Available online at www.sciencedirect.com
SCIENCE DIRECT®

Journal of Hydrology 318 (2006) 250–261

Journal of Hydrology

www.elsevier.com/locate/jhydrol

A simulation model for predicting hourly pan evaporation from meteorological data

J.M. Molina Martínez, V. Martínez Alvarez*, M.M. González-Real, A. Baille

Agricultural and Food Department, Polytechnic University of Cartagena, Paseo Alfonso XIII, 48, 30203 Cartagena (Murcia), Spain

Received 2 August 2004; revised 8 April 2005; accepted 6 June 2005

Abstract

The objective of this study was to develop and validate a simulation model of the evaporation rate of a Class A evaporimeter pan (E_{pan}). A multilayer model was first developed, based on the discretization of the pan water volume into several layers. The energy balance equations established at the water surface and within the successive in-depth layers were solved using an iterative numerical scheme. The wind function at the pan surface was identified from previous experiments, and the convective processes within the tank were accounted for by introducing an internal 'mixing' function which depends on the wind velocity. The model was calibrated and validated using hourly averaged measurements of the evaporation rate and water temperature, collected in a Class A pan located near Cartagena (Southeast Spain). The simulated outputs of both water temperature and E_{pan} proved to be realistic when compared to the observed values. Experimental data evidenced that the convective mixing process within the water volume induced a rapid homogenization of the temperature field within the whole water body. This result led us to propose a simplified version of the multilayer model, assuming an isothermal behavior of the pan. The outputs of the single layer model are similar to those supplied by the multilayer model although slightly less accurate. Due to its good predictive performances, facility of use and implementation, the simplified model may be proposed for applied purposes, such as routine prediction of Class A pan evaporation, while the multilayer model appears to be more appropriate for research purposes.

Keywords: Energy balance; Surface temperature; Wind function; Mixing coefficient

1. Introduction

The evaporation process represents a major component of the energy and water balance of natural and agricultural ecosystems. Estimation of the water loss by evaporation is of primary importance for monitoring, survey and management of water resources, at a farm scale as well as at a regional or catchment's scale. Methods developed and improved within the last fifty years (Allen et al., 1998) for estimating the evaporation from water bodies (Penman, 1948) and vegetated lands (Monteith, 1965) used determined climate variables as input data. Along with this approach, the method based on measurements of the evaporation rate from a water tank, E_{pan}, was commonly used as a substitute in

* Corresponding author. Fax: +34 968 32 57 32.
E-mail address: victoriano.martinez@upct.es (V. Martínez Alvarez).

0022-1694/$ - see front matter © 2005 Elsevier Ltd All rights reserved.
doi:10.1016/j.jhydrol.2005.06.016

regions where the input climate variables are not available. Although the use of pan evaporation data is still widespread, few detailed studies have been carried out in order to get more insight on the energy and mass balance of such devices, and on their dynamic behavior with respect to the different variables, parameters and processes that determine the evaporation rate. Emphasis was generally put in determining and adjusting the values of E_{pan} for obtaining the reference rate of evaporation, E_0, or evapotranspiration, ET_0, using an empirical coefficient, K_{pan}, for both agricultural (Doorenboos and Pruitt, 1977; Allen et al., 1998) and hydrological applications (Linsley, 1958; Linsley et al., 1992). Data of E_{pan} are generally available and used at a daily or weekly scale, which may explain why only few studies have been devoted to a better understanding of the process taking place at shorter time scales. However, more knowledge about the short term energy and water balance of evaporation tanks would allow to improve the interpretation of the daily pan evaporation data along with the rules of thumb that are presently applied for extrapolating E_{pan} to larger areas of water or cropped lands. Furthermore, measurements of E_{pan} in hydrological or agroclimatic networks are subject to various sources of errors and uncertainties, so that they need to be checked against an estimated E_{pan} value derived from climate data, that could be used as a criterion for assessing the reliability of measurements.

The state-of-the-art of pan evaporation modelling by means of mechanistic models is rather limited. The main work was the study of Jacobs et al. (1998), which represents at our knowledge the first intent in investigating and modeling the physical underlying processes that drive the daily evolution of variables such as the surface temperature, T_s, and the temperature field. Previous works (Wartena and Borghorst, 1961; Thom et al., 1981; Pereira et al., 1995) dealt with models that did not include a mechanistic description of the driving processes.

In what refers to the issue of estimating the evaporation of large water bodies (dams, lakes), the number of models proposed in the literature is much larger. They generally describe the energy and mass exchanges at a monthly scale, but some of them may be applied at a daily scale (Harleman, 1982). Among these models, a special mention can be made to the *diffusion* models, as the model proposed by Losordo and Piedrahita (1991), which allows a detailed description of energy and mass exchanges at the water surface as well as within the water volume. The main characteristic of this type of model is that the absorption of the incoming solar radiation is considered to take place all along the water depth, and not only at the water surface.

The main objective of the present study is to develop and validate a short term (hourly) model of the evaporation from a Class A pan, based on the estimation of T_s and applying empirical mass transfer equations. Our applied purpose would be to further use this model as a tool for predicting the evaporation of agricultural water reservoirs by extrapolating the validated pan model to water bodies of larger areas (1000–50,000 m^2) and low depth (5–10 m).

2. Materials and methods

2.1. Experimental set up

The data required for the model calibration and validation was obtained from a specific experimental set up implemented in the Experimental Station of the University of Cartagena (Spain, 37.41 lat. N). Two identical Class-A pans were used for the experiments which were located on an uncultivated field following the recommendations of the US Geological Survey. The first tank was completely monitored for measurements of the evaporation rate, E_{pan}, and microclimatic variables (wind speed, air temperature and humidity, water temperature, solar and net radiation), The second tank, measuring only E_{pan}, was used to check the reliability of the evaporation data supplied by the first one. The details of the apparatus, sensors and data acquisition system can be found in Molina et al. (2002a).

2.1.1. Evaporation and water temperature measurements

Measurements of E_{pan} were performed using a system of communicating vessels in which each pan was connected with flexible pipe to an auxiliary reservoir mounted on an electronic balance (Sartorius BP 4100, resolution ± 0.1 g) allowing continuous