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DETERMINATION OF FLOW CHARACTERISTICS IN THE VEGETATED COMPOUND CHANNELS

(PENENTUAN CIRI-CIRI ALIRAN DI DALAM SALURAN MAJMUK YANG BERTUMBUHAN)

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DETERMINATION OF FLOW CHARACTERISTICS IN THE VEGETATED COMPOUND CHANNELS

(Keywords: compound channels, overbank flow, vegetation, stage-discharge, velocity, roughness)

Floods are frequent events occur in the Asia, Europe and many parts of the world. The recent floods in Malaysia such as in the states of Johor, Pahang, Kelantan, Terengganu and Kedah resulted huge damages to buildings, infrastructures, crops and also human suffering. In overbank flow conditions, a large momentum exchange takes place between main channel and floodplain flows. An experimental study on the effects of submerged vegetation on floodplain and one-line emergent vegetation along the edge of floodplain on the river hydraulics during flooding is carried out in the laboratory. It is important to understand the hydraulic processes in order to maintain the rivers as safe and environmental-friendly. The results on stage-discharge relationship, longitudinal velocity profiles and roughness parameter for inbank and overbank flows in a straight compound channel are presented in this report. It is found that the vegetation influences stage-discharge where retardation of flow takes place. The high velocity zone is observed to be in main channel and less fluid momentum transfer takes place with the presence of vegetation. Also, channel roughness increases for vegetated floodplain.

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PENENTUAN CIRI-CIRI ALIRAN DI DALAM SALURAN MAJMUK YANG BERTUMBUHAN

(Kata kunci: saluran majmuk, aliran limpahan, tumbuh-tumbuhan, aras air – kadar alir, halaju, kekasaran)

Banjir kerap berlaku di benua Asia, Eropah dan banyak tempat di seluruh dunia. Kejadian banjir terkini di Malaysia seperti di negeri-negeri Johor, Pahang, Kelantan, Terengganu dan Kedah telah memusnahkan bangunan, infrastruktur, tanam-tanaman, dan kesengsaraan kepada manusia. Ketika limpahan air berlaku, pertukaran momentum telah berlaku di antara aliran di dalam saluran utama dan dataran banjir. Satu kajian makmal ke atas kesan-kesan tumbuh-tumbuhan di atas dataran banjir ke atas hidraulik saluran terbuka telah dijalankan. Adalah penting untuk memahami proses-proses hidraulik untuk kelestarian sungai. Keputusan hubungan aras air terhadap kadar alir, profil halaju dan parameter kekasaran untuk aliran di dalam saluran yang lurus dipersembahkan di dalam lapuran ini. Kajian mendapati tumbuh-tumbuhan telah memperlahankan aliran dan meningkatkan aras air di dalam saluran. Zon halaju yang tinggi berada di dalam saluran utama dan pemindahan momentum dihalang oleh kehadiran tumbuh-tumbuhan. Didapati juga bahawa pekali kekasaran meningkat untuk dataran banjir yang bertumbuhan.

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NOMENCLATURE

A	=	Area of flow
AR	=	Aspect ratio = B/H
B	=	Width of the main channel
D	=	Hydraulic depth
d	=	Diameter of tree
Dr	=	Relative depth = h / H (Floodplain depth / main channel depth
Fr	=	Froude number
g	=	gravitational acceleration
H	=	Main channel depth
h	=	Depth on floodplain
N	=	Vegetation density
n'	=	Average vegetation density
n	=	Manning's roughness
P	=	Wetted perimeter
Q	=	Discharge
R	=	Hydraulic radius
S_w	=	Slope of water surface

S_f	=	Energy gradient
S_o	=	Channel bed slope
T	=	Top width of channel
U	=	Measured longitudinal velocity
Um	=	Cross-sectional mean velocity
U/Um	=	Normalized velocity
μ	=	Fluid dynamic viscosity
y_o	=	Normal flow depth
y_c	=	Critical flow depth
y	=	Measured flow depth
ρ	=	Fluid density

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Flooding are becoming common events in Malaysia and many parts in the world. Meteorological change due to global warming has been identified as one of the contributing factors. Floods cause loss of life, human suffering and damages to buildings, roads, bridges and also crops. The latest major floods occurred in the states such as Johor, Pahang, Kelantan, Terengganu and Kedah. It was estimated damages from floods in December 2006 and January 2007 were at more than RM 100 millions (USD 28.42 millions). The floods, the worst in decades, inundated thousands of homes and businesses mostly in Malaysia's southern Johor state, where the number of evacuees peaked at 90,000. The government had also estimated that floods in central and western states had cost farmers and livestock breeders an estimated RM 36.36 million in losses *(http://news.yahoo.com, 11 January 2007).*

A compound channel consists of a main channel and one or two floodplains. It is one the interesting subjects being studied in the field of hydraulic engineering. Riparian vegetation has become an integral component of flood channel. Emergent vegetation along river banks is important for erosion control and habitat creation. Vegetation generally increases the flow resistance, and changes velocity distribution. The effects of vegetation on flow resistance in open channels have been investigated. Jang and Shimizu (2007) experimentally studied the influence of riparian vegetations on a braided erodible river. It was found out that behaviour of vegetated rivers is complex and its influence is not yet fully known. In overbank flow during flooding, the interaction between the floodplains and main mobile bed channel is considerably more complex than for non-erodible channel (Cao *et al*., 2007).

Flow in open channel can be classified as inbank, bankfull and overbank. Their flow behaviours are different. Many open channel hydraulics textbooks discussed the characteristics of inbank and bankfull flows (Chow, 1959; French, 1985; Chanson, 2004). The hydraulic of overbank flow in open channel is different from the other two flow conditions. The velocity gradient between main channel and floodplain in straight compound channels results in lateral mass and momentum transfer mechanism.

1.2 Statement of problem

The most notable feature of the relationships is the discontinuity at bankfull, with a reduction in discharge as flow depth rises just above the bankfull level. If the overbank flow depth continues to rise, floodplain discharge and velocity will increase rapidly until equalization of main channel and floodplain discharge and velocity occurs. This leads to decrease of momentum transfer from main channel to floodplain and may lead to a reversal in direction of momentum transfer at larger flow depths.

The flow behaviors in rivers are different for non-vegetated and vegetated floodplains. Thus, it is interesting to study flood hydraulics in rivers with no vegetation and vegetation on their floodplains. The results of study can enhance the understanding in the river management.

1.3 Scope of work

A study on flood hydraulics in a straight non-mobile bed channel has been carried out in the Hydraulics Laboratory, Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM), Skudai. The aim of the research is to enhance the knowledge on the river hydraulics due to the presence of riparian vegetations in a compound channel.

The project focuses on the characteristics of overbank flow in a straight compound channel. An existing mobile bed model tank is used in the study. Modifications are made in the working section to provide a main channel with single floodplain and to stimulate vegetations along the edge of the floodplain. The study is divided into three main cases: smooth floodplain, submerged vegetation on floodplain and combined submerged and emergent vegetations on floodplain. The stage-discharge relationship, velocity distribution and global Manning's n in the channel are studied.

1.4 Objectives of study

The implementation of laboratory experimental study is to investigate the stage-discharge relationship and flow characteristics due to the floodplain vegetations. The objectives of the study are:

i. To determine the relationship between stage-discharge and flow resistance (Manning's n) in a straight compound channel with non-vegetated (smooth) floodplain, floodplain with submerged vegetation and combination of submerged and emergent one-line vegetation,
ii. and to determine the streamwise (longitudinal) velocity distribution in a compound channel for non-vegetated and vegetated floodplain,

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The need for flood control has been provided through the creation of compound channel. In many areas, flooding cannot be allowed because of infrastructure and also the channel cannot be oversized. Effect from enlargement size of the channel would lead to channel instabilities, erosion and sedimentation problem. Retention time for the flow might be reduced and thus will accelerate the flow due to reduced roughness and channel length. A compound channel is an effective low–cost solution. In general, it will provide adequate flood management allowing for morphological and hydraulic characteristics of the river during low flow.

Compound channel is a combination of elementary sections. Usually, the combination of elementary section would be either in trapezium and rectangular section or double rectangular and double trapezoidal section. The channel can be divided into three parts. The first section is inbank flow, where the water flows in a main channel. After the main channel is full with water, the condition is said to be bank full. The last section, where the flow start to abundant the floodplain, the stage is said to be overbank (Figure 2.1).

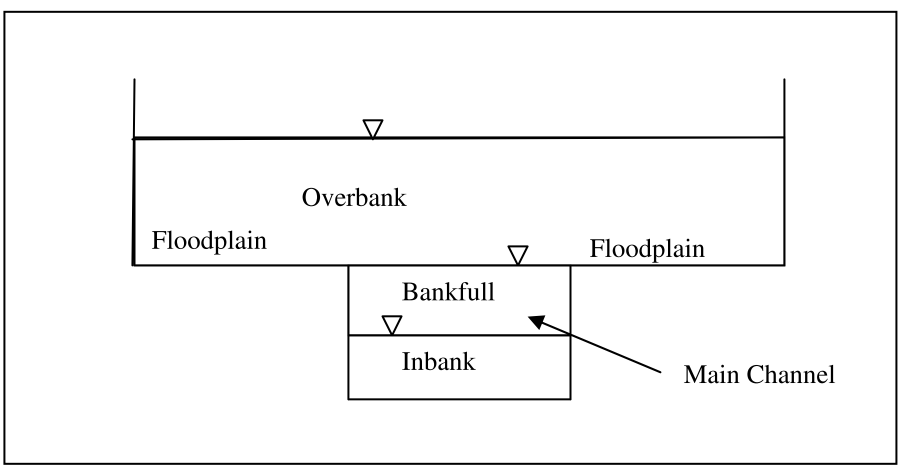

Figure 2.1: Cross section of a two- stage channel

2.2 Types of flow

Open channel flow can be classified into many types and described in various ways. The following classification is made according to the change in flow depth with respect to time and space. There are two types of flow which are steady flow and unsteady flow. Flow in open channel is said to be steady if the depth of flow does not change or if it can be assumed to be constant during the time interval under consideration. The flow is unsteady if the depth changes with time. In most open-channel problems, it is necessary to study flow characteristics only under steady conditions. However the change in flow condition with respect to time is of major concern, the flow should be treated as unsteady (Chow, 1959).

Most of the theoretical calculations in open channel are conducted under uniform flow. Achieving uniform flow for each experiment also allows fairness in initial condition, so that data can be compared. Open channel flow is said to be uniform if the depth of flow is the same at every section of the channel (Chow, 1959; French, 1985). Uniform flow can be in 2 conditions that are steady or unsteady, depending on whether or not the depth changes with time. Steady uniform flow is the fundamental type of flow treated in open channel hydraulics. The depth of the flow does not change during the time interval under consideration (Figure 2.2). The establishment of unsteady uniform flow would require that water surface fluctuate from time to time while remaining parallel to the channel bottom. The term "uniform flow" is, therefore, used here after to refer only to steady uniform flow (Chow, 1959).

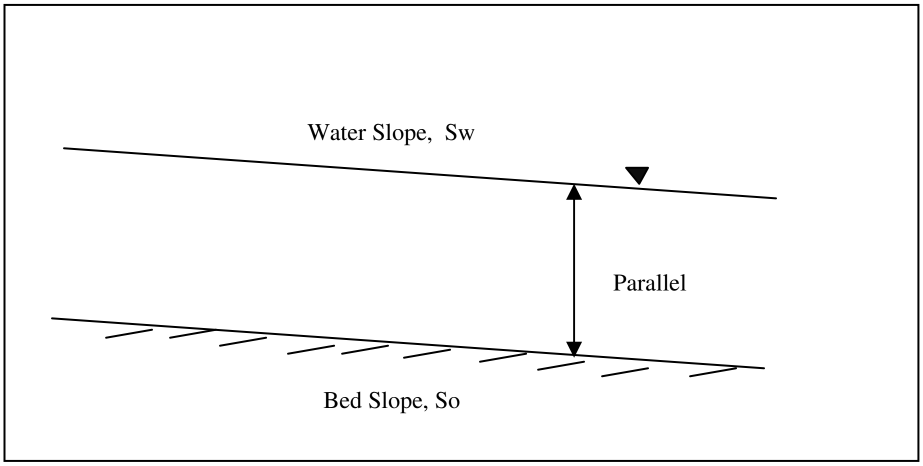

Figure 2.2: The establishment of uniform flow in open channel

2.3 Primary flow

Primary flow may be supercritical, critical or subcritical. The Froude number is a useful criterion of the type of flow present in an open channel. The Froude number is equal to 1.0 for critical flow, more than 1.0 for supercritical and less than 1.0 for subcritical flow (Chow, 1959). Subcritical flow is the most common type in alluvial rivers apart from in youthful stages where velocity may be much greater. Subcritical flow is tranquil or streaming and is characterized as slow and deep fluid motion (French, 1985; Chow, 1959). Disturbance to subcritical flow are propagated both upstream and downstream (Chow, 1959).

2.4 Overbank flow

Overbank flow generally occurs when a river is in flood, this is when most erosion occurs and therefore it has been used in several mobile bed experiments

(Thornton *et al.* 2000). Many researchers have found that the interface between the water flowing in the floodplain and that in the main channel to be complicated with secondary flows and turbulence. At this interface are a high horizontal shear layer, stream wise and vertical vortices, velocity retardation and acceleration and momentum transfer, (Shiono and Muto, 1998). It has been found that water flowing from the floodplain to the main channel or vice versa can affect the sediment transport for the channel this interaction is most efficient when the ratio of floodplain depth to channel depth (Relative Depth, Dr) is 0.1 to 0.3 (Knight and Shiono, 1996).

However, by increasing relative depth, bulge in the contours in the shear layer will be seen. This is proven by (Sun and Shiono, 2009) for one-line emergent vegetation along the edge of floodplain. This phenomenon is typical for a deep water depth of compound channel flows. As the water depth increases, the bulging phenomenon will becomes more and more pronounced (Figure 2.3) as a result of secondary current and high fluid momentum transfer.

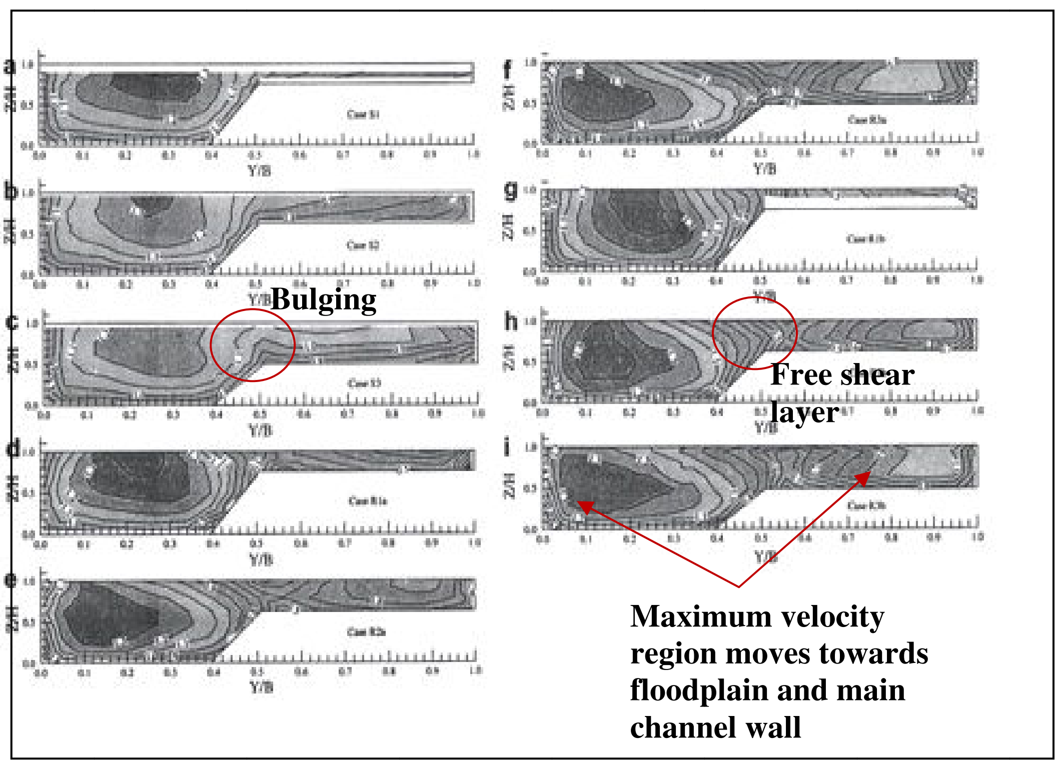

Figure 2.3: Bulging phenomenon and free shear layer (Sun and Shiono, 2009)

2.5 Compound channels with vegetated floodplain

According to Naot *et al.* (1996), the flow pattern for a channel compounded with a vegetated floodplain varies depending on the vegetation density. The variation is caused by the location, type and density vegetation used. Different vegetation densities will result to different behaviors of flow. Calculations for a rectangular vegetated floodplain are as given in Equation (2.1). The experiments with a non-dimensional vegetation density will give a result, where if the vegetation density increases, the flow in the floodplain area is considerably attenuated.

$$N = 100\ n'\ HD \tag{2.1}$$

in which N is vegetation density, n' is average vegetation density (rods per area unit), H is depth of the channels and D is average vegetation diameter.

The secondary current at the main channel are augmented with increasing vegetation density in the floodplain, resulting in a shift of the streamwise velocity maximum away from the vegetated domain as shown in Figure 2.4 with different values of N but at the same depth. The energy of turbulence is shown in Figure 2.5. It is assumed, by introducing vegetation into turbulence flow will result to additional production of turbulence energy and with increasing vegetation density, the energy at vegetated floodplain is gradually attenuated *(*Shimizu and Tsujimoto, 1995*).*

For $N > 16$, a domain of homogenous turbulence develops until at $N > 32$, it occupies almost all the vegetated floodplain. In addition, towards the downstream end of the calculations, the flow becomes fully developed, and. At the same time, with increasing vegetation density, $N > 8$ the intensity and dimension of the turbulence energy peak, developing at the free shear layer at the floodplain threshold increase (Naot *et al.*, 1996).

N = 2
4
8
16
32

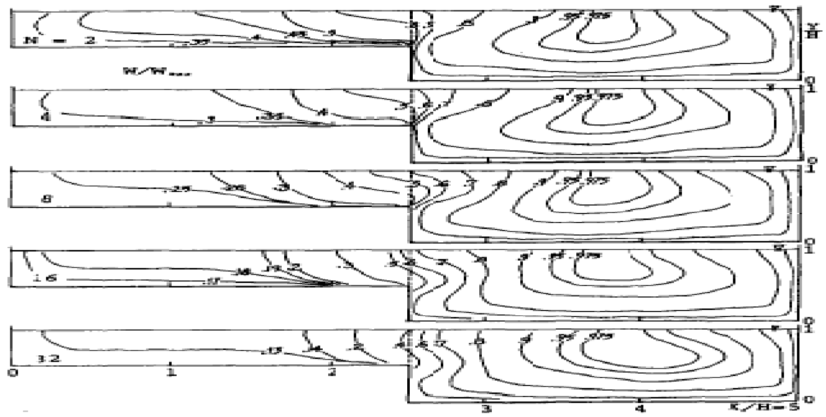

Figure 2.4: Calculated velocity contours

N = 2
4
8
16
32

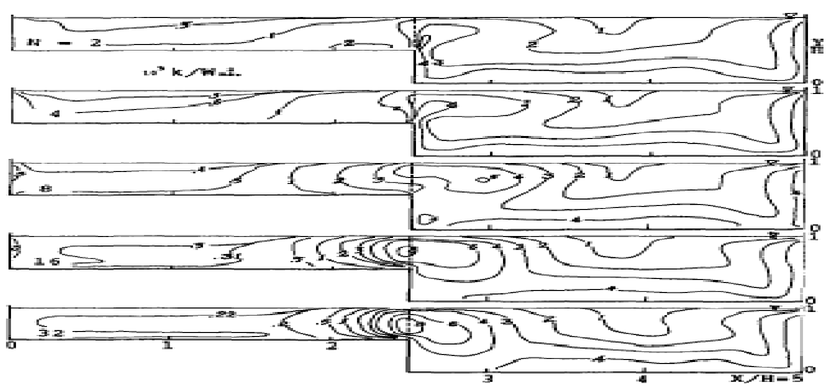

Figure 2.5: Calculated turbulence energy contours

2.6 Flow velocity

The velocity in channel usually depends on the presence of obstruction in the channel. The existence of vegetation on surface on the channel such on floodplain, corner or at the base of main channel, will cause water near it to move slowly as the density of vegetation increases. However, as the relative depth or the water level above the floodplain increases further, the interaction effect becomes less because there is likely to be less difference between main channel and floodplain velocities, (Hin Joo *et al*., 2007).

2.7 Secondary flow

Secondary flow is defined as a flow normal to that in the longitudinal flow direction. The most significance differences in the flow characteristics from those in a straight compound channel are the generation mechanism of secondary flow and turbulence mixing (Shiono and Muto, 1998). Secondary currents, distort the longitudinal velocity pattern and boundary shear stress distribution and are therefore important as they affect the flow resistance (Zulhilmi and Shiono, 2006). Secondary flow can be classified in two kinds. The first kind is driven by turbulence and the second one is driven by the geometry of the channel. Secondary flow for overbank flow structure is controlled by the flow interaction in the cross-over section, the flow is said to be different from those in a meandering channel because of the interaction between the floodplain flow and the main channel flow. Secondary flow is highly responsible for bank erosion process (Zulhilmi and Shiono, 2006). Figure 2.6 shows typical secondary flow in a compound channel.

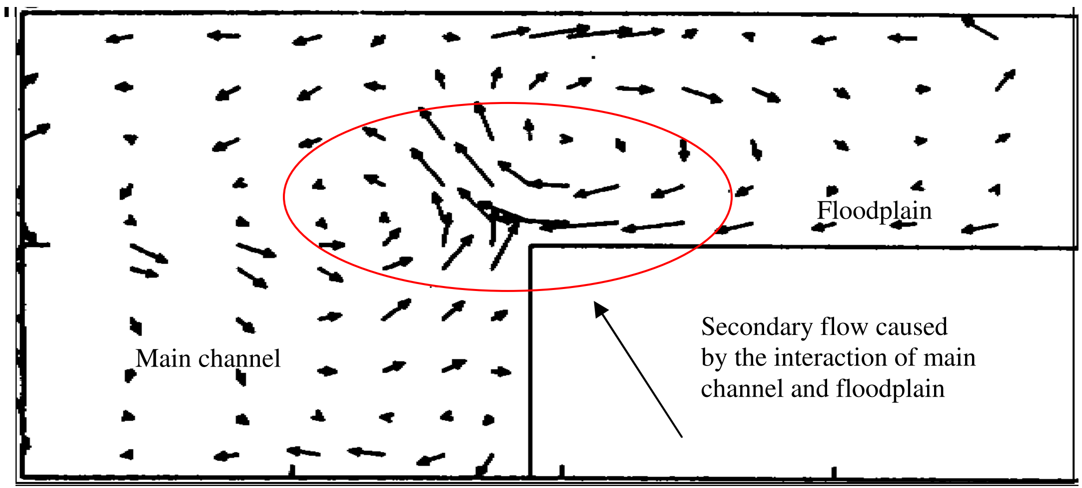

Figure 2.6: Secondary Flow in Compound Channels

2.8 Manning's roughness coefficient

The roughness of the main channel is determined by measuring the velocity of water flowing along the main channel for several elevations but not overflowing the floodplain. From the repetition of water, the Manning's roughness coefficient and discharge can be determined through the Manning's equation. All experiments are conducted in uniform flow condition. (Hin Joo *et al.,* 2007)

$$n = \frac{AR^{\frac{2}{3}}S^{\frac{1}{2}}}{Q} \qquad (2.2)$$

where A is wetted area, R is hydraulic radius, Q is discharge, S is channel bed slope and n is Manning's n roughness coefficient.

2.8.1 Factors affecting Manning's roughness coefficient

There are many factors that contribute to the flow behavior in open channels. The followings are factors that have been defined as the primary causes to the changes.

i. Surface Roughness: the surface roughness is represented by the size and shape of the grains of the material forming the wetted perimeter and producing a retarding effect on the flow.

ii. Vegetation: vegetation may be regarded as a kind of surface roughness, but it also markedly reduces the capacity of the channel and retards the flow. This effect depends mainly on height, density, distribution, and type of vegetation.

iii. Channel irregularity: channel irregularity comprises of irregularities in wetted perimeters and variations in cross section, size and shape along the channel length. In natural channels, the irregularities are presence of sand bars, sand waves, ridges and depressions, and holes and humps on the channel bed. These irregularities definitely introduce roughness and other factors.

iv. Channel alignment: a smooth curvature with large radius will give a relatively low value of Manning's n; whereas a sharp curvature with severe meandering will increase the n value.

v. Size and shape of channel: an increase in hydraulics radius, R may either increase or decrease the n value, depending on the condition of the channel.

Figure 2.7 shows the effect of vegetation on the Manning's n value at various flow depths.

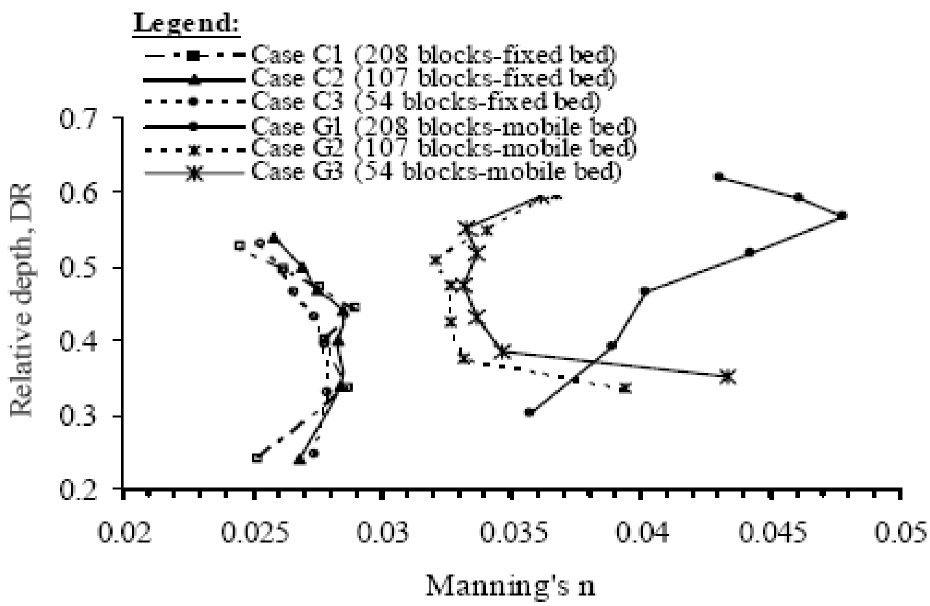

Figure 2.7: Manning's n with difference case of resistance (Zulhilmi and Shiono, 2006).

2.8.2 Effect of stage-discharge on *n* value

The n value for most streams becomes smaller with increase in stage and discharge. In shallow water, the irregularities of the channel bottom are exposed and their effects become pronounced. However, the n value may be large at high stages if the bank is rough and grassy. When the discharge is too high, the stream may overflow its bank and the portion of the flow will be along the floodplain. The n value of the floodplain is generally larger than that of the main channel. Its magnitude depends on the surface condition or vegetation. If bed and banks of the channel are equally smooth and regular and the bottom slope is uniform, the value of n may remain constant at all stages. A constant n is usually assumed in the flow computation. This happens mostly in artificial channels. On floodplain, the value of n usually varies with the depth of vegetation submergence at low stages. Figure 2.8 shows the effect on Manning's roughness coefficient due to the increment of vegetation density.

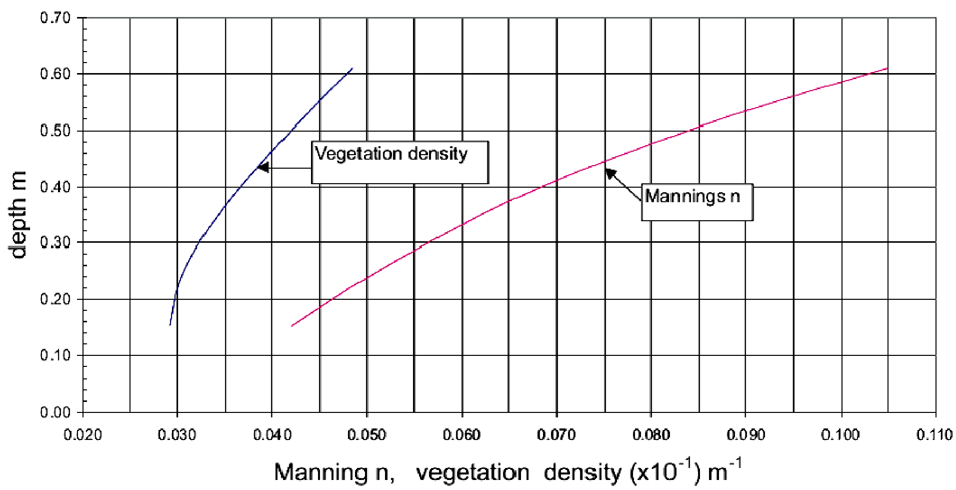

Figure 2.8: Relationship between vegetation density, flow depth and Manning's n

2.8.3 Effect of tree spacing and density

Vegetations such as trees and shrubs commonly present along the banks of rivers and the edge of floodplain, both naturally or by design for erosion prevention and landscaping. For example, according to Malaysian Palm Oil Board, MPOB (2008), the average spacing between trees is about 8 m with the mean tree diameter of 0.55 m. Due to less information on knowledge regarding with effect of such marginal vegetation on flow structure and flow resistance has led researchers to study them

The drag force and momentum transfer in the channel depend on the vegetation density. The effect of momentum transfer and free shear layer seems to be more pronounced and cleared with the presence of more quantities of rod along the edge of floodplain (Sun and Shiono, 2009). A ratio between floodplain and main channel flows has been found from overbank experiments with vegetated floodplains (Thornton *et al,* 2000). The experiments have proven that this effect is significant for small relative depth where high vegetation reduces the velocity on the floodplain. The ratio between the floodplain and the main channel flows decreases when vegetation density is high. However, less vegetation will cause the ratio of flows to increase.

By introducing roughness on the floodplain will increase the Manning's n value. The value will keep increasing until the vegetation is fully submerged. Water level in the channel will further increase. According to Zulhilmi and Shiono (2006), high vegetation density will increase the stage-discharge in compound channels (Figure 2.9).

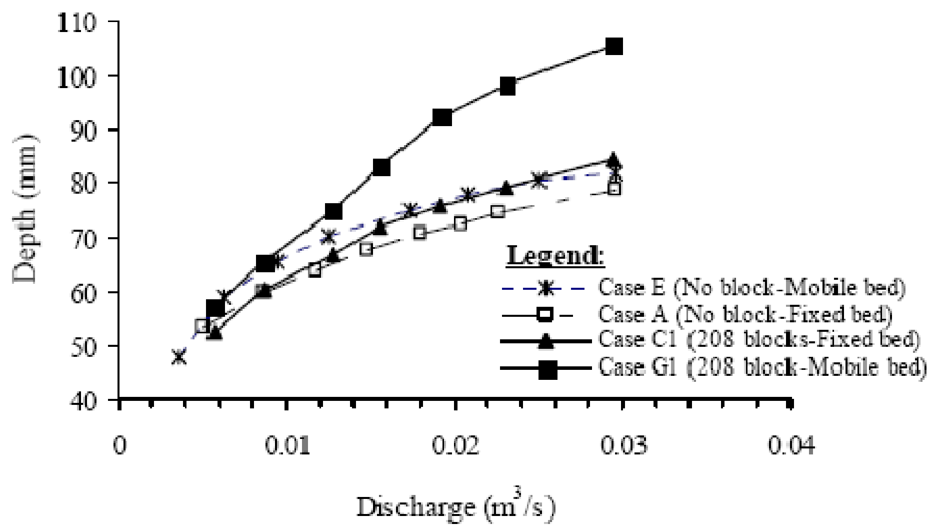

Figure 2.9: Stage-discharge relationship for different vegetation densities on floodplain (Zulhilmi and Shiono, 2006).

2.8.4 Density and spacing of vegetation

Streambank erosion is strongly influenced by the density and type of riparian vegetation. Re-vegetation of unstable streambanks and maintaining healthy riparian vegetation is a relatively cheap way of providing a solution to streambank erosion and stability in the longer term.

However, many river engineers commonly disagree with dense bankside vegetation regarding it as a dis-benefit. Their reason is although it increases roughness and gives extra flow resistance, it in turn reduces the capacity leading to flooding. Bank vegetation is therefore often 'harvested' or 'cleared and snagged'. Additionally, trees and shrubs may generate serious bank scour through the local acceleration of flow around their trunks, in this regard, the density of vegetation is probably an important factor" (Thornton *et al*., 1990).

2.8.5 Vegetation providing roughness and flow resistance

The roughness elements of vegetation implies that the vegetation acts as a kind of a damper or buffer zone, reducing the velocity of the water flowing through it by forcing it around the complexities of trunks, brunches and exposed roots. The State of Queensland Department of Natural Resources and Mines (2002) has found that "effective strategies for combating scour are generally aimed at reducing flow speed through re-vegetation and in some cases through strategic bank or channel work". Other sources advice that plants on the bank will slow down the water flow around that area and this will reduce scour.

2.8.6 Stage – discharge relationship

Conditions in a natural river are rarely stable for any length of time and thus the stage – discharge relationship must be checked regularly especially after flood flows. The stage – discharge relationship can be represented by in three ways, as a graphical plot of stage versus discharge (the rating curve), in tabular form (rating table), and as a mathematical equation, In a vegetated compound channel (or rough plain), there are factors which affect the discharge capacity. The factors are:

i. Relative depth of the floodplain flow to the main channel,
ii. Roughness of the floodplain compared with the roughness of the main channel,
iii. Ratio of the floodplain width to the main channel width,
iv. The number of floodplain,
v. The side slope of main channel, and
vi. Aspect ratio of the main channel.

In determining the discharge capacity, viscosity is not a major factor to take into account. The major factor is said to be the depth of flow on the flood plains relative to that in the main channel. When the water level arises and inundated floodplain, the water on the flood plain will be slower than in the main channel. This will cause interference between the flow in main channel and from floodplain. Maximum reduction from the interference is so called "discharge deficit". The degrees of interference between the floodplain flow and the main channel show different trends as the flow depth varies. Extra roughness on the floodplain will tend to have a lower discharge. Because of the lower discharge capacity from the floodplain, it will retard the overall discharge. Usually smooth channel will able to carry a higher discharge capacity but there is a point where at a certain depth, the discharge capacities in main channel and floodplain are equal as the flow depth further increases. As the water depth on floodplain is further increased, the effect of interaction will become less. Discharge usually will become higher as the width of the floodplain increase (Hin Joo *et al*., 2008)

2.9 Physical model

Physical model is a model which implies a similar condition as at site. This model is scaled down into a size which is easy to handle and for a research purpose. Recommended scales for river models are 1/100 to 1/1000 for horizontal dimensions and 1/20 to 1/100 for vertical dimensions *(*Raghunath, 1967*)*. For river models that involve the study of scour and sediment transport, the change in water surface is gradual and thus gravity has little effect on flow compared to friction. Similitude to the field for studies of erosion and scour in open channel moveable bed models cannot be attained analytically and is thus a process of trial and error requiring vast experiment and judgments. Accurate data is required.

River models are often vertically distorted or also called as "distorted model" to obtain objective such as accommodating the models in the available space and to develop sufficient tractive cause to develop tractive movements in mobile bed models. Distortion of river models usually varies from two to ten. Time scale is also distorted compared to field conditions, this is achieved by increasing discharge for a relatively short time. There are various formulas available for consideration of these distortions such as that by Einstein and Ning Chien for timescale. Material forming the model may also not be to scale; the main features in selecting a material are availability, cost and properties (Raghunath, 1967).

There are many formulas now available for calculating various aspects of flow behavior or sediments transport, this has been compared and tested by various researchers to see how they are actually applied to the field and laboratory and what their limitations are. Most formulae are obtained by a combination of a physical reasoning. For a fixed bed channel, parameter is needed to calculate the boundary shear stress, drag coefficient or a friction factor. As a dimensional analysis, it has been practice to measure a wide variety of data. In order to achieve the analysis, a set of parameters will be needed. In floodplain analysis, parameters that can be measured will consist of velocity (V), aspect ratio of the main channel (AR), slope of the channel (S), relative overbank flow depth (Dr), fluid Density (ρ), fluid viscosity (μ), gravity (g) etc.

Dimensional analysis is a mathematical technique using dimensions where variables are combined into dimensionless products and eliminating insignificant variables. From dimensional analysis, the result can be shown in a formed of qualitative rather than quantitative relationships, but when combined with experimental procedures, it may be made to supply quantitative results and accurate predictions equations. For an experimental study which deals with many variables, the Buckingham (π) theorem is suitable to be applied. The method is discussed in many fluid mechanics textbooks including Raghunath (1967).

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

The aim of this study is to determine the characteristics of flow through straight compound channels with smooth and vegetated single floodplain. The flow characteristics in which have been mentioned earlier are shown in forms of stage-discharge relationship, velocity distribution and Manning's roughness coefficient. Stage-discharge relationship gives an understanding on how stage (or water depth) in the main channel varies with discharge. Plotting the velocity contour illustrates the interaction between main channel and floodplain flows in compound channels.

A study on flood hydraulics in a straight non-mobile bed channel has been carried out in the Hydraulics Laboratory, Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM), Skudai. The project focuses on the characteristics of overbank flow in a straight compound channel. An existing mobile bed model tank is used in the study. Modifications are made in the working section to provide a main channel with single floodplain and to stimulate vegetations along the edge of the floodplain. The study is divided into three main cases: smooth floodplain, submerged vegetation on floodplain and combined submerged and emergent vegetations on floodplain.

Emergent rigid vegetation (tree) spacing is determined through the principle of hydraulic similarity. The geometric similarity which is related to scale ratio is applied to suite the size of trees from local condition at site. The data are obtained from the Malaysian Palm Oil Board (MPOB) regarding to the spacing and average diamater of trees.

3.2 Experimental Setup

The experiments in this study are carried out in straight rectangular non-mobile bed channel with 4000 mm long, 610 mm wide and 200 mm high with a fixed longitudinal gradient of 1:1000 as shown in Figures 3.1 and 3.2. The longitudinal gradient of 1:1000 is chosen to represent some of Malaysian rivers condition (Lai, S.H. *et al.*, 2008a). A submersible pump with maximum flow rate of 9 liter/s (l/s) is used to supply water in re-circulating flume

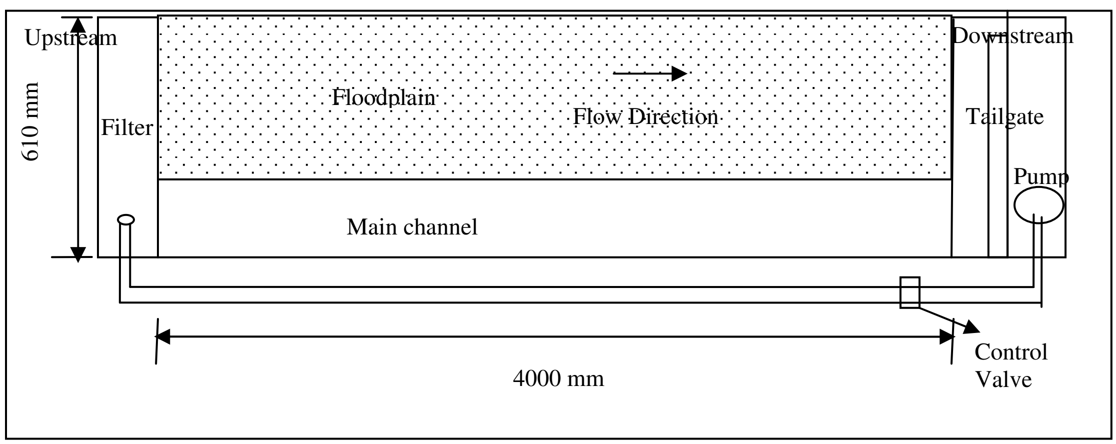

Figure 3.1: Plan view of experimental arrangement channel

Figure 3.2: The piping system for water re-circulation in the flume

Floodplain is built within the channel (Figure 3.3) using waterproof plywood. The width of the floodplain is about 0.37 meter, while the main channel is having 0.23 meter width, across the section of the channel. Meanwhile, a thin carpet layer is used to simulate submerged vegetation such as grass. Meanwhile 20 mm diameter wooden rods are used to represent rigid emergent vegetations such trees. The spacing between rods is 16d where d is the rod diameter. The rods are placed at a distance of 1d from the edge of floodplain. Manual point gauge is used to measure the depth of water.

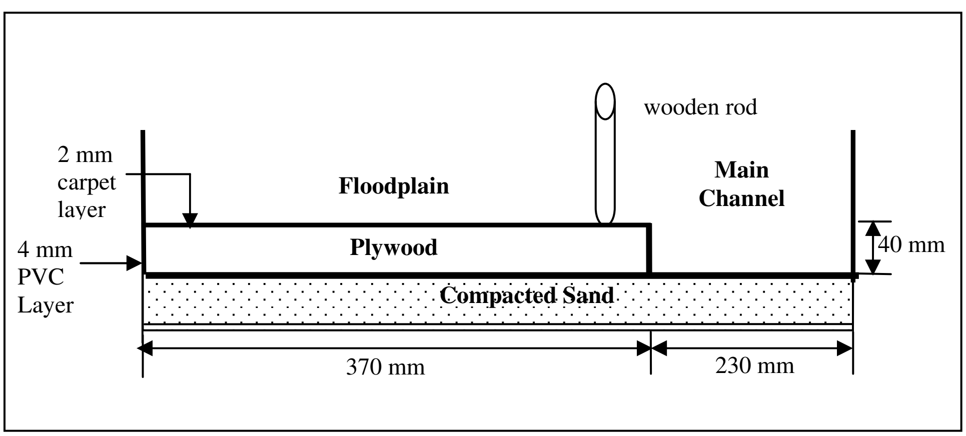

Figure 3.3: Detail cross section of two-stage channel

3.3 Velocity measurement

Velocities in the channel are measured at various points across the compound channel (Figure 3.6) for different relative depths. A Nixon Steamflo 403 miniature current meter is used to record the point velocities (Figures 3.4 and 3.5).

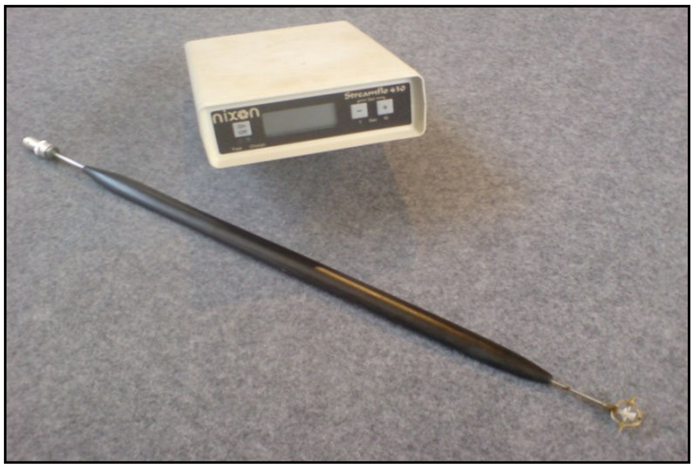

Figure 3.4: Nixon Streamflo 403 miniature current meter

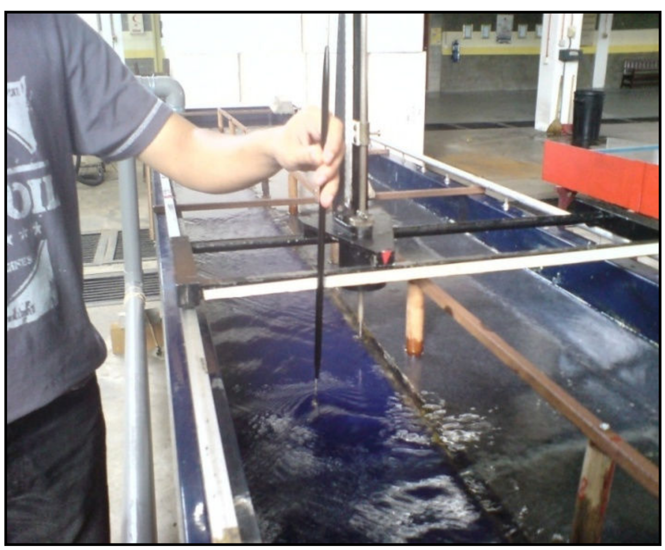

Figure 3.5: Velocity measurement in main channel

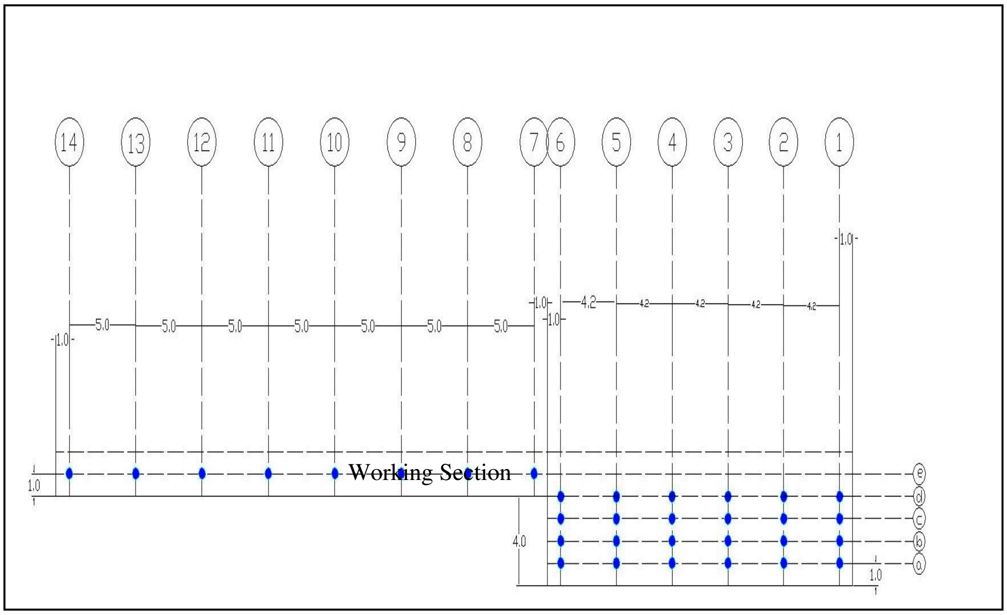

Figure 3.6: Points for velocity measurement across the compound channel

3.4 Discharge measurement

An ultrasonic flowmeter, Portaflow 300 is used to measure discharge of water in pipe supplied into the flume. Sensor transducer Set A is attached the pipe and reading of flow rate is displayed on the control unit screen (Figure 3.7). Properties of the pipe such as the diameter, temperature of the water, pipe lining and material used has to be inserted. The maximum pipe diameter that can be used for this type of transducer is 90 mm. Table 3.1 shows the input used while deploying the Portaflow 300.

Figure 3.7: The Portaflow 300 components: consists of sensor transducer (left) and control unit (right)

Table 3.1: Properties of materials for the experiment

Pipe properties	value
Pipe Lining	2 mm
Pipe Material	epoxy*
Water Temperature	28°
Pipe thickness	3 mm
Pipe Diameter	80 mm

*epoxy = material similar to plastic

3.5 Preparation of experimental

The layout of experimental setup is as illustrated in Figure 3.1 earlier. Among the main task in performing the experiment is establishment of uniform flow in the channel. This is due to the assumption of quasi-uniform applied in the data analysis.

3.5.1 Establishment of uniform flow

This experiment will be conducted under assumption of quasi-uniform flow condition. By definition, uniform flow occurs in open channel when the depth, flow area and velocity at every cross section are constant (Chow, 1959; French, 1985). In such situation, the energy grade line (S_f), slope of water surface (S_w) and channel bed (S_o) are all parallel. Therefore, the following condition can be stated as:

$$S_f = S_w = S_o \tag{3.1}$$

The establishment of uniform can be achieved by adjusting the tailgate at downstream of the flume for any selected discharge. Normally, it takes some time to ensure uniform flow has been achieved in the experimental work. A manual point gauge is used to measure the bed and water surface levels in the middle of main channel. Then, the bed slope and water surface slope are calculated to ensure that the condition in Equation 3.1 is satisfied.

3.5.2 Vegetation used

The experiment is carried out to simulate local trees such as oil palm. Information obtained from the Malaysian Palm Oil Board (MPOB) on the size of tree and the spacing has been referred. The average spacing between oil palm trees is about 8 m while its mean diameter is 50 cm. Thus, the average spacing between trees is 16d.

The rod size used in the study is 2.5 cm in diameter (d). A similar spacing between rods of 16d is adopted in the experiment (Figure 3.8). The rods are arranged as one-line emergent vegetation along the edge of floodplain at a distance of 1d (Figure 3.9). In addition, a 2 mm thick carpet layer is used as submerged vegetation

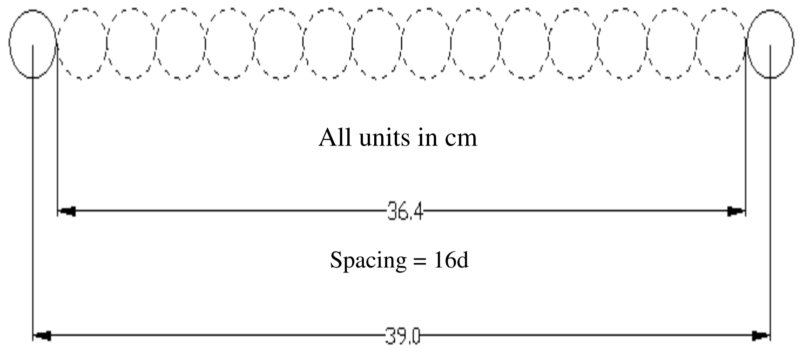

Figure 3.8: Spacing between rods (trees) along the floodplain

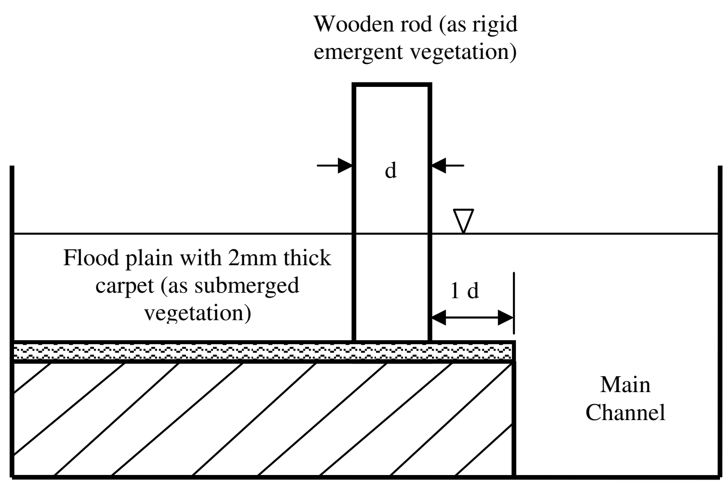

Figure 3.9: Lateral spacing of rigid emergent vegetation on floodplain

3.6 Calibration of profiler rails

The initial stage prior performing the experiment is to make sure that rails on both sides of flume are horizontal, running longitudinally and laterally. This is very important because the datum for flow depth measurement must be setup as horizontal. This is to ensure that the measured water surface and channel bed slope are accurate.

The transverse rails were found to be satisfactorily level. However, the profiler still needs a modification and maintenance to make sure it serves well to collect data. Figure 3.10 shows the reference axes in data collection and analysis. In this analysis, due to error from bed of channel, and point gauge, a correction has been made and best section which is assume to be suitable for collecting of data in sections B,C,D,E,F and G. (Figure 3.11). The height measured at each section from B to G has to be corrected with value as shown in Figure 3.11.

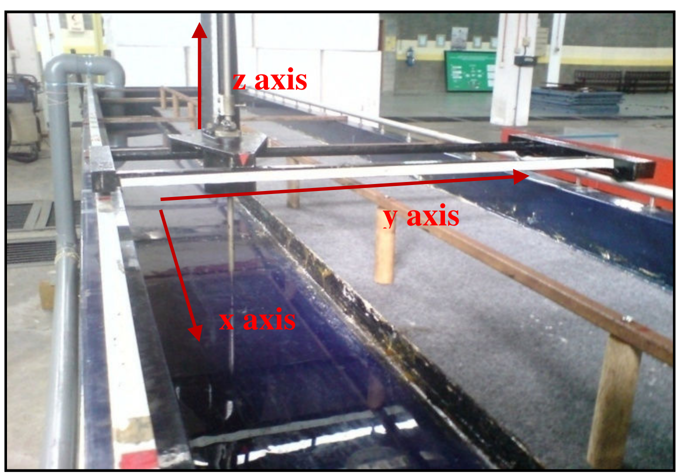

Figure 3.10: Reference axes used in experimental data collection and analysis

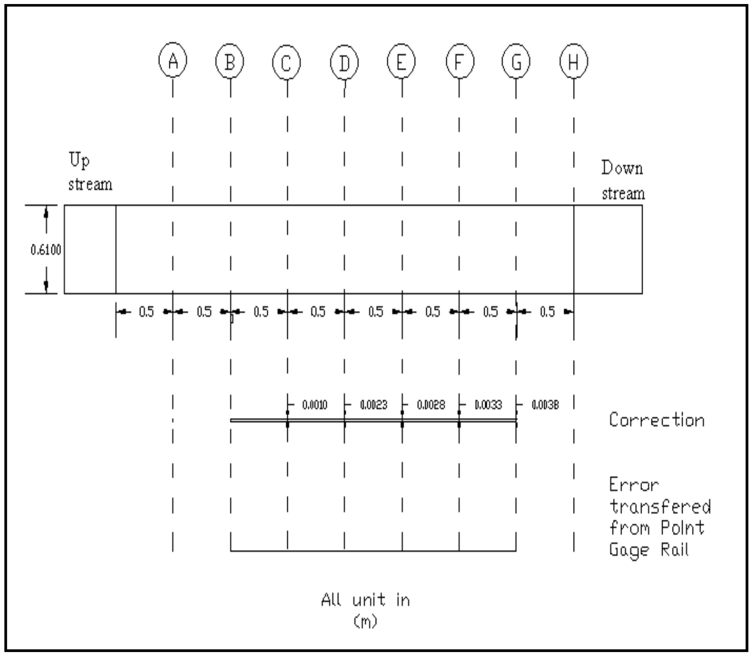

Figure 3.11: Correction values for sections of data measurement

3.7 Experimental procedures

After experimental is set-up, model is tested and data from experiment is recorded. The experimental procedures are:

Part 1 –Establishment of uniform flow

i. Run the submersible pump to supply the required discharge,

ii. Control the tailgate until water inundated the floodplain area,

iii. Allow the water flow to stabilize,

iv. Adjust the tailgate until the measured water depths along the main channel is uniform,

v. Record the water depths along the main channel.

Part 2 –Record data

i. Record the water levels in main channel and floodplain,

ii. Measure the flow velocities at different points across the channel,

iii. Process is repeated for various discharges in the channel.

CHAPTER 4

DISCUSSIONS OF RESULTS

4.1 Introduction

The aim of this study is to determine the characteristics of flow in a straight compound channel with smooth and vegetated single floodplain. The characteristics studied are stage-discharge relationship, velocity distribution and Manning's roughness coefficient. Stage-discharge relationship gives an understanding on how stage (or water depth) in the main channel varies with discharge. Plotting the velocity distribution or contour illustrates the interaction between main channel and floodplain flows in compound channels.

The study consists three parts: smooth (non-vegetated) floodplain, submerged vegetation on floodplain and combination of submerged and emergent vegetations on floodplain. The results are presented in forms of stage-discharge relationship, streamwise velocity distribution across the channel, and Manning's n roughness coefficient.

4.2 Flow and water depth profile

4.2.1 Compound channel with no-vegetation (smooth) floodplain

The relationship between water depth (stage) in main channel and discharge in longitudinal direction is analysed. Table 4.1 summarised the heights of bed and water surface in main channel for various discharges. The results are as shown in Figures 4.1a 4.1e. **Appendix A** shows the details data of the water and bed levels.

Table 4.1: Measured water depth and bed height for various discharges

	Height of water surface (mm)					
Chainage	Discharge, Q (L/s)					
(mm)	Bed (mm)	Q=3.60	Q=3.40	Q=3.10	Q=2.80	Q=2.40
1000	5	55.23	52.87	48.23	43.89	35.5
1500	3.587	55.943	53.553	48.943	44.803	36.213
2000	2.374	56.556	54.146	49.456	45.516	36.83
2500	2.427	55.803	53.393	48.803	44.763	36.173
3000	2.427	55.203	52.693	48.203	44.263	35.673
3500	1.897	54.133	52.523	48.033	44.194	35.603

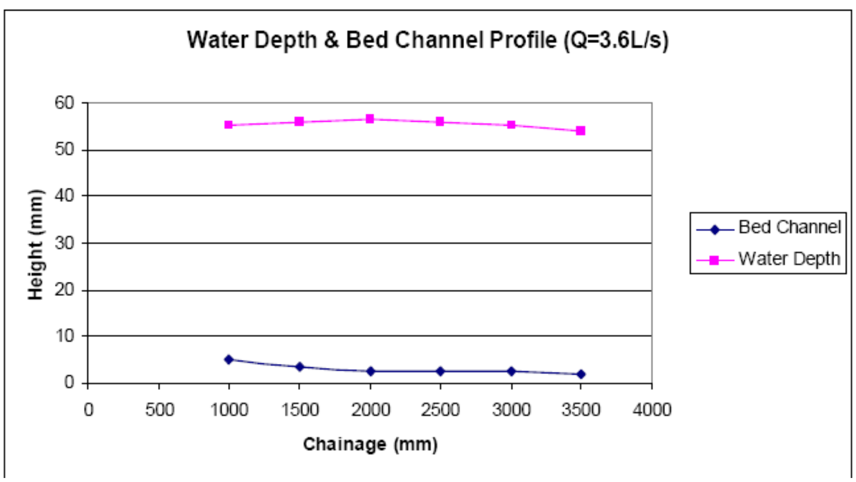

Figure 4.1a: Water depth and bed channel profile for Q=3.6 L/s

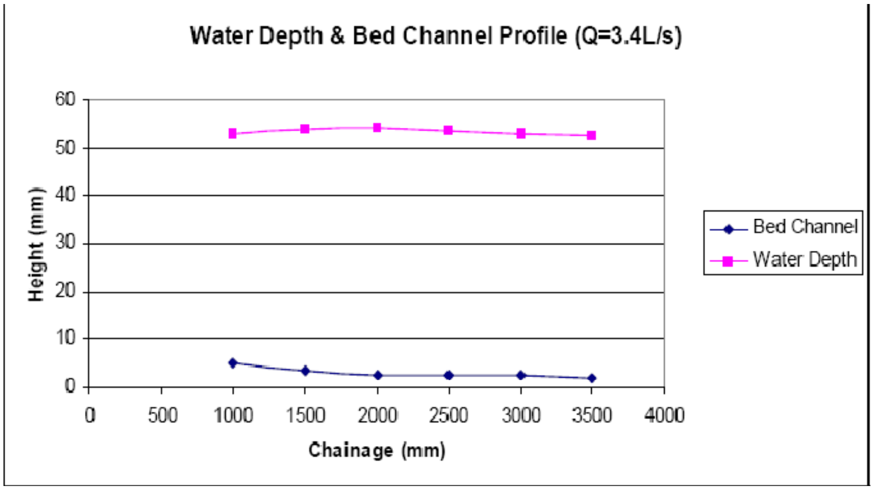

Figure 4.1b: Water depth and bed channel profile for Q=3.4 L/s

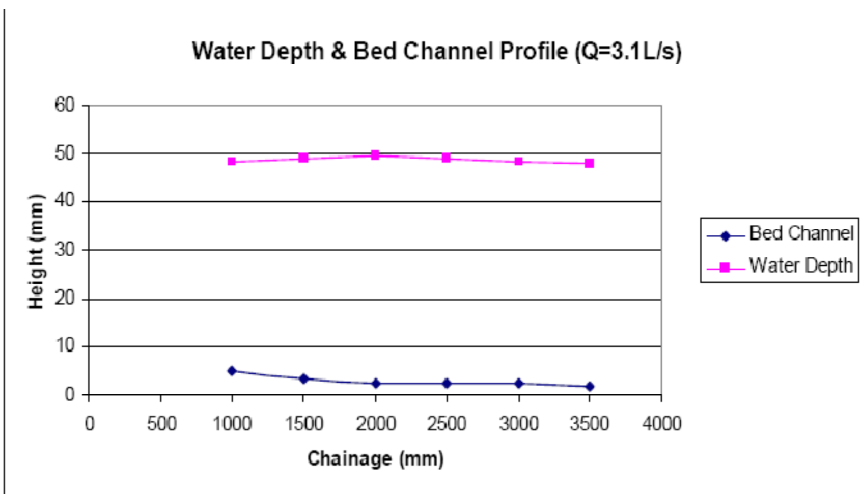

Figure 4.1c: Water depth and bed channel profile for Q=3.1 L/s

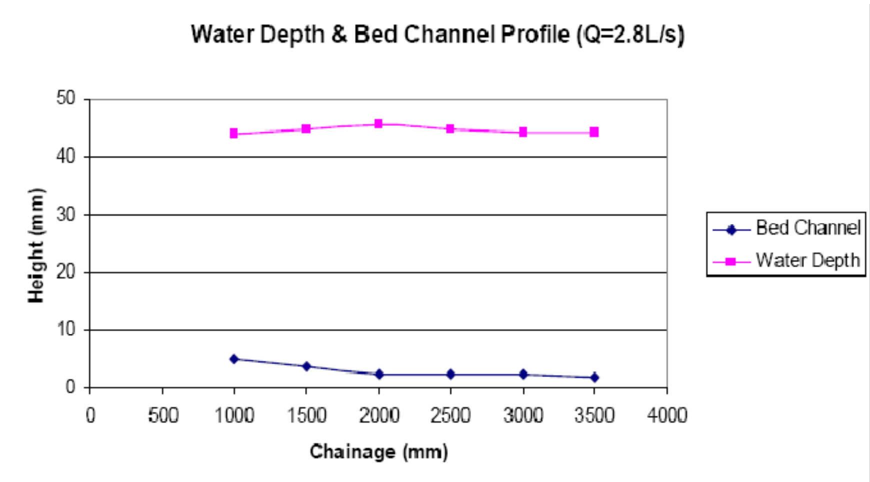

Figure 4.1d: Water depth and bed channel profile for Q=2.8 L/s

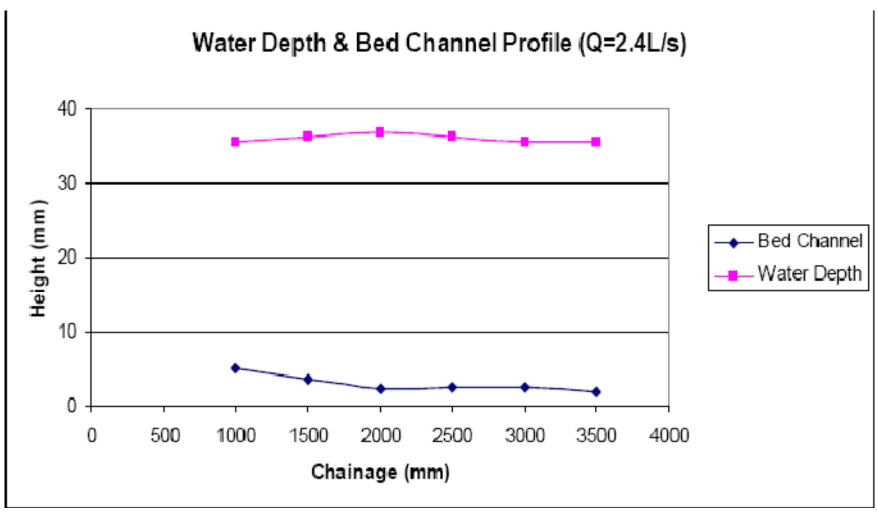

Figure 4.1e: Water depth and bed channel profile for Q=2.4 L/s

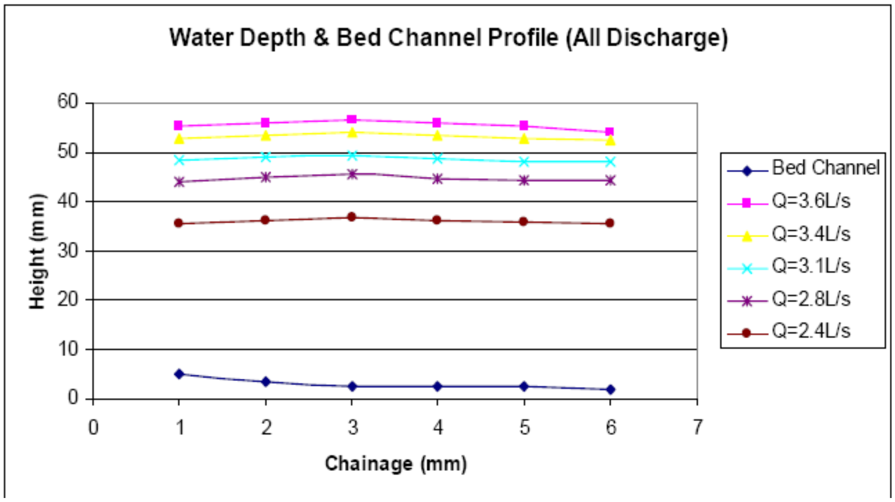

Figure 4.2: Water depth and bed slope profiles for all discharges

Figure 4.2 shows profiles of water surface and channel bed for all discharges. It seems that the water depth and the bed channel profiles are parallel to each other. Therefore, the quasi-uniform flow is achieved in the channel.

4.2.2 Compound channel with submerged vegetation on floodplain

Table 4.2 shows the summary of water surface and bed slope for all discharges. It denotes the point section used to read water surface levels and bed levels at the key chainages for every 500 mm along the channel, starting from 1000 mm (point B) to the 3500 mm (point G). The points have been converted to graphical and numerical slopes to determine the development of uniform flow.

Data in Table 4.2 are plotted in graphical forms as shown in Figures 4.3a to 4.3e. The figures illustrate the longitudinal section of water level and bed slope in the channel. From the figures, it can be seen that the best fit lines are used to generate linear line of water surface slope and channel bed slope. It is to show that both of them are identical and parallel for uniform flow. In this experiment, the water and bed slopes are 0.001.

Table 4.2: Summary of water level and bed slope for all discharges

Section	L (mm)	Bed Level (mm)	Water Depth(mm)				
			Q=3.60 (L/s)	Q=3.40 (L/s)	Q=3.10 (L/s)	Q=2.80 (L/s)	Q=2.40 (L/s)
B	1000	5.00	55.23	52.62	51.40	45.72	35.50
C	1500	3.59	55.94	53.23	52.11	46.57	36.21
D	2000	2.37	56.56	53.48	52.63	47.23	36.83
E	2500	2.43	55.80	52.99	51.97	46.61	36.17
F	3000	2.43	55.20	52.19	51.17	46.07	35.67
G	3500	1.90	55.13	52.02	51.00	46.02	35.60

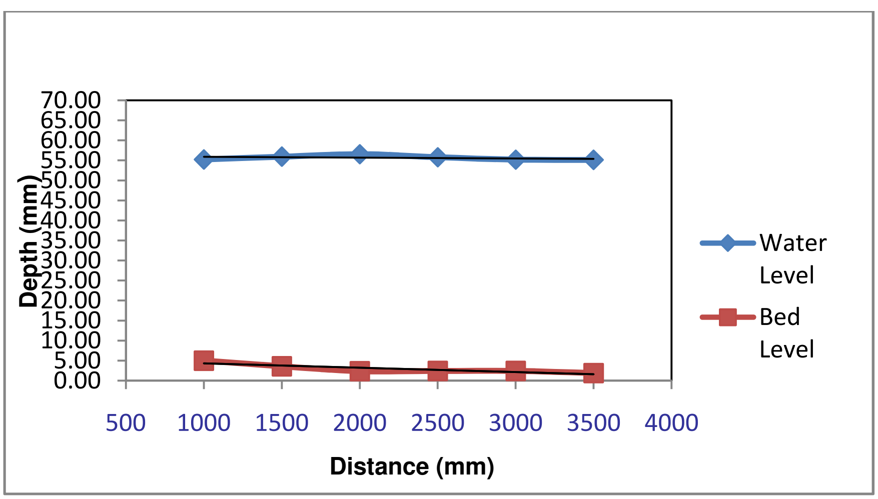

Figure 4.3a: Water surface level and bed slope Profile for Q = 3.60 L/s

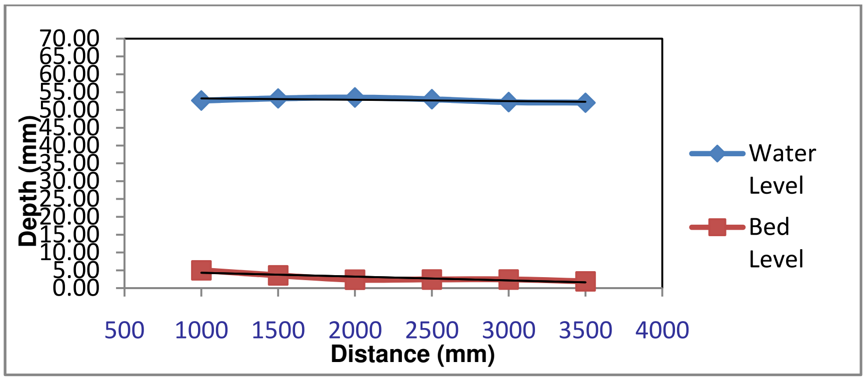

Figure 4.3b: Water surface level and bed slope profile for Q = 3.40 L/s

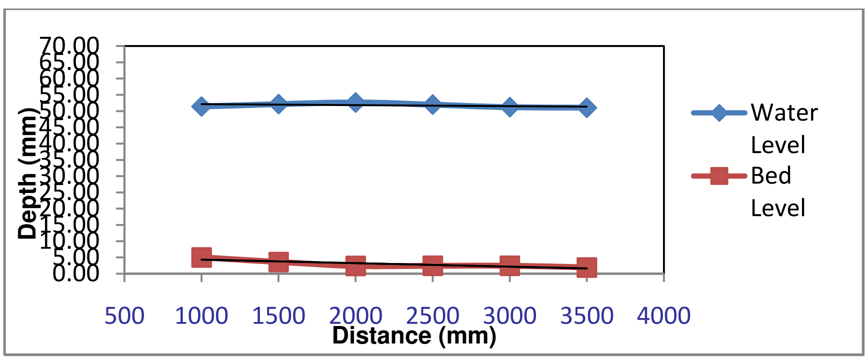

Figure 4.3c: Water surface level and bed slope profile for Q = 3.10 L/s

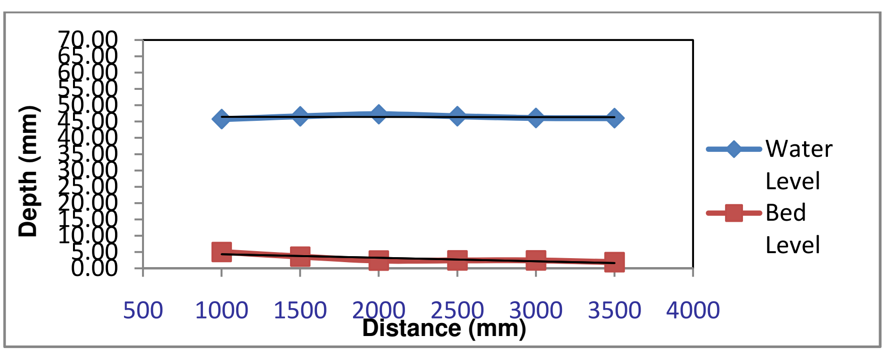

Figure 4.3d: Water surface level and bed slope profile for Q = 2.80 L/s

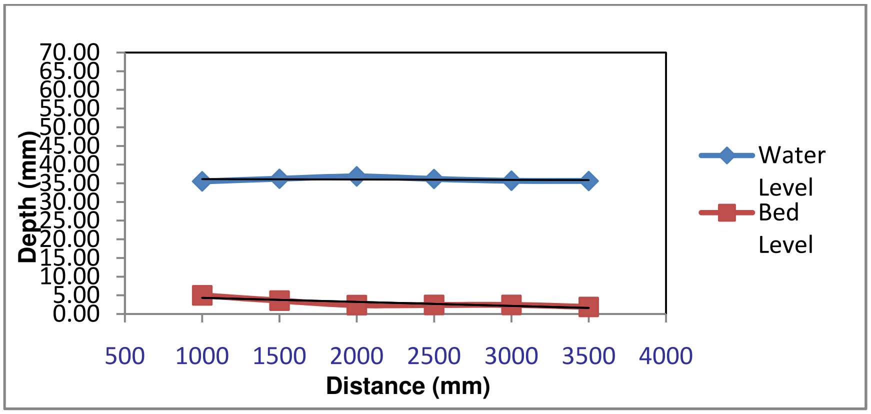

Figure 4.3e: Water surface level and bed slope profile for Q = 2.40 L/s

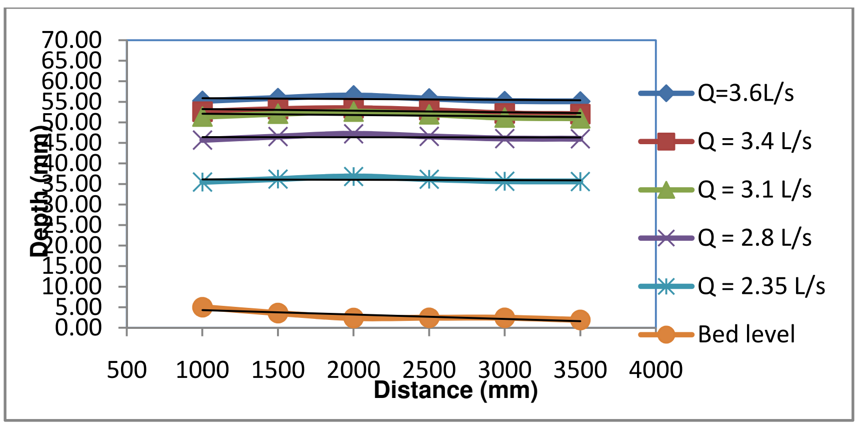

Figure 4.4: Water surface levels and bed slope profile for all discharges

4.2.3 Compound channel with submerged and emergent vegetations on floodplain

The condition for uniform flow to happen has been discussed earlier. Again, water surface level and channel bed level are measured to make sure that they are parallel. In order to obtain accurate readings, three flow depths are measured across main channel for any section. Then, the average depth is taken for stage value for the section. Table 4.3 shows a summary of calculation for free surface and channel bed slope for Q = 3.60 L/s.

Table 4.3: Determination of water level and slope for uniform flow

Discharge	3.60 L/s	Tailgate set at = 4.3 cm			
Time (min)	120 min				
Section		Level in main channel (mm)			
Distance (mm)	Water	Slope	Bed	Slope	Depth
B = 1000	62.53		0.12	0.05	0.05 53
C = 1500	61.97	0.00112	3.587	0.001	58.383
D = 2000	61.41	0.00116	2.374	0.001	59.036
E = 2500	60.85	0.00116	2.427	0.001	58.423
F = 3000	60.29	0.00112	2.427	0.001	57.863
G = 3500	59.73	0.001	1.897	0.001	57.833
Mean		0.00112		0.001	58.178

It is found that the water slopes are not slightly differ from bed slope (So = 0.001). During the experimental work, uniform flow in channel with vegetation is difficult to occur. Water slope measured from the experiment is tends to be steeper. The slopes after correction and calibration are acceptable at average of 0.00143.

Example of water slope (S_w) calculation at section B:

Water depth = (62.53 – 61.97) = 0.56 mm

Channel length = (1500 – 1000) = 500 mm

Thus, S_w = 0.56/500 = 0.0112 (as shown in Table 4.3).

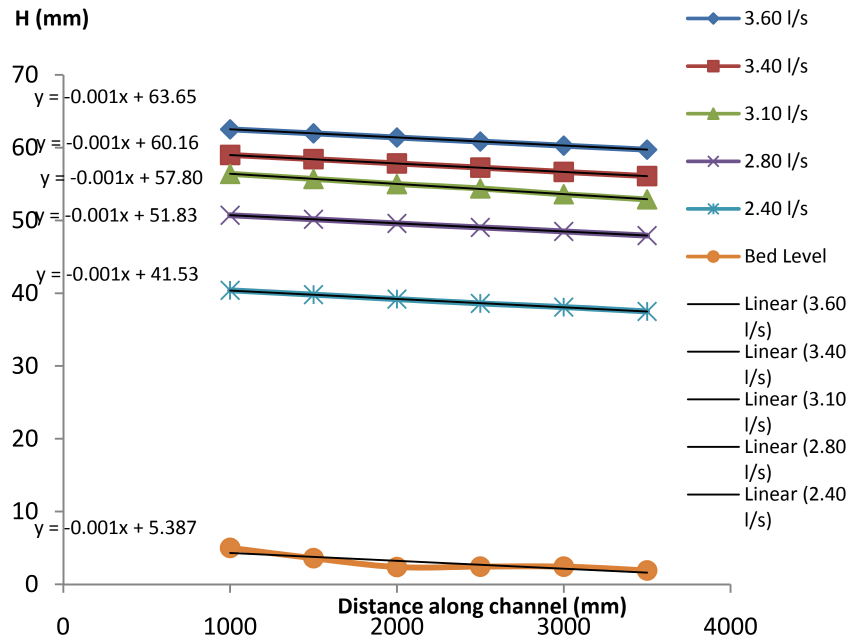

Figure 4.5: Water and bed slopes for all discharges

From Figure 4.5, it can be seen that the best fit lines were used to generate linear equations to give water and bed slopes. From the equation given, since the bed slope is fixed, it is taken at average slope of 0.001 and slope of water is varies from 0.00112 to 0.0014. For each case, the slope is measured at 10 minute interval after water starts to flow. To make sure the water is uniform, the slope is measured twice. Table 4.4 shows an average of slope for two time intervals (20 minutes) readings.

Table 4.4: Summary of water slopes at the middle of the main channel (y = 505 mm)

Q (L/s)	t (min)	t (min)	Avg. S_w
	0 - 10	11 - 20	
3.60	0.00114	0.00110	0.00112
3.40	0.00118	0.00114	0.00116
3.10	0.0016	0.0012	0.0014
2.80	0.00113	0.00111	0.00112
2.40	0.00118	0.00114	0.00116

Table 4.5 shows the calculated difference between So and Sw for all discharges in the channel. The presence of emergent and submerged vegetations actually slows down the flow due to their resistance. This affects the water surface profile. It is found that more difficult to achieve uniform flow in channel with vegetated floodplain.

Table 4.5: Percentage difference between S_o and S_w

Q (L/s)	S_o	Avg. S_w (from Table 4.4)	% difference
3.60	0.001	0.00112	12
3.40	0.001	0.00116	16
3.10	0.001	0.00140	14
2.80	0.001	0.00112	12
2.40	0.001	0.00116	16

4.3 Stage-discharge relationship

The changes of water depth with variation of discharges are presented as stage-discharge relationship. The three cases studied in a straight compound channel with single floodplain are: smooth floodplain, submerged vegetation on floodplain, and combination of submerged and emergent vegetations on floodplain.

4.3.1 Smooth floodplain

Table 4.6 shows the depth of flow for various discharges in a compound channel with smooth floodplain. The depths of flow are measured in the middle of main channel. The data are later plotted in a graphical form as shown in Figure 4.6.

Figure 4.6 shows that the discharge increases with depth of flow. When the flow reaches the overbank, the graph shows a little increase of the water depth. This is due to the interaction between the main channel and floodplain. The interaction causes the decreases the discharge in the main channel and increases the discharge on the floodplain, ending up in decreasing the total discharge capacity of the channel.

Table 4.6: The measured discharges and water depth in smooth floodplain compound channel

Discharge, Q (L/s)	Water depth, H (mm)
3.6	55.48
3.4	53.19
3.1	48.61
2.8	44.57
2.4	36

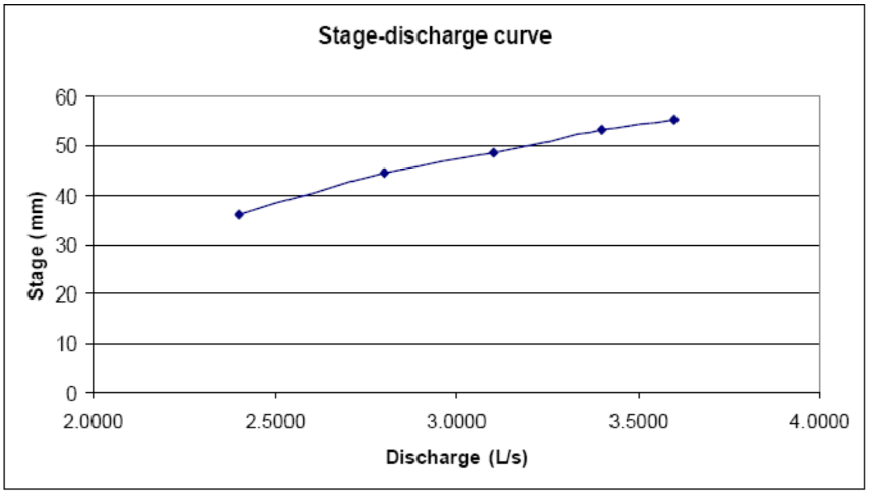

Figure 4.6: Stage-discharge relationship

Figure 4.7 presents the relationship between the relative depth (Dr) and discharge in the compound channel. Relative depth is defined as the ratio of flow depth on floodplain (h) to total flow depth in the main channel (H). The value of Dr less than indicates inbank flow while zero value is bankfull flow.

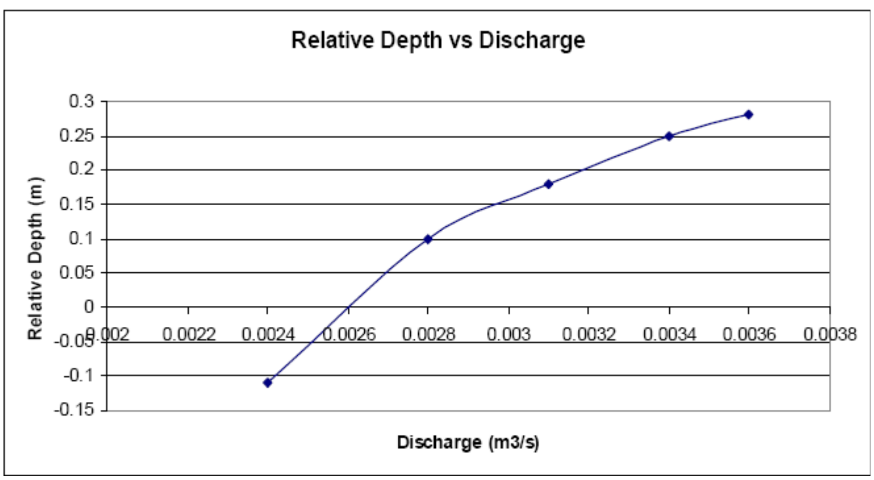

Figure 4.7: The curve of relative depth vs. discharge.

4.3.2 Submerged vegetation on floodplain

Table 4.7 shows, the stage-discharge measurement in a compound channel with submerged vegetation on its floodplain.

Table 4.7: Stage-discharge for submerged vegetation on floodplain

Flow	Q (L/s)	H (mm)
Overbank	3.60	55.64
	3.40	52.80
	3.10	51.71
	2.80	46.43
Inbank	2.40	36.00

The measured data are the plotted as shown in Figure 4.8. It shows the relationship between water depth and the discharge in the channel.

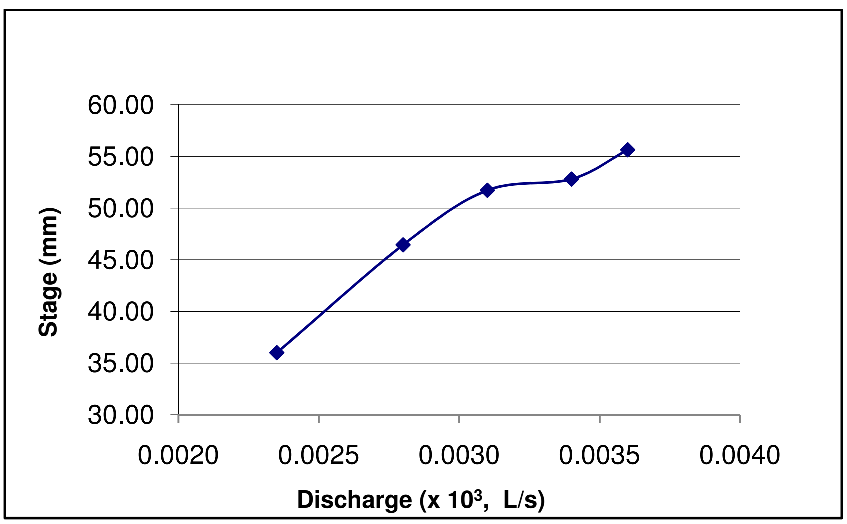

Figure 4.8: Stage-discharge relationship in a compound channel

The graph shows that the discharge increases with the depth of flow. In this case, the rating curve behaves similar with Zulhilmi and Shiono (2006). It clearly shows that the water depth steadily increases with increase in discharge. However, there is a break point at bankfull depth of around 3.10 L/s and at flow depth of 51 mm where the slope of the graph flatten and decrease when reaches bankfull stage. After the bankfull stage, the graph back to normal and increases again with increase of discharge. Moreover, the reduction of discharge when the flow is overbank, due to the interaction between the main channel and floodplain. The interaction can significantly reduce the main channel velocity when the flow is overbank. This is because of rough floodplain reduces the floodplain flow velocity. Thus, it reduces the overall discharge capacity of the channel and increases the water depth. This means that the flow are disturbed due to the floodplain roughness (submerged vegetation).

4.3.3 Submerged and emerged vegetations on floodplain

The data for stage discharge curves of the channel with vegetation are shown in Table 4.8. It shows that the depth of water decreases with reduction of discharge in the channel. Data from table is plotted as a graph and is presented in Figure 4.9. Water will inundate the floodplain area and will flow over the bank at discharge of 2.80 L/s to 3.60 L/s. The discharge less than 2.70 L/s represent inbank flow.

Table 4.8: Summary of data for stage-discharge relationship

Flow type	Q (L/s)	H (mm)
overbank	3.6	58.178
	3.4	54.363
	3.1	51.714
	2.8	46.43
inbank	2.4	36

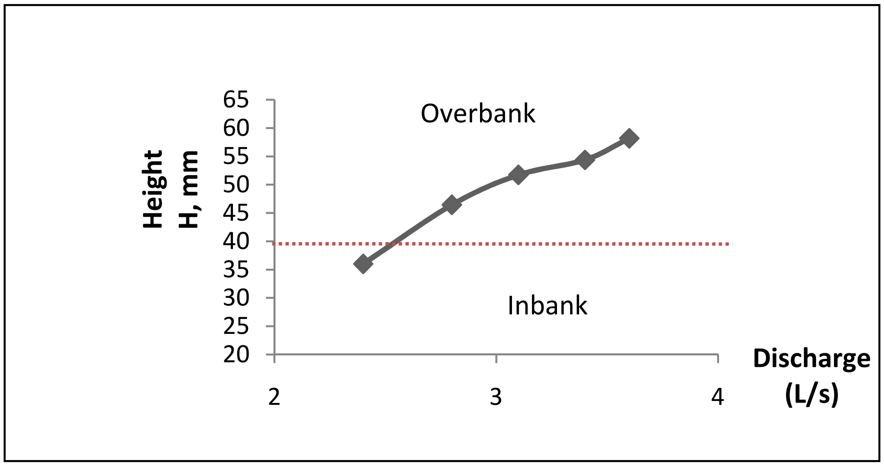

Figure 4.9: Stage-discharge relationship for inbank and overbank flows.

In Figure 4.9, water depth increases steadily with discharge. Slope of graph is steeper for overbank flow in vegetated compound channels as compared to non-vegetated channels (Hin Joo *et al.*, 2008). The floodplain with vegetation carries less discharge than smooth floodplain. This is due to roughness on the floodplain which reduces the velocity of flow on the floodplain. It can be concluded that roughness on the floodplain retards the overall discharge capacity of the channel.

4.4 Determination of Manning's n

The Manning's roughness coefficient (Manning's n) represents flow resistance in open channels. The Manning's n is calculated by using equation (2.2).

4.4.1 Compound channel with smooth floodplain

The following is an example of Manning's n calculation for a specified discharge using equation (2.2):

$Q = 3.60\ L/s = 0.0036\ m^3/s$

$A = 0.018488\ m^2$

$R^{2/3} = 0.0878$

$So^{1/2} = 0.0358$

$n = [0.018488 \times 0.0878 \times 0.0358] / 0.0036$

$\mathbf{n = 0.0161}$

Figure 4.10 shows the Manning's n for different depth of inundation which is represents by relative depth, Dr.

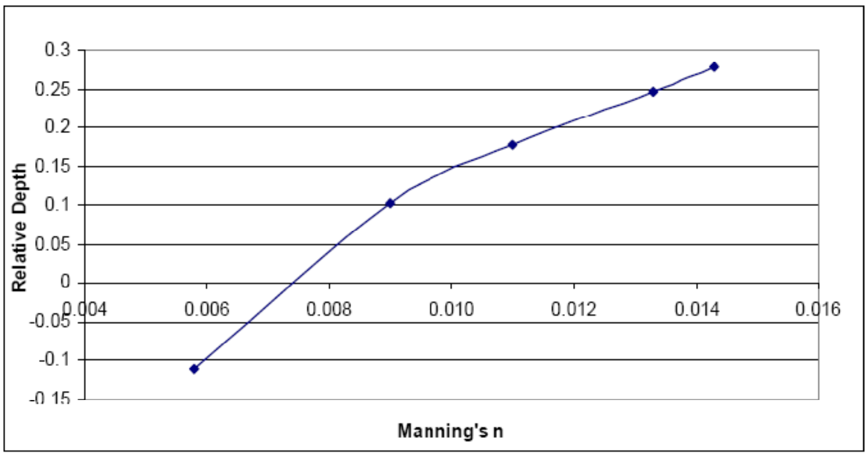

Figure 4.10: The relationship between Dr and Manning's n

Figure 4.10 shows the Manning's n varies from 0.0058 to 0.0143. The smallest Manning's n is for inbank flow (Dr = - 0.11). As overbank flow occurs, Manning's n increases with relative depth.

4.4.2 Compound channel with submerged vegetation

Table 4.9 shows the calculated Manning's n for various relative depth in the compound channel by applying equation (2.2).

Table 4.9: Calculation of Manning's roughness coefficient, n

Q (m^3/s)	A (m^2)	$R^{2/3}$	$\sqrt{So}$	Flow	***n***	Dr = (h/H)
0.0036	0.02069	0.0881	0.0358		**0.0163**	0.281
0.0034	0.01836	0.0836	0.0349	Overbank	**0.0159**	0.242
0.0031	0.01676	0.08203	0.0374		**0.01556**	0.227
0.0028	0.01352	0.0718	0.0334		**0.01158**	0.138
0.0024	0.00864	0.0915	0.034	Inbank	**0.011204**	-0.111

The results in Table 4.9 are plotted in a graph as shown in Figure 4.11. Relative depth, Dr is the ratio of floodplain water depth, h and main channel water depth, H.

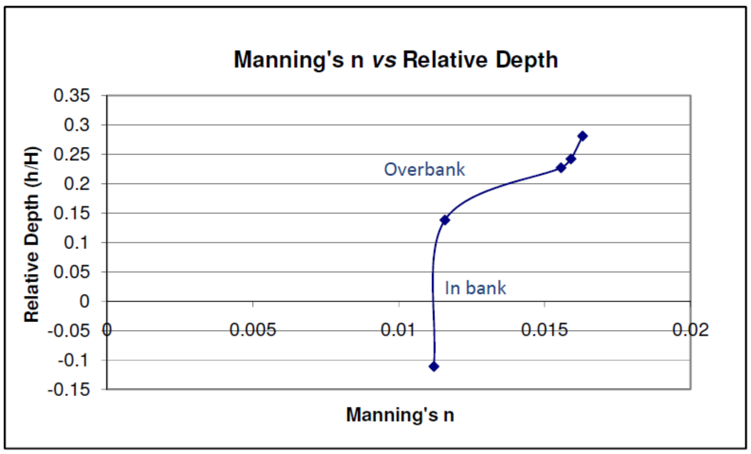

Figure 4.11: Manning's n with relative depth

Figure 4.11 shows the Manning's n varies from 0.0011 for inbank flow to 0.0016 for overbank flow. The Manning's n increases with relative depth when water flows overbank. This means that resistance to flow increases when depth of inundation increases. The result agrees with values of n in literatures. The typical values for Manning's n for smooth surface in range of 0.009 to 0.013 and for floodplain well-built cover with thick (carpet) in range of 0.015 to 0.018 (Chow, 1959).

4.4.3 Compound channel with submerged and emergent vegetations

Again, equation (2.2) is used to calculate Manning roughness coefficient, n. The summary of calculated Manning's n is given in Table 4.10. It gives Manning's n for different relative depths. As found in 4.4.2, Manning's n for overbank flow increases with discharge in the channel where Manning's n value of 0.0116 at Dr = 0.14 increases to 0.0179 at Dr = 0.31. The presence of vegetation on floodplain provides more resistance (as roughness) to the flow on the floodplain. The Manning's n is lowest at 0.0112 for inbank flow. The bed of main channel is basically considered as smooth without vegetation. The result is also presented in Figure 4.12.

Table 4.10: Summary of Manning's n for vegetated floodplain

Flow type	h (mm)	H (mm)	n	Relative depth, Dr
Overbank	18.18	58.18	0.0179	0.313
	14.363	54.36	0.0159	0.264
	11.714	51.72	0.0158	0.2265
	6.43	46.43	0.0116	0.138
Inbank	-4	36.00	0.0112	-0.111

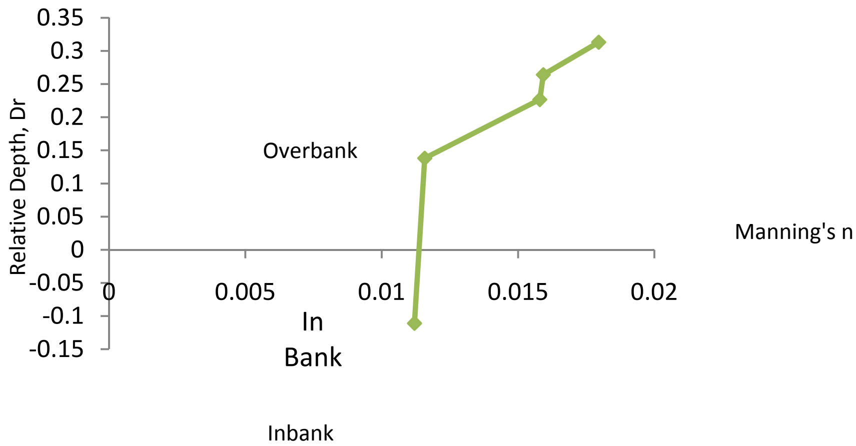

Figure 4.12: Manning’s n and relative depth

According to Zulhilmi Ismail (2006), value of Manning’s n at a relative depth of more than 0.5 is almost the same with the value at a relative depth of 0.25 for a fixed-bed channel with resistance on a floodplain. For this experiment, due to the limitations, the effect is not taken into account.

4.5 Calculation of Froude Number, Fr

Flow in open channels in governed by gravitational force. In order to assess the effect of gravity, Froude number (Fr) is calculated using the following equation:

$$Fr = \frac{U}{\sqrt{\mathrm{gD}}} \tag{4.1}$$

in which U is depth-averaged velocity (m/s), g is gravitational acceleration (m/s^2) and D is the hydraulic depth (m). T is a top width of the channel (m). Table 4.11 shows the calculated Fr for this study.

Table 4.11: Calculation of Froude number, Fr

Flow	Q (L/s)	A (m^2)	T (m)	D (m)	g (m/s^2)	U (m/s)	Fr
Overbank	3.6	0.02069	0.60	0.03	9.81	0.238	0.41
	3.4	0.01836	0.60	0.03	9.81	0.257	0.47
	3.1	0.01676	0.24	0.07	9.81	0.296	0.36
	2.8	0.01352	0.24	0.06	9.81	0.30	0.40
Inbank	2.4	0.00864	0.24	0.04	9.81	0.210	0.35

From Table 4.11, it Froude number ranges from 0.35 to 0.41. Therefore, the flow in the compound channel can be classified as subcritical. Flow with Froude number less than 1.0 is classified as subcritical (Chow, 1959).

4.6 Longitudinal velocity distribution

The presented distribution of longitudinal (stream-wise) velocity is to illustrate the mechanism of momentum transfer from main channel flow to floodplain flow. The flow analysis are carried in term of normalized velocity (u/Um) where u is measured velocity and Um is the mean velocity of a particular channel cross section.

4.6.1 Smooth channel

Velocity distribution is very important to analyse the velocity behaviour in the channel especially between main channel and floodplain. **Figures 4.13** to **4.17** show the normalized velocity (u/U_m) for different discharges in a smooth channel.

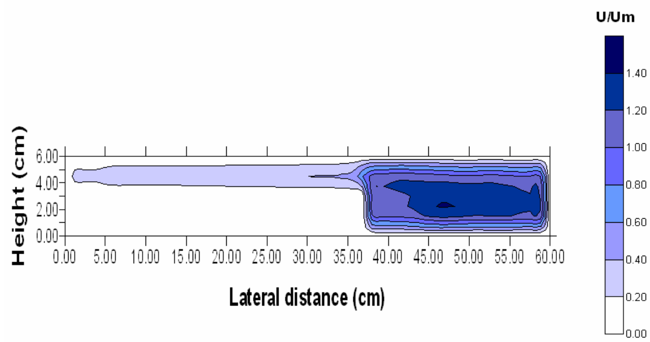

Figure 4.13: Velocity distribution for discharge 3.6 L/s

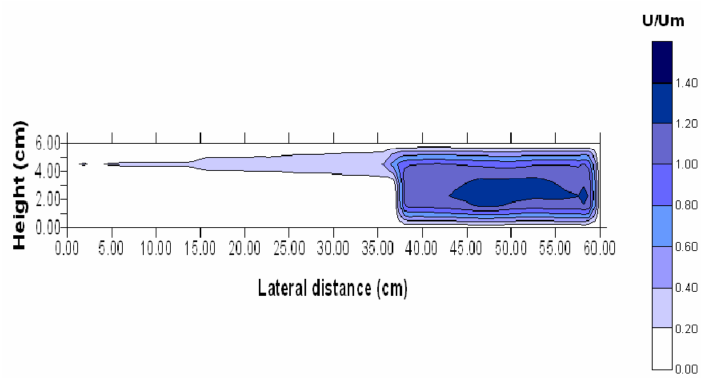

Figure 4.14: Velocity distribution for discharge of 3.4 L/s

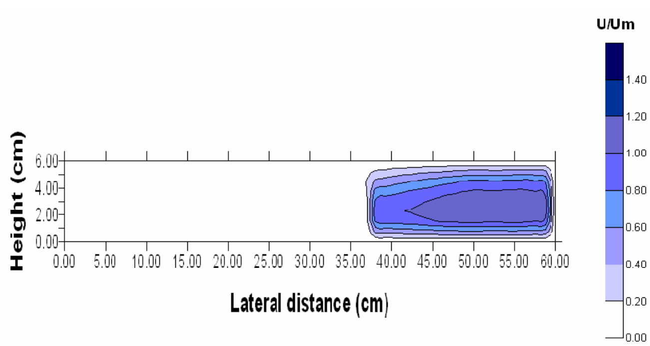

Figure 4.15: Velocity Distribution Contour for Discharge 3.1 L/s

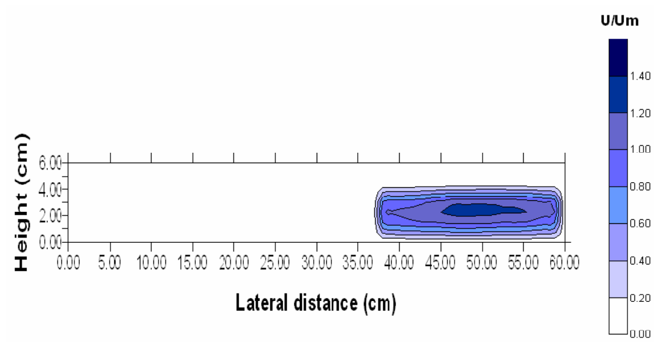

Figure 4.16: Velocity Distribution Contour for Discharge 2.8 L/s

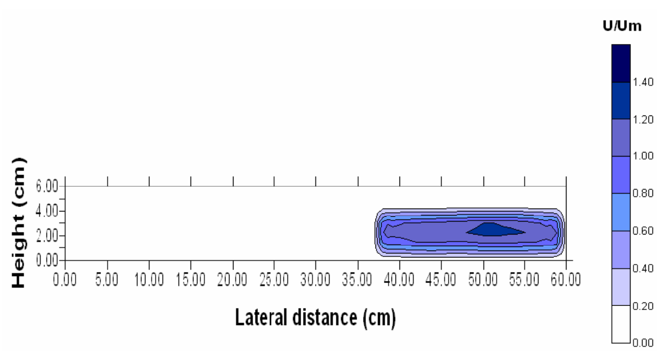

Figure 4.17: Velocity Distribution Contour for Discharge 2.4 L/s

In **Figures 4.13 and 4.17**, there is a bulge in the contour between the main channel and the floodplain. The pattern is quiet similar as reported by Sun and Shiono (2009). The bulge is due to the secondary current and momentum transfer from the main channel to the floodplain. In the figures, the maximum velocity takes place in the middle of main channel, and decreases towards the channel walls and bed.

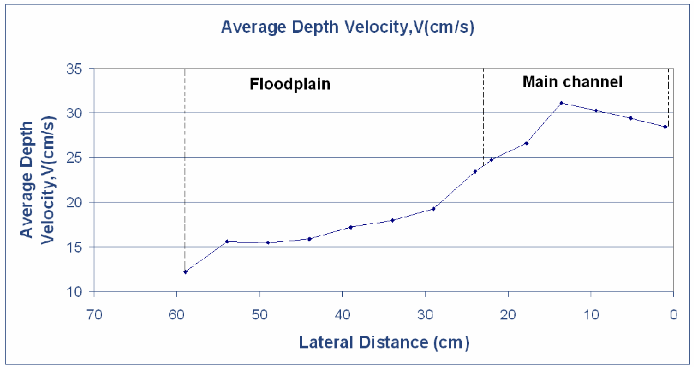

Figure 4.18: Depth-averaged velocity for Q = 3.6 L/s

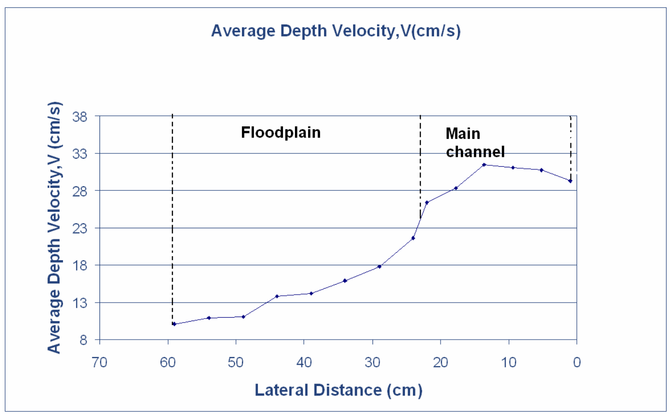

Figure 4.19: Depth-averaged velocity for Q = 3.4 L/s

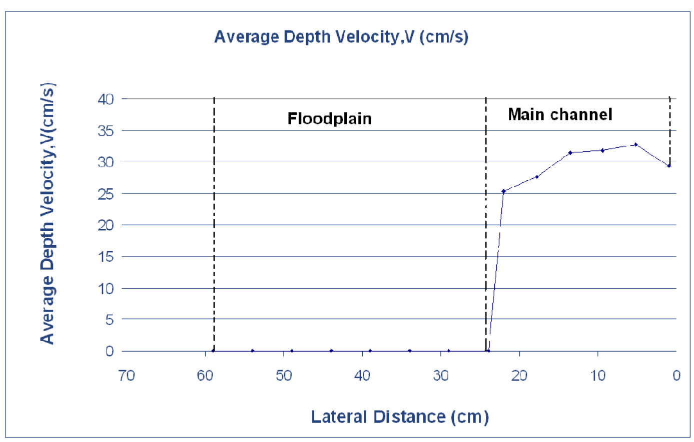

Figure 4.20: Depth–averaged velocity for Q = 3.1 L/s

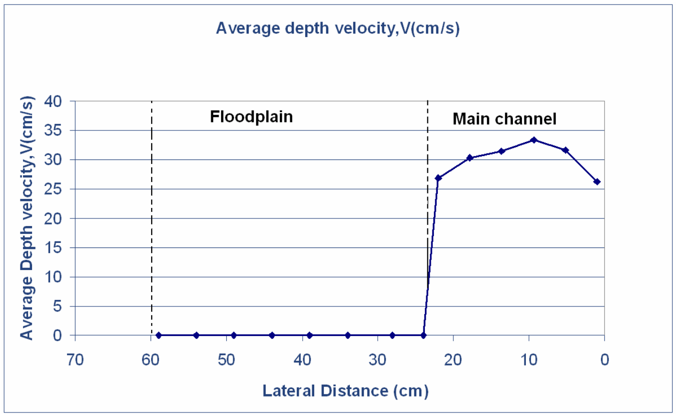

Figure 4.21: Depth-averaged velocity Q = 2.8 L/s

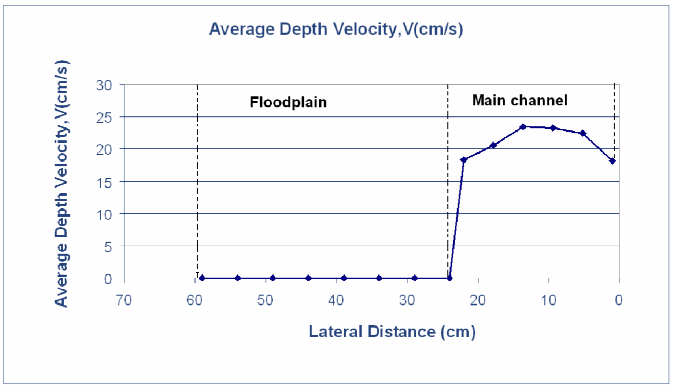

Figure 4.22: Average Depth Velocity for Discharge 2.4 L/s

Figures 4.18 to **4.22** show the lateral distributions of depth-averaged velocity. It is observed that velocity increases with the discharge in the channel. The velocity in floodplain in recorded when the discharge exceeds 3.1 L/s. As the discharge becomes larger, the main channel velocity decreases due to momentum (velocity) transfer between main channel and floodplain, as illustrated in Figures 4.18 and 4.19.

4.6.2 Submerged vegetation

Figures 4.23 to 4.27 show the (U/Um) patterns for various discharges in a compound channel with submerged vegetation on floodplain. As observed in the previous case, the maximum velocity occurs in the middle of main channel. This is due to less resistance between water and channel boundaries (walls, bed). The velocity in the channel is affected by surface roughness (friction) and drag force.

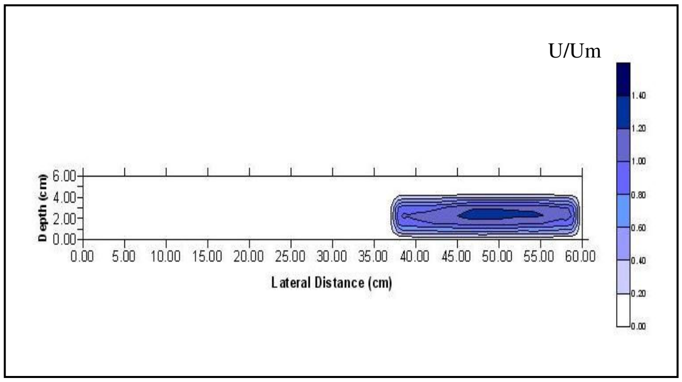

Figure 4.23: Velocity pattern for inbank flow with Q = 2.40 L/s

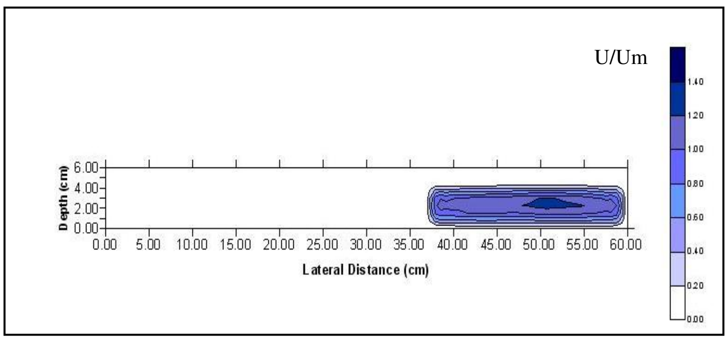

Figure 4.24: Velocity pattern for overbank flow with Q = 2.8 L/s (Dr = 0.138)

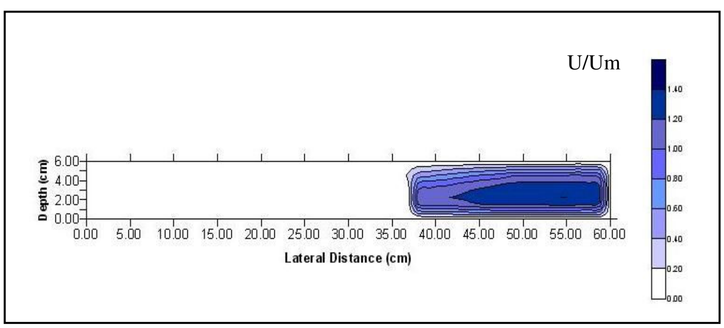

Figure 4.25: Velocity pattern for overbank flow with Q = 3.1 L/s (Dr = 0.227)

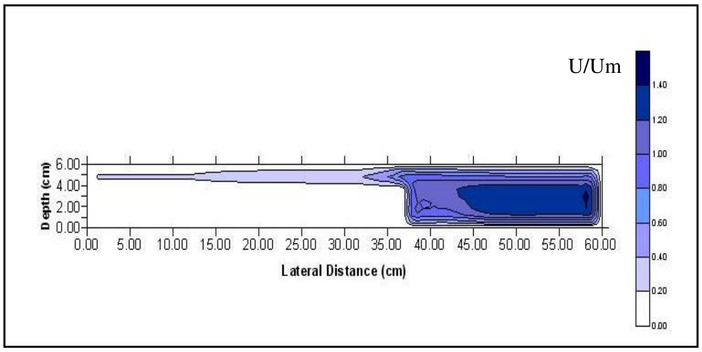

Figure 4.26: Velocity pattern for overbank flow with Q = 3.4 L/s (Dr = 0.242)

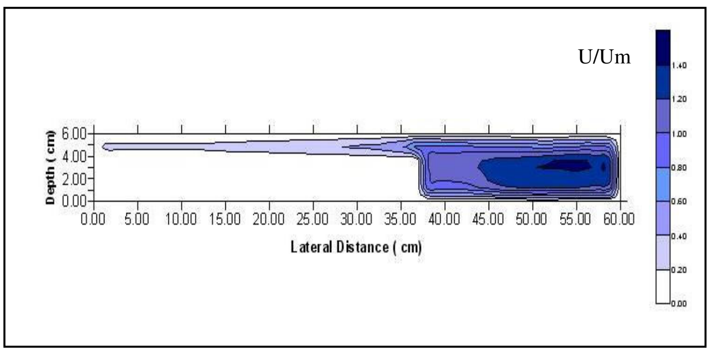

Figure 4.27: Velocity pattern for overbank flow with Q = 3.6 L/s (Dr = 0.281)

When overbank flow occurs, water from main channel starts to move into the floodplain (**Figure 4.24**). Further momentum transfer takes place the relative depth increases, as shown in **Figures 4.25 to 4.27.** What can be observed is the maximum velocity zone moves toward the main channel wall as depth of inundation (Dr) increases. This phenomenom is associated with momentum transfer between main channel and floodplain and secondary current, as explained by Shiono and Knight (1991).

The lateral distributions of depth-averaged velocity in the compound channel are as illustrated in **Figures 4.28 to 4.32.**

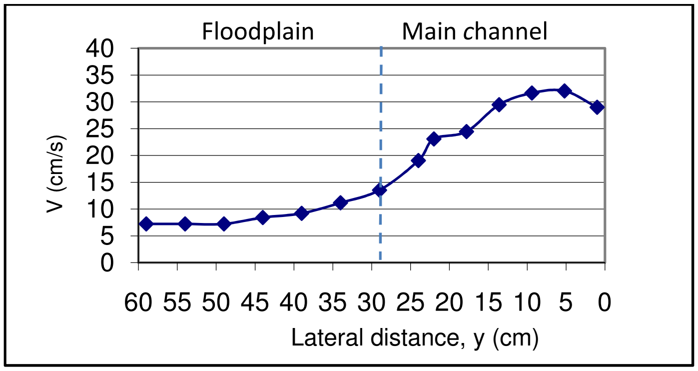

Figure 4.28: Lateral depth-averaged velocity for overbank flow with Q = 3.6 L/s

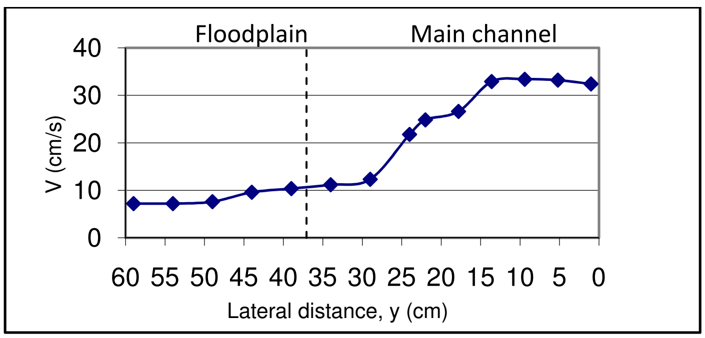

Figure 4.29: Lateral depth-averaged velocity for overbank flow with Q = 3.4 L/s

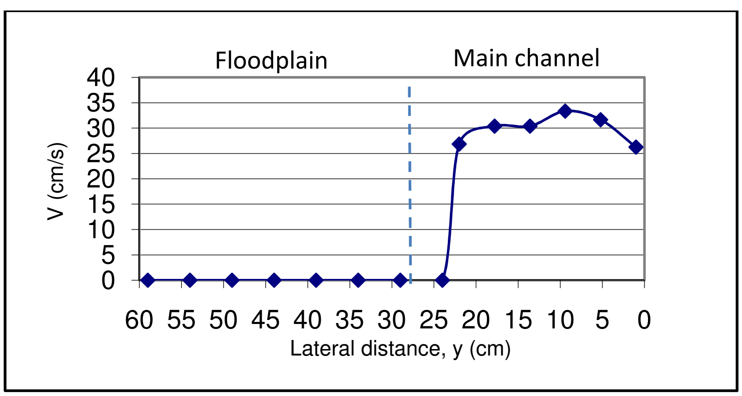

Figure 4.30 : Lateral depth-averaged velocity for overbank flow with Q = 3.1 L/s

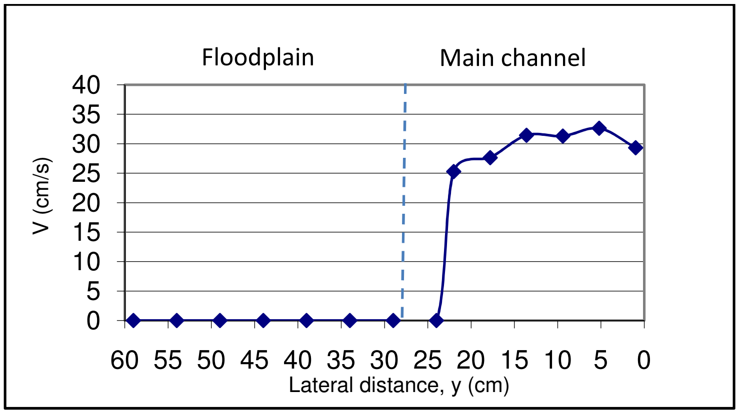

Figure 4.31 : Lateral depth-averaged velocity for overbank flow with Q = 2.8 L/s

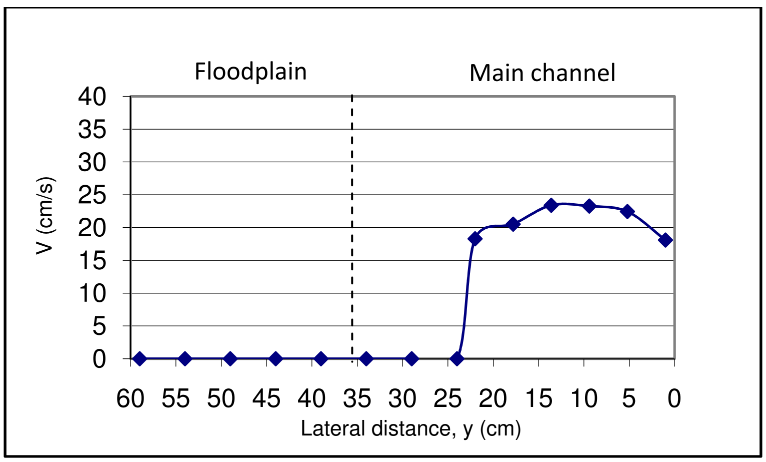

Figure 4.32 : Lateral depth-averaged velocity for inbank flow with Q = 2.4 L/s

Figures 4.28 and 4.29 show the depth-averaged velocity in the channel for high relative depth of flow, Dr. For these situations, the momentum (energy) transfer between main channel and floodplain is clearly can be seen from the Figures. However, the velocity on floodplain is smaller compared to case of smooth floodplain in Section 4.6.1. Meanwhile for small Dr (shallow inundation on floodplain), the velocity on floodplain is very small and almost cannot be measured by the miniature current meter during the experiments. This is due to resistance by the vegetation on the floodplain. As a result, the floodplain region serves as storage for shallow overbank instead of conveying the water, as discussed by Lai, S.H. *et al.* (2008a).

4.6.3 Combination of submerged and emergent vegetations

Velocity distributions in a compound channel with combination of vegetations are shown in Figures 4.33 to 4.46. The results are presented in term of normalised velocity (*U*/*Um*) for overbank flow with relative water depths (Dr) of 0.31, 0.26, 0.23 and 0.14, respectively.

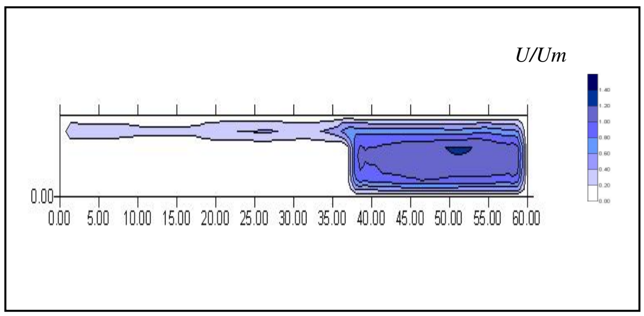

Figure 4.33: Normalised velocity distribution for

Q = 3.60 L/s (Dr = 0.31)

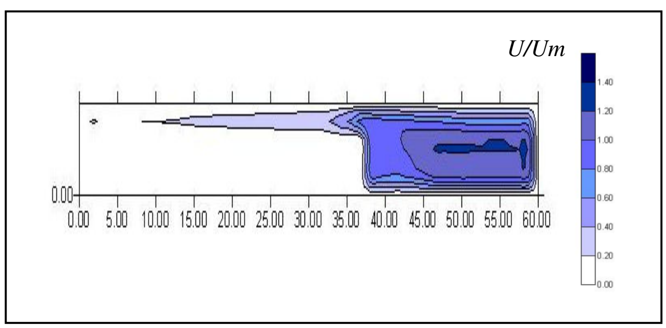

Figure 4.34: Normalised velocity distribution for

Q = 3.40 L/s (Dr = 0.26)

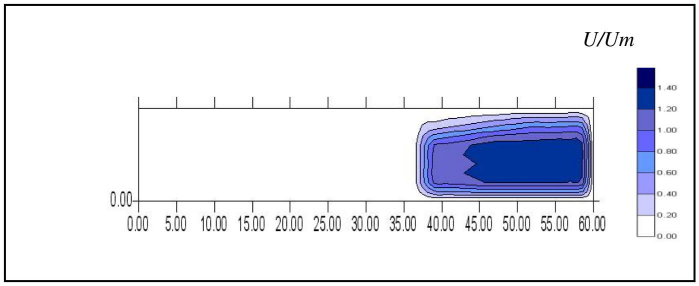

Figure 4.35: Normalised velocity distribution for

Q = 3.10 L/s (Dr = 0.23)

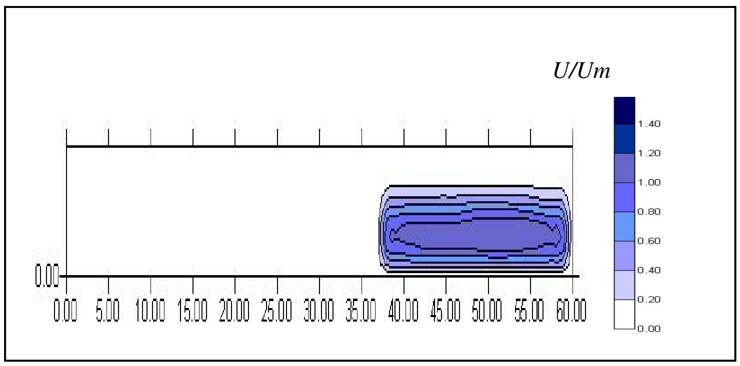

Figure 4.36: Normalised velocity distribution for

Q = 2.80 L/s (Dr = 0.14)

Figure 4.33 shows velocity distribution at a relative depth, Dr of 0.31. The velocity distribution shows that there is an area with a maximum velocity in the main channel. The velocity in main channel has been distributed to the floodplain area due to momentum transfer between both sections. It can be seen that bulging effect takes place between the main channel and floodplain. According to Sun and Shiono (2009), the effect of bulge is typical for deep water in compound channel flow. As the water depth increases, the bulging phenomenon becomes more prominent. Tominaga and Nezu (1991) in Sun and Shiono (2009) said that this phenomenon is caused by the secondary currents and the transfer of high-momentum fluid from the main channel to the floodplain.

For a floodplain with emergent vegetation, Pasche and Rouve (1985) and Sun and Shiono (2009) observed a “free shear layer” alongside the vegetative interface zone. However, in this study, the velocity patterns do not show the “free shear layer” in the vegetated zone. The reason is the numbers of trees (vegetation density) used in the experiment is small to cause formation of “free shear layer” in the channel. However, a similar result shows that the maximum velocity zones move toward the main channel wall in the main channel and towards the floodplain wall on the floodplain.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

The experimental study has developed understanding on the hydraulics of flood in compound channels with smooth and vegetated floodplains. The work covers the relationship between stage-discharge, roughness coefficient (Manning's n) and velocity distribution in the channels.

The presence of vegetations on the floodplains either as submerged or emergent has significant of the open channel hydraulics. The impacts are clearly shown in the water level changes and velocity distribution in the compound channel.

5.2 Conclusion

This study is carried out based various previous researches including Zulhilmi and Shiono (2006) and Sun and Shiono (2009). Among important conclusions can be drawn from this study are:

i. Vegetations on floodplain retard water flow and cause the water level in the main channel to increase by almost 10% compared to channel with smooth floodplains. Also, the conveyance capacity of vegetated compound channel is reduced.
ii. The roughness coefficient (in this study: Manning's n) for channel with vegetated floodplain is bigger than channel with smooth floodplain.
iii. Velocity distribution takes place due to momentum transfer as water overflow from main channel into floodplains. The presence of vegetation disturbed the momentum transfer process.

5.3 Recommendation

This study is an initial effort to understand the effect of vegetation on the river hydraulics during flooding. Current practice of vegetation removal in catchments especially the riparian vegetation for development needs good understanding on the significant impacts in order to better manage the rivers for their sustainability. It is really hope this research has provided some understanding on floodplain management. More works should be carried out to provide further understanding on the impacts of activities on the floodplains.

Some of further works to be carried out in the laboratory are:

i. The effect of vegetation densities on river hydraulics during flooding for non-mobile bed straight channels
ii. The effect of vegetation densities on river hydraulics during flooding for mobile bed straight channels
iii. The effect of vegetation densities on river hydraulics during flooding for mobile bed meandering channels
iv. The effect of vegetation densities on river hydraulics during flooding for mobile bed meandering channels

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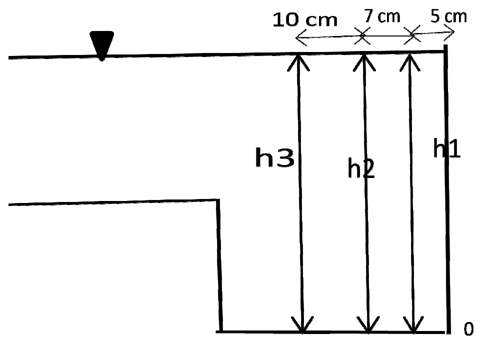
APPENDIX A1

Example of Experiment Data

Measurement of height of water and slope at 3.6 l/s

Q = 3.60 l/s

Tail Gate set at = 4.3 cm



Section B

Length	0.1.0 m			Average, h
Width from, 0	0.05	0.07	0.1	
Height	h1	h2	h3	
	0.0618	0.062	0.0634	0.0625
Bed	0.0053	0.0044	0.0047	0.005

Section C

Length	0.1.0 m			Average, h
Width from, 0	0.05	0.07	0.1	
Height	h1	h2	h3	
	0.0615	0.0622	0.0634	0.062
Bed	0.0075	0.0066	0.0066	0.0035

Section D

Length	0.1.0 m			Average, h
Width from, 0	0.05	0.07	0.1	
Height	h1	h2	h3	
	0.0619	0.062	0.0629	0.061
Bed	0.0081	0.0075	0.0074	0.0023

Section E

Length	0.1.0 m			Average, h
Width from, 0	0.05	0.07	0.1	
Height	h1	h2	h3	
	0.062	0.061	0.062	0.0608
Bed	0.0014	0.001	0.0014	0.0024

Section
F

Length	0.1.0 m			Average, h
Width from, 0	0.05	0.07	0.1	
Height	h1	h2	h3	
	0.0605	0.062	0.0629	0.0602
Bed	0	0.0009	0	0.0024

Section
G

Length	0.1.0 m			Average, h
Width from, 0	0.05	0.07	0.1	
Height	h1	h2	h3	
	0.0603	0.0614	0.0622	0.0597
Bed	0.005	0.003	0.003	0.0018

Calculation of water depth and slope at 3.4 l/s

Discharge	3.4 l/s	Tailgate set at = 5.0 cm			
Time (min)	120 min				
Section	(Main Channel, mm)				
L (mm)	Water	Slope	Bed	Slope	Depth
B = 1000	59		5	0.001	54
C = 1500	58.42	0.00116	3.587	0.001	53.42
D = 2000	57.84	0.00115	2.374	0.001	55.466
E = 2500	57.26	0.00116	2.427	0.001	54.833
F = 3000	56.68	0.00118	2.427	0.001	54.253
G = 3500	56.1	0.00114	1.897	0.001	54.203
Average		0.00116		0.001	54.363

Calculation of water depth and slope at 3.3 l/s

Discharge	3.3 l/s	Tailgate set at = 5.6 cm			
Time (min)	120 min				
Section	(Main Channel, mm)				
L (mm)	Water	Slope	Bed	Slope	Depth
B = 1000	56.4		5	0.001	51.4
C = 1500	55.7	0.0014	3.587	0.001	52.113
D = 2000	55	0.0014	2.374	0.001	52.626
E = 2500	54.4	0.0012	2.427	0.001	51.973
F = 3000	53.6	0.0012	2.427	0.001	51.173
G = 3500	52.9	0.0014	1.897	0.001	51
Average		0.0014		0.001	51.714

Calculation of water depth and slope at 2.8 l/s

Discharge	2.8 l/s	Tailgate set at = 7.5 cm			
Time (min)	120 min				
Section	(Main Channel, mm)				
L (mm)	Water	Slope	Bed	Slope	Depth
B = 1000	50.72		5	0.001	45.72
C = 1500	50.16	0.001	3.587	0.001	46.573
D = 2000	49.6	0.001	2.374	0.001	47.226
E = 2500	49.04	0.0014	2.427	0.001	46.613
F = 3000	48.5	0.001	2.427	0.001	46.073
G = 3500	47.92	0.0012	1.897	0.001	46.023
Average		0.00112		0.001	46.43

Calculation of water depth and slope at 2.35 l/s

Discharge	2.35 l/s	Tailgate set at = 5.0 cm			
Time (min)	120 min				
Section	(Main Channel, mm)				
L (mm)	Water	Slope	Bed	Slope	Depth
B = 1000	40.4		5	0.001	35.5
C = 1500	39.8	0.0012	3.587	0.001	36.213
D = 2000	39.2	0.0012	2.374	0.001	36.83
E = 2500	38.6	0.0012	2.427	0.001	36.173
F = 3000	38.1	0.001	2.427	0.001	35.673
G = 3500	37.5	0.0012	1.897	0.001	35.603
Average		0.00116		0.001	36

Example calculation of Manning's n for Q = 3.6 l/s

Bank	Q(l/s)	H(m)	P(m)	R	$R^{2/3}$	So	√So	n
Over Bank	3.6	58.178	0.7264	0.0284	0.0933	0.00112	0.0335	0.01796
	3.4	54.363	0.7188	0.02555	0.086742	0.00116	0.034	0.01593
	3.1	51.714	0.7135	0.0235	0.08203	0.0014	0.0374	0.01556
	2.8	46.43	0.7029	0.01924	0.0718	0.00112	0.0334	0.01158
Inbank	2.4	36	0.312	0.0277	0.0915	0.00116	0.034	0.011204

From equation (2.2): $n = \dfrac{AR^{\frac{2}{3}}So^{\frac{1}{2}}}{Q}$

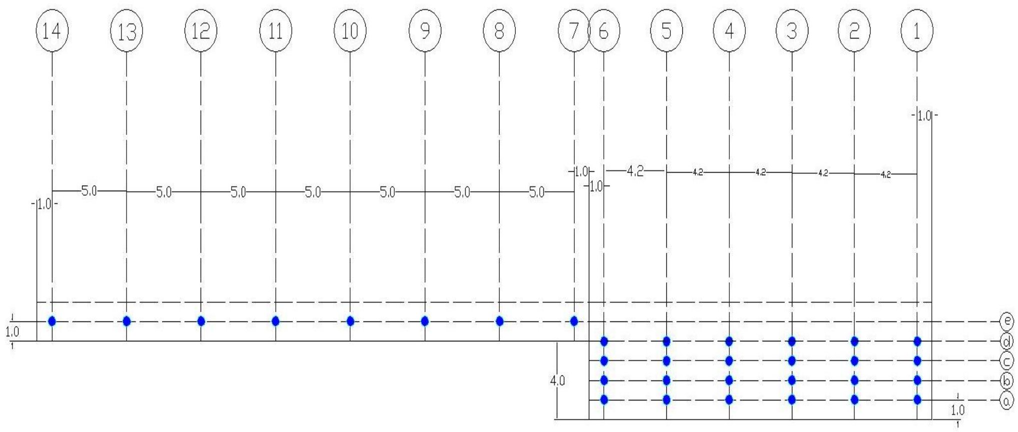
$$= \frac{(0.0269)(0.0933)(0.0335)}{0.0036}$$

$n = \underline{0.01796}$

APPENDIX A2

Example Velocity Data

Velocity Point (Submerge and emergent Floodplain)



	Q=3.6l/s						
	Point 1						
	Section 1		Section 2		average		**average**
	Hz	v(cm/s)	Hz	v(cm/s)	(Hz)	v(cm/)	**v/V**
a	4.4	24.54331	4.2	23.75591	4.30	24.15	**0.85**
b	5.6	29.26772	5.4	28.48031	5.50	28.87	**1.01**
c	5.8	30.05512	5.6	29.26772	5.70	29.66	**1.04**
d	5.9	30.44882	5.1	27.29921	5.50	28.87	**1.01**
	Point 2						
	Section 1		Section 2		average		**average**
	Hz	v(cm/s)	Hz	v(cm/s)	(Hz)	v(cm/)	**v/V**
a	4.6	25.33071	4.9	26.51181	4.75	25.92	**0.91**
b	5.3	28.08661	6.1	31.23622	5.70	29.66	**1.04**
c	5.9	30.44882	6.4	32.41732	6.15	31.43	**1.10**
d	5.8	30.05512	7	34.77953	6.40	32.42	**1.13**
	Point 3						
	Section 1		Section 2		average		**average**
	Hz	v(cm/s)	Hz	v(cm/s)	(Hz)	v(cm/)	**v/V**
a	4.9	26.51181	4.9	26.51181	4.90	26.51	**0.93**
b	5.3	28.08661	5.4	28.48031	5.35	28.28	**0.99**
c	6.7	33.59843	6.3	32.02362	6.50	32.81	**1.15**
d	7.8	37.92913	7.5	36.74803	7.65	37.34	**1.31**

	Point 3						
	Section 1		Section 2		average		**average**
	Hz	v(cm/s)	Hz	v(cm/s)	(Hz)	v(cm/)	**v/V**
a	5.8	30.05512	4.6	25.33071	5.20	27.69	**0.97**
b	6.3	32.02362	5.8	30.05512	6.05	31.04	**1.09**
c	6.5	32.81102	6.8	33.99213	6.65	33.40	**1.17**
d	6.1	31.23622	6.7	33.59843	6.40	32.42	**1.13**

	Point 4						
	Section 1		Section 2		average		**average**
	Hz	v(cm/s)	Hz	v(cm/s)	(Hz)	v(cm/s)	**v/V**
a	5.6	29.26772	3.4	20.6063	4.50	24.94	**0.87**
b	5.9	30.44882	4.9	26.51181	5.40	28.48	**1.00**
c	5.6	29.26772	5.9	30.44882	5.75	29.86	**1.04**
d	4.9	26.51181	6.7	33.59843	5.80	30.06	**1.05**

	Point 5						
	Section 1		Section 2		average		**average**
	Hz	v(cm/s)	Hz	v(cm/s)	(Hz)	v(cm/s)	**v/V**
a	4.3	24.14961	3.2	19.8189	3.75	21.98	**0.77**
b	5.6	29.26772	4.8	26.11811	5.20	27.69	**0.97**
c	5.6	29.26772	5.4	28.48031	5.50	28.87	**1.01**
d	4.4	24.54331	5.9	30.44882	5.15	27.50	**0.96**

	Floodplain						
	Section 1		Section 2		average		**average**
	Hz	v(cm/s)	Hz	v(cm/s)	(Hz)	v(cm/s)	**v/V**
7	2.5	17.06299	3.2	19.8189	2.85	18.44	**0.65**
8	1.6	13.51969	0.8	10.37008	1.20	11.94	**0.42**
9	2.4	16.66929	1.6	13.51969	2.00	15.09	**0.53**
10	2.4	16.66929	1.1	11.55118	1.75	14.11	**0.49**
11	0.6	9.582677	0.5	9.188976	0.55	9.39	**0.33**
12	0.6	9.582677	0.3	8.401575	0.45	8.99	**0.31**
13	1.9	14.70079	0.1	7.614173	1.00	11.16	**0.39**
14	1.9	14.70079	0.1	7.614173	1.00	11.16	**0.39**
					V(total) =	**800.15**	
					V(average)=	**28.58**	

APPENDIX A3

Graph Indicator for Longitudinal Velocity

Graph indicator versus longitudinal velocity for Nixon Streamflo 404 velocity meter