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Flow Characteristics through Grassed Open Channels

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Abstract- Vegetation in waterways plays a significant role in improving and restoring the waterways environs. But, in open channel flow, vegetation often causes flow resistance changes. The main objective of the present paper is to study the flow characteristics Manning coefficient, velocity ratio, submergence ratio, and relative top width of the natural canal for two cases. In the first case, there is no grass in the canal and the second case is canal with different heights of vegetation. The common kind of vegetation in the present study is Polygonum Serrulatum. The two cases were examined under different water discharges with variable water depths. The measured discharges in the field ranged from 11.9 to 129.25 L/s. Velocities for different water depths were exactly measured every 100 m long in the longitudinal direction and every 0.5 m in the cross-sectional direction. It is found that, the value of the Manning coefficient in case of studying the grassed canal ranged from 0.014 to 0.4302 and ranged from 0.0123 to 0.081 in the case of un-grassed canal. The values of Manning coefficient increase with increasing value of grass height. The values of the Manning coefficient in case of un-submerged vegetation with grass height equal to 67 cm, 90 cm, and 115 cm are greater than submerged vegetation with other heights. Using the Statistical Package for the Social Sciences (SPSS) program empirical formulas were derived to determine the flow characteristics.

Keywords: - Manning coefficient, Specific energy, Submerged, Un-Submerged, Vegetation.

I. INTRODUCTION

Vegetation in nature can be either flexible (grass) or rigid (woody species), and either submerged or un-submerged in low and high flow periods. The effects of these kinds of vegetation in the roughness of flow need to be determined using different methods. Vegetation in open channels retards the flow of water by causing loss of energy through turbulence and drag forces on moving water. The presence of vegetation has a major effect on the flow resistance. A tremendous number of authors have studied experimentally and theoretically the effect of vegetation on flow characteristics. Wu et al. (1999) investigated the variation of vegetative roughness Coefficients with the flow depth for submerged and un-submerged conditions of grass. Manning's equation was used to convert the drag coefficient into the roughness coefficient. They compare their results with the previous laboratory and field tests. Wilson et al. (2003) explore the effect of two forms of flexible vegetation on the turbulence structure experimentally within a submerged Canopy and in the surface flow region above. The methods used for quantifying the bending stiffness, flexural rigidity and drag force-velocity relationship of the vegetation were outlined. Wilson (2007) investigated the variation of hydraulic roughness parameters with flow depth for submerged flexible vegetation called

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Canopies. Flexible grass Canopies are used experimentally to examine the impact of stem height, grass type and degree of submergence on the flow resistance properties. He showed that Manning's n increases with decreasing flow depth reaching an asymptotic constant at lower levels of vegetation submergence. The coefficient of discharge (CD) value was found to be strongly correlated to the vegetation height and follows a power-law relationship.

Yusuf et al. (2009) explored the suitability of numerical models in estimation of the velocity and flow resistance in open channels with totally submerged flexible vegetation. A three-dimensional numerical model has been employed to simulate the effects of various characteristics of selected flexible vegetation to the velocity distribution and flow resistance. The accuracy of the numerical model compared to experimental results was measured in terms of mean absolute error.

Nehal et al. (2012) used non-submerged artificial vegetation to simulate Acorus Calamus L in water flume to investigate its influence on flow resistance and velocity distribution. They showed that the flow depths, Manning resistance coefficient, and discharge depends significantly on the vegetation density and patterns. Muhammad et al. (2016) studied the velocity distributions in the grassed channel using natural submerged vegetation. Axonopus Compressus commonly known as Cow grass was planted in the vegetated zone. To achieve this, velocity profiles were measured using Acoustic Doppler Velocimeter (ADV) in order to obtain the stream-wise and vertical velocity profiles along several vertical and cross-sections.

Bora and Misra (2018) studied the impact of the flexibility of vegetation on flow resistance experimentally. Manning's n is used to denote the resistance coefficient. The results show a decreasing trend in resistance with the increase in the flexibility of vegetation. The flow resistance is found to be more in rigid vegetation than a flexible one.

Pour et al., (2019) made an experimental work in two conditions of Gate Fully Open (GFO) and Gate Partially Open (GPO) to estimate Manning's roughness in the modular channel. The results indicate that the hydraulic performance of the modular channel is very similar to vegetated channel and Manning's n in the GFO is lower than those in the GPO conditions. Two equations with high accuracy were developed to predict Manning's n in both conditions.

Tong et al. (2019) investigated the flow through a Y-shaped confluence channel partially covered with rigid vegetation on its inner bank using Acoustic Doppler Velocimeter (ADV). They showed that the velocity in non-vegetated area is greater than in the vegetated area. The turbulent kinetic energy of the non-vegetated area was smaller than that of the vegetated area.

Recently, the amount of water in Egypt is decreasing, since there is some problems in the canal networks. One of these problems is vegetation growth in the canal. In this study, the effect of vegetation on flow in canals is presented. An attempt is made to investigate the effect of vegetation on flow in canal. Also, the study includes the effect of roughness coefficient.

II. METHODOLOGY

The famous equation used for determination of the flow discharge in open channels is proposed by Manning's as follows:

$$n = \frac{1}{Q} A R^{2/3} S^{1/2} \qquad (1)$$

In which n is the Manning coefficient, Q is the discharge, A is the cross-sectional area, R is the hydraulic radius ( ), is the wetted perimeter, and S is the bed slope of the canal.

The discharge Q can be calculated using cross-sectional area and mean velocity as:

$$Q = AV \qquad (2)$$

In which V is the mean velocity

Manning coefficient depends on gravity constant, g, vegetation height, hgr, flow depth, y, hydraulic mean depth, yh, and flow velocity, V.

$$n = f\,(h_{gr}, y, V, g.\, y_h, E). \qquad (3)$$

Thus, by dimensional analysis and using the approach of Buckingham's π-theorem, equation (3) becomes:

$$n = f\left(\frac{h_{gr}}{y}, \frac{V}{V_{\max}}, F_r, \frac{T}{y}, \frac{yh}{y}, \frac{Er}{y}, \frac{Q}{Vy^2}\right) \qquad (4)$$

III. FIELDWORK

Fieldwork was carried out at the South East of El-Mahalla El Kubra in El-Garbia Governor, Egypt. This Ganabia has located between 30o57’21.9’’ N and 30o57’46’’ N latitudes and 31o11’36.6’’ E and 31o11’40’’ E longitudes, (Manal et al (2020)). Ganabia 9B length is 1330 m, 330 m is covered and 100 m is lined with pitching with mortar, Plate (1), and the other parts are earthen.

Eig 1. Plate (1) Part of the lined canal.

The earthen part of Ganabia 9B was studied in the case of un-grassed, Plate (2), and grassed (covered by vegetation kind of Polygonum Serrulatum), Plate (3).

Fig 2. Plate (2) Ganabia 9B in the case of un-grassed.

Fig 3. Plate (3) Polygonum Serrulatum along the Ganabia 9B in earthen part.

Bahr Shebein feeds main canal with water which called bahr El-Mallah, then water of bahr El-Mallah goes to 35 distributed canal. The total length of bahr El-Mallah and distributed canals equal 151 km. There are 10 Ganabias parallel to bahr Shebein. Ganabia 9B one of them is chosen to be studied which lies at km 31.78.

This Ganabia is used for irrigation 230 feddan. There are two small field Mesqas behind intake and at km (0.5). Side slope of Ganabia 9B is 1:1. Designing a longitudinal slope is zero but at the time of measurements is 4.5 cm/km. Water-surface elevations, land levels, bank levels, and bed levels were obtained from leveling. The longitudinal section of the Ganabia 9B shown in Figure (1).

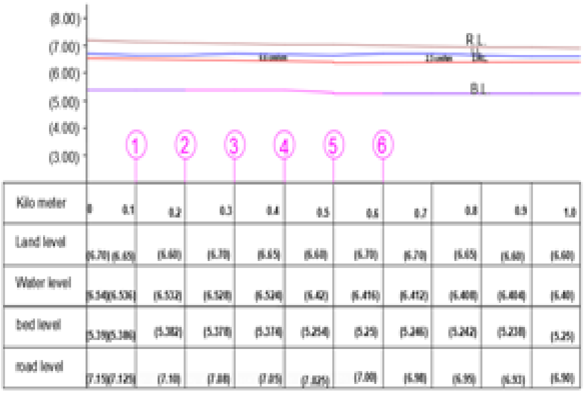

Fig 4. Longitudinal section of the Ganabia 9B.

In the present study, two cases are studied in the field. The first case is no grass in the canal, and the second is canal with different grass height equal 28, 46, 67, 90, and 115 cm. Grass heights were measured manually with a measurement tape. The common kind of vegetation in the study is Polygonum Serrulatum. This type is considered vascular plants.

1. Velocities and Water Depths Measurements:
Velocities and water depths are exactly measured every 100 m long in the longitudinal direction, every 0.5 m in the cross-sectional direction and every 5 cm in the vertical direction. The velocity in the Ganabia 9B canal is measured at different six cross-sections using the Flow Tracker device. Plate (4) shows the Flow Tracker with all major components labeled. At the six cross-sections, water depths, real widths, and flow velocities were measured.

Fig 5. Plate (4) The Flow Tracker with all major components labeled.

A rectangular weir was established at 700m from the beginning of the canal. This weir was used to obtain steady flow with constant discharge and water surface along the canal.

2. Discharge Measurements:

The discharge of flow was calculated using a cross-sectional area and the mean velocity using Eq. (2), Figure (2). In which B is the total width of cross section and B is the distance measured from total width

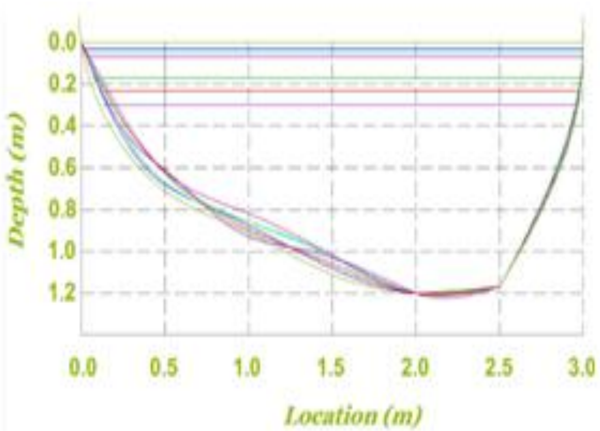

Fig 6. First cross-section at 100 m.

IV. RESULTS AND ANALYSIS

The main objective of the present paper is to study the flow characteristics of the grassed and un-grassed canal. The flow characteristics are the Manning coefficient, n, grassed height, , the velocity ratio, , relative top width, , hydraulic mean depth, yh, and relative specific energy, Er. Manning coefficient is calculated from the Manning equation (Eq. (1)) using the discharge from Eq. (2). The flow velocity (V) measured using Flow Tracker device, and yh is the hydraulic mean depth calculated from the field data.

1. Relationship between velocity ratio (Vr) and Manning's coefficient (n):

- Velocity ratio is the ratio between mean velocity and maximum velocity (V/Vmax).
- The maximum value of velocity from all results of the grassed and un-grassed canal equals 0.338 m/sec.
- Figure (3) presents the relationship between velocity ratio (Vr) and Manning's coefficient (n) for un-grassed and grassed canal with different values of grass heights. It can be noticed that, The best fit for un-grassed canal and grassed canal is power.
- The value of Manning's coefficient (n) increases with the decreasing value of velocity ratio. At the same value of velocity ratio, the mean values of Manning's coefficient for the case of un- grassed canal are greater than grassed canal cases and the mean values of Manning's coefficient increase with decreasing value of grass heights. This may be happened because the consumption of water by vegetation increased with increasing value of grass heights.
- The Manning's coefficient tends to be a definite value when the velocity increases to a certain point. The difference between all curves is slightly small, so that, these curves may be replaced by one curve for each grassed and un-grassed canal.

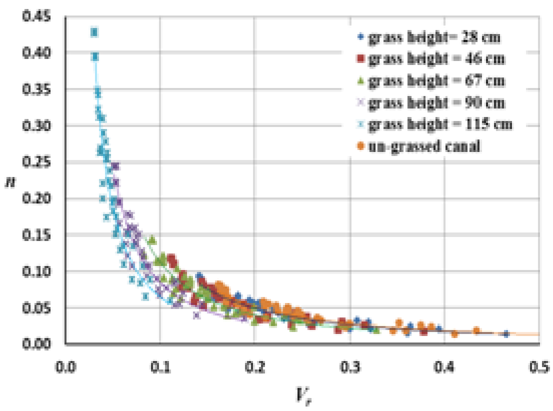

Fig 7. Relationship between (Vr) and (n) for un-grassed and grassed canal for all height.

2. Comparison between the present study and the previous works:

Figure (4) shows Vr - n relationship using the data for the present study and compared with the data of (Hamimed. A, et al. 2013) and (Muhammad., 2018). It is found that, the Manning's (n) varies as power form with the velocity ratio (Vr). It follows that the data obtained in this study has same trend with that of (Hamimed. A, et al. 2013), and (Muhammad et al.,

2018) in the case of grassed canal. R2 for Hamimed (2013) = 0.946, R2 for Muhammad (2018) = 0.796, and R2 for present study = 0.909.

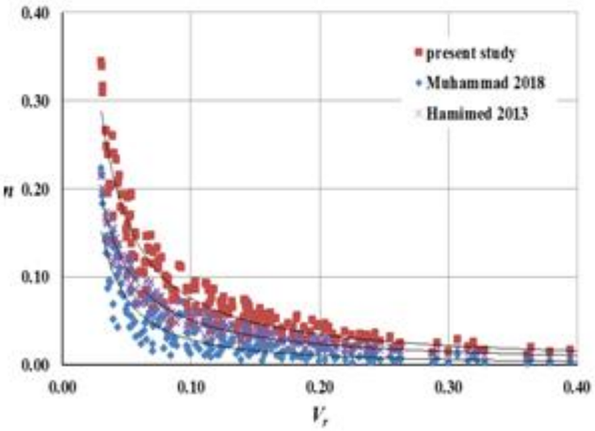

Fig 8. Overall Vr – n relationship comparison with data collected (Hamimed, et al. 2013) and (Muhammad, et al. 2018).

The maximum and minimum values of the Manning coefficient (n) for grassed and un-grassed canal that produced from fieldwork are given in Table (1).

Table 1. Maximum and minimum values of the Manning coefficient from fieldwork.

Case	n_{min}	n_{max}
No Grass	0.0123	0.0810
Grass height = 28cm	0.0140	0.0929
Grass height = 46cm	0.0172	0.1175
Grass height = 67cm	0.0198	0.1439
Grass height = 90cm	0.0225	0.2448
Grass height = 115cm	0.0326	0.4302

3. Relationship between relative top width (T/y) and Manning coefficient (n):

Figure (5) shows the relationship between relative top width (T/y) and Manning's coefficient (n) for different values of average grass heights and the case of the un-grassed canal. The sample of calculated values of (T/y) is shown in Table (2). It can be noticed that the mean value of Manning's coefficient (n) decreases with the increasing value of (T/y). This result may happen due to the increasing value of water flow depth. The best fit for these results is the power form.

The mean values of the Manning's coefficient for the case of the un-grassed canal are smaller than the grassed canal. The mean values of the Manning's coefficient increase with the increasing value of average grass heights. The difference between curves decreases with increasing value of (T/y) and the effect of (T/y) on Manning's coefficient in the average grass heights equal 28, 46, and 67 cm is smaller than the other heights.

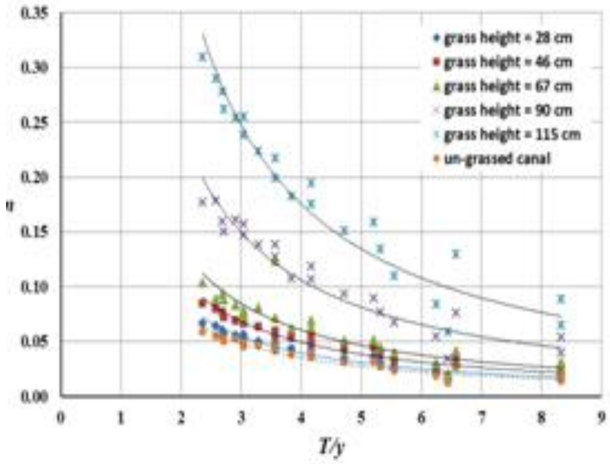

Fig 9. Relationship between (T/y) and (n) for grassed and un-grassed canal.

4. Relationship between relative hydraulic Mean depth (yh/y) and Manning's coefficient (n):

Figure (6) shows the relationship between relative mean water depth (yh/y) and Manning's coefficient (n) for grassed and un-grassed canal with the different values of grass heights. It can be noticed that the value of Manning's coefficient (n) increases with the increasing value of relative mean water depth.

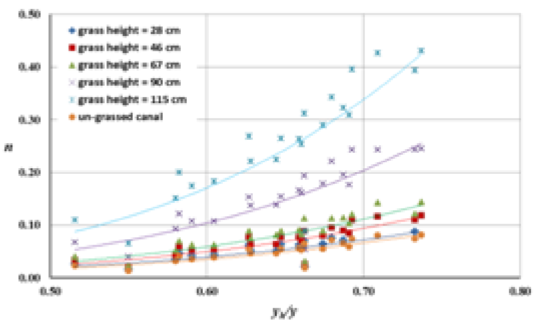

Fig 10. Relationship between (yh/y) and (n) for grassed and un-grassed canal.

The mean values of Manning's coefficient increase with increasing value of grass heights. The difference between curves increase with increasing values of (yh/y). the effect of grass heights equal 90 and 115 cm is greater than the other heights, and the effect of un-grassed canal is smaller than grassed canal. The best fit for results of grassed canal is power.

5. Relationship between (A/y2) and Manning's coefficient (n):

Figure (7) shows the relationship between (A/y2) and Manning's coefficient (n) for different values of average grass heights and the case of the un-grassed canal. The best fit for these results is the power form. It can be noticed that the value of Manning's coefficient (n) decreases with the increasing value of (A/y2).

The mean values of the Manning's coefficient for the case of the un-grassed canal are smaller than the grassed canal. The mean values of the Manning's coefficient increase with the increasing value of average grass heights. The difference between curves decreases with increasing value of (A/y2) and the effect of (A/y2) on Manning's coefficient in the average grass heights equal 28, 46, and 67 cm is smaller than the other heights.

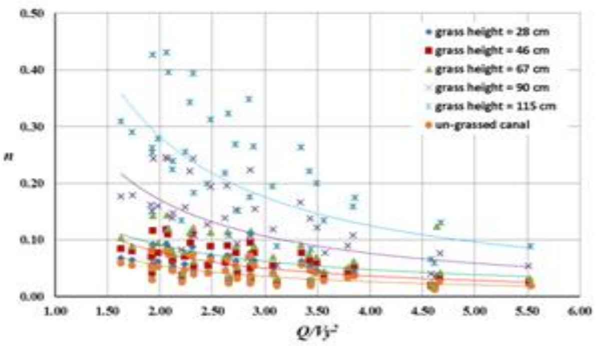

Fig 11. Relationship between (A/y2) and Manning's coefficient (n).

V. STATISTICAL ANALYSIS

Using the SPSS program, formulas are derived between parameters affecting the flow through the canal under observation. The main objective of these formulas is calculating the Manning coefficient knowing velocity ratio and Froude number for un-grassed canal, equation (5) adding to these parameters the grass height for grassed canal, equation (6).

1. Case of the un-grassed canal:

Froude number and velocity ratio as a function of the Manning coefficient.

$$n = 0.002(V_r)^{-0.371}(F_r)^{-0.814} \quad R^2 = 0.983 \quad \textbf{(5)}$$

2. Case of the grassed canal

Froude number, submergence ratio, and velocity ratio as a function of the Manning coefficient.

$$n = 0.002\left(\frac{y}{h_{gr}}\right)^{0.078} / (F_r)^{0.717}(V_r)^{0.451}$$

$$R^2 = 0.998 \qquad \textbf{(6)}$$

Using field results, some of results are chosen randomly and the others are used to make validation using the equations which derived from SPSS program.

3. Relationship between observed Manning coefficient (n) and predicted Manning coefficient (np).

Figure (8) shows the relationship between observed Manning coefficient (n) and predicted Manning coefficient (np) for grassed and un-grassed heights. It is found that, the values of observed Manning coefficient (n) increase with increasing value of predicted Manning coefficient (np) and presented by the following equations:

3.1 For grassed canal:

$$n_{predicted} = 0.791\, n_{observed} - 0.0003 \qquad R^2 = 0.996 \quad (7)$$

3.2 For un-grassed canal:

$$n_{predicted} = 1.314\, n_{observed} - 0.002 \qquad R^2 = 0.993 \quad (8)$$

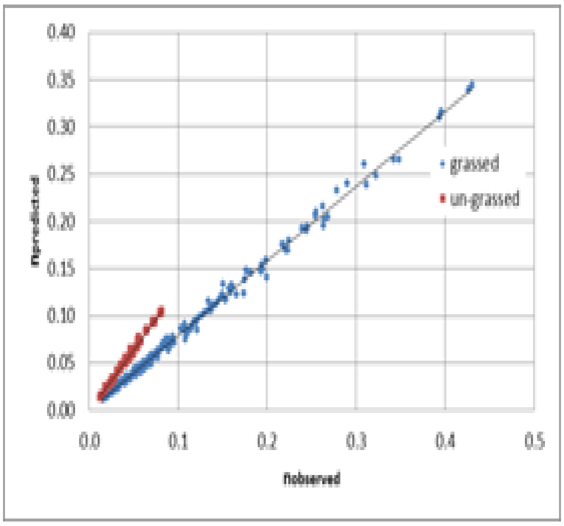

Fig 12. Relationship between (unobserved) and (unpredicted).

Table 2. A sample of implementation of measured and calculated data for grassed and un-grassed canal.

Grass heights	Q	V	V/Vmax	R	y_h	T/y	F_r	y_c	E_r
Un-grassed canal	0.0577	0.1390	0.4112	0.1600	0.1660	8.3333	0.1089	0.1130	2.6669
	0.0580	0.1000	0.2959	0.2155	0.2320	5.5556	0.0663	0.1130	3.9956
	0.0583	0.1170	0.3462	0.1913	0.1993	8.3333	0.0837	0.1130	2.6658
	0.0583	0.0715	0.2115	0.2575	0.2718	6.5217	0.0438	0.1130	4.0758
	0.0575	0.0660	0.1953	0.2746	0.2904	6.0000	0.0391	0.1130	4.4292
Grass height = 28 cm	0.0698	0.0886	0.2621	0.5957	5.3191	0.0504	0.1030	4.5686	0.0698
	0.0698	0.0710	0.2101	0.4308	3.8462	0.0362	0.1118	5.8177	0.0698
	0.0698	0.0799	0.2364	0.5833	5.2083	0.0432	0.1118	4.2970	0.0698
	0.0698	0.0536	0.1586	0.4179	4.4776	0.0260	0.1118	5.9950	0.0698
	0.0698	0.1571	0.4648	0.9032	6.4516	0.1065	0.1118	2.7852	0.0698
	0.0483	0.0878	0.2598	1.1500	6.2500	0.0598	0.0940	4.2629	0.0483

Grass height = 46 cm	0.0483	0.0628	0.1858	0.8679	4.7170	0.0362	0.0940	5.6428	0.0483
	0.0483	0.0717	0.2120	1.2105	6.5789	0.0441	0.0940	4.0464	0.0483
	0.0483	0.0466	0.1379	0.8364	5.4545	0.0253	0.0940	5.8524	0.0483
	0.0483	0.0414	0.1225	0.7797	5.0847	0.0212	0.0940	6.2777	0.0483
Grass height =67 cm	0.0493	0.0626	0.1852	1.4255	5.3191	0.0356	0.0890	5.2833	0.0493
	0.0493	0.0502	0.1485	1.0308	3.8462	0.0256	0.0975	6.6683	0.0493
	0.0493	0.0564	0.1669	1.3958	5.2083	0.0305	0.0975	4.9252	0.0493
	0.0493	0.0379	0.1121	1.0000	4.4776	0.0184	0.0975	6.8727	0.0493
	0.0493	0.1110	0.3284	2.1613	6.4516	0.0752	0.0975	3.1863	0.0493
Grass height = 90 cm	0.0223	0.0406	0.1201	2.2500	6.2500	0.0276	0.0691	5.7938	0.0223
	0.0223	0.0290	0.0858	1.6981	4.7170	0.0167	0.0691	7.6742	0.0223
	0.0223	0.0331	0.0979	2.3684	6.5789	0.0203	0.0691	5.5025	0.0223
	0.0223	0.0215	0.0636	1.6364	5.4545	0.0117	0.0691	7.9633	0.0223
	0.0223	0.0192	0.0568	1.5254	5.0847	0.0098	0.0691	8.5424	0.0223
	0.013	0.026	0.079	2.875	6.250	0.018	0.058	6.863	0.013

Grass height = 115 cm			
0.0139	0.0139	0.0139	0.0139
0.0121	0.0134	0.0194	0.0179
0.0358	0.0396	0.0574	0.0530
1.9492	2.0909	3.0263	2.1698
5.0847	5.4545	6.5789	4.7170
0.0062	0.0073	0.0119	0.0103
0.0583	0.0583	0.0583	0.0583
10.120	9.4342	6.5183	9.0913
0.0139	0.0139	0.0139	0.0139

VI. CONCLUSIONS

The characteristics of the grassed canal are studied. The following conclusions could be obtained from the present study: The average value of the Manning coefficient in case of grassed canal increases with increasing value of grass height, and the value of it in the case of the un-grassed canal is less than that in case of grassed canal.

The value of the Manning coefficient in case of study with a grassed canal ranged between 0.014 and 0.4302, but in the case of un-grassed ranged between 0.0123 and 0.081. The mean values of the Manning coefficient increase with increasing value of grass height.

The values of the Manning coefficient in case of un-submerged vegetation with grass height equal to 67 cm, 90 cm, and 115 cm are greater than submerged vegetation with other heights. The values of the velocity ratio increase with decreasing value of grass height. Relative specific energy is higher in the un-grassed canal than in the grassed one, and decreases with an increasing value of the submergence ratio.

The mean value of Manning's coefficient (n) decreases with the increasing value of (T/y) and (A/y2). The value of Manning's coefficient (n) increases with the increasing value of relative mean water depth. Using the SPSS program, statistical equations are derived giving the characteristics of flow in the case of the grassed and un-grassed canal with different values of discharge.

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Notation

The following symbols are used in this paper:
A: Cross-sectional area;
: Elementary area in the whole water area;
B: Total width of cross section;
b: Distance measured from total width;
Cd: Discharge coefficient;
g: Acceleration due to gravity;
hgr: Vegetation height;
n: Manning coefficient;
P: Wetted perimeter;
Q: Discharge of flow;
R: Hydraulic radius;
S: bed slope of the canal;
T: Top width of the canal;
V: Flow mean velocity;
Vmax: Flow maximum velocity;
Vr: Velocity ratio;
: Point velocity at each point in the cross-section;
y: Water depth;
yh: Hydraulic mean depth;
α: Energy coefficient.