EVALUATION OF SEDIMENT SIZE FOR FLOW ESTIMATION IN ALLUVIAL CHANNEL

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TABLE OF CONTENTS

CHAPTER 1 INTRODUCTION

CHAPTER 2 LITERATURE REVIEW

CHAPTER 3 METHODOLOGY

CHAPTER 4 RESULTS AND DISCUSSIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

A	cross sectional area [m^2]
a	individual partial cross section area [m^2]
B	width [m]
B_i	coefficient value
C_0	constant [C_0=2.3/K]
Cu	uniformity coefficient
D	vertical distance between water surface and streambed [m]
d	particle size [m]
d_{50}	median particle size
d_m	mode particle size
f	friction factor
f_w	sidewall friction factor
f_b	bed friction factor
Fr	Froude number
g	gravitational acceleration [ms^{-2}]
H	total depth [m]
h	flow depth [m]

K	Karman's coefficient [K=0.4]
k_s	Nikuradse's equivalent grain roughness
m_1	correction factor for meandering and curvature of the channel
n	Manning roughness coefficient [$\mathrm{m}^{1/3}\mathrm{s}^{-1}$]
n_b	basic n value
n_1	value correction factor due to surface irregularities
n_2	value for variations in shape and size of the channel cross section
n_3	value for obstructions in the channel
n_4	value for vegetation and flow conditions
P	wetted perimeter [m]
R^2	coefficient of determination
Q	flow discharge [m^3/s]
R	hydraulic radius [m]
Re	Reynolds number
$r_{v\mathrm{m}}$	corrected vegetation-related hydraulic radius
r_v	vegetation related hydraulic radius
S	hydraulic gradient slope
T	temperature of water [$^0\mathrm{C}$]
V	flow velocity [ms^{-1}]

v	mean velocity of the flow normal to the partial cross section area
x	measurement point
Y_0	average depth [m]
λ	vegetation density
u^*	shear velocity
σ_g	Geometric standard deviation

LIST OF ABBREVIATION

ADCP	Acoustic Doppler Current Profiler
ADV	Acoustic Doppler Velocity
ASCE	American Society of Civil Engineers
BS	British Standard 1377: Part 2: 1990:9.3
CFD	Fluid Dynamic Model
EDM	Electronic Distance Meter
GEP	Gene Expression Programming
GIS	Geography Information System
ISO	International Organization for Standardization
JUPEM	Department of Survey and Mapping Malaysia
MSMA	Urban Stormwater Management Manual for Malaysia
RMSE	Root Mean Square Error
USACE	US Army Corps of Engineers
USCS	Unified Soil Classification System
USGS	United State Geological Survey

PENILAIAN SAIZ SEDIMEN UNTUK MENENTUKAN KADAR ALIRAN DALAM SALIRAN ENDAPAN

ABSTRAK

Penganggaran aliran dalam saliran endapan adalah satu amalan yang paling biasa dalam bidang kejuruteraan sungai. Kebanyakan kaedah telah diperkenalkan dalam usaha untuk meningkatkan ketepatan penentuan pekali kekasaran dan penganggaran aliran dengan berdasarkan saiz endapan. Walau bagaimanapun, kebanyakan kajian ini adalah berdasarkan keadaan makmal unggul seperti aliran dan pemendapan yang seragam. Kaedah-kaedah yang diperolehi adalah tidak sesuai digunakan dalam saluran dengan bentuk yang tidak teratur. Kepentingan kajian ini adalah untuk menentukan pekali kekasaran dengan pemilihan saiz endapan ke arah pengagihan pemendapan yang tidak seragam dalam saluran dengan bentuk yang tidak teratur. Beberapa persamaan yang dikenali telah dikaji dengan penilaian dan perbandingan penganggaran aliran rintangan. Dalam kajian ini, sejumlah 167 set data telah dikumpulkan. 31 set data yang dikumpulkan dari Sungai Jawi telah digunakan untuk menentukan ciri-ciri hidraulik bagi Sungai Jawi. 136 set data yang dikumpulkan daripada lapan sungai yang telah dipilih daripada kajian sebelumnya ini telah digunakan untuk menilai persamaan yang sedia ada berasaskan untuk penentuan rintangan aliran. Melalui kajian ini, tiada persamaan yang menganggarkan aliran dengan tepat. Mod saiz endapan, d_{65} telah dicadangkan untuk mewakili campuran endapan penganggaran aliran. Dalam akhir kajian ini, satu persamaan baru telah diperkenalkan berdasarkan jumlah 167 set data. Persamaan ini adalah bertujuan untuk menetukan rintangan aliran dengan nisbah jejari hidraulik dan purata kedalaman aliran kepada mod saiz endapan. Keputusan telah menunjukkan peningkatan terhadap percanggahan dalam anggaran aliran berdasarkan penggunaan d_{65}. Persamaan baru yang diperkenalkan telah menunjukkan prestasi yang terbaik dengan R^2=0.991 dalam penganggaran aliran untuk sungai yang dikaji di Semenanjung Malaysia dengan saiz endapan, d_{65}.

EVALUATION OF SEDIMENT SIZE FOR FLOW ESTIMATION IN ALLUVIAL CHANNEL

ABSTRACT

Flow estimation in alluvial channel is one of the most common practices in river engineering. A lot of methods are introduced in water resources field towards increasing the accuracy of determining the roughness coefficient as well as estimating the flow based on sediment size. However, most of these studies are mainly based on idealized laboratory conditions such as uniform flow and uniform sedimentation. These derived methods do not satisfy for channel with irregular shapes. The interest of this study is to determine the roughness coefficient in term of choices of sediment size towards non uniform sedimentation distribution in irregular channel. A few relevant well known equations are used in evaluating and comparing the flow resistance estimation. In this study, a total number of 167 sets of field data were collected. 31 sets data which collected from Sungai Jawi were used to investigate the hydraulic characteristics of Sungai Jawi. Another 143 sets field data of eight selected rivers collected from previous studies were used to evaluate the accuracy of existing well known equations for determining the flow resistance. Throughout the analysis, none of the method estimates the flow accurately. Sediment mode size, d_{65}, was proposed to represent the sediment mixture for flow estimation purpose. At the end of this study, an equation had been developed based on the total 167 sets of data. This equation is intended to determine the flow resistance with the ratio of hydraulic radius and averaged flow depth to the sediment mode size. The results show an improvement to the discrepancy of flow estimation based on the applicable d_{65}. The newly developed equation is proven to give

the best performance with R^2=0.991 to estimate the flow capacity for studied rivers in Peninsular Malaysia based on sediment size of d_{65}.

CHAPTER 1

INTRODUCTION

1.1 Background

Flow estimation is one of the most common tasks in river engineering. The estimation of flow through the channels is complex because of the variability of natural river shape and surface condition. Flow estimation for irregular channel is very difficult due to the inconsistent of river bed materials and river shapes which may influence their natural flow behavior. There are some factors which influencing the value of roughness coefficient with certain levels of difficulty in determining these factors. Therefore, a lot of methods are introduced in water resources field towards increasing the accuracy of determining the roughness coefficient. In this study, suitability of a few methods in determining roughness coefficient which is commonly known as flow resistance will be investigated before further analysis for river flow estimation is carried out.

In recent years, many studies have been carried worldwide to discover the complex phenomenon in river engineering such as momentum transfer, apparent shear and secondary current that occur in rivers especially during flooding condition. Studies had also being carried out in low flow analysis as well as to derive a reliable method for flow estimation. This type of phenomenon had been extensively studied as to understand the flow estimation due to the effect of geomorphological which include the studies done by Strickler (1923), Meyer-Peter and Muller (1948), Lane and Carlson (1953), Limerinos (1970), Bray (1979), Brownlie (1983), Bruschin (1985) and Diaz

(2005). This phenomenon is due to boundary layer effect, bed shear stress, and the sedimentation roughness. However, most of these studies are mainly based on idealized laboratory conditions such as uniform flow and uniform sedimentation. These derived methods are not satisfied for channel with irregular shapes. As a conclusion, there is yet no generally accepted method for flow estimation in different shapes of channel.

Research for the understanding of roughness coefficient had been carried out by few research institutions and in United States, for example, US Army Corps of Engineers (USACE) and United State Geological Survey (USGS). It is necessary to focus in studying the river channel behaviour and to evaluate the existing flow estimation methods developed by previous researchers. At the end of this study, a suitable method for flow estimation in river is developed.

1.2 Problem Statements

Determining the roughness coefficient has become an important issue in river engineering for river or natural channel flow estimation. According to Barnes (1967), the ability to evaluate the roughness coefficient must be developed through experience for the sake of flow estimation quality assurance. Since the estimation of roughness coefficient requires experience, this study will be useful as it determines the suitability of the methods in river flow estimation in Peninsular Malaysia.

From the previous studies, d_{50} is the median sediment size, which is widely used to represent a sediment mixture (Shields, 1936; Yalin, 1963; Bagnold, 1980). This assumption for d_{50} had been made due to equality of the mode, median, and mean values for natural sediment coincidentally. According to Almedeij (2003), the selections of sediment size is very important in bed load transport (Einstein, 1950; Misri et al., 1984) and hence will influence the flow estimation indirectly. The selection of the sediment size depends on the mode from the numbers of data that had been collected at field studies. Throughout the years, different sediment size had been used by a few researchers for flow prediction, such as d_{50} (Strickler, 1923; Chang, 2006), d_{75} (Lane and Carlson, 1953) and d_{90} (Meyer-Peter and Muller, 1949). Flow estimation methods applied for river in Malaysia have been successfully developed by a few of researchers. These methods include of flow simulation in laboratory by using mathematical modeling of flow pattern due to sedimentation at Ijok River (Noor Shahidan et al., 2012); determination of *Manning's n* by using Gene Expression Programming (GEP) for computation of flow rate (Azamathulla, 2012); and revised equations for *Manning's n* for sand bed river based on 163 data in Malaysia (Ab. Ghani et al., 2007). However, some of the established methods are insufficiently applied for the river in Malaysia due to the different site conditions mainly in term of river geometrically and the side boundary effect. Furthermore, the rapid flows of rivers in Peninsular Malaysia will increase the difficulty in data collection especially during monsoon season.

The interest of the study is to determine the roughness coefficient in term of the sediment size selection towards non uniform sedimentation and river with irregularity shapes in Peninsular Malaysia. Thus, Sungai Jawi has been chosen for data collections in order to observe the flow pattern and hydraulic characteristic of rivers. The combination of all the data which collected from river in Malaysia by previous researchers and current study were then evaluated and compared by using *Manning's n*. This study is necessary to give a better accuracy for flow estimation based on roughness effect towards the hydraulic field.

1.3 Objectives

The objectives of this study are as below:-

a) To evaluate the sediment size of alluvial channel for flow estimation
b) To propose an accurate flow estimation method in term of sediment size for rivers in Peninsular Malaysia

1.4 Scopes of Present Study

The study focuses on flow estimation method for the common rivers in Malaysia. Field study was carried out at Sungai Jawi, Relau in Kedah state (Figure 1.1). The distance of the site is 14 kilometers away from Engineering Campus, Universiti Sains Malaysia, Nibong Tebal, Penang. Apart from this, six sets of field data were obtained from previous studies (Abdul Ghaffar, 2003). These data were collected from Sungai Pari, Manjoi; Sungai Pari, Buntong; Sungai Raia, Kampung Tanjung; Sungai Raia, Batu Gajah; Sungai Kinta, Ipoh; and Sungai Kampar, Station KM34. The hydraulic parameters collected included of flow rate, flow depth, width of river, hydraulic slope of river and sediment data. With the collected hydraulic parameters, river cross section and hydraulic radius could be determined. All data collected were assumed to be from uniform flow condition and non uniform sedimentation. The analysis of the study is carried out under different slopes condition, roughness coefficient and various flow rates with different flow depths.

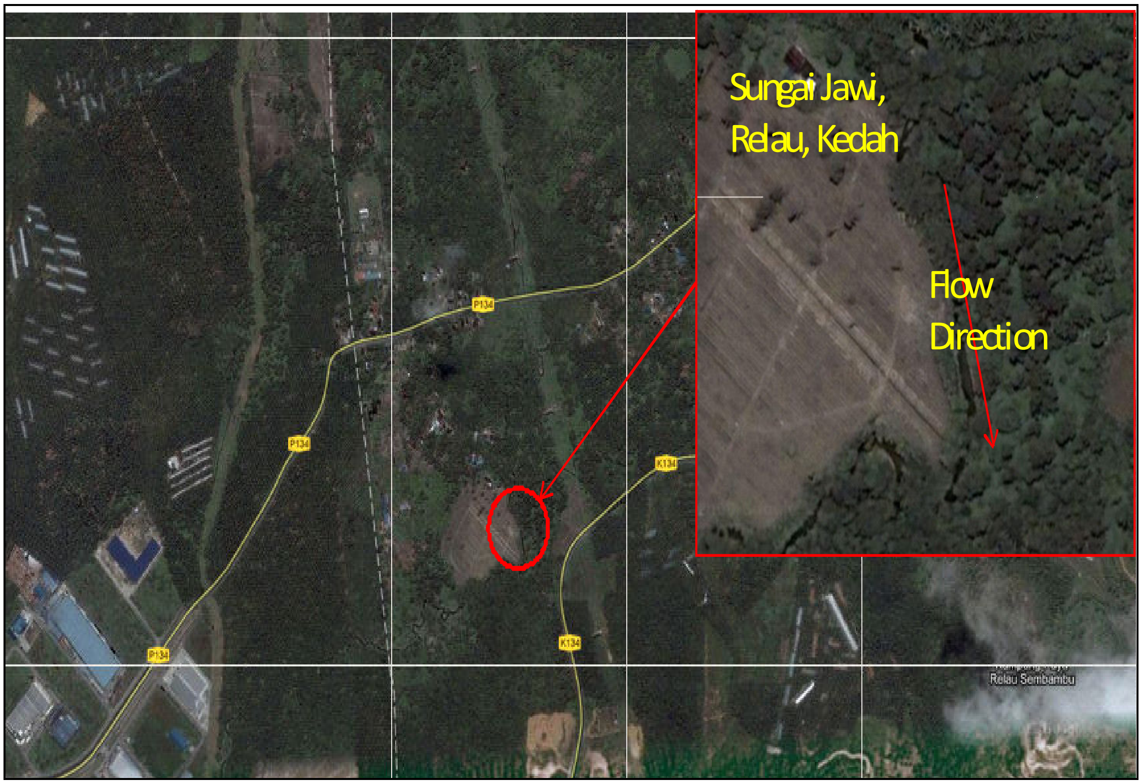

Figure 1.1: Location of Sungai Jawi, Relau, Kedah

1.5 Outline of Thesis

This thesis consists of five chapters. Following this introductory chapter, Chapter 2 gives a review of previous researchers on the factors which affecting the accuracy of flow estimation and the methods to use for flow estimation. Chapter 3 describes the methodology and selected site which also involves some detail measurement techniques, laboratory procedures and data analysis methods. The evaluation of previous existing methods in flow estimation and the derivation of flow estimation method is presented in Chapter 4. Finally, Chapter 5 summarizes the overall study. Conclusions and recommendations were made for future research work to further the present study. A list of relevant references and appendices are given at the end of the thesis.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Alluvial channel is defined as a channel which is formed by sediment deposition in a flowing stream. The alluvial channel is usually found in stream or river which carries a lot of different types of materials such as sand, pebbles, cobbles or gravel and large variation in flow discharge will be observed. Generally, the alluvial channels will change with time by the river geomorphology. River geomorphology is a scientific study of processes to form the shape of the river. The evolution of alluvial channel may due to sediment transportation, erosion and climate change.

Alluvial channels are self-formed morphologies which are set by sediment transportation, sediment deposition and climate change (Whipple, 2004). The formation of the alluvial channel is depending on the environmental control such as the river hydraulic and hydrology, sediment characteristics and geotectonic. In the past, many researchers had attempted to develop a flow equation for the purpose of estimating flow at alluvial channel from readily available hydraulic, hydrologic, and geomorphologic parameters such as the irregular perimeter and inconsistence depth across the river. The changes of geomorphologic parameters are due to the changes in term of landform of the river along the time. However, most of them had met with only limited success due to the difficulties in selection of parameters in order to estimate the flow accurately. Hence, clear understanding of the alluvial channels is important in river management and environmental management in order to improve the flow estimation method.

2.2 Flow Estimation Methods in Alluvial Channel

Flow estimation is a common task in hydraulic study, either in closed pipe conduit or open channel. This is very important in flood control, works and decisions making which is related to the water resources management such as flood risk and drought (Stuckey and Reed, 2000). An accurate estimation is vital for flow resistance coefficient as well as flow discharge estimation.

Generally, flow rate (*Q*) is defined as the ratio of the amount of water (in volume) passing through a fixed time with a unit of time and is usually expressed in cubic meter per second (m^3/s). The flow discharge is found to be increasing gradually from upstream to downstream. Somehow, the flow discharge can be affected by various factors, such as climate change, geometrical shape of channel, steepness of longitudinal slope, composition of channel, channel roughness and etc. (Chow, 1959). Various methods as well as empirical formulas have also been proposed for flow discharge calculation as well as flow resistance estimation from the previous studies.

The two point velocity method where the velocities at two-tenth and eight-tenth of the depth, has been re-investigates (Nguyen and Fenton, 2004). This method is applied and used to estimate the roughness for three rivers in Australia (Acheron River, Merrimans Creek and Tambo River) based on logarithm velocity distribution. A sensitivity analysis is used to compare and evaluated with others applicable methods. The empirical formula used to compare are Lacey, Riggs, Bray, Sauer and Dingman. The results from the two point velocity method are found better than using other empirical formula. This method is recommended to estimate the flow resistance for any rivers where two point velocity data are easily collected in river.

2.2.1 Stage and Discharge Relationship

Stage and discharge relationship which is also known as rating curve is a common method used to estimate the flow in natural or artificial open channel based on the depth of the stream either in uniform flow or non uniform flow condition. The power or polynomial curves are generated from the rating curve in terms of table or graphical methods. The rating curve is essential in order to estimate the flow during or under a flood occurrence. This relationship can be in simple or complex form depending on the flow regime and geometrical of the river. (Azamathulla et. at., 2011) . The minimum requirement for the analysis of rating curve needs to be at least 12 to 15 measurements based on ISO regulation 1100-2 (ISO, 2010).

Rating curve is a traditional and the most common method in river engineering to estimate and simulate the flow discharge for an open channel in uniform flow condition. However, in practically, the non uniform flow usually occurs in a river with certain conditions. These conditions will occur when the gradient of surface varies for unsteady flow, the cross section of river changes with erosion and deposition of sediment, and the flow resistance changes with river bed and the geometrical effect. The error will even become worst with the extrapolation method for overbank discharge estimation. This is due to the complex 3D turbulent structure and flow interactions between main channel and flood plain (Lai, 2008).

According to Leonard (2000), it is very difficult to establish a reliable rating curve and it is often impossible during the unstable measurement of cross section. The objective of his study is to develop a modified *Manning's* equation to express flow discharge as a function of hydraulic radius and water surface gradient as well as stage discharge relationship. The rating curve is highly dependent on the accuracy of the parameter that determines the water surface gradient. The finding of this study is that the result from flow estimation varies widely and inaccurate flow estimation was observed during high flow. The changes in cross section resulted from erosion or deposition had induced a modification of hydraulic radius. Due to these reasons, the traditional method for flow estimation in non uniform flow and higher flow were found to be not very accurate (Carter, 1973; Potter and Walker, 1985). This may lead to the underestimation or overestimation of discharge capacity.

2.2.2 *Manning's n* Equation

An Irish engineer, Robert Manning, is also known as the creator of *Manning's n* formula. Seven best known formulas were chosen by Manning which include of Du Buat (1786), Eyelwein (1814), Weisbach (1845), St. Venant (1851), Neville (1860), Darcy and Bazin (1865), and Ganguillet and Kutter (1869), were compared and evaluated based on a given slope and varies hydraulic radius from 0.25m to 30m (Bertrand-Krajewski, 2006).

The mean value of the seven velocities was found for each condition where *Manning's n* equation was developed as a simple formula for open channel flow as stated in Equation 2.1:

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

(2.1)

where V is the velocity of the flow, n is *Manning's n* coefficient, R is hydraulic radius, and S is hydraulic gradient slope for an open channel.

Manning's n equation is a well known empirical equation in river engineering. This equation has been widely accepted which can be used to describe the flow behaviour under closed conduit or simple open channel. Theoretically, *Manning's n* coefficients are only constant for a certain depth of flow under uniform and steady flow (Chow, 1959). However, uniform flow condition is seldom occurred in a natural stream because of the stream alignment and the differences of cross section along the stream. Furthermore, the inaccuracy of predicting the flow resistance increases especially during flood flow in irregular channel which may due to the irregularity of channel shape and the interaction of flow between flow in flood plain and main channel (Chow, 1959). Based on above consideration and limitation, *Manning's n* equation is not appropriately applicable in relatively low or high flow under non uniform flow conditions.

2.2.3 Factors Affecting *Manning's n* Roughness Coefficient Value

According to Chow (1959), the values of *Manning's n* are listed to be a constant in Table 2.1 based on bed materials in the channel. However, a channel does not have a constant *Manning's n* under different conditions in realistic. In fact, the values of

Manning's n are highly depended on the affecting factors which include (Chow, 1959):

i. Surface Roughness – Surface roughness is presented by the size and shape of the grains of the material forming the wetted perimeter and producing a retarding effect on the flow. In general, fine grains result in a relatively low value of *Manning's n* and vice versa.
ii. Vegetation – The effect of vegetation towards value of *Manning's n* depends on height, density, distribution and type of vegetation.
iii. Channel Irregularity – The channel irregularities include irregularities in wetted perimeter and variations in cross section, size, and shape along the channel length. In general, a gradual and uniform change in cross section, size and shape will not appreciably affect the value of *Manning's n*, but an abrupt change or alternation of small and large sections results the needs of large value of *Manning's n*.
iv. Channel Alignment – Smooth curvature with large radius will give a relatively low value of *Manning's n*, whereas sharp curvature with severe meandering will increase *Manning's n*.
v. Silting and Scouring – In general, silting may change a very irregular channel into a comparatively uniform channel and thus decrease the value of *Manning's n*. Scouring may do the reverse and increase the value of *Manning's n*.
vi. Obstruction – The presence of log jams and bridge piers tends to increase *Manning's n.*

vii. Size and Shape of Channel – An increase of hydraulic radius may either increase or decrease the *Manning's n*. Though, there is no strong evidence about this factor as an important factor in influencing the *Manning's n.*

viii. Stage and Discharge – The *Manning's n* value in most streams decreases with increase in stage and in discharge.

ix. Seasonal Change – The value of *Manning's n* may increase in the growing season and diminish in the dormant season.

x. Suspended Material and Bed Load – The suspended material and the bed load, whether moving or not moving, would consume energy and cause head loss or increase the apparent channel roughness.

Table 2.1: Type of channel and description of *Manning's n* for natural channels (top width at floodstage < 3m) in three stages of flow (Chow, 1959)

Main Channel	***Manning's n***		
	Minimum	**Normal**	**Maximum**
i. clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
ii. same as above, but more stones and weeds	0.030	0.035	0.040
iii. clean, winding, some pools and shoals	0.033	0.040	0.045
iv. same as above, but some weeds and stones	0.035	0.045	0.050
v. same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
vi. same as "iv" with more stones	0.045	0.050	0.060
vii. sluggish reaches, weedy, deep pools	0.050	0.070	0.080
viii. very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150

Cowan (1956) developed a recognized procedure to compute and estimate the *Manning's n* coefficient which may be affected by these factors:

$$n = (n_b + n_1 + n_2 + n_3 + n_4)m_1 \tag{2.2}$$

where n_b is a basic *n* value for a straight, uniform, smooth channel in the natural bed and boundary materials involved, n_1 is a value correction factor due to surface irregularities, n_2 is a value for variations in shape and size of the channel cross section, n_3 is a value for obstructions in the channel such as log jammed or bridge pier, n_4 is a value for vegetation and flow conditions, and m_1 is a correction factor for meandering and curvature of the channel. The value of n_b to n_4 and m_1 can be referred to Chow (1959).

This approach was followed by few researchers to study the flow resistance in open channel in order to have the knowledge and deep understanding for the related study. Several methods on determination of *Manning's n* coefficient have been studied which related to the flow estimation in a natural river. The following include some methods from various researchers:

(a) Strickler (1923) had developed an empirical formula for circular pipe which introduce one parameter to describe *Manning's n* coefficient value based on median particle size, d_{50}:

$$n = \frac{1}{21.1} d_{50}^{1/6} \tag{2.3}$$

In early 19th century, this friction formula is a fundamental in theoretically and applied hydraulics. Therefore, the verification of flow estimation is begun from that time, in order to predict the uncertainty rates of the *Manning's n* coefficient accurately.

(b) Another attempt had been made by Peter-Meyer and Muller (1948) to derive an empirical formula of bed load transport based on experimental data.

$$n = \frac{1}{26} d_{90}^{1/6} \tag{2.4}$$

A mixture of particle size from 0mm to10mm was analysed with square meshed sieve. A single 'effective diameter' was introduced to characterize the mixture. Based on Strickler formula and Nikuradse's diagram, a coarser particle size, d_{90} has been chosen instead of d_{50} to adopt in the formula based on smooth bed in natural river with not fully developed turbulence condition (Strickler, 1923).

(c) In straight gravel bed channels, the boundary friction is a major factor affects the *Manning's n* coefficient value when the sediment bed load transport is minimal. Consequently, Lane and Carlson (1953) had seek the empirical formula from the relationship between *Manning's n* coefficient and the particle size based on Strickler formula:

$$n = \frac{1}{21.14} d_{75}^{1/6} \tag{2.5}$$

(d) According to Barnes (1967), *Manning's n* coefficient could be determined by using color photographs and descriptive data for 50 stream channels. Cross sections of typical rivers were also included to determine *Manning's n* coefficient value by referring to a typical roughness coefficient table and by examining the geometry of typical channels from which the roughness coefficients were known. Slope-area method was used for flow estimation which only applicable to turbulent flow in fully rough channel. However, this method would be impractical with difficulties in matching the similarity geometry condition of the channel for the selection of *Manning's n* coefficient.

(e) Determination of *Manning's n* coefficient had also been studied by Limerinos (1970) based on measured bed roughness in natural channel. 50 sets of flow measurement were obtained at eleventh sites on California streams for the purpose to estimate the *Manning's n* coefficient by using Manning formula. Initially, the particle sizes d_{16}, d_{50} and d_{84} were used to analyse the characteristic of bed particle size. Throughout the analysis, d_{84} particle size had been chosen to represent the measure of roughness height. Hydraulic radius, R and particle size d_{84} had then been used to define the relationship with *Manning's n* coefficient. A formula for natural alluvial channels was developed as:

$$n = \frac{0.0926 R^{1/6}}{1.16 + 2.0 \log\left(\frac{R}{d_{84}}\right)} \tag{2.6}$$

(f) Bray (1979) had derived an equation in logarithmic form base on data collected from 67 gravel bed channels in Alberta, Canada. The equation was used to verify the relative high in bank flow with the computing average velocity in natural channel. Limerinos-Manning's equation and Lacey's equation were used to compare with Bray's equation due to the similar condition applicable for gravel bed channels in term of particle size. Throughout the analysis, Limerinos-Manning's equation is the most suitable formula in estimation of average velocity in gravel bed river where else Lacey's equation provides satisfactory result without using the roughness parameter. The data collected include averaged depth, Y_o instead of hydraulic radius, R and median particle size, d_{50} in deriving the formula:

$$n = \frac{0.113 Y_o^{1/6}}{1.09 + 2.2 \log_{10}\left(\frac{Y_o}{d_{50}}\right)} \tag{2.7}$$

(g) Brownlie (1983) had collected 77 sets data where 75 percent were from laboratory flume studies and 25 percent from field studies. A significant agreement by using field and flume data are demonstrated by using twenty-two sets data from a total of 77 sets data. Brownlie's equations were modified from statistical analysis method to express the bed roughness parameter times the particle size. The parameters used for the derivation of Bray's equation consists of hydraulic radius (R), median particle size (d_{50}) and hydraulic slope (S):

$$n = \left[1.893\left(\frac{R}{d_{50}}\right)^{0.1374} \times S^{0.1112}\right] \times 0.034 d_{50}{}^{0.167} \tag{2.8}$$

(h) Bruschin (1985) had derived an equation based on numerical modeling with dimensional analysis for flow regime determination. The purpose of this study is to investigate the relationship which similar with Bray's equation and can be used in a wide range under uniform flow condition. The model was found out to be performed relatively better by using laboratory and field data. An equation was formed as:

$$n = \frac{d_{50}^{\ 1/6}}{12.38} \times \left(\frac{R}{d_{50}} \times S \right)^{1/7.3} \tag{2.9}$$

(i) Diaz (2005) had proposed an alternative method of determining *Manning's n* coefficient by considered the averaged depth, hydraulic slope and Froude number which may be applied in shallow flow depth channel and channel with steep slope.

$$n = \frac{Y_0^{\ 1/6} S^{1/2}}{\sqrt{9.81} Fr} \tag{2.10}$$

Froude number (*Fr*) was found to be essential and useful in computing the *Manning's n* coefficient based on Diaz's finding. However, the difficulties in obtaining the Froude parameters will cause the complexity in application of Diaz's equation.

(j) Ab. Ghani (2007) had collected a total of 163 data from sand bed rivers in Malaysia which intended to revise the flow resistance estimation methods. The major rivers studied were Kinta River catchment with 122 data from Ab. Ghani et al. (2003), followed by Langat River with 23 data from Ariffin (2004) and Kulim River with 18 data from Chang (2006). These studied rivers are used to evaluate the existing flow resistance and to develop a new equation for the similarity conditions whereby the studied site area were densely forested.

Evaluation of the existing flow estimation methods have been done where the equations are based on seven equations in terms of particle size; the ratio of averaged flow depth or hydraulic radius over particle size; and combination of hydraulic slope, particle size, and hydraulic radius or averaged flow depth. The existing flow resistance estimations are found to underestimate or overestimate the measured *Manning's n* value for studied river due to natural and irregular condition of the rivers. Hence, two equations are recommended to determine *Manning's n* value which applicable for sand bed stream in Malaysia in term of median particle size (d_{50}) (Chang, 2006):

$$n = 4\times10^{-8}\left(\frac{Y_o}{d_{50}}\right)^2 - 5\times10^{-5}\left(\frac{Y_o}{d_{50}}\right) + 0.0582 \tag{2.11}$$

$$n = 5\times10^{-8}\left(\frac{R}{d_{50}}\right)^2 - 7\times10^{-5}\left(\frac{R}{d_{50}}\right) + 0.0622 \tag{2.12}$$

Figure 2.1 and Figure 2.2 show the relation between *Manning's n* and the ratio of averaged flow depth or hydraulic radius to median particle size with correlation, $R^2 = 0.87$ for both equation. Overall, the researcher believed that both equations have an error less than 10% in estimating the flow discharge rate for the data collected for river in Malaysia (Chang, 2006).

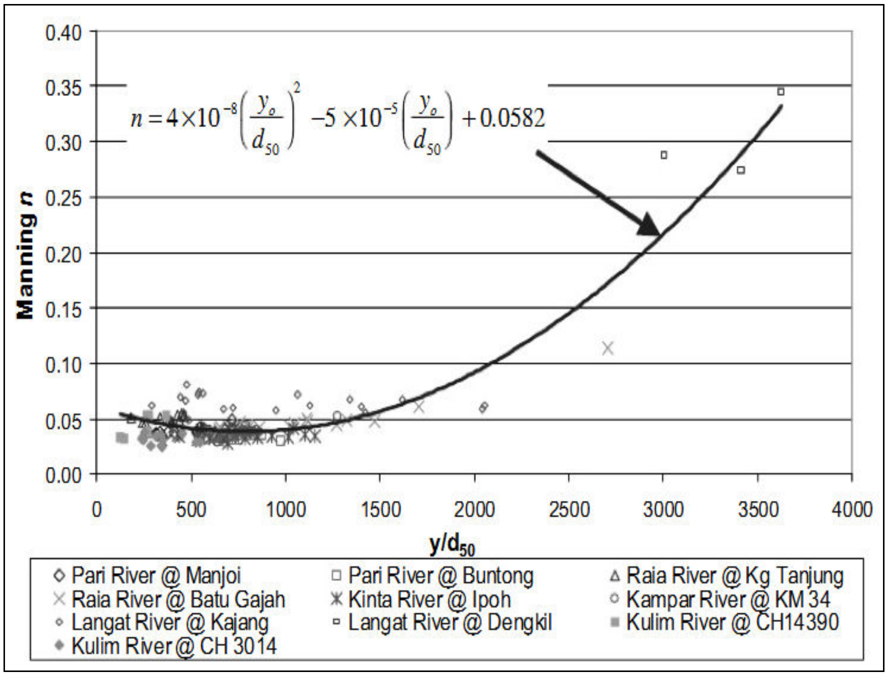

Figure 2.1: *Manning's n* against ratio of averaged depth to median particle size (Chang, 2006)

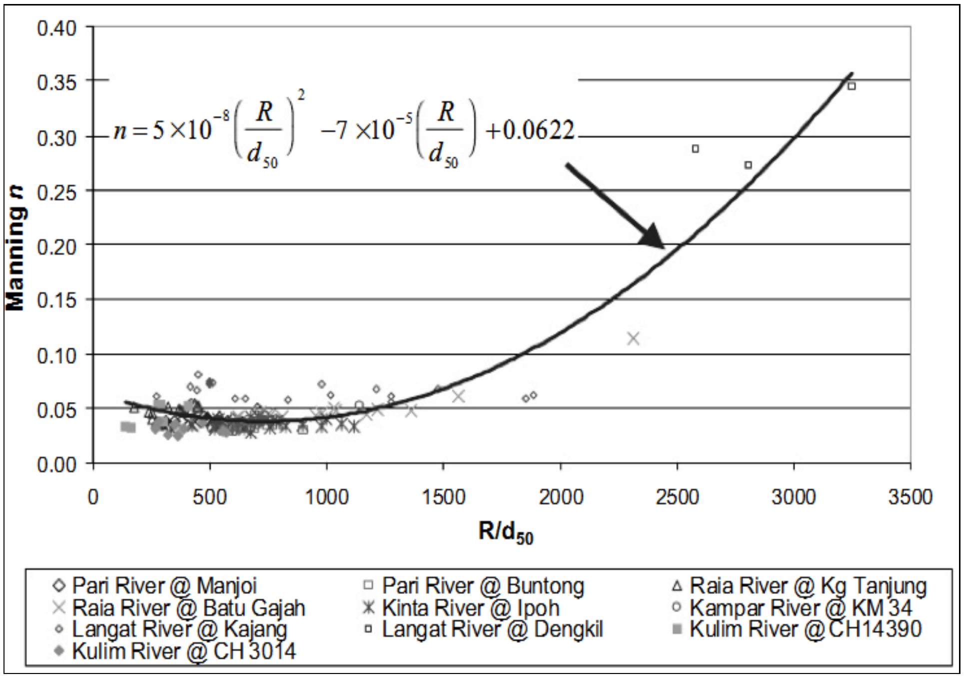

Figure 2.2: *Manning's n* against ratio of hydraulic radius to median particle size (Chang, 2006)

To date, the predictions of *Manning's n* coefficient are still improving with developing of new flow estimation equation in order to obtain a better accuracy and good resistance predictor for flow estimation. This prediction includes many factors as discussed previously. The effort of researcher in the focus of flow estimation derivation by using various modern techniques will be appreciated essentially in the guidance of flow estimation.

2.2.4 Statistical Analysis Method

Statistical analysis is a quantitative approach and process (data gathering, measuring, classifying, computing, describing, synthesizing, analyzing, and interpreting systematically) in determination of the previous existing problem to predict the future event (Jaggi, 2007). It is essential to verify the possibility of prediction by making conceptual and mathematical understanding using modeling. The crucial part of this analysis is that the assumption must be true for a model to be correctly developed. This will lead to the significant finding and the relation of the variables can be shown clearly by using the developed model. Thus, statistical analysis method is introduced in river engineering in order to compute and analyse the uncertainty parameter of flow estimation based on some assumptions made.

Low flow estimation by using statistical analysis had been done by Garcia-Martino et al. (1996) with the application of Geography Information System (GIS) in humid Montane regions in Puerto Rico. An equation had been developed for flow estimation in low flow watersheds. Evaluation of the parameters for 21 geomorphic, ten stream channels, nine relieves, seven geologies, four climates and two soil parameters based on digital elevation models and land use, geology, soils, and stream network coverage.

In this study, a correlation analysis with dependent and independent variables was used for further investigation of flow capacity in low flow channel. Among these variables, the selected parameters were applied to develop the statistical model by using multiple regression analysis. The models were then compared and selected according to the basis of the Mallow Cp statistic, the adjusted R^2, the Press statistic, the degree of co-linearity, and an analysis of the residual. The best model has been developed based on watershed parameters which can be measured easily without using GIS, with adjusted standard error of 82.8%. As a conclusion, it is very important to determine the appropriate technique and procedure in selecting the suitable parameters in flow estimation for low flow condition.

2.2.5 Acoustic Doppler Current Profiler

Theoretically, some assumptions of flow estimation have been made for alluvial channel where uniform flow and sedimentation occurred. However, these assumptions are not applicable in reality due to the geometrical and roughness effects on alluvial channel. Hence, Acoustic Doppler Current Profiler (ADCP) is adopted to improve the accuracy in this study.

Recently, the use of ADCP is widely used and accepted by researchers for velocity measurements in rivers and streams. It has become one of the important tools to map velocity field that are used for aquatic habitat assessment and numerical modeling validation purpose (Jacobson et al., 2004). However, one of the weaknesses of this tool is it is unable to measure the velocity for a very shallow stream flow due to the blanking distances system with minimum of 20 to 25cm. The latest transducer development has reduced this blanking distance to reduce the flow disturbance near the transducer.

Mueller (1990) had studied the errors of ADCP in velocity measurement which caused by the flow disturbance by using 3D computational fluid dynamic model (CFD). This model was then introduced and validated with field data, laboratory observations and numerical modeling to determine the effect on measured velocities towards the flow disturbance. The purpose of CFD is to evaluate the effect of different flow condition on actual velocity pattern and the velocity profile from the ADCP. The shape, draft, and deployment mechanism of ADCP in stream or river can affect the observed measurement bias and resulting in increasing of error occurs in ADCP. The present of Acoustic Doppler Velocity (ADV) or ADCP will increase or decrease the turbulent kinetic energy. The CFD simulation had validated that there is a large varies of velocity between the fields measured data and CFD simulation result due to the non uniform flow occurred in the majority of rivers and streams.

Previous study done by Vermeyen (2003) had determined the withdrawal characteristics from Lake Mead for stratified and destratified reservoir condition which is important for operations of the associated water treatment facilities. The methodology of this research was based on three pumping flow rates which were $25m^3/s$, $19m^3/s$ and $10m^3/s$. Velocity profile data were collected by using ADCP and ADV. The researcher stated that the accuracy of ADCP measurement techniques was depended on the equilibrium of the velocity which happened in the layer with constant flow depth. The function of using ADV is to verify ADCP bottom tracking so that the boat motion can be minimized in order to increase the accuracy of usable data collection. The data were chosen from all of the extracted data from ADCP with standard error of velocity which less than average velocity and the standard deviation of the depth less than ±4 cm. These data were considered as good data. The error can be reduced by collecting extended data or larger number of samples so that the developed model can be calibrated with the use of bottom tracking to resolve the boat motion from the velocity measurements.

Muste (2010) had furthered the research on near transducer errors in ADCP measurements based on experimental findings. This research had been carried out due to the acoustic interference which had induced the flow disturbance. It is unable to measure the velocity accurately near to the transducer and bed. The flow disturbance had been induced by hydraulic parameters such as Reynolds, Froude number and boat motion with mounted ADCP based on large eddy simulation. The experiment had been done in uniform, fully developed and open channel flow which is consistent with the horizontal homogeneity assumed by the ADCP algorithm under selected flow condition. The purpose of this research is to provide estimations of the contribution of individual elemental errors to the total near-transducer biases. The results showed that the ADCP bias lower the velocity profile with respect to the undisturbed velocity profiles. The multi beam configuration effect will reduce the blanking distance and hence improve the accuracy of the tools. Analytical relationship is required for estimating the data collection time needed to provide adequate turbulent flow characteristics.