leblanc site.
Fig. 4. Observed 1984, observed 1985 to 1986 and predicted watertable for 1984 and 1986 on the Chollet site, where calibration was done using 1984 and 1986 data.

Table II: Statistical analysis of the watertable depth estimation accuracy using the standard error of estimate (SEE) and coefficient of determination ($R^2$) generated from the calibration (C) and validation (V) steps with 1984-1986 watertable observations (N is the number of observations)

<table>
<thead>
<tr>
<th>Site and Year</th>
<th>N</th>
<th>SEE (mm)</th>
<th>$R^2$</th>
<th>Season Average estimated (mm)</th>
<th>Season Average observed (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palardy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C: 1985-1986</td>
<td>295</td>
<td>95</td>
<td>0.79</td>
<td>1048</td>
<td>1006</td>
</tr>
<tr>
<td>V: 1984</td>
<td>12</td>
<td>58</td>
<td>0.81</td>
<td>1329</td>
<td>1353</td>
</tr>
<tr>
<td>Leblanc</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C: 1985-1986</td>
<td>230</td>
<td>87</td>
<td>0.75</td>
<td>1660</td>
<td>1659</td>
</tr>
<tr>
<td>V: 1984</td>
<td>15</td>
<td>144</td>
<td>0.83</td>
<td>1769</td>
<td>1891</td>
</tr>
<tr>
<td>Chollet</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C: 1986</td>
<td>161</td>
<td>76</td>
<td>0.57</td>
<td>1325</td>
<td>1324</td>
</tr>
<tr>
<td>V: 1984</td>
<td>14</td>
<td>435</td>
<td>0.33ns</td>
<td>1402</td>
<td>1765</td>
</tr>
<tr>
<td>C: 1984,1986</td>
<td>175</td>
<td>118</td>
<td>0.56</td>
<td>1346</td>
<td>1360</td>
</tr>
<tr>
<td>Rideau</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>V: 1982</td>
<td>197</td>
<td>103</td>
<td>0.95</td>
<td>1240</td>
<td>1277</td>
</tr>
</tbody>
</table>

ns: not significant at 0.05
indicate a good agreement between observed and predicted watertable depths. On May 13 and June 24, the observed watertable rose, whereas the estimated watertable did not rise. On October 29, observed watertable rose higher than the estimated one. De Jong et al. (1989) suggested that at least two mechanisms, hysteresis and a preferential flow through the soil macrostructure, could account for these marked rises. Neither factor is taken into account by the model described here.

The analysis of the estimated parameters (Table III) shows that the porosity did not vary markedly among the three drained sites. For the Palardy and Leblanc sites, the optimized values of porosity corresponded to the difference in gravimetric soil moisture observations when the watertable retreated downward from 0.9 to 1.3 m and from 1.5 to 1.9 m depth, respectively.

The optimized maximum outflow values, \( F_m \), varied more among sites than porosity, but they could be directly related to drain spacing (Table I). The corresponding drop in the watertable depths, \( H_d \), shown in Table III could be related to values observed in the field over the period used for the calibration. For the Ottawa site, \( H_d \) was close to the hydraulic conductivities measured at the 0.8 - 1.2 m depth using the Guelph permeameter (De Jong et al. 1989). Maximum

Table III: Estimated parameters in the watertable function for the four test sites (identified by owner names)

<table>
<thead>
<tr>
<th>Site name</th>
<th>Porosity ( P (%) )</th>
<th>Outflow ( F_m ) (mm)</th>
<th>Maximum watertable depth (mm)</th>
<th>Watertable drop ( H_d ) (mm/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Palardy</td>
<td>15.1</td>
<td>1.93</td>
<td>1450</td>
<td>12.8</td>
</tr>
<tr>
<td>Leblanc</td>
<td>15.0</td>
<td>7.00</td>
<td>1700</td>
<td>46.6</td>
</tr>
<tr>
<td>Chollet(^c)</td>
<td>11.0</td>
<td>0.80</td>
<td>1500</td>
<td>117.0</td>
</tr>
<tr>
<td>Chollet(^d)</td>
<td>14.5</td>
<td>2.70</td>
<td>2000</td>
<td>18.5</td>
</tr>
<tr>
<td>Rideau</td>
<td>4.0</td>
<td>0.92</td>
<td>1800</td>
<td>23.0</td>
</tr>
</tbody>
</table>

\(^b\) at the top of the bottom layer
\(^c\) using 1986 for calibration
\(^d\) using 1984 and 1986 for calibration

![Observed and predicted watertable for 1982 using Ottawa site.](image)

Fig. 5. Observed and predicted watertable for 1982 using Ottawa site.
watertable depth remained close to the deepest value observed in 1985-86.

**Sensitivity analysis**

Results from the sensitivity analysis are presented in Table IV. The sensitivity to porosity is shown in Fig. 6. The sensitivity to outflow (not shown) was almost identical to the sensitivity shown by porosity. In both cases, the sensitivity to overestimation in these two parameters was less than sensitivity to underestimated. The decreasing rate of response with increasing depth, $D_w$, is the result of the variable outflow, $F_w$, which decreases as the bottom layer runs out of water.

Sensitivity to the maximum watertable depth was higher than to porosity and outflow. Consequently, a 10% maximum range was then used in Table IV instead of a 50% maximum range. Underestimation of the maximum watertable depth will reduce the thickness and the capacity of the bottom layer and will cause a faster rise in the predicted watertable depth for the same amount of rain.

**CONCLUSION**

A watertable function based on porosity, outflow and the maximum watertable depth has been developed and tested successfully in the St. Hyacinthe and Ottawa areas. Statistics generated from the comparison of the model with data not used in the development and calibration processes, tend to justify the use of this watertable function to estimate watertable fluctuations on farms with subsurface drains. Potential was also found for application in an undrained field. Watertable depth estimations are not very sensitive to porosity or maximum outflow, although there is increased sensitivity if these two parameters are overestimated.

The dependence on the three empirical parameters (porosity, maximum depth and outflow) indicates a general limitation of the model with respect to site specific applications. This study demonstrated that once calibrated, a model which is comprehensive of root water activity, yet comprised of reasonably simple computations and driven by daily weather observations, can be made sensitive to possible watertable intrusions into the root zones. The linking of a watertable function with a multi-soil layer crop growth model opens the possibility of modelling the short-term impact of restricted deep soil aeration on root activity and crop growth. Further analysis of the application of this sub-model to a broader range of plant-soil-water interactions is continuing, based on soil water measurements taken in corn fields. Similar testing with other crops is also required.

A distinctive feature of this watertable simulation is the concept of a one day delay in surface infiltration, characteristic of versions three and four of the Versatile Budget. The one day delay function, which splits the root zones in the top soil above the watertable into two drainage layers, prohibits infiltration water from reaching the watertable on the same day that it precipitated on the soil surface. This means that the watertable response to daily weather events is both de-
Table IV: Sensitivity analysis based on Chollet site and 1986 watertable observations (N= 161 observations).

<table>
<thead>
<tr>
<th>Case</th>
<th>SEE (mm)</th>
<th>R²</th>
<th>Season Average of the Watertable Estimated Depth (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porosity</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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Layered and dampened, which is realistic of the heavy clay based soils of the St. Lawrence Lowlands and the Ottawa Valley. Results in Figs. 2 to 5 all illustrate that, although the magnitudes may differ, the timing of sharp peaks in watertable depths exhibits good agreement between simulations and observations. Furthermore, the observed rises in the watertable consistently illustrated a one day delayed response to the larger rainfall amounts in Figs. 2 to 5.

The watertable function described here can enhance the role of the Versatile Budget in monitoring eastern Canadian soil moisture conditions in real time and this enhancement will be available in Version Four (VB4). In the monitoring role, which is the real-time operation of the model in support of current day-to-day decision making, the goal of the model is to show changes from normal expectations. Since the watertable function showed good temporal response, valuable regional information can be generated by treating model output as representative of a generalized hypothetical field. Preliminary testing of this application is being done in collaboration with the Montreal weather office.

This model might also be used to assess deterioration of drainage installations in specific fields. Where the model would demonstrate the expected response to weather variations over a period of years, a rising trend in observed watertable depths relative to the model estimates would signify such a deterioration. The model described here could be calibrated from measurements taken during installation of the drains. The advantage of using the watertable sub-model in the VB4 is that crop growth patterns and production practices can be considered in the analysis.

ACKNOWLEDGMENT

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