REGIME EQUATIONS FOR EGYPTIAN IRRIGATION CANALS (CASE STUDY: 'DAKAHLIYA GOVERNORATE')

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ABSTRACT

The main objective of this research work is to choose the best regime approach to be used for the design purpose of Egyptian irrigation canals, after the construction of High Aswan Dam. A hydraulic study for some Egyptian irrigation canals in Dakahliya Governorate was carried out to obtain the required data. These canals have different degrees with 20 successive cross-sections for El-Mansuriya and El-Bahr El-Sagheer canals; and 10 consecutive ones for Bahr-Tnah and Om-Glagel canals with discharge value varies between 0.40 m^3/s and 234.7 m^3/s. Moreover, the comparative study between different equations was performed using statistical significance tests, namely F-test, T-test, and M.A.E. It was found that no conventional regime approach can be completely applied at 95% level of confidence. However, results of some equations of each approach could be considered. Lacey (1930) equation to compute wetted perimeter resulted in reasonable value of M.A.E equal to 8.55%. Moreover, Simons; and Albertson (1960) formulae could be used to estimate hydraulic radius and mean water depth, with M.A.E equal to 8.03% and 12.45%, respectively. Also, estimated values of average water depth using Bakry (1985) approach, with M.A.E equal to 12.07%, can be accepted for relatively high discharge values. Furthermore, Zidan (1991) regime equations for small irrigation canals in Dahakliya governorate can be applied to calculate wetted perimeter and top width, with M.A.E equal to 12.00%, and 9.54%. In addition, new regime equations between cross section properties; and between these properties and the discharge were derived under local conditions.

Keywords: Egyptian canals, Regime equations, Significance tests, Lacey, Simons and Albertson, Bakry.

1 INTRODUCTION

Irrigation process has been practiced from ancient time to the present one using a network of irrigation canals. These canals transmit water from the supply source to the irrigation field like veins transmitting blood in human's body. They have been designed based on scientific basics only since the past century. Canal design process varies from country to country depending on the local conditions such as soil formations, sediment transport, and maintenance process. Proper design of open channels is required to determine the economics of the project. It involves the selection of channel alignment, shape, size, and bottom slope.

In Egypt, the total area of agricultural land represents the main part of the national income. This area is completely dependent on The Nile River for irrigation purpose through a huge network of canals because of the scarcity of rainfall along the irrigation season. The irrigation network in Egypt, including rayyahs, main canals, branch canals, major and minor distributaries, and field channels must be well-designed to convey the required amount of water for different purposes.

Changes in the channels regime were observed in Egypt before and after the construction of High Aswan Dam. Before the construction of the dam, the design of stable channels was carried out using empirical relationships derived from field observations as the sediment transport was significant. After the construction of High Aswan Dam, the regime condition of canals has changed due to the changes of solid suspensions, so the design concepts of these canals have changed. Many investigators have tried to relate dependent variables as width, depth, and longitudinal slope of the cross section to independent variables such as discharge. Design equations given by Ministry of Water Resources and Irrigation before the construction of High Aswan Dam are not applicable to be used. Therefore, a new design concept is recommended to match with the new prevailing conditions.

2 LITERATURE REVIEW

2.1 Open Channel Design Concepts

Many concepts are available for the design of stable hydraulic cross sections. These methods can be summarized as follows (Saleh, 1984):

2.1.1 Maximum permissible velocity

This method is based on the assumption that scour will not occur if the velocity does not exceed a particular value called maximum permissible velocity (Akan, 2006).

2.1.2 Semi-empirical approach

The design process is carried out based on the known hydraulic relationships such as flow resistance formulae.

2.1.3 Tractive force method

This method is based on the shear stress which the soil of the canal can sustain. The drag force exerted on the cross section is used in the design process based on the principle that no scour nor filling will occur when working under the limiting tractive force condition.

2.1.4 Live bed approach

This method is based on the motion of sediment particles without any effect on the equilibrium of the channel cross section. It is used in the design of canals depending on the flow resistance and sediment transport equations.

2.1.5 Stable hydraulic section

The section of an erodible channel at which no scour will occur at a minimum water area for a given discharge is called stable hydraulic section. The method is based on the tractive force that exerted on the cross section and an empirical profile is assumed for the design process in the shape of ellipse and parabola (Chow, 1959).

2.1.6 Regime approach

Regime or equilibrium theory can be considered as one of the milestones of river engineering, as it used for the design of stable hydraulic channels. The term regime means stable that no change will occur over a period of one or several years (Yalin and Da Silva, 1999). Natural channels are self-formed channels that are made by the balance of scour and deposition to achieve stable or regime conditions at a specified flow carrying sediment. If a certain flow runs for a long time, the channel characteristics like width, depth, and slope may either increase or decrease depending on the process that will occur, whether it will be scour or sedimentation. For open channels carrying sediment particles, if the velocity is smaller than a certain value called minimum permissible velocity, a deposition process will occur. In contrast, if the velocity is larger than another particular value called maximum permissible velocity, an erosion process may occur (McLean, 1997). Each process will continue to occur for a long time until the channel reaches a stage at which no change will happen in the cross section. Stability could be defined as the ability of a stream to transport the flow carrying sediments without aggrading or degrading while maintaining a consistent dimension, pattern, and profile (Huang et al., 2002). This condition can be called the regime condition or stable channel. In other words, there will neither scour nor sedimentation if the channel reaches the regime state (Sarma, 2015).

2.2 Regime Conditions in Open Channels

Lacey classified the regime condition into two types (Masood, 2014):

2.2.1 Initial regime:

The channel may be in an initial regime condition if the cross section properties remains unaffected while the bed slope of the channel might vary. Initial regime condition starts with the operation of the channel after finishing from construction.

2.2.2 Final regime:

Lacey defined the final regime as a channel that adjusts its hydraulic properties such as cross section area to achieve permanent stability according to its discharge and silt grade. The cross section becomes flatter and takes the shape of semi-ellipse in case of coarser silt. In contrast, it attains the shape of a semi-circle if the silt grade is finer. Final regime condition is attained after a long time from construction.

2.3 Research Studies Concerning Conventional Regime Formulae

In 1895, Robert kennedy, an engineer in Punjab irrigation department, was the first one to propose the non-scouring non-silting velocity. His study was based on 22 different stable irrigation canals in India and he suggested the following equation in SI units (Saleh, 1984; Hey, 2006):

$$V_c = 0.55\ D^{0.64} \tag{1}$$

Where:

V_c : non-silting non-scouring velocity; and

D : mean water depth of the cross section.

Lacey (1930) introduced the cross section properties as a function of discharge and Lacey's silt factor, based on a large set of data for stable channels in India with discharge value ranges from 0.03 m^3/s to 300 m^3/s and d_{50} varies between 0.1 mm and 0.6 mm. Lacey's equations are given as follows (Das, 2008):

$$P = 4.83\ Q^{0.5} \tag{2}$$

$$d_{50} = \frac{f_l^{\,2}}{2.52} \qquad d_{50} \text{ in (mm)} \tag{3}$$

$$A = \frac{2.28\ Q^{5/6}}{f_l^{\,1/3}} \tag{4}$$

$$R_h = \frac{0.47\ Q^{1/3}}{f_l^{\ 1/3}} \tag{5}$$

$$V = \frac{0.44\ Q^{1/6}}{f_l^{\ 1/3}} \tag{6}$$

$$S_f = \frac{f_l^{\ 5/3}}{3169.8\ Q^{1/6}} \tag{7}$$

Where:

P : wetted perimeter of the cross section;
Q : discharge of the cross section;
d_{50} : soil grain diameter that 50 percent of the material is finer by weight;
f_l : Lacey's silt factor;
A : water area of the cross section;
R_h : hydraulic radius of the cross section;
V : mean velocity of the cross section; and
S_f : friction slope.

In 1952, Blench used the regression analysis to determine his regime equations using a broad range of data from stable canals in India, Pakistan and Egypt with sand beds and slightly cohesive-to-cohesive banks (Mazumder, 2006). The basic three channel dimensions, namely width, depth, and longitudinal friction slope are calculated using Blench equations as follows (Bakry, 1985; Thomas et al., 2002):

$$B = \left(\frac{f_b\ Q}{f_s}\right)^{0.5} \tag{8}$$

$$f_b = 0.579\ \sqrt{d_{50}}\ (1 + 0.12\ c_c) \qquad d_{50} \text{ in (mm)} \tag{9}$$

$$D = \left(\frac{f_s\ Q}{f_b^{\ 2}}\right)^{1/3} \tag{10}$$

$$S_f = \frac{f_b^{\ 5/6}\ f_s^{\ 1/2}\ \nu^{0.25}}{3.63\ \left(1+\frac{c_{sc}}{233}\right)\ g\ Q^{1/6}} \tag{11}$$

Where:

B : mean water width of the cross section;
f_b : bed factor;
f_s : side factor;
C_c : Coefficient of gradation curvature;
ν : kinematic viscosity of water;
c_{sc} : bed material sediment concentration; and
g : gravitional acceleration;

f_s = 0.1 for friable banks; f_s = 0.2 for silty, clay, and loam banks; and f_s = 0.3 for tough clay banks.

Simons and Albertson (1960) derived a modified regime equations based on data from channels in the United States and India. They expanded the range of conditions that used in the previous equations given by Lacey, and Blench and derived the following formulae for five categories of canals:

$$P = k_1\, Q^{0.5} \quad (12)$$

$$B = 0.9\, P \quad (13)$$

$$T = 1.09\, B + 0.66 \quad (14)$$

$$R_h = k_2\, Q^{0.36} \quad (15)$$

$$D = 1.21\, R_h \qquad (R_h \le 2.1\text{m}) \quad (16)$$

$$D = 0.61 + 0.93\, R_h \qquad (R_h > 2.1\text{m}) \quad (17)$$

$$V = k_3 \left(R_h{}^2\, S_f\right)^{n_s} \quad (18)$$

$$\frac{V^2}{g\, D\, S_f} = k_4 \left(\frac{V\, B}{D}\right)^{0.37} \quad (19)$$

Where:

T : top width; and

k_1; k_2; k_3; k_4; n_s: empirical coefficients depending on soil material type, Table 1.

Table 1. Empirical values of Simons and Albertson regime equations.

Type of material	k_1	k_2	k_3	k_4	n_s
Sand bed and bank	6.34	0.572	9.28	0.33	0.33
Sand bed and cohesive bank	4.71	0.984	10.67	0.54	0.33
Cohesive bed and bank	3.98	0.407	-	0.87	-
Coarse non-cohesive material	3.17	0.253	10.87	-	0.29
Sand bed and cohesive bank with heavy sediment load	3.08	0.374	9.71	-	0.29

2.4 Regime Equations for Egyptian Irrigation Canals

Before and after the erection of High Aswan Dam, there are changes in the regime of Egyptian irrigation canals which were noticed. Many research studies to get a practical precise approach for the design of such canal have been derived as follows:

2.4.1 Regime equations before the construction of High Aswan Dam

Many investigators have derived equations, related to the regime before the construction of High Aswan Dam as follows (Saleh, 1984; Bakry, 1985):

In 1921, Buckly derived the following relation for Egyptian irrigation canals:

$$D = 0.1\left[\left(\frac{S_f}{2} + 4\right)\right] B^{1/2} \quad (20)$$

In 1930, Ghaleb used the following empirical relationship to calculate the maximum allowable velocity based on observations for thirteen canals from different parts of Egypt with an average sediment concentration of about 1600 p.p.m:

$$V_o = p\, D^{0.727} \quad (21)$$

Where:

V_o : maximum allowable velocity; and

p : constant that depends on sediment nature = 0.284

In 1963, El-Banna suggested a diagram for the design of trapezoidal non-silting canals with side slope 1:1 of irrigation Egyptian canals based on the following empirical equation:

$$V = 0.15 + 0.15\, D \quad (22)$$

2.4.2 Regime equations after the construction of High Aswan Dam

In 1980, El-Attar derived the following equations for Egyptian channels in regime (Mohamed, 2013):

$$D = L_1\, Q^{0.314} \quad (23)$$

$$\frac{D}{B} = L_2\, Q^{-1/6} \quad (24)$$

$$S_f = L_3\, Q^{-1/6} \quad (25)$$

Where:

L_1; L_2; L_3: coefficients that depend on channel characteristics and category.

In 1982, Khattab et.al derived the following relationships for stable irrigation canals: (Bakry and Khattab, 1992)

$$A = H_1\, Q^{r_1} \quad (26)$$

$$R_h = H_2\, Q^{r_2} \quad (27)$$

$$D = H_3\, Q^{r_3} \quad (28)$$

$$V = H_4\, (R_h^{\,3}\, S_f)^{r_1} \quad (29)$$

Where:

H_1; H_2; H_3; H_4; r_1; r_2; r_3: empirical coefficients depending on the characteristics of the channel.

Ministry of Irrigation and Water resources regime equations developed by Bakry (1985) can be given for stable irrigation Egyptian canals as:

- For canals of sand bed and banks with discharge values range from 90 m^3/s to 350 m^3/s:

$$A = 9.816\, Q^{0.65} \quad (30)$$

$$R_h = 1.078\, Q^{0.25} \quad (31)$$

$$P = 9.106\, Q^{0.4} \quad (32)$$

$$D_{avg} = 1.464\, Q^{0.205} \quad (33)$$

$$D = 1.05\ Q^{0.27} \tag{34}$$

$$T = 9.35\ Q^{0.38} \tag{35}$$

$$B = 0.965\ P - 1.35 \tag{36}$$

$$V = 19.44\ (R_h{}^3\ S_f)^{0.58} \tag{37}$$

- For canals of sandy loam beds and cohesive banks with discharge values vary between 2 m^3/s and 150 m^3/s:

$$A = 7.274\ Q^{0.65} \tag{38}$$

$$R_h = 0.827 Q^{0.25} \tag{39}$$

$$P = 8.786\ Q^{0.4} \tag{40}$$

$$D_{avg} = 1.118\ Q^{0.205} \tag{41}$$

$$D = 0.86\ Q^{0.27} \tag{42}$$

$$T = 8.41\ Q^{0.38} \tag{43}$$

$$B = 0.96\ T - 0.96 \tag{44}$$

$$V = 38.37 (R_h{}^3 S)^{0.58} \tag{45}$$

Where:

D_{avg} : average water depth of the cross section.

Zidan (1991) gave the following regime equations based on data for distributary irrigation canals in Dakahliya governorate as follows:

$$R_h = 0.909\ D - 0.047 \tag{46}$$

$$B = 0.633\ P - 0.072 \tag{47}$$

$$Y_{max} = 1.447\ R_h + 0.129 \tag{48}$$

$$B = 0.568\ T + 1.031 \tag{49}$$

$$B = 4.662\ D + 0.769 \tag{50}$$

$$B = 5.48\ D \tag{51}$$

$$A = 4.37\ Q^{0.55} \tag{52}$$

$$P = 6.635\ Q^{0.246} \tag{53}$$

$$R_h = 0.705\ Q^{0.227} \tag{54}$$

$$B = 4.12\ Q^{0.248} \tag{55}$$

$$D = 0.805\ Q^{0.221} \tag{56}$$

$$T = 5.584\ Q^{0.3} \tag{57}$$

$$Y_{max} = 1.157\ Q^{0.19} \tag{58}$$

Where:

Y_{max} :max water depth

3 FIELD WORK

3.1 Site Description

The present study was carried out for four man-made stable Egyptian irrigation canals in Dahakliya Governorate. These canals are El-Mansuriya, El-Bahr El-Sagheer, Bahr-Tnah, and Om-Glagel as shown in Figure 1. They were carefully selected to cover a wide range of data with different canal degrees, starting from main canals to distributer ones. For each canal, a reach, that work with the full capacity throughout the irrigation season, was chosen to get the required data. The selected reaches can be defined as:

❖ **El-Mansuriya canal**

The first reach was chosen from the main canal called El-Mansuriya. It is fed with water from El-Tawfiqy rayyah. It consists of twenty cross sections, starting from cross section No. 1 at km: 0.50 to cross section No. 20 at km: 19.50 with a length of 19 km. and a distance of 1 km between each cross section

❖ **El-Bahr El-Sagheer canal**

The second reach was selected from El-Bahr El-Sagheer branch canal, which takes its water from El-Mansuriya canal at km: 16.50. It starts from cross section No. 1 at km: 0.50 to cross section No. 20 at km: 19.50 with a total length of 19 km and a step of 1 km between each cross section.

❖ **Bahr-Tnah canal**

The third reach was chosen from the branch canal, namely Bahr-Tnah, which is fed with water from El-Mansuriya canal at km: 37.50. It contains ten cross sections at a step of 3 km., starting from cross section No. 1 at km: 0.50 to cross section No. 10 at km: 27.50 with a length of 27 km.

❖ **Om-Glagel canal**

The fourth reach was from Om-Glagel canal, the distributary canal, that takes its water from El-Mansuriya canal at km: 43.00. Ten cross-sections were chosen in the reach at a distance 2 km apart, starting from cross section No. 1 at km: 0.30 to cross section No. 10 at km: 18.30 with a total length of 18 km.

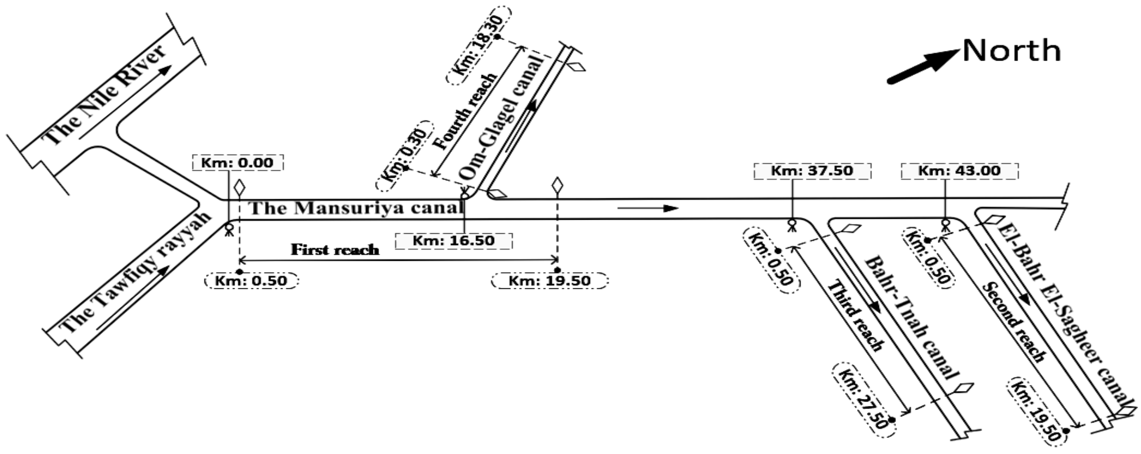

Figure 1. A detailed map for canals under study.

3.2 Field Data Collection

The Bray-stoke current meter was used for velocity measurements. Using the velocity measurements data, the velocity-area method was used to calculate the discharge varying from 0.40 m^3/s to 234.70 m^3/s. Also, the different cross section properties were estimated such as cross section water area, wetted perimeter, and hydraulic radius.

In order to calculate Manning's coefficient, three soil samples were taken for each cross section at each location of velocity measurements. Grain size distribution curves were plotted using a logarithmic scale to get the different grain sizes, showing that the soil is fine sand with some silt.

To determine water surface profiles, the tilting level, and leveling staff were used to measure the water level at each cross section of canals under study. The friction slope (S_f) can be taken equal to the water surface slope (S_w), as the velocity head is very small and can be neglected.

4 METHOD OF THE ANALYSIS

The analysis process was divided into two parts. On one hand, the statistical significance tests, namely F-test and T-test, were used in order to determine the applicability of the conventional regime equations to be used for canals under study. The calculated values for each regime equation were compared to the actual ones using these significance tests. F-test is used to compare between the variance of the two samples while T-test compares between the mean values of the two samples. The calculated values of F-test and T-test were compared to their corresponding critical ones at 95% level of confidence to determine if the regime equation is accepted or rejected. In addition, measured values of each hydraulic property were plotted against the calculated ones in a 45 degree graph to show the variance around the line of perfect agreement (L.P.A). Also, the mean absolute error was used in the analysis process to estimate the accuracy of each equation. It is an average of the errors between a calculated and measured quantities to determine how close they are.

On the other hand, the linear and non-linear regression analyses using Excel and SPSS were carried out to derive new relationships between different properties under the local conditions.

5 DISCUSSION AND ANALYSIS

In order to get the best regime approach for canals under study, the analysis process has been divided into two parts as follows:

5.1. Applicability of Previous Formulae to be used

In this section, the applicability of some regime equations derived by Lacey, Blench, Simons and Albertson, and Bakry using the corresponding statistical significance tests. Also, Zidan regime formulae for small irrigation canals in Dakahliya Governorate were checked to be applied under the local conditions. The study has been carried out based on discharge ranges, Table 2, as follows:

Table 2. Discharge ranges used in the study.

Canal	Discharge range (m^3/s)
El-Mansuriya	98.60 → 234.70
El-Bahr El-Sagheer	27.95 → 75.08
Bahr-Tnah	6.09 → 19.43
Om-Glagel	0.40 → 4.94
El-Mansuriya & El-Bahr El-Sagheer	27.95 → 237.70
Bahr-Tnah & Om-Glagel	0.40 → 19.43
All canals under study	0.40 → 234.70

5.1.1 Lacey's regime equations

It is obvious from the comparison process between the actual values and calculated ones using Lacey's regime equations at 95% level of confidence based on the results of statistical significance tests that:

- Wetted perimeter can be calculated with M.A.E equal to 8.55% for discharge value ranges from 0.40 m^3/s to 234.70 m^3/s, because there is no significant difference between the actual and estimated values as demonstrated in Figure 2. It is clear from the figure that there are over-estimated values of wetted perimeter at high discharges related to El-Mansuriya canal which increase the error to reach a value of 13.70%.
- Cross section water area can be estimated for all canals under study with a relatively high value of M.A.E equal to 18.39% as illustrated in Figure 3. M.A.E can be reduced to 11.65% for discharge values related to Bahr-Tnah and Om-Glagel canals.
- There is no significant difference between the actual and computed values of hydraulic radius with M.A.E equal to 14.28% for small discharge values of Bahr-Tnah and Om-Glagel canals.
- The results of computing mean velocity and friction slope are not accepted for all ranges of discharge under study as there is a significance difference between the actual values and calculated ones with high values of M.A.E.

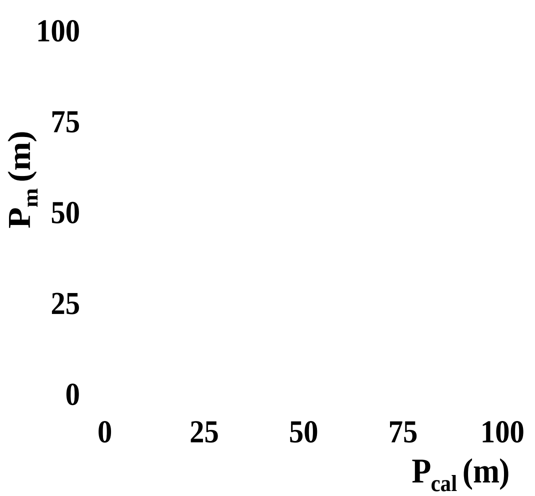

Figure 2. Measured wetted perimeter values against calculated ones using Lacey's regime equation.

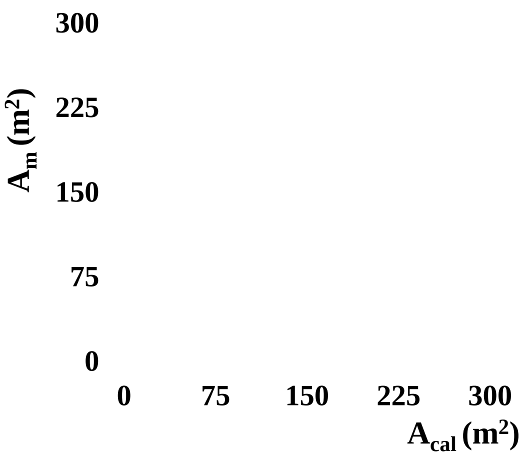

Figure 3. Measured cross section water area values against calculated ones using Lacey's regime equation.

Referring to the Previous results, there is a deviation between the actual and calculated parameters using some regime equations, given by Lacey. The Indian canals, which much of data were given for Lacey equation, had sand bed of (0.10 mm $\leq d_{50} \leq$ 0.60 mm) and a slightly cohesive to cohesive banks. Also, the discharge range for Lacey equations was between 0.03 m^3/s and 300 m^3/s. A further limitation of Indian data is that the sediment of canals is usually less than 500 p.p.m.

5.1.2 Blench's regime equations

For different regime equations proposed by Blench, the side factor equal to 0.2 for silty, clay, and loam banks was used in the calculation process. By comparing the actual properties of cross sections, related to canals under study to the calculated ones using F-test, T-test, and M.A.E at 5% degree of significance, it is evident that:

- Estimation of mean width and mean depth values gives rejected values, because there is a significant difference between the calculated and actual values for each variable
- Generally, friction slope can be calculated for all canals under study for discharge varies between 0.40 m^3/s and 234.70 m^3/s with M.A.E equal to 25.36% as shown in Figure 4. However, the value of error can be reduced to 15.50% for small discharge ranges, related to Bahr-Tnah and Om-Glagel canals.

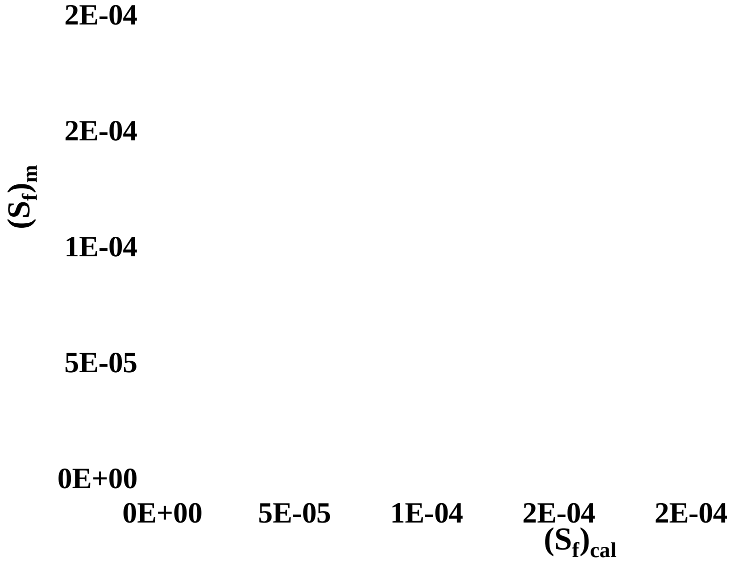

Figure 4. Measured friction slope values against calculated ones using Blench's regime equation.

Upon the previous results for Blench regime equations, it is noticeable that some of Blench's regime relationships are rejected because Blench used Lacey's data with more general data from India and Pakistan and some data from Egypt.

5.1.3 Simons and Albertson's regime equations

In order to check the applicability of regime equations derived by Simons and Albertson to be used for canals under study, the calculated properties of the cross sections of canals under study using these equations are compared to the actual ones based on the corresponding statistical significance tests. To calculate the values of cross section properties, the values of $k_1 = 6.34$, $k_2 = 0.572$, $k_3 = 9.28$, $k_4 = 0.33$, and $n_s = 0.33$ were selected from Table 1 for sand bed and bank material type, which is relatively similar to canals under study soil type. The results of the statistical tests for Simons and Albertson's regime equations at 95% level of confidence show that:

- There is no significant difference between the actual values of hydraulic radius and calculated ones with M.A.E = 8.03% as demonstrated in Figure 5. So, Simons and Albertson regime equation can be applied to estimate hydraulic radius for all canals under study for discharge ranges from 0.40 m^3/s to 234.70 m^3/s.
- Simons and Albertson regime equations can be applied to all canals under study to calculate the mean depth and mean velocity values for discharge varies between 0.40 m^3/s and 234.70 m^3/s, as they give accepted values with M.A.E equal to 12.45% and 12.79%, respectively. The value of error can be reduced from 12.45% to 6.20% for high discharge range of El-Mansuriya canal, but it can be lowered from 12.79% to 8.62% for small canals, namely Bahr-Tnah and Om-Glagel canals.
- Calculation of wetted perimeter, mean water width, and top width values gives unaccepted results, because there is a significant difference between the actual and calculated values for each parameter with a relatively high value of M.A.E

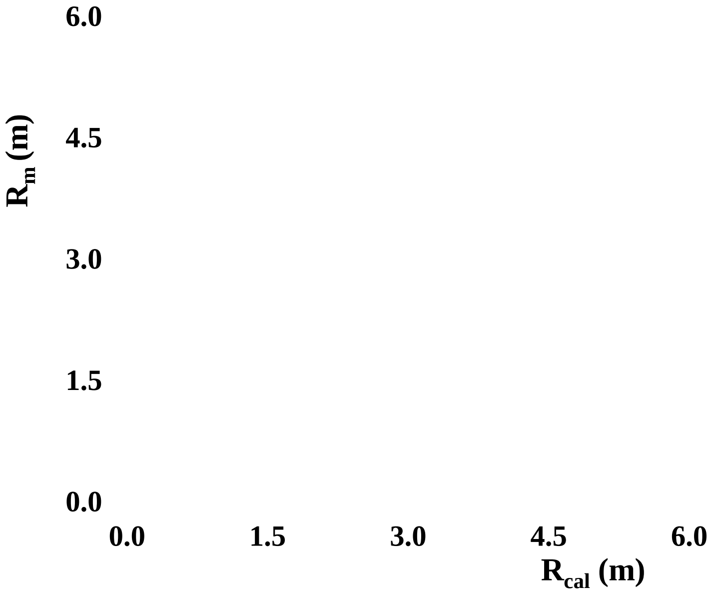

Figure 5. Measured hydraulic radius values against calculated ones using Simons and Albertson's regime equation.

Based on the previous results and analysis:

- Accepted regime equations, derived by Simons and Albertson can be satisfactory used for canals under study, but there is a deviation of these equations which cause incompatibilities in these equations results. The defect is that the value of (P * R_h) is not equal to the value of (B * Y_{max}), or the value of (T * D) to determine the cross section water area (A). The difference between the three values is usually less than 15%, which could be accepted.
- Some of Simons and Albertson equations are not suitable to be used for canals under study as Simons and Albertson derived their equations based on a collection of field data from north American canals and some Indian canals.

5.1.4 Bakry's regime equations

The applicability of regime formulae for sand bed channels suggested by Bakry are checked to be used for canals under study by using the corresponding significance tests. These equations are used by The Ministry of Irrigation and Water Resources for the design purpose of stable Egyptian irrigation canals. The statistical tests are based on the actual properties of the cross sections against the calculated ones. It is noticeable from the statistical analysis at 95% level of confidence that:

- Calculating average depth values are accepted only for high discharge canals, El-Mansuriya & El-Bahr El-Sagheer, for discharge value varies between 27.95 m^3/s and 234.70 m^3/s with M.A.E equal to 12.07%, as there is no significant difference between the actual and calculated values. For other discharge ranges, there is a deviation from the line of perfect agreement, Figure 6.
- Regime equations, suggested by Bakry for computing hydraulic radius and mean velocity are valid only for for high discharge canal, El-Mansuriya canal, with discharge value ranges from 98.60 m^3/s to 234.70 m^3/s, as there is no significant difference between the actual and calculated values of each property.
- Bakry's regime formulae for estimating cross section water area, wetted perimeter, top width, mean water width, and mean velocity values are rejected for all values of discharges under study, as there is a significant difference between the actual and calculated values of each parameter.

6.0
4.5
$(D_{avg})_m$ (m)
3.0
1.5
0.0
0.0 1.5 3.0 4.5 6.0
$(D_{avg})_{cal}$ (m)

Figure 6. Measured average depth values against calculated ones using Bakry's regime equation.

Bakry derived regime relationships for Egyptian irrigation canals of sand bed and banks. He used data from canals, namely El-Monufia, El-Bagoria, Bahr El-Nazla, El-Nagar, El-Naanaia, El-Sersawiya, with discharge varies between 90 m^3/s and 350 m^3/s. The difference in case studies and conditions such as discharge range is the main cause of the unaccepted values of cross section properties, estimated using Bakry's regime equations, compared to the actual ones.

5.1.4 Zidan regime equations

Zidan's regime equations were mainly derived for distributary irrigation canals in Dakahliya governorate in Egypt for discharge, having max value equal to 9.32 m^3/s and max value of d_{50} equal to 0.10 mm for soil, varied between clay and silt. Referring to the results of statistical significance tests, namely F-test, T-test, and M.A.E at 95% level of confidence, it is clear from the comparison between the measured and calculated values of parameters that:

- Zidan regime equations give acceptable values of wetted perimeter and top width with M.A.E equal to 12.00%, and 9.54%, as there is no significance difference between the actual and calculated values, as illustrated in Figures 7 and 8, respectively.
- Computation of cross section water area, hydraulic radius, mean water width, and mean water depth results in over-estimated with rejected value of M.A.E, although these equations are accepted using F-test or T-test.

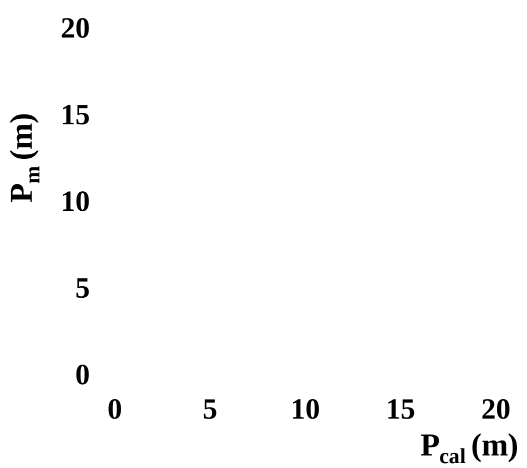

Figure 7. Measured wetted perimeter values against calculated ones using Zidan regime equation.

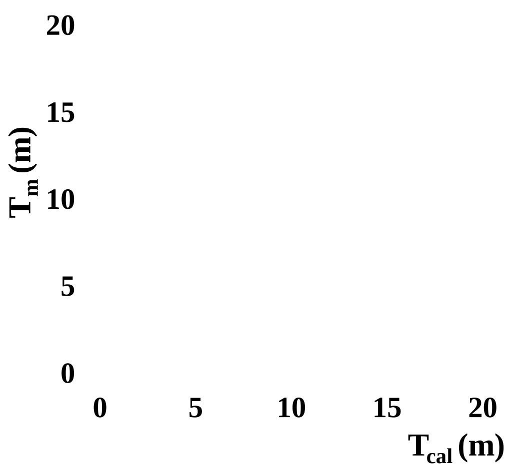

Figure 8. Measured top width values against calculated ones using Zidan regime equation.

5.2 New Approach Equations

In the previous section, no regime approach among Lacey, or Blench, or Simons and Albertson, or Bakry, is completely applicable to be used for canals under study due to the difference in case studies and conditions. In this section, new regime equations have been presented for canals under study for different data ranges, that are presented in Table 3. The deduced equations cover a wide range of most variables affecting the design of equilibrium canals in Egypt. The following regime relationships are derived for all canals under study for discharge ranges from 0.40 m^3/s to 234.70 m^3/s; and d_{50} varies between 0.10 mm and 0.72 mm. and can be divided into two categories:

Table 3. Data ranges for different parameters used in the study.

Parameter	Data ranges	
	Min	Max
A	1.45 m^2	270.72 m^2
P	4.21 m	61.45 m
R_h	0.34 m	4.41 m
T	4.00 m	59.30 m
D	0.36 m	4.57 m
D_{avg}	0.37 m	5.80 m
B	2.39 m	41.02 m
Y_{max}	0.60 m	6.60 m

- <u>Relationships between cross section properties and discharge.</u>

$A = 2.77\ Q^{0.84}$ $R^2 = 0.99$ M.A.E = 3.60% (59)

$P = 5.88\ Q^{0.44}$ $R^2 = 0.99$ M.A.E = 4.22% (60)

$R_h = 0.47\ Q^{0.40}$ $R^2 = 0.99$ M.A.E = 3.07% (61)

$$B = 3.73\ Q^{0.43} \qquad R^2 = 0.99 \qquad M.A.E = 5.04\% \qquad (62)$$

$$D = 0.50\ Q^{0.40} \qquad R^2 = 0.99 \qquad M.A.E = 3.86\% \qquad (63)$$

$$D_{avg} = 0.55\ Q^{0.43} \qquad R^2 = 0.99 \qquad M.A.E = 6.42\% \qquad (64)$$

$$T = 5.56\ Q^{0.44} \qquad R^2 = 0.99 \qquad M.A.E = 5.54\% \qquad (65)$$

$$Y_{max} = 0.74\ Q^{0.40} \qquad R^2 = 0.99 \qquad M.A.E = 4.53\% \qquad (66)$$

- <u>Relationships between cross section properties.</u>

$$B = 0.63\ P - 0.06 \qquad R^2 = 0.98 \qquad M.A.E = 8.08\% \qquad (67)$$

$$B = 0.64\ T - 0.08 \qquad R^2 = 0.97 \qquad M.A.E = 8.60\% \qquad (68)$$

$$Y_{max} = 1.57\ R + 0.09 \qquad R^2 = 0.97 \qquad M.A.E = 8.65\% \qquad (69)$$

$$R_h = 0.97\ D - 0.012 \qquad R^2 = 0.99 \qquad M.A.E = 0.72\% \qquad (70)$$

$$B = 9.10\ D - 0.75 \qquad R^2 = 0.99 \qquad M.A.E = 3.77\% \qquad (71)$$

$$B = 8.02\ D^{1.09} \qquad R^2 = 0.99 \qquad M.A.E = 4.46\% \qquad (72)$$

$$R_h = 0.82\ {D_{avg}}^{0.93} \qquad R^2 = 0.99 \qquad M.A.E = 3.72\% \qquad (73)$$

$$D = 1.03\ R_h + 0.01 \qquad R^2 = 0.99 \qquad M.A.E = 0.69\% \qquad (74)$$

6 CONCLUSIONS

From this research work, it could be concluded that:

- The applicability of conventional regime equations has been checked using statistical significance tests at 95% level of confidence to be used under the local conditions. No conventional regime approach was completely valid due to the difference in case studies and conditions, but some equations of each approach could be applied as follows:

a) Lacey (1930) regime equations could be used for estimating wetted perimeter with M.A.E equal to 8.55%, respectively.

b) Only friction slope values can be calculated using regime equations derived by Blench in 1952, with a relatively high value of M.A.E equal to 25.36%

c) Computing hydraulic radius, mean depth, and mean velocity resulted in accepted values with M.A.E equal to 8.03%, 12.45%, and 12.79%, respectively using Simons and Albertson (1960) regime equations.

- Bakry (1985) regime equations could be applied for discharge ranges from 27.95 m^3/s to 234.70 m^3/s to estimate average depth values with M.A.E equal to 12.07%.
- The values of wetted perimeter and top width with M.A.E equal to 12.00%, and 9.54% could be considered using Zidan (1991) regime equations.
- New regime equations have been deduced for all canals under study with 0.40 $m^3/s \leq Q \leq$ 234.70 m^3/s; and 0.10 mm $\leq d_{50} \leq$ 0.72 mm.

RECOMMENDATIONS

For future studies, it is recommended to:

- Computer programs for getting stable canal section properties as a function of discharge and soil properties can be developed.
- More data of Egyptian irrigation canals are required to get more accurate relationships.

NOTATION

The following symbols are used in this paper:

A	: Water area of the cross section;
A_{cal}	
A_m	
B	: Mean water width of the cross section;
C_c	: Coefficient of gradation curvature;
C_{sc}	: Bed material sediment concentration;
D	: Mean water depth of the cross section;
D_{avg}	: Average water depth of the cross section;
$(D_{avg})_{cal}$	: Calculated average water depth of the cross section;
$(D_{avg})_m$	: Measured average water depth of the cross section;
d_{50}	: Soil grain diameter that 50 percent of the material is finer by weight;
f_b	: Bed factor;
f_l	: Lacey's silt factor;
f_s	: Side factor;
g	: Gravitational acceleration;
H_1	: Empirical coefficient depending on the characteristics of the channel;
H_2	: Empirical coefficient depending on the characteristics of the channel;
H_3	: Empirical coefficient depending on the characteristics of the channel;
H_4	: Empirical coefficient depending on the characteristics of the channel;
k_1	: Empirical coefficient depending on soil material type;
k_2	: Empirical coefficient depending on soil material type;
k_3	: Empirical coefficient depending on soil material type;
k_4	: Empirical coefficient depending on soil material type;
L_1	: Coefficient depending on channel characteristics and category;
L_2	: Coefficient depending on channel characteristics and category;
L_3	: Coefficient depending on channel characteristics and category;
n_s	: Empirical coefficient depending on soil material type;
P	: Wetted perimeter of the cross section;
P_{cal}	: Calculated wetted perimeter of the cross section;
P_m	: Measured wetted perimeter of the cross section;
p	: Constant that depends on sediment nature = 0.284;
Q	: Discharge of the cross section;
R_h	: Hydraulic radius of the cross section;
$(R_h)_{cal}$	: Calculated hydraulic radius of the cross section;
$(R_h)_m$	: Measured hydraulic radius of the cross section;
r_1	: Empirical coefficient depending on the characteristics of the channel;
r_2	: Empirical coefficient depending on the characteristics of the channel;
r_3	: Empirical coefficient depending on the characteristics of the channel;
S_f	: Friction slope;
$(S_f)_{cal}$	: Calculated friction slope;
$(S_f)_m$	: Measured friction slope;

S_w	: Water surface slope;
T	: Top width of the cross section;
T_{cal}	: Calculated top width of the cross section;
T_m	: Measured top width of the cross section;
V	: Mean velocity of the cross section;
V_c	: Non-silting non-scouring velocity;
V_o	: Maximum allowable velocity; and
Y_{max}	: Maximum water depth of the cross section;

Greek Symbols:

ν	: Kinematic viscosity of water.

Abbreviations:

L.P.A	: Line of perfect agreement;
M.A.E	: Mean absolute error;
ppm	: Parts per million;
SI	: International system of units; and
SPSS	: Statistical package for the social sciences software.

REFERENCES

Akan, A.O. (2006). "Open Channel Hydraulics". Butterworth-Heinemann.

Bakry, M.F. (1985). "Practical Regime Design of Egyptian Canals". M.Sc. Thesis, Faculty of Engineering, Department of Civil Engineering, Cairo University, Egypt, P.215.

Bakry, M.F. and Khattab, A.F. (1992). "Regime Behavior for Alluvial Stable Egyptian Canals". Irrigation and Drainage Systems, Vol. 6, pp.27–36.

Das, M.M. (2008). "Design of Channels". PHI Learning Pvt. Ltd., New Delhi.

Hey, R.D. (1979). "Flow Resistance in Gravel-Bed Rivers". Journal of The Hydraulics Division, Vol. 105, No. 4, pp.365–379.

Huang, H.E., Nanson, G.C. and Fagan, S.D. (2002). "Hydraulic Geometry of Straight Alluvial Channels and The Principle of Least Action". Journal of Hydraulic Research, Vol. 40, No. 2, pp.153–160.

Lacey, G. (1930). "Stable Channels in Alluvium". Proceedings of Lacey on Stable Channels in Alluvium, No. 4736.

Masood, A. (2014). "A Concept of Regime Theory in Unlined Canals". International Journal of Scientific & Engineering Research, Vol. 5, No. 8, pp.740–746.

Mazumder, S.K. (2006). "Limitations of Lacey's Theory for Estimation of Bridge Scour". Science Direct, Vol. 64, pp.207–220.

Mohamed, H.I. (2013). "Design of Alluvial Egyptian Irrigation Canals using Artificial Neural Networks Method". Ain Shams Engineering Journal, Vol. 4, No. 2, pp.163–171. Available at: http://dx.doi.org/10.1016/j.asej.2012.08.009.

Saleh, M.M. (1984). "Design of Stable Alluvial Channels". M.Sc. Thesis, Faculty of Engineering, Department of Civil Engineering, Cairo University, Egypt, P.171.

Sarma, A. K. (2015). "Lecture Notes on Hydraulics". Department of Civil Engineering, Indian Institute of Technology, Guwahati.

Simons, D.B. and Albertson, M.L. (1960). "Uniform Water Conveyance Channels in Alluvial Materials". Journal of The Hydraulics Division, Vol. 86, No. 5, pp.33–71.

Thomas, W.A., Copeland, R.R. and McComas, D.N. (2002). "SAM Hydraulic Design Package for Channels". Technical Report, U.S Army Corps of Engineers, Engineer Research and Development Center.

Xiao, Y., Shao, X.J. and Yang, Y. (2014). "A Cusp Catastrophe Model for Alluvial Channel Regime and Classification of Channel Patterns". Geoscience Model Development Discussions, P.11.

Zidan, A.A. (1991). "Regime Equations For Irrigation Canals". Mansoura Engineering Journal, MEJ, Vol. 16, No. 1.