Simulation and Validation of Pan Evaporation Using COMSOL Multiphysics^{È} Software

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Abstract: The four foot diameter class A evaporation pan is used by the scientific community as the standard for determining evaporation rates for a number of purposes. COMSOL provides the necessary tools to adequately develop synthetic estimates of evaporation values for input into hydrologic simulation models and other earth science applications.

Keywords: Class A, Evaporation, Pan, Hydrologic, Simulation

1. Introduction

The evaporation of liquid water is a process that involves the transport of water molecules across the interface between the liquid water surface and the vapor phase, as well as the movement of water vapor molecules away from the near water surface into the bulk atmosphere. The physics of diffusion provides a means of quantification of this molecular movement from which insight into the controlling factors of evaporation can be gained.

Many equations have been developed by the scientific community to quantify the evaporation process with most, if not all, based upon empirical studies that fit curves based on meteorological parameters to measured evaporation rates. Table 1 presents a compilation of a number of these equations.

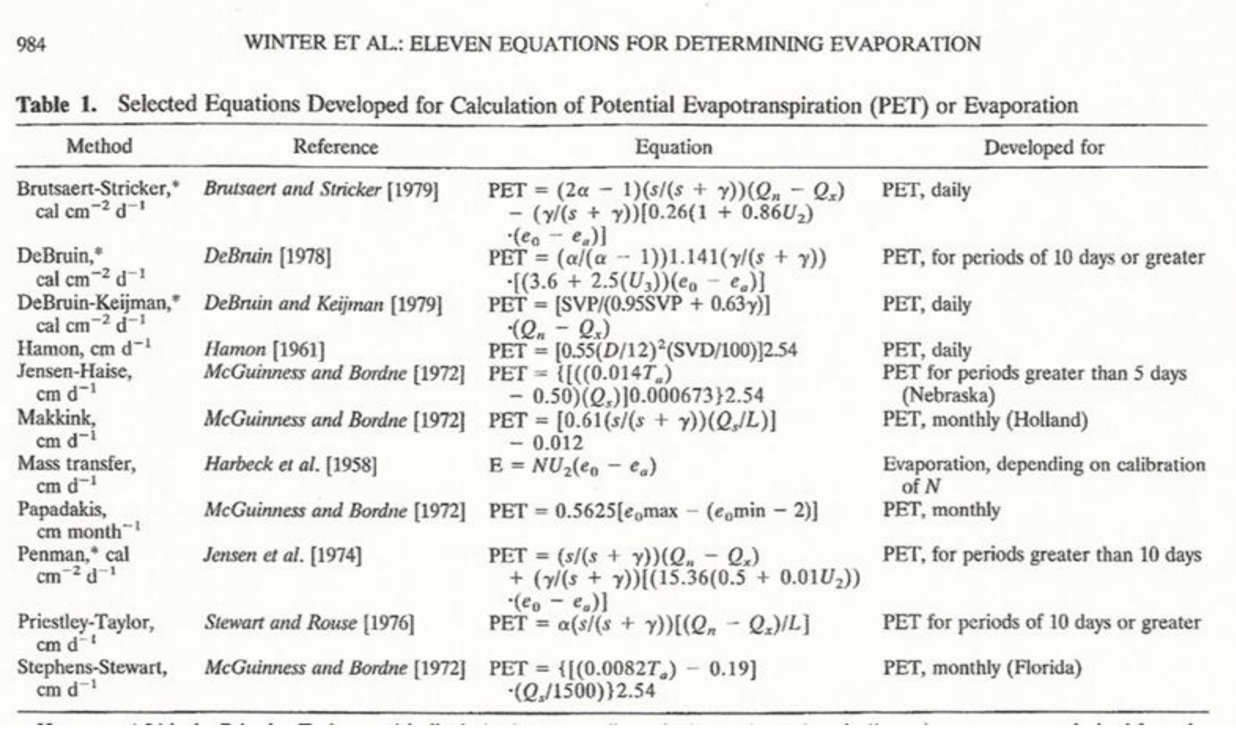

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Table 1. Selected Equations Developed for Calculation of Potential Evapotranspiration (PET) or Evaporation

Method	Reference	Equation	Developed for
Brutsaert-Stricker,* cal cm^{-2} d^{-1}	*Brutsaert and Stricker* [1979]	$PET = (2\alpha - 1)(s/(s + \gamma))(Q_n - Q_x) - (\gamma/(s + \gamma))[0.26(1 + 0.86U_2) \cdot (e_0 - e_a)]$	PET, daily
DeBruin,* cal cm^{-2} d^{-1}	*DeBruin* [1978]	$PET = (\alpha/(\alpha - 1))1.141(\gamma/(s + \gamma)) \cdot [(3.6 + 2.5(U_3))(e_0 - e_a)]$	PET, for periods of 10 days or greater
DeBruin-Keijman,* cal cm^{-2} d^{-1}	*DeBruin and Keijman* [1979]	$PET = [SVP/(0.95SVP + 0.63\gamma)] \cdot (Q_n - Q_x)$	PET, daily
Hamon, cm d^{-1}	*Hamon* [1961]	$PET = [0.55(D/12)^2(SVD/100)]2.54$	PET, daily
Jensen-Haise, cm d^{-1}	*McGuinness and Bordne* [1972]	$PET = \{[((0.014T_a) - 0.50)(Q_s)]0.000673\}2.54$	PET for periods greater than 5 days (Nebraska)
Makkink, cm d^{-1}	*McGuinness and Bordne* [1972]	$PET = [0.61(s/(s + \gamma))(Q_s/L)] - 0.012$	PET, monthly (Holland)
Mass transfer, cm d^{-1}	*Harbeck et al.* [1958]	$E = NU_2(e_0 - e_a)$	Evaporation, depending on calibration of *N*
Papadakis, cm $month^{-1}$	*McGuinness and Bordne* [1972]	$PET = 0.5625[e_0max - (e_0min - 2)]$	PET, monthly
Penman,* cal cm^{-2} d^{-1}	*Jensen et al.* [1974]	$PET = (s/(s + \gamma))(Q_n - Q_x) + (\gamma/(s + \gamma))[(15.36(0.5 + 0.01U_2)) \cdot (e_0 - e_a)]$	PET, for periods greater than 10 days
Priestley-Taylor, cm d^{-1}	*Stewart and Rouse* [1976]	$PET = \alpha(s/(s + \gamma))[(Q_n - Q_x)/L]$	PET for periods of 10 days or greater
Stephens-Stewart, cm d^{-1}	*McGuinness and Bordne* [1972]	$PET = \{[(0.0082T_a) - 0.19] \cdot (Q_s/1500)\}2.54$	PET, monthly (Florida)

Table 1. Evaporation Equations

The four foot diameter class A evaporation pan, displayed in Figure 1, is used by the scientific community as the standard for determining evaporation rates at a specific location for a number of purposes. COMSOL provides the necessary tools to adequately develop synthetic estimates of evaporation values for input into hydrologic simulation models, soil moisture estimates and other earth science situations when deployment or access to pan evaporation studies are not available for a specific location or time period.

Figure 1. Class A Evaporation Pan

The COMSOLalternative to the evaporation pan and/or to the empirical equation approach to estimating evaporation relies upon the first principals of physics, using the fluid flow and mass transfer equations available in the Laminar Flow and Transport of Diluted Species Interfaces in COMSOL Multiphysics. These equations are of the form:

$$\rho\frac{\partial \mathbf{u}}{\partial t} + \rho(\mathbf{u}\cdot\nabla)\mathbf{u} = \nabla\cdot[-p\mathbf{I} + \mu(\nabla\mathbf{u} + (\nabla\mathbf{u})^T)] + \mathbf{F}$$

$$\frac{\partial c_i}{\partial t} + \nabla\cdot(-D\nabla c_i) + \mathbf{u}\cdot\nabla c_i = R_i$$

where:

- ρ **=** density
- t = time
- ∇ = differential (gradient) operator
- c = concentration of the species i
- D = denotes the diffusion coefficient
- R = reaction rate expression for the species i
- $\mathbf{u}$ = velocity vector
- I = identity matrix
- p = pressure
- μ = dynamic viscosity.

2. Methodology and Data

Evaporation simulations can be conducted in either the steady-state or time dependent mode. Steady state simulations use time period averages of commonly collected meteorological parameters such as air temperature, humidity, atmospheric pressure, etc. Time dependent simulations use continuous time series data files over the period of interest and the time step desired.

The 2D model geometry displayed in Figure 2 shows an evaporation pan sited in an open area 100 feet wide similar to that shown in Figure 1. The area under the pan is open to air flow. The domain height of 30 feet allows for complete development of the air flow velocity profile over the pan.

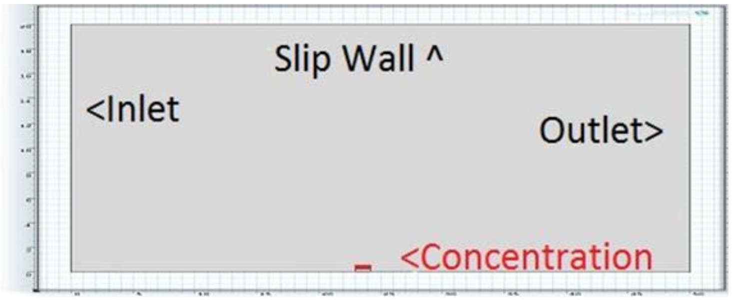

Figure 2. Model Geometry

Parameters used in the simulation include the following:

Ambient air temperature.

Air – water vapor diffusion coefficient. Montgomery presents information on air-water diffusion coefficients. The diffusion equation developed by Fuller, Schettler and Giddings (1966) has been shown to predict water-air diffusion to within about five percent of observed values and is a reasonable tool to estimate the influence of temperature and pressure on diffusion (evaporation). Their equation is directly proportional to temperature, expressed in degrees Kelvin, raised to the 1.75 power. The equation is inversely proportional to pressure, expressed in atmospheres, raised to the 1.0 power. The value used in the simulation described here was .000025 meters squared per second for the diffusion coefficient.

Absolute humidity of surrounding atmosphere.

Saturation vapor pressure at the air-water interface.

3. Analysis and Results

Figures 3 and 4 present the results of the simulation. Figure 3 displays the velocity field developed over and around the evaporation pan. Note that the domain height allows for an unconstrained velocity field to develop. Figure 3 also presents the flux of water vapor movement away from and around the pan.

Figure 4 presents a comparison of average monthly evaporation rates for various average wind velocities entering the domain versus measured evaporation rates at a location in Washington State. The simulated rates compare favorably at the 4 mile per hour average wind velocity for the months of April through September. Meteorological input data and pan evaporation data for comparison was obtained from the Western Regional Climate Center.

Specifically, data used in this analysis was from the Puyallup, Washington Experiment Station collected during the years 1931 to 1995.

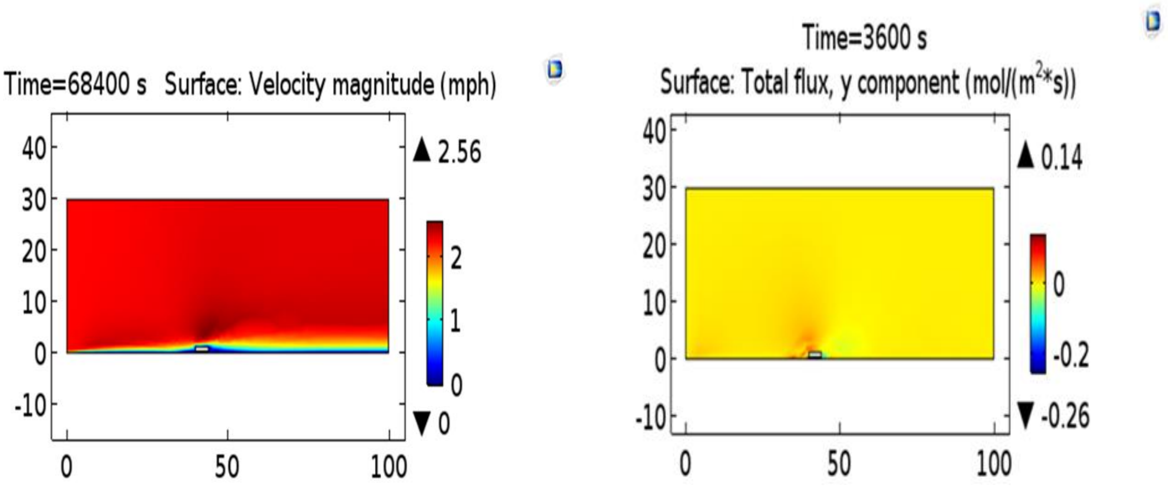

Figure 3. Simulation Results

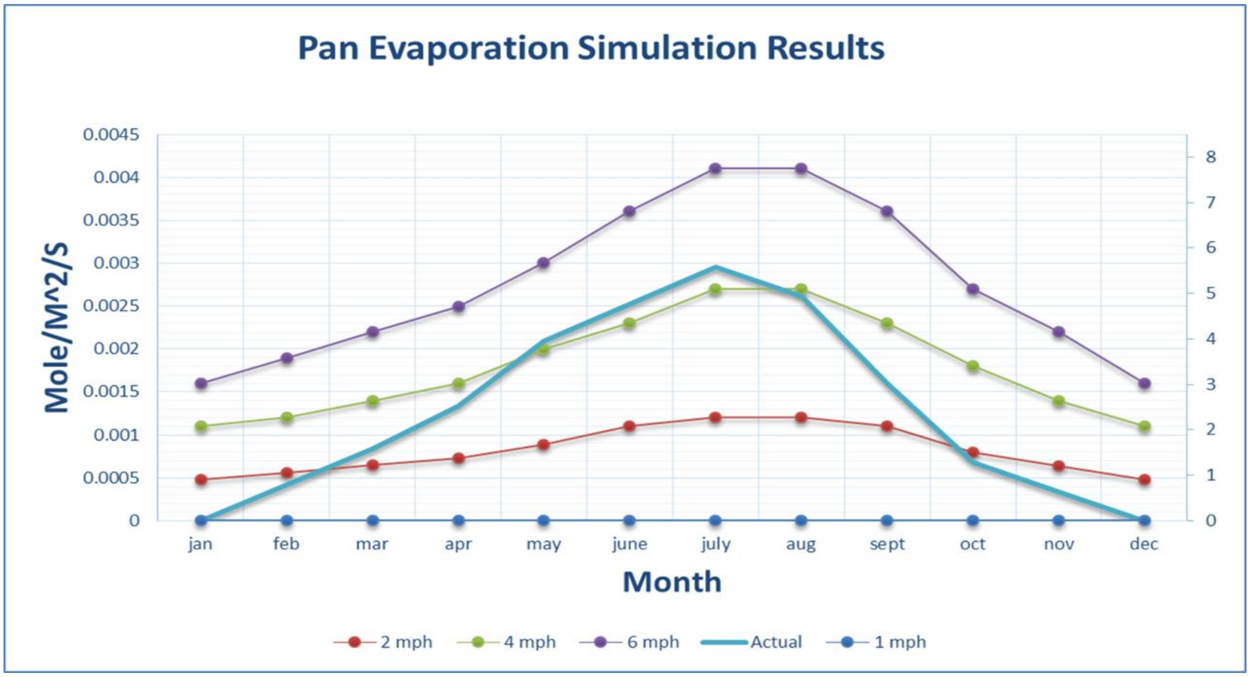

Figure 4. Validation Comparison

4. Conclusions

The simulations, based upon monthly average meteorological parameters compare favorably to the measured values for pan evaporation. Simulations of site specific time series data can be expected to provide similar results. It is reasonable to conclude that the procedure and simulation information presented here can be used, as a minimum, for further investigation and analysis of evaporation simulations.

5. References

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