Manning roughness coefficient in vegetated open channels

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ABSTRACT

Manning equation is one of the most common equations used in estimating the mean velocity and discharge in open channels. The equation depends on some measured hydraulic parameters as water surface slope and hydraulic radius of open channel cross-section in addition to the Manning roughness coefficient. Estimating the value of Manning’s roughness coefficient is dependent on the nature of the channel, the number of obstacles that resist the channel flow and the field engineers experience. In vegetated channels, the percentage of infestation seems to be the most effective parameter on the roughness coefficient value. Through this study, based on laboratory investigation and physical model several trials were conducted to deduce an equation to predict the value of the Manning’s roughness coefficient in the vegetated channel based on measured parameters as weed infestation percentage, water surface slope. Two simple equations were deduced based on these parameters to practically estimate the value of the Manning roughness coefficient in vegetated open channels. The results of these equations were successfully verified using field measurements.

Introduction

Open channels are mostly suffering from aquatic weeds. More than 82% of Egyptian canals and drains are extremely infested by all types of aquatic weeds (Khattab & El-Gharably, 1987). Recently, this percentage is expected to be increased due to the change in water quality of water and decrease in actual water depths of most of Egyptian canals and drains. Aquatic weeds are classified into three main types, submerged, floating, and ditch bank weeds. Submerged aquatic weeds have the greatest effect on the open channel’s efficiency. The primary impact of weed infestation is increasing the resistance to the flow and reducing the conveyance capacity (Pilto, 1986).

Manning’s equation is one of the most common equations that estimate the flow discharge in open channels.

\[ Q = \frac{A}{n} R^{2/3} S^{1/2} \]

Where Q is flow discharge, A is the cross-section area, n is Manning’s roughness coefficient; R is the hydraulic radius and S water surface slope. For vegetated channels, all the hydraulic parameters in the equation could be measured in the field except the roughness coefficient which can be estimated based on the experience and the evaluation of weed infestation in open channels.

The weed infestation could be estimated as a percentage of the cross-sectional area. Eco- sounds equipment can easily detect the presence of submerged weed and the percentage of infestation as shown in Figure 1.

Several studies were conducted to investigate the effect of weed infestation on the hydraulic efficiency and different hydraulic parameters of vegetated channels.

Wan Yusof et al. (2017) based on an experimental investigation using natural vegetation to detect the relation between Manning’s roughness coefficient and drag coefficient in vegetated channels, there is a strong correlation between them.

Han, Zeng, Chen, and Huai (2016) stated that vegetation in open channels is an important design factor. It effects on local water depth, water velocity profile, and has varying influence depending on the type of vegetation.

Pu, Hussain, and Shao (2014) concluded that vegetation in open channels acting as an obstruction to flow, generating turbulence and affecting the flow velocity distribution and water depth as sedimentation in canal cross-section.

Wu, Shen, and Chou (1999) mentioned that the vegetation type and distribution pattern in open channels cross-sections affect the velocity profiles due to the effect of vegetation drag which contributed highly to flow roughness.

Chow (1959) developed five degrees of retardance for vegetated channels.

Ree and Palmer (1949) investigated experimentally the relation between n and VR (the product of mean velocity and hydraulic radius which is suggested as
a suitable criterion for estimating retardance coefficient. They concluded that the degree of vegetal retardance mainly depends on the tallness and density of cover, particularly the tallness.

Kouwen, Unny, and Hill (1969) found that the plastic strips behave almost similar to aquatic weeds in natural channels, especially regarding, waving motion and bending of the strips. Also, Kouwen and Unny (1973) studied the effect of stiffness of artificial flexible elements, which can be presented through the varying amount of bending strips on the relative roughness throughout the channel.

Also, Elgamal (1990) investigated experimentally the effect of density and height of submerged vegetation on flow resistance in a trapezoidal wooden flume. Elgamal concluded that the flow resistance increased with increasing the height or density of weeds.

Abdelsalam, Kattab, Khalifa, and Bakry (1991) studied the effect of submerged vegetation on flow resistance in wide channels for three cases of vegetal distribution across the channel cross-section (bed and two sides, bed and one side, and bed only). It was concluded that the vegetation infestation percentage had a small effect on the flow resistance for infestation percentage of less than 15%. While the distribution shape of submerged weeds along the wetted perimeter of canal cross-section had a more considerable effect.

Bakry (1989) stated that the flow shear resistance and consequently Manning’s roughness coefficient are increasing with increasing bed vegetation density due to the resultant increase in the projected wetted perimeter length.

Pilot and Dawson (1989) concluded that the increase of water velocity during the growth season of the submerged weeds decreases the Manning’s roughness for constant hydraulic radius. Also, the decrease in the vegetation density reduces the Manning’s roughness coefficient and the water levels as well.

Elsamman, Abdin, and Ibrahim (1999) investigated experimentally the flow resistance of vegetated open channels. They concluded that the increase in submerged weed density of channel sides has a minor impact on flow resistance. On the other hand, increasing weed density on the channel bed has a remarkable effect on increasing flow resistance.

Rizalihadi and Safiana (2015) investigated the flow resistance due to the presence of (Acorus calamus) vegetation. They stated that the flow resistance is converted to the Roughness coefficient with the aid of Manning’s equation. The flow resistance is increased with increasing vegetation density. Manning’s roughness coefficient is consequently increased between 1.5–2.4 times.

Pu et al. (2019) used an analytical model to investigate the impact of drag coefficient and friction coefficient on the flow with flexible vegetation. It was concluded that the variation in the values of drag and friction coefficient within a certain range is high accurate index to the vegetation drag and friction forces. Also, the velocity distribution is dominantly influenced by the drag coefficient.

All these studies concluded that the weed infestation has a remarkable effect on hydraulic efficiency and hydraulic characteristics of open channels. The properties of vegetation have a dominant influence on flow resistance.

In the present research, based on experimental investigation and physical model, the relation between Manning’s roughness coefficient of the vegetated channel and vegetation infestation and other measured hydraulic characteristics were discussed. The value of the roughness coefficient in vegetated channels could be practically and easily estimated.

**Experimental facilities**

The experiment was carried out in the hydraulic lap of the Channel Maintenance Research Institute of the National Water Research Center, Egypt. A horizontal reinforced concrete flume of a trapezoidal cross-section is used. The dimensions of the flume are 16.22 m long, 0.6 m bed width, 0.42 m maximum depth, and 1:1 side slopes as shown in Figure 2. The flume is supplied with
water from an underground reservoir of dimensions; 24.10 m long, 1.75 m wide, and 1.50 m depth. The flume inlet is 4.52 m length, 1.63 m width, and 1.16 m height. The excess turbulence is dissipated using two vertical reinforced concrete walls and the bed ramp of slope 3:1 downstream them. The water depth is controlled using a tilted tailgate located at the end of the channel. The water is drained through the outlet basin of dimensions 0.96 m long, 1.63 m wide, and 1.21 m height and then the two ~8 inches diameter pipes. Branched flexible elements are fitted with different densities on plastic sheets. It is prepared from materials that have the properties and shape to simulate the most common types of submerged weeds. The dimension of branched flexible elements are 1 cm wide, 0.2 cm thick, and 10 cm height and the width is divided into four branches. The length of the infested reach was 4.0 m. Three weed densities were applied (0.25 stem/cm², 0.0625 stem/cm², and 0.028 stem/cm²). Five weed distributions were applied (bed and two sides, bed and one side, bed only, two sides, and one side).

There were two cases of experimental measurements were applied according to the upstream depth of vegetated reach. The two cases were: i) case A where the upstream depth was increased compared to the depth of the smooth case, ii) case B where the upstream depth of the reach infested by weed was decreased with partially closing the sluice valve until the upstream depth is equal to the depth in the no weeds case. Six flow discharges were operated through the experiment (47.90, 44.08, 40.29, 37.51, 32.25, and 26.44 L/s). The total number of runs is 180 in addition to 6 runs of the smooth case. For each run water surface profile is surveyed and recorded, also the flow discharge in case B is measured.

The accuracy of measuring discharge is 0.01 liter while the accuracy of measuring water level is 0.01 mm. The design of experimental work runs is shown in Table 1. The used physical model scale was (symmetrical scale 1:10) to simulate open channels of bed width 6.00 m having flow discharge ranging from 8.36 to 15.15 m³/s. The investigated data is a part of the measured data applied for the study of hydraulic characteristics of vegetated channels.

### Results and discussion

The effect of the presence of aquatic weeds on Manning’s roughness coefficient could be discussed in the present section. Also, two equations for predicting the value of Manning’s roughness coefficient in vegetated channels were deduced

#### Effect of aquatic weeds with different characteristics on Manning’s roughness coefficient

Through the conducted experiment, three weed densities (0.25 stem/cm², 0.0625 stem/cm², and 0.028 stem/cm²). Five weed distributions were applied (bed and two sides,
bed and one side, bed only, two sides, and one side). In each run, the corresponding Manning’s roughness coefficient was calculated. Both of weed density and distribution have a remarkable effect on the values of the roughness coefficient. Figures (3), (4), and (5) show the result of the experiment for the three weed densities. The experiment results show that Manning’s roughness coefficient is directly proportional to weed density. The average value of roughness coefficient in high weed density was decreased by 12.7% and 34.5% when applying medium and low weed densities respectively. The experiment showed also that the presence of aquatic weed in open channel bed has a higher effect on roughness coefficient when compared with weeds on side slopes. It was noticed also that the gap between the different values of (n) for different weed distribution cases is decreased with decreasing weed density. The submerged weeds in bed show different behaviors according to flow velocity. In low flow velocities, the submerged bed weed is erected with its full height. With increasing flow velocity, the weed stem starts to bend with reducing its height and resistance to flow. This explains the decrease in (n) values for the first three cases of weed distribution (including weed in bed) with increasing flow discharge. For the fourth and fifth cases of weed distribution (weeds on side slopes), there is a minor change in (n) values with changing the weed density and weed discharge.

**Figure 3.** Manning’s roughness coefficient for different weed distributions of high weed density (0.25 stem/cm²).

**Figure 4.** Manning’s roughness coefficient for different weed distributions of medium weed density (0.0625 stem/cm²).
**Manning roughness coefficient in terms of weed infestation percentage**

In each run, weed infestation percentage is calculated based on the blocked area of the flume channel hydraulic cross-section according to weed density, weed distribution, and bed weed height through the applied run. Weed densities percentage ranged from 63.65% to 3.03%. Two equations relating Manning’s roughness coefficient in vegetated open channels and both of weed infestation percentage and water surface slope were deduced using linear stepwise regression analysis. In linear stepwise regression; the less effective variables are excluded the most related variables are entered. The deduced equations were:

\[
\frac{n}{n_o} = 0.089W_{inf} + 1.037 \quad \text{(2)}
\]

\[
\frac{n}{n_o} = 0.067W_{inf} + 240.434S + 0.969 \quad \text{(3)}
\]

Where; \(n\) is Manning roughness coefficient of vegetated open channel, \(n_o\) is Manning roughness coefficient of non-vegetated open channel, \(W_{inf}\) is the percentage of weed infestation in open channel. \(S\) is the water surface slope.

The equations show that the most related variables on Manning’s roughness coefficient in vegetated open channels are weed infestation percentage and water surface slope. The results of the analysis of variance (ANOVA) test for the deduced equations no. (2, 3) is shown in Table 2. ANOVA test is used to determine whether there is any statistical significant difference between the means of the independent data groups. The different coefficients of the different variables in the equations and their significance are shown in Table 3. Figures (6, 7) show the comparison between the values of the measured Manning roughness coefficient and the predicted values from the two equations. The resulted trend lines equations are:

\[
\left( \frac{n}{n_o} \right)_{\text{measured}} = 0.9966 \left( \frac{n}{n_o} \right)_{\text{predicted}} - 0.003 \quad \text{R}^2 = 0.85 \quad \text{(4)}
\]

\[
\left( \frac{n}{n_o} \right)_{\text{measured}} = 1.0016 \left( \frac{n}{n_o} \right)_{\text{predicted}} - 0.001 \quad \text{R}^2 = 0.89 \quad \text{(5)}
\]

It means that the predicted values for Manning’s roughness coefficient from equations No. (4) and (5) are very close to that measured in the physical model and it could be highly accurate index to evaluate its values in vegetated open channels. The resulting trend line representing the two equations almost coincide with the trend line of the ideal case \(\frac{n}{n_o}\). predicted = \(\frac{n}{n_o}\) measured). It was noticed that the value of the determination coefficient \(\text{R}^2\) for Equation (5) is higher than that of Equation (4) which means that Equation (3) is more accurate than Equation (2).

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**Figure 5.** Manning’s roughness coefficient for different weed distributions of low weed density (0.028 stem/cm²).

**Table 2.** Results of the ANOVA test.

| Model        | Sum of Squares | df | Mean Square | F     | Sig  |
|--------------|----------------|----|-------------|-------|------|
| 1 Regression | 345.477        | 1  | 345.477     | 1004.86 | 0.000 |
| Residual     | 61.197         | 178| 0.344       |       |      |
| Total        | 406.674        | 179|             |       |      |
| 2 Regression | 363.044        | 2  | 181.522     | 736.406 | 0.000 |
| Residual     | 43.630         | 177| 0.246       |       |      |
| Total        | 406.674        | 179|             |       |      |
Table 3. Coefficient and significance of different variables in Equations (2, 3).

| Model | Unstandardized Coefficients | Standardized Coefficients | Correlations |
|-------|------------------------------|---------------------------|--------------|
|       | B               | Std. Error | Beta | t     | Sig. | Partial | Part |
| 1     | (Constant)   | 1.037      | 0.073 | 14.243 | 0.00 | 0.922  | 0.922 |
|       | $W_{inf}$    | 0.089      | 0.003 | 0.922  | 31.700 | 0.00   | 0.823  | 0.475 |
| 2     | (Constant)   | 0.969      | 0.062 | 15.581 | 0.00 | 0.536  | 0.208 |
|       | $W_{inf}$    | 0.067      | 0.003 | 0.698  | 19.276 | 0.00   | 0.536  | 0.208 |
|       | S             | 240.434    | 28.481 | 0.306  | 8.442  | 0.00   | 0.536  | 0.208 |

Figure 6. Comparison between measured and predicted Manning’s roughness coefficient (Equation 2).

Figure 7. Comparison between measured and predicted Manning’s roughness coefficient (Equation 3).

Verification of the deduced equations

Bakry (1992) investigated the flow resistance in open channel cross-sections with composite roughness due to aquatic weed based on field measurements applied on two main Egyptian canals (Kalabia and Asfoun). The measured field data of the different cross-sections of the two canals (weed infestation percentage and water surface slope) were used to predict the corresponding values of the Manning roughness coefficient.
using Equations (2) and (3). The predicted values of the Manning roughness coefficient were compared with the calculated ones in the field. Figure (8) shows that the predicted values by the two equations within the same range of the calculated values in the field. It also has a similar trend. The trend line representing the field calculated values lies between the points that represent the predicted values of the two equations. It was noticed that the values of Manning’s coefficient predicted by Equation (3) are closer to the trend line that represents the calculated values.

**Practical application**

The process of detecting the flow discharge in the field is depending mainly on measuring the flow velocity in several vertical sections through the channel cross-section to calculate the value of mean velocity. Also, the channel’s cross-section must be surveyed to detect its cross-section area. Then we can detect the flow discharge as the result of multiplying the value of mean velocity by the value of the cross-section area. This process needs a lot of effort and expensive equipment taking into consideration that the electromagnetic sensor must be used in vegetated channels. Now a day’s modern equipment can easily detect the flow discharge directly but it is very expensive. Equation (2) and (3) can allow the engineer in the field to predict the flow discharge easily with his simple surveying tools and equipment. The field engineer is asked to survey the canal cross-section to detect cross-section area (A) and wetted perimeter (p) also water surface slope (s) must be measured. The weeds infestation percentage must be determined by visual inspection or by echo-sound equipment, which is very cheap if compared with velocity measurement instruments. By using one of the two Equations (2) or (3), the value of (n) could be predicted. Then manning’s equation could be applied to calculate the flow discharge.

**Conclusions and recommendations**

Based on the result experimental measurements and the analysis result data, it could be concluded that:-

- Weed infestation percentage in vegetated channels is the dominant parameter that affects the value of Manning’s roughness coefficient.
- Detecting submerged weed infestation percentage in vegetated channels now days gets easier by using Echo-Sound sonar equipment.
- Bed weed infestation has a dominant effect on the values of Manning’s roughness coefficient. On the other hand, side slope infestation has a minor effect.
- Two equations relating Manning’s roughness coefficient in vegetated open channels with weed infestation percentage and water surface slope were deduced using linear stepwise regression analysis.
- The predicted values of Manning’s roughness coefficient by the deduced two equations are in the range of calculated values based on field measurements and having the same trend.

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