IMPROVING THE HYDRAULIC PERFORMANCE OF AL-RAYAH AL-TAWFIKY CANAL BY REHABILITATING THE MOST EFFECTIVE REACHES

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ABSTRACT

The irrigation network in Egypt suffers from several hydraulic issues such as changing in canal geometry (scouring and siltation) which may have occurred due to faulty design or insufficient maintenance programs. That is why Al-Rayah Al-Tawfiky is selected for this research. Al-Rayah Al-Tawfiky is a part of Damietta branch on Nile River. It is very essential to irrigation process in Delta as it passes through three governorates (El-Qalyobia, El-Dakahlia and Damietta, Ends at El Manzala Lake). The total length of Al-Rayah Al-Tawfiky is 175 Km, however, this research is carried out on a reach of 37 km length (from inlet regulator to Gamgra regulator at km 37.00) with average bed width of 52m. The main objectives of this research are: determine the reaches of the canal, which need rehabilitation, based on the analysis of actual collected data; to deduce an empirical equation relating the hydraulic parameters, and to state the hydraulic effects of rehabilitating the most effective reaches on the hydraulic performance of Al-Rayah Al-Tawfiky. For this purpose, different rehabilitation scenarios were simulated using SOBEK1D model. The results for each senario take into consideration water levels, velocities, and discharge at different locations along Al-Rayah Al-Tawfiky.

Keywords: Rehabilitation, Hydraulic Performance, Water, SOBEK1D, Improving Efficiency

1 INTRODUCTION

The Ministry of Water Resources and Irrigation (MWRI) is formulating the national water policy to face the challenges of water scarcity. The policy's overall objective is to utilize the available conventional and non-conventional water resources to meet the socio-economic and environmental needs of the country.

The water situation in Egypt nowadays is critical, and need more attention to canals' network, which have total length of 33,000 Km. the efficiency of the network is lowered to more than 50% (Abu-Zeid, M., 2007), as a result water conveyance capacity (WCC) had a sudden drop and the canals' network became no longer able to perform its function optimally.

(Bos and Nugteren, 1990) presented the most widely accepted concepts and definitions of irrigation efficiencies. They divided the overall project efficiency into various components as the water delivery system - conveyance, distribution, and field application. (Molden and Gates, 1990) described a number of performance measures for the evaluation and design of new or rehabilitated irrigation water delivery systems, and (Clemmens, 1990), defined the term of Delivery Performance Ratio (DPR) as the ratio of actual discharge to design discharge.

Rehabilitation of irrigation canals is essential to improve hydraulic performance and efficiency of canals and to decrease annual cost of maintenance works. Therefore, (A.Y.Al-Sary, 2015) used SOBEK1D model to study the effects of regular and irregular changes in canal cross sections, which may occur during improper maintenance. The results explained that the hydraulic performance and efficiency of irrigation canals are more sensitive to change in bed levels than in case of increasing canal width.

The flow capacity that a channel can carry without spilling over the banks is a useful information in dealing with river flooding and open-channel problems. It's well known that the flow capacity is a function of the channel geometry, slope, and roughness, but the discharge that a channel can carry also depends on the tail water level at the channel exit; although there is no direct method to determine the carrying capacity as a function of the tail water level. (Ben Chie Yen ,2000) explained how to use hydraulic performance graph (HPG) method for determination of flow capacity of a single channel reach, natural or human-made, and of a number of reaches together as a system. An (HPG) is a plot summarizing the backwater profiles for all possible flow conditions in an open-channel reach, expressed in the form of water surface elevations (stages) or depths at the ends of the channel reach for different constant discharges.

Vegetation decreases the effective flow area and increases the roughness. Vegetation growth is more pronounced in clear water; however, the nutrients in water with sediment may help the growth of weeds. The degree of obstruction by vegetation is highly variable and depends upon the type, height, density and flexibility of the vegetation, submerged or un-submerged conditions, water level, and flow velocity (Depeweg H, et.al, 2014). In any irrigation canal system, maintaining the limiting velocity of the flowing water is an important parameter for appropriate functioning, and expecting the performance of the canals. The velocity exceeding the permissible limit leads to scouring and erosion of the canal; however, velocity less than permissible impacts on silt deposition and growth of unwanted plants. The water velocity depends mostly on the roughness factor.

(A.A.Kulkarni, R. Nagarajan, 2018) Studied the impacts of vegetation growth on the conveyance efficiency of irrigation canals, and concluded that the canal conveyance capacity is quite sensitive to corrected roughness factor based on weeds on canal side slopes and on canal bed. With the increase in roughness factor based on aquatic weeds, average canal conveyance capacity is reduced by approximately 21.90%, which would require serious attention and further investigation of canal behavior for different water release scenarios.

(A.Y.Al-Sary, 2015) used SOBEK1D model to study the effects of regular and irregular changes in canal cross sections occurring during improper maintenance, (Fahmy.S. Abdelhaleem,et al, 2015) used SOBEK1D model to simulate the Nile River in Upper Egypt, studying the effect of Grand Ethiopian Renaissance Dam (GERD) construction on the Aswan High Dam (AHD) level, and the water supply to Egypt.

This research aims to identify the most effective parameters that affect the hydraulic characteristics, setting up a strategy to determine the most inefficient reaches for open channel. These reaches need rehabilitation, improving the hydraulic efficiency for open channels by rehabilitating the most inefficient reaches, which has a great effect on Limitation the costs of rehabilitation of open channels.

2 DIMENSIONAL ANALYSIS

Any physical relationship must be expressed in dimensionless form; therefore, the relationship between the variables can be obtained through a method called Buckingham's π theorem. The final equation obtained is in the form of: $(\pi_1, \pi_2, \pi_3, \dots\dots\dots, \pi_{n-m})$, and only the variables, which affect the problem, are considered. The variables used in dimensional analysis are defined and classified into three groups as follows: Fluid characteristics (Fluid density (ρ), Dynamic viscosity (μ)), and Geometric characteristics: Cross Section Area (A), Top Width (T_w), Scour Area ($A_{sc.}$), Sediment Area ($A_{sed.}$), Hydraulic Radius (R), Wetted Perimeter (P), and Conveyance Factor ($AR^{2/3}$), and Kinematic characteristics: Flow Discharge (Q), Flow mean Velocity (V), Gravitational acceleration (g). Equation (1) illustrates the general relationship between the above variables.

$$f(\rho, \mu, A, T_w, A_{sc.}, A_{sed.}, R, P, (AR^{2/3}), n, Q, V, g) = 0 \quad (1)$$

Finally, the hypothetical relationships can be written as in eq. (2)

$$AR^{2/3} = A^{4/3} \, . f\left(A_{sc.}/A_{sed.} \, , R/P \, , T_w/\sqrt{A} \, , Q/A.V\right) \quad (2)$$

3 DATA COLLECTION AND FIELD MEASURMENTS

A case study of Al-Rayah Al-Tawfiky was carefully selected to include most probabilities of infections with water conveyance problems, and to verify the validity of the relevant estimated formulas. Thereupon, site investigations and field measurements for the selected case study are carried out. The total length of Al-Rayah Al-Tawfiky for the case study reach is 37 Km, with average bed width 52 m, and it distributes water to eleven (11) sub-canals, it was designed to serve an irrigated area 324450 feddan approximately. he area of study includes three (3) head regulators, fifteen (15) bridges distributed along Al-Rayah Al-Tawfiky, one (1) power station at Km. 36.000, and four (4) water stations. Fig. (1) presents a satellite images for the case study area on Al-Rayah Al-Tawfiky.

Figure 1. Satellite Images for the case study area on Al-Rayah Al-Tawfiky

The designed data was obtained from the Directorate of Irrigation in Qaloubia; it includes the designed details of El Rayah El Tawfiky, sub-canals that are fed directly from it.

3.1 Cross-Sections measurements

The field measurements carried out by the research team of Channel Maintenance Research Institute (CMRI), National Water Research Center (NWRC) in 2017 to illustrate the morphological changes along the case study reach a surveying works of (344) three hundred and forty four actual cross sections were measured (cross section every 100m) before implementing the rehabilitation works in 2017, (123) rehabilitated cross section were measured (cross section every 129m) after implementing the rehabilitation works in 2018 by using high technology instrument to represent the area of study. The actual cross sections were plotted and compared with the designed cross sections. Fig. 2 show the layout for Al-Rayah Al-Tawfiky (from Inlet Regulator to Gamgra Regulator at Km. 37.000).

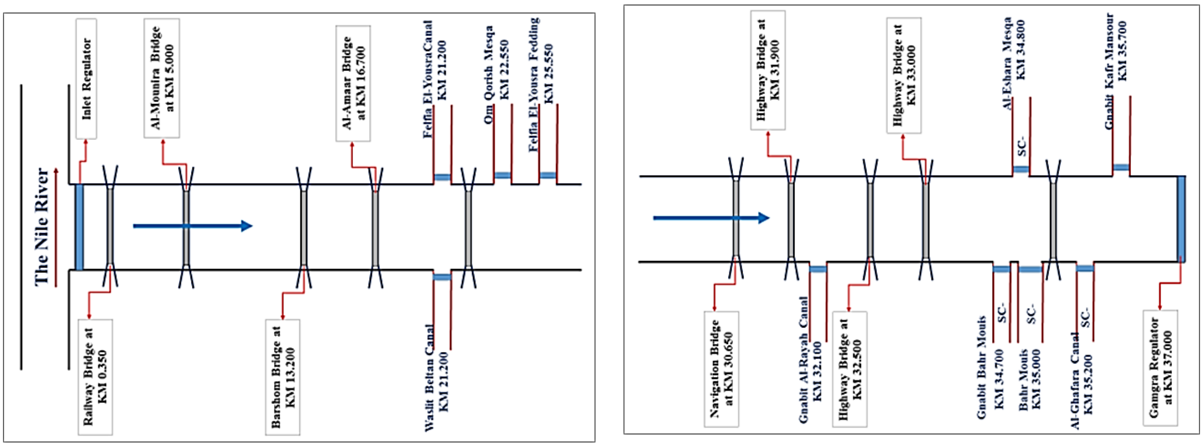


Figure 2. The layout for Al-Rayah Al-Tawfiky (from Inlet Regulator to Gamgra Regulator at Km. 37.000)

3.2 Flow Mean Velocity (V):

The flow mean velocity (V) was computed from an average of velocities, which measured at vertical survey locations across the section. At each vertical location, two velocity measurements were carried out at 0.2 and 0.8 of flow depth from the water surface, or a single measurement was taken at 0.5 or 0.6 of the flow depth at shallow depths. The discharges at (10) ten locations along Al-Rayiah Al-Tawfiky were measured, besides the discharges of (11) sub-canals which are fed directly from Al-Rayiah Al-Tawfiky were also measured.

4 NUMERICAL MODEL

The hydrodynamic simulation models are one of the most important tools for understanding the hydraulic behavior of main irrigation open channel, in this research SOBEK1D model was used to simulate the selected canal. The SOBEK software is produced by Delft Hydraulic Institute and has been widely used for a range of similar studies internationally and within Egypt. The main advantage of implementing SOBEK 1D hydrodynamic model in this study is the relationship between the model behavior and reality, and it features with effectiveness and being familiar with the studied problems. (Prinsen and Becker, 2011) mentioned that SOBEK-1D Model has been successfully applied on river systems all over the world. It's a software package is based on a finite difference numerical model to solve the Saint-Venant equations in 1D and 2D (continuity and momentum equation) by means of a staggered grid, as given below.

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = q_{lat} \qquad (3)$$

Where: (A) wetted area [m^2], (q_{lat}) lateral discharge per unit length [m^2/s], (Q) discharge [m^3/s], (t) time [s], (x) distance [m].

$$\frac{\partial Q}{\partial t} + \frac{\partial (Q^2/A)}{\partial x} + g.A\left[\frac{\partial h}{\partial x}\right] + \frac{gQ\,|Q\,|}{C^2 AR} - Wf\,.\frac{\tau_{wi}}{\rho_w} = 0 \qquad (4)$$

Where: (t) Time [s], (g) Gravity acceleration [m/s^2] (9.81), (h) Water level [m] (with respect to the reference level), (C) Chézy coefficient [$m^{½}$/s], (R) Hydraulic radius[m], (w_f) Flow width [m], (τ_{wi}) Wind shear stress [N/m^2], (ρ_w) Water density [kg/m^3].

5 RESULTS AND DISCUSSIONS

The hydraulic characteristics for every cross section were determined, and analyzed to illustrate the relations between these characteristics and the hydraulic conveyance parameter ($AR^{2/3}$). The most effective parameter, which has a significant effect on the hydraulic conveyance parameter ($AR^{2/3}$) was identified by analyzing the data with (SPSS) software. Table 1. illustrates the coherence between the hydraulic characteristics and the hydraulic conveyance.

Table 1. The coherence between the hydraulic characteristics and the hydraulic conveyance

Model		Unstandardized Coefficients		t	Significant	Adjusted R square
		B	Std. Error			
1	(Constant)	0.132	0.057	2.342	0.020	0.974
	Scour Area (A_{sc})	0.797	0.034	23.525	0.000	
	Hydraulic Radius (R)	0.729	0.036	20.345	0.000	
	Top Width (T_w)	0.055	0.024	2.242	0.026	
	Sediment Area (A_{sed})	-0.898	0.033	-27.490	0.000	

The deduced equation from analyzing the actual data is expressed as following:

$$AR^{2/3}_{\left(\frac{act.}{des.}\right)} = 0.797\, A_{sc_{\left(\frac{act}{des}\right)}} + 0.729\, R_{\left(\frac{act}{des}\right)} + 0.055\, T_{w_{\left(\frac{act}{des}\right)}} - 0.898\, A_{Sed._{\left(\frac{act}{des}\right)}} + 0.132 \quad (5)$$

The data analysis explained that the sedimentation area ($A_{sed.}$) influences the conveyance parameter more than the other hydraulic characteristics. Therefore, the infected reach with sedimentation was identified to implement the rehabilitations works on it. Fig. 3 illustrates the sedimentation area for every cross section along Al-Rayah Al-Tawfiky. Based on sedimentation area and continuity, Fig. (3) indicates that the reach which needs rehabilitation is from Km. 9.450 to Km. 25.350 with almost 15.9 Km. long.

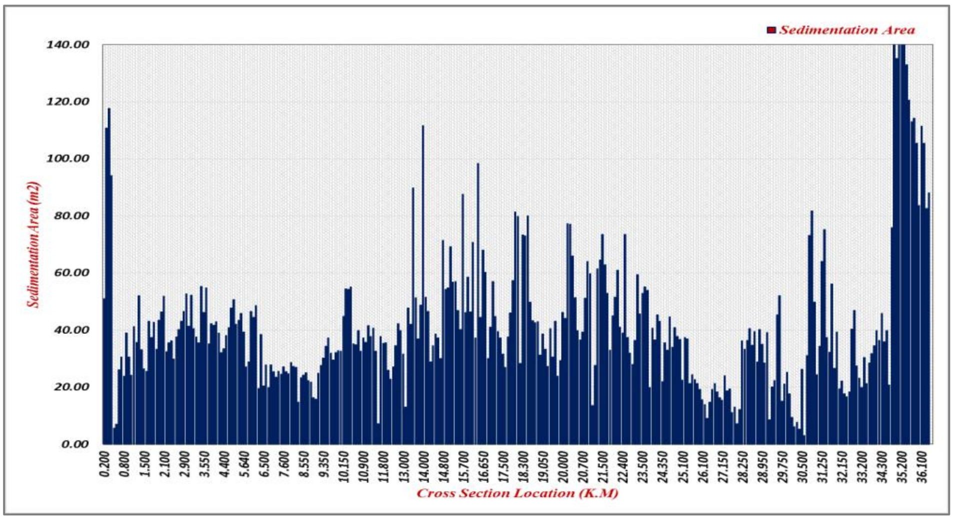


Figure 2. The sedimentation area for every cross section along Al-Rayah Al-Tawfiky

To express the relation between rehabilitation length (L_R), water surface profile (W.S.P), and velocity distribution along Al-Rayah Al-Tawfiky six rehabilitation cases are implemented on the actual case; where each one has a fixed cumulative increase of 2.500km. So, the percentage of increase can be expressed as (16%, 32%, 47.5%, 63%, 78%, and 100%) respectively. In addition, three rehabilitation cases are carried out to explain the impact of changing the rehabilitation location on water surface profile (W.S.P), and velocity distribution along Al-Rayah Al-Tawfiky. Each of them represents a percentage 50% of the total rehabilitation length (L_R) with different locations as shown in Table 2. presents the suggested rehabilitation cases used in the research.

Table 2. The suggested rehabilitation cases used in the research

Case No.	Description	Rehabilitated Reach Length (KM)	% (L_R)
1.0	Rehabilitation reach from KM 9.450 to KM 12.000	2.500	16%
2.0	Rehabilitation reach from KM 9.450 to KM 14.500	5.000	32%
3.0	Rehabilitation reach from KM 9.450 to KM 17.000	7.550	47.50%
4.0	Rehabilitation reach from KM 9.450 to KM 19.500	10.000	63%
5.0	Rehabilitation reach from KM 9.450 to KM 22.000	12.500	78%
6.0	Rehabilitation reach from KM 9.450 to KM 25.350	15.900	100%
7.0	Rehabilitation reach from KM 9.450 to KM 17.450	8.000	50%
8.0	Rehabilitation reach from KM 13.450 to KM 21.450	8.000	50%
9.0	Rehabilitation reach from KM 17.450 to KM 25.350	8.000	50%

5.1 Influence of Rehabilitation Length (L_R)

The area of study was divided into three reaches; the rehabilitated reach and the two reaches upstream and downstream it. The influence of rehabilitation length (L_R) on the water surface profile (W.S.P), and on the velocity distribution along Al-Rayah Al-Tawfiky were presented in each case.

5.1.1 Water Surface Profile (W.S.P)

Water surface profile shows that the depth of water upstream the rehabilitation works is inversely proportional to the rehabilitation length (L_R). The differences in water level (ΔW.L) between the rehabilitated water surface profile and the actual water surface profile in the six rehabilitation cases (1, 2, 3, 4, 5, and 6) increases gradually up to the maximum at the beginning of rehabilitated reach, then it decreases gradually along the rehabilitated reach to the zero at the end of it. It is obvious that the rehabilitation works have no effect on water surface profile in the downstream reach, which means that the rehabilitated water surface profile is the same as the actual water surface profile). Fig. 4 illustrates the results for (W.S.P) of the suggested rehabilitation cases.

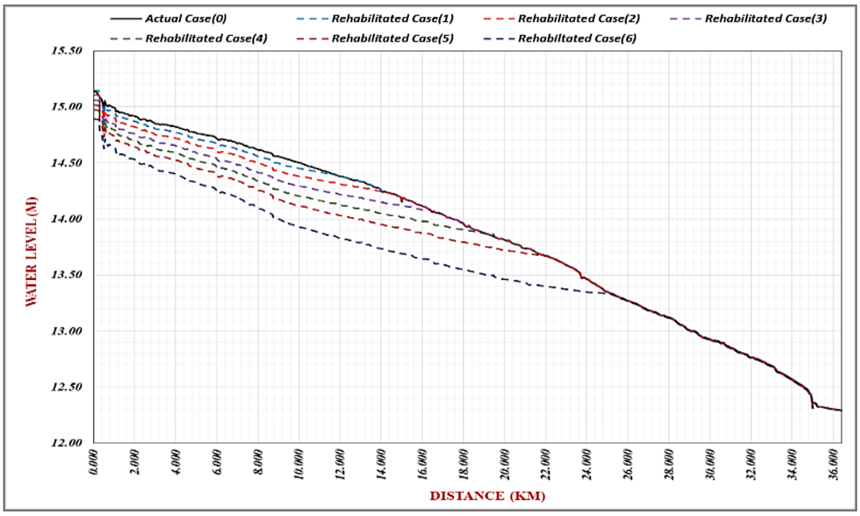


Figure 3. Water Surface Profile (W.S.P) along the case study area for the suggested rehabilitation cases

5.2.1 Water Velocity Distribution

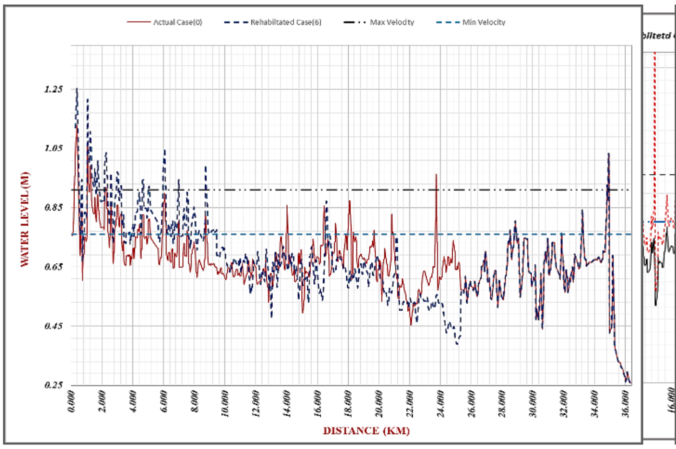
Fig. (5), and Fig. (6) show that compared to the velocity distribution in the actual case the rehabilitation works increase the average mean velocity (V_m) in the upstream reach, and decrease it along the rehabilitated reach. Actually, the rehabilitation works don't affect on the velocity distribution at downstream reach, and also the rehabilitation don't have a significant effect on the water velocity distribution until the rehabilitation length (L_R) exceeds 50% of total rehabilitation length.

5.2 Influence of the Location of Rehabilitation Reach

To explain the impact of the rehabilitation reach location on the water surface profile (W.S.P), and on the velocity distribution along Al-Rayah Al-Tawfiky, three rehabilitation cases were studied with the same rehabilitation length (L_R) (case 7, 8, and 9). It's measured as 50% of the total rehabilitation length (L_R).

5.1.2 Water Surface Profile (W.S.P)

Fig. (7) indicates that the three rehabilitation cases (7, 8, and 9) have the same effect on the water surface profile in the upstream reach. Whenever the location of the rehabilitation reach is far, the influence of rehabilitation works on the water surface profile is extended. The difference in water level (ΔW.L) between the rehabilitated water surface profile and the actual water surface profile in the three cases gradually increases in the upstream reach to reach the maximum at the beginning of rehabilitated reach, and then decreases gradually along the rehabilitated reach to the zero at the end of it.



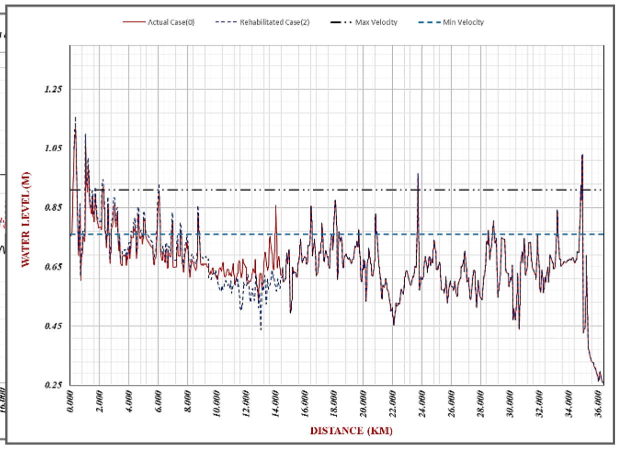


Figure 4. Velocity distribution Profile along the case study area for rehabilitation case (6)

Figure 5. Velocity distribution Profile along the case study area for rehabilitation case (2)

In rehabilitated case (9), there is a sudden drop in water levels at the beginning of the rehabilitated reach as it acts as a weir, which may have adversely effect on velocity distribution. This drop is a result of the presence of 50% of the total infected reach with sedimentation before the rehabilitated reach. Fig. (7) illustrates the water surface profile for the three cases.

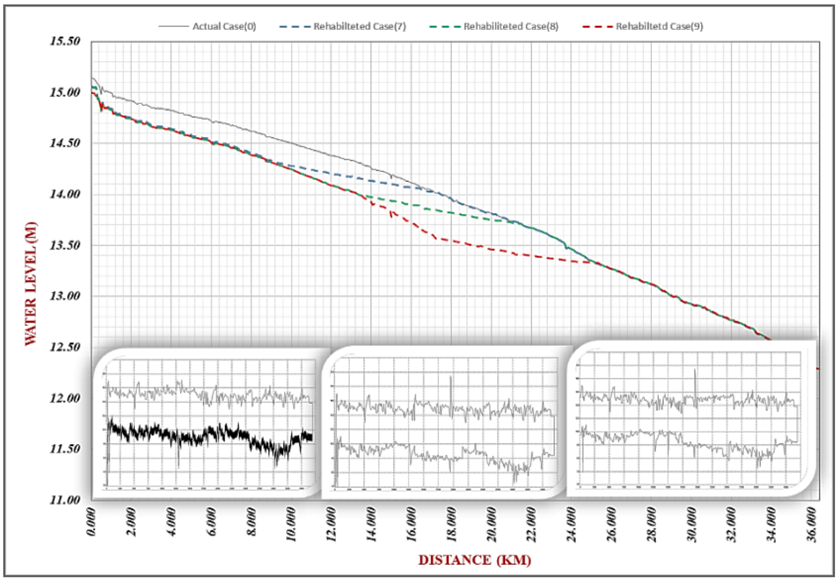


Figure 6. Water Surface Profile (W.S.P) along the case study area for the suggested rehabilitation cases

5.2.2 Velocity Distribution Profile

The rehabilitation works decrease the velocity distribution along the rehabilitated reach in comparison to the actual case, and don't affect the velocities distribution at the downstream reach.

In case (9); the mean velocity before the rehabilitated reach exceeds the permissible velocity, and that's may be due to the sudden drop in water levels at the beginning of the rehabilitated reach as it may acts as a weir.

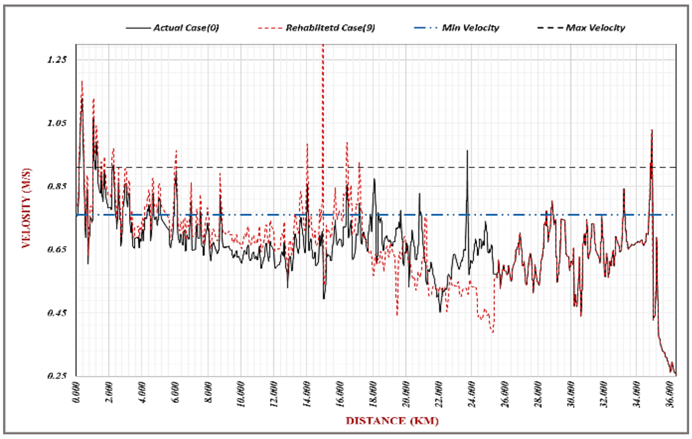


Figure 7. Velocity distribution Profile along the case study area for rehabilitation case (*9*)

5.3 Discharge Analyzing

Different scenarios carried out for estimating the increasing value of the inlet discharge (ΔQ_{in}) which each rehabilitation case can accommodate. This value is determined basically on the water level in the downstream at the end of studied reach (at Gamgra Regulator KM 37.000). This water level (W.L) is classified into two main cases; in the first one, the water level (W.L) at Gamgra Regulator is fixed as the actual case, while in the second one, W.L is variable in the downstream at Gamgra Regulator based on the inlet discharge (Q_{in}).

The water level at downstream of the reach under study can be estimated from the following equation:

$$W.L_{@D.S} = 0.0093\ Q_{in} + 10.567 \quad (5)$$

This equation is deduced from the analysis of actual data for water level at Gamgra Regulator for different discharges at Inlet Regulator in the last eight years from 2009 to 2017.

The results for estimating the increasing value of the inlet discharge (ΔQ_{in}) in rehabilitation cases are tabulated in Table 3. This table illustrates the maximum value of discharge (ΔQ) which can be added in each rehabilitation case and the improving percentage in the efficiency of Al-Rayah Al-Tawfiky in comparison with the design state.

Table 3. The added discharge (ΔQ) in each rehabilitation case, and the improving percentage in the efficiency of Al-Rayah Al-Tawfiky compared with with the design state

Case No.	**Description**	**%** **(L_R)**	**Increasing percentage in (ΔQ_{in})** Water level at Downstream		**Improving Percentage in Inlet Discharge (Q_{in})** Water level at Downstream	
			Fixed W.L at (12.28)	Variable W.L	Fixed W.L (12.28)	Variable W.L
1.0	Rehabilitation reach from KM 9.450 to KM 12.000	16%	10% $Q_{in-act.}$	7.5% $Q_{in-act.}$	85.37% $Q_{in-Des.}$	83.42% $Q_{in-Des.}$
2.0	Rehabilitation reach from KM 9.450 to KM 14.500	32%	7.50% $Q_{in-act.}$	5% $Q_{in-act.}$	83.42% $Q_{in-Des.}$	81.49% $Q_{in-act.}$
3.0	Rehabilitation reach from KM 9.450 to KM 17.000	50%	10% $Q_{in-act.}$	7.5% $Q_{in-act.}$	85.37% $Q_{in-Des.}$	83.42% $Q_{in-Des.}$
4.0	Rehabilitation reach from KM 9.450 to KM 19.500	63%	12.50% $Q_{in-act.}$	10% $Q_{in-act.}$	87.31% $Q_{in-Des.}$	85.37% $Q_{in-Des.}$
5.0	Rehabilitation reach from KM 9.450 to KM 22.000	78%	17.50% $Q_{in-act.}$	15% $Q_{in-act.}$	91.19% $Q_{in-Des.}$	89.25% $Q_{in-Des.}$
6.0	Rehabilitation reach from KM 9.450 to KM 25.350	100%	25.00% $Q_{in-act.}$	22.5% $Q_{in-act.}$	97.01% $Q_{in-Des.}$	95.07% $Q_{in-Des.}$
7.0	Rehabilitation reach from KM 9.450 to KM 17.450	50%	12.50% $Q_{in-act.}$	10.0% $Q_{in-act.}$	87.31% $Q_{in-Des.}$	85.37% $Q_{in-Des.}$
8.0	Rehabilitation reach from KM13.450 to KM12.000	50%	15.00% $Q_{in-act.}$	12.5% $Q_{in-act.}$	89.25% $Q_{in-Des.}$	87.31% $Q_{in-Des.}$
9.0	Rehabilitation reach from KM17.450 to KM25.350	50%	15.00% $Q_{in-act.}$	12.5% $Q_{in-act.}$	89.25% $Q_{in-Des.}$	87.31% $Q_{in-Des.}$

By analyzing the results represented in Table.3 it is noticed that whenever the rehabilitation length (L_R) increases, the value of the increasing rate in discharge (ΔQ_{in}) increases. At the same rehabilitation length (L_R), when water level at downstream is fixed the produced water surface profile is lower than the produced one when the water level at downstream is variable. Implementing the rehabilitation works can increase the capacity of Al-Rayah Al-Tawfiky by 25% (fixed W.L at downstream), 22.50% (variable W.L at downstream) of actual inlet discharge ($Q_{in-Act.}$), thus improving the capacity to be 97.01% (fixed W.L at downstream), 95.07% (variable W.L at downstream) of the designed inlet discharge ($Q_{in-Des.}$). By studying the results there is a direct relation between the rehabilitation length (L_R), and the value of the increasing rate in discharge (ΔQ_{in}). These relations are expressed in Eq. (6), and (7).

In Case (Variable Water Level at downstream):

$$\Delta Q_{in}(\%) = 0.1905\ (L_R\%) + 0.8107 \qquad (6)$$

In Case (Fixed Water Level at downstream):

$$\Delta Q_{in}(\%) = 0.1905\ (L_R\%) + 0.0299 \qquad (7)$$

6 CONCLUSIONS

The analysis of the aforementioned results and interpretation the results of the suggested rehabilitation cases yielded the following conclusions:

- The sedimentation area ($\boldsymbol{A_{sed.}}$) affects on the conveyance parameter more than the other hydraulic characteristics.
- Water surface profile upstream the rehabilitation works have an inverse relation with rehabilitation length (L_R).
- The rehabilitation works have no effect on water surface profile in the downstream reach (the rehabilitated water surface profile is the same as the actual water surface profile).
- The rehabilitation works decrease the velocities distribution along the rehabilitated reach.
- The rehabilitation don't have a significant effect on the water velocity distribution until the rehabilitation length (L_R) exceeds 50% of total rehabilitation length.
- Whenever the rehabilitation length (L_R) increases, the value of the increasing rate in discharge (ΔQ_{in}) increases.
- At the same rehabilitation length (L_R), the case of fixed water level at downstream has a produced water surface profile lower than the case of the variable water level.
- Implementing the rehabilitation works increase the capacity of Al-Rayah Al-Tawfiky by 25%, and 22.5% of actual inlet discharge for the fixed W.L case and the variable case respectively. This improving the capacity to be 97.01%, and 95.07%) respectively of the designed inlet discharge ($Q_{in-Des.}$).
- The best scenario depends on the required discharge to pass through the canal, and these scenarios are considered operation scenarios for Al-Rayah Al-Tawfiky
- If the main objective is to reach the design state, the best scenario is case 6, which produces the highest improving in the capacity.

ABBREVIATIONS

- A: CROSS SECTION AREA (m^2)
- $A_{sc.}$: SCOUR AREA (m^2)
- $A_{sed.}$: SEDIMENT AREA (m^2)
- $A_{sc.(\frac{act}{des})}$: RATIO BETWEEN SCOUR AREA AND DESIGN AREA
- $A_{sed.(\frac{act}{des})}$: RATIO BETWEEN SEDIMENT AREA AND DESIGN AREA
- $AR^{2/3}$: CONVEYANCE FACTOR
- $AR_{(\frac{act}{des})}{}^{2/3}$: RATIO BETWEEN ACTUAL CONVEYANCE AND DESIGN CONVEYANCE
- CMRI: CHANNEL MAINTENANCE RESEARCH INSTITUTE
- DPR: DELIVERY PERFORMANCE CAPACITY
- G: GRAVITATIONAL ACCELERATION (m/s^2)
- HPG: HYDRAULIC PERFORMANCE GRAPH
- L_r : REHABILITATION LENGTH (KM)
- MWRI: MINISTRY OF WATER RESOURCES AND IRRIGATION
- P: WETTED PERIMETER (m)
- Q: FLOW DISCHARGE (m^3/s)
- Q_{IN} : INLET DISCHARGE (m^3/s)
- ΔQ_{IN} : THE INCREASING VALUE IN INLET DISCHARGE (m^3/s)
- $Q_{IN-ACT.}$: ACTUAL INLET DISCHARGE (m^3/s)
- $Q_{IN-DES.}$: DESIGN INLET DISCHARGE (m^3/s)
- R: HYDRAULIC RADIUS (m)
- $R_{(\frac{ACT.}{DES.})}$: RATIO BETWEEN ACTUAL AND DESIGN HYDRAULIC RADIUS

- T_W : TOP WIDTH (m)
- $T_{w_{(\frac{act}{des})}}$: RATIO BETWEEN ACTUAL AND DESIGN TOP WIDTH
- V: FLOW VELOCITY (m^2/s)
- V_M : FLOW MEAN VELOCITY (m^2/s)
- W.C.C: WATER CONVEYANCE CAPACITY
- $W.L_{@D.S}$: WATER LEVEL AT DOWNSTREAM (m)
- ΔW.L: DIFFERENCE IN WATER LEVEL (m)
- W.S.P: WATER SURFACE PROFILE
- P: FLUID DENSITY
- μ: DYNAMIC VISCOSITY

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