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A Scenario Analysis of the Impact of Improved Water Distribution at the Tertiary Level on Water Savings in the Irrigation System

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Abstract: Efficient operation and management of an irrigation system plays an important role in the sustainability of irrigated agriculture. Egypt faces great challenges in enforcing policies to improve the performance of the existing delivery system by implementing more effective irrigation technologies. The objective of this study is to assess the hydraulic behavior of the irrigation network and to investigate the optimal supply-flow discharge. Hydrologic Engineering Center River Analysis System (HEC-RAS Model) was employed in this study. This model was applied to the El-Wasat command area in the Nile Delta by presenting three main cases with more practical operation at lifting points operation. Each case applies three proposal scenarios. These scenarios suggest different ways of delivery scheduling for improved lifting points along with a proposal. The three proposed scenarios in this study are *uncontrolled continuous flow*, *demand schedule*, and *flexible arranged schedule*. Practical cases of operation are presented in different ways for the pumped water unit at lifting points that are *one time*, *lag time*, and *migrate time.* Demand scheduling and/or the flexible arranged scheduling scenarios succeeded in completing full turns through different sections of improved branch canal by different cases of lifting point operation. Especially, flexible arranged scheduling is a better choice for improving water distribution among lifting points in terms of stable water delivery. The study illustrated that the way to improve equitable water allocation should be to reduce water losses downstream of the lifting points as the cultivation of rice crops will be reduced as regulated by the government. The water delivered downstream of the head regulator should be distributed among lifting points through the flexible internal rotation.

Key words: HEC-RAS, simulation, improved irrigation system, tertiary canal, the Nile Delta

1. Introduction

Irrigation, the single largest use of water resources, accounts for about 84% of all withdrawals in Egypt [1]. However, with increasing municipal and industrial needs, its share of water is likely to go down. The challenge is to produce more food with even less water for agriculture as cities and industries take an increasing share and recognizing the need to leave enough water for the environment conservation. The traditional irrigation system in the Nile Valley and Delta relies on gravity flow and pumping through about 30,000 km of public (main and branch) canals and about 80,000 km of private (tertiary or mesqa) canals in the Nile Delta system [2]. The improvement of irrigation systems in the Nile Delta is one of the most important attempts to implement more effective irrigation technologies in Egypt by improving the existing delivery system. One major initiative involves applying the concept of demand delivery in the main irrigation system by installing new automated control gates in branch canals and includes the construction of

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improved tertiary canals. The improved tertiary canals are raised above ground level or take the form of pressurized pipelines to allow for improved distribution along their length from a single lifting point (pump unit) at the head [3].

To improve the performance and efficiency of the irrigation system, irrigation and drainage canals must be managed appropriately; that is, control must function adequately. The main function of an irrigation canal is to deliver water in an accurate and flexible way. According to Burt (1987) [4], J. Schuurmans et al. (1999) [5], water delivery is said to be accurate if the actual supply matches the intended supply, and is considered flexible if the delivery meets the changing water requirements of the users. This main function can be translated into a water level control problem consisting of two parts: First, the water levels in the canals located just upstream of the off-takes and control structures need to be controlled within a sufficiently small range. Second, the water level preferably should be controlled by adjusting the control structures located at the upstream ends of the canal reaches. Several possibilities exist for improving irrigation systems in the Nile Delta through a water-level control strategy. These include automatic gates through branch canals or automatic electronic devices at the head of head regulator. Gates that function as automatic water-level controllers have been developed to control the water level just downstream of the gate.

Chambers (1988) [6] & Bhadra A. et al. (2010) [7] indicated that canal irrigation performance can be improved by shifting the focus of the policy makers and researchers to managing the main canal system instead of trying to improve the distribution of water among the users below the outlet level. Successful irrigation system operation and planning depends on quantifying supply and demand and equitably distributing the supply to meet the demand, if possible, or to minimize the gap between the supply and the demand. The water users' associations (WUAs) have shown that this has improved the irrigation system in the Nile Delta. The equity of water distribution at the mesqas level has improved as the WUAs' rules for farmer participation in the operation and management of the irrigation system have been applied. WUAs have established policy to elect outlet leaders at each mesqa. The leader's job is to plan the scheduling of water at the outlet (gate or valve) and make sure that this outlet follows the irrigation schedule [3]. However, they lack the commitment to identify a plan for cultivating suitable crops between themselves according to the rules of the WUAs because the Egyptian government sets limits for rice planting (50%) according to the availability of water, but farmers exceed the limits by anywhere from 13 to 100 % [3, 8].

Water saving has come to be seen as one of the main objectives of any irrigation scheme, mainly the improved irrigation system in old land (the Nile Delta and Valley) in Egypt [9]. The overall saving at the branch canal level may therefore be rather limited. The physical improvements should largely eliminate the possibility of direct losses from branch canals and tertiary canals (especially tail losses). This irrigation system may also contribute indirectly to reducing surface run-off and percolation losses both by avoiding over-irrigation by head farmers and by improving on-farm water management. So, the main objective of this paper is to evaluate the water management options in the old land within the improvements of the Egyptian irrigation system. The paper also presents some clear strategies or scenarios for to ensure water saving. This will be achieved through the establishment of a water management model. This model covers the operational performance of the water-delivery system (branch canals) to assist in understanding the hydraulic performance of the irrigation system when pump operation units cover the operation at the tertiary canal.

2. Hydraulic-Model Description

2.1 Simulation Program

The simulation program is a model embodying the variables and relationships that characterize an operating irrigation system [10]. The model simulated decision-making at several levels within an irrigation system from the operators of the system, to the farmers, to crop-growth response to irrigation water provided. Fig. 1 is a flow chart that shows the operation of program in this study. At the start of a run, basic data are input to the program including the *selected branch canal (B.C*). Basic information includes the geometry of the irrigation network, the number of lifting points with its areas, the number of farmers, etc. After selecting the irrigation system, the subroutine divides into two secondary subroutines: (*Insert Crop Pattern*) and (*WL Data in B.C*). The first subroutine requires inserting cropping patterns that cover the number of fields for each crop along with their percentage of the area for each lifting point. After that, the program begins to calculate the water requirements corresponding to an irrigation season through the tertiary canal level (*Calculate $Q_{Req.}$ through T.C*) and then converts to calculate the water demand at each lifting point during the irrigation periods (*Calculate Q-Required at Head Lifting Point*). This process connects with the CROPWAT model for calculating water requirements. The second subroutine requires inserting water level data records through irrigation networks that have been selected. This process draws a waterline profile of an irrigation network that depends on a database of geometry data (*Draw Water Surface Profile through B.C*). Once the basic data has been set as data input to program, the operator decides the proposed scenario of the irrigation time schedule among lifting points (*Assume Schedule Time for Operation Lifting Points*). The program converts water requirements at lifting points to water surface profiles through the irrigation network (*Convert Q to WL at Head Lifting Point*). After that, the chart shows that the number of loops and iterations per loop are applied in relation to the boundary conditions of the program. The boundary conditions are water level criteria for the limitation of tail escape, new automatic control gates, and head regulator of the irrigation network. Each loop carries out a number of iterations of the proposed irrigation schedule. This process is continued until the end of the irrigation period. When the final irrigation period has been completed, the final step of the program run is to print out an optimal irrigation time schedule to use during the irrigation season (*Print Schedule Time for Operation among Lifting Points*).

2.2 HEC-RAS Unsteady Flow Model

The Hydrologic Engineering Center-River Analysis

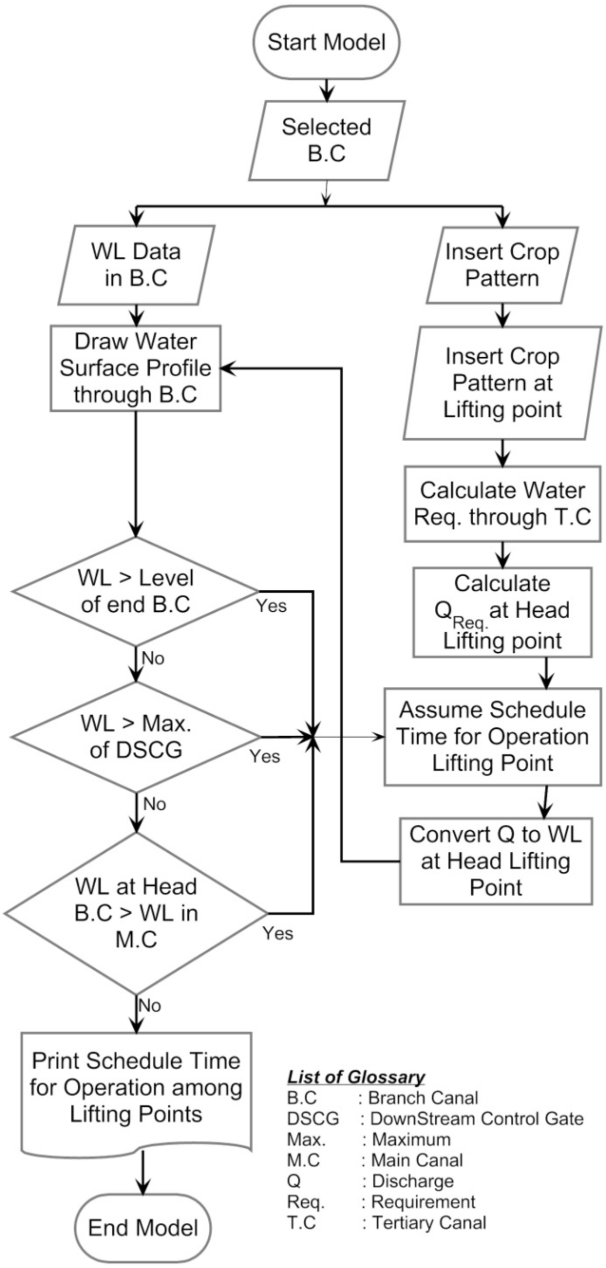


Fig. 1 Flow chart of the demand and delivery simulation at the scale model unit.

System (HEC-RAS) is designed by U.S. Army Corps of Engineers to perform one-dimensional hydraulic calculations for a full network of natural and constructed channels. Water surface profiles are computed from one cross section to the next by solving the energy equation with an iterative procedure called *the standard step method*. The effects of various obstructions such as bridges, culverts, weirs, and gates may be considered in the computations. This paper is to apply the HEC-RAS model (version no. 4.1.0).

Unsteady flow means that the water depth and/or velocity vary with time. In such a case, the longitudinal acceleration is considered, while the vertical and transverse accelerations are neglected. The unsteady flow equation solver was adapted from Dr. Robert L. Barkau's UNET model [11, 12]. Two governing algebraic equations must be explicitly solved because the flow and the elevation of the water surface are both unknown. One of the governing equations is the conservation of water momentum, and the other is the conservation of water volume. A governing equation of conservation of water volume must be explicitly solved for flows and elevations.

Motion Equation:

$$\frac{\partial Q}{\partial t} + gA\frac{\partial y}{\partial x} + \frac{\partial Q^2/A}{\partial x} = gA(S_0 - S_F) \quad (1)$$

Mass Equation:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q \quad (2)$$

where

Q: flow rate; *A*: cross-sectional area; *y*: height of water surface above the minimum point in the cross section; *x*: distance along the channel; *t*: time; *g*: gravitational acceleration; *q*: inflow into channel over or through the sides (lateral flow); S_0: bottom slope of the channel, positive with decline downstream; and S_F: friction slope.

3. Description of Study Area

The El-Wasat command area is selected as the study area because, Paddy rice, one of the most common crops in this area, contributes 40% of the total crop production in Egypt during the summer season. This area is located on the northern edge of the Middle Delta. Due to its location, toward the end of the system, El-Wasat command area receives usually suffers from a shortage of irrigation water. Moreover, farmers tend to plant more fields with paddy rice than the limit set by the government (at 50%), and this causes increased water demand [13]. Therefore, the imbalance of water supply and demand is exacerbated. The El-Wasat area is fed from the tail reaches of the feeder main canal (Mit Yazeed). The feeder main canal is a carrier canal located on the left side of the Bahr Shebeen canal at km 96.50 (Fig. 2). The 63.00 km-long canal feeds an area of about 88,200 ha through 19 branch canals. Various cross regulators are located on the Mit Yazeed canal in order to control water allocation to the different regions served by the canal. El Wasat sub-catchment area is served by the El-Wasat cross regulator located at km 34.70. This catchment area contains three irrigation districts: the Kafr El-Shakh district, the El-Rayed district, and the Sidi Salim districts. There are not adequate control points to distribute water among them. As a result, the performance for tail locations in the canal system is worse than that for head locations [14]. The present study is confined to the irrigation system located in the Kafr El-Shakh district that is called the Dakalt canal. This canal is an earthen branch canal located at km 41.07 on the right side of the Mit Yazeed canal. The canal is about 11.4 km long and serves a command area of about 2,344 ha. Design bed widths vary between 2.0 m and 5.0 m, while the design maximum water levels vary between (+3.4 m) and (+1.1 m). Average bed slope is about 10 cm/km. The concrete tail escape at the end of the canal drains excess water in drain No. 7, El-Asfal, which is one of two main drains serving the area. The Dakalt canal has 17 sub-branches; four have one lifting point, and so they are modeled as direct lifting points, while the others are concentrated at the head location of the canal. The capacity of the Dakalt canal is 79 lifting points through its network (Fig. 3).

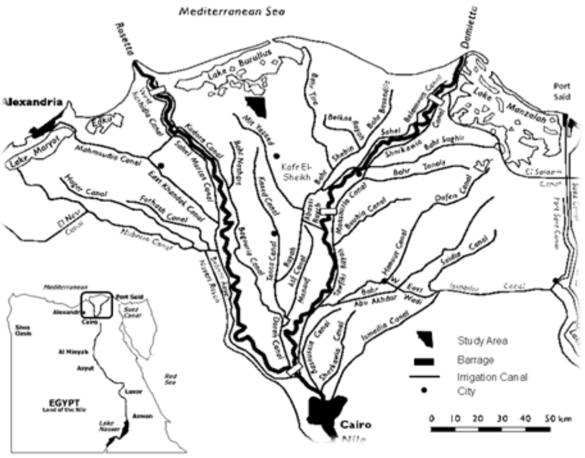


Fig. 2 Layout of the irrigation networks in Wasat command area [3].

Fig. 3 Layout of the irrigation networks in the Dakalt canal.

4. Model Setup

The hydraulic irrigation network is divided into homogeneous sections (*Reach*), the reaches being located between an upstream node and a downstream node. Relations among reaches occur only at the nodes (*Junction*). One can create a different reach for a lined canal zone (low roughness) and an unlined canal zone (high roughness). The division into reaches does not influence the results of the hydraulic calculation. If different regulating or control devices exist across the canal, they can be integrated within a reach and do not need any special division.

4.1 Geometry Data of the Irrigation System

In general, the cross section of the Dakalt canal is within the design cross section for most of the canal. The bed level is lower than the design bed level for many locations. Regarding the bed width, the actual cross sections are close to the design cross section for most of the locations except at the end of the canal when it is smaller than the design cross section. Another point that affects the flow through the canal and its branches is the intake level of the sub-branches and the direct lifting points on the branch canal along with water structures such as bridges, wires, gates, etc. All intakes are covered by the minimum water level, but the head upstream from each of them is different. For head regulators, it is still used to control the canal. The head regulator has two sluice gates. The situation of this gate is bad. For the most efficient management through this study, the control of irrigation water in the head of the branch canal would be modified in this simulation and changed from manual operation to self-operation intended to act in response to the water level downstream. Table 1 presents the main data of types of structures throughout the improved irrigation canal.

4.2 Assumptions and Approximations

It might be impossible to investigate each piece in the canal and its sub-branches. Due to the lack of information, some assumptions were imposed, and some approximations were assumed as follows:

Lifting point efficiency: Efficiency of the pump units in the lifting points is required to calculate the water supply to adjust the water required downstream of the lifting point. The efficiency of the pump units in the lifting points is between 70 and 80% depending on the field survey for all lifting points.

Meaning of the coefficient value: Manning's coefficient values are different from one location to another. This makes some Manning value more suitable even it is not the suitable one. In the Dakalt canal, a constant Manning's (n) value (0.028) was used earth canal excavated in alluvial silt soil, with deposits of sand on the bottom and growth of grass.

Adopting the initial condition: The main problem in the simulation models is treating the dry conditions. In addition, the change from subcritical to supercritical flow pushes the program to a condition of instability. Due to frequent changes in the levels and conditions on both investigated canals with their sub-branches and in the structures, the program was very sensitive to any change in input. To avoid zero depth problems, some adjustments were made to the model. Certain values were respected as possible, and adjustments were made in some assumed data such as initial conditions.

Adopting the boundary conditions: At the tail end of most of the sub-branches, flow hydrographs were used at boundary conditions with zero discharge values as the ends are dead. Flow hydrographs require defining the initial water level, and there was a survey for such values. However, an adjustment was made to keep from stopping the program. In this study, we use the observed tail escape level in the end of the Dakalt canal to compare with results of different scenarios.

Table 1 List of data of main structures in the Dakalt canal.

Structure	Location (km)	Description	Q_Design (m^3/sec)	Water Level (m) (max/min)	Bed Level (m)	Width Level (m)
Head regulator	0	Sluice gate	3.6			
Concrete Br.	0.7	Old				
Head regulator	1.15	Downstream control gate Reliva P 255×170	3.6	+3.4/+2.48 +2.6/+2.45	+1.06 +1.06	7.5 7.5
Concrete Br.	1.378	Old				
Cross regulator (El-Wazaria)	2.865	Sluice gate				
Concrete Br.	3.1	New				
Concrete Br.	5.0	Old				
Cross regulator	5.15	Downstream control gate Reliva P 135x90	2.3	+2.6/+1.78 +1.4/+1.38	+0.70 +0.25	6.0 6.0
Cross regulator (Helal)	5.575	Sluice gate				
Concrete Br.	7.4	Old				
Concrete Br.	7.6	Old				
Concrete Br.	8.0	Old				
Cross regulator	8.4	Downstream control gate Reliva C 140x70	0.6	+1.4/+1.16 +1.1/+1.05	+0.10 -0.20	4.0 4.0
Concrete Br.	8.6	Old				
Tail escape	11.4	Cylindrical 1.44 diameter		+1.25		

4.3 Crop-based Irrigation Operation

Summer season was selected for the model runs as its water demand is higher than the winter owing to the greater demand by the paddy fields. Most of the lifting points have areas that are over 70% paddy field and are located in head and middle locations of branch canals. In order to schedule water supply to the Dakalt canal and its sub-branches, the model that is carried out will depend on bilateral rotation of the area of rice. This rotation divides the full length of the irrigation canal into two roughly equal sections. Each section irrigates 4 days (On days), and is not allowed to irrigate during any other section on stop-work days (Off days). This leaves one off day between two sections and so on with each section. The period of rotation is 10 days for irrigation where land is irrigated once. The month with the highest water requirement for all crops, especially rice, is June. So, this study will simulate water demand downstream of the lifting point in this month only.

4.4 Operating Settings

The first step in operating the lifting point unit is deciding the optimal water management through the tertiary canal level because it allows for flexibility of delivery stream size and equitable water distribution — and for less fuel expense per volume of water pumped. In this study, we propose three cases or ways of operating lifting point units as presented in Fig. 4.

First case: "One Time" means all lifting points in one turn that operate at one time. From the figure, it shows the peak period of operation beginning at 5:00 a.m., gradually decreasing capacity through the end of operating hours for all lifting points that shared in the same turn.

Second case: "Lag Time" means all lifting points in one turn that operate by the lag method. These case objectives decrease the total capacity of lifting points in one turn to almost half. The figure shows that operation hours of all lifting points are constant throughout the day that shared in the same turn.

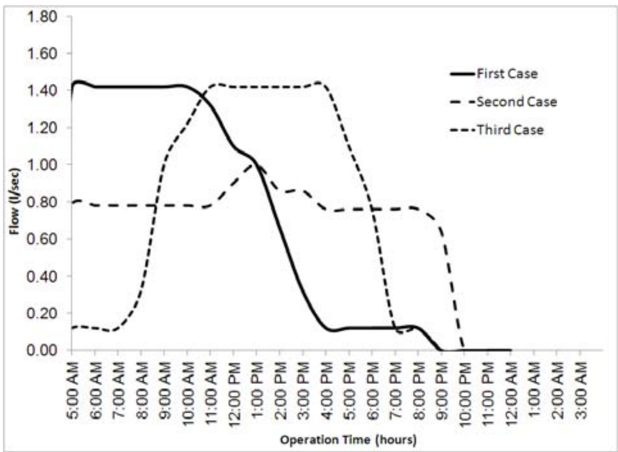


Fig. 4 Operation cases for united lifting points.

Third case: "Migrate Time" means shifting the hours of peak operation from the beginning of the day to the middle. The figure shows that operation time increases gradually from the beginning of operation hours until the middle of day, and then decreases gradually to the end of the day.

5. Application of the Model and Scenarios

5.1 Discussion

More than 70 tertiary canals (Offtakes) deliver irrigation water directly from the Dakalt canal to to the fields. Many factors influence equitable irrigation allocation. Irrigation systems that deliver water to many offtakes can be difficult to manage because of limited water flow, human intervention, malpractice, and various other management and operational inefficiencies. These result in decreasing volumes of water delivered to downstream offtakes. Irrigation schedules are often adjusted to accommodate cultural practices too. Therefore, it may imply the need to give more attention to offtakes in order to maintain deliveries within an acceptable range of variation.

5.2 Model Verification

Calibration the model was made by comparing the calculated values with the observed values. This includes water levels and discharges at different locations of both investigated canals. The downstream of head regulator of Dakalt Canal was selected to check verification of the model. Different Manning coefficients were assumed (1/n =25, 30, 35, 40) at different sections along the Dakalt canal, as shown in Fig. 5. The obtained water flow from the program were compared with the measured water flow at the same canal section. It can be noticed that the measured water flow was very close to the calculated water flow at 1/n = 35. Therefore, this value of Manning coefficient is selected in the numerical analysis model.

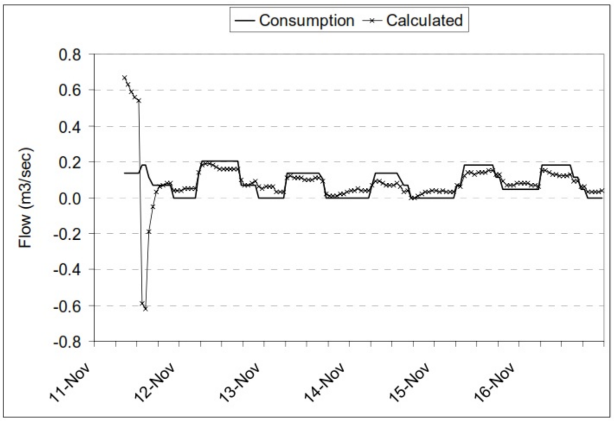
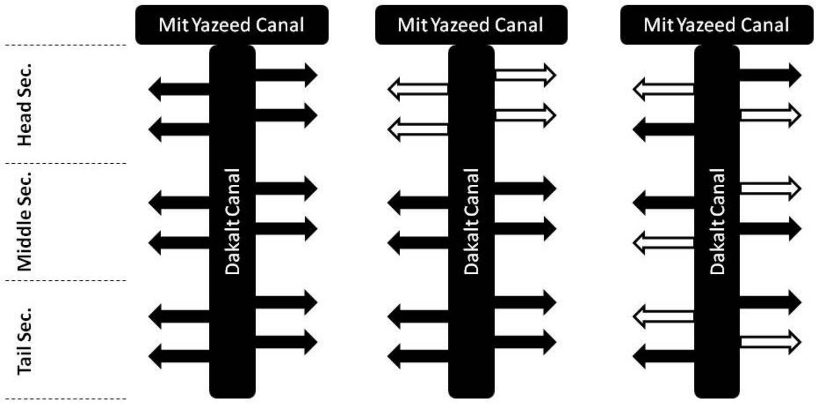


Fig. 5 Total consumption and measured discharges.

This study conducts an analysis of operational performance using hydraulic simulation modeling by introducing the simulation methods to case studies that deal with the irrigation system operation. This study aims to improve the water distribution to the branch canals by proposing alternative rules of operation at the tertiary canal level. These alternative scenarios are proposed within the given strategy of water management as shown in Fig. 6.

5.2.1 Running under the Uncontrolled Continuous Flow

As the term implies, water flows continuously through the Dakalt canal, and all the tertiary canals in this system start to operate at one turn without controlled rules or structures as shown in Fig. 6(a). If the irrigation system is run entirely on continuous flow, it can waste much water, invariably causing a tail-end problem in which farmers close to the water source take most of the water, while farmers at the tail-end of the canal system get no water at all. However, small schemes for paddy can nevertheless be run successfully with continuous flow, especially if the source of the water is a run-of-the-river diversion weir. With this system, there is no attendant risk of wasting stored water, nor is there any power as in a lift scheme. Large schemes are often operated on a partially-continuous flow basis, with the head reach of the main canal flowing constantly and rotational scheduling taking over farther down the canal system [15].

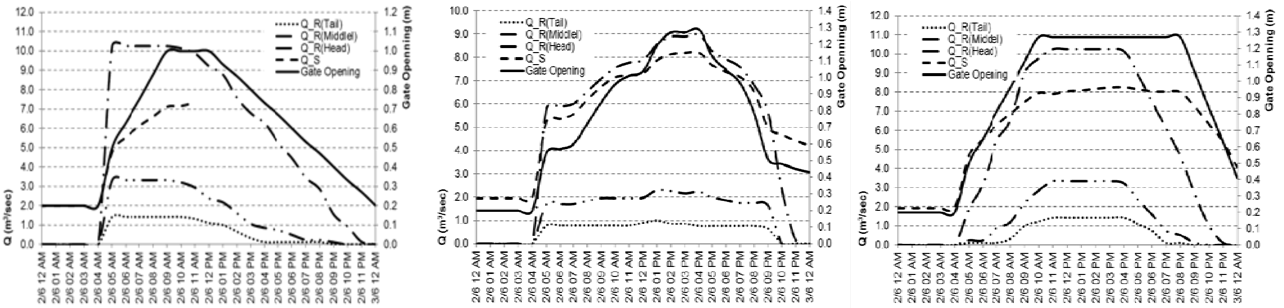


(a) Continuous flow (b) Demand scheduling (c) Arranged scheduling

Fig. 6 Sketch of proposed scenarios.

In this scenario, the calculated consumption rates were to be applied to all lifting points with three cases of lifting point operation. The results of this scenario are shown in Fig. 7. For the first case, the model stopped running on the first day of operation at 11:00 a.m. For the third case, the model stopped running completely after the first day of operation. While for the second case, the model was completed to the end of the first turn, which means it was running four complete days. The first case stopped due to a water shortage; the waterline profile became zero in the middle and the tail reaches of the Dakalt canal. In addition, the waterline was unstable in the end reaches of the sub-branches. The third case had the same situation as the first case. This is because the design of this canal under the rotation system before being improved was around (3.6-4 m^3/sec), while the capacity load of the canal can reach 1.6 times the capacity of this design (6-7 m^3/sec) [14]. However, the water required downstream of the irrigation system was 10 cm^3/sec for both cases as shown in Fig. 7(a) and (c). This means that the maximum capacity of the Dakalt canal cannot sufficiently deliver all this water demanded at one time. In addition, the velocity of the downstream control gates that were installed throughout the Dakalt canal for opening and/or closing cannot pursue accumulating water levels upstream of these gates, which causes flooding upstream and shortage of flow downstream.

In the second case in Fig. 7(b), decreased water demand downstream of the head regulator matched the maximum capacity of the canal for flow delivery. On the other hand, this case did not improve water saving through the irrigation network because excess water ran to drainage at end of the Dakalt canal as shown in Fig. 8. In addition, some sub-branches in the head location of the Dakalt canal had water scare through its tail reaches during model running.



(a) First case (b) Second case (c) Third case

Fig. 7 Results of first scenario downstream of the head regulator of the Dakalt canal.

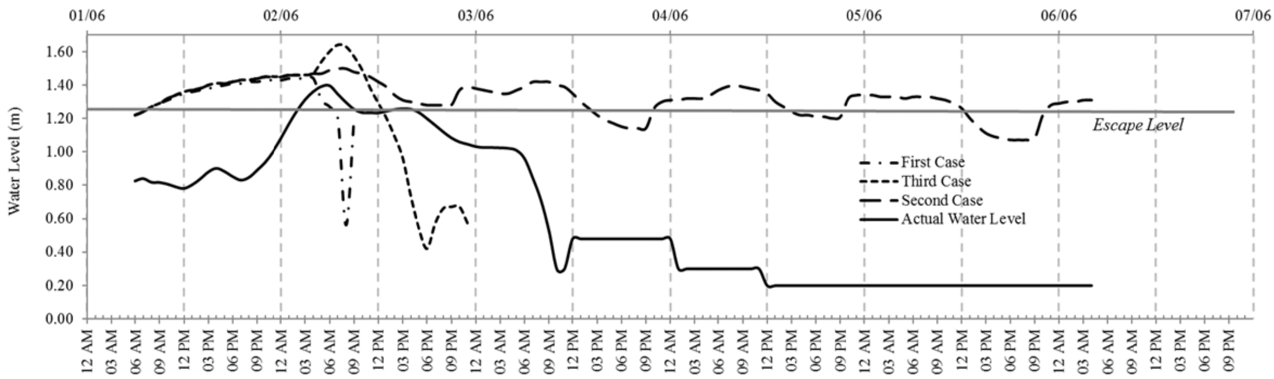
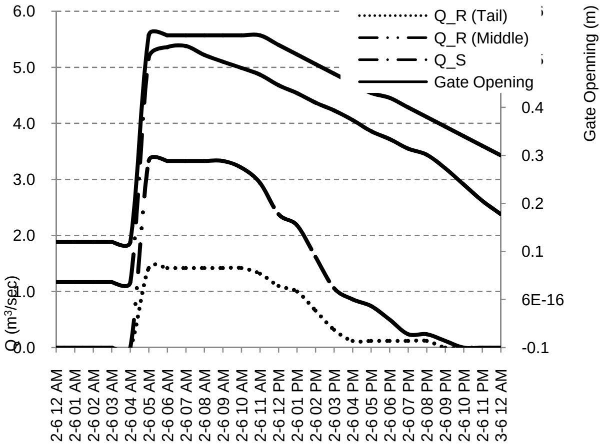


Fig. 8 Water surface profiles at the tail escape in the Dakalt canal through three cases for the first scenario.

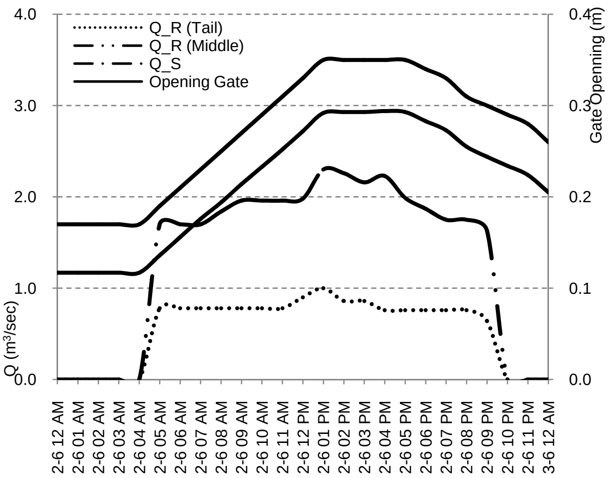
5.2.2 Running under the Demand Scheduling

In a demand schedule, water supply is controlled from the bottom up, that is, from the farmers, who take water as they need it while applying a rotation schedule along the Dakalt canal system. Water is fed down each tertiary canal, and the other level is closed until its turn comes around again, as seen in Fig. 6(b). This regular 10-day schedule is made from two levels that are among lifting points. The first level, the middle and tail location together, starts the first turn. The second level, the head location, starts the next turn. The advantages of demand scheduling are that it is flexible and can accommodate individual farmers' needs. Demand scheduling also reduces problems in management and decreases loading on the Dakalt canal to deliver flow. Consequently, it can be very efficient in water use and distribution. Its basis is the downstream control gates of the canal, and the discharge is controlled by the end user from the downstream end of the system. According to Laycock (2007) [15], the schedule offers the chance for increased crop yield, savings in labor costs, a reduction in water wasting, and a consequent reduction in problems of salinity and drainage. It means a free choice of crops as long as water is available, but also an increased capacity at the downstream end of the system.

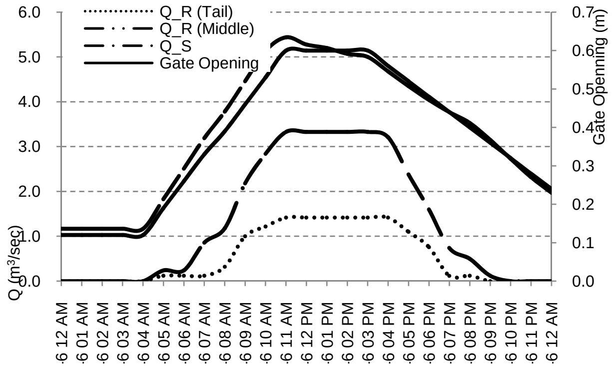
The results of this scenario are shown in Fig. 9. The three case models ran to the end of the day of operation for the first and second turn's periods. The main reason is that maximum water demand downstream through both turns was lower than and/or equal to this system's maximum operating capacity (~7 m^3/sec). On the other hand, some of the sub-branches located in the head were exposed to water shortages in the end reaches through three cases. This is a normal situation because these sub-branch canals are not ready to deliver flow at the same time for all areas served by all the lifting points.



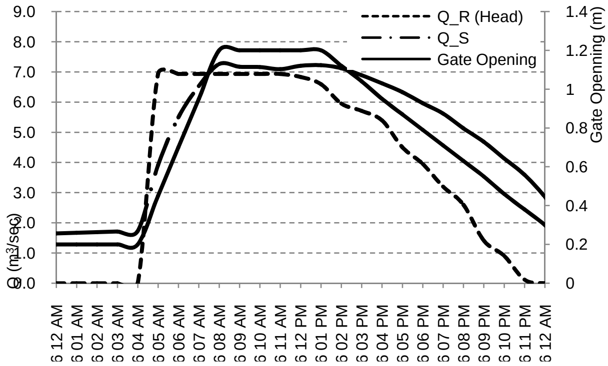
(a) First case (First turn)



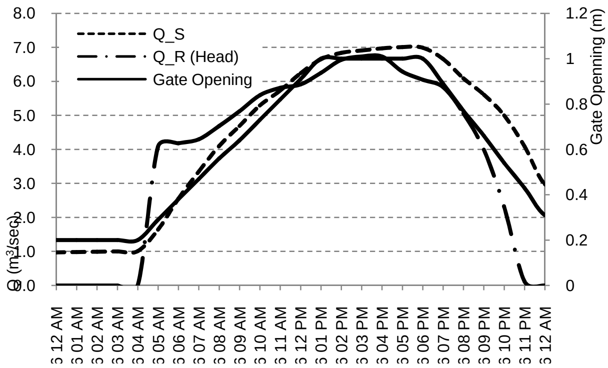
(b) Second case (First turn)



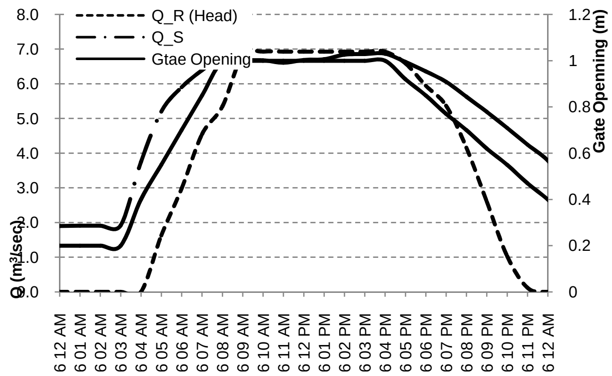
(c) Third case (First turn)



(d) First case (Second turn)



(e) Second case (Second turn)



(f) Third case (Second turn)

Fig. 9 Results of second scenario downstream of the head regulator of the Dakalt canal.

By comparing water surface profiles for three cases at the end of the Dakalt canal in Fig. 10, we found there were losses of water draining through the first turn when operating the middle and tail locations at the same time. While the second turn was operating, there was not water loss from operating the head reach only through this turn. The second case demonstrates a good way for operating the lifting in the second scenario because the volume of water lost to draining was lower than in other cases because the average water level through the first turn is 1.3 m, while the average water level is 1.7 m and 1.5 m for the first and third cases, respectively. The third case causes water shortages during the running.

5.2.3 Running under the Flexible Arranged Scheduling

Flexible arranged scheduling is similar to the idea of demand scheduling, driven purely by demand. Arranged scheduling imposes some degree of self-management, usually through a water users' association among tertiary canals level. In its most elementary form, a record is kept of the number of farmers on each tertiary canal level wishing to take water on any particular day. If this exceeds a threshold amount established during the design, some farmers will be scheduled for the following turn as shown in Fig. 6(c).

Through this simulation, we selected partial lifting points from all sections of the Dakalt canal (head, middle, and tail) to work together in one turn, and on the following turn, we selected other lifting points. So, we proposed some rules for this selection to help flexible arranged scheduling. The rules are as follows: (i) Select one lifting point from two lifting points in the same location through one turn; (ii) Select one lifting point from both sides through one turn; and (iii) The total water demand in one turn is better to convergent with total water demand in the second turn.

The results of this scenario are shown in Fig. 11. The models of the three cases ran completely to the end of the day of operation for the first and second turn's periods. The main reason for these cases is that the maximum water demand downstream through both of the turns was lower than and/or equal to the maximum operating capacity of this system (~7 m^3/sec). In addition, all of the sub-branches in different locations operated without exposed water shortages in the end reach through three cases. This is a normal situation because these sub-branch canals deliver flow at one time for all areas served with half of its capacity.

By comparing water surface profiles for three cases at the end of the Dakalt canal in Fig. 12, we found water losses through draining for all three cases through both turns. However, the third case is a good way to operate lifting in the third scenario because the volume of water lost to draining was lower than in the other cases. For the first and the third cases, the water surface profile was regulated in flow and stability of distribution throughout the Dakalt canal, while for the second case, the volume of water loss was high and unregulated through the Dakalt length.

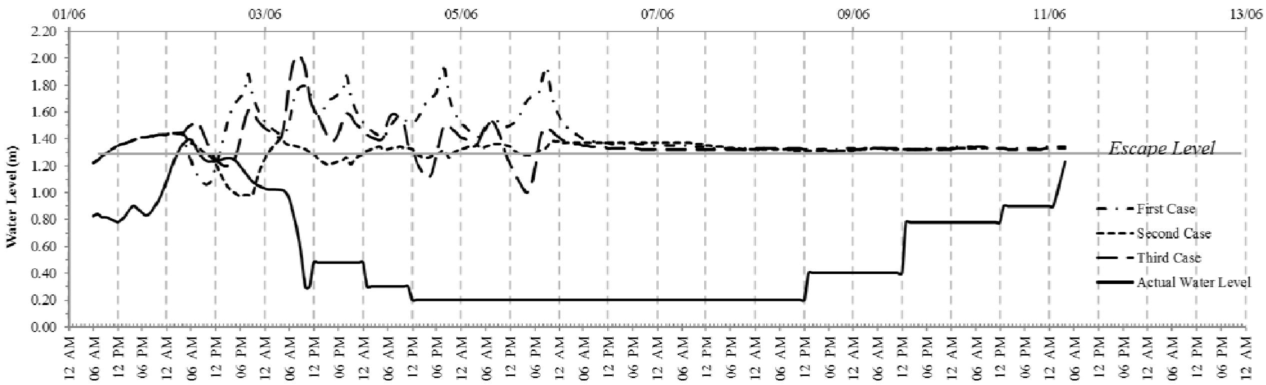
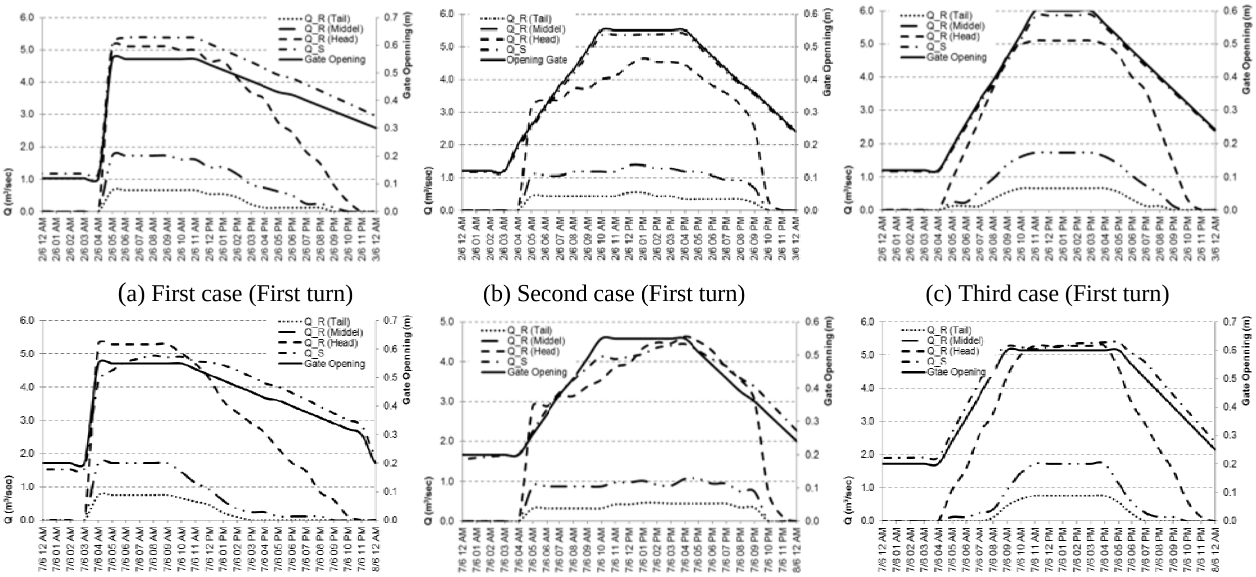


Fig. 10 Water surface profiles at the tail escape in the Dakalt canal through three cases for the second scenario.



(a) First case (First turn) (b) Second case (First turn) (c) Third case (First turn)

(a) First case (Second turn) (b) Second case (Second turn) (c) Third case (Second turn)

Fig. 11 Results of third scenario downstream of the head regulator of the Dakalt canal.

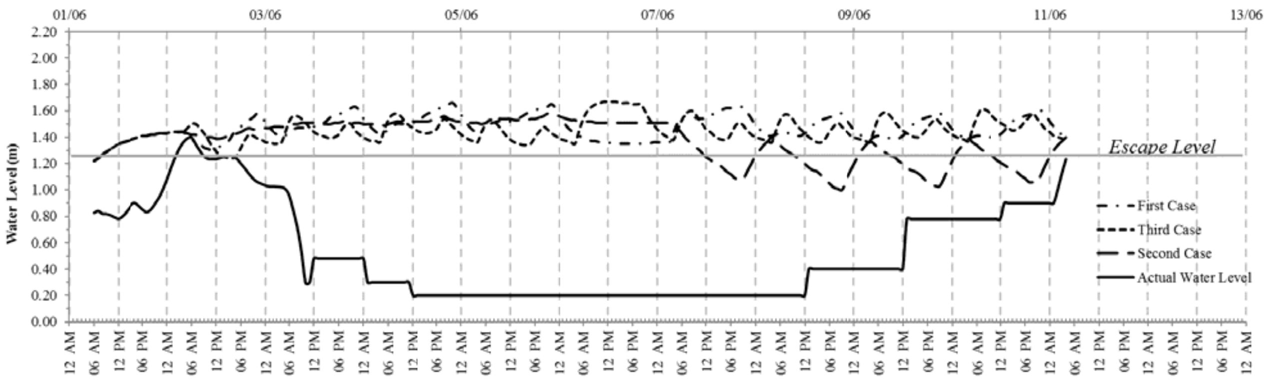


Fig. 12 Water surface profiles at the tail escape in the Dakalt canal through three cases for the third scenario.

5.3 The Best Model

The uncontrolled continuous flow scenario is difficult to apply through the Dakalt canal because the capacity of the irrigation network is not compatible with its maximum water demand for all tertiary canals if it is required at one time. Demand scheduling and/or flexible arranged scheduling scenarios succeeded in completing the full turn period through different sections by different cases of lifting point operation. However, demand scheduling is not recommended because if too many lifting points on one section of irrigation network want to water at the same time, then unless the capacity of the system is very large, the physical limitations of the system will be surpassed, and some lifting points will experience a failure of or reduction in the water supply, especially the sub-branches. Flexible arranged scheduling imposes some degree of self-management, usually by water users' associations, as they successfully manage water distribution from the tertiary canal level to their fields. This scheduling improves the stability of water allocation through the canal's length. This scenario improves on continuous flow's idea through an improved irrigation system with a rotation system at the same time. In addition, the responsibility of water users' associations should extend from the tertiary canal level's management to include the branch canal level to improve their positive effect on ensuring equal distribution through the tertiary canal level.

6. Conclusions

This study uses a hydrodynamic model to assess the hydraulic behavior of the irrigation network and then to investigate the optimal supply flow discharge. One such model is the Hydrologic Engineering Centre River Analysis System (HEC-RAS) for performing one-dimensional hydraulic calculations. This model was applied on the improved irrigation system (the Dakalt canal) at the El-Wasat command area in the Nile Delta.

Three main cases presenting practical operation at lifting points taken by three proposed scenarios were achieved. The scenarios suggest different ways of delivery scheduling among improved lifting points with proposal and the physical structures' situation of system. Practical cases of operation are presented in different ways for pumped water at lifting points. In this study also, a comparison among proposed irrigation simulation scenarios is presented. It was concluded that these proposed scenarios improved water distribution through the irrigation system and improved chances of the farmers at end location becoming equal with farmers at head. Demand scheduling and/or flexible arranged scheduling scenarios succeeded in completing full turns through different sections by different methods of lifting point operation. However, the flexible arranged scheduling is a better choice for improving water distribution among lifting points by achieving stability for water deliveries throughout the length of the branch canal. However, these scenarios do not achieve water saving through improved irrigation systems because of some reasons related to behavior as well as the geometry of the irrigation system. On other hand, the main reason is the absence of crop production planning among different locations served by the main canal, especially for rice cultivation in the summer. Most of lifting points serve some areas over 70% of paddy fields instead of 50% that determined by the government which are located in the head and middle locations of the branch canal. This causes increased water demand. Re-planning the crop production among farmers becomes essential, especially rice crop, as well as applying the law with regard to violators.

For the geometry problems, losses of water delivered through the irrigation network as a result of narrow cross sections and the presence of many bridges throughout the irrigation canal are causing problems for operating the automatics gates. The flexible arranged scheduling imposes some degree of self-management, usually by water users' associations, who successfully manage water distribution from the tertiary canal level to their fields. This scheduling improves stability of water allocation through the canal's length. This scenario improves on continuous flow's idea through an improved irrigation system with a rotation system at the same time. Water users' associations have had positive effects on saving irrigation time and on water distribution equity among farmers. Therefore, it is essential to expand the responsibility of water users' associations from the tertiary canals to the branch canals as well due to their success in operating the tertiary canal.

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