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Validation of G-Pipe Simulation Model under Egyptian Conditions

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ABSTRACT

Surface irrigation is considered one of the most common and extensive methods used for irrigation in the old lands of Delta and Nile valley in Egypt. Many furrow systems operate at significantly lower efficiencies. To improve the efficiency of surface irrigation methods, the use of gated pipes is claimed to be one of the ways to achieve higher efficiencies, since it is considered one of the most efficient methods for conveying and distributing irrigation water over the entire field. Therefore, G-Pipe simulation model has been developed with the aim to simulate water distribution along the pipeline of the irrigation system for making a decision to select the optimal specification of the irrigation system. This work was carried out at the Experimental Farm of the Faculty of Agriculture, Ain Shams University, and Qalubia Governorate, Egypt. The objective of this study was to validate G-Pipe simulation model (gated pipe simulation model, developed by University of Southern Queensland, Australia). The outflow and pressure head at every gate along the pipeline of gated pipes irrigation system [6 inch diameter, 12 and 6 m length with gates (circle shape with 34 mm diameter) at 0.7 m spacing between gates] were measured under zero level to validate the G-Pipe simulation model Version 1.3. Validation of G-Pipe simulation model for 12 m length of gated pipeline (16 gates with 0.7 m spacing) under zero level of the pipeline revealed that the data of measured discharge from gates and head at gates along the pipeline were closer to that predicted by using total outflow as a primary condition input than that predicted by using head after valve as a primary condition input. Generally, the highest values of regression and correlation (> 0.8) of the relationship between measured and predicted values of outflow from gates (q, L/ sec) and the pressure head at gates along the pipeline (h, m) were obtained for the shorter pipeline than the longer one. Finally, calculated and predicted water distribution uniformity values under experiment conditions confirm that there is no significant difference between the measured and predicted water distribution uniformities (98.21 and 98.31%, respectively) for the 6 m length (8 gates) gated pipeline under zero level of the pipeline. Generally, it is highly acceptable to predict water distribution uniformity of 6 m length pipeline by using total outflow or head after valve as a primary input (98.21, 98.32 and 98.31%, respectively) under zero level of the pipeline.

Keywords: distribution uniformity; outflow; pressure head; irrigation management; regression coefficient

INTRODUCTION

Validation is the process of determining that the system actually fulfills the purpose for which it was intended in such a way that it answers the question “is it the right system?”, “is the knowledge base correct?” or ”is the program doing the job it was intended to do?” [12]. There are many examples on the validation of simulation models which are used in the predicting or simulating a subject in agriculture such as that mentioned by Raine *et al*. [9] on SIRMOD [the surface irrigation simulation model (version 2.12)], and by Ragab *et al*. [8] on SALTMED model, and by Aftab *et al*. [1] on a simple soil moisture simulation model to address irrigation water management issues.

Surface irrigation is considered one of the most common and extensive methods used for irrigation in the old lands of Delta and Nile valley in Egypt. Although well designed and managed furrow-irrigation systems have the potential to operate at application efficiencies above 90% [3], many furrow systems operate at significantly lower efficiencies. To improve the efficiency of surface irrigation methods (border and furrow), the use of gated pipes is claimed to be one of the ways to achieve this goal,

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since it is considered one of the efficient methods for conveying and distributing irrigation water over the entire field. Therefore, G-Pipe simulation model has been developed with the aim to simulate water distribution along the pipeline of the irrigation system for making a decision to select the optimal specification of the irrigation system. Smith *et al*. [10] developed a computer tool (G-Pipe) for the simulation and design of gated and lay flat pipes commonly used for furrow irrigation.

G-Pipe was created based on the theory by Smith *et al*. [10]. The program utilizes only four equations as follows:

1. Friction Losses:

The friction loss is the loss in energy due to the roughness of the pipe. A number of different equations can be used. G-Pipe uses the Hazen Williams equation:

$$V = 0.849 * C_{HW}\left(\frac{h_f}{L_o}\right)^{0.54}\left(\frac{D}{4}\right)^{0.63}$$

Where:

V = the flow velocity, m/sec.

C_{HW} = the Hazen Williams coefficient (constant for a given material).

h_f = the energy loss due to friction, m.

L = the pipe length, m.

D = the pipe diameter, m.

1.1. Minor Losses:

The minor loss is the name given to describe the energy loss caused by disruption of the flow. These losses are typically caused by valves, fittings, sudden expansions and contractions, and pipe bends. The minor loss is typically represented in the energy balance as a "K" term multiplied by the square of the flow velocity divided by gravity (9.81) multiplied by 2.

$$Minor\ loss = \frac{KV^2}{2g}$$

2. The continuity equation:

$$Q = Q_c + Q_o$$

3. The energy equation, with α = 1.1 and $\Delta h = 0$:

The energy in the pipeline at any point is a summation of the static head Z, pressure head and kinetic energy term.

$$E = Z + \frac{P}{\rho g} + \frac{\alpha V^2}{2g}$$

Where:

Z = the height above a datum point,

P = the pressure in the pipeline

g = the acceleration due to gravity

ρ = the density of water (1000 or 1 if P is measured in m)

α = the *Coriolis coefficient* (G-Pipe uses a value of 1.1)

V =the average velocity of flow in the pipeline.

It then follows that energy must be conserved between any two points in the pipeline. Any differences must be accounted for by the friction loss and minor losses.

4. The outlet characteristics:

4.1. Orifice formula:

$$Q_o = C_d\, a_o \sqrt{2gh_p}$$

C_d = 0.65, which is a commonly accepted value for a sharp-edged orifice.

4.2. Conservation of energy:

The flow from an outlet in the pipe is calculated by applying the Bernoulli's equation across the outlet. After some simplification the pressure recovery (gain) in the pipeline as the water flows past an outlet can be calculated by:

$$\frac{\Delta h_f}{h_v} = 1 - \left(\frac{V_c}{V}\right)^2$$

Where

h_v = the velocity head term

V_c = the flow velocity downstream of the outlet

V = the flow velocity upstream of the outlet.

The simulations were initialized by specifying the discharge continuing past the last outlet in the section of pipeline and pressure at that outlet. Discharges from and pressures at each of the outlets were then calculated. This simplicity, combined with the speed of computer calculation, allows an exact analysis and design to be performed. The computer program was also used to investigate certain factors which influence the uniformity of outflows from a long pipeline. Those investigated were longitudinal slope of the pipeline, pipe diameter, number of gates, gate area, and mean gate outflow.

Jensen [5] reported that the expression of evaluating uniformity distribution through the variation of flow through orifices along the lateral line named flow variation along the lateral line “q_{var}” (the uniformity distribution increased as flow variation decreased).

$$q_{var} = \frac{q_{max} - q_{min}}{q_{max}}$$

Where:

q_{var} = the orifice flow variation

q_{max} = the maximum orifice flow along the lateral line lit/sec, and

q_{min} = the minimum orifice flow along the lateral line lit/sec.

Smith *et al*. [10] stated that measure gated pipe uniformity is required, so that the effect of the variation of particular parameter on outflow uniformity can be quantified. The measure of variability selected was the range of the outflows, which is defined as the difference between the maximum and minimum outflows along the pipeline, expressed as a percentage of the mean outflow. Also they indicated that uniformity can be increased by using short pipelines, gates with small openings and high gate discharges, though in many cases this will be at the expense of higher operating cost.

This work aims to validate G-Pipe simulation model under variable conditions of gated pipes irrigation system in Egypt.

Material and Methods

To validate the model, observed data was undertaken at the Experimental Farm of the Faculty of Agriculture, Ain Shams University, Qalubia Governorate, Egypt.

Irrigation water analysis:

Samples from irrigation water source were taken for chemical analysis according to Klute and Dirksen [6]. Table (1) shows **c**hemical properties of irrigation water in the experimental site.

Table 1: Chemical analysis of irrigation water in the experimental site, Qalubia Governorate, Egypt.

pH	EC	Soluble cations (meq/ L)				Soluble anions (meq/ L)			SAR
	(dS/m)	Ca^{++}	Mg^{++}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{--}	CL^{-}	
7.2	0.33	1.63	0.77	2.59	0.31	2.40	0.4	2.50	2.40

Gated pipes distribution system can be considered as one of the most suitable and acceptable water distribution system for improving surface irrigation in the old valley in Egypt. A gated pipe, as USDA [11] stated, is a portable pipe made of metal usually aluminum, with a number of small gates along one side through which water can be run into corrugations, furrows or borders.

1. Experimental work of the gated pipes irrigation system:

*a. Water source***:** water source is well water, the total depth of well is 45 m; water depth from ground surface is 4-5 m; and diameter of the well is 6".

b. Pump and Engine: Centrifugal pump (4"/3" suction and delivery diams, 70 m^3/ h discharge rate; and 60 m head) drive by diesel engine (3 pistons; and 45 hp).

c. Filtration unit: sand media filter (two tanks; 48" diam.; 3" /3" inlet and outlet diams.; 35 m^3/h discharge rate for each and back flushing at pressure differential across a sand media filter is generally 0.8-1 bar by valve unit).

d. The gated pipes irrigation system: the tested gated pipes irrigation system was a single length of 6" diameter light weight aluminum pipe 6 m length with infinitely adjustable plastic sliding gates. The gates were located at 70 cm spacing and were circle shape, (area 9.0746 cm^2), when fully open. The pipe is available in 6 m length and uses a spigot and fancet rubber ring jointing system.

e. Calibration of gated pipe line: For Calibration of gated pipe line a stand was used (120 cm length and 12 inches diam.), it contains three holes (Fig. 1) as following: (1) inlet hole, 2" diam. above the stand, is connected with the stand through 2" Ball valve. (2) outlet hole, 4" diam. at the bottom of the stand, is connected with the stand through 3" Ball valve to joint flange 6" to connect the gated pipe line. (3) overflow hole, 1" diam. above the stand, is connected with the stand through 1" Ball valve for establishing water level. (4) indicator tube transparent (¾ inch). Water was applied to the test pipe, and then the measurements were taken as the following:

e. 1. Discharge past the first gate in the pipeline using a flow meter installed before the pipeline.

e. 2. Outflow from the gates by measuring the time to fill a 20 liter bucket (with all gates fully open).

e. 3. Pressure heads in the pipe using a piece of a tube which was attached tightly to the outside of the gate. Raise the tube into the air until the water stops flowing out. Measure the distance from the water level in the tube to the center of the gate (the head, m).

G-Pipe is a computer tool for the simulation and design of gated and layflat pipes commonly used for furrow irrigation. G-Pipe was created based on the theory by Smith *et al*. [10]. The inputs (necessary to run the simulation process) and the outputs of the program described in Fig. 2.

Distribution uniformity:

The uniformity of water distribution should be experimentally tested through experimental work in the field. Therefore, the uniformity of water distribution of gated pipes system along its pipeline was tested using:

a**.** The calibration tank to feed the gated pipeline by fixed level of water (discharge and pressure head).

1. A stop watch: whenever time was concerned, it was measured using a stop watch.
2. A plastic tin (20 liter capacity) was used to collect the discharged water from each gate.
3. A steel tape scale was used to measure the height of water, m.
4. Spirit bubble level was used to assure that the gated pipeline was kept, as much as possible, in a horizontal position.
5. The measure of variability selected was the range of outflows along the pipeline, expressed as a percentage of the mean outflow. Algebraically,

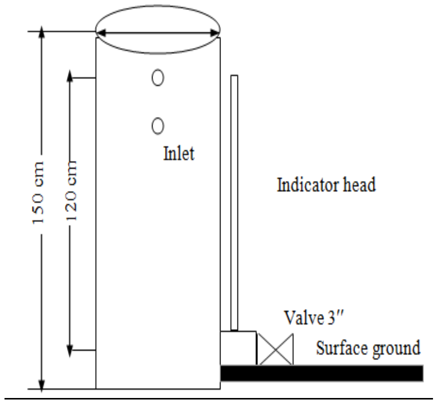


Fig. 1: Tank for calibration of gated pipe.

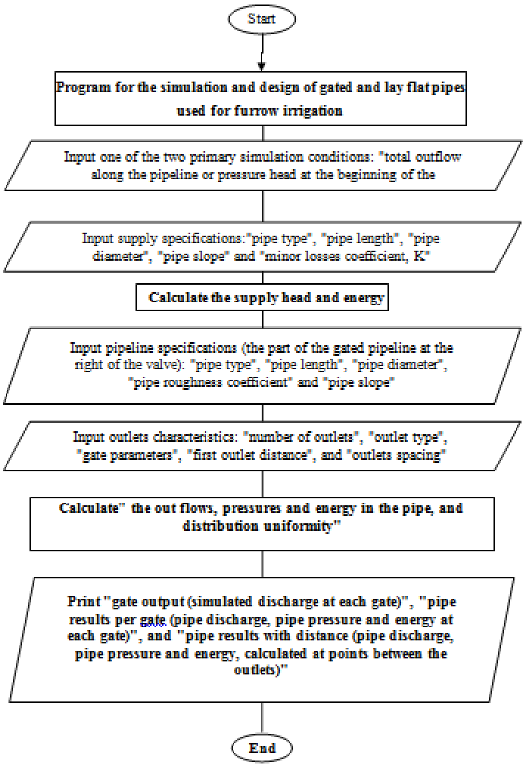


Fig. 2: Flow chart components of G-Pipe simulation model program for simulating outflow and pressure at gates along the pipeline of gated pipes irrigation system.

Results and Discussion

Validation of G-Pipe simulation model:

The outflow and pressure head at every gate along the pipeline of gated pipes irrigation system [6 inch diameter, 12 and 6 m length with gates (circle shape with 34 mm diameter) at 0.7 m spacing between gates] were measured under zero level to validate the G-Pipe simulation model Version 1.3 (Gated/Lay flat Pipe Simulation Model copyright 2007 developed by Malcolm Gillies, which is a computer simulation model for the design of gated pipes system as used for furrow irrigation, depends on four mathematical water flow hydraulics models. The inputs were illustrated in Table 2.

Data shown in Table 2, are the inputs of G-Pipe simulation model to simulate gated pipes irrigation system under field conditions by using two different primary conditions of G-Pipe simulation model (total outflow, 15.6 L/sec, or input head after valve at the beginning of the pipeline, 57 cm). The predicted outputs of G-Pipe simulation model (outflow from gates along the pipeline and pressure head at every gate along the pipeline) depend on the considered primary conditions, as well as the predicted distribution uniformity.

Table 2: Inputs of G-Pipe Simulation Model.

Supply		Pipeline		Outlets	
Name	Value	Name	Value	Name	Value
Pipe type:	Rigid	Pipe type	Rigid	Outlet type	Circle
Pipe length:	0	---	----	Gate diameter	0.034 m
Pipe diameter:	0.148 m	Pipe diameter	0.148 m	First outlet distance	0.55 m
Pipe Roughness:	145	Pipe Roughness	145	Outlet spacing	0.7 m
Slope:	0 m/m	Slope	0 m/m	---	---
Extra energy losses:	0.064	----	----	---	---

a. Validation of G-Pipe simulation model for 12 m length of gated pipeline (16 gates with 0.7 m spacing) under zero level of the pipeline:

Figs. (3-a) and (3-b) show the measured and predicted values of discharge from gates and pressure head at gates along the gated pipeline, respectively. The predicted values of discharge from gates and pressure head at gates along the gated pipeline were measured by using two different primary inputs of G-Pipe simulation model (total outflow, 15.6 L/sec, and head after valve at the beginning of the pipeline, 57 cm). The trend of measured discharge from gates and head at gates along the pipeline revealed that data are closer to that predicted by using total outflow as a primary condition input than that predicted by using head after valve as a primary condition input.

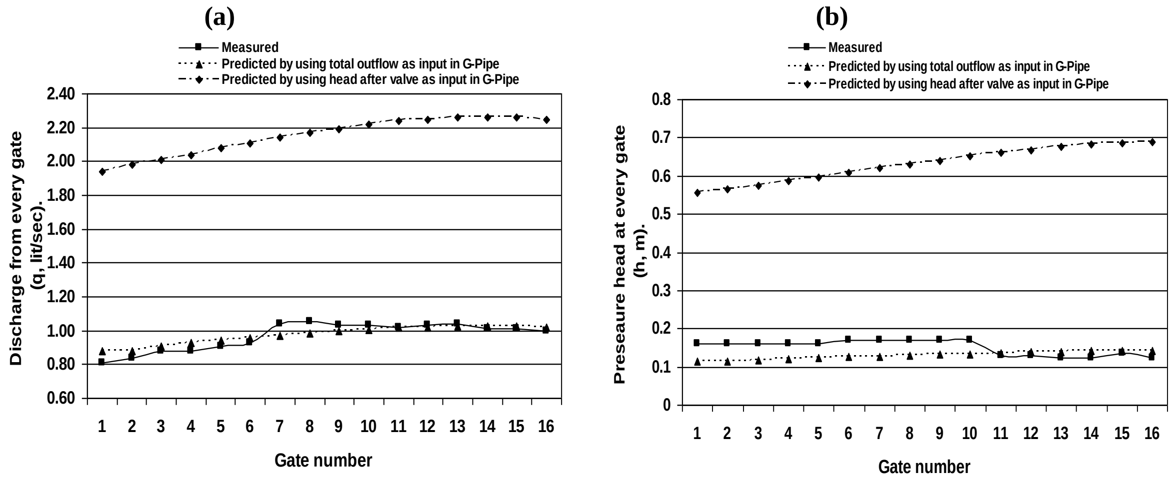


Fig. 3: (a) Measured and predicted discharge from every gate (b) Measured and predicted head at every gate, along gated pipeline (12 m length and 16 gates) under zero slope of pipeline by using two different *G-pipe* simulation model as a primary conditions (total outflow or head after valve inputs).

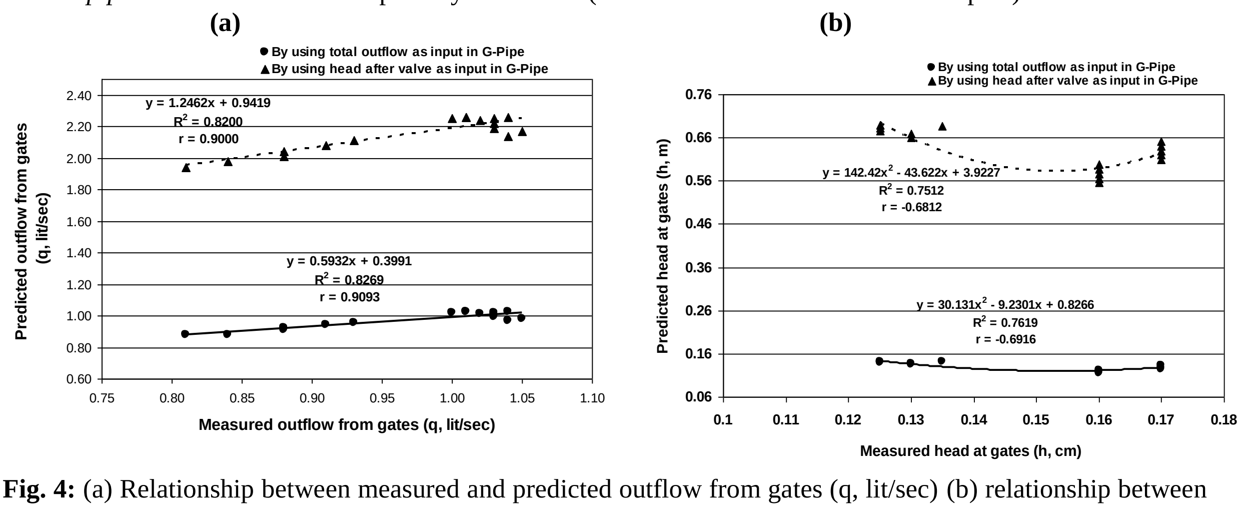


Fig. 4: (a) Relationship between measured and predicted outflow from gates (q, lit/sec) (b) relationship between measured and predicted head at gates (h, m), along gated pipeline (12 m length and 16 gates) under zero slope of pipeline by using two different *G-pipe* simulation model as a primary conditions (total outflow or head after valve inputs).

Figs. (4-a) and (4-b) show the relationship between measured and predicted outflow from gates (q, L/ sec), and head at each gate along the gated pipeline (12 m length and 16 gates) under zero slope of pipeline, respectively, by using two different primary conditions of G-pipe simulation model (total outflow or head after valve). The regression and correlation analysis between measured and predicted values of outflow from gates along the pipeline give a high regression and correlation values (> 0.8) by using total outflow as a primary condition input of G-pipe simulation model [R^2 = 0.8269 and r = 0.9093]. Accordingly, using of total outflow as a primary condition input of G-Pipe simulation model was more suitable for predicting outflow (q, L/ sec) from gates along the gated pipeline than using of head after valve at the beginning of the pipeline input [R^2 = 0.82 and r = 0.9].

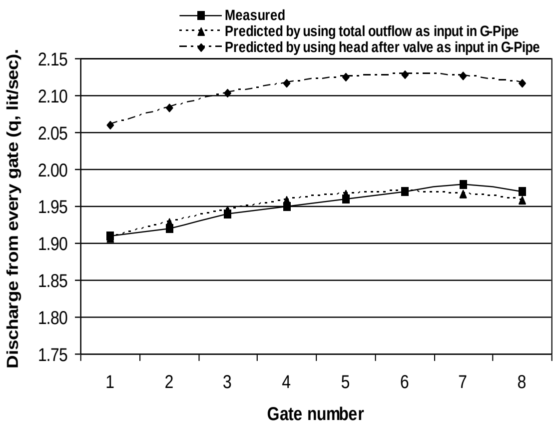
On other hand, the trend of regression analysis of the relationship between measured and predicted head at every gate along the gated pipeline (12 m length and 16 gates) under zero level of pipeline was medium negative (Fig., 4-b). Whereas, using of total outflow as a primary condition input of G-Pipe simulation model exhibited the highest medium negative correlation (-0.6916) and the highest positive value of regression (0.7619).

Generally from Figs. (4-a) and (4-b), G-Pipe simulation model (by using of total outflow as a primary condition input) is very acceptable to predict the discharge from gates along the gated pipes irrigation system (6 inch diameter, 12 m length and 16 gates with 0.7 spacing between gates), but it is not acceptable for predicting the pressure head at gates along the gated pipeline because of the low values of regression and correlation values (< 0.8) by using the two different primary condition inputs of G-Pipe simulation model.

b. Validation of G-Pipe simulation model for 6 m length of gated pipeline (8 gates with 0.7 m spacing) under zero slope of the pipeline:

For one pipe of gated pipes irrigation system (6 inch diameter, 6 m length, and 8 gates with 0.7 spacing), it is suitable to use total outflow as a primary condition input of G-Pipe simulation model, according to the low differences between measured and predicted values of outflow from gates along the pipeline (Fig. 5-a). Thus, it is acceptable to use G-Pipe simulation model for simulating and predicting outflow from gates.

(a)



(b)

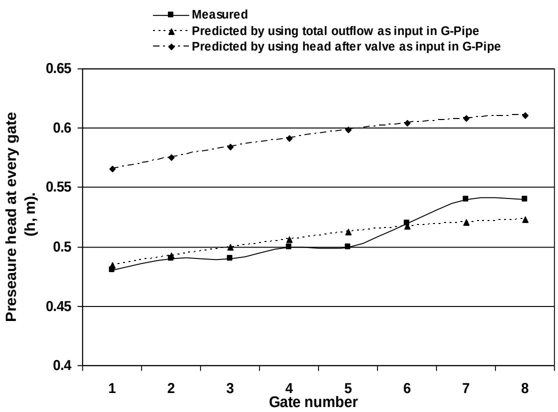
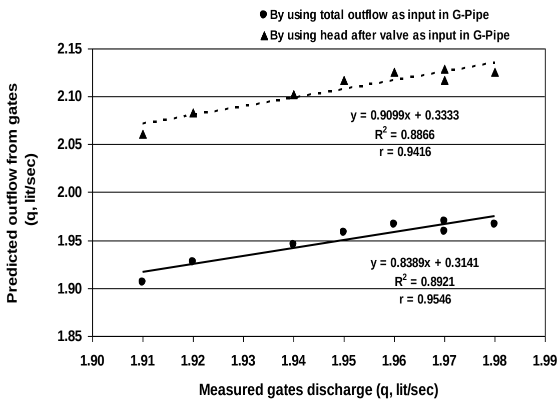


Fig. 5: (a) Measured and predicted discharge from every gate (b) Measured and predicted head at every gate, along gated pipeline (6 m length and 8 gate) under zero level of the pipeline by using two different G-pipe simulation model as a primary conditions (total outflow or head after valve inputs).

(a)



(b)

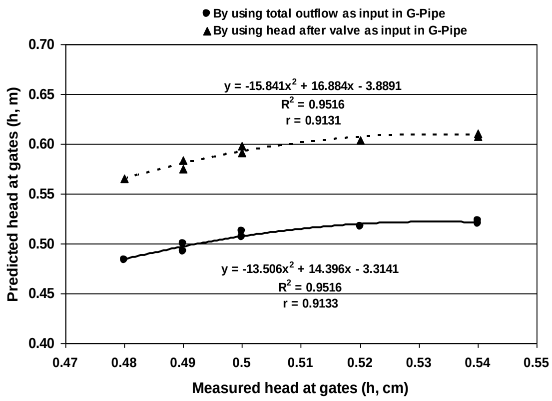


Fig. 6: (a) Relationship between measured and predicted outflow from gates (q, L/sec) (b) relationship between measured and predicted head (h, m), along gated pipeline (6 m length and 8 gate) under zero slope of pipeline by using two different G-pipe simulation model as a primary conditions (total outflow or head after valve inputs).

The regression analysis of relationship between measured and predicted outflow from gates (q, L/sec) along gated pipeline (6 m length and 8 gate) under zero level of pipeline (Fig. 6-a) gives its highest positive values of regression and correlation (higher than 0.8) by using total outflow as a primary condition input of G-pipe simulation model. From the regression and correlation values which were obtained from the relationship between measured and predicted pressure head at gates along the pipeline (Fig. 6-b), it is clear that no significant deference was obtained by using either the total outflow or the head after valve as a primary condition input to predict the head at gates along the gated pipeline (6 m, and 8 gates), whereas R^2 equaled 0.9516 for the two different primary condition inputs, and r equaled 0.9131 and 0.9133 for them, respectively.

Generally and briefly from Figs. (4-a), (4-b), (6-a), and (6-b), the highest values of regression and correlation (> 0.8) of the relationship between measured and predicted values of outflow from gates (q, L/ sec) and the pressure head at gates along the pipeline (h, m) were obtained for the shorter pipeline than the longer one. In other words by using G-Pipe simulation model, the exact predicted values of outflow from gates (q, L/ sec) or the pressure head at gates along the pipeline (h, m) were obtained by decreasing the gates number along the pipeline. And G-pipe simulation model is more acceptable to simulate and predict the outflow discharge and pressure head at gates along the 6 m length gated pipeline (8 gates) than using of 12 m length gated pipeline (16 gates).

Finally, calculated and predicted water distribution uniformity values under experiment conditions (Table, 3) confirm that there is no significant difference between the measured and predicted water distribution uniformities (98.21 and 98.31%, respectively) for the 6 m length (8 gates) gated pipeline under zero level of the pipeline. Generally, it is highly acceptable to predict water distribution uniformity of 6 m length pipeline by using total outflow or head after valve as a primary input (98.21, 98.32 and 98.31%, respectively) under zero level of the pipeline.

Table 3: Calculated and predicted water distribution uniformities along the gated pipeline of gated pipes irrigation system under zero level of the pipeline.

Pipeline length (m)	Primary condition input of G-pipe simulation model	Water distribution uniformity, %	
		Calculated	Measured
12	Total outflow	87.94	92.23
	Head after valve		92.75
6	Total outflow	98.21	98.32
	Head after valve		98.31

Conclusions:

Generally, results could be summarized in the following points:

(1) using of simulation models is a good tool to manage irrigation practice under Egyptian clay loam soil conditions. (2) using of G-Pipe simulation model for predicting water distribution uniformity for gated pipes irrigation system is acceptable.

(3) G-pipe simulation model is more acceptable to simulate and predict the outflow and pressure head at gates along the 6 m length gated pipeline (8 gates) than using of 12 m length gated pipeline (16 gates) under Egyptian conditions.

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