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RATIOS OF CUTBACK-ADVANCE TIME AND CUTBACK-INITIAL INFLOW FOR BORDER IRRIGATION

(Received: 9.5.2002)

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ABSTRACT

The ratio of cutback time to advance time has been investigated *via* simulating sloping borders with free out-flow. Also, the ratio of cutback inflow to initial inflow has been investigated. The simulation was accomplished utilizing a zero inertia model that describes the movement of water along the borders. The flow was cutback when the maximum application efficiency for a given irrigation parameter was obtained. The irrigation parameters considered were four infiltration families, three slopes, three roughness coefficients, three depths, and two field lengths. The results revealed that there was no unique relationship between the times of cutback and advance. It however was found that the ratio of the cutback time to the advance time was mostly less than one. From a frequency analysis, 80 % of the values of the cutback to the advance ratio are less than 1.0. The ratio of cutback-initial inflow ranges generally from 0.2 to 0.8. The frequency analysis implies that 60 % of the values of the cutback-initial inflow ratio fall in a domain of about 0.4-0.6.

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1. INTRODUCTION

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1. INTRODUCTION

Automation of irrigation systems becomes increasingly and essentially a must. It can help reduce the labor and energy requirements and water consumption. In surface irrigation, automation has been practiced for decades, particularly with variable inflow rate systems, cutback and cablegation as examples. One of the most common methods of minimizing tailwater is to reduce the inflow when the water advance phase is completed (Walker and Skogerboe, 1987). Nevertheless, cutback inflow patterns have been found to be the most efficient system over cablegation and constant (Alazba and Fangmeier 1995). The actual time and degree of cutback are the option of the designer (Cuenca, 1989). Usually, it is aimed to cutback flow when the advance reaches the outlet end of the irrigated field, *i.e.,* cutback time equals advance time. The final inflow rate is equal to one-half the initial flow rate (Cuenca, 1989). This practice may not be a proper strategy of irrigation management and may not allow water conservation. It in fact may lead to a poorly efficient system since it is not appropriate for cutback time or/and cutback flow. To assess the proper cutback time relative to advance time, i.e., the ratio of cutback-advance time (*RCAT*), in addition to cutback flow relative to initial flow (*ROQ*), a simulation of open-end borders with free out flow was performed. The efficiencies were obtained by simulations of the flow across sloping, open-end basins using the zero-inertia option (Strelkoff and Katopodes 1977) in the SRFR program developed by Strelkoff (1993).

2.MATERIALS AND METHODS

2.1. Input data and ranges

The performance of a border irrigation system depends on several input variables that include infiltration, slope, roughness, length, and depth of water. Input data included four Soil Conservation Service (SCS) infiltration families (IFs) 0.25, 0.5, 1.0, and 2.0 (U.S. Soil Conservation Service. (1974). three slopes (S_o) 0.001, 0.0025, and 0.005; three roughness coefficients (Manning's n) 0.04, 0.15, and 0.25; three depths of water ($\bar{d}_{lq}$) 50, 100 and 150 mm, and two lengths (L) 200 m and 400 m.

The IF is presented by the a and k parameters in the Kostiakov (1932) equation which takes the following form:

$$Z = kt^{a} \tag{1}$$

where Z = cumulative depth infiltrated (mm); and t = time (h). The exponent a and the coefficient k (cm/h^a) are empirical coefficients taken from Sritharan (1992) are shown in Table 1 for each IF. Also, the depth of water is replaced by the volume applied, V_a, in order to reduce the number of simulations required to obtain the maximum application efficiency, E_a. The volume applied is computed by:

$$V_a = \frac{L \times \bar{d}_{lq}}{\bar{E}_a} \tag{2}$$

where L = length (m); $\bar{d}_{lq}$= average depth of water infiltrated in the low quarter (mm); and $\bar{E}_a$ = a presumed average application efficiency taken as 80 %. For a given $\bar{d}_{lq}$, it is evident from (2) that V_a depends on the field length. For $\bar{d}_{lq}$ values of 50, 100, and 150 mm and L = 200 m, the volumes are 12, 24, and 36 m^3/m, respectively and for L= 400 m, the volumes are 24, 48 and 72 m^3/m respectively.

Table 1. Infiltration families and coefficients for the Kostiakov equation (Sritharan 1992).

IF (3)	$k(mm/h^a)$ (2)	a (3)
0.25	23	0.556
0.5	33	0.621
1.0	52	0.701
2.0	84	0.730

2.2. Cutback inflow hydrograph parameters

Referring to Figure 1, the cutback inflow hydrograph consists of four parameters, namely initial inflow rate (Q_o), application time (T_{appl}), and ratio of cutback flow (ROQ) and ratio of cutback time (ROT). For a certain combination of the input parameters, the hydrograph parameters should be varied until the maximum application efficiency is obtained. Since the volume under the hydrograph was known, one parameter was computed while varying the others to obtain the maximum application efficiency. The inflow hydrograph parameter computed was the time of application determined from the following equation:

$$T_{appl} = \frac{V_a}{Q_o\left(ROT + ROQ - ROT * ROQ\right)} \quad (3)$$

where T_{appl} = the time of application (min), V_a = volume applied per unit width (m^2); and Q_0 = initial inflow rate per unit width and ROT and ROQ are the time and discharge ratios, respectively, expressed as :

$$ROQ = \frac{Q_{cbk}}{Q_o} \quad (4)$$

$$ROT = \frac{T_{cbk}}{T_{appl}} \quad (5)$$

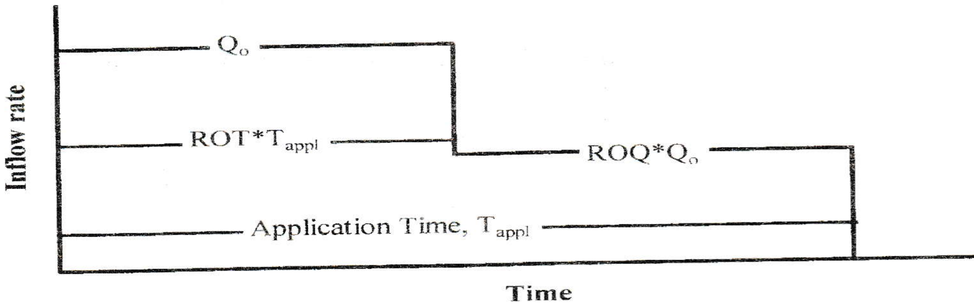

Figure 1. Sketch of cutback inflow hydrograph shape.

where Q_{cbk} = cutback inflow rate and T_{appl} and T_{cbk} = application and cutback times.

The initial values of Q_o, ROT and ROQ are q_{max}, 0.5 and 0.5, where Q_{max} is the maximum allowable inflow rate. The inflow hydrograph parameter that requires special consideration is the initial inflow rate, q_o. This is because soil erodibility and border height impose certain restrictions or limitations on values of Q_o. It should not exceed the maximum inflow rate, Q_{max}, so that soil erosion is avoided nor give a depth of flow, y, greater than the dike height, d_h,, so that overflow does not occur. When the soil erodibility causes the restrictions on q_o, maximum allowable inflow rate, Q_{max}, is obtained using the empirical method proposed by SCS (U.S. Soil Conservation Service. (1974) where Q_{max} is expressed as a function of slope of run, S_o, and type of crop, sod and non-sod, by

$$Q_{max} = C\, S_o^{-0.75} \qquad (6)$$

where Q_{max} is in m^3/sec-m; S_0 = field slope in m/m and C = an empirical coefficient equal to 3.53 x 10^{-4} for sod, and 1.756 x 10^{-4} for non-sod. In simulations with roughness n = 0.25 the value of C for sod was used while for simulations with n = 0.04 and 0.15 the C was taken for nonsod. When the dike height causes the restrictions on q_o, maximum allowable inflow rate is obtained via Manning (1889) equation,

$$Q_{max} = \frac{c_u}{n} y_{max}^{5/3} S_o^{1/2} \qquad (7)$$

where C_u = a unit conversion equal to 1.0 $m^{1/2}/sec$ (1.486 $ft^{1/2}/sec$); and y_{max} = maximum allowable depth of flow assumed to equal 0.15 m. The actual value of Q_{max}, therefore, is the lesser of (6) and (7).

2.3. Performance Parameters

The low quarter concept proposed by the On-Farm Committee (1978) was used to compute the irrigation performance parameters, expressed as follows:

$$E_a = \frac{\bar{d}_{lq}}{d_{appl}} x100 \qquad (8)$$

$$E_s = \frac{\bar{d}_s}{\bar{d}_{lq}} x100 \qquad (9)$$

$$DU = \frac{\bar{d}_{lq}}{\bar{d}_{inf}} x100 \qquad (10)$$

where E_a = water application efficiency (%); E_s = water storage efficiency (%); DU = low quarter distribution uniformity (%); $\bar{d}_{lq}$ = average low quarter depth of water infiltrated (mm), d_{appl} = average depth of water applied (mm); $\bar{d}_s$ = average depth stored (mm), relative to $\bar{d}_{lq}$, that is the average depth of infiltrated depths less than or equal to the average depth stored in the low quarter (mm), and $\overline{d}_{Inf}$ is the average infiltrated depth of water (mm).

2.4. Criteria

For a given set of input data, IF, S_o, n, L, and V_a, the flow is to be cutback when maximum E_a is obtained. This would require that one inflow hydrograph parameter is varied while holding the others constant until the maximum E_a is achieved. To assure high uniformity and adequacy or storage efficiency, DU and E_s should be equal to or greater than 90 % and 95 %, respectively. These values, however, may not be met when q_o reaches its max. In this case, the application efficiency obtained for q_{max} is considered as maximum E_a. These conditions can mathematically be expressed as:

E_a is to be maximized with the following constraints:

$E_s \geq 95$ % , DU ≥ 90 %. and $Q_0 \leq Q_{max}$

Appendix I . NOTATION

The following symbols are used in this paper:

a	= exponent in the Kostiakov infiltration function;
C	= an empirical coefficient; c_u = unit conversions;
DU	= distribution uniformity;
$\overline{d}_{lq}$	= average low quarter depth of water infiltrated;
d_{appl}	= average depth of water applied;
$\overline{d}_s$	= average depth stored;
E_a	= application efficiency;
E_s	= storage efficiency;
$\overline{E}_a$	= presumed average application efficiency taken as 80 %;
IF	= infiltration families;
K	= coefficient in Kostiakov equation;
L	= field length;
n	= Manning's roughness Coefficient;
Q_o	= initial inflow rate;
Q_{cbk}	= final or cutback inflow rate;
Q_{max}	= maximum inflow rate;
S_o	= field slope;
t	= time from the start of inflow;
T_{appl}	= application time;

$RCAT$	= ratio of cutback-advance time;
ROQ	= ratio of cutback-initial inflow;
ROT	= ratio of cutback-application time;
V_a	= applied water volume;
y	= water depth;
y_{max}	= maximum water depth;
Z	= infiltrated water depth;

3. RESULTS AND DISCUSSION

3.1. Ratio of cutback-advance time

Figure 2 depicts the relationship between the cutback time and the advance time. There was no unique relationship between T_{cbk} and T_{adv} as can be reflected from the scattered data. This is due to the interactions of several irrigation parameters, input parameters. Figure 3 shows the ratio of cutback-advance time versus the number of simulations. The figure depicts that the values of *RCAT* mostly fall in the domain of 0.2 to 1.5. Nevertheless, most *RCAT* values were less than one. A frequency analysis was accomplished to find out the number of RCAT values falling in a certain range. Figure 4 depicts that about 80 percent of RCAT values were less than one. Recalling that *RCAT* is usually one, Figures 3 and 4 emphasize the reconsiderations of the *RCAT* value that is being practiced, *i.e.*, RCAT is usually taken to be equal to unity. It can be concluded that cutting back the flow when water reaches the field outlet is inefficient criterian. The proper cutback time should be accomplished with a more theoretical approach.

3.2. Ratio of cutback-initial inflow

Figure 5 shows the ratio of cutback-initial inflow versus the number of simulations. The figure implies that *ROQ* values were less than 0.8 and the values of *RCAT* fall in the domain of 0.2 to 0.8. From the frequency analysis, as depicted in Figure 6, about 90 % of the pints fall in the domain 0.2 to 0.6 and 60 % (average of 90 and 30 %) of the points fall between 0.4 and 0.6. It turns out that cutting back the initial flow to about half is likely efficient. It however is recommended to use a criterion that is mathematically sound.

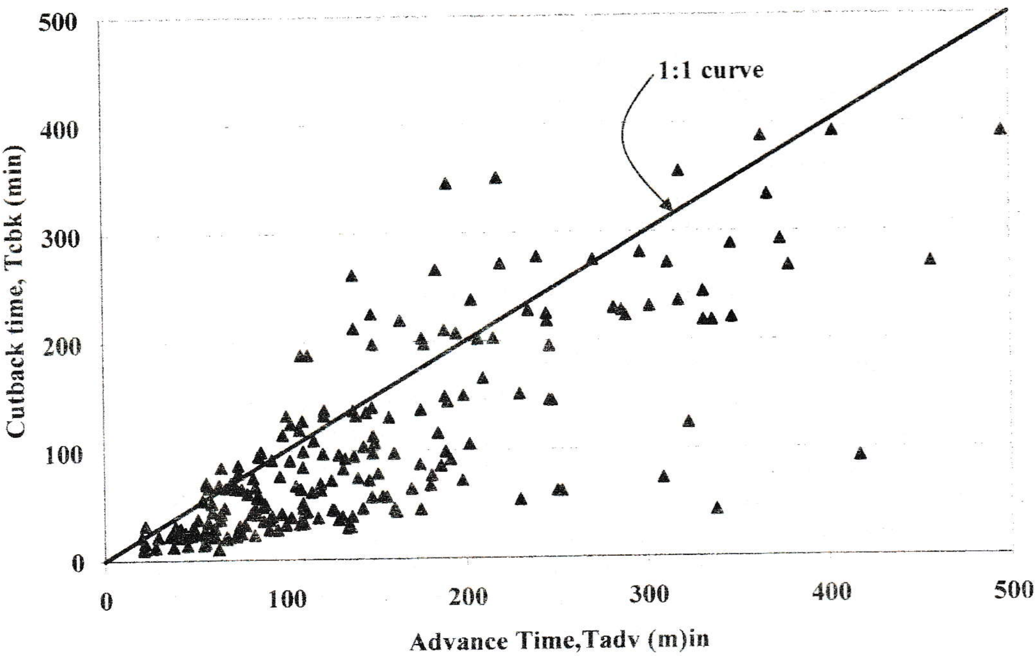

Figure 2 : Relationship between cutback time and advance time.

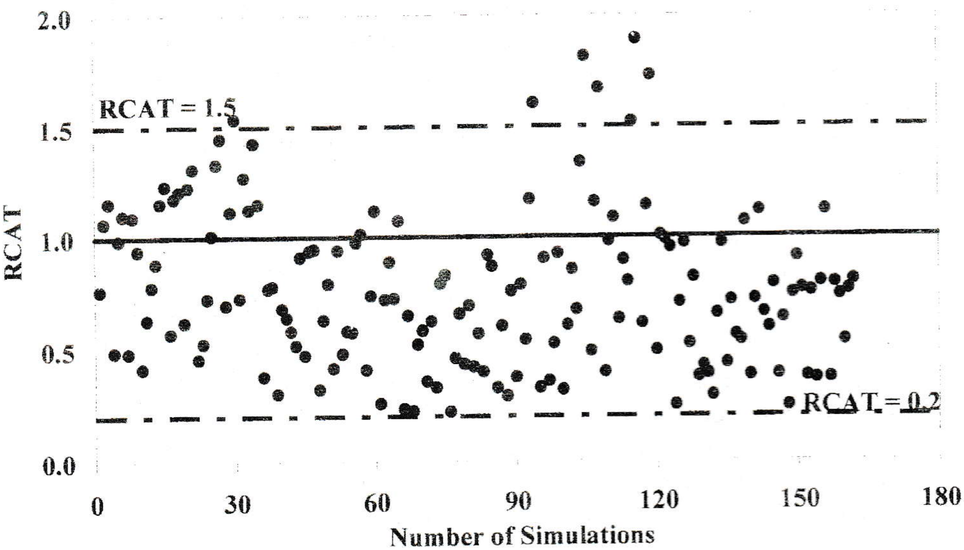

Figure 3. Ratio of cutback-advance time vs. number of simulations.

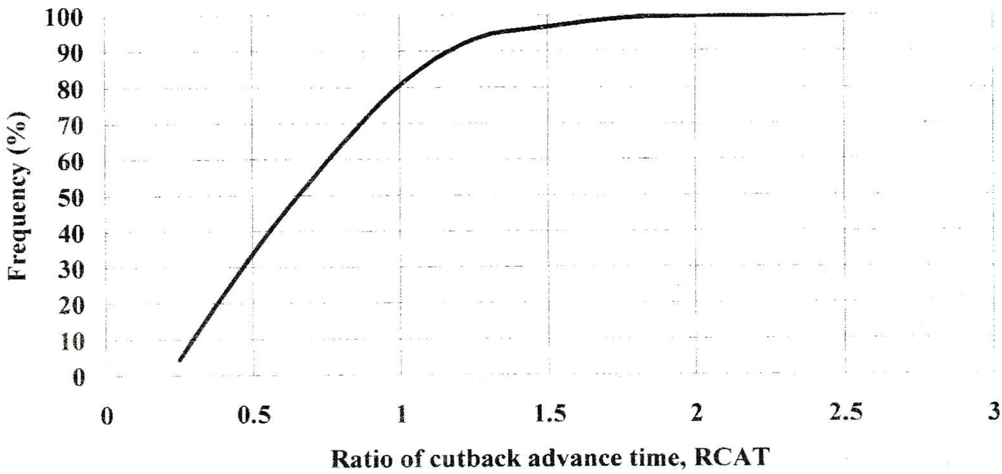

Figure 4. Frequency of ratio of cutback-advance time.

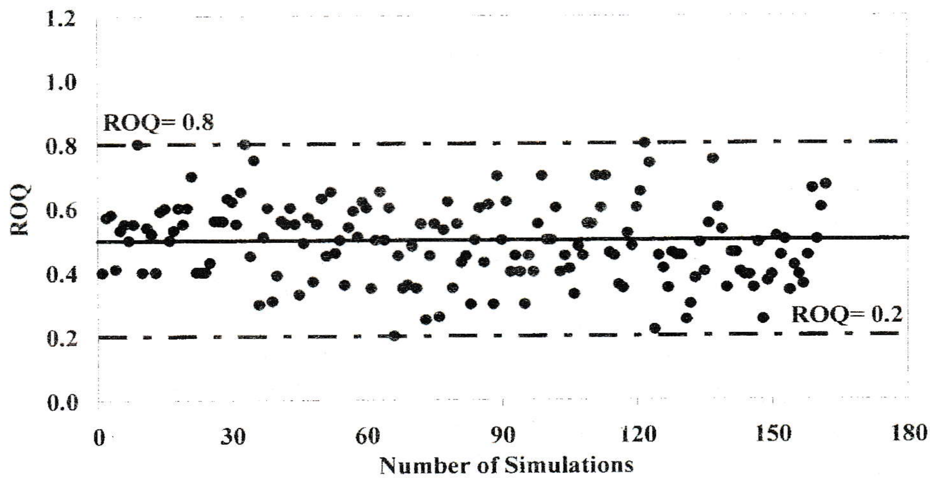

Figure 5 : Ratio of cutback-inflow vs. number of simulations.

3.3. Relationship of ROQ and RCAT

The previous section showed that the practiced criterion of cutting the initial inflow to half will apparently lead to efficient border irrigation systems. This result encourages developing a relationship between *ROQ* and *RCAT* . Therefore, an attempt was made to obtain such relationship. Unfortunately, it was not possible to obtain a mathematical formulation to relate *ROQ* to *RCAT*. An alternative approach was tried by relating *ROQ* to *ROQ/RCAT*. Figure 7 shows that an expression relating *ROQ* to *ROQ/RCAT* is possible to obtain. The relationship has been found to have the following form:

$$RCAT=-0.7854 \cdot ln\left(\frac{ROQ}{RCAT}\right)+0.4757 \tag{11}$$

where *RCAT* is the ratio of cutback time to advance time and *ROQ* is the ratio of cutback inflow to initial inflow. Eq. 11 can be written as follows:

$$RCAT=0.7854 \cdot ln\left(\frac{RCAT}{ROQ}\right)+0.4757 \tag{12}$$

The practically used value of *ROQ* is usually taken to be equal to 0.5. As previously mentioned, the *ROQ* values resulted from the current study are mostly between 0.4 and 0.6, about 60 % of the totals. This leads to the notion that the use of 0.5 for *ROQ* sounds acceptable. In contrast, the *RCAT* has no certain trends and has high variations. Thus, the use of Eq. 11 or Eq. 12 will give a guidance to the proper value of *RCAT* for a given input parameters. The *ROQ* can be taken 0.5 or any value ranges from 0.4 to 0.6, or even from 0.2 to 0.8.

It should be noted that the solution of equation, 11 or 12, is iterative. A numerical technique, Newton-Raphson as an example, can be used to solve for *RCAT*. It should be noted that Eqs. 11 and 12 were developed for maximum application performance of border irrigation according to the criteria presented earlier. Thus, Eqs. 11 and 12 may be misused and its use should be with caution. It should also be bared in mind that the values of *RPQ* and *RCTA* would never mathematically be zeros. Physically, this condition is satisfied by the definitions of *ROQ*, *ROT*, and the ratio of cutback-advance time.

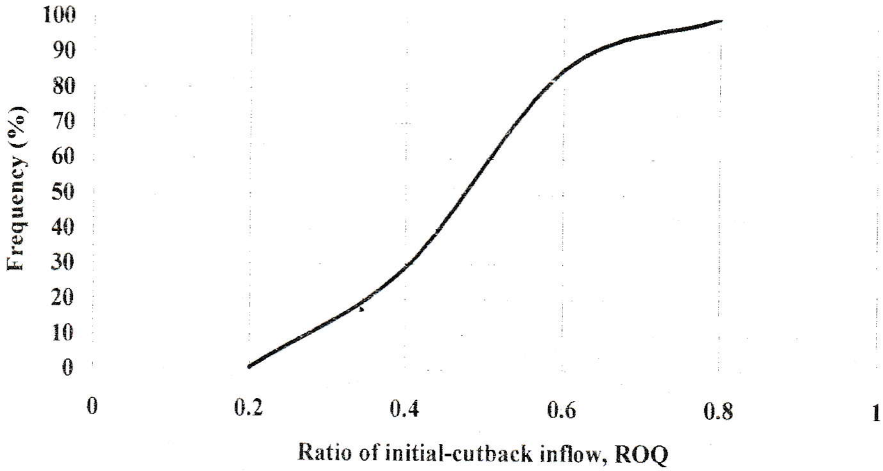

Figure 6. Frequency of ratio of cutback-initial inflow

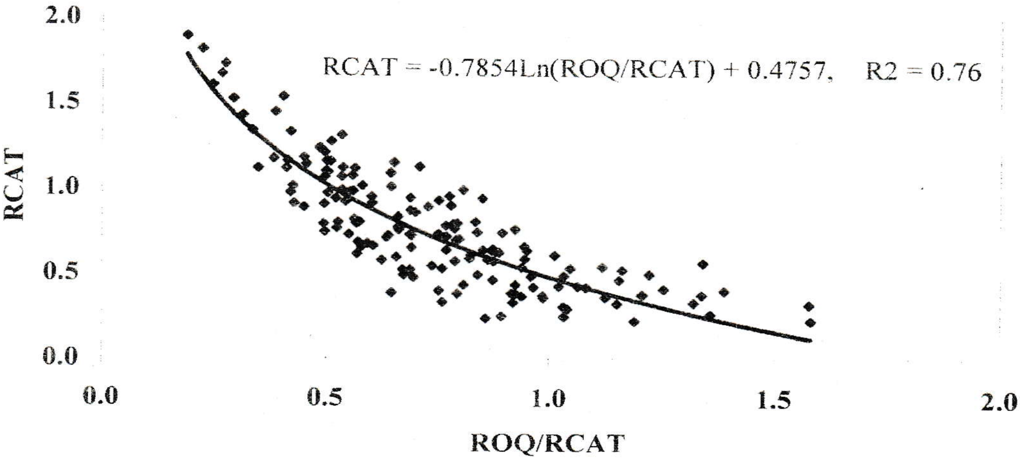

Figure 7. Relationship between ratios of RCAT and ROQ/RCAT

CONCLUSIONS

Sloping open-end borders were simulated to assess the ratios of cutback time to advance time and cutback inflow to initial inflow. The simulation was accomplished for wide ranges of the input parameters using a zero inertia model implemented in a computer program developed by Strelkoff (1993). It was found from simulations that the time of cutback was mostly less than the advance time, *RCAT*<1.0. It turns out that the strategy of cutting back the flow when the water front reaches the field end is not an appropriate practice and should be altered. Furthermore, the use of 0.5 for *ROQ* seems theoretically acceptable and appropriately practical.

4. REFERENCES

Alazba A. A. and Fangmeier D. D. (1995). Hydrograph shape and border irrigation efficiency." Journal of the Irrigation and Drainage Division, ASCE 121 (IR6):452-457.

Cuenca R. H. (1989). Irrigation system design: An engineering approach. Prentice-Hall, Inc., Englewood Cliffs, New Jersey.

Kostiakov A. N. (1932). On the dynamics of the coefficient of water percolation in soils and the necessity for studying it from a dynamic point of view for purposes of amelioration. Trans. Sixth Com. Inter. Sol Soil Sciences, Russian part A, 17-2.

Manning R. (1889). On the flow of water in open channels and pipes. In transactions, Meeting of Institution of Civil Engineering of Ireland, Dublin 20:161-207.

On-Farm Irrigation Committee of the Irrigation and Drainage Division. (1978). Describing irrigation efficiency and uniformity. Journal of the Irrigation and Drainage Division, ASCE 104 (IR1):35-41.

Sritharan S. I. (1992). Equivalent Kostiakov parameters for SCS infiltration families. Journal of the Irrigation and Drainage Division, ASCE 118 (IR1):192-197.

Strelkoff T. (1993). SRFR: A Computer Program for Simulating Flow in Surface Irrigation. U.S. Department of Agriculture, Agricultural Research Service. Phoenix, Arizona.

Strelkoff T. and Katopodes N. D. (1977). Border irrigation hydraulics with zero inertia. Journal of the Irrigation and Drainage Division, ASCE 103(IR3):325-342.

National Engineering Handbook (1974). Border irrigation. Chapter 4, Se Conservation Service (SCS), USDA.

Walker W. R., and Skogerboe G. V. (1987). Surface irrigation: Theory and practice. Prentice Hall, Inc., Englewood Cliffs, New Jersey.

النسب بين زمن الغلق الأولي وزمن التقدم وبين تدفق الغلق الأولي والتدفق الأساسي فى الرى

عبد الرحمن على العذبه

قسم الهندسة الزراعية-كلية الزراعة- جامعة الملك سعود-الرياض -المملكة العربية السعودية

ملخص

تم في هذا البحث دراسة العلاقة بين زمن الغلق الأولي وزمن التقدم من خــلال المحاكاة النظرية لشرائح الري المائلة ذات النهايات المفتوحة. كما تم من خلال المحاكاة معرفة النسبة بين تدفق الغلق الأولي والتدفق الأساسي للماء الداخل لشــريحة الــري. وقــد تم عمل المحاكاة باستخدام نموذج العطالة الصفري الذي يصف حركة الماء فوق سطح التربة على طول شريحة الري. وتمت عملية الغلق الأولــي للتدفق عند الحصول على أقصى كفاءة تطبيق وذلك لكل مجموعة محددة مــن عوامل الري. ولقد اشتملت عوامل الري على أربع عوائل للتسرب، وثلاثة مــيول، وثلاثة عوامل للخشونة، وثلاثة أحجام للتدفق، وطولين للشريحة. وبينت النتائج عدم وجود علاقة محددة بين زمن الغلق الأولي وزمن تقدم الماء، كما بينت أن نسبة زمن الغلق الأولي إلى زمن التقدم كانت في الغالب أقل من الواحد. وجد مــن خلال التحليل التكراري أن ٨٠ % من قيم النسبة بين الزمنين كانت أقل من ١,٠. أما بالنسبة للعلاقة بين تدفق الغلق الأولي والتدفق الأساسي فقد بينت النتائج أن النسبة تتراوح بين ٠,٢ إلى ٠,٨، ومن خلال التحليل التراكمي وجد أن ٦٠ % من قيم النسبة بين تدفق الغلق الأولي والتدفق الأساسي تقع في المدى من ٠,٤ إلى ٠,٦.

المجلة العلمية لكلية الزراعة – جامعة القاهرة – المجلد (٥٤) العدد الأول (يناير ٢٠٠٣) : ٤١-٥٤.