



Alexandria University  
**Alexandria Engineering Journal**

[www.elsevier.com/locate/aej](http://www.elsevier.com/locate/aej)  
[www.sciencedirect.com](http://www.sciencedirect.com)



## ORIGINAL ARTICLE

# Updated regime equations for alluvial Egyptian canals

Fahmy Salah Abdelhaleem<sup>a,\*</sup>, Ahmed Mostafa Amin<sup>b,1</sup>,  
 Mohammad Mahmoud Ibraheem<sup>c,2</sup>

<sup>a</sup> Civil Engineering Department, Benha Faculty of Engineering, Benha University, P.O. 13512, New Benha, Qalubia Governorate, Benha, Egypt

<sup>b</sup> Hydraulics Research Institute, National Water Research Center, Egypt

<sup>c</sup> Civil Engineering Dept., Shoubra Faculty of Engineering, Banha University, Egypt

Received 28 February 2015; revised 5 December 2015; accepted 9 December 2015

## KEYWORDS

Alluvial channels;  
 Regime theory;  
 Channel design;  
 Fluvial hydraulics;  
 Egypt

**Abstract** Real accuracy of several regime relationships for designing stable alluvial channels in Egypt was determined. Extensive field measurements had been carried out on 26 Egyptian stable canals, which cover various categories of irrigation canals starting from distributary, branch to carrier canals in Egypt. Analysis of 1484 velocity profiles for 371 cross sections was employed in order to formulate new regime equations characterizing Egyptian canals. The functional formulations to include the flow depth, cross section area, hydraulic radius and mean velocity were achieved. This research compared the deduced formulas from the measured data with the equations derived by other researchers for stable channel design. It was found that the derived formulas are reliable and could help in the design of Egyptian canals to convey a discharge ranging from 0.11 to 287.5 m<sup>3</sup>/s (0.0095–24.84 millions m<sup>3</sup>/day).

© 2015 Faculty of Engineering, Alexandria University. Production and hosting by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

## 1. Introduction

Networks of canals systems are used to convey, distribute and deliver water for different uses. Vast majority of canals all over

the world are earthen canal. Open channels are normally designed to safely convey the design rate of flow and to be operated with low maintenance costs. The criteria for designing stable channels are that the entering sediment is kept in suspension; the flow velocity should not be higher than the critical value which could erode the bed or bank materials, and should not be low to allow the suspended sediment particles to settle along the channel bed. This in other words means that the channel is in a regime when the rate of the entering sediment equates to out. The regime theory was initiated by British Engineers involved in the design and construction of irrigation sand-silt canals in India [1–5], etc. This method was based on collecting comprehensive field data for the

\* Corresponding author. Mobile: +20 1065540781.

E-mail addresses: [Fahmyhri@gmail.com](mailto:Fahmyhri@gmail.com), [fahmy.hri@bhit.bu.edu.eg](mailto:fahmy.hri@bhit.bu.edu.eg) (F.S. Abdelhaleem), [a.amin@hri-egypt.org](mailto:a.amin@hri-egypt.org) (A.M. Amin), [drmebraheem@yahoo.com](mailto:drmebraheem@yahoo.com) (M.M. Ibraheem).

<sup>1</sup> Mobile: +20 1065540780.

<sup>2</sup> Mobile: +20 1225009723.

Peer review under responsibility of Faculty of Engineering, Alexandria University.

<http://dx.doi.org/10.1016/j.aej.2015.12.011>

1110-0168 © 2015 Faculty of Engineering, Alexandria University. Production and hosting by Elsevier B.V.

This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

**Nomenclature**

|       |  |       |   |
|-------|--|-------|---|
| $A$   | cross-section area (m <sup>2</sup> )             | $W$   | top width (width at water surface) (m)        |
| $b$   | bed width (m)                                    | $z$   | side slop of the channel; and                 |
| $C$   | Chezy coefficient                                | $\nu$ | water kinematic viscosity (m <sup>2</sup> /s) |
| $d$   | average flow depth (m)                           |       |   |
| $d_s$ | median size of sediment particle = $d_{50}$ (mm) |       |   |
| $R$   | hydraulic radius, ( $R = A/P$ ) (m)              |       |   |
| $P$   | wetted perimeter of the water cross-section (m)  |       |   |
| $Q$   | discharge (m <sup>3</sup> /s)                    |       |   |
| $S$   | channel slope (cm/km)                            |       |   |
| $V$   | mean flow velocity (m/s)                         |       |   |

**Abbreviations**

|      |   |
|------|---|
| AHD  | Aswan high dam                              |
| GPS  | global positioning system                   |
| HRI  | hydraulics research institute               |
| MWRI | ministry of water resources and irrigation  |
| SPSS | statistical package for the social sciences |

geometrical and flow parameters of stable channels. Data were then analyzed to formulate a set of equations that correlate flow and channel geometrical parameters.

Abdel-Aal [6] reviewed the design of stable alluvial channels and he concluded that Simons and Albertson's method is the most applicable one that gave values close to his studied canals.

A sound background can be found in the literature for designing the Egyptian canals in regime after the construction of the Aswan High Dam (AHD) e.g. [7–17].

Bakry and Khattab [13] deduced the following empirical equation for the mean velocity as follows:

$$V = K \cdot d_s^{1.6} \quad (1)$$

where  $V$  is the mean flow velocity (m/s),  $d_s$  is the particle diameter (mm) and  $K$  is a coefficient depending on the channel bed material, and Bakry [10] proposed the following formula:

$$V = 0.396R^{1.45}S^{0.282} \quad (2)$$

in which  $R$  is the hydraulic radius (m) and  $S$  is the longitudinal bed slope (m/m).

Khattab et al. [11] analyzed data of 23 stable earthen canals in Egypt, and developed the following equations:

$$d = 1.43Q^{0.24} \quad (3a)$$

$$A = 9.816Q^{0.65} \quad (4a)$$

$$R = 1.078Q^{0.25} \quad (5a)$$

$$V = 19.44(R^3S)^{0.58} \quad (6a)$$

where  $d$  is the water depth (m),  $Q$  is the discharge (m<sup>3</sup>/s) and  $A$  is the cross section area (m<sup>2</sup>). Eqs. (3a)–(6a) were valid for canals having sand bed and banks, and conveying discharges ranging from 90 to 200 m<sup>3</sup>/s.

Moreover, they developed the following formulas for discharges ranging from 2 to 200 m<sup>3</sup>/s and for canals having sand to sandy loam bed and cohesive banks (silt clay):

$$d = 1.17Q^{0.24} \quad (3b)$$

$$A = 7.247Q^{0.65} \quad (4b)$$

$$R = 0.827Q^{0.25} \quad (5b)$$

$$V = 38.37(R^3S)^{0.58} \quad (6b)$$

Khattab et al. [14] analyzed data collected from 322 observations from canals having sandy loam bed and cohesive banks in Egypt and then presented a group of designing regime type equations as follows:

$$d = 1.031Q^{0.254} \quad (7)$$

$$A = 8.05Q^{0.664} \quad (8)$$

$$R = 0.8335Q^{0.2672} \quad (9)$$

$$V = 23.277(R^3S)^{0.568} \quad (10)$$

The previously derived formulas [14] are very close to Eqs. (3b)–(5b) that are presented by [11]. This is not surprising because Khattab et al. [14] collected their data from the same cross-sections and from the same canals. But there is discrepancy in the mean flow velocity equation; this is due to velocity variations across the selected sections during the period of measurement.

Ali [15] used the method of synthesis of dimensional analysis and field data collected from the Ministry of Water Resources and Irrigation (MWRI) in Egypt to develop the following relationships in SI units:

$$d = 0.92Q^{0.4} \quad (11)$$

$$S = 7.5 \times 10^{-3}(d_s)^{0.415}Q^{-1/6} \quad (n \leq 0.04) \quad (12)$$

$$S = 3.6 \times 10^{-3}(d_s)^{0.415}Q^{-1/6} \quad (n > 0.06) \quad (13)$$

in which  $n$  is the Manning's coefficient.

El-Alfy [17] accumulated data that measured by MWRI in the period between 1980 and 1995 and employed these data to propose the following formulas for silty soil canals having a discharge range from 0.22 to 4.9 m<sup>3</sup>/s.

$$d = 0.9966 Q^{0.4034} \quad (14)$$

$$A = 5.5538 Q^{0.72} \quad (15)$$

$$R = 0.8557 Q^{0.5574} \quad (16)$$

$$S = 11.689 Q^{0.6346} \quad (17)$$

Furthermore, he deduced the following equations for canals having a discharge range from 2.50 to 322 m<sup>3</sup>/s:

(a) Silty sand soil canals

$$d = 1.0909Q^{0.2019} \quad (18a)$$

$$A = 5.513Q^{0.7187} \quad (19a)$$

$$R = 0.7842Q^{0.2611} \quad (20a)$$

$$S = 2.12Q^{0.29} \quad (21a)$$

(b) Silty soil canals

$$d = 1.0628Q^{0.1759} \quad (18b)$$

$$A = 5.413Q^{0.632} \quad (19b)$$

$$R = 0.756Q^{0.1786} \quad (20b)$$

$$S = 2.16Q^{0.279} \quad (21b)$$

Mohamed [18] applied the artificial neural networks (ANNs) method to estimate the main parameters which are used in the design of stable alluvial channels by comparing the previously deduced formulas. Also, he concluded that the regime equations for earthen canals in Egypt need more investigations to refine their practical use.

All the above investigations of Egyptian canals in regime after the construction of the AHD showed that their used data were recorded until 1995. Moreover their collected bed material samples were just used for classifying the bed and/or bank of each canal. The collected bed materials do not incorporate in their formulas. After a flood season of 1998/1999, the flow rate of Egyptian canals was increased and this may change the regime of these canals.

It is also appeared that, most of the previous regime equations considered the discharge as the only parameter in the estimation of the flow depth, cross section area, hydraulic radius, longitudinal water surface slope and the mean flow velocity of stable canals. *This is in conflict with the fact that canals with weak bed/banks tend to be wider than those with strong bed/banks for the same discharge.*

The objective of this study was to verify the real performance of the aforementioned design equations in terms of accuracy and reliability especially after a flood season of 1998/1999, focusing mainly on the analysis and comparison of these formulas with measured data. Using more than 371 data sets of cross-sectional profiles that were recently measured (the period between 2007 and 2013) and taking into account the soil material sizes, new equations will be proposed for designing stable canals in Egypt.

## 2. Material and methods

### 2.1. Field measurements

During the period from 2007 till 2013, 26 stable canals in Upper Egypt, Middle Egypt and Delta were surveyed through different survey missions of the Field Measurements Department of the Hydraulics Research Institute of the National Water Research Center in Egypt. Data for 371 cross sections on 26 canals in regime in Egypt were collected; four of the canals were in the upper Nile Valley, one in the lower Nile Valley, six in the Fayoum depression, and 15 in the Nile Delta, [Table 1](#).

For each of the 371 cross sections, three to eight velocity profiles were measured (depending on the shape of the cross section), and three point velocity measurements were carried out for each velocity profile. Therefore, in total, about 2968 point velocities were measured. These velocity profiles were applied to accurately determine flow discharge at a specified canal section. For each cross section, the depth of water was measured using Echo sounder instrument that installed on a rubber boat and attached to a Global Positioning System (GPS) unit, (for position measurements) and then the top width was recorded. The top width was split into 3–8 parts (verticals) to indicate the place of velocity profiles. The point velocities were measured in the vertical direction from the bed to the water surface by using a Propeller current meter with horizontal axis to consider the unevenness of the bed. In order to calculate the mean velocity and the flow discharge, point velocity measurements were used and the velocity-area method was applied. The longitudinal water surface slope was measured by surveying along the central axis of the canal in selected stable reaches. Accordingly, in each reach, two cross sections were selected and water surface was marked in both cross sections. Then, the water slope was determined by dividing the difference in water surface elevations by the distance between the two cross sections. A Van-Veen grab sampler was used to collect 3 soil material samples at the same locations of each velocity cross section (one sample for bed and two samples for banks). The bed samples were analyzed to provide the grain sizes of soil materials.

**Table 1** General location of considered canals.

| Location            | Canal name  |
|---------------------|---|
| Upper valley canals | Kalabiya, Asfoun, East Naga-Hammadi, and West Naga-Hammadi  |
| Lower valley canals | Ibrahimiya  |
| Fayoum canals       | El-Gmehoria, Bahr El-Gharq, Bahr El-Bashawat, Bahr El-Gargaba, Bahr El-Nazla, and Bahr Desya  |
| Delta canals        | El-Ismaila, El-Basosiya, Behery Rayah, Tawfiki Rayah, Bahr Mowais, Menoufi Rayah, El-Bagouria, Mit Yazeed, Port said, Abbasi Rayah, Omer Bey, Dahtoura, El-Nubarria, El-Mahmoudiaa, and East Rashidia |

**Table 2** Range of used data.

|            | Discharge $Q$ ( $m^3/s$ ) | Mean flow depth $d$ (m) | Cross-section area $A$ ( $m^2$ ) | Hydraulic radius $R$ (m) | Bed slope $S$ (cm/km) | Median particle size $d_{50}$ (mm) |
|------------|---------------------------|-------------------------|----------------------------------|--------------------------|-----------------------|------------------------------------|
| Min. value | 0.11                      | 0.40                    | 1.00                             | 0.24                     | 2.03                  | 0.040                              |
| Max. value | 287.5                     | 5.42                    | 398.35                           | 4.89                     | 8.54                  | 0.394                              |

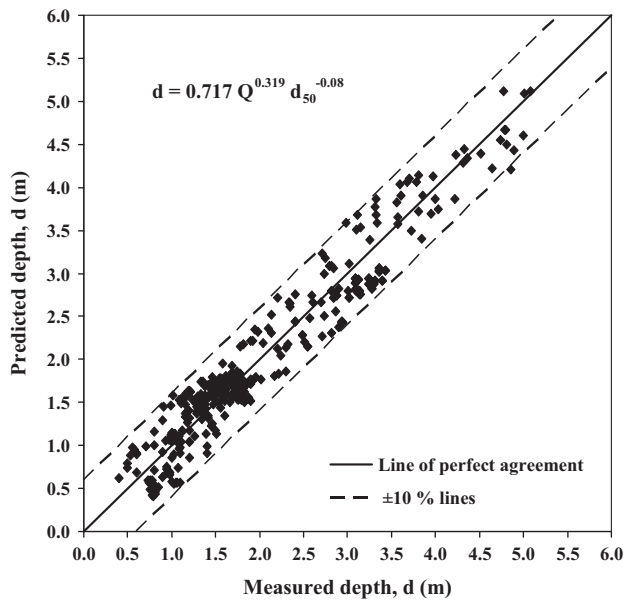


Figure 1 Observed and predicted average water depth.

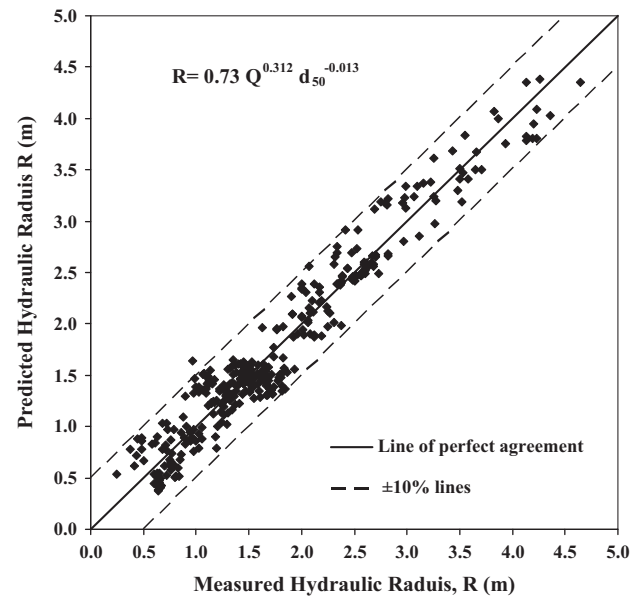


Figure 3 Observed and predicted hydraulic radius.

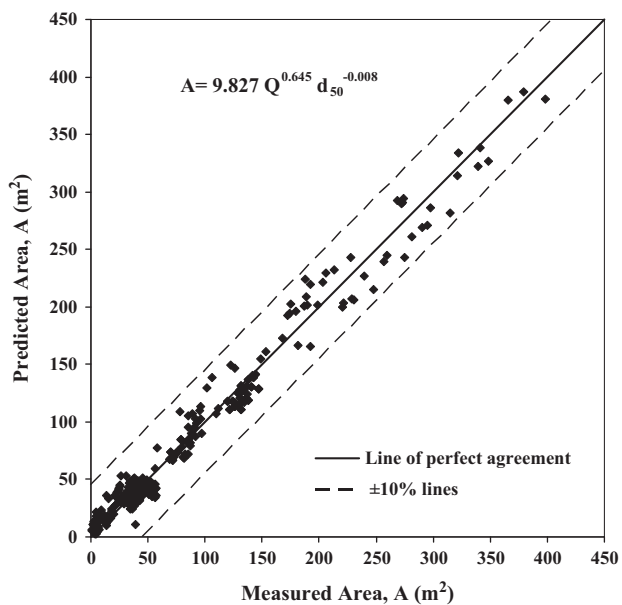


Figure 2 Observed and predicted cross-section area.

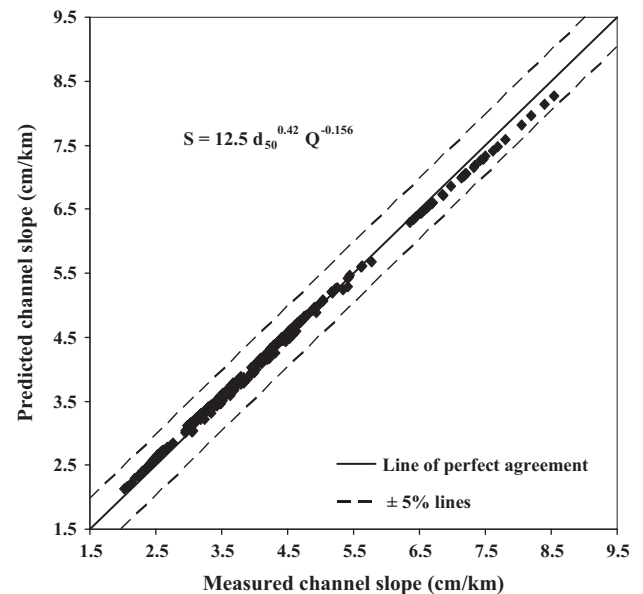


Figure 4 Observed and predicted channel slope.

## 2.2. Data analysis

Based on a preliminary analysis of the measured data by using velocity variations across the selected sections during the period of measurement, it should be pointed out that observations in the selected canal reaches during different seasons revealed that the sections were generally stable. The data sets of field measurements (water depth, water slope, velocity, and median particle size) were analyzed and the inaccurate measurements were excluded. Analysis of field data, in this case, produced errors not higher than  $\pm 1\%$ . Each measured cross section was plotted on AutoCAD software in order to determine the cross-sectional area,  $A$ , wetted perimeter,  $P$ , bed width,  $b$ , and the top width,  $W$ . The average flow depth of each cross

section was obtained as  $d = (A/W)$ , [19]. Table 2 shows the range of geometric and hydraulic data sets measured for considered Egyptian canals.

## 3. Results and discussions

### 3.1. Updating of regime formulas

The statistical software package (SPSS) was used to derive stepwise multiple regression equations using 371 sets of field measurements, while a nonlinear regression analysis was performed to express depth, area, hydraulic radius, longitudinal water slope and mean velocity as a power function of the flow discharge  $Q$ , and median grain size  $d_{50}$ . The derived equations

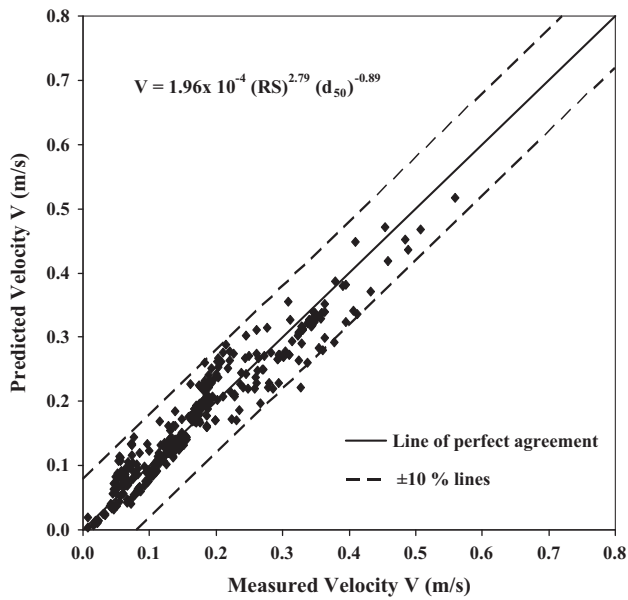


Figure 5 Observed and predicted mean flow velocity.

for the prediction of stable channel characteristics are expressed as follows:

$$d = 0.717Q^{0.319} d_{50}^{-0.08} \tag{22}$$

$$A = 9.827Q^{0.645} d_{50}^{-0.008} \tag{23}$$

$$R = 0.73Q^{0.312} d_{50}^{-0.013} \tag{24}$$

$$S = 12.5Q^{-0.156} d_{50}^{0.42} \tag{25}$$

$$V = 1.96 \times 10^{-4} (RS)^{2.79} d_{50}^{-0.89} \tag{26}$$

where  $d$  is the average flow depth (m),  $Q$  is the discharge ( $m^3/s$ ),  $d_{50}$  is the median particle size (mm),  $R$  is the hydraulic radius (m),  $S$  is the channel slope (cm/km), and  $V$  is the mean flow velocity (m/s).

By close inspection of the foregoing deduced equations, Eqs. (22)–(24), the bed material size has weak exponents in case of estimation of the depth, cross-sectional area, and hydraulic radius. This means that the flow discharge is the dominant variable in the determination of geometrical parameters at regime method for stable Egyptian canals. However, the grain size is effective parameter in calculating the slope and the mean velocity Eqs. (25) and (26). These findings agree well with the results of Afzalimehr et al. [19].

The coefficients of determination,  $R^2$  for these equations are relatively high between 88% and 97% of the variance in the dependent variable being explained by the variance in the independent variables. The comparisons between the measured depth; cross-sectional area; hydraulic radius; slope; the mean velocity; and those computed by Eqs. (22)–(26) are depicted in Figs. 1–5. Plots also show the line of perfect agreement and  $\pm 10\%$  lines.

### 3.2. Comparison of existing equations

Comparison between the developed and existing equations is essential in order to test the updated equations and to identify the effect of the bed material samples on the values of the exponents in the regression equations. Figs. 6–10 show the comparison of the foregoing equations that reported in the literature with the derived equations. The comparison revealed that the calculated water depth from the derived formula for low and high values of discharge was close to El-Alfy [17] (b). The calculated cross-sectional area was close to Khattab et al. [11] (a). The comparison showed that the calculated hydraulic radius using the derived formula for low values and high values of discharge was close to Khattab et al. [11] (a), and Khattab et al. [14], respectively. The comparison revealed that the calculated mean flow velocity from the derived formulae was close to Khattab et al. [14].

Other formulas were either overestimated or underestimated comparing to those measured. This implies that the

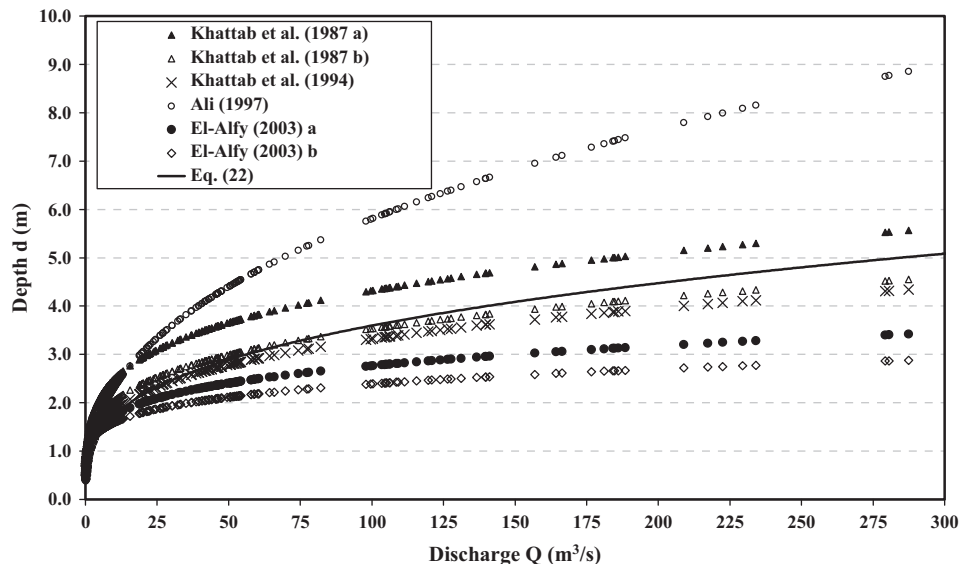


Figure 6 Relation between average water depth and discharge.

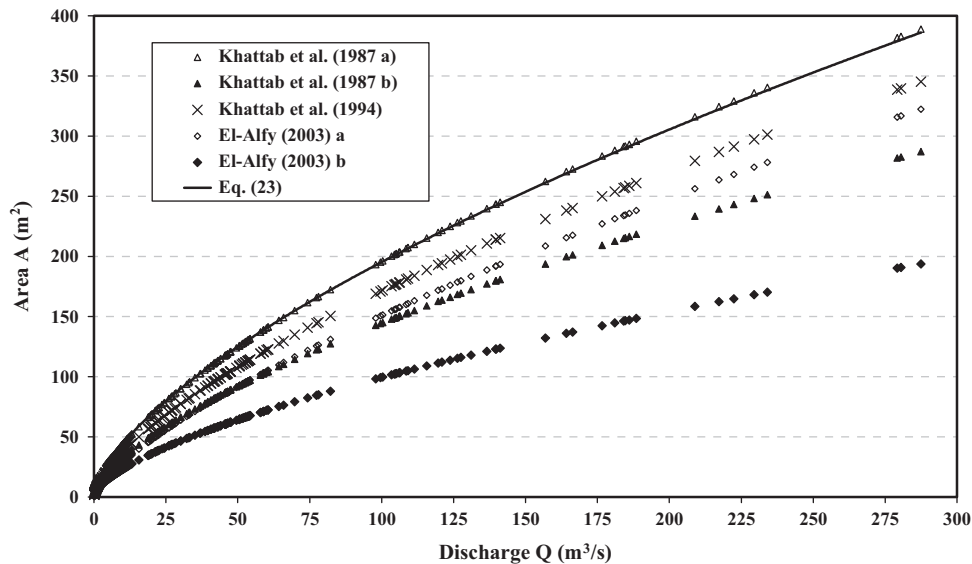


Figure 7 Relation between Cross-Sectional Area and Discharge.

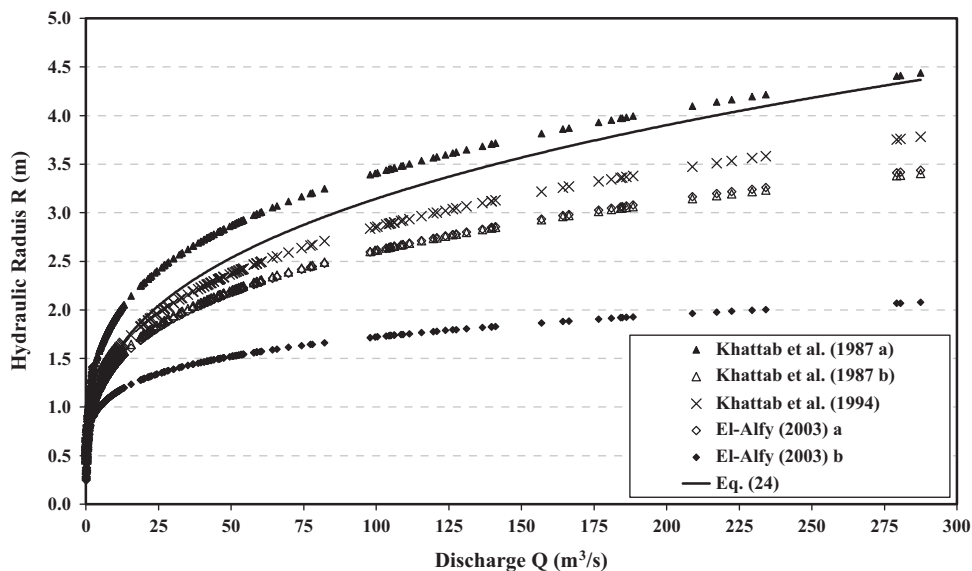


Figure 8 Relation between hydraulic radius and discharge.

existing equations exclude the effect of soil material parameter and other formulas were derived for the canals with different hydraulic characteristics.

Eq. (25) shows that the flow rate is not an effective parameter in the prediction of the slope and the grain size is controlling parameter in the slope and velocity equations, Figs. 9 and 10. This is due to the fact that velocity distribution does not depend on the flow depth variation [20]. For this reason when there is no bed form, the upstream of channel condition can be represented by the grain size. This may clarify why the exponent of discharge in slope equation (Eq. (25)) is small. This justification is valid for sandy loam bed canals where sediment particles transport near the bed. This study shows that when using the flow discharge as input variable to estimate slope,

due to small discharge exponent, this variable is not the dominant variable for slope computation.

### 3.3. Verification of the developed formulas

Throughout the following section, independent data for stable cross sections in Egypt enable the predictive capability of the aforementioned equations to be compared with those developed in this paper. To design a stable channel (El-Bohiala Canal at Mit Ghamr, south Ad-Daqahliyah, Egypt) to carry a discharge of  $18.78 \text{ m}^3/\text{s}$ , the median size sediment is  $0.134 \text{ mm}$ , and the measured longitudinal water surface slope is  $3.33 \text{ cm/km}$ . The comparisons between the actual canal and those calculated by the aforementioned formulas



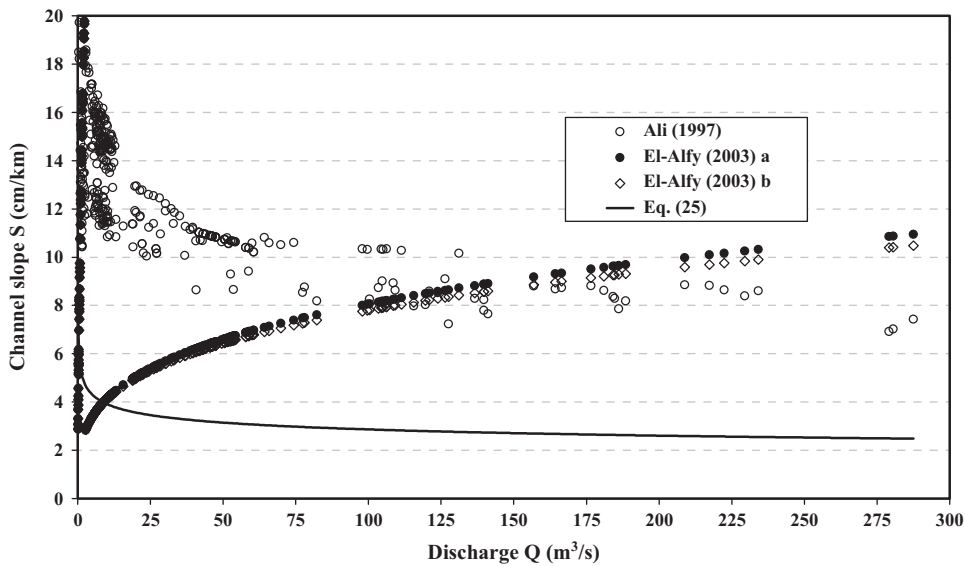


Figure 9 Relation between channel slope and discharge.

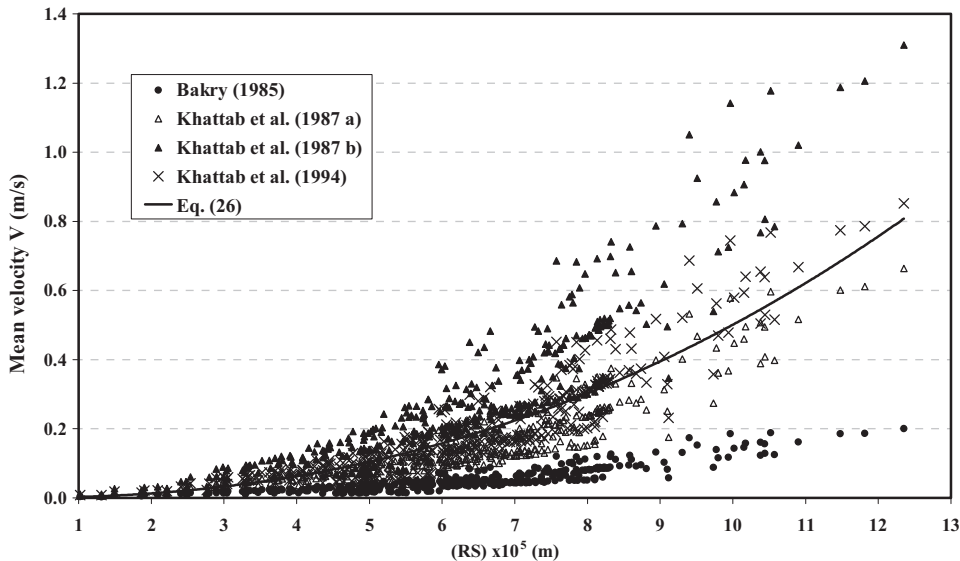


Figure 10 Relation between mean flow velocity and values of RS.

Table 3 Application of different design equations for El-Bohiaa Canal, Egypt.

| Method                  | Mean flow depth |                    | Cross-section area         |                    | Hydraulic radius |                    | Channel slope    |                    | Mean velocity  |                    |
|-------------------------|-----------------|--------------------|----------------------------|--------------------|------------------|--------------------|------------------|--------------------|----------------|--------------------|
|                         | <i>d</i> (m)    | Relative error (%) | <i>A</i> (m <sup>2</sup> ) | Relative error (%) | <i>R</i> (m)     | Relative error (%) | <i>S</i> (cm/km) | Relative error (%) | <i>V</i> (m/s) | Relative error (%) |
| Measured parameters     | 2.4             | –                  | 71.710                     | –                  | 1.920            | –                  | 3.33             | –                  | 0.211          | –                  |
| The new design formulas | 2.15            | –10.42             | 66.420                     | –7.38              | 1.870            | –2.60              | 3.40             | 2.10               | 0.207          | –1.90              |
| Bakry [10]              | –               | –                  | –                          | –                  | –                | –                  | –                | –                  | 0.056          | –73.46             |
| Khattab et al. [11] (a) | 2.89            | 20.42              | 66.060                     | –7.88              | 2.240            | 16.67              | –                | –                  | 0.153          | –27.49             |
| Khattab et al. [11] (b) | 2.37            | –1.25              | 48.770                     | –31.99             | 1.720            | –10.42             | –                | –                  | 0.302          | 43.13              |
| Khattab et al. [14]     | 2.17            | –9.58              | 56.440                     | –21.29             | 1.830            | –4.69              | –                | –                  | 0.202          | –4.27              |
| Ali [15]                | 2.97            | 23.75              | –                          | –                  | –                | –                  | 11.37            | 241.44             | –              | –                  |
| El-Alfy [17] (a)        | 1.97            | –17.92             | 45.382                     | –36.71             | 1.687            | –12.14             | 4.96             | 48.95              | –              | –                  |
| El-Alfy [17] (b)        | 1.78            | –25.83             | 34.554                     | –51.81             | 1.227            | –36.09             | 4.89             | 46.85              | –              | –                  |

are listed in Table 3. Also the percentage relative errors associated with each equation were calculated and are presented in Table 3.

The associated errors when using the current developed formulas for depth, area, hydraulic radius, slope and mean velocity were 10.42, 7.38, 2.6, 2.1 and 1.90%, respectively. The proposed equations presented in this paper give practical design procedures in terms of accuracy and reliability for the Egyptian stable canals after the construction of the AHD, and these formulas should be used with caution to the limitation of the considered data.

#### 4. Conclusions

The attainable results from the Field and statistical study for the design of stable canal in Egypt were presented and the following conclusions are drawn:

- Updated regime formulas presented in this paper give practical and acceptable design procedures for the Egyptian stable canals for a discharge ranging from 0.11 to 287.5 m<sup>3</sup>/s.
- Computed geometrical and flow parameters using the derived formulas are close to those calculated by some existing equations for the same values of discharge and the same soil type.
- When regime method is applied to design stable channels, discharge is not the only controlling variable for the prediction of channel slope and mean flow velocity.
- Sediment grain size parameter should be incorporated in design equations of the channel slope and velocity of hydraulic geometry of stable canals.
- Independent data of El-Bohiala Canal in Egypt, benchmarked the predictive capability of the developed formulas. The equations developed in this paper provide an improvement of those developed by other investigators.

These results could be of benefit in the hydraulic design of stable Egyptian canals.

#### Acknowledgments

The field data described in this paper were measured during different survey missions of the Field Measurements Department of the Hydraulic Research Institute of the National water Research Center, Egypt. We would like to acknowledge the support of HRI.

#### References

- [1] L.B. Leopold, T.J. Maddock, Hydraulic Geometry of Stream Channels and Some Physiographic Implications, U.S. Geol. Survey. Prof. Paper., vol. 252, 1953, p. 55.
- [2] D.B. Simons, M.L. Albertson, Uniform water conveyance channels in alluvial materials, *Trans. ASCE* 128 (Part 1) (1963) 65–107.
- [3] G. Lacey, A general theory of flow in Alluvium, in: *Proc. J.I.C. E.* (London), vol. 27, 1964, p.16.
- [4] T. Blench, Regime theory design of canals with sand bed, *J. Irrigation Drainage Div. ASCE* 96 (2) (1970) 205–213.
- [5] V.P. Singh, On the theories of hydraulic geometry, *Int. J. Sediment Res.* (18) (2003) 196–218.
- [6] F.M. Abdel-Aal, Design of stable channels, *Ain Shams Sci. Bull.* 31 (4) (1996) 200–208.
- [7] S.T. El-Attar, Design of Open Channels. Ph.D. thesis, Assiut Univ., Egypt, 1980.
- [8] M.M. Saleh, Design of Stable Alluvial Channels. M.Sc. Thesis, Cairo University, Egypt, 1984.
- [9] A.A. Zidan, A Comparative Study of Conventional Regime Equations, the Bulletin of the Faculty of Engineering, vol. 9, no. 1, El Mansoura University, 1984.
- [10] M.F. Bakry, Practical Regime Design of Egyptian Canals. M.Sc. Thesis, Cairo University, Egypt, 1985.
- [11] A.F. Khattab, M.M. Abu-Seida, Z-El-Gharably, M.F. Bakry, Practice of Canal Design in Egypt, 13th Conference, ICID, Rabat, Morocco, 1987.
- [12] A.A. Zidan, Regime Equations for Irrigation Canals, the Bulletin of the Faculty of Engineering, vol. 16, no. 1, El Mansoura University, 1991.
- [13] M.F. Bakry, A.F. Khattab, Regime behaviour for alluvial stable Egyptian canals, *Irrig Drain Syst.* 6 (1992) 27–36.
- [14] A.F. Khattab, M.N. Hammad, Abd-El-Hafiz, H.A. Badawy, Design of Canals in Sandy Soils. Water Science. In: 16th Issue, National Water Research Centre, Egypt, 1994.
- [15] N.A. Ali, Regime Behavior of Artificial Channels in Alluvium, *Bulletin of the Faculty of Engineering*, vol. 25(1), Assiut University, 1997.
- [16] T.A. El-Samman, A. Awad, Redesign of Canals Using Regime Theory. International Conference on Integrated Management of Water Resources in the 21st Century, Cairo, Egypt, 1999.
- [17] K.S. El-Alfy, A regime study of Egyptian irrigation canals, in: 7th. Inter. Water Tech. Conference, IWTC VII, Cairo, Egypt, 2003.
- [18] H.I. Mohamed, Design of alluvial Egyptian irrigation canals using artificial neural networks method, *Ain Shams Eng. J.* 4 (2) (2013) 163–171 (Egypt).
- [19] H. Afzalimehr, M. Abdolhosseini, V.P. Singh, Hydraulic geometry relations for stable channel design, *J. Hydrol. Eng. ASCE* 15 (2010) 859–864.
- [20] M.S. Yalin, *Mechanics of Sediment Transport*, second ed., Pergamon, Oxford, U.K., 1977.