EVALUATION OF MUSKINGUM - CUNGE MODEL WITH SIRMOD SOFTWARE MODELS IN FURROW IRRIGATION ADVANCE PHASE IN SHAHID CHAMRAN UNIVERSITY FIELDS

COMPARAISON DU MODEL MUSKINGUM-CUNGE AVEC LE MODELE DU LOGICIEL SIRMOD DANS LA PHASE D'AVANCE D'IRRIGATION PAR SILLON DANS LES PARCELLES DE L'UNIVERSITE SHAHID CHAMRAN

Mehdi Bahrami[1], Saeed Boroomandnasab[2] and Meysam Salarijazi[3]

ABSTRACT

Prediction and calculation of advance and recession curves in furrows require a series of accurate field measurements which is both time consuming and expensive. The aim of this research was to apply a flood routing method in simulation of advance rate in furrow irrigation and comparing it with results of SIRMOD models. Muskingum – Cunge model was used with 27 series of field data and compared with SIRMOD results. Field experiments were performed in Shahid Chamran University field area, Ahwaz, Iran. The tests were conducted in 3 furrows 60, 80 and 90 m long, 3 discharges of 1, 1.25 and 1.5 ls^{-1} and with 3 replications. For evaluation of the results, 4 indices: average prediction error of model (E_r), distribution around 45° line (λ), coefficient of determination (R^2) and average relative error of model (E_a) were used. According to the results, estimated values of advance phase in all models were more than observed values. Hydrodynamic and Zero Inertia models showed the best results with 11.19% average relative error. Average relative error by the Muskingum – Cunge was 13.475. The study showed that the Muskingum – Cunge model is a suitable model for predicting of advance phase in furrow. Kinematic wave model gave the weakest results with 34.46% average relative error. Results indicated that with a smaller furrow length and higher inlet discharge, predictability of the Muskingum – Cunge model would be better. Finally, the

1 Department of Irrigation & Drainage, Water Sciences Engineering Faculty, Shahid Chamran University, Ahwaz, Iran, Email: mehdibahrami121@gmail.com.

2 Department of Irrigation & Drainage, Water Sciences Engineering Faculty, Shahid Chamran University, Ahwaz, Iran, Email: boroomandsaeed@yahoo.com.

3 Young Researchers Club, Islamic Azad University, Ahvaz Branch, Iran. Email: Meysam.salarijazi@gmail.com

results showed that the Muskingum – Cunge model was simple and found to effectively simulate the hydraulics of the advance phase in furrow irrigation.

Keywords: *Furrow irrigation; Muskingum – Cunge; SIRMOD; Advance phase*

RESUME

La prédiction et le calcul des courbes d'avance et de récession des sillons exigent une série des mesures précises de terrain qui consomme tant de temps que chère. Le but de cette recherche était d'appliquer une méthode de propagation des crues pour simuler le taux d'avance d'irrigation par sillon et comparer les résultats avec ceux des modèles SIRMOD. Le modèle Muskingum - Cunge a été utilisé avec 27 séries de données de terrain et comparé avec les résultats de SIRMOD. Les expérimentations sur le terrain ont été faites dans la parcelle de l'Université Shahid Chamran à Ahwaz en Iran. Les tests ont été menés sur 3 sillons de longueur de 60, 80 et 90 m, avec 3 débits de 1, 1,25 et 1,5 ls^{-1} en utilisant 3 répétitions.

Pour évaluation des résultats, 4 indices suivants ont été utilisés : erreur de prédiction moyenne du modèle (E_r), distribution autour de ligne 45° (λ), coefficient de détermination (R^2) et erreur relative moyenne du modèle (E_a). Selon les résultats, les valeurs évaluées de la phase d'avance de tous les modèles ont été observées. Les modèles hydrodynamique et d'inertie Zéro ont donné des meilleurs résultats avec l'erreur relative moyenne de 11,19 %. L'erreur relative moyenne du modèle Muskingum – Cunge était de 13,475. L'étude a montré que le modèle Muskingum - Cunge est un modèle approprié pour prévoir la phase d'avance de sillon. Le modèle de vague cinématique a donné des résultats les plus faibles avec l'erreur relative moyenne étant de 34,46 %. Les résultats ont indiqué qu'avec une petite longueur de sillon et un haut débit d'admission, la prévisibilité du modèle Muskingum - Cunge serait meilleure. Finalement, les résultats ont montré que le modèle Muskingum - Cunge était simple à utiliser et simulait de manière efficace l'hydraulique de la phase l'avance du système d'irrigation par sillon.

Mots clés: *Irrigation par sillon, Muskingum – Cunge, SIRMOD, phase avance.*

1. INTRODUCTION

Flow in surface irrigation systems is unsteady and non-uniform with reducing discharge, because of infiltration and surface storage. State of advance and recession on soil surface are important parameters in the design and evaluation of surface irrigation. Forecast of advance and recession can be made using two approaches. The first approach is based on hydrodynamic equations of mass and energy (or momentum) conservation or some approximations thereof. Hydrodynamics of surface irrigation have been extensively studied (Oweis 1983; Schmithz, and Seus 1992; Shayya et el. 1993; Abbasi et al. 2003; Esfandiari and Maheshwari 2001; Todini 2007; Bautista and Wallender 1992). The second approach is based on the principle of mass conservation and on an assumption of storage-discharge relation which replaces the energy equation. Several investigators have used this approach (Singh and Yu 1987; Singh and Scarlatos 1988; Fang and Singh 1990; Khooshab 2000; Choudhury 2007). Singh and He (1988) used a mathematical model, based on volume balance and Muskingum type storage-discharge relation, for design and evaluation of furrow irrigation systems. They used weighting coefficients in Muskingum model which are calibrated with experimental data. Thus, these coefficients are constant, whereas they are really variable relative to time and place. The relative error of simulated results was less than 7% for predicted advance phase. Singh and Scarlatos (1988) applied a composite model based on continuity equation and Muskingum approach in border irrigation. They used weighting coefficients too, as change in percent of each these coefficients can affect on result.

In these studies two points were considerable: first, surface flow profile at advance phase was assumed linear, whereas it doesn't occur and inlet discharge to advance phase segment increase gently. Other point is fixed weighting coefficients, whereas they aren't fixed and are function of flow conditions.

Khooshab (2004) combined Muskingum-Cunge and volume balance models and proceeded to flow routing at border advance phase. Sensitivity analysis on model parameters showed that roughness coefficient, slope and time step would be the most effective on θ coefficient computation. Mean relative error of the model was 10%.

This paper develops a mathematical model based on volume balance and an empirical Muskingum-Cunge storage-discharge relation to simulate the water front advance rate in furrow irrigation and compare it with the results of hydraulic models (extant SIRMOD software). The Muskingum – Cunge model operation was performed with 27 series of field data and compared with SIRMOD results.

2. MATERIALS AND METHODS

A. Governing equations:

Governing equations in proposed approach are Manning, volume balance, Lewis-Kostiakov and mass conservation. Components of the Muskingum-Cunge model are the same as used equations in the Muskingum model, but routing parameters are computed by using of hydraulic parameters. Continuity equation that is demonstrator of volume balance at the time period is as:

$$\frac{dv}{dt} = I(t) - O(t) \tag{1}$$

Where $\frac{dv}{dt}$ = volume variation per time; $I(t)$ = the inflow; $O(t)$ = the outflow. Storage volume is a function of inflow and outflow:

$$S = K\left[OI + (I - \theta)O\right] \tag{2}$$

θ = Dimensionless coefficient; K= the storage parameter which is analogous to travel time. Continuity equation for time steps N and N+1 is written as:

$$O^{N+1} = C_1 I^N + C_2 O^{N+1} + C_3 O^N \tag{3}$$

Coefficients of equation can be computed as:

$$C_1 = \frac{0.5\Delta T - K\theta}{K(1-\theta) + 0.5\Delta T} \tag{4}$$

$$C_2 = \frac{0.5\Delta T + K\theta}{K(1-\theta) + 0.5\Delta T} \tag{5}$$

$$C_3 = \frac{K(1-\theta) - 0.5\Delta T}{K(I-\theta) + 0.5\Delta T} \tag{6}$$

As sum of coefficients C_1, C_2 and C_3 equal unity.

And:

$$K = \frac{\Delta X}{C} = \frac{\Delta X}{\partial q / \partial A} \tag{7}$$

$$\theta = 0.5 - \frac{Q}{2BS_0 C\Delta X}(1 - \frac{4}{9}F^2) \tag{8}$$

Where $C = \sqrt{gy}$ is flood velocity; B = width of water surface; F = Froud number; ΔX = the furrow segment length; S_0 = furrow slope.

An important difference between furrow irrigation and river conditions is due to infiltration phenomenon in field. Infiltration can affect this cycle as an outflow similar to lateral channels pour to or branch from major channels or rivers. With this assumption, following relations are presented:

$$O^{N+1} = C_1 I^N + C_2 I^{N+1} + C_3 O^N \pm Q_{LATERAL} \tag{9}$$

$$O^{N+1} = C_1 I^N + C_2 I^{N+1} + C_3 O^N - C_4 \left[\frac{G^N + G^{N+1}}{2} \right] \tag{10}$$

$$C_4 = \frac{1}{K(1-\theta) + 0.5\Delta T} \tag{11}$$

G^N and G^{N+1} = infiltration rate at two consecutive infiltration opportunity times.

Duration of advance phase in each place segment is determined by using volume balance as:

$$\Delta X = \frac{\left[\frac{O^{N+1} + O^N}{2}\right]\Delta T}{\delta_y A_0 + \delta_Z Z_0} \qquad (12)$$

Where δ_z = subsurface flow shape factor; δ_y = surface flow shape factor; A_0 = cross section; Z = infiltrated water depth; O^N and O^{N+1} = outflow in advance phase at beginning and ending of time step ΔT.

Depth of infiltrated water is determined by using Lewis-Kostiakov equation as:

$$Z = kT^a + f_0 T \qquad (13)$$

B. SIRMOD software:

This software was presented by Walker (1989). It is simple in application and includes Hydrodynamic, Zero Inertia and Kinematic Wave models. In this software, Lewis-Kostiakov equation is used for description of infiltration features.

C. Experimental data:

Field experiments were conducted from September 2008 to September 2009 in Shahid Chamran University field area, Ahwaz, Iran. The tests were performed using three furrows with length of 60, 80 and 90 meters, slope of 0.001, three discharges of 1, 1.25 and 1.5 liters per second and three replications. The advance, run off and flow depth were measured in each irrigation operation. Average roughness coefficient was measured using Manning's equation and coefficients of Lewis-Kostiakov equation were measured using two points method. Program of advance phase prediction was written using Visual Basic software. Then, advance curves obtained with Muskingum-Cunge model (MC) were compared with results of models of Hydrodynamic (HD), Zero Inertia (ZI) and Kinematic Wave (KW). The measured advances were compared with simulated values.

3. RESULTS AND DISCUSSION

Results pointed out that the predicted advance values in all models were greater than the observed values (Table 1). This could be because of soil moisture before irrigation, whereas this parameter can not be incorporated in the models. Also results indicated that predictions of Hydrodynamic and Zero Inertia models were similar, which corroborates the result of Esfandiari and Maheshwari (2001). Average relative error of the Muskingum-Cunge is 13.47%, which point out that this model is suitable for prediction of the water front advance in furrows.

Table (1): Average values of needful parameters for evaluation of models

Model	Obs. No.	λ	APE	R^2	ARE
HD	209	1.0746	7.46	98.99	11.19
ZI	209	1.0746	7.46	98.99	11.19
KW	233	1.3678	36.78	98.64	34.46
MC	192	1.1894	18.94	98.40	13.47

APE = Average prediction error; ARE = Average relative error

Figures 1-3 are relevant to adaptation of observed and predicted points. Minimum of average values of λ and maximum of R^2 belong to the Hydrodynamic and Zero Inertia models (figure 1). Values of ARE = 34.46%, λ = 1.3678 and R^2 = 98.64 are demonstrator of Kinematic Wave model weakness than other models at this study (Table 1 and Fig. 2). λ = 1.1894 and R^2 = 98.40 are demonstrator of the Muskingum-Cunge model's fitness to predict of furrow advance phase (Fig. 3).

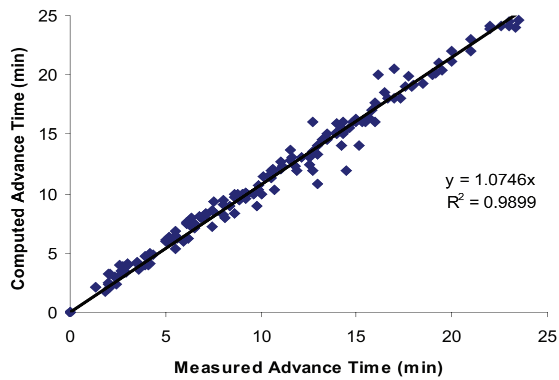

Fig. 1. Computed and Measured Advance time by Hydrodynamic and Zero Inertia

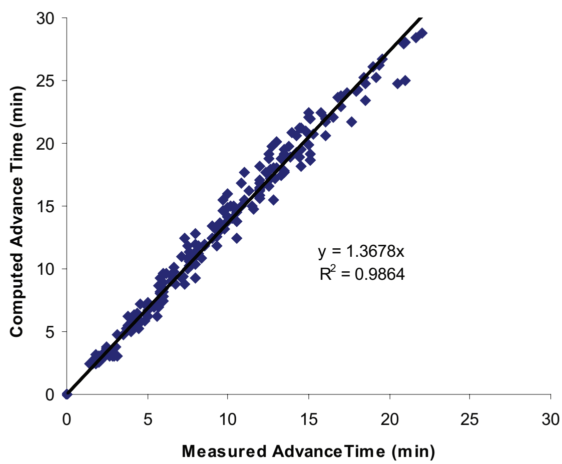

Fig. 2. Computed and Measured Advance time by Kinematic Wave

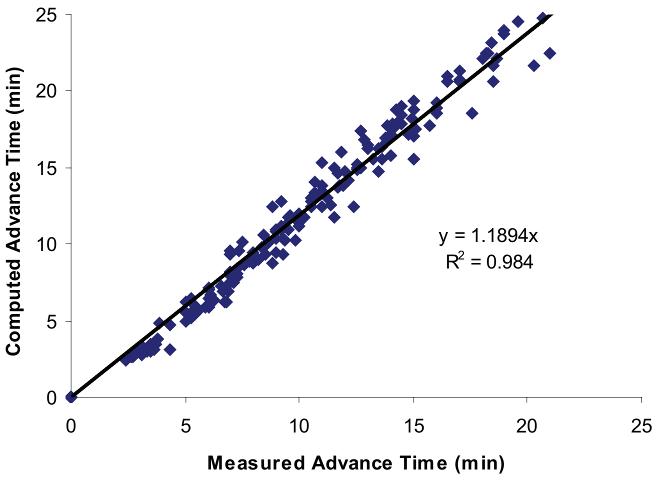

Fig. 3. Computed and Measured Advance time by Muskingum-Cunge

Investigation of Muskingum-Cunge model results indicated that with a smaller furrow length and the higher inlet discharge; predictability of the model will be better. Therefore, with increase in infiltration, decreasing of inlet discharge and increase in roughness coefficient that cause advance lag, furrow diverged from river condition and the Muskingum-Cunge model will not have a high ability at this status.

Considering the results can be said that hydrologic methods applying to surface irrigation systems design is possible. Nonnecessity to calibration, little input data and simple solution are advantages of these methods.

4. SUMMARY AND CONCLUSIONS

Many researchers have tried to solve the basic flow equations with different methods in surface irrigation. They have used well-known models such as Zero Inertia, Kinematic Wave, Full Hydro Dynamic and Volume Balance. The basic goal of this research is application of a flood routing method in simulation of water front advance rate in furrow irrigation and comparing the outcome with the results of SIRMOD software models. Muskingum–Cunge model was operated with 27 series of field data and compared with SIRMOD results. Field experiments were performed in Shahid Chamran University's fields, in Ahwaz, Iran. Experiments were conducted in three furrows with length 60, 80 and 90 meters, with three discharges 1, 1.25 and 1.5 liter per second and at three repetition. According to this research results, estimated values of advance phase in all models is more than observed values. Hydrodynamic and Zero Inertia models owned the best results with 11.19 percent average relative error. Average relative error in Muskigum-Cunge was 13.47 percent, this object shows that mentioned model is suitable for prospect of advance phase in furrow. Kinematik wave model gained the weakest results with 34.46 percent average relative error. Results show that with a smaller furrow length and the higher inlet discharge, predictability of the Muskingum – Cunge model will be better. Finally, the results showed that the Muskingum – Cunge model is simple and found to effectively simulate the hydraulics of the advance phase of furrow irrigation.

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