Biosystems Engineering (2006) **93** (3), 335–346
doi:10.1016/j.biosystemseng.2005.12.006
SW—Soil and Water

A Simulation Model to generate the Demand Hydrographs in Large-scale Irrigation Systems

R. Khadra; N. Lamaddalena

Irrigation Engineering Department, CIHEAM, Bari Institute, Italy; e-mail of corresponding author: lamaddalena@iamb.it

(Received 13 January 2005; accepted in revised form 9 December 2005; published online 3 February 2006)

The study reports the development of a model for the generation of daily volumes and hourly discharge hydrographs, withdrawn from on-demand pressurised irrigation systems. The model is based on the simulation of the water budget at the level of each single hydrant. Under the hypothesis that the initial soil moisture is at field capacity, once the soil water reserve falls down a pre-defined limit value, irrigation occurs. The farmer's management strategy was simulated using a stochastic approach allowing for the generation of the initial time of each irrigation at each hydrant. The aggregation of the hydrant hydrographs generates the discharge hydrographs at the upstream end of the network. The calibration of the model was carried out comparing the generated and measured hydrographs at the upstream end of an irrigation network in Southern Italy. The results obtained are satisfactory even though they require further verifications. The comparison has generally shown a good correspondence, particularly for daily withdrawn volumes. The simulated hourly discharges showed, sometimes, hourly peaks higher than the measured ones. The proposed model, when well calibrated, can be used for the design of new irrigation systems as well as for the analysis of existing ones.

1. Introduction

Large pressurised irrigation systems allow for better services and higher distribution efficiency as compared to open channel systems. Systems operating on-demand offer the greatest opportunity to meet irrigation requirements as farmers decide when and how much water to take from the network (Labye *et al.*, 1988; Lamaddalena & Sagardoy, 2000). A number of preliminary conditions have to be satisfied: (i) an adequate water tariff of withdrawn volumes, (ii) delivery devices equipped with flowmeter, flow limiter, pressure control and gate valve, and (iii) an adequate design for conveying the demand discharge during the peak period by delivering the minimum pressure head at hydrants for on-farm irrigation equipment.

One of the most important uncertainties in an on-demand system is the calculation of the discharges from the network. As farmers control the irrigation, it is impossible to know, *a priori*, the hydrants operating simultaneously. In such systems, the nominal discharge attributed to each hydrant is much greater than the expected share, so that the hydrant operates for less than 24 h. As a result, the probability of all hydrants being open simultaneously is very low. Thus, it would not be reasonable to design the network for a discharge equal to the sum of the hydrants capacities. These considerations have justified the use of probabilistic approaches for computing the discharges in on-demand systems. However, variabilities related to the discharges flow occur in such systems in relation to scheduling decisions over time depending on the cropping pattern, crops grown, meteorological conditions, on-farm efficiency and management strategy. These variabilities may produce failures related to the design options. Therefore, designers and managers should have an adequate knowledge of the hydraulic behaviour of the system.

The advent of on-demand large-scale irrigation systems in the early 1960s, in France, fostered the development of statistical models to compute the design flows. Examples of such models are the first and the second formula of Clément (1966). Although these

Notation

D_{cycle}	duration, days
D_{MA}	management allowable deficit, %
d	duration of stage, day
d_R	root depth
E_a	on-farm irrigation efficiency
E_{Tc}	actual crop evapotranspiration, mm d^{-1}
E_{T0}	reference evapotranspiration, mm d^{-1}
e	residuals
F	cumulated frequency distribution of the withdrawals
F_A	autocorrelation function
f	frequency distribution of the withdrawals
I	irrigation requirement, mm d^{-1}
K_c	crop coefficient
N	random number
N_p	total population of discharges
P_e	effective rainfall, mm d^{-1}
Q	discharge relative to the peak period, $l\,s^{-1}$
q	hydrant discharge, $l\,s^{-1}$
R_A	regression coefficient
R_B	regression coefficient
S_d	sowing date, Julian day number
t	Julian day number
t_{irr}	irrigation duration, h
u_d	random generator number
V	volumes, m^3
W	soil water content, mm d^{-1}
W_A	available soil water content, mm m^{-1}
W_g	ground water contribution, mm d^{-1}
W_0	allowable depletion, mm d^{-1}
μ	average discharge relative to the peak period, $l\,s^{-1}$

Subscripts

d	day
GS	growth stage
h	hour
i	crop
in	initial
j	hydrant
k	field
L	lag
max	maximum
min	minimum
n	net
T	total
t	time

models are theoretically sound, the assumptions governing the determination of the parameters do not take into account the actual functioning of an irrigation system.

In view of these limitations, a number of researchers tackled the problem by simulating irrigation strategies (CTGREF, 1974, 1977; Béthery, 1990; Lamaddalena & Ciollaro, 1993). Maidment and Hutchinson (1983) modelled the demand pattern over a large irrigation area taking into account the size of the irrigated area, the soil type, the cropping pattern, the irrigation strategy and the weather variation. However, the demand hydrograph had to be averaged out over time in order to avoid unrealistic water demands, which were very high one day and very low the next day. Abdellaoui (1986) proposed a demand model based on the queuing theory. The model generated irrigation water demand hydrographs at any node of an irrigation system by maintaining the soil water balance. This model allowed the determination of the design capacity of an irrigation system, but it is difficult to apply to an on-demand pressurised system because of the short time steps required.

The queuing theory does not consider the farmer's management strategy, nor the topographic location of the hydrants. Fields are usually irrigated even when the system is saturated, with a pressure lower than the minimum required for an appropriate on-farm operation, and hydrants located on a favourable topographic site receive first water despite the queue order, because of the low head the requirement.

The Environmental Protection Agency (EPA) of the United States has developed a model called EPANET (Rossman *et al.*, 1993; Rossman 2000), that performs an extended period simulation of hydraulic and water quality behaviour within pressurised pipe networks. This software requires the demand hydrograph at each node as an input data and does not generate it. Teixeira *et al.* (1995) presented a simulation model to calculate the crops irrigation requirements in the peak period according to the soil type, the cropping pattern, the irrigation method efficiency and the percentage of the irrigated area. The main interest of this model is the possibility of simulating several scenarios and, therefore, allowing the identification of appropriate design conditions, which may be found in order to improve flexibility in operation and management activities. The model does not compute the discharges flowing into the irrigation network.

Walker *et al.* (1995) developed the Command Area Decision Support Model (CADSM) for estimating an