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Performance and Sensitivity of Irrigation Offtakes.

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PERFORMANCE AND SENSITIVITY OF IRRIGATION OFFTAKES

أداء وحساسية مآخذ قنوات الرى

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خلاصة :

غالبا ما تتسبب إدارة وتشغيل قنوات الرى بطريقة غير دقيقة فى توزيع غير فعال وغير عادل للمياه. لذا فإن ضبط المنشآت الهيدروليكية على امتداد قنوات الرى يهدف إلى حالة هيدروليكية الغرض منها تحقيق رغبة الإدارة المائية، إلا أن ذلك قد يؤدى بدوره إلى حالة من السريان الغير مستقر فى قنوات الرى عند بداية التشغيل لفترة ما حتى الوصول إلى حالة جديدة من السريان المستقر. ولدراسة كفاءة توزيع المياه لمآخذ قنوات الرى تم استخدام عاملين من عوامل الأداء والتى تأخذ تأثير السريان الغير مستقر أحدهما هو نسبة الأداء للتصرف والعامل الأخر هو كفاءة التشغيل.

يوجد نوعان من الحساسية لمآخذ الرى أحدهما الخاص بالتسليم والتى تعنى تأثير الاضطراب على توزيع المياه لقناة التوزيع خلال مآخذ المياه. والنوع الأخر الخاص بالحمل والتى تعنى التأثير على التصرف فى القناة الموصلة للمياه. تمكن مؤشرات الحساسية هذه من التعرف على مآخذ الرى الحساسة للاضطراب لتقدير التفاوت المسموح به فى التشغيل ولدراسة الأداء وحساسية مآخذ الرى تم اختيار جزء من ترعة البوهية خلف قناطر ميت غمر على الرياح التوفيقى. حساسية التوزيع على امتداد هذا الجزء استنتج لكل مأخذ باستعمال كلا من المحاكاة الهيدروليكية والطريقة التحليلية.

ABSTRACT

Inaccurate operation and management of irrigation canals often cause inequitable and inefficient water distribution. The adjustment of hydraulic structures along irrigation canals aims to maintain a hydraulie targeted state in order to satisfy the water management objectives. This causes unsteady flow in the canals at the initiation of revised operation till it attains a new steady state. For evaluation of water distribution efficiency to offtakes of irrigatinn canals, two operation performance parameters, which take into account the effect of unsteady flow, were used. The first one is the delivery performance ratio and the second parameter is the operation efficieney. Two types of sensitivity in the analysis of offtakes were considered. The first one is the sensitivity of delivery which considers the impacts of the perturbation on the delivery to the dependent canal through the offtake. The second type is the sensitivity of conveyance which takes into account the effects on the conveyance discharge of the parent canal. Sensitivity indicators enable the identification of sensitive offtakes and assessment of their operational tolerance. Performance and sensitivity analysis for a reaeh of El-Bohia canal downstream Met Ghamr regulator was studied using the numerical hydraulic simulation. Sensitivity of delivery along this reach was estimated for each offtake using both the numerical hydraulic simulation and the analytical approach.

INTRODUCTION

An irrigation system is a set of structures used to convey, control and distribute water to irrigation units. Due to increasing water demands, accurate control of the water flow in any irrigation system is becoming more and more important, but in practice control of water in many irrigation systems is still rather poor.

Unsteady flow in irrigation canal is nearly always a transient phenomenon due to the predominant influence of frietion. The duration of this transient flow phenomenon, or the system response time, ean be considerable for open canals. The system response time can be defined as the period of time which is needed to transform from one steady state into

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another steady state. The impact of unsteady flow on the water distribution will become significant if the operation time interval is short compared to the system response time.

Control of structure is needed to reach or to maintain a desired state of the system. The hydraulic state of the system is defined by the water levels and flow rates, which might vary in time and place. Gates along the canal have to be continually adjusted to maintain a desired water level or offtake discharge. If gates are not set properly and on the right time, water will either be spilled or shortage of water will occur downstream.

In a free surface delivery network, disturbances are externally created by any change of the inflow or the outflow, or internally generated by the structures themselves. External perturbation ean occur as a result of uncontrolled return flow from drainage or an unscheduled variation of withdrawal. Internal perturbations ean occur as a result of the structure operation or due to any deviation of the structure setting.

Good performance indicators should reflect to which extent actual supplies match intended supplies. Sensitivity analysis of irrigation offtakes aims to show the propensity of the system to be affected by perturbations and to help engineers of irrigation agency to identify the location of the sensitive points or sensitive parts of the system in order to minimize possible deviations. Also, it may help to monitor the irrigation system with only limited number of points. These points should be selected on the basis of their sensitivity.

The operational performance and sensitivity analysis for El-Bohia canal at the reach between Met Ghamr regulator and Barhamtosh regulator were investigated using a mathematieal model in which various hydraulic perturbations can be modeled. The length of the reach under study is 16 km and the number of offtakes along this reach is 9 offtakes. Layout of the reach under study is shown in Fig. 1.

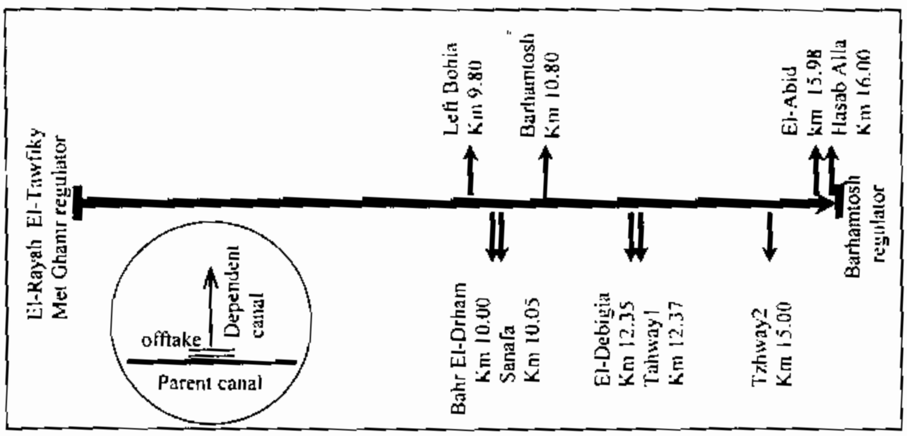

Fig.(1) Layout of the reach under study.

This paper focuses on offtakes performance and sensitivity to demonstrate their use and give more attention to those offtakes where sensitivity is high, in order to maintain deliveries within an acceptable range of variation.

PERFORMANCE OF INDIVIDUAL OFFTAKES

Two sources of water management losses can be distinguished. The first one is referred as "scheduled losses" and is a result of the fact that the scheduled delivery does not exactly follow the water requirements. The second one is called "operational losses" and is a result of the fact that the actual deliveries to the offtakes are not exactly equal to the scheduled deliveries.

In the mathematical model, where the stage discharge curves of all offtakes structures are known exactly and where the operational instruction are followed precisely, the operational losses are a result only of the unsteady flow phenomena.

For the evaluation of the simulated water distribution, two operation performance parameters were defined [6,7]. The first one is called the Delivery Performance Ratio (DPR), which specifies the extent to which an offtake receives its intended supply. The second one is called the operation efficiency (e_o) and specifies the amount of water lost by inappropriate allocation of the water to an offtake. The two parameters are given as follows [6,7]:

$$DPR = \frac{V_e}{V_i} \bullet 100\% \qquad (1)$$

$$e_o = \frac{V_e}{V_a} \bullet 100\% \qquad (2)$$

where DPR = delivery performance ratio

e_o = operation effieiency

V_a = volume aetually delivered (m^3)

V_e = volume effectively delivered (m^3)

V_i = volume intended to be delivered (m^3)

The intended volume to be delivered (V_i) is defined in terms of the beginning and end of supply time, an intended flow rate and an allowable range of variation in flow. The actual volume of water received by an offtake (V_a) is calculated by integration of the supplied flow rate and time. The aetual volume supplied is considered to be an effective volume only when the moment of supply is within the user's defined period of supply and when the flow rate is within the allowable rang of flow rates. Also, The effective volume can never exceed the intended volume. An operation efficiency of 100% indicates that no water has been spilled but this does not mean that offtake received enough water.

OFFTAKE SENSITIVITY

Offtake system is eomposed of the upstream parent canal, the offtake structure, and the dependant canal downstream of the offtake. Main variables for offtake sensitivity analysis are offtake's discharge (q), ongoing discharge in the parent canal (Q), discharge deviation through the offtake (Δq), discharge deviation in the parent canal (ΔQ), water level change in the parent canal (ΔH_{US}), and water level change in the dependant canal (ΔH_{DS}).

An increase or decrease in the offtake discharge produces an impact on the discharge in both of the parent eanal and the dependant canal. An increase in the offtake discharge means that more water is made available for the users of the command area (delivery) and less water is left in the parent canal (convey).

Sensitivity indicator of delivery considers the impaet on dependent canal (command area), while sensitivity indicator for conveyance focuses on the effect of variation of withdrawal on the ongoing flow in the parent canal [8,9,10]. Sensitivity indicator for delivery S_1 is defined as the relative change of delivery discharge ($\Delta q/q$) divided by the absolute change of water depth (ΔH_{US}) in the parent canal, and is written

$$S_1 = \frac{\Delta q/q}{\Delta H_{US}} \qquad (3)$$

The basic hydraulic equations of offtakes structure can be written as follows:

$$q = aA(w)(H_{US} - H_{DS})^{\alpha} \qquad (4)$$

$$q = b(H_{DS} - H_{REF})^{\zeta} \qquad (5)$$

where $A(w)$ = flow section through offtake expressed as function of setting w; w = setting variable of offtake (opening or height); a, b = discharge coefficient; H_{US} = water level in parent canal upstream of offtake; H_{DS} = water level in dependent canal downstream of offtake; and H_{REF} = fixed downstream level taken in dependent canal.

The exponent α can usually be set to 1/2 for undershot conditions and 3/2 for overshot conditions. The exponent ζ will be set to 1/2 for undershot conditions, to 3/2 for overshot conditions and to 5/3 for large rectangular channel under normal conditions [9,10]. Equation (4) reflects the discharge through the structure for the available head losses, and equation (5) relates the discharge to the dependent canal flowing condition.

Sensitivity indicator of delivery can be computed by differentiating (4) and (5) with respect to H_{US} [10] as

$$S_1 = \frac{\alpha}{H_E} \qquad (6)$$

where H_E = head loss equivalent of offtake.

Head loss equivalent, H_E, of a particular offtake, is equal to the head loss of the same kind of offtake (overshot or undershot), having the same sensitivity value but with free flow downstream conditions. Expression of H_E can be written as :

$$H_E = (H_{US} - H_{DS}) + \frac{\alpha}{\zeta}(H_{DS} - H_{REF}) \qquad (7)$$

Sensitivity indicator of conveyance of offtake S_2 is defined as the ratio of the relative variation of ongoing discharge in the parent canal to the change of water height in the parent canal, as a result of deviation (Δq) in the offtake discharge [9,10]

$$S_2 = \frac{\Delta Q/Q}{\Delta H_{US}} \qquad (8)$$

Assuming the variation of ongoing discharge in the parent canal is equal to the variation of offtake discharge, i.e., $\Delta Q = \Delta q$, this indicator can be written as

$$S_2 = \frac{\Delta q/Q}{\Delta H_{US}} \qquad (9)$$

Then by multiplying (9) by q/q and substitute for S_1 from (6), the sensitivity of conveyance can be written as:

$$S_2 = \frac{q}{Q}\frac{\alpha}{H_E} \qquad 10)$$

Background and more details on offtake sensitivity can be found in Renault 1999 [8], Renault and Hemakumara 1999 [10], and Renault 2000 [9].

The input perturbations can be classified into three types. The first one is the downward effect, where upstream water depth perturbation in the parent canal produces an impact on the offtake discharge. The second type is the upward effect, where downstream flow perturbation in the dependent canal produces an impact on the diverted discharge from the parent canal. The third one is the setting effect, where perturbation of the setting of offtake makes an impact on the discharge in both of the dependant canal and the parent canal. In this paper only the first and second types are considered.

HYDRAULIC SIMULATION

Mathematical model was used to study the effect of hydraulic perturbation on offtakes discharge along El-Bohia canal in the reach between Met Ghamr regulator and Barhamtoch regulator. Models of one dimensional gradually varied unsteady flow in rivers can be used as a basis for the model required for the simulation and evaluation of unsteady flow in controlled (irrigation) canals. These models are based on both the equation of continuity and the equation of momentum of De Saint Venant which are partial differential equations of the first order. These equations can be represented as:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_l \tag{11}$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\beta \frac{Q^2}{A}\right) + gA\frac{\partial h}{\partial x} + gA\,S_f = 0 \tag{12}$$

where A = wetted cross-sectional area; g = acceleration of gravity; Q = discharge (through A); q_l = lateral inflow per unit length; h = water level ; t = time; x = space; and S_f = friction slope; β = momentum distribution coefficient.

To solve the set of these two equations, they are replaced by finite difference equations which can be solved numerically. Implicit finite difference Preissmann scheme, a well known, widely applied, and stable scheme [2,4,5] was used to construct the mathematical model. The major feature of the Preissmann scheme compared with the other schemes is its simple structure with both flow and geometrical variable in each grid point [1]. This implies a simple treatment of boundary conditions and a simple incorporation of structure and bifurcation points.

Necessary data of boundary conditions and calibration for the reach under study were obtained from the ministry of irrigation. The model used a computational grid with a space increment of 200 meters and with a time increment of 12 minutes, which is the time of each gate adjustment approximately. After a change in inflow rate had been made and the gates had been set in their new position, the system transformed into a new steady state. So, the period of simulation was based on the largest response time of the reach under study (this equal to 10 hours for the reach under study). The response time is defined as the time needed to transit from one steady state into another steady state [7]. The upstream boundary condition was a specified flow rate at Met Ghamr regulator and the downstream boundary condition was a specified water level at Barhamtoch regulator.

Effective treatment and appropriate evaluation of frictional resistance are vital to successful calibration for the model of one dimensional unsteady flow. The calibration of a model is based on the measured hydrographs which should be reproduced by the model as closely as possible [3]. When a high level of calibration and verification can be achieved, then it may be possible to extent the application of the model beyond the limits of the data used in the verification process.

The mathematical model of El-Bohia was calibrated using different values of Manning's roughness coefficient. Measured water levels at offtakes were used for the process of calibration. Simulated Stage hydrographs were compared with the measured values at offtakes locations along El Bohia canal to get the best value of Manning's roughness coefficient. Fig. 2 depicts the water level comparison at the offtake of Debigia canal. The simulated results obtained by applying n = 0.022 was found, as shown in figure (2), to be more accurate than those obtained by applying both n = 0.021 and n = 0.023 separately to the mathematical model.

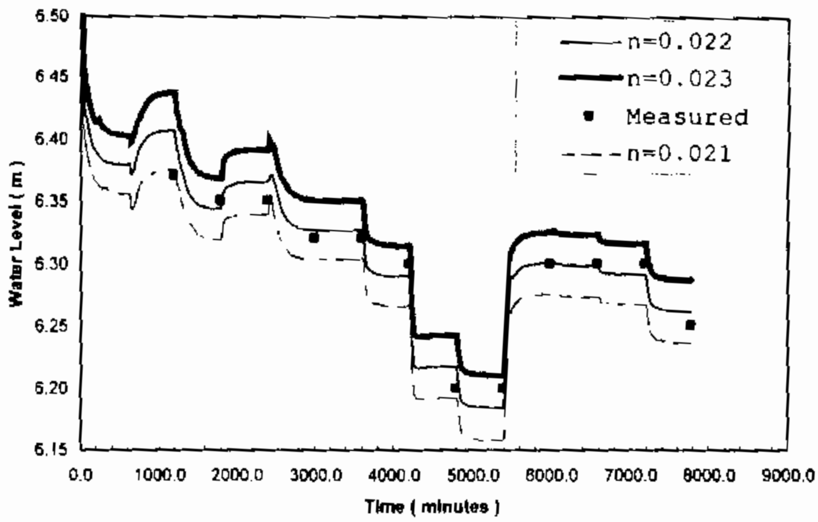

Fig. 2. Comparison between measured and simulated water level at Debigia Canal for different values of Manning roughness coefficient.

RESULTS AND ANALYSIS

Evaluation of The Performance of Offtakes

To investigate the operational performance of El-Bohia canal using delivery schedules, ideally a complete year hydrograph should be simulated. However, this would take too much time and effort as the model time step 12 minutes. Therefore, only the most interesting period was simulated, namely the period of unsteady flow. The results obtained for the period of unsteady flow was converted into results for the periods of time equal to the period between gate adjustments. After a change in inflow rate had been made and the gates had been set in their new position, the flow transformed into a new steady state. So, the period of simulation was 10 hours, which was equal to the response time of El Bohia canal.

The results of the simulations are depicted in Table 1 for 10 hours and two weeks simulation periods. The operation efficiency of 100% indicates that no water was spilled but this does not mean that the offtake did not suffer from water deficiency. The delivery performance ratio (DPR) of 100% indicates that the offtake received enough water but it does not mean that no water was spilled. Therefore both parameters should be considered in the evaluation.

The results of simulations reflect operational losses only and, therefore, they should be expected to be higher than those found in practice, because in the computer simulation the instruction are followed perfectly.

Table 1 Results of simulations for the offtakes performance.

Name of offtake	10 hours period						2 weeks	
	DPR			e_o			DPR	c_o
	Min.	Mean	Max.	Min.	Mean	Max.		
Left Bohia	93.1%	97.1%	100%	99.3%	99.94%	100%	98.3%	100%
Bahr El-Drham	93.8%	97.3%	100%	99.9%	99.99%	100%	98.2%	100%
Sanafa	92.3%	97.1%	100%	99.6%	99.97%	100%	98.4%	100%
Barhamtosh	90.6%	96.7%	100%	98.3%	99.87	100%	98%	100%
El-Debigia	88.3%	96.4%	100%	97.3%	99.79%	100%	97.3%	100%
Tahway1	91.3%	96.8%	100%	97.3%	99.79%	100%	98.1%	100%
Tahway2	92.2%	96.5%	100%	93.6%	99.5%	100%	98.2%	100%
El-Abd	82.7%	93.6%	100%	89.6%	99.2%	100%	95.1%	100%
Hasab Alla	88.7%	96%	100%	93.7%	99.52%	100%	97%	100%

The results show that the offtakes suffered from water deficiency during the 10 hours simulation period (the period of unsteady flow) more than that for the 2 weeks simulation period. So, The effect of unsteady flow due to operation, would be more significant if the system was operated more frequently. Also, The simulated results depicted in Table 1 show that each gate of offtakes and each regulator require a little adjustment to reach a perfect performance.

Offtakes Sensitivity

Sensitivity analysis considers the initial and the final hydraulic subsequent to a perturbation generated by a change of setting. Sensitivity of delivery for Bohia canal was estimated for each offtake using two methods. The first method computes the indicator using results obtained from hydraulic simulation through formula (3). The second method computes the indicator through the analytical formula (6). The results shown in Fig. 3 indicates good agreement between the two method. The standard error and correlation coefficient between analytical sensitivity indicators and the corresponding simulated ones are about 1.85% and 0.99 respectively for the whole range from 0.409 to 0.872. Therefore, it can be concluded that the simulation validated the sensitivity indicator approach for reflecting the general behavior of the system and particularly, in detecting sensitive offtakes within the system.

Variations of offtake absolute sensitivity of delivery and conveyance are displayed in Fig. 4. Some statistical information of offtakes sensitivity are shown in Table 2.

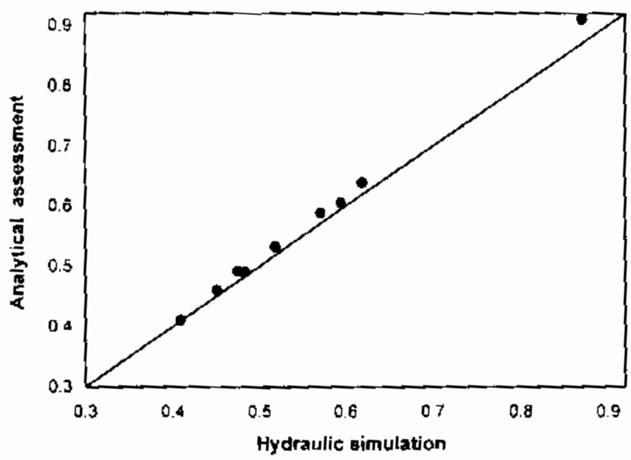

Fig. 3 . Offtake Delivery Sensitivity -Analytical Assessment Results (Eq. 6) Versus The Simulated Ones.

Sensitivity of delivery and conveyance are low for El-Bohia canal. Most offtakes of El Bohia canal have low sensitivity to perturbations. Only two offtakes might be considered a little different (Tahway2 and El-Abd) for having indicators above 0.6.

Hasab Alla nfftake illustrates the advantage of looking at several indicators. It has S_1 value less than 0.6 but is quite sensitive for conveyance S_2 value equal to 0.28. This is due to the fact that the diseharge of Hasab Alla offtake represents a high proportion (20% approximately) of the ongoing flow in the parent canal (El-Bohia canal). Hence this delivery point and the next downstream cross-regulator must be monitored carefully.

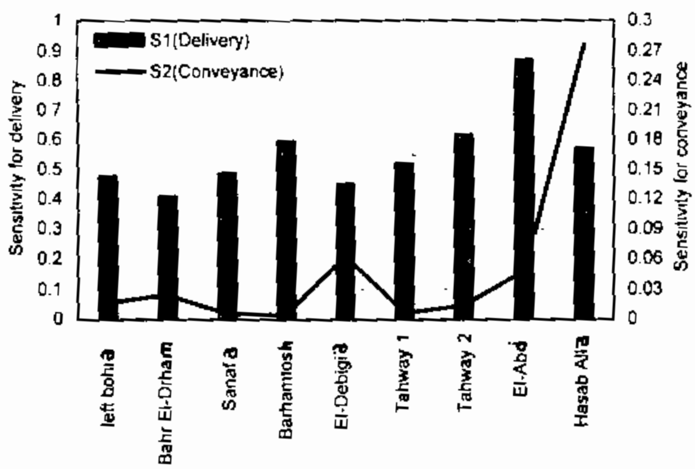

Fig. 4. Offtake Senstivity Indicators of Bohia Canal for The Reach under Study.

Table 2. Statistical information on the sensitivity indicators of El-Bohia canal

Indicator	Mean	Variance	Standard deviation
Sensitivity of delivery	0.556	0.018815	0.137167
Sensitivity of conveyance	0.050829	0.007517	0.086703

SUMMARY AND CONCLUSIONS

To study the hydraulic performance of offtakes along a reach of El-Bohia canal for non-uniform unsteady flow conditions, a flow model of nonprismatic controlled canals was developed. In the mathematical model where the stage discharge curve of offtakes structures are known exactly and where the operational instruction are followed precisely, the operational losses are only due to the unsteady flow phenomenon in the canal system.

The simulated results depicted in Table 1 show that the offtakes structures and main regulator requires a little adjustment to reach a perfect performance. Also, it is clear that the operational losses due to unsteady flow phenomenon can be neglected if the period between gates adjustment is long, in comparison with the response time of the system.

In addition to using a hydrodynamic flow model to study the effect of unsteady flow on the water distribution for normal operational eonditions, the model can be used to review the system's behavior for extraordinary conditions. extraordinary conditions can oceur as a result of unscheduled variation of withdrawal or due to any deviation of the structures setting.

Sensitivity of delivery for Bohia canal was estimated for each offtake using two methods. The first one is the hydraulic simulation through formula (3) and the second method is the analytical formula (6). The results shown in Fig. 3 indicates well agreement between the two method. Therefore, it can be concluded that the simulation validated the sensitivity indicator approach for reflecting the general behavior of the system and particularly, in detecting sensitive offtakes within the system.

Analytical approach(formulae (6), (7) and (10)) is based on physical eharacteristics which can be easily measured or assessed in-site as part of the routine activities. It does not require sophisticated tools or measurements to be effective and therefore it gives a suitable application in any system.

Sensitivity analysis is a good tool which can help engineers of irrigation agency to identify the location of the sensitive offtakes and regulators along irrigation system for operating them more carefully and efficiently.

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NOTATION

The following symbols are used in this paper

a = discharge coefficient;
A = wetted cross-sectional area;
$A(w)$ = flow section through offtake expressed as function of setting w;
b = discharge coefficient;
DPR = delivery performanee ratio;
e_o = operation efficiency;
g = acceleration of gravity;
H_{DS} = water level in dependent canal down stream of offtake;
H_{REF} = fixed downstream level taken in dependent canal;
H_{US} = water level in parent canal upstream of offtake;
q = offtake's discharge;
q_l = lateral inflow per unit length;
Q = discharge (through A), ongoing discharge in the parent canal;
S_1 = Sensitivity indicator for delivery;
S_2 = Sensitivity indicator of conveyance;
S_f = friction slope;
t = time;
V_a = volume actually delivered;
V_e = volume effectively delivered;
V_i = volume intended to be delivered;]
w = setting variable of offtake (opening or height);
x = space;
α = exponent in Offtake discharge equation; The will set to1
β = momentum distribution eoefficient;
ζ = exponent in discharge equation at entrance of dependent eanal;
ΔH_{DS}= water level change in the dependant canal;
ΔH_{US}= water level ehange in the parent canal;
Δq = discharge deviation through the offtake; and
ΔQ = discharge deviation in the parent canal.