CHAPTER 1

INTRODUCTION

1.1 Background

Weeds growth in the open channel play a significant effect on the efficiency of the water channel flow and also the water distribution properties. As weeds especially aquatic weeds cause flow resistance due its shape and density, they are said to cause several problem related to the water flow such as disruption of the speed and direction of the flow current, reduction of flow velocity, reducing water flow, heightening the water level of the channel and also obstructing the water to reach to the canal end. (El-Shamman, 2007). However, the degree of flow resistance that the aquatic weeds may affect depends on the density, maturity and type of the vegetation which governs the performance of the channels. (Pitlo, 1990). This research will study the behavior of the velocity and discharge towards the presence of vegetation in the open channel flow.

In the other hand, there are several formula have been derived to estimate discharge of open channel flow. The most common equation to analyze open channel flow is the Manning Equation. To use the Manning Equation, the difficult part is in the designation of the roughness coefficient (Yen et. al, 2009). It is involving judgments and skills to do the proper selection. Selecting Manning coefficient for some experts like senior engineer, may come from years of practice, meanwhile for inexperienced engineer, it may be challenging and may not be accomplished without the aid from the table of Manning's roughness coefficients to proceed with the calculation.

Manning's coefficient of roughness for grassed channels is known as the retardance coefficient. (Chow, 1959). Currently, very few research are being done to correlate the plants and the hydrodynamics. This may due from vegetation's complex and unique mechanisms. Retardance coefficients of a channel flow vary dramatically due to the flexible quality of aquatic plants and also their oscillating mobility behavior.

Consequently, this research aims to determine the hydraulic characteristics of open channel with the presence of the vegetation in the channel.

1.2 Problem Statement

Presence of vegetation natural open channel can reduce flow velocity during flood events and protect from erosion flow. However, there are still lack of abundance of research regarding the effect of presence of vegetation in open channel flow. This is due to large variety of vegetative types available over different climates in different places of the world versus the limited research findings.

Three types of vegetation prone to Malaysian climate (Japanese grass, Cow grass, and Pearl grass) are to be tested to understand the open channel behaviour when it is infested by vegetation. Understanding and evaluating flow resistance due to vegetation is a critical task in designing and restoration of open channel flow such as in bio-swale design in Malaysia.

1.3 Objectives

1. To determine the velocity and discharge of three types of studied vegetation in open channel flow.
2. To establish the relationship between retardance coefficient of the vegetations and channel discharge, velocity and flow depth.

1.4 Scope of Study

This research will focus on determining experimentally the hydraulics characteristics of vegetated open channel flow but limited to three types of vegetation namely cow grass (Axonopus Compressus), Japanese grass (Zoysia Japonica Steud) and Pearl grass (Hedyotis Corymbosa (L.) Lamk.). Through experimentation, hydraulic behavior and characteristics of these grasses will be obtained and hydraulic relationships will be drawn out.

CHAPTER 2

LITERATURE REVIEW

2.1 Effect of Vegetation in Open Channel Flow

Vegetation on open channel flow such as river or vegetated swales can reduce flow velocity during flood events and protect them from erosion flow. This phenomenon occur when the leaf or the stems of the vegetation induce a resistance to the flow. Resistance occurs in term of surface roughness capable of reducing flow velocity and decreasing fluid shear stress.

The vegetative resistance varies with the flow depth or the degree of submergence, as both of flow depth and submergence of vegetation will influence the degree of interaction between the external organs of the vegetation (that produce resistance) with the flowing water.

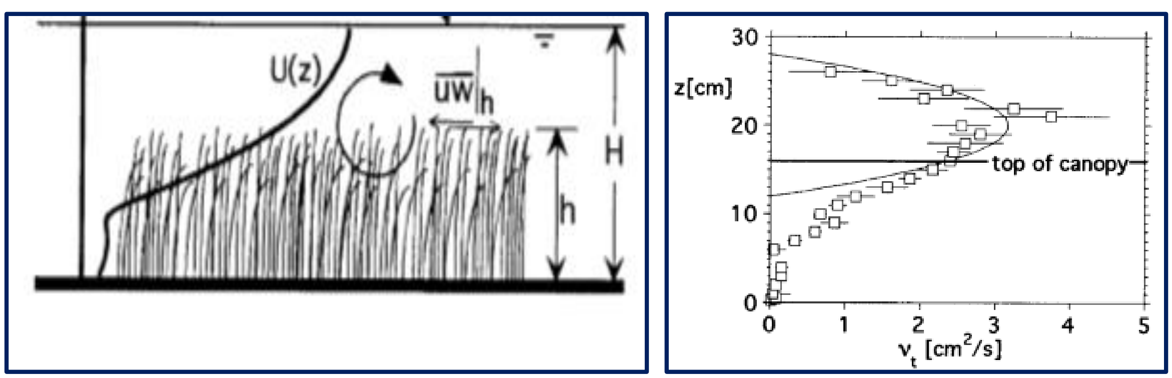

Figure 2.1: Velocity profile variation in flume with presence of vegetation

2.2 Retardance Coefficient of Vegetation

Although much research has been done on Manning's roughness coefficient, n, for stream channels, very little has been done concerning the roughness values for densely vegetated flood plains. The n value is determined from the values of the factors that affect the roughness of channels and flood plains. In densely vegetated flood plains, the major roughness is caused by trees, vines, and brush. The n value for this type of flood plain can be determined by measuring the vegetation density of the flood plain.

The Manning's equation is represented by:

$$Q = \frac{1}{n} AR^{2/3}S^{1/2} \text{ (SI unit)}$$

Where,

Q = volumetric water flow rate passing through the stretch of channel, in m^3/s

A = cross-sectional area of flow perpendicular to the flow direction, in m^2

S = bottom slope of channel, m/m (dimensionless)

n = Manning roughness coefficient (empirical constant), dimensionless,

R = hydraulic radius = A/P in m, where

A = cross-sectional area of flow as defined above,

P = wetted perimeter of cross-sectional flow area, in m

There are many research are done on Manning's roughness coefficient, n for stream channel, but yet has been carried out regarding the roughness coefficient for densely vegetated open channel flow. The n value is obtained from the values of the factors that affect the roughness of channel and overflow grasslands. In vegetated streams, hydraulics drag may be classified into three components, which are soil grain roughness, form roughness, and vegetative roughness. In most vegetated streams, vegetative roughness dominates the flow resistance (Fenzl, 1962; Temple et. al., 1987).

2.3 Techniques and Methods by Previous Researchers

2.3.1 Field Studies on Vegetated Open Channel

Field study on vegetation and flow interaction is done by first selecting an area that is to be assessed. As per field study conducted by K. D. Massey on 2002, he chose a section from a small agricultural stream of Spoon River in Illinois. Then topographic map of the study area is conducted to allow cross section of channel to be drawn out. Characteristics of the said cross-sections is also surveyed using rod and level. Meanwhile, to obtain 3-Dimensional velocity data, acoustic Doppler Velocimeter (ADV) is used. The data used in this study were gathered by an ADV consisting of a laboratory probe attached to submersible field electronics. From the obtained data, post-processing of the data is a common step to be taken to ensure the quality of the data obtained (by removing data that seems to be an error).

2.3.2 Laboratory Flume Experiment

Flume are common apparatus used to test hydrological behavior of open channel flow. Flume studies give researchers advantage of a desired experimental surrounding where researcher are free to isolate unwanted parameters from hydraulic forces and channel response. It is important so that the data collection and interpreting will be easier. Problems that may appear related to in field-based research also can be avoided (Thompson and Wohl, 1998).

There many kind of flume studies investigating hydraulic effect of vegetation such as drag coefficient with submerged vegetation (Garcia et. al., 2004), hydrodynamic behavior and flow resistance (Pasche and Rouve, 1985; Naot et. al., 1996; Darby, 1999; Nezu and Onitsuka, 2001).

Other flume study but may not related to this research focus is studies of change in channel platform and dimensions (Gran and Paola, 2001; Bennett and Alonso, 2003), which, their results indicated that as vegetation mass over volume increases, braiding intensity decreases, lateral mobility decreases, maximum channel depths increases and channel relief increases.

2.3.3 Findings and Recommendations from Previous Researcher Regarded Vegetated Open Channel

Table 2.1 Previous studies on vegetated flow from 1999 to 2015

No.	**Author (s)**	**Title of Paper**	**Findings / Results**	**Recommendation (s)**
1.	Fu-Chun Wu, Hsieh Wen Shen, Member, ASCE, and Yu-Ji Chou, (1999)	Variation of roughness coefficient for unsubmerged and submerged vegetation	1) The vegetal drag coefficient of vegetation can be represented by a general equation stated below for the submerged and unsubmerged condition 2) General equation: $C'_D = \frac{f(S,T)}{R^k}$ 3) The value of *k* is identical to the data of Ree-Palmer and Kouwen et. al.(approximately to the – 2 power of R)	1) Variation of manning's equation *n* in the boundary zone and zone thickness should be further investigated
2.	Kyle Donald Massey, (2002)	The influence of bank vegetation on flow structure within a small agricultural stream: implications for channel stability	1) Location of the maximum energy of the turbulence and maximum shear stress occur at the riverbank (boundary between vegetated and non-vegetated zone in the stream) 2) Vegetation especially grass, leads the reduction of the flow velocity and turbulence near	1) Further research on the influence of the bank vegetation on the channel stability

			the riverbank of the small channel	
3.	Juha Jarvela, (2002)	Flow resistance of flexible and stiff vegetation: a flume study with natural plants	1) Leaves on vegetation double or triple the friction factor compared to leafless vegetation 2) The friction factor increase with depth almost at linear behavior 3) The number of roughness elements per unit area is lower in sedges than in the case of grasses 4) The friction factor is also dependent on the changing flow velocity. 5) Doubling the density of leafless willows approximately also doubled the f values for the same flow conditions.	1) Velocity distributions and turbulence inside and above the vegetation layer should be studied in more details by referring this experiments as a useful reference basis.
4.	Martin J. Baptist, (2003)	A flume experiment on sediment transport with flexible, submerged vegetation	1) These flume experiments have shown that vegetation reduces the bed shear stress by 80%. 2) The increased turbulence levels in between the vegetation are capable of picking up the sediment more	N/A

			effectively and thus bringing the sediment in suspension	
5.	Juha Jarvela, (2004)	Determination of flow resistance caused by non-submerged woody vegetation	1) Procedure taken in this paper is able and highly relevant to estimate flow resistance of woody vegetation in both leafless and leafy condition 2) In both condition of leafy and leafless, the procedure will be more accurate when the flow depth is close to the vegetation depth.	1) Procedure can be improve by learning the plant structure parameters and drag coefficients for further types of trees and bushes 2) Further study on the vertical distribution of the proposed area and the leaf area.
6.	Maeve McBride,W. Cully Hession, Donna M. Rizzo and Douglas M. Thompson, (2007)	The influence of riparian vegetation on near-bank turbulence: a flume experiment	1) Turbulence caused by the artificial grass cover was reduced with increasing water level in non-forested runs 2) In forested runs, where dowels were persistent obstructions, phenomena of vortex shedding was apparently augmented with increased discharge	1) Further testing with erodible beds and banks to investigate whether boundary shear stress based on TKE is an appropriate estimation 2) Further discover how bank morphology might react and relate with the

				turbulent flow field
7.	Tarek A. El-Samman, (2007)	Velocity distribution in vegetated channels	1) Flow was directed to the right side in case of weed distributions B2S and B with different selected weed densities and discharge 2) Velocity profile distribution was not consistently distributed in channel infested by submerged weeds 3) The weeds dispersal on bed and weeds compactness affect the velocity distribution.	1) Further exploration on the phenomenon of directing the flow towards the right side is required.
8.	Andrea D'Alpaos, Stefano Lanzoni, Marco Marani, and Andrea Rinaldo, (2007)	Landscape evolution in tidal embayment: modelling the interplay of erosion, sedimentation, and vegetation dynamics	1) Marsh erosion/deposition manners intensely affected by the potential colonization by halophytic vegetation	1) Modeling comparative sea level changes essential to be considered when addressing long-term tidal morpho-dynamics.
9.	Yen-Chang Chen, Su-Pai Kao, Jen-Yang Lin, Han-Chung Yang, (2009)	Retardance coefficient of vegetated channels estimated by	1) At a small Froude number and velocity, the retardance coefficient of vegetated canals rise to levels higher than those of non-vegetated canals.	N/A

		the Froude number	2) As Froude number and velocity increase, the value of retardance coefficient slowly comes near to that of a non-vegetated channel and is insignificant	
10.	Alexander N. Sukhodolov and Tatiana A. Sukhodolova , (2010)	Case study: Effect of submerged aquatic plants on turbulence structure in a lowland river	1) Bulk resistance of flow in the vegetated channel using Manning's equation with averaged depths and speeds can overemphasizes the resistance because of the violation of correlation between shear stresses and flow depth.	1) Further research on closer link between biomechanical properties of plants and their interactions with flow
11.	J.D.Shucksmith, J.B. Boxall, and I. Guymer, (2011)	Determining longitudinal dispersion coefficients for submerged vegetated flow	1) A more advanced technique for calculating dispersion coefficients in submerged vegetation based on the N-zone Chickwendu [1986] model has been tested against the measured data and delivers more precise results than the two-zone model	1) Further research is required to describe mixing layer penetration in real vegetation natures and diffusivity levels inside vegetated flow
12.	W. M. van Dijk, R. Teske,W. I. van de Lageweg,and M. G.	Effects of vegetation distribution on experimental river channel dynamics	1) The canal becomes narrower and deeper for experiments with vegetation 2) Bank erosion rates decrease for increasingly vegetated banks	1) Future experiments should include combination of different ways of seed dispersion

	Kleinhans, (2013)		3) Bank stabilization leads to fitted bends with an uneven bank line 4) Hydraulic resistance due to inconsistent vegetation leads to sediment deposition upstream of the vegetation	and more realistic flood regimes
13.	M. M. Muhammad, K. W. Yusof, M. R. ul-Mustafa, A. A. Ghani. (2015)	Vegetated Open Channel Flow For Urban Stormwater Management: A Review	1) This review suggests that there is a need to use a natural vegetation instead of artificial materials as it will mislead the discharge determination.	1) More research is required using natural vegetation in order to overcome the shortfall of artificial vegetation.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 Materials

In this study, the author used three types of vegetation to study the vegetated open channel flow characteristics. Japanese Grass, Cow Grass and Pearl Grass are selected as the three types are among the most common grasses that can easily available in the market. (They are also suitable for Malaysia's climate)

3.1.1 Japanese Grass (*Zoysia Japonica Steud)*

Japanese Grass for this study was obtained from the nursery near UTP campus (Semaian Seri Iskandar Sdn. Bhd.). As for the readily nurtured Japanese grass are sold in arbitrary height, the height of the grass was measured upon experimentation to record the approximate height of the grass. 5-m of Japanese grass is laid across the flume to allow established flow regime.

3.1.2 Cow Grass (*Axonopus Compressus*)

Cow grass was also obtained from the Semaian Seri Iskandar Sdn. Bhd. Average height of the cow grass was taken prior to the flume experimentation. 5-m of cow grass is laid across the flume to allow established flow regime.

3.1.3 Pearl Grass (*Hedyotis Corymbosa (L.) Lamk.*)

Pearl grass was obtained from the Hock Loke Siew Nursery in Ipoh. Similar to other two grasses, average height reading of the pearl grass was taken prior to the flume experimentation. 5-m of pearl grass is laid across the flume to allow established flow regime.

Figure 3.1: Japanese grass, Cow grass, and Pearl grass

3.2 Equipment

Rectangular flume attached with discharge regulator was used to create the flow. Depth gauge was used for determining the water depth upon experimentation. Flow meter was used to obtain cross-sectional velocities in certain sections of the flume infested by vegetation.

No.	Equipment	Diagram	Uses
1)	Rectangular Flume with Discharge Regulator pump		For laboratory scale open channel experiment set-up
2)	Depth gauge		To measure the depth of water in the upstream and downstream of the Cow grass in the flume
3)	Flow Meter		To measure the discharge of the experiment run and to measure velocity of the flow
4)	River rock		To stabilize inflow of the water prior to approaching the vegetation.

Table 3.1: Set of material needed for laboratory flume experiment

3.3 Methodology

Figure below shows the flow chart of the methodology involved in this study.

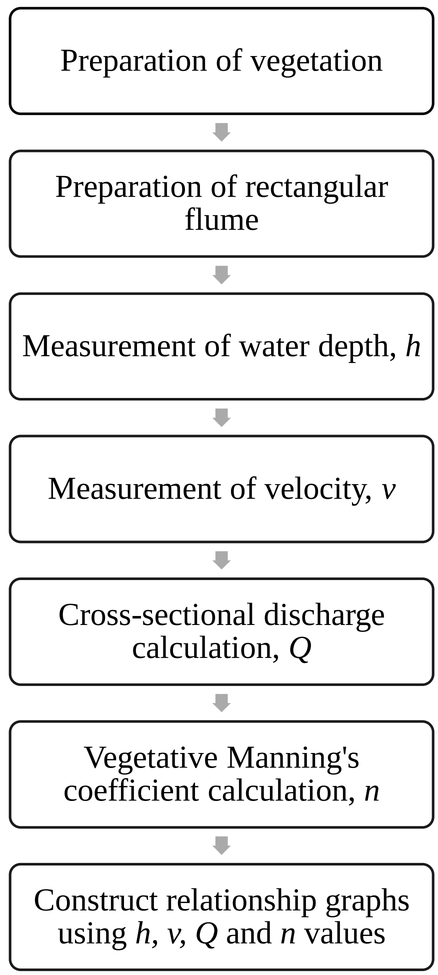

Figure 3.2: Flow chart of methodology

3.3.1 Preparation of Vegetation

All three vegetation types were prepared for 5m strip-long each, whereby several patches of an individual patch (50cm) of readily sold vegetation were combined together using underlying net and cable ties. This approach was implemented to ensure that the vegetation patches are continuous and held in place upon water flowing on top and not driven downstream. After laying the 5m vegetation strip onto the flume, several readings of vegetation height was taken across several location along the 5-m strip and it was averaged.

Figure 3.3: Tying vegetation strip onto 10m plastic mesh

Type	Height 1 (mm)	Height 2 (mm)	Height 3 (mm)	Height 4 (mm)	Height 5 (mm)	Height 6 (mm)	Height 7 (mm)	Height 8 (mm)	Height 9 (mm)	Avg. Height (mm)
Japanese grass	37	36	36	36	38	34	40	48	50	**39**
Cow grass	86	81	96	89	79	104	62	76	74	**83**
Pearl grass	47	38	35	41	36	41	35	33	29	**37**

Table 3.2: Average height of three vegetation prior to experiment

3.3.2 Preparation of Rectangular Flume

Rectangular flume was prepared in such a way that the 10m stretch of flume length was configured into three sections; river rock section, vegetation section, and free bed-surface section. The length of each section was 1m, 5m and 4m respectively. In river rock section, one meter of river rock was loosely laid onto the section, acting as the flow stabilizer before the flow reach the vegetation section. Meanwhile, at the vegetation section, the 5m long vegetation strip was carefully put in place, and was made sure that the strip was levelled throughout the entire length.

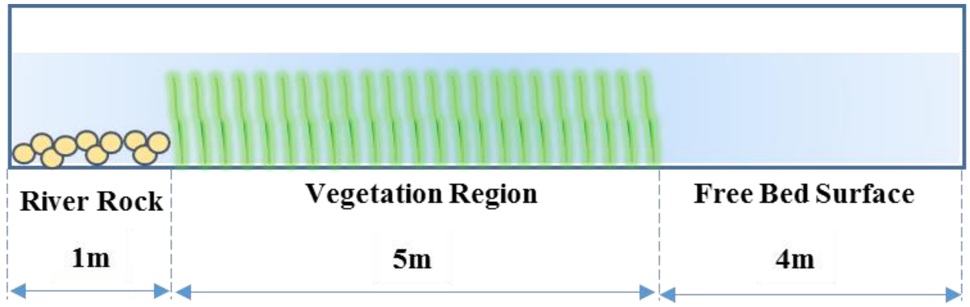

Figure 3.4: Designation of rectangular flume layout

3.3.3 Measurement of Velocity, *v*

Velocity was taken at several cross-section of the vegetation region using current meter (Figure 3.5). It is generally known that velocity measurement should be made at *0.2d*, *0.6d* and at *0.8d* and then these values should be averaged. This will give high accuracy of velocity data. However, for this experiment, only medium accuracy measurement is needed. In medium accuracy measurement, it is sufficient to take the velocity at approximately *0.6d* of the flow at each cross section.

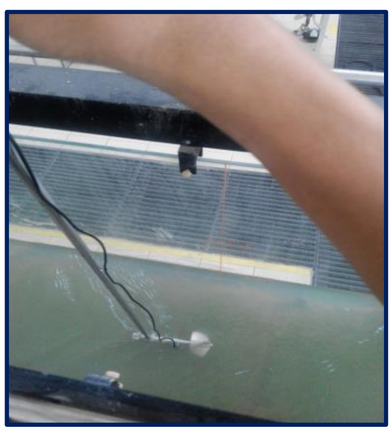

Figure 3.5: Measuring velocity using flow meter

3.3.4 Calculation of Cross-Sectional Discharge, *Q*

Discharge at a cross-section of a point in the flume can be easily obtained by multiplying the cross-sectional velocity measured with the area of the flow cross-section. Given in equation as $Q = Av$, where Q is discharge, A is area of water flow in rectangular flume, and v is cross-sectional velocity. A is actually a product of b x d, where b is fixed to the width of the rectangular flume = 0.31m, and d are variable values according to flow depth characteristics. Discharge calculation are as follows:

$Q = Av;$

Since $A = bd;$

Therefore, $Q = (bd)\,v$

Where,

A= area of water, b = width of flume, d = flow depth, v = cross-sectional velocity, and Q = cross-sectional discharge

3.3.5 Calculation of Vegetative Manning's Coefficient, *n*

Manning equation tells that discharge, Q is a product of Manning's n, hydraulic radius, R, *and* slope, S.

Where,

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

Rearrange the equation above will gives,

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

Whereby, Q, A, R and S values were obtained in the experimentation data collection.

3.4 Project Milestone

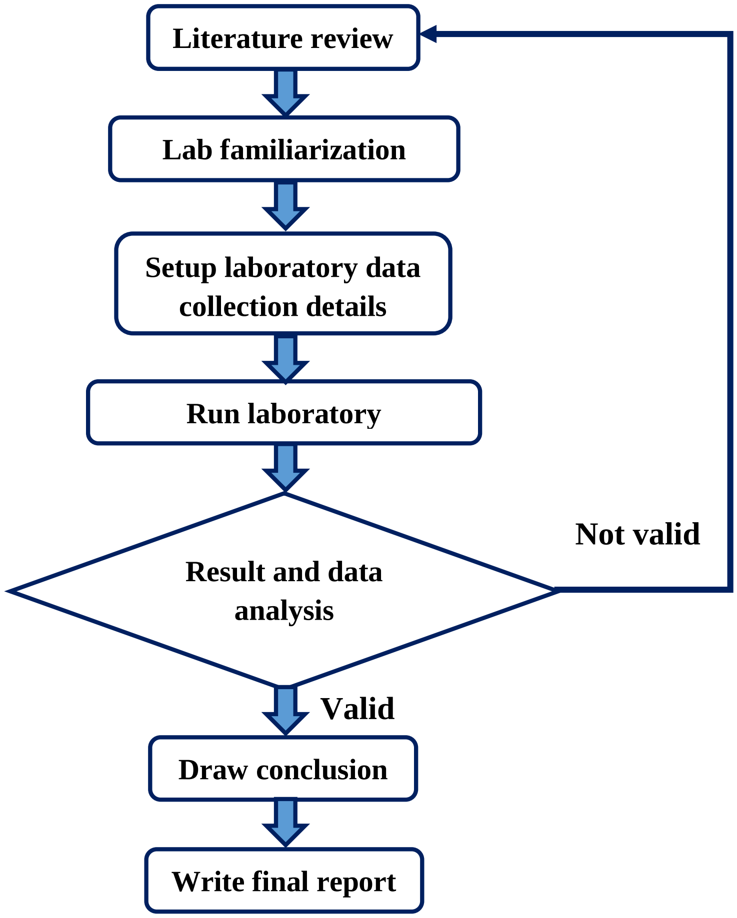

Figure 3.6: Experimental flow chart

3.5 Project Gantt Chart

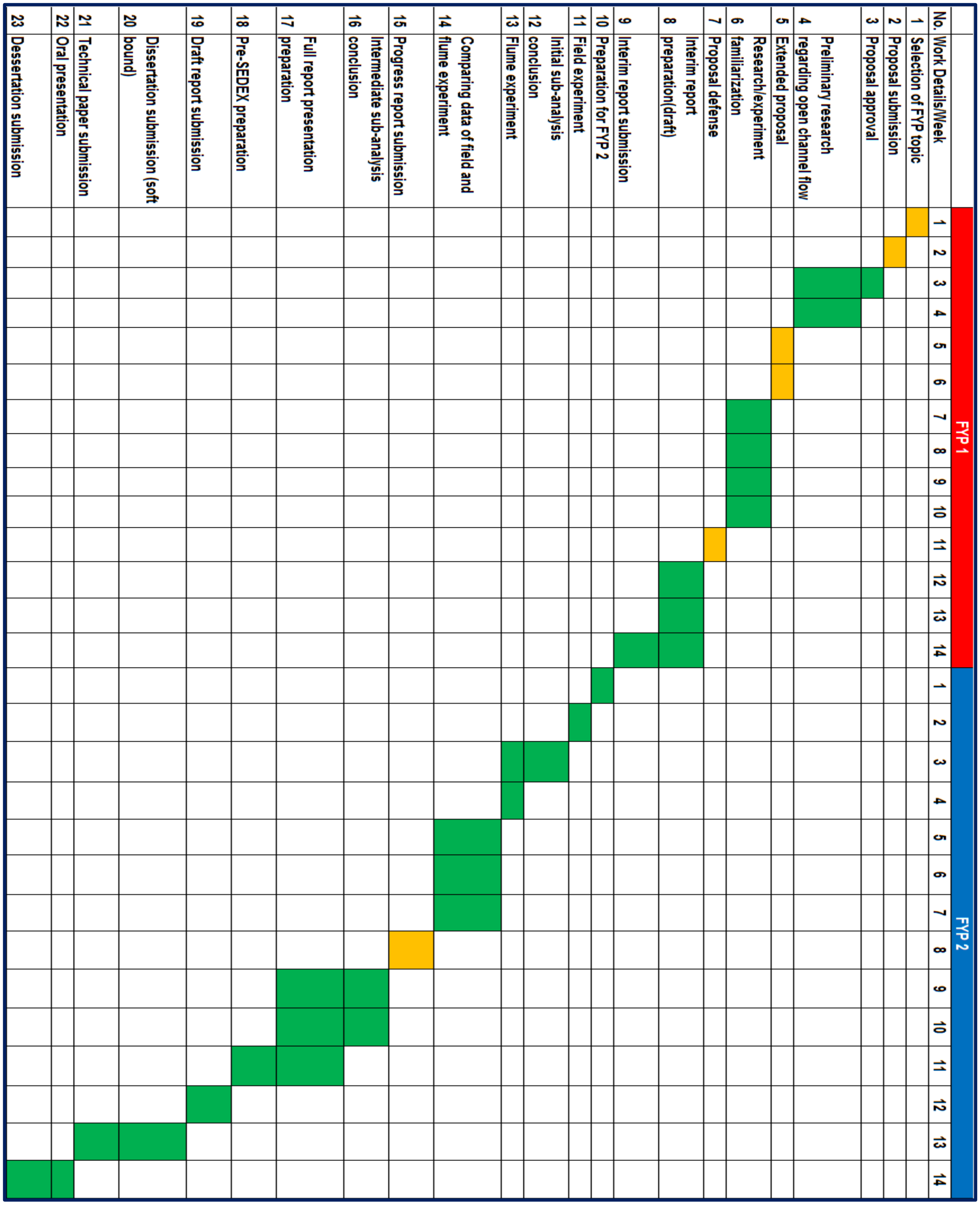

Figure 3.7: Project Gantt chart

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Flow Rating Curve

Experiment conducted on Japanese grass, Cow grass and Pearl grass shows a relationship between hydraulic characteristics of those grasses in term of flow depth, velocity, discharge and also manning's retardance coefficient. Following are the flow rating curve for the grasses. According to Figure 4.1, measured flow depth data and discharge for Japanese grass in different cross section namely in the inlet, middle and outlet shows that discharge increases as the flow depth increases. This behavior is due to the fact that flow depth is actually directly proportional to discharge, if we refers to Manning's equation $Q = \frac{1}{n}AR^{2/3}S^{1/2}$. The graph also indicates that, in any given discharge values, the value of flow depth at inlet will be the highest. This is due to the higher retardance value of Manning's coefficient of the grass in the inlet due to obstruction of the leafy grass. In outlet however, the retardance force is lower due to transition phase of vegetative area to non- vegetative area.

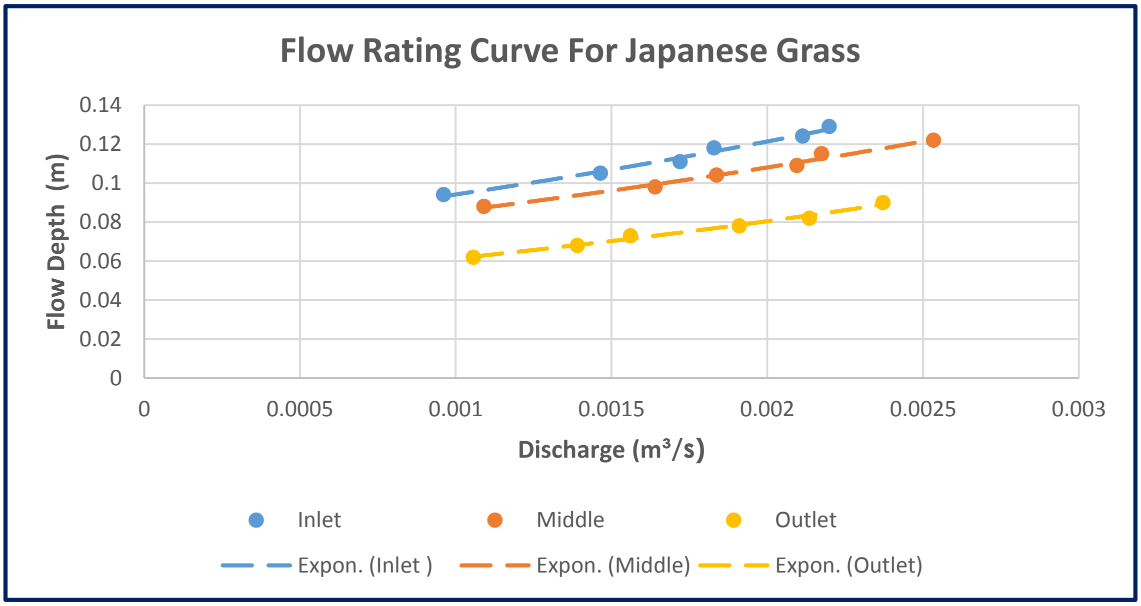

Figure 4.1: Flow rating curve graph for Japanese grass

In comparison, according to Figure 4.2, measured flow depth data and discharge for Cow grass shows that discharge increases as the flow depth increases. This behavior is similar with the Japanese grass whereby as flow depth increases, the discharge increases.

However it is observable that with a similar value of flow depth, the magnitude of discharge differs between Japanese grass result and Cow grass result. For example, flow depth of 0.12m (middle section) in Japanese grass experiment yielded $0.0025m^3/s$ of discharge, comparatively, flow depth of similar value in Cow grass (middle section) yielded $0.00135m^3/s$ which is lower.

This is anticipated that the height of the Cow grass which is higher (83cm versus 39cm) plays a role in reducing the discharge of water per unit time. This behavior reveals that height of the vegetation plays a significant role to impede the water flow in open channel.

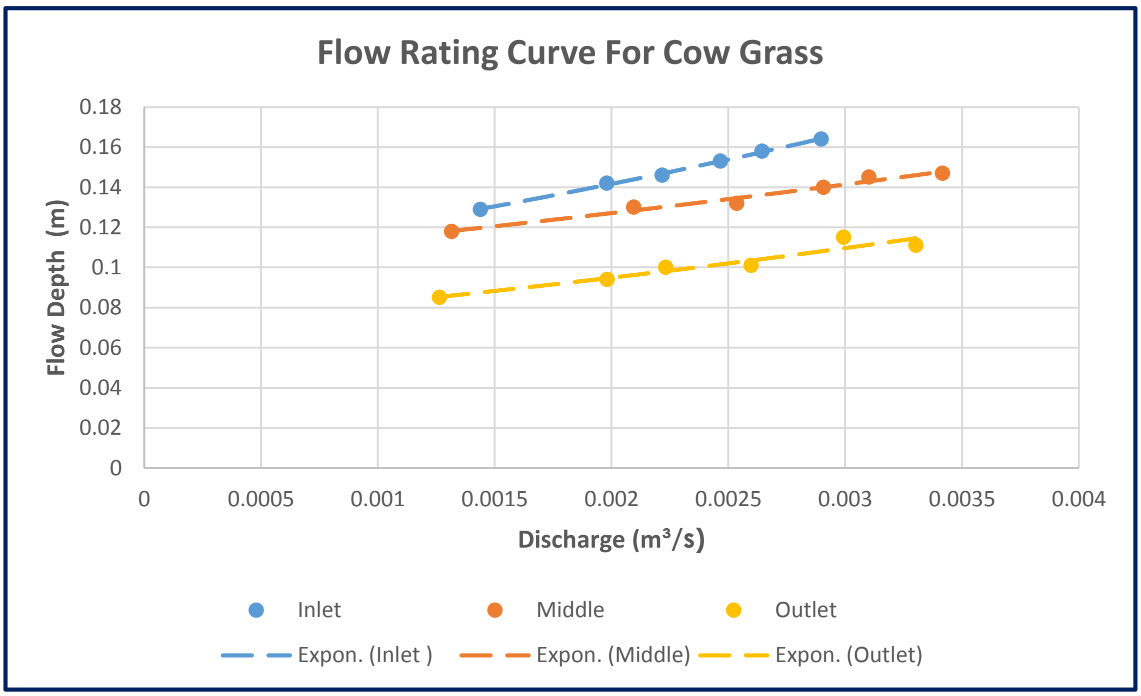

Figure 4.2: Flow rating curve graph for Cow grass

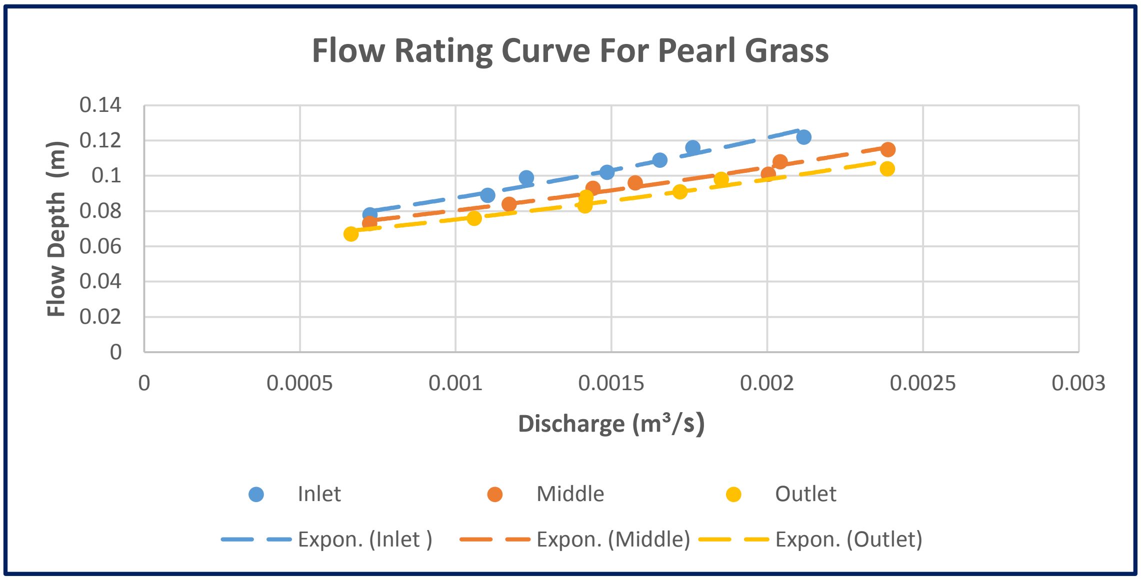

Figure 4.3: Flow rating curve graph for Pearl grass

The behavior of higher height of grass give more resistance to water flow per unit time is further supported by the result of Pearl grass (37cm) whereby at 0.12m flow depth, it yielded 0.0024m^3/s which nearest value to 0.0025m^3/s of Japanese grass (39cm). As both height are nearly similar, the values obtained for the discharge are also nearly similar. Meanwhile, Cow grass discharge obtained was 0.0015m^3/s for similar flow depth. This indicated that non-consistency in discharge values may be resulted by the higher height of Cow grass during experimentation (83cm). This observation give a note to the author that constant vegetation height is required in the future research to make the comparison between three grasses will be more accurate in analysis.

Through these evaluation of flow rating curve of Japanese grass, Cow grass and Pearl grass, it is observable that all three grasses (Japanese grass, Cow grass and Pearl grass) behave normally like other leafy vegetation types that ever tested by previous researchers, where the previous findings concludes that in open channel infested by vegetation, water flow discharges increases as flow depth of the channel increases.

4.2 Relationship of Flow Depth with Manning's *n*

In Figure 4.4, the graph describes the behavior of Japanese grass. The behavior pattern shows that there are small decrement of Manning's value n when there is increment of flow depth. The Manning's equation however, is contradicting with this behavior whereby the equation of Manning's indicates that $Q = \frac{1}{n} A R^{2/3} S^{1/2}$ where, $A = bd$, and after rearranging the equation gives:-

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

Which, in above equation tells that, Manning's n is directly proportional to flow depth, d. In other words, when flow depth decreases, the value of Manning's n should be in the increasing manner. This behavior based on equation logic however denies the author finding (represented by the graph 'n-Y' curve) and also denies the findings found by Diaz (2005), Chen et.al. (2009) and Noor Aliza Ahmad et.al. (2011) that described that low Manning's value was obtained for higher depth of flow. Based on the logic of the equation and the evidence of the findings of previous researchers, the author concludes that error may encountered in his finding and previous researcher that should be revised in further research.

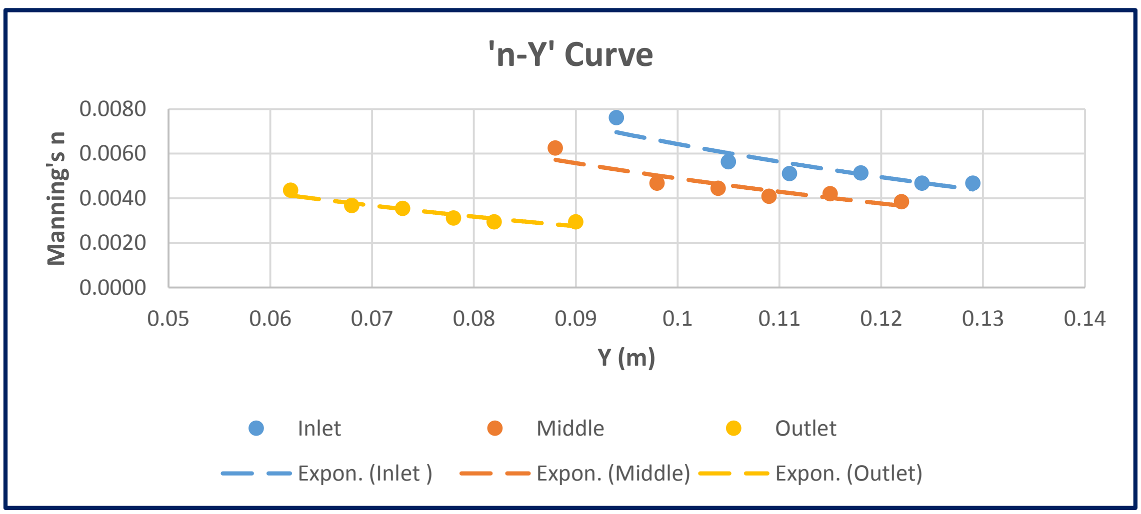

Figure 4.4: 'n-Y' curve for Japanese grass

Figure 4.5 also shown the similar pattern of relationship between flow depth and Manning's retardance coefficient, *n* for the Cow grass species. As the flow depth increases, the retardance coefficient, *n* decreases. As for comparison, the magnitude of retardance coefficient, *n* of Cow grass is bigger than that of Japanese grass. For example, for equal value of flow depth, Y = 0.13m (for middle section), Japanese grass recorded 0.004 in *n* value, while Cow grass recorded 0.008 is *n* value, which is half the magnitude. This is anticipated that the height of the Cow grass is again the cause of this difference in result.

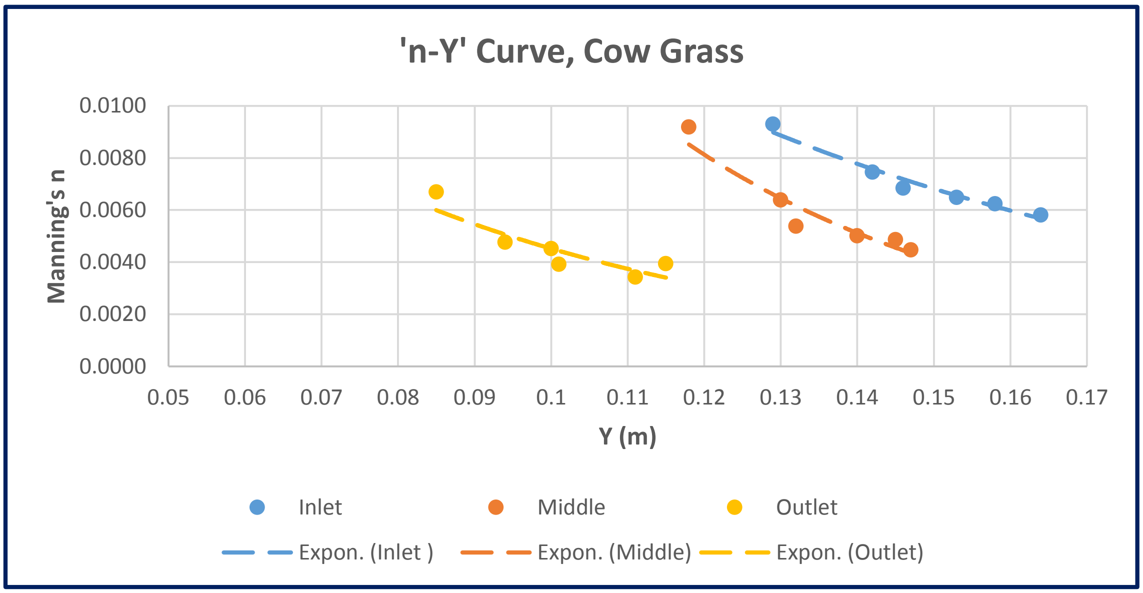

Figure 4.5: 'n-Y' curve for Cow grass

Meanwhile, figure 4.6 below shows the result of relationship of 'n-Y' of the Pearl grass whereby the similarity between the Pearl grass and Japanese grass is expected. In the figure 4.6 below, if the flow depth is extrapolated to 0.12m, the value of retardance coefficient *n* is 0.004, similar to that Japanese grass. This is the second observation and preliminary conclusion that height of the grass (vegetation) play and important roles in determining hydraulic characteristic in vegetated open channel flow experiment.

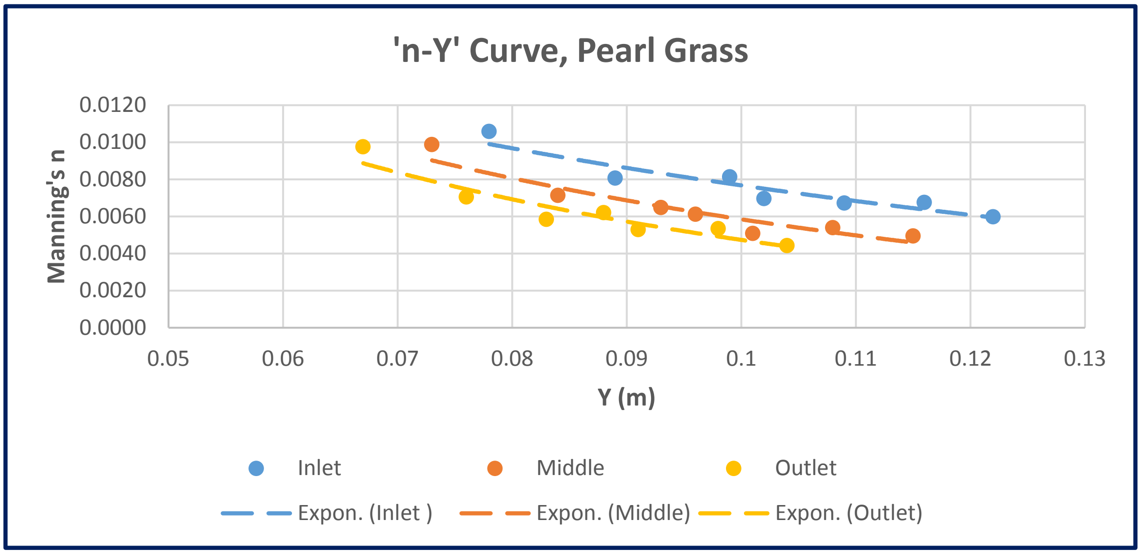

Figure 4.6: ‘n-Y’ curve for Pearl grass

4.3 Relationship of Velocity with Manning’s *n*

For relationship of Manning’s n and velocity shown in Figure 4.7 to Figure 4.9, the data plotted describes that retardance coefficient of the all three grasses decreases along the increases of velocity. This can be further emphasized by referring the following equations:-

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

Equally,

$$v = \frac{1}{n} R^{2/3} S^{1/2}$$

By restructuring the position of *v* and *n* in the equation,

$$n = \frac{1}{v} R^{2/3} S^{1/2}$$

The equation tells that *n* is a function of *v* when the values of *R* and *S* are left as constant. Therefore, it is clear that as velocity of the flow increases, the manning coefficient, *n* decreases. Furthermore, the graphs pattern also give an idea that, if extrapolated, or after further increment of velocity of the channel flow, the manning coefficient will be a constant value.

The figure 4.7 below shows the relationship of retardance coefficient, *n* with velocity of Japanese grass throughout the inlet, middle and outlet section of the rectangular flume. In the graph, the pattern tells that there are close relationship between those sections whereby the curve are close between each other, in the other words, the values of retardance coefficient, *n* for individual sections are quite similar for equal value of velocity.

This phenomenon gives an idea that there will be variance in magnitude of velocity in between the sections for an equal flume discharge, but for the effect of magnitude of equal velocity towards each individual sections will not give a significant variance for the retardance coefficient, *n* experienced by all sections.

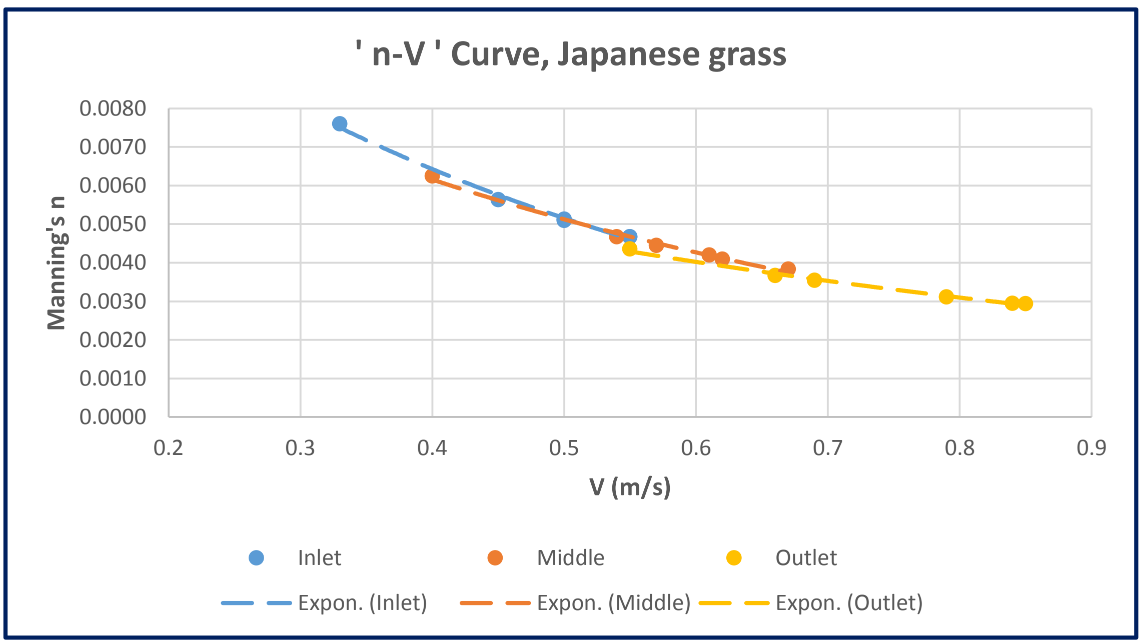

Figure 4.7: 'n-V' curve for Japanese grass

Figure 4.8 below shows the result for 'n-V' for Cow grass, whereby the pattern of increasing velocity resulted in the decreasing of retardance coefficient, n is observable. To understand the effect of height of 83cm of the Cow grass compared with the height of Japanese grass and Pearl grass of 39cm and 37cm respectively, the value of retardance coefficient for equal value of velocity is observed.

For value of velocity $0.4m^3/s$, the values of retardance coefficient are 0.006, 0.0083, and 0.008 for Japanese grass, Cow grass and Pearl grass respectively. This indicates that, the height of the Cow grass makes the value of the retardance coefficient higher than that of Japanese grass, however, the high value of Pearl grass, which, quite near to the value of Cow grass, indicates that, Pearl grass has a shape characteristics that helps it to gain higher retardance coefficient value, depend less on the height of its grass.

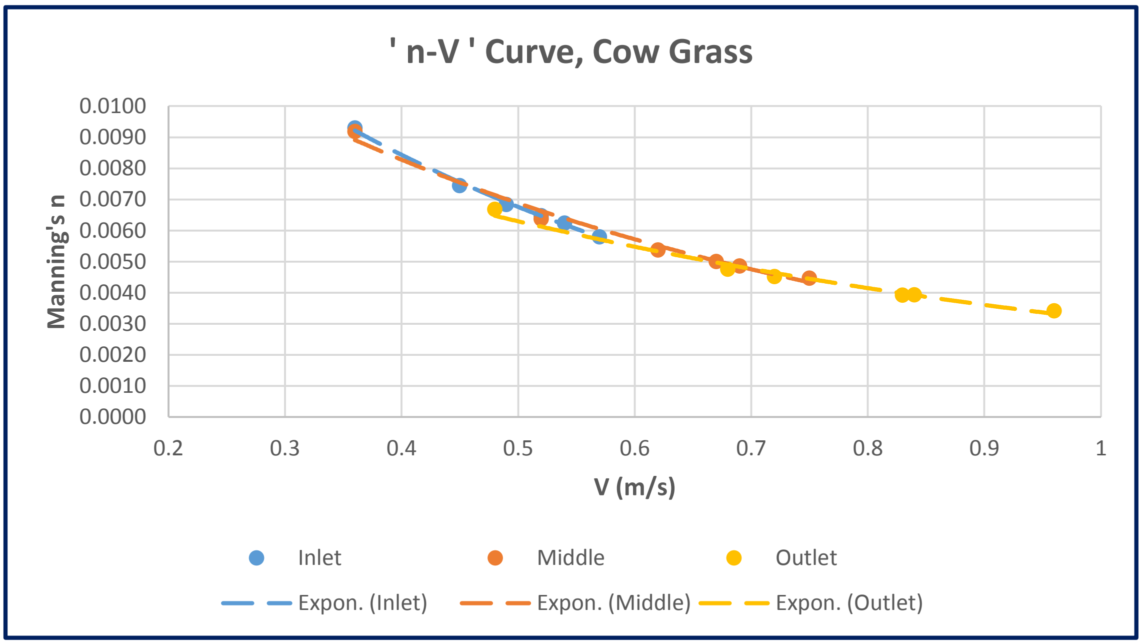

Figure 4.8: 'n-V' curve for Cow grass

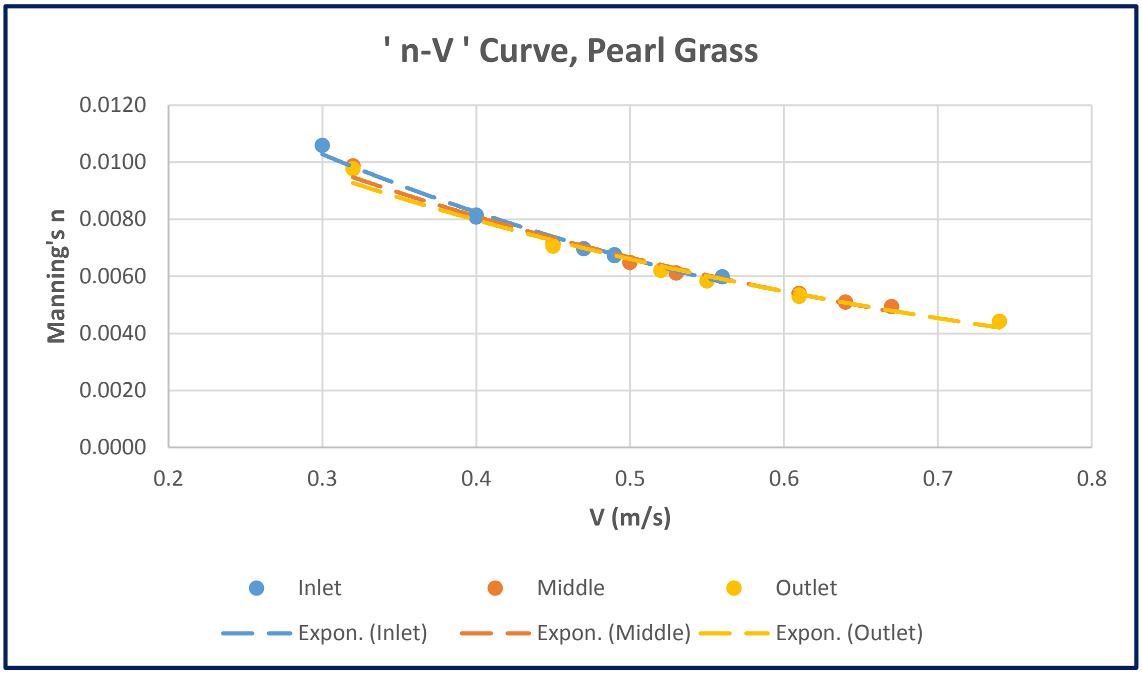

Figure 4.9: ‘n-V’ curve for Pearl grass

Figure 4.9 above shows the relationship between velocity and retardance coefficient for Pearl grass. From the lines, it is clearly seen that the velocity in any sections throughout the rectangular flume will result in consistent value of retardance coefficient.

Based on these observation of pattern, it can be concluded that every section of the open channel infested by the grass that experience equal magnitude of velocity, will exert the approximately same magnitude of retardance coefficient, *n*. In that case, it eventually gives an approximately same magnitude of drag towards the flow of water.

However, bear in mind that, the same or equal magnitude of velocity throughout the open channel flow, will hardly be achieved due to the effect of velocity damping as water travels from upstream to downstream.

4.4 Relationship of Discharge with Manning's *n*

Figure 4.10 to Figure 4.12 indicates the relationship between the Manning's n and flow discharge of the flume experiment. It can be observed that as the discharge value increases, the value of Manning's n is decreases, which is correlated to increment of flow depth as per Figure 4.4 to Figure 4.6 graphs. Equation of Manning also tells if the Manning's retardance coefficient *n* decreases, discharge *Q increases.* :-

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

As the flow depth, *d* increases, the value of the area increases, as *A* =*bd*. When the area, *A* increase the discharge is also will directly increase. Then, when we refer to the equation above, the higher in value of *Q* in left-hand side of the equation, will effect on lower value of Manning's retardance coefficient, *n* in the right-hand side.

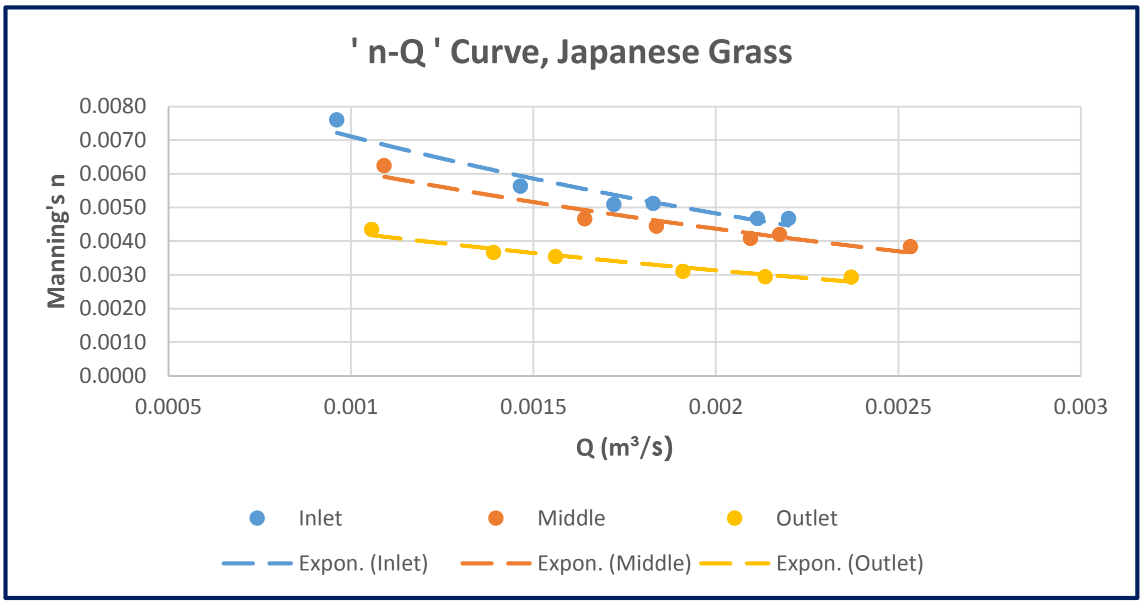

Figure 4.10: 'n-Q' curve for Japanese grass

In figure 4.10 also can be observed that the value of cross-sectional discharge are different between inlet, middle and outlet section. This is due to interrelated effect of flow depth, velocity that form the value of cross-sectional discharge. However, although this variation is occurring, the pattern and the behavior of the grass is kept the same, which is, increasing in discharge value, result in decreasing Manning's retardance coefficient value.

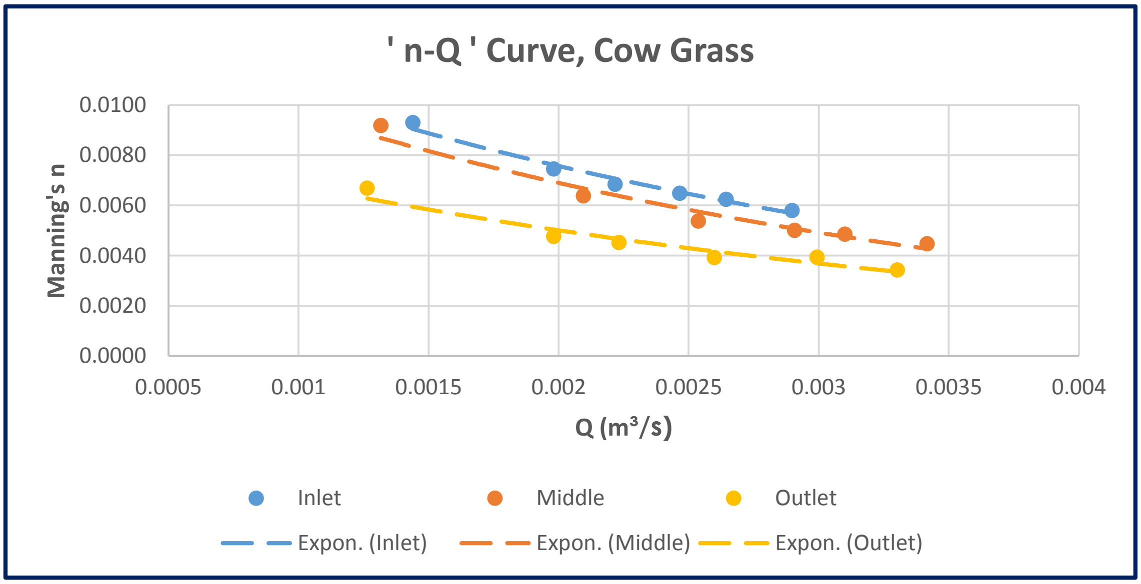

Figure 4.11: 'n-Q' curve for Cow grass

As for figure 4.11, the relationship between Manning's retardance coefficient, n and cross-sectional discharge, Q for Cow grass is shown. In the graph, the cross-sectional discharge applied is ranging from 0.00125 m^3/s to 0.0034m^3/s, which gave a range of Manning's coefficient of 0.003 to 0.0095.

As for comparison, the range of cross-sectional discharge that Japanese grass yielded was in between 0.0009m^3/s to 0.0026m^3/s. This range of value then resulted in Manning's retardance value in between 0.003 to 0.0075. Comparatively, the Cow grass yielded more retardance than the Japanese grass. This is another partial conclusion that indicates the significant effect of height of Cow grass to the entire experiment.

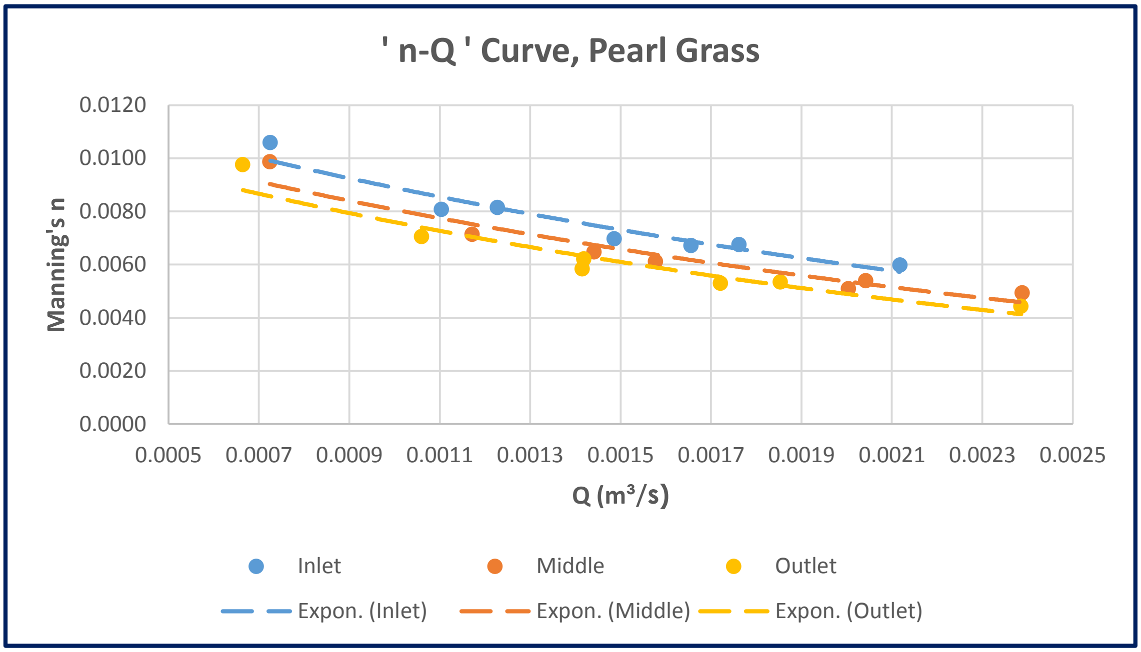

Figure 4.12: ‘n-Q’ curve for Pearl grass

Figure 4.12 above shows the relationship of Pearl grass in term of discharge – retardance coefficient. The values of cross-sectional discharge are in between $0.0006m^3/s$ to $0.0024m^3/s$ and the range of the Manning’s retardance coefficient value are in between 0.004 to 0.015, which, in comparison with Japanese grass and Cow grass, the result of Pearl grass on the retarding performance is the best.

Based on these findings of the relationship of cross-sectional discharge and Manning’s retardance coefficient, it can be concluded that Pearl grass is the best choice of vegetation to act as the retarder of the water flow in the open channel flow that use the approach of infesting the channel with natural vegetation.

However, collectively, the performance of the Cow grass based on the result of relationship of ‘Flow Rating Curve’, ‘n-Y Curve’, ‘n-V Curve’ indicate that Cow grass is the overall best of choice to be used in the vegetated open channel flow system.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Research Conclusion

Through the experiment, the author manage to determine the velocity and discharge of three types of studied vegetation in open channel flow using proper hydraulics instrument. With the reliable data, the relationship of the presence of vegetation in the open-channel flow were successfully determined.

By comparison of graphs of depth flow characteristic, velocity characteristic, and discharge characteristic over the computed Manning's *n* values, it can be concluded that characteristic of Japanese grass, Cow grass and Pearl grass are found to behave in similar pattern.

The finding emphasis that, if there are an increase in channel discharge, there will be an increase in the flow depth. Besides, as flow depth increases, velocity will also increases. Eventually, when the velocity increases, manning's retardance coefficient will decreases and play minimal effect on impeding the channel flow.

These findings were not conflicting the finding of previous researchers on the effect of the leafy vegetation towards the open channel flow, but it does support and complement the theory. The difference was just the species of the leafy vegetation used in this experiment. However, benefit from this experiment was, it is clear to the author that most of the leafy vegetation – regardless of the species, share the same hydraulic characteristic, as far as the research scope is concerned.

All in all, after evaluating the graphs, it is come into conclusion that in all circumstances (flow depth, velocity and discharge), Cow grass will yield higher manning's value. Higher value of manning's value *n* means the grass will impede the water flow better than Pearl grass and Japanese grass. Therefore, it can be concluded that Cow grass is the most suitable grass to be planted in open channel flow especially in vegetated open channel system.

5.2 Recommendation for Future Study

Several recommendations can be proposed based on the conditions of the vegetation upon the experimentation. The present study only focus on the several parameters that affect the retardancy of vegetation towards open channel flow such as species of vegetation, discharge and velocity.

Therefore, it is proposed to study other parameters including the effect of vegetation density, effect of several height difference of vegetation, and also the effect when the slope of the channel varies. Vegetation condition when exposed to these kind of parameters might results with different behavior than present results.

The author found that through this flume based experiment, the author are only comparing the result of his experiment with previous researchers that mostly worked with different species of vegetation. There are limited resources that provide site experiment data on the vegetation that author worked on. This constraint limiting author effort to verify the validness of flume experimental data obtained. Therefore, it is proposed to simultaneously working on flume experiment data collection and site experiment data collection under one research topic to fully understand and verify the theory using these kind of vegetation species.

Lastly, it is a concern for the author that the slope of all the grasses (vegetation) were not consistent for all (1:1000) as they was supposed to be. Although previous researchers found that effect of slope on the channel characteristic is minimal, but to emphasize the effect of the parameters studied, the unrelated parameters should be made into constant whenever possible.

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