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DEVELOPMENT OF A MODEL FOR ESTIMATING CURRENT AND FUTURE IRRIGATION WATER DEMAND IN CANADA

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ABSTRACT An increasing competition for water coupled with an unpredictable changing climate will affect future food production. To sustain agriculture, a robust framework for allocating water is essential for promoting efficient use and maximizing the value of this limited resource. To help water managers and decision-makers achieve this objective, an agricultural water demand model that is specific to Canadian climate, soil and crop conditions was designed using a Matlab program with Graphical User Interface (GUI). The model was designed using the Food and Agriculture Organisation's (FAO)-56 Penman-Monteith equations for computing reference evapotranspiration (ETo) and the crop coefficient (Kc) values were estimated using local data. The model estimates annual net, gross and 10-day irrigation water requirements (IWR) for wet, dry and normal weather conditions. It also estimates future IWR by accounting for expected changes in climate using downscaled data from the Canadian Regional Climate Model (CRCM). The model was tested with bell pepper, tomato, raspberry and peach grown in southern Ontario. Analysis of the 1971-2000 rainfall data for Chatham – Kent, Essex, Niagara and Haldimand Norfolk weather stations showed that 1976, 1990, 1981 and 1985 with rainfall depths of (293mm, 405mm, 335mm and 381mm) respectively were the wet years. The percentage increase in rainfall for 2011-2040 ranged from 20% - 53% despite the projection that rainfall for the study areas will be 10% less. Future water demand by bell pepper, tomato and raspberry are expected to increase by 19 – 27% while water demand by peach is expected to decrease by 23%. Expected changes in future IWR are: increase by 10 - 60% for raspberry; decrease by 19 - 24% and 0.2 - 18% for peach and tomato respectively. The percentage difference between future and current IWR for bell pepper ranged from -2 to 2%.

Keywords: Climate change, Matlab, Model, Irrigation water requirement.

INTRODUCTION Increasing water scarcity is now a global concern and the water resources of many regions of the world are insufficient to satisfy competing demands. Ward et al. (2006) described the urgency to recognize agricultural water management as a key mechanism of solving water resources problems. Agriculture accounts for about 70% of global water resources withdrawal (FAO, 2002; WRI 2005). About 92% of Canada's agricultural water use is through irrigation (Beaulieu et al, 2007). Irrigation water has enabled farmers to increase crop yields by reducing their dependence on rainfall patterns, thus boosting the average crop production while decreasing the inter-annual variability (Diamond et al., 1997; Tubiello, 2005). Water for agriculture is lost in evaporation and transpiration, thereby requiring more insight into the efficiency of irrigation methods currently used by farmers. Irrigation must become more efficient to sustain food production (Glieck 2002; Oster and Wilchens, 2003; Rockstrom et al., 2007) as climatic fluctuations and change are likely to reduce available water and increase drought (IPCC, 2007). The challenge for irrigated agriculture is to increase crop production with existing water allocations or even increase crop production with less water (Smith and Munoz, 2002).

In a situation where competition for limited water resources intensifies due to increasing population, potential climate change impacts and expansion of the agricultural sector among other reasons, a robust framework for estimating irrigation water demand under varying weather conditions, crop management options and irrigation technologies becomes more and more important for water managers to ensure conservation and continuous water supply to the fields. Accurate estimation of irrigation demands (and other water uses) is a key requirement for better-informed water management (Maton et al., 2005) and such information could be generated with the aid of computer models. The most important benefit of applying models, however, is their ability to explore different scenarios and their outputs are often referred to as projections. Data availability often determines the model choice as there is no universal model; each model is adapted to specific environments or to new problems (Van Ittersum et al., 2003).

Many models have been used to simulate water requirements for crop irrigation (Allen et al., 1998; Doorenbos and Pruitt, 1977; Doorenbos and Kassam, 1979; Van Aelst et al., 1988). Bastiaansen et al., (2007) described irrigation and drainage process models as bucket, pseudodynamics, Richards-equation based, Soil-Vegetation-Atmosphere Transfer (SVAT) models, multidimensional and crop production models. Models are useful for estimating water use, water allocation and current water status. It is used to simulate runoff, infiltration, soil water storage, evapotranspiration, capillary rise and percolation within the irrigation system and to predict impact of agricultural management practices (e.g. Vanclooster et al, 1995).

Though vast research has been carried out on irrigation water models, far less has been done using Canada's climate, crops and soil data. Each model has its strengths, weaknesses and data requirements and a universally appropriate and versatile model does not exist. The development of a certain model should depend on the specific task and in case of crop water and irrigation demand model the inputs are specific. Therefore the emphasis of this study is to develop a model that estimates the current and future agricultural water demand based on irrigation technology and projected changes in climate change in Canada. The computer model was developed with Matlab™ program and tested with horticultural crops grown in southern Ontario.

MATERIALS AND METHODS

Study area High value horticultural crops are intensively cultivated in southern Ontario (Statistics Canada, 2006); these crops require irrigation to meet their evapotranspirative needs (Madramootoo, 2006). Bell pepper (Capsicum *annuum*), tomato (*Lycopersicon esculentum*), raspberry (Rubus *niveus*) and peach (Prunus *persica*) were selected in Chatham-Kent, Essex, Haldimand-Norfolk and Niagara counties of southern Ontario to test the model. These counties were chosen because of their intensive irrigated vegetable and fruit production (de Loë et al., 2001; Marshall Macklin Monaghanm et al., 2003). Bell peppers are typically planted in Chatham-Kent around the last week in May and harvested during the last week of August. Tomatoes, which are grown in large quantities in Essex County are planted in mid-May and harvested around mid-September, the planting and harvesting dates for raspberry are mid-May and the third week of October while that of peach are early May and mid-August, respectively.

Data The average 30-year climatic data of Sarnia Airport (42.99N, 82.3W), Windsor Airport (42.28N, 82.96W), St Catharines (43.2N, 79.2W) and Delhi (42.87N, 80.55W) was used for Chatham-Kent, Essex, Niagara and Norfolk-Haldimand counties respectively. The data were obtained from Environment Canada (Environment Canada, 2004). The crop and soil data were obtained from FAO-56 (Allen et al., 1998), OMAFRA (2004), and personal conversation with some of the growers. The crop data used for the model are: K_c values, length of the crop growth stages, root depths and the fraction of available soil water permitting unrestricted evapotranspiration. The soil data utilized consisted of typical values for the soil depth and available soil water content at field capacity and permanent wilting point of the region, neglecting the ground water contribution. The Canadian Regional climate Model (CRCM) (Music and Caya, 2007) was used for generating climate predictions for the period 2011 – 2040.

Model Development The model was developed in Matlab version 2009a using a Graphical User Interface. Matlab is a high-level language and interactive environment that enables one to perform computationally intensive tasks faster than with traditional programming languages such as C, C++, and FORTRAN (The MathWorks, 2008). The model was designed to be simple, user friendly and run in MS Windows. The crop, soil and climatic data of the four counties under study are incorporated into the model. A flowchart is presented in figure 1 showing the inputs and outputs of the model. The model has file, edit and calculation menus. The analysis starts with the selection of location and the crop type from the file menu, the edit menu allows the user to add, delete or update crop and the calculation menu presents the crop water requirement, total irrigation water requirement. The irrigation efficiency can be altered depending on the type of irrigation system used.

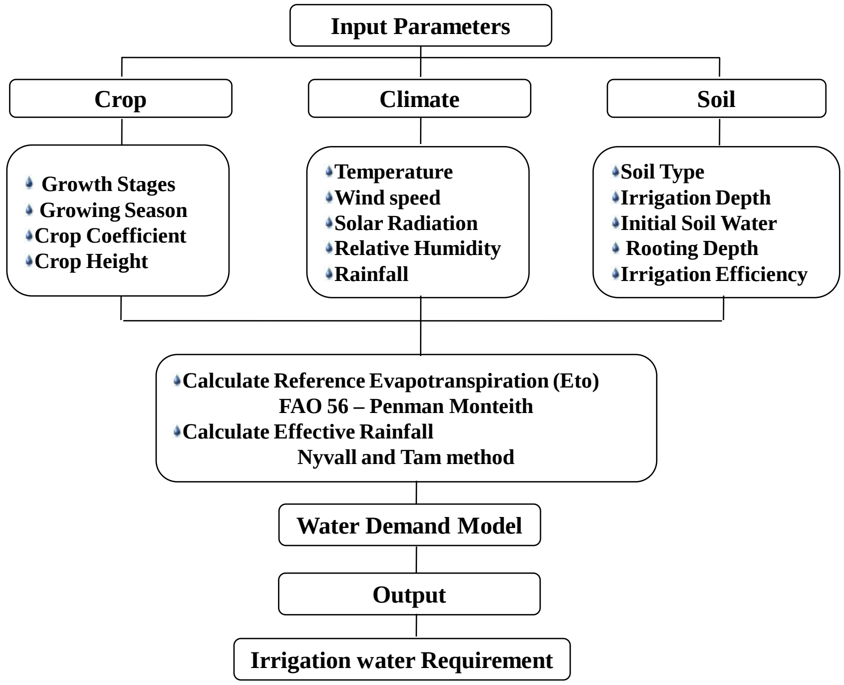

Figure 1. Flowchart of the model

The 5 sequential steps for estimating irrigation water requirements by the model are:

- Computation of reference evapotranspiration (ETo)
- Determination of crop coefficient (Kc)
- Analysis of yearly rainfall data series
- Calculation of effective rainfall
- Estimation of irrigation water requirement

The model estimates the ETo based on the generally acceptable FAO 56 Penman-Monteith equation (Allen et al, 1998), and also allows the user to input manually calculated ETo.

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (1)$$

Where ETo - reference evapotranspiration (mm/d),

Rn - net radiation at the crop surface (MJ m-2day-1),

G - soil heat flux (MJ m-2day-1)

T - mean daily air temperature at 2 m height (oC),

u_2 - wind speed at 2 m height (ms-1),

es - saturation vapour pressure (kPa)

ea - actual vapour pressure (kPa),

es - ea - saturation vapour pressure deficit (kPa),

Δ - slope vapour pressure curve (kPaoC-1),

γ - psychrometric constant (kPaoC-1).

The crop factor Kc was calculated following the procedure by Allen et al., (1998) while the effective rainfall was estimated using the method by Nyvall and Tam (2005) (equation 2)

$$P_{eff} = (R - 5) * 0.75 \quad (2)$$

Frequency Analysis of rainfall A frequency analysis was carried out using the yearly rainfall data series for 30 years (1971-2000) to determine the amount of rainfall that can be expected with a specific probability or return period using the RAINBOW program (Raes et al., 1996; 2006). In this program, the Weibull method of estimating probabilities was used (Chow et al, 1988).

Estimation of Future Irrigation Water Requirements The model calculates ETo with generated minimum and maximum temperatures (2011 – 2040) from the Canadian Regional Climate Model version 4.2 (CRCM 4.2) The projected rainfall data for (2011 – 2040) obtained from Climate change projections for Ontario (Colombo et al., 2007) was used to estimate the effective rainfall. The CRCM was developed jointly by the Université du Québec à Montréal and the Meteorological Service of Canada (Caya and Laprise, 1999). CRCM4.2 is driven by CGCM3 which is forced to consider future scenario based on the IPCC "observed 20th century" scenario for years 1961-2000 and the SRES A2 scenario for years 2001-2100 over the North-American domain (AMNO).

RESULTS AND DISCUSSION Analysis of the 1971-2000 rainfall data for Chatham – Kent, Essex, Niagara and Haldimand Norfolk weather stations showed that 1976, 1990, 1981 and 1985 with rainfall depths of (293mm, 405mm, 335mm and 381mm) respectively were the wet years. The percentage increase in rainfall for 2011-2040 compared with 1971- 2000 ranged from 20% - 53% despite the projection that rainfall for the study areas will be 10% less. ETo output and irrigation water requirement is shown in figure 2 and 3 respectively. Future crop water demand increases by 19 – 27% for bell pepper, tomato and raspberry while it decreases by 23% for peach, which might be due to the projected temperature which affected the reference evapotranspiration (Table 1). Current and future irrigation water requirements (IWR) are presented in Table 2.

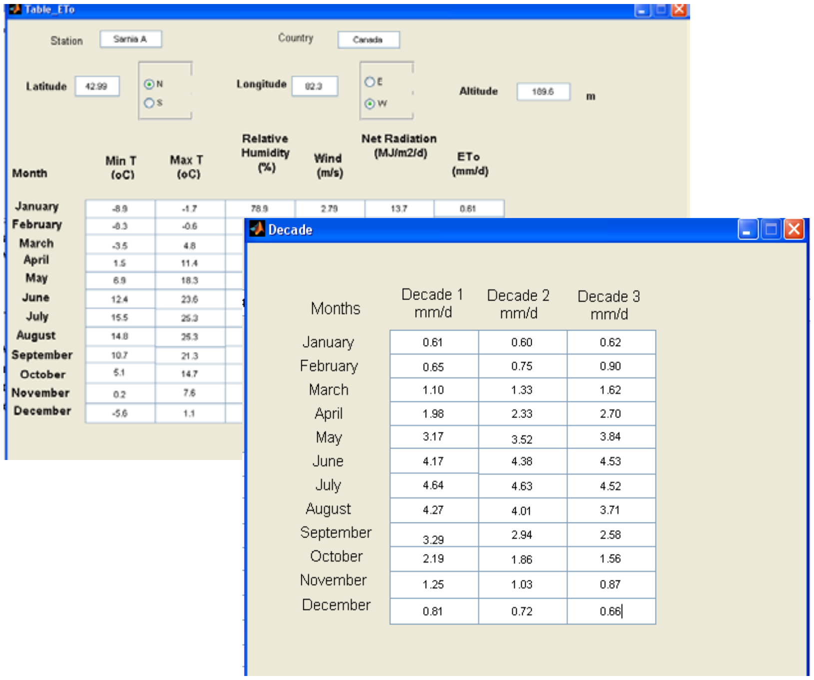

Figure 2. ETo output

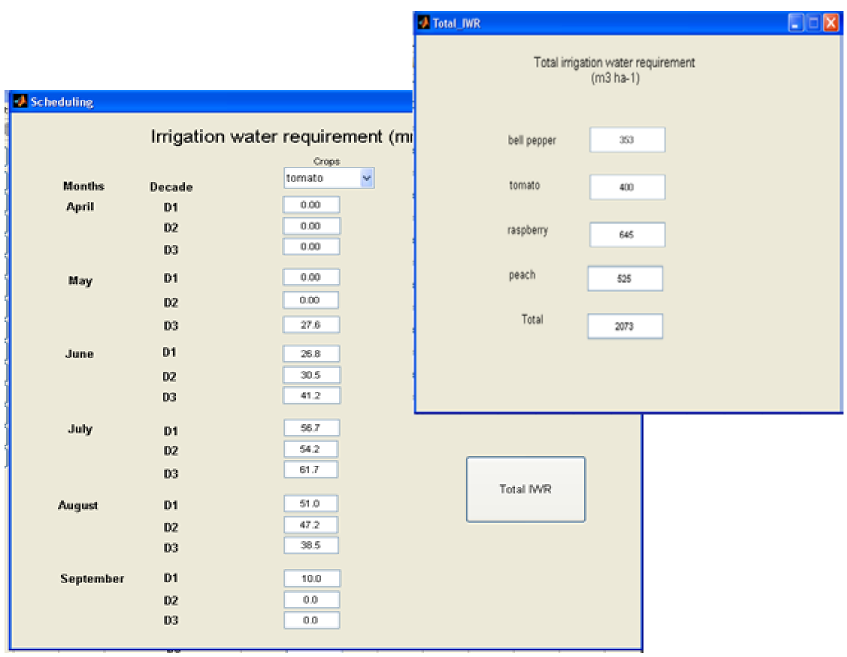

Figure 3. Irrigation water requirement

Table 1. Crop water demand

Crops	Current crop water demand (mm)	Future crop water demand (mm)	% difference (%)
Bell pepper	365.9	464.2	27
Tomato	443.2	547.2	24
Raspberry	429.2	511.3	19
Peach	427.9	328.3	-23

Table 2. Irrigation water requirement

			Irrigation water requirement (m^3/ha)			
Crop type	Soil type	Irrigation efficiency	Wet weather condition	Normal weather condition	Dry weather condition	Year 2025
Bell pepper	Loamy sand	0.90	4035	4200	4193	4118
Tomato	Sandy loam	0.90	5172	5065	5301	5054
Raspberry	Sandy loam	0.90	3637	3585	5301	5835
Peach	Loamy sand	0.75	6536	6716	7005	5292

The quantitative storage capacity depends on the type of soil and the rooting depth of the crop. Bell pepper and peach grown in loamy sand showed an increasing trend in current IWR, that is, highest amount of irrigation water is required in the dry weather conditions while the lowest amount of water is required in the wet weather condition. The current IWR for tomato and raspberry under normal weather condition was slightly lower than wet weather condition. This could be due to the fact that some of the rain during the wet season is drained away because the soil is at field capacity, hence the excess rain does not contribute to plant growth. Most of the bell pepper, tomato and raspberry produced in the study area are under surface or subsurface irrigation system having an efficiency of 90% while overhead gun with an efficiency of 75% is used for peach production. There is a slight variation in current IWR and future IWR for bell pepper and tomato (vegetable) while the changes in irrigation water requirements for the fruit crops; peach and raspberry is considerably high. The percentage change in future irrigation water requirement of the crops compared with their current irrigation water requirements is shown in Table 3. Future IWR for raspberry was considerably higher than the current IWR. The use of regulated deficit irrigation which many researchers (Bryant, 2009; Chaves et al., 2007; Cline, 2009; Fereres and Soriano, 2007) have shown to be successful for fruits can be applied to reduce water use.

Table 3. Comparison of future and current irrigation water requirement

Crops	Future scenario vs Wet weather (%)	Future scenario vs Normal weather (%)	Future scenario vs Dry weather (%)
Bell pepper	2.1	0.4	-1.8
Tomato	-17.9	-0.2	-4.7
Raspberry	60.4	62.7	10.1
Peach	-19.0	-21.2	-24.5

CONCLUSION A model that estimates current and future agricultural water demands based on projected changes in climate in Canada was developed with Matlab and tested with bell pepper, tomato, raspberry and peach grown in southern Ontario. The model estimates the reference evapotranspiration and annual and 10 day irrigation requirement accurately and saves time (validated with manual calculation). From the model results current and future IWR for the crops varies as irrigation water use depends on crop and soil type, climatic conditions and management practices. Therefore, the amount of water to be allocated should be determined prior to allocation. This model is useful to water planners and managers involved in water allocation and management. Further work on the model will address daily calculation of irrigation requirement and scheduling.

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