

MANNING ROUGHNESS COEFFICIENT FOR GRASS-LINED CHANNEL

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Received: Oct 12, 2005; Revised: Feb 10, 2006; Accepted: Mar 20, 2006

Abstract

A laboratory study has been conducted to analyze the effects of different types of vegetation on the Manning roughness coefficient, n in an open channel, and to develop relationships between the characteristics of the vegetation (density, degree of submergence and distribution) and Manning's, n . Two type of vegetation were used in this study, namely Napier grass and Cattail grass. The impact of each type of vegetation on the resistance of flow in open channel (Laboratory flume) was examined. The laboratory flume is rectangular in cross section and has dimensions of 12 m length, 0.3 m width and 0.3 m height. An area-velocity flow meter was used to measure the mean velocity, and Manning's equation was adopted to determine the value of overall roughness, n . The results show that Manning's, n , for flows with Napier grass increased with the increase in flow depth for both submerged and unsubmerged conditions. The increment in Manning's, n was found to be 282% when the degree of submergence (Y/H) for high grass density increased from 0.5 to 0.875. In the presence of Cattail grass and for high density, the effects were reversed and the decrease in Manning's, n was found to be 41% for same increase in degree of submergence. This is attributed to the physical characteristics of the Cattail grass, which has no branching stems and leaves. For low density of Napier grass, the values of Manning's, n decreased with the incerase of Reynolds number, Re , for both submerged and unsubmerged vegetation. However, for a higher density, this phenomenon only occurred for submerged vegetation. In the case fo unsubmerged vegetation the values of Manning's, n increased with the increase of Re . But for Cattail grass, the values of Manning's, n decreased with increase of Re for all grass densities and for submerged and unsubmerged flow conditions. A linear relationships were found between Manning's, n and grass density for both submerged and unsubmerged flow conditions and the coefficient of determination for the relationships ranges form 0.93 to 0.96. When the density increased form 20 veg/m² to 40 veg/m² the value of Manning's, n increased by 35% for Napier grass and 25% for Cattail grass. It was found the degree of increment in Manning's n with the grass density is depending on flow depth, vegetation type, and vegetation arrangement.

Keywords: Vegetation density, Manning roughness coefficient, open channel, flow resistance

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Introduction

Vegetation can be found growing naturally on the beds of channels or on the riverbanks or where it has been purposely planted. It is often classified by its shape and the locations where it grows. Vegetation growing on the river floodplains typically comprises various combinations of trees, herbs, shrubs, hedges, bushes and grasses. The in-channel vegetation usually consists of aquatic plants and these may be divided into four categories: emergent, submerged, floating-leaf, and free-floating. The presence of vegetation in river channels provides both benefits and problems. From an environmental point of view, aquatic plants are essential parts of natural aquatic systems and form the basis of a waterbody's health and productivity. From an engineering point of view, vegetation can improve the strength of bank materials through buttressing and root reinforcement. However, invariably aquatic plants become over abundant or unsightly and require control.

The obvious problems related to excessive growth are retardation, a reduction in hydraulic capacity and flooding. Although the flow capacity can be increased by complete or partial removal of vegetation, this solution will lead to erosion of the banks and increase the sediment load carried by flowing water. Unrestricted growth of such vegetation in a channel can lead to a complete loss of its hydraulic capacity. Therefore, it is essential that the balance between the risk and benefit of having vegetation in the channel is weighed and a proper engineering judgment be made. The objectives of this study are to analyze the effects of Napier and Cattail grasses on hydraulic roughness, and to develop empirical relationships between the characteristics of the flow and the characteristics of the vegetation.

Historical Background

The vegetation in a channel influences the flow across the channel and the degree of influence depends on the vegetation characteristics such as vegetation species, distribution, flexibility, degree of submergence and density as well as flow

characteristics, including flow area, depth and boundary characteristics. This is based on the findings of the work conducted by researchers in the past, and only selected works are presented in this study.

The main effect of vegetation in the channel is on the velocity of flow. The average water velocity at a channel cross-section tends to decrease, due to flow resistance from the stems and leaves of the vegetation. Vegetation generally increases roughness or flow resistance (Fischenich, 2000). Increases in roughness due to vegetation can be much higher than that due to a channel's particle size alone (Chow, 1959). Thompson and Roberson (1976) developed a theory to predict the flow resistance in vegetated open channels. The theory uses small diameter cylinders to simulate vegetation roughness elements with flow conditions that may be either partially or fully submerged. They presented an analytical method to predict the effect of flexible vegetation on flow resistance. Righitii and Armanini (2002) reported that the vegetation effect varies seasonally. Vegetation in the wet season gives less resistance to flow compared with vegetation that is partially submerged during the dry season. Shih and Rahi (1982) concluded that the n value in marshland was significantly increased by vegetation. The n value increased with the decrease in flow depth and varied from 0.26 to 0.55 for the water hyacinth and from 0.16 to 0.43 for mixed vegetation with flow depth ranging between 65 to 40 cm. Petryk and Bosmajian (1975) presented a flow resistance model for unsubmerged vegetation conditions. They developed a quantitative procedure for predicting the Manning n value as a function of flow depth and vegetation density. An experimental study has been conducted by Wu *et al.* (1999) using artificial roughness to investigate the variation of resistance with flow depth both in submerged and unsubmerged conditions. Kao and Barfield (1978) made their study to predict the flow hydraulics for vegetated channels. Simulated dense vegetation with random blade arrangement and different blade flexibilities was used to determine the hydraulic properties of small, non-submerging depths. Abdelsalam *et al.*

(1992) stated that most irrigation canals were designed by applying Manning's equation. The presence of submerged weeds makes the application of Manning's equation for design of wide channels inadequate due to the variation of the retardation coefficient over a wide range. Maghdam and Kouwen (1997) obtained a mathematical model for estimation of roughness for unsubmerged and flexible vegetation in floodplains and vegetated zones of rivers. They concluded that in the presence of vegetation the Manning's, n value increases proportionally to the square root of flow depth and is inversely proportional to the mean velocity for submerged conditions. The effect of density of vegetation on the flow characteristics has been investigated by Kouwen and Unny (1973).

Materials and Methods

Experiments were conducted in a 12 m long, 0.32 m wide and 0.32 m deep glass-walled flume

(Figure 1). The slope of the flume is fixed at 0.5%, which is a typical slope of plant-covered brooks (Stephan and Gutknecht, 2002). Discharge is pumped into the flume from a circulation storage tank. The water levels were maintained at a desired level by adjusting the downstream weir, which can be raised and lowered by a gear system (Figure 2). The height was set with a high degree of accuracy. The flow depths were measured along four different points along the flume to ensure a uniform flow condition. The test stretch was 2.5 m long and located at a distance of 4 m from the channel inlet. The vegetation was planted in 5 metal boxes which were filled with soil. Each box had dimensions of 0.5 m length, 0.32 m width and 0.1 m height. The schematic drawing of the experimental set-up is shown on Figure 3.

The mean velocities of flow in a channel with vegetation of different densities were measured using an area-velocity flow meter. The mean velocities were then used to compute



Figure 1. General view for the flume



Figure 2. View for end weir of the flume

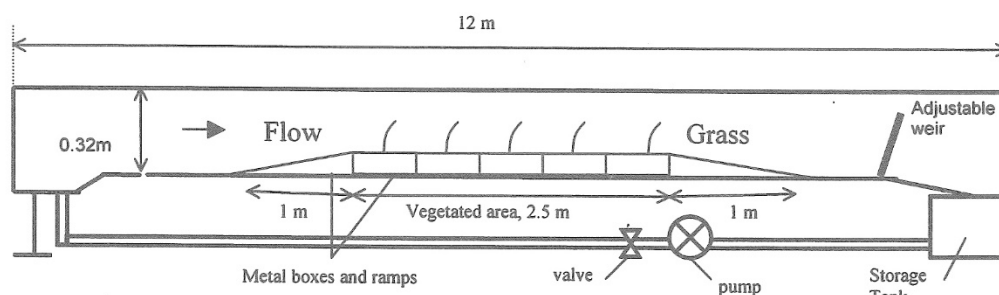


Figure 3. Schematic diagram for the experimental setup (Not to Scale)

Manning's roughness coefficient using Manning's equation. The height of vegetation, H , was kept constant at 0.15 m. The measurements were taken at a different flow depth, Y , or in other words at a different degree of submergence (Y/H). $Y/H > 1$ indicates that the plants were submerged when the value $Y/H < 1$ indicates otherwise.

In this study two types of vegetations were used, namely Napier grass (*Pennisetum Purpureum*), which is quite flexible and Cattail

grass (*Typha SPP*), which has a rigid stem (Figure 4). These grasses are quite common in rivers and streams around the country (Malaysia). The vegetations were collected and trimmed to the desired height (0.15 m) and then replanted in the channel after covering their roots with wet sponge to keep them alive for 2 - 3 days (Figure 5 and 6). The plants were carefully selected so that they have almost same size, same physical characteristic and roughly at same age. Table 1 shows the grasses details



Figure 4. Cattail grass in the field

Experimental Designs

The summary of the experiments carried out in this study is described in Tables 2 and 3 for types of grass used (Napier grass and Cattail grass). For a control and checking mechanism, the tests were also carried out without vegetation.

To investigate the relationship between flow depth and Manning's n , a fixed set of five-flow depth (0.1, 0.12, 0.14, 0.17 and 0.19 m) was adopted, and a uniform flow was set in this study. Flow is considered uniform when the cross-section and flow depth remain constant along the length of the flume. The height of the



Figure 5. Arrangement of Cattail grass inside the flume

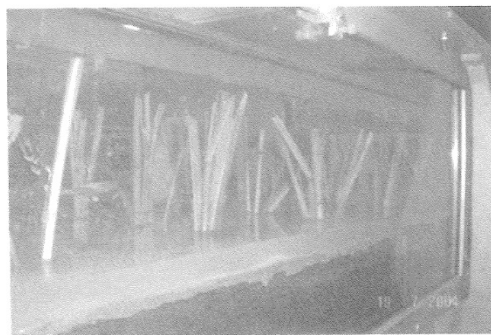


Figure 6. Napier grass in boxes inside the flume

Table 1. Details for Napier and Cattail grasses

Common name	Scientific name	Class
Napier grass; Elephant grass	<i>Pennisetum purpureum</i>	Invasive Grass Weeds
Cattail	<i>Typha spp.</i>	Invasive Grass Weeds

Table 2. Details of experiments (Napier grass)

Experiment number	Density of grass (No. of veg/m ²)	Experiment objectives	Range of flow depth (m)	Arrangement
1 - 5	100	Variation of n value with flow depth and density	0.19 - 0.1	Both sides of the channel
6 - 10	80	Variation of n value with flow depth and density	0.19 - 0.1	Both sides of the channel
11 - 15	60	Variation of n value with flow depth and density	0.19 - 0.1	Both sides of the channel
16 - 20	40	Variation of n value with flow depth and density	0.19 - 0.1	Both sides of the channel
21 - 25	20	Variation of n value with flow depth and density	0.19 - 0.1	Both sides of the channel
26 - 30	60	Variation of n value with vegetation arrangement	0.19 - 0.1	Both sides of the channel
31 - 35	60	Variation of n value with vegetation arrangement	0.19 - 0.1	Channel center
36 - 40	60	Variation of n value with vegetation arrangement	0.19 - 0.1	Staggered distribution across the channel
41	-	Without vegetation	0.19 - 0.1	-

plants was fixed during the experiments and the selected height was 0.15 m. Experiments were carried out with both submerged and unsubmerged conditions. The mean velocity was measured at three locations in the vegetated zone (Figure 8) and the average of the mean velocity was used to calculate the Manning's roughness coefficient, *n*. The experiments were repeated for five different densities of plant vegetation;

20, 40, 60, 80 and 100 veg/m².

To investigate the effects of vegetation density on Manning's *n*, five sets of densities of vegetation (20, 40, 60, 80 and 100 veg/m²) with different flow depths were used to test the relationship between vegetation density and Manning's, *n*. The vegetation was arranged at both sides of the channel and a vegetation height of 0.15 m was used.

Table 3. Details of experiments (Cattail grass)

Experiment No.	Density of grass (No. of veg/m ²)	Experiment objectives	Range of flow depth (m)	Arrangement
1 - 5	100	Variation of n value with flow depth and density	0.19 - 0.1	Both sides of the channel
6 - 10	80	Variation of n value with flow depth and density	0.19 - 0.1	Both sides of the channel
11 - 15	60	Variation of n value with flow depth and density	0.19 - 0.1	Both sides of the channel
16 - 20	40	Variation of n value with flow depth and density	0.19 - 0.1	Both sides of the channel
21 - 25	20	Variation of n value with flow depth and density	0.19 - 0.1	Both sides of the channel
26	-	Without vegetation	0.19 - 0.1	-

To investigate the effects of vegetation arrangement on Manning's, n , three different vegetation arrangements for Napier grass only were tested. The first arrangement was used to simulate the vegetations in one row at the center of the channel; the second arrangement was used to simulate the vegetation in two rows at both sides of the channel edge. The third arrangement was used to simulate the staggered distribution of vegetation across the channel length. Figure 7 shows a schematic diagram of the above distributions.

The flow velocity measurement was carried out at three different locations in the flume. The distance of these locations from the flume inlet were 4.25 m, 5.25 m and 6.25 m and Figure 8 shows a definition sketch of the locations.

The Manning's formula is used to find the roughness coefficient, n for the channel with and without vegetation. The discharge, hydraulic radius and slope are required to find the roughness

coefficient n from Manning's Equation;

$$V = \frac{1}{n} R_h^{\frac{2}{3}} S_o^{\frac{1}{2}} \quad (1)$$

where V is velocity of flow (m/sec), n is overall roughness coefficient, R_h is hydraulic radius (m), A is flow area (m²), P is wetted perimeter (m), S_o is slope of the channel bed

Samples of Calculation

The Manning's, n for the flume with vegetation is computed using the following data which was collected from laboratory experiment,

For depth of flow, $Y = 0.19$ m

The flow area, $A = 0.0608$ m²

Wetter perimeter, $P = 0.7$ m

Hydraulic radius, $R_h = 0.087$ m

Channel slope, $S = 5:1000$

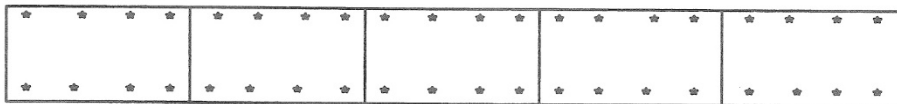
Average velocity, $V_{avg} = 0.15$ m/s

(determined from the experiments)

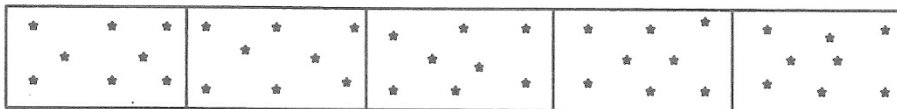
By applying Manning's equation



(a)



(b)



(c)

Note: for each box, different arrangements with same vegetation density were used

Figure 7. Vegetation arrangements; Vegetation at
(a) the center of the channel,
(b) both sides of the channel,
(c) staggered distribution across the channel section

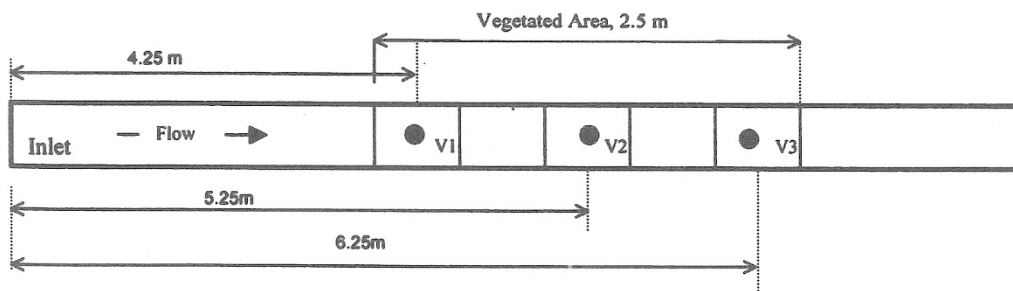


Figure 8. Locations of velocity measurement in the flume

$$n = \frac{1}{0.15} * (0.086857)^{\frac{2}{3}} * (0.005)^{\frac{1}{2}}$$

It is found that the value of Manning's n , for overall flume is equal to 0.092.

The Manning's, n for the flume without vegetation is computed from the following data which was collected from the laboratory experiment,

For depth of flow, $Y = 0.19$ m
 The flow area, $A = 0.0608$ m²
 Wetted perimeter, $P = 0.7$ m
 Hydraulic radius, $R_h = 0.087$ m
 Channel slope, $S = 5:1,000$
 Average velocity, $V_{avg} = 0.29$ m/s
 (determined from the experiments)

By applying Manning's equation

$$n_o = \frac{1}{0.29} * (0.074)^{\frac{2}{3}} * (0.005)^{\frac{1}{2}}$$

It is found that the value coefficient of roughness, n_o for the flume without vegetation is equal to 0.047.

The vegetation roughness coefficient was calculated using the Soil Conservation Service Method (SCS). The vegetation roughness coefficient (n_{veg}) is determined using the following formula:

$$n = n_o + n_{veg} \quad (2)$$

where n_{veg} is roughness coefficient contributed by vegetation only not including the flume boundary roughness, n is roughness coefficient with vegetation, and n_o roughness coefficient without vegetation

The overall Manning's, n for the flume is computed from the following values of the coefficients of roughness for the flume as shown below:

Roughness coefficient with vegetation,
 $n = 0.092$

Roughness coefficient without vegetation,
 $n_o = 0.047$

Vegetation roughness coefficient,
 $n_{veg} = 0.092 - 0.047 = 0.045$

The data was analyzed using regression analysis by fitting the data to different models. The selected model describing the best relationship for variables of the collected data

was the one which gave highest value for the coefficient of determination.

Results and Discussion

The results obtained are the mean velocity measured from the experiments and the roughness coefficient for the channel. Reference is made to the samples of calculation, the coefficient of roughness was determined for the flume with various conditions and these conditions are flume with vegetation, flume without vegetation. Also contribution of the vegetation to the total roughness in the flume was determined using Equation (2). The contribution of the boundary to the flume roughness can be determined by subtracting the total roughness from that due to vegetation only. The impact of the vegetation on Manning's, n for the flume is studied for various flow rates. The variables included are degree of submergence (Y/H), grass density (D_v), Reynolds number (Re), and arrangement of vegetations. The results are also compared with the previous studies done by other researchers.

Variation of Manning's n with the Degree of Submergence (Y/H)

Manning's, n is plotted against the degree of submergence (Y/H) as shown in Figure 9. The degree of submergence is defined as the ratio of flow depth (Y) to the height of vegetation (H). The maximum increase in the value of Manning's, n for Napier grass was found to be 282% (for high density of 100 veg/m²) and when the Y/H increased from 0.5 to 0.875. These results show a good agreement with the finding of Jarvela (2002) for both Submerged and unsubmerged conditions. The relationships between Manning's, n and the degree of submergence for submerged and unsubmerged vegetation with high and low grass density are represented by

$$n = 0.0535 \ln(Y/H) + 0.0242 \text{ for low density } R^2 = 0.906 \quad (3)$$

$$n = 0.0542 \ln(Y/H) + 0.0341 \text{ for high density } R^2 = 0.87 \quad (4)$$

Jarvela (2002) concluded that the resistant coefficient was dependent mainly on flow depth

and increased when the flow depth increased. Also the results of present study found in agreement with the results obtained by Maghdam and Kouwen (1997) particularly when density of vegetation is low.

The comparison of the relationships between the Manning's, n and degree of submergence (Y/H) for Cattail grass with the same relationships for Napier grass was found different. The difference can be attributed to the fact that Cattail grass has no branching stems in addition to the rigidity of grass stems. For Cattail grass, the relationships indicate that when flow depth increased (led to a reduction in) the roughness coefficient decreased. Figure 10 shows

the relationship between the Manning's, n and degree of submergence (Y/H) for Cattail grass. For example, when Y/H increased from 0.5 to 0.875 the Manning's, n decreased approximately by 41%. The relationship are represented by

$$n = -0.0158 \ln(Y/H) + 0.0116 \text{ for low density } R^2 = 0.9074 \quad (5)$$

$$n = -0.0162 \ln(Y/H) + 0.0185 \text{ for high density } R^2 = 0.8355 \quad (6)$$

The results of present study were in agreement with the results obtained by Wu *et al.* (1999) for unsubmerged vegetation. Wu *et al.* (1999) indicated that the roughness coefficient of the unsubmerged vegetation depends only on

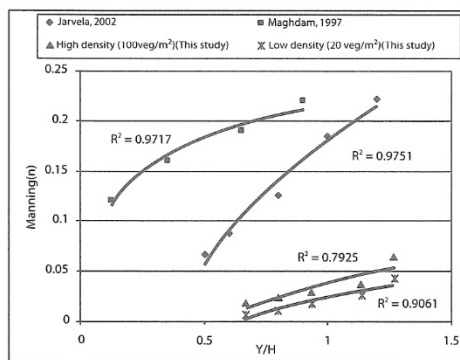


Figure 9. Relationships between Manning's, n and the degree of submergence, Y/H for high and low density for Napier grass

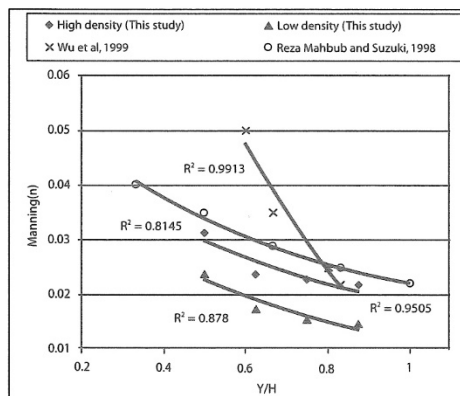


Figure 10. Relationships between Manning's, n and degree of submergence, Y/H for Cattail grass for high and low density of Cattail grass

the depth of flow while for submerged vegetation, the roughness coefficient tends to be at a constant value or rise as submergence starts to occur. In present study, the computed Manning's, n for Cattail grass was found in agreement with Reza Mahbub and Suzuki, (1998). The Manning's n decreased with increasing flow depth and decreased with increasing velocity.

Variation of Roughness Coefficient, n , with Reynolds Number, Re

Basically, the Reynolds number is the measure of the ratio of inertia forces to viscous forces. An inertia force occurs due to the changes in the velocity (ΔV) or the acceleration (a) of the mass (m) of the water per Newton's Law of motion ($F = ma$). The flow in open channel also can be classified as laminar, transitional, and turbulent depending on the variables governing the Reynolds number as described by the following formula (Chow, 1959):

$$Re = \frac{VR_h}{\nu} \quad (7)$$

where ν is kinematic viscosity of the water, R_h , V are defined before.

Figure 11 shows the relationship between the Manning's, n and Re for low and high vegetation densities for Napier grass. It is found for low grass densities of Napier grass, any increase in the values of Re led to a decrease in the values of Manning's, n for both submerged

and unsubmerged flow conditions. But for high grass densities, the values of Manning's n decrease with the increase of Re and this finding is limited only for the case of submerged vegetation. In the case of unsubmerged vegetation, values of Manning's n increase with the increase of Re . The relationships are in the form of

$$n = 5 \times 10^{-9} Re^2 - 0.0002 Re + 1.6766 \quad \text{High density } R^2 = 0.8816 \quad (8)$$

$$n = 1 \times 10^{-9} Re^2 - 6E - 5 Re + 0.7241 \quad \text{Low density } R^2 = 0.7149 \quad (9)$$

For the Cattail grass, n values decreased with the increase of Re for all densities and for submerged and unsubmerged flow conditions. Figure 12 show relationship between Manning's, n and Re for Cattail grass. The relationships between the Manning's, n and Re are in the form of

$$n = 9 \times 10^{-9} Re^2 - 4 \times 10^{-5} Re + 0.0624 \quad \text{High density } R^2 = 0.98545 \quad (10)$$

$$n = 5 \times 10^{-9} Re^2 - 3 \times 10^{-5} Re + 0.05 \quad \text{Low density } R^2 = 0.9975 \quad (11)$$

Variation of Manning's Roughness Coefficient, n , with Vegetation Density D_v

The effect of vegetation densities (High and low) for both Napier grass and Cattail grass on the values of the Manning's, n was studied

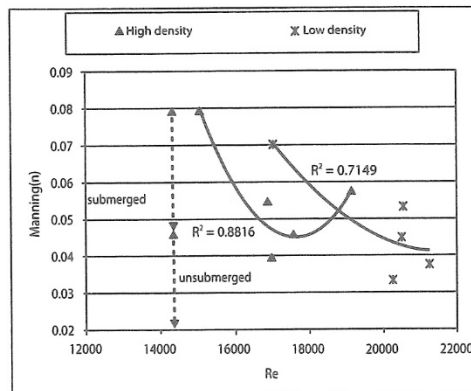


Figure 11. Roughness coefficient vs Re for different densities, D_v for Napier grass

by varying the vegetation density at different flow depths for the same flow rate. The increment in densities of Napier grass and Cattail grass led to increase in the value of Manning's, n as shown in Figure 13 and 14 for Napier grass, it is found when the flow depth is kept constant and the grass density increased from 20 veg/m² to 40 veg/m² (doubled) the value of Manning's, n increased by 35%. For Cattail grass, it is found that when the flow depth is kept constant and the grass density increased from 20 veg/m² to 40 veg/m² (doubled) the value of Manning's, n increased by 25%. Figure 15 shows a linear the relationship between Manning's n and vegetation density, D_v for Napier grass but for both submerged and unsubmerged flow conditions

and it is found in agreement with the findings of Shih and Rahi (1982).

Variation of Mannig Roughness Coefficient, n with Vegetation Arrangement

Reference is made to Figure 7, three types of vegetation arrangements for Napier grass were used to simulate their effects on the roughness coefficient. The densities were kept constant at a rate of 60 veg/m². The results show that when vegetation was located at the sides of the flume gave highest values of Manning's, n while the other vegetation arrangement gave less effect on Manning's, n . This is because when the vegetation was located at the side of the flume approximately two third of the flow area was

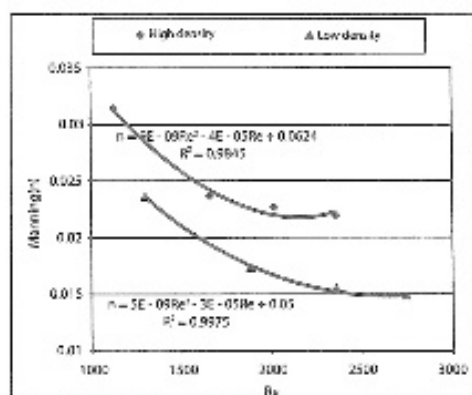


Figure 12. Roughness coefficient vs Re for different densities, D_v for Cattail grass

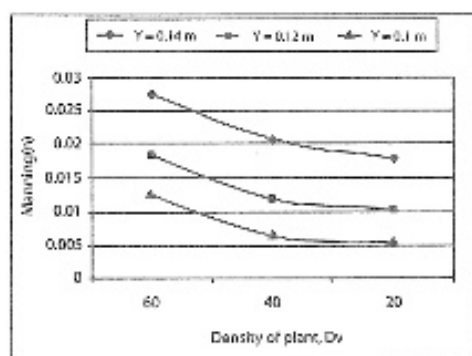


Figure 13. Roughness coefficients, n vs density of plant for Napier grass

resisted by the vegetation, while in other arrangements only one thirds of the flow area was resisted by the vegetation. Figure 16 show the relationships between Manning's, n and the degree of submergence for different grass arrangements.

Conclusions

This study presents the effect of vegetation on the Manning's, n in an open channel. Two types of vegetation have been selected to carry out the experiment and these are Napier grass (*Pennisetum purpureum*) and Cattail grass (*Typha SPP*). An empirical relationships between the characteristics of the vegetation and the

Manning's, n were proposed. The relationships between Manning's, n and the degree of submergence (Y/H) were found to be logarithmic for all studied cases. The coefficient of determination, R^2 for the relationships ranges from 0.84 to 0.98. For Napier grass, the results show that the maximum increase in the values of Manning's, n was found to be 282% when the value of Y/H increased from 0.5 to 0.875 while for the Cattail grass, the effect was reversed and decrease in the value of Manning's n was found to be 41% for the same increase in the value of Y/H . This is related to effect of branching stems (resistance to the flow) which was existed in Napier grass while Cattail grass has no branching stems (less resistance to the flow).

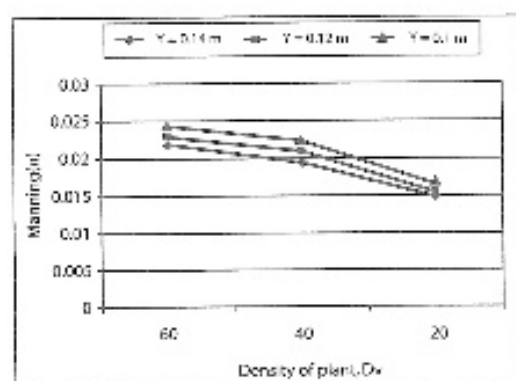


Figure 14. Roughness coefficients, n vs density of plant for Cattail grass

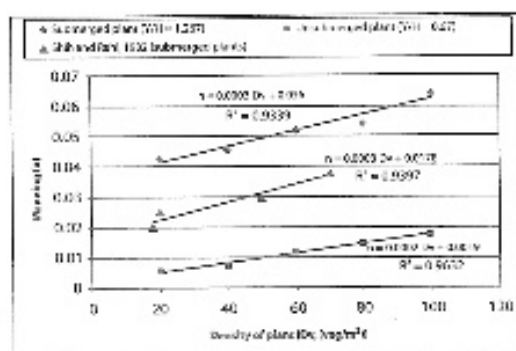


Figure 15. Roughness coefficient vs vegetation density for both submerged and unsubmerged vegetation (Napier grass)

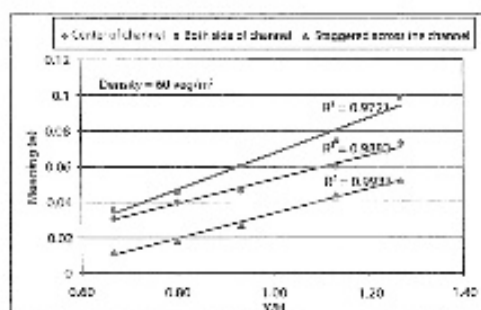


Figure 16. Manning's n vs Y/H for three different vegetation arrangements for Napier grass

For low density of Napier grass (20 veg/m^2), the Manning's, n decrease with the increase in the values of Reynolds number, Re for both submerged and unsubmerged flow conditions. For the high density of Napier grass (100 veg/m^2) the values of the Manning's n decrease with the increases of Re for submerged vegetation only but for unsubmerged vegetation, the value of Manning's, n increased with the increase in Re . For Cattail grass the value of Manning's n decreased with the increase of Re for all densities and all flow conditions.

For Napier grass, it was found that there is a linear relationship between Manning's, n and the vegetation density, D_v , for both submerged and unsubmerged vegetation. The value of Manning's n increases by 35% when the density increase from 20 veg/m^2 to 40 veg/m^2 but for Cattail grass the increment in Manning's, n was found to be 25%. The degree of increment in Manning's, n with the grass density is depending on flow depth, vegetation type, and vegetation arrangement.

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