Baseline ET for a Pre-Development LID Community and Validation of Temperature-Based ET Models

Evapotranspiration de base pour un quartier à développement à faible impact et validation de modèles d'évapotranspiration basés sur la température

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RÉSUMÉ

L'évapotranspiration (HE) est un élément important de l'environnement. Cette recherche a utilisé deux modèles basés sur la température, le modèle FAO Penman-Monteith et la méthode Hargreaves, pour estimer l'évapotranspiration de référence ($\mathrm{ET_0}$) d'un quartier à développement à faible impact (LID) en Ontario, Canada. La comparaison entre les résultats modélisés et l'évapotranspiration réelle ($\mathrm{ET_a}$) collectées par un capteur de type Smart Field Lysimeter SFL-300 (METER GROUP AG) a été effectuée. Les résultats montrent que bien que les deux modèles surestiment l'évapotranspiration de référence ($\mathrm{ET_0}$), le modèle FAO Penman-Monteith a une plus grande précision pour $\mathrm{ET_0}$ et cette précision augmente avec la longueur des calculs. L'étude en cours sur l'ET sera utilisée comme intrant dans le modèle SWMM pour le scénario de pré-développement. Les données recueillies à partir d'une station climatique voisine seront utilisées pour une analyse plus poussée afin d'évaluer l'adéquation des modèles d'estimation de $\mathrm{ET_0}$.

ABSTRACT

Evapotranspiration (ET) is an important component to hydrologic cycle. This research used two temperature-based ET models, FAO Penman-Monteith model and the Hargreaves Method, to estimate the reference evapotranspiration ($\mathrm{ET_0}$) for pre-development conditions for a proposed LID neighborhood in Ontario, Canada. Modelled results were compared with actual evapotranspiration ($\mathrm{ET_a}$) data collected by a Smart Field Lysimeter SFL-300 (METER GROUP AG). Results showed that although both temperature-based models overestimate $\mathrm{ET_0}$, the FAO Penman-Monteith model has higher accuracy and that accuracy increases with longer time steps. ET data from this research will be used as an input for a pre-development SWMM model of the site. The data collected from a nearby climate station will be used for further analysis to evaluate the suitability of temperature-based $\mathrm{ET_0}$ models.

KEYWORDS

Baseline, Evapotranspiration, Lysimeter, Models

1 INTRODUCTION

Evapotranspiration (ET) is an important component in the hydrology cycle. Urbanization increases impervious surfaces and changes the water cycle by eliminating infiltration and evapotranspiration processes. The rapid urban growth leads to several negative impacts including urban heat island effects, flooding, and water pollution. Low Impact Development aims to reduce the negative environmental impacts of urbanization on our water resources. This research is assessing the pre-developed conditions for a proposed neighbourhood, Creek Side Village, located in Burford, Ontario, Canada. The proposed development will convert a 20.2 ha fallow field property into a mix-density senior residential community. When constructed Creek Side Village plans to manage 100% of its runoff through LID systems. The nearby Whitemans Creek receives runoff from the area and sandy soils on site providing high permeability support the installation of LID technologies including permeable pavements, infiltration trench, and vegetated filter strip (MTE Consultants Inc., 2018). The long-term goal of this work is to study the impacts of neighbourhood-level LID on site hydrology, evapotranspiration, and water quality.

2 METHODS

A SFL-300 Smart Field Lysimeter (METER GROUP AG) is used to measure the real time actual evapotranspiration (Et_a) of the site by calculating the weight difference of the lysimeter soil column and the drainage water bottle which maintains the lysimeter lower boundary. The lysimeter was installed in July 25th, 2017 and it collected data throughout the summer and fall until Nov 5th, 2017 at a 1-minute time step. 103 days raw data of the lysimeter mass (LYW) and the drainage bottle weight (SWW) were collected and smoothed. The daily actual evapotranspiration ($\mathrm{ET_a}$) is estimated by the equation below (UMS, 2014).

$$\mathrm{ET_{a,i}} = \mathrm{P} - \frac{\Delta\mathrm{LYW_i} + \Delta\mathrm{SWW_i}}{\pi\left(\frac{0.3}{2}\right)^2}$$

Where $\mathrm{ET_{a,i}}$ is the actual evapotranspiration at day i (mm/day); $\Delta\mathrm{LYW_i}$ is the weight change of the lysimeter soil column from day i-1 to i (kg); $\Delta\mathrm{SWW_i}$ is the weight change of the water draingae bottle from day i-1 to i (kg).

In order to evaluate the relation of $\mathrm{ET_a}/\mathrm{ET_0}$, the reference evapotranspiration ($\mathrm{ET_0}$) was estimated using both the standard FAO Penman-Monteith procedure and the Hargreaves Method with daily time step. According to the standard FAO Penman-Monteith method, the $\mathrm{ET_0}$ can be estimated with the minimum data of temperature ($\mathrm{T_{max}}$ and $\mathrm{T_{min}}$) using the equation (Allen, R.G., et al. 1998). The wind velocity at 2m height ($\mathrm{u_2}$) was estimated as 2 m/s since the $\mathrm{ET_0}$ is not highly sensitive to the normal range of wind speed with small crop height (Allen, R.G., et al. 1998).

$$\mathrm{ET_0} = \frac{0.408\Delta(\mathrm{R_n} - \mathrm{G}) + \gamma\frac{900}{\mathrm{T} + 273}\mathrm{u_2}(\mathrm{e_s} - \mathrm{e_a})}{\Delta + \gamma(1 + 0.34\mathrm{u_2})}$$

Where $\mathrm{ET_0}$ is the reference evepotranspiration (mm/day) ; Δ is the slope vapour pressure curve (kPa$℃^{-1}$) ; $\mathrm{R_n}$ is the net radiation at the crop surface ($\mathrm{MJ\ m^{-2}day^{-1}}$) ; G is the soil heat flux density ($\mathrm{MJ\ m^{-2}day^{-1}}$) ; T is the air temperature at 2 m height (℃) ; $\mathrm{u_2}$ is the wind speed at 2 m height (m/s) ; $\mathrm{e_s}$ is the saturation vapour pressure (kPa) ; $\mathrm{e_a}$ is the actual vapour pressure (kPa) ; $\mathrm{e_s} - \mathrm{e_a}$ is the saturation vapour pressure deficit (kPa) ; γ is the psychrometric constant (kPa$℃^{-1}$).

The Hargreaves method uses the following equation (Hargreaves and Samani, 1985).

$$\mathrm{ET_0} = 0.0023(\mathrm{T_{mean}} + 17.8)(\mathrm{T_{max}} - \mathrm{T_{min}})^{0.5}\mathrm{R_a}$$

Where $\mathrm{T_{mean}}$ is the daily mean temperature (℃); $\mathrm{T_{max}}$ is the daily maximum temperature; $\mathrm{T_{min}}$ is the daily minimum temperature; $\mathrm{R_a}$ is the extraterrestial radiation ($\mathrm{MJ\ m^{-2}day^{-1}}$).

3 RESULTS

Figure 1 plots daily $\mathrm{ET_a}$ and $\mathrm{ET_0}$ in the summer and fall of 2017. $\mathrm{ET_a}$ measured by the lysimeter ranges from 0 to 6.66 mm/day while $\mathrm{ET_0}$ estimated by Penman-Monteith and Hargreaves ranges from 0.93 to 5.65 mm/day and 1.73 to 14.26 mm/day, respectively. Both FAO Penman-Monteith and the Hargreaves equations appear to overestimate daily ET. Although both FAO Penman-Monteith and Hargreaves equation use the same temperature data to estimate $\mathrm{ET_0}$, FAO Penman-Monteith model produced more reasonable results. Figure 2 plots daily $\mathrm{ET_0}$ estimated using Penman equation vs. $\mathrm{ET_a}$. The models underestimated ET the most during high temperatures and dry days. Even at a daily time-step the temperature-based Penman-Monteith equation poorly matched observed ET data (Fig. 2 R^2=0.159)

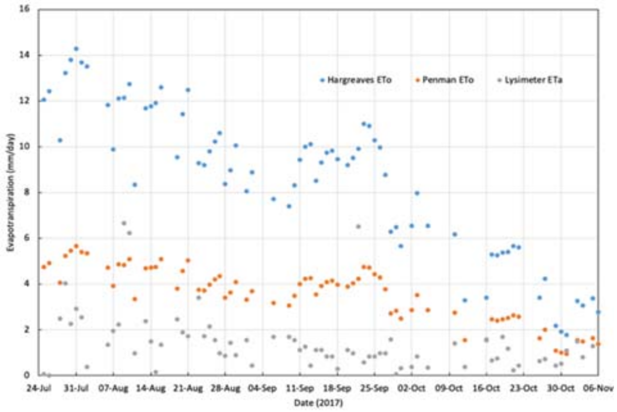

Figure 1 Comparison of ET_a and ET_o using Penman and Hargreaves Method

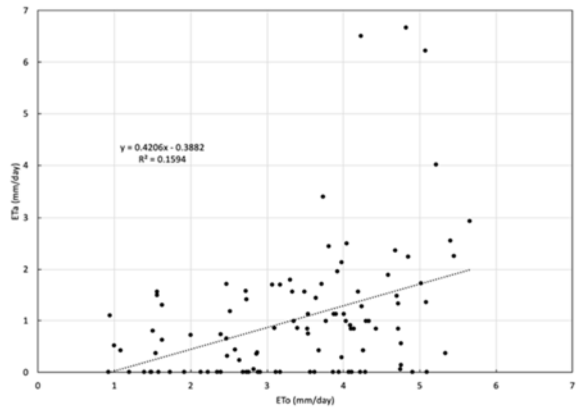

Figure 2 Daily ET_a vs ET_o (using Penman equaiton)

Due to know inaccuracy of temperature-based ET equations at small (i.e. daily) time steps average 7-day and monthly ET_0 rates were also calculated with the Penman-Monteith equation. Figure 3 and Figure 4 plots average 7-day and monthly ET_0 vs ET_a, respectively. The modelled ET rates were noticeably improved with an R^2 of 0.44 and 0.616 for the 7-day and monthly data, respectively. Although the increasing of calculation time step improves the accuracy of the temperature-based FAO Penman-Monteith equation, its application in displaying the variation of ET_0 in different climate conditions is very limit. For example, the calculation procedure of FAO Penman-Monteith equation with monthly time step is applying the average of the maximum and minimum temperature to the equation and failed to show the actual evapotranspiration energy exchange due to the lack of meteorological data.

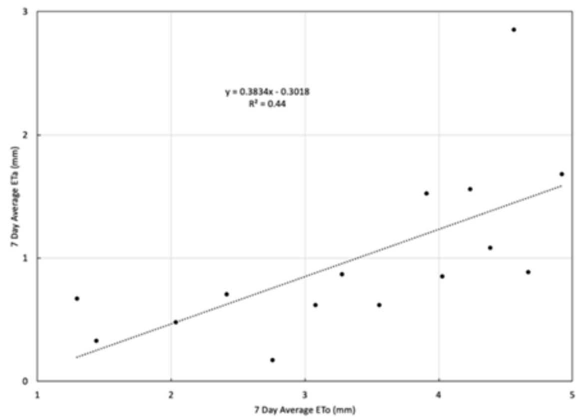

Figure 3 7 days average ET_a vs ET_o (using Penman= equaiton)

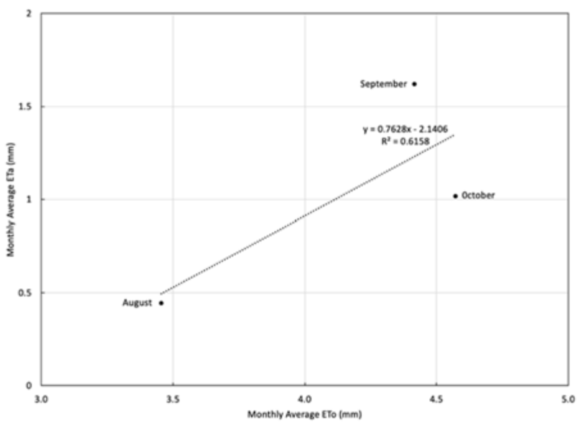

Figure 4 Monthly Average ET_a vs ET_o (using Penman equaiton)

The accuracy of the FAO Penman-Monteith equation could be improved through the inclusion of an appropriate crop coefficient. In 2017, the site was seeded with peas but also allowed to grow volunteer/blow in plants. The land was unirrigated and did not received any crop management (e.g. pest control, fertilizer etc). Figure 5 presents daily ET_a/ET_0 during the study period. The ratio of ET_a/ET_0 ranges from 0 to 1.54 and the curve on the figure shows the frequent high ET_a/ET_0 ratios in October when cooler and wetter weather became more common. The peak of the curve occurred in August with a monthly average ratio of 0.36 while September and October had monthly average ratios of 0.27 and 0.23, respectively. The lower ratio August also resulted from crop harvesting from the end of August to early Septermber. According to Allen et al. (1998), the single crop coefficient for peas is 1.1 to 1.15 during mid and end season. Compare the ratio of ET_a/ET_0 with the reference crop coefficient, lower estimation of the ratio as a higher estimation of ET_0 during normal days can be concluded.

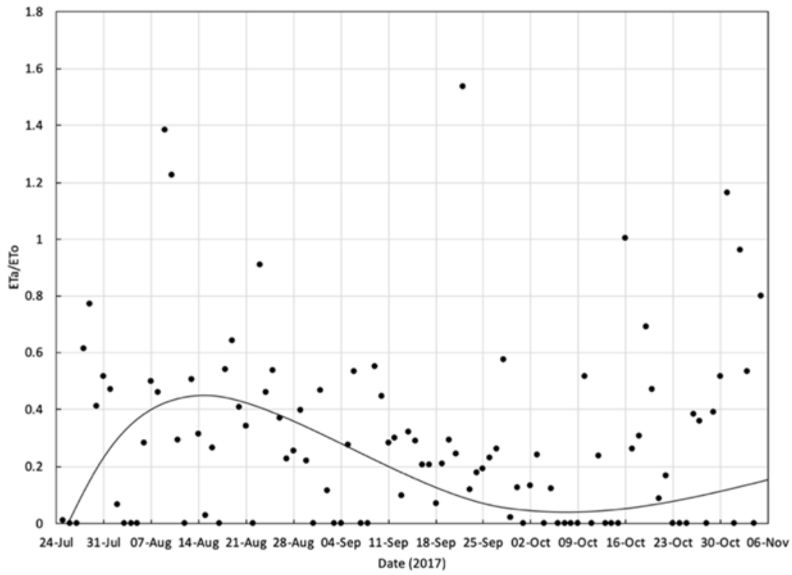

Figure 5 Daily $\mathrm{ET_a}/\mathrm{ET_0}$ During Investigation Period

4 CONCLUSION AND FUTURE WORK

To summarize, measurements of actual evapotranspiration collected with a Smart Field Lysimeter were presented in this study. A total 103 regular days observations of $\mathrm{ET_a}$ were analyzed. To verify the $\mathrm{ET_0}$ model with only temperature data, standard FAO-Penman method and Hargreaves method were used and compared. In consider the higher accuracy of FAO-Penman method, different time step $\mathrm{ET_0}$ were analyzed using Penman equation. The results showed that longer time step will decrease the inaccuracy of temperature based $\mathrm{ET_0}$ model. The research work for this project is still ongoing. ET data will be used as a parameter in constructing a SWMM model for pre-development conditions of the site. Additional climate data is currently being collected from a nearby climate station and will be used for further analysis to evaluate the suitability of temperature-based $\mathrm{ET_0}$ models and standard FAO-Penman models.

LIST OF REFERENCES

Allen, R.G., Pereira, L.S., Raes, D., Smith, M., 1998. Crop Evapotranspiration - Guidelines for Computing Crop Water Requirements – FAO Irrigation and Drainage Paper 56.

H. Hargreaves, G., & A. Samani, Z. (1985). Reference Crop Evapotranspiration from Temperature. *Applied Engineering in Agriculture*, *1*(2), 96–99. https://doi.org/https://doi.org/10.13031/2013.26773

MTE Consultants Inc., 2018. Creek Side Village Burford, Ontario Preliminary Function Servicing & SWM Report.

UMS, 2014. SmartField-Lysimeter User Manual.