UNIVERSITI SAINS MALAYSIA

SEDIMENT TRANSPORT IN SUNGAI KULIM, KEDAH

by

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LIST OF ABBREVIATION

AMSL = Above Mean Sea Level

ARI = Average recurrence interval

CH = Chainage

DID = Department of Irrigation and Drainage

DOE = Department of Environment

DWR = Department of Water Resources

EDM = Electronic Distance Meter

FISRWG = Federal Interagency Stream Restoration Working Group

GSTARS = Generalized Stream Tubemodel for Alluvial River Simulation

HEC = Hydrologic Engineering Centre

Hr = Hour

LB = Left Bank

MDK = Majlis Daerah Kulim

RB = Right Bank

RL = Reduce Level

SAM = Sediment Analysis Model

SDAR = Scour and Deposition Model of Alluvial Rivers

USACE = United States Army Corps of Engineers

USGS = United States Geological Survey

WL = Water Level

WS = Water Surface

LIST OF SYMBOLS

Symbol	Definition
A	Flow area (m^2)
b	Section width of the channel (m)
B	River width
C_m	Suspended Solid Concentration
Cu	Uniformity coefficient
C_v	Sediment Concentration in ppm by volume
d_{50} , d , D_{50}	Sediment diameter where 50% of bed material is finer
d_i	Size of particle intermediate axis for which i% of sample of bed material is finer
FR	Froude Number
DT	Size of the time step
DZ	Change in elevation during the current time step (m)
g_b	Sectional bed load transport rate
Gr	Gradation coefficient
h_s	Width of Helley-Smith sampler nozzle (m)
n, N	Manning's roughness coefficient
P	Wetted perimeter of cross section of flow (m)
Q	Flow discharge (m^3/s)
T_b	Bed load transport rate (kg/s)
T_j	Total bed material load transport rate (kg/s)
T_s	Suspended load transport rate (kg/s)
T_t	Suspended load discharge (m^3/s)
QS	Bed material discharge for all size fractions (m^3/s)
R	Hydraulic radius
R^2	Correlation coefficient

S	Channel slope
S_o	Water-surface slope
T	Time the bed load sampler on the bed
TDZ	Total or accumulated change in elevation (m)
V	Average flow velocity
$\overline{w_i}$	Mean weighted bed load sample of the vertical for *n* section
y_o, y	Flow depth
Y	Horizontal coordinate (elevation) of a point on channel boundary at a cross- section (m)
Z	Vertical coordinate (elevation) of a point on channel boundary at a cross- section (m)
σ_g	Standard deviation of bed material

PENGANGKUTAN ENDAPAN DI SUNGAI KULIM, KEDAH

ABSTRAK

Kesan pembangunan yang mendadak telah membawa impak kepada hidrologi dan geomorfologi sesuatu kawasan tadahan. Pembangunan yang mendadak ini terutamanya di kawasan tadahan sungai akan meningkatkan hasil endapan dan seterusnya bukan sahaja menjejaskan morfologi sungai, kestabilan sungai dan mengakibatkan kerosakan yang serius pada struktur hidraulik sepanjang saluran sungai yang menyebabkan banjir di kawasan bandar. Dengan itu, kestabilan saluran sungai berdasarkan pembangunan yang sedia ada dan masa hadapan perlu diramal dan dinilai. Kajian ini dijalankan dengan menggunakan data yang dicerap sehingga tahun 2006 untuk menilai pengangkutan endapan di Sungai Kulim, Kedah, Malaysia. Kajian ini cuba memberi gambaran keseluruhan tentang perubahan saluran dan fenomena pengangkutan endapan di Sungai Kulim. Sejumlah 24 sampel bahan dasar telah dicerap dari empat lokasi (CH 20000, CH 14390, CH 3014 dan CH 0) dan 14 data hidraulik serta endapan termasuk kadaralir, beban endapan dasar, beban endapan terampai dan jumlah beban endapan telah dicerap dari dua lokasi (CH 14390 dan CH 3014) dalam tempoh 2004 ke 2006. Data tersebut digunakan untuk menjalankan analisis dan penilaian terhadap persamaan Manning dan persamaan pengangkutan endapan. Dua persamaan Manning baru iaitu Persamaan 4.3 dan 4.4 dengan pekali sekaitan, $R^2 = 0.86$ telah dibangunkan untuk diaplikasikan di sungai saiz sederharna di Malaysia. Keputusan penilaian persamaan jumlahan pengangkutan endapan yang sedia ada bagi dua lokasi di Sungai Kulim menunjukkan Persamaan Engelund & Hansen memberikan keputusan yang paling baik untuk saluran pasir dan mencapai peratusan data yang mempunyai nisbah kelainan antara 0.5 ke 2.0 sebanyak 33.33% di CH 14390 dan 62.50% di CH 3014. Model FLUVIAL-12, merupakan model perbatas-hakis yang telah dipilih dalam kajian ini untuk meramalkan perubahan profil dasar saluran, kelebaran dan topografi saluran. Persamaan

Engelund-Hansen dan pekali kekasaran Manning, n = 0.030 telah dipilih semasa perbandingan profil paras air dan dasar dilakukan dalam proses penentukuran dan penyelakuan model. Perbandingan antara data geometri saluran tinjauan dengan pengukuran di tapak dari Oktober 2004 hingga November 2006 telah menunjukkan terdapat perubahan terhadap keratan rentas setelah beberapa banjir berlaku dari 1991 hingga 2003. Ramalan paras dasar yang hampir dengan paras dasar cerapan semasa 2004 ke 2006 oleh FLUVIAL-12 telah mengesahkan hakisan berlaku di sepanjang 14.4 km saluran sungai. Keputusan model simulasi bagi penyelakuan keadaan sedia ada, masa hadapan dan jangka panjang menunjukkan saiz endapan dan geometri saluran Sungai Kulim mempunyai perubahan yang ketara. Walau bagaimanapun, keputusan model menunjukkan perubahan terhadap keratan rentas adalah terhad dan hakisan di sepanjang saluran akan berkurangan pada masa depan. Dengan ini, Sungai Kulim diramal stabil pada kebanyakan lokasi.

SEDIMENT TRANSPORT IN SUNGAI KULIM, KEDAH

ABSTRACT

Effect of rapid urbanization has accelerated the impact on the catchment hydrology and geomorphology. Such rapid development which takes place in river catchment areas will result in higher sediment yield and it will not only affects river morphology, but also river channel stability, causing serious damages to hydraulic structures along the river and also becoming the main cause for serious flooding in urban areas. Therefore, it is necessary to predict and evaluate the river channel stability due to the existing and future developments. This study was carried out at Sungai Kulim in Kedah state, Malaysia, by means of evaluation on sediment transport using recently observed data up to year 2006. The present study attempts to give an overview of the channel changes and sediment transport phenomena in Sungai Kulim. A total of 24 samples of bed materials were collected from four locations (CH 20000, CH 14390, CH 3014 and CH 0), and 14 river hydraulics and sediment transport data sets including discharge, bed load, suspended load and total load were collected from two locations (CH 14390 and CH 3014) from 2004 to 2006. The data were used to analyze and evaluate existing Manning equations and sediment transport equations. Attempts were also made to derive new Manning equations (Equations 4.3 and 4.4) with a correlation coefficient, $R^2 = 0.86$ for application to the moderate-size channels in Malaysia. The results of evaluation for total load equations at the two locations along Sungai Kulim show that Engelund & Hansen equation gave the best prediction for sand bed stream and yielded highest percentage of data with discrepancy ratio in between 0.5 and 2.0 (33.33% at CH 14390 and 62.50% at CH 3014). An erodible-boundary model, FLUVIAL-12 which simulates inter-related changes in channel-bed profile, width variation and changes in bed topography was selected for this study. Engelund-Hansen equation and roughness coefficient, $n = 0.030$ were selected for the model which was calibrated and validated for water surface profile and bed elevation. The comparison of the surveyed river geometry data in September 1991 and field measurements from October 2004 to November 2006 shows that there has been a change in cross section after several flood occurrences from 1991 to 2003. The predicted bed levels by FLUVIAL-12 were almost similar to the observed bed level from 2004 to 2006, this confirmed that channel bed degradation occurred along the 14.4 km study reach. The model simulation results for existing conditions, future conditions and long-term modeling show that the sediment size and channel geometry in Sungai Kulim changed significantly. However, modeled results show that future changes in cross sectional geometry will be limited and erosion along the reach will slow down from 2006 to 2016, thus Sungai Kulim was predicted to be stable at most locations.

CHAPTER 1

INTRODUCTION

1.1 Background

River is a dynamic system governed by hydraulic and sediment transport processes. Over time, the river responses by changing in channel cross section, increased or decreased sediment carrying capacity, erosion and deposition along the channel, which affect bank stability and eventually cause morphology changes. Rapid urbanization has accelerated impact on the catchment hydrology and geomorphology. Developments in river catchment areas will cause dramatic increase in the surface runoff and resulting in higher sediment delivery. When this happens, it will not only affect river morphology, but also cause instability in the river channel and hence inflicting serious damage to hydraulic structures along the river and reducing channel capacity to convey the flood water to downstream. Therefore, it is necessary to evaluate and predict the river channel stability for the purpose of river rehabilitation due to the existing and future developments in the river catchment.

This study was carried out at Sungai Kulim, a natural stream in Kedah, Malaysia. Frequent floods that occur in Sungai Kulim catchment have caused extensive damage and inconvenience to the community, especially the flood event in October 2003, which is an event of about 100 year ARI. Hence, previous studies for Sungai Kulim (DID, 1996; Yahaya, 1999; Lee, 2001; Ibrahim, 2002; Koey, 2004) were conducted to determine the river behaviors and the effectiveness of the flood mitigation projects due to rapid urbanization. The data available from these studies, including river survey geometry data, sediment data and hydrology data were up to year 1999 and limited. These data, together with those from the present study (up to 2006) will be evaluated and used to predict river stability for future development. This will allow evaluation of river stability over a 16-year period by considering the effect of changes in cross section and sediment load.

1.2 Objectives

The primary objectives of the study are as follow:

1. To evaluate Sungai Kulim sediment transporting capability due to rapid urbanization
2. To examine river stability due to changes made by nature or human
3. To determine effect of flooding due to rapid urbanization

1.3 Study Site

This study was carried out on Sungai Kulim in Kedah state, Malaysia, by analyzing and evaluating sediment transport using newly observed data up to 2006. This study would give an overview of the channel changes and sediment transport phenomena, which cause river bank and bed stability problems in Sungai Kulim.

Sungai Kulim catchment (Figure 1.1) is located in the southern part of the state of Kedah and in the northwestern corner of Peninsular Malaysia. At the headwaters, Sungai Kulim catchment is hilly and densely forested. Sungai Kulim originates from the western slopes of Gunung Bongsu Range and flows in a north-westerly direction. The river slopes are steep and the channel elevations drop from 500 m to 20 m above mean sea level (AMSL) over a distance of 9 km. The central area of the catchment is undulating with elevations ranging from 100 m down to 18 m AMSL.

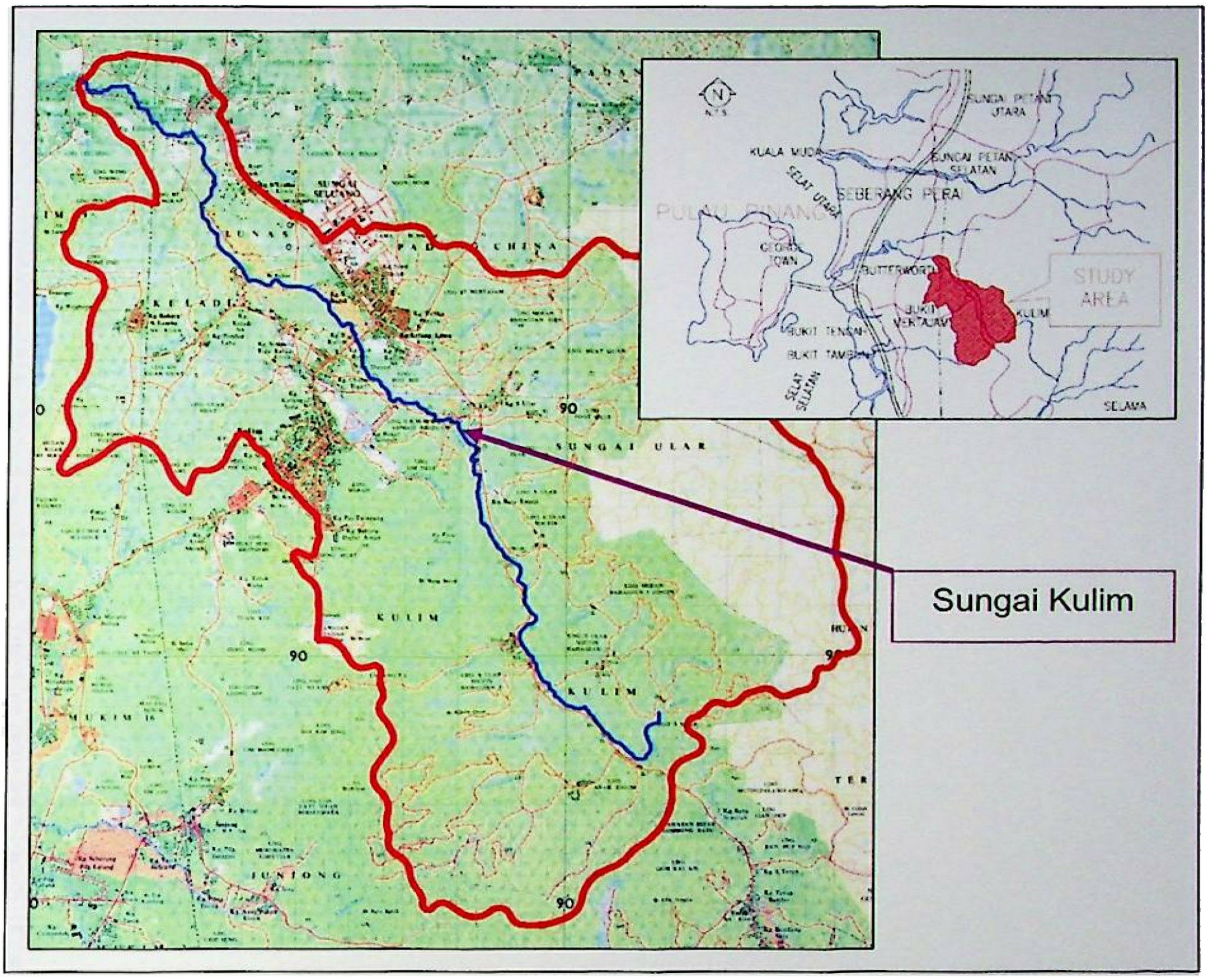


Figure 1.1: Topographical Map of Sungai Kulim Catchment

Currently, the catchment area is undergoing rapid urban development with oil palm and rubber plantations being replaced by rapid urbanization. More specifically, the areas around Kulim town and lower reach of Sungai Kulim as shown in Figure 1.2, with green color represent forested and purple color represent developed areas. This is likely to increase the magnitude of flood. This will also result in discharge and bed erosion increment or scouring and deposition.

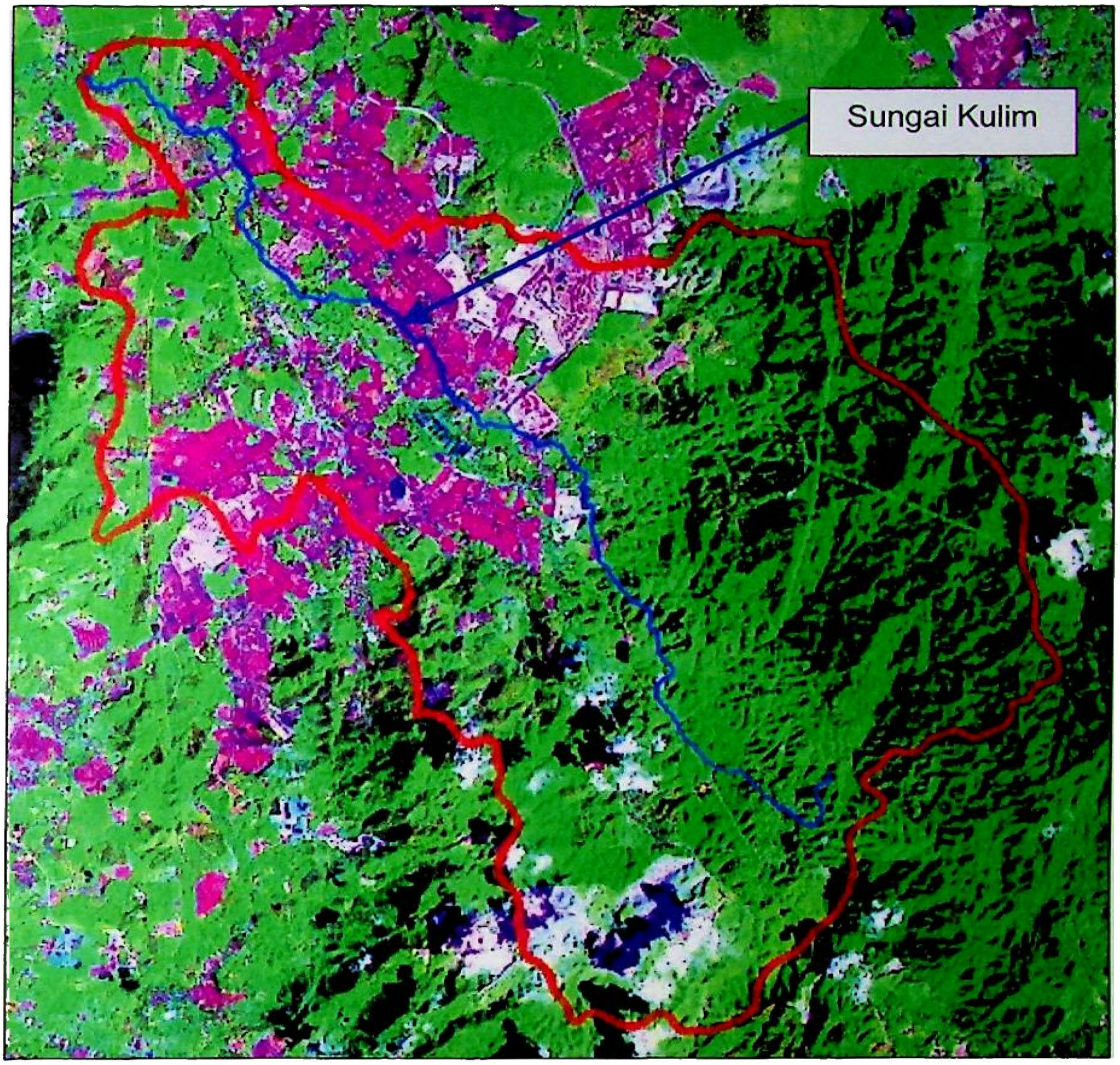


Figure 1.2: Areal Photo of Sungai Kulim Catchment

1.4 Scope of Research

The scope and limitations of the research are as follow:

a) The extraction of hydraulic and sediment data were focused to the Sungai Kulim (CH 14390 to CH 0) in Kedah State.

b) Evaluation of existing Manning's n equations were limited to most commonly used equations namely Strickler (1923), Meyer-Peter & Muller (1948), Lane & Carlson (1953), Limerinos (1970), Bray (1979), Brownlie (1983) and Bruschin (1985) equations. The evaluation of Abdul Ghaffar (2003)'s equation based on Sungai Kinta catchment, Malaysia has also been carried out in this study.

c) Evaluation of existing sediment transport equations were limited to most commonly used equations namely Einstein bed load function (Einstein, 1942, 1950), Einstein-Brown's equation (Brown, 1950), Meyer-Peter-Muller's equation (1948), Shields' equation (1936), Duboys' equation (1879), Yang's equation (1972), Engelund-Hansen's equation (1967), Ackers-White's equation (1973) and Graf's equation (1971). Besides that, the evaluation of Shanker's equation which developed by Sinnakaudan (2003) based on Malaysian rivers has been carried out in this study.
d) One dimension steady flow hydraulic model (FLUVIAL-12) was used to simulate the sediment transport and flow condition in Sungai Kulim.
e) River hydraulic data used for sediment transport modeling using FLUVIAL-12 were limited to the data obtained from 1991 to 1993 June and 1997 to 2006 June.

1.5 Structure of Thesis

This thesis is divided into six (6) chapters. Chapter 1 briefly introduces the research, including objectives and scope of works for the study. Chapter 2 contains literature review of relevant studies regarding to data collection, sediment modeling and river rehabilitation. Chapter 3 describes the research methodology which was used in this research and site description, including the climate, hydrology, and geology of Sungai Kulim. The river hydrology and hydraulic data, field measurements and laboratory test are also included in this chapter. In Chapter 4, the result of sediment analyses and summary are described. Chapter 5 presents the sediment transport modeling using FLUVIAL-12 and Chapter 6 contains conclusions and recommendations for this research.

Appendix A provides the comparison of sediment size distribution for a total of 24 data at four locations, while Appendix B shows the computation of bed load at CH 14390 and CH 3014 using seven-point measurement method. The summary of the computed bed load and sediment characteristic at the two locations along Sungai Kulim is shown in Appendix C. Appendix D and Appendix E provide the computation of bed load using three-point measurement method and computed suspended load at CH 14390 and CH 3014. The summary of measured and computed n from the Equations 2.1 to 2.8, Equations 4.3 and 4.4 for representative data for Sungai Kulim, Sungai Kinta and Sungai Langat are given in Appendix F. Appendix G is a sample of the FLUVIAL-12 output.

CHAPTER 2

LITERATURE REVIEW

2.1 Sediment Transport

An alluvial river frequently adjusts its cross-section, longitudinal profile, course of flow and pattern through the processes of sediment transport, scour and deposition. In order to sustain cultural and economic developments along an alluvial river, it is essential to understand the principles of sediment transport for application to the solution of engineering and environmental problems associated with natural events and human activities. Sediment can be defined as fragmented material which is formed by physical and chemical weathering of rocks. The transport of sediment through a river system consists of multiple erosional and depositional cycles. Many sediment particles are intermittently stored in alluvial deposits along the channel or floodplain, and ultimately re-entrained via bank and bed erosion. Total sediment loads consist of suspended load (the fine-grained fraction transported in the water) and bed load (the coarse-grained fraction transported along the channel bed). The transport of sediment through the stream depends on the sediment supply (size and quantity) and the ability of the stream to transport the sediment.

2.2 Sediment Data Collection and Analysis

River surveys, flow measurement and field data collection provide the basic physical information such as sediment characteristics, discharge, water surface slope, etc., which is needed for the planning and design of river engineering. For each particular location, river surveys, flow measurement and field data are collected using appropriate equipment and instrument. Various types of sampler, measuring and procedures are used to obtain such information in Malaysia as well as other countries around the world. The sediment data collection and analysis are discussed in the following sections.

2.2.1 Sungai Kinta Catchment

A total of 122 sediment data were obtained from May 2000 until October 2002 at Sungai Kinta Catchment (Figure 2.1) in the river sediment collection and analysis project (Ab. Ghani et al., 2003). Data collection including discharge, water-surface width, flow depth, water-surface slope, bed load, suspended load and bed material has been carried out at four rivers, namely Sungai Kinta, Sungai Pari, Sungai Raia and Sungai Kampar by referring to Hydrological Procedure (DID, 1976; DID, 1977) and recent manuals (Yuqian, 1989; USACE 1995, Edwards & Glysson, 1999; Lagasse et al., 2001; Richardson et al., 2001). Details of data collection and analysis are given in Ab. Ghani et al. (2003). Six study sites (Figures 2.1 and 2.2) were chosen based on the following criteria:

(a) Natural reach (undeveloped upper or middle reach), which is less than 30% catchment development: Sungai Kampar @ KM 34 (Figure 2.2a).

(b) Natural reach (Developed middle reach), which is more than 30% development: Sungai Raia @ Kampung Tanjung (Figure 2.2b) and Batu Gajah (Figure 2.2c).

(c) Modified reach (Developed middle reach), which is more than 30% development: Sungai Kinta (Figure 2.2d), Sungai Pari @ Manjoi (Figure 2.2e) and Buntong (Figure 2f).

Range of Data

Table 2.1 shows a summary of the data collected at the six study sites with respective range of discharge (Q), water-surface width (B), flow depth (y_o), hydraulic radius (R), water-surface slope (S_o), mean sediment size (d_{50}), aspect ratio (B/y_o) bed load (T_b), suspended load (T_s) and total load (T_j).

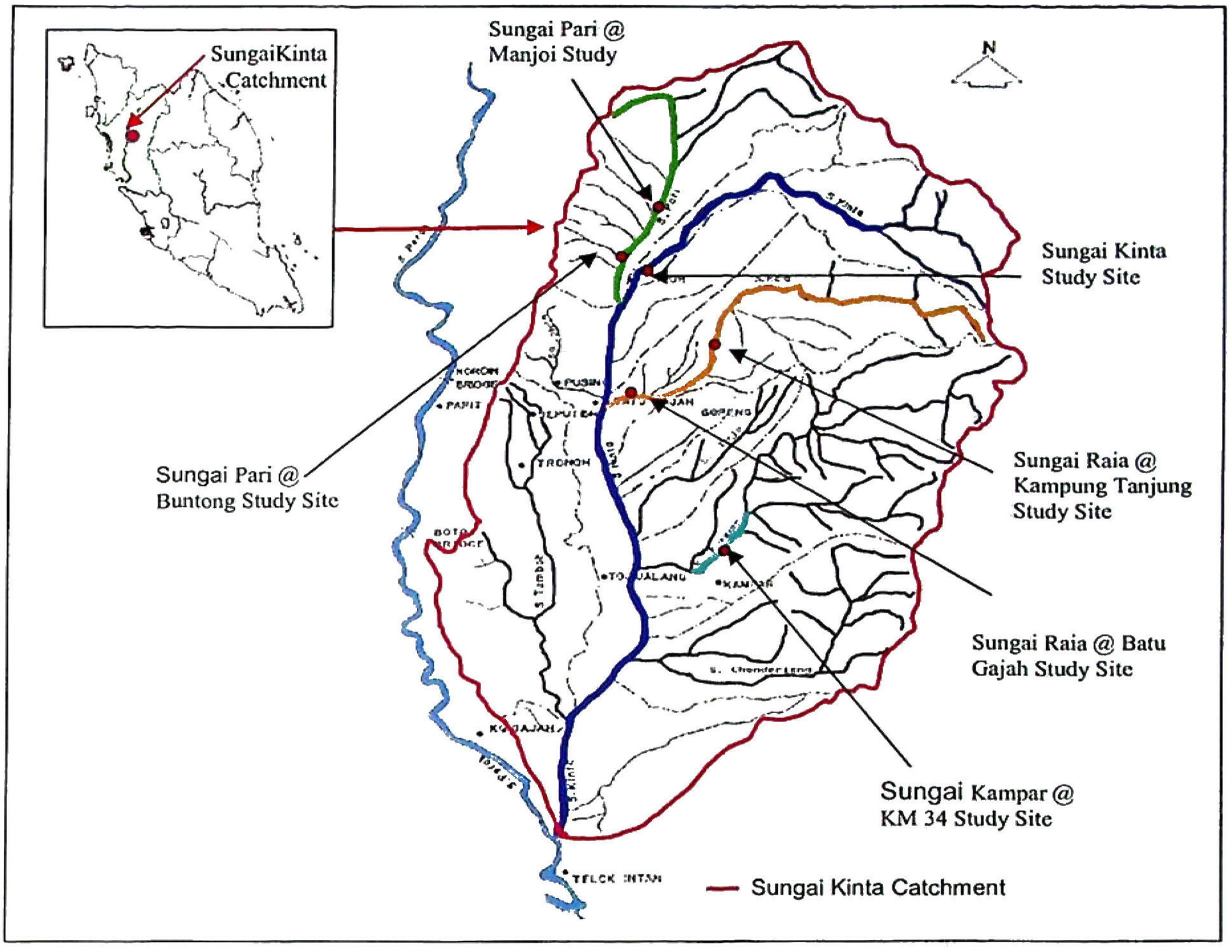
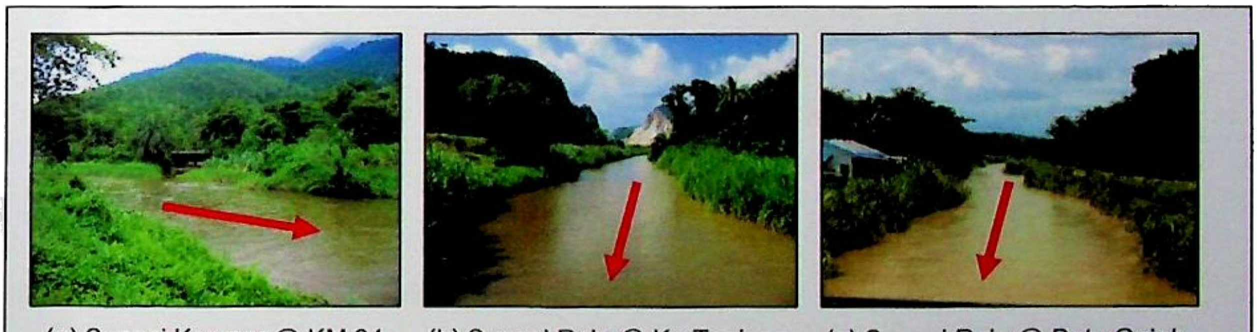
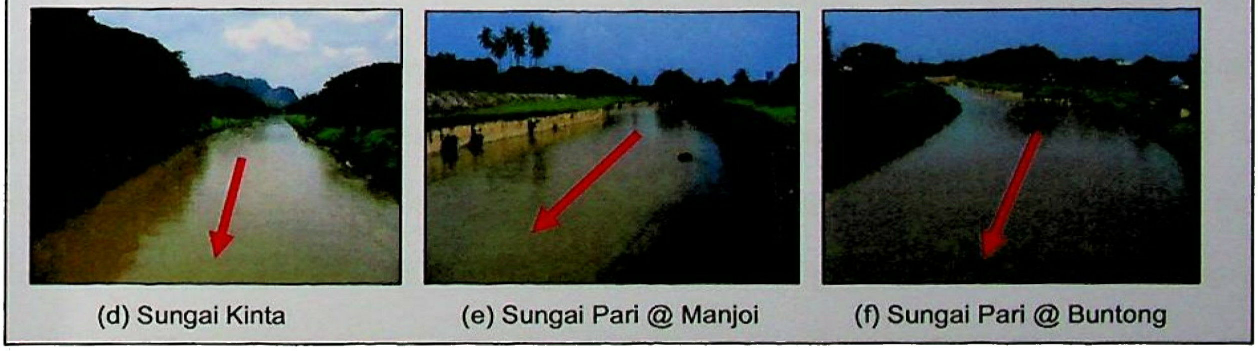


Figure 2.1: Study Sites at Sungai Kinta Catchment



(a) Sungai Kampar @ KM 34 (b) Sungai Raia @ Kg Tanjung (c) Sungai Raia @ Batu Gajah



(d) Sungai Kinta (e) Sungai Pari @ Manjoi (f) Sungai Pari @ Buntong

Figure 2.2: Morphological View of Sungai Kinta Catchment Study Sites

The mean sediment sizes for all sites showed that the study reaches are sand-bed stream with d_{50} range from 0.40 to 3.00 mm. The aspect ratios for the four rivers are between 11 and 107 indicating that they are moderate-size channels. The water-surface slopes of the study reaches were determined by taking measurements of water levels over a distance of 200 m along the cross section is located (FISRWG, 2001). For all the study sites, the water-surface slopes were found to be mild with ranges in between 0.001 and 0.004.

Table 2.1: Range of Field Data for Sungai Kinta Catchment (Ab. Ghani et al., 2003)

Study Site	Sungai Kampar @ KM 34	Sungai Raia @ Kampung Tanjung	Sungai Raia @ Batu Gajah	Sungai Kinta @ Ipoh	Sungai Pari @ Manjoi	Sungai Pari @ Buntong
No. of Sample	21	20	21	20	20	20
Discharge, Q (m^3/s)	7.98 - 17.94	3.60 - 8.46	4.44 - 17.44	3.80 - 9.65	9.72 - 47.90	9.66 - 17.04
Water surface width, B (m)	20.2-21.1	22.2-25.6	17.3-20.8	24.6-28.0	20.3	19.3-19.5
Flow depth, y_o (m)	0.55-1.28	0.24-0.49	0.41-1.76	0.35-0.57	0.69-1.87	0.68-0.89
Hydraulic radius, R (m)	0.52-1.14	0.23-0.47	0.39-1.51	0.31-0.55	0.65-1.77	0.63-0.81
Water surface slope, S_o	0.0010	0.0036	0.0017	0.0011	0.0011	0.0012
Mean sediment size, d_{50} (mm)	0.85 - 1.10	0.60 -1.60	0.50 - 0.85	0.40 - 1.00	1.70 - 3.00	0.85 -1.20
B/y_o	17 – 38	46 – 107	12 – 45	48 – 86	11 – 29	22 – 29
Bed load, T_b (kg/s)	0.40 - 1.25	0.20 - 1.82	0.25 - 1.37	0.02 - 1.21	0.40 - 0.80	0.35 - 0.79
Suspended load, T_s (kg/s)	0.10 - 1.49	0.07 - 1.39	0.09 - 2.04	0.21 - 12.31	0.79 - 16.81	0.67 - 4.41
Total load, T_j (kg/s)	0.57 - 2.47	0.65 - 2.11	0.47 - 2.69	0.23 - 12.82	1.25 - 17.62	1.03 - 4.89

Sediment Transport Data Analysis

The scatter plots of bed load transport against discharge and total load transport against discharge are shown in Figures 2.3 and 2.4. The observed flow range is between 3.60 m^3/s to 47.90 m^3/s, carrying total sediment load between 0.57 kg/s to 17.62 kg/s. The sediment ratings show that the points scatter widely, although the transport rate is sensitive to discharge. These scatter plots will be used to compare with the calculated sediment load by using existing sediment transport equations for the study sites.

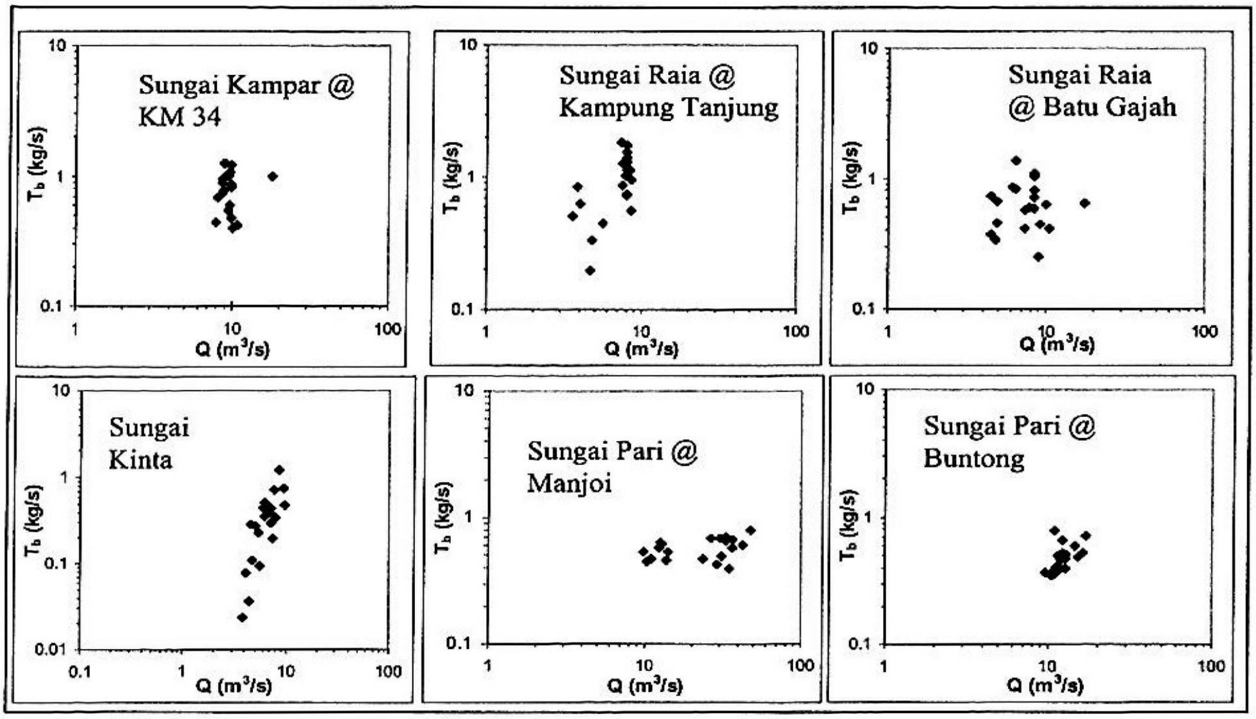


Figure 2.3: Bed Load Rating Curves for Sungai Kinta Catchment
(Ab. Ghani et al., 2003)

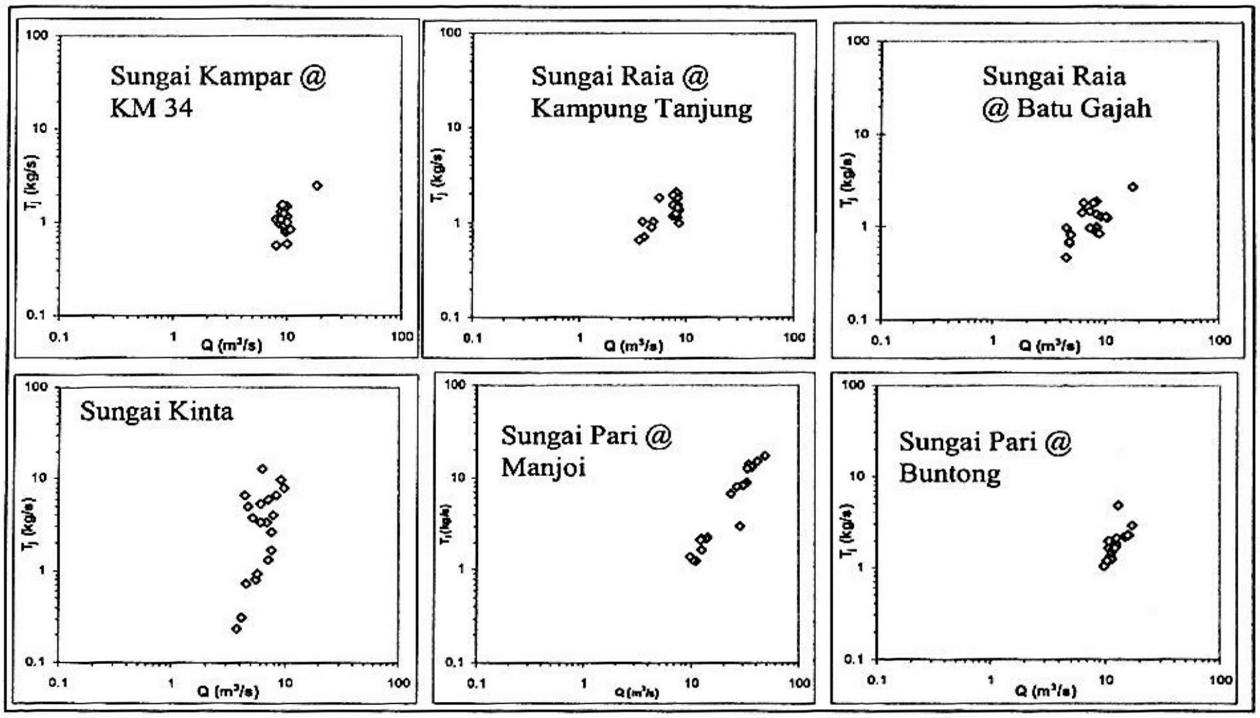


Figure 2.4: Total Load Rating Curve for Sungai Kinta Catchment
(Ab. Ghani et al., 2003)

The additional calculation of bed load transport rate by using three-point measurement method (4 sections) has also been carried out (Ab. Ghani et al., 2003). Figure 2.5 shows comparison of bed load transport rate obtained using seven-point measurement method (8 sections) and three-point measurement method (4 sections). The bed load transport rates are not much difference between the two methods. Therefore, the rusults suggested that bed load measurement in a small stream can be carried out using the three-point measurement method with advantages in terms of time, cost and man power.

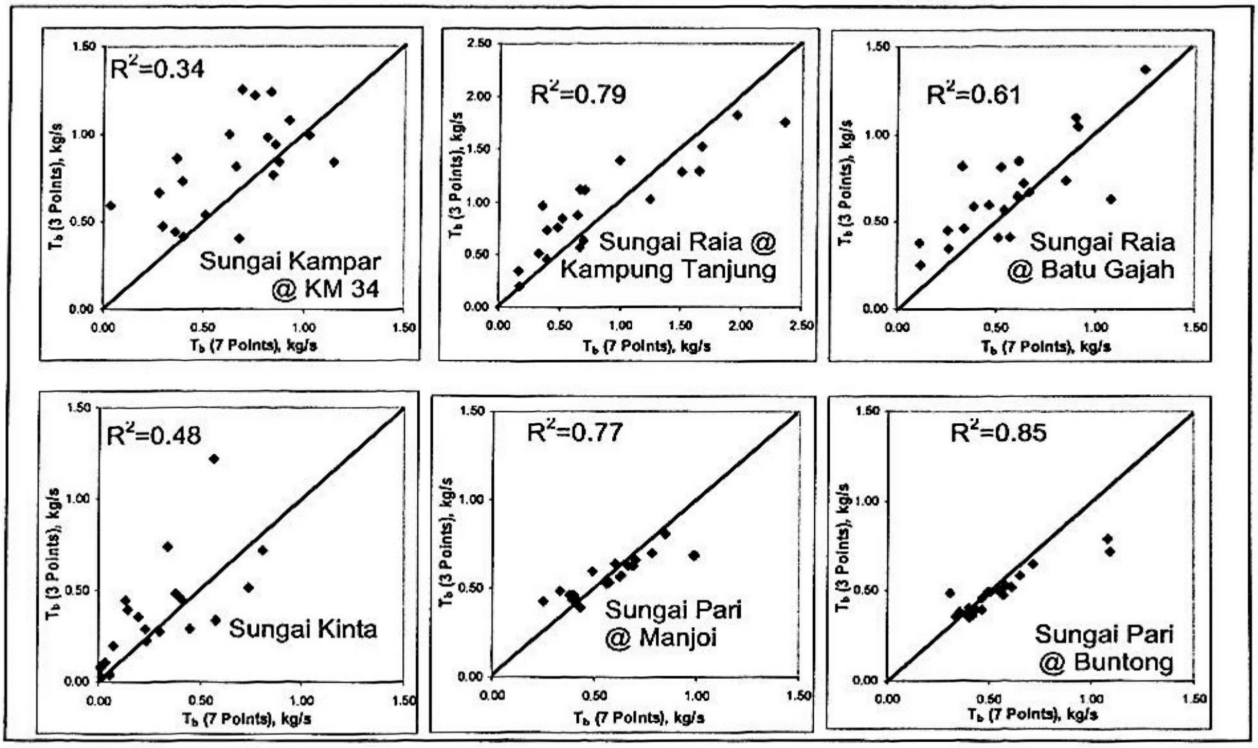


Figure 2.5: Comparison of Computed Bed Load Transport Rate between Seven-Point Measurement Method and Three-Point Measurement Method (Ab. Ghani et al., 2003)

Flow Resistance

Research on determination of Manning *n* value at the Sungai Kinta catchment was started by Abdul Ghaffar (2003). Six manning equations were chosen for evaluation and the equations can be categorized as follow:

Category 1: Equations based on bed sediment size (d_{50})

Strickler (1923): $n = \frac{1}{21.1} d_{50}^{1/6}$ (2.1)

Meyer-Peter & Muller (1948): $n = \frac{1}{26} d_{90}^{1/6}$ (2.2)

Lane & Carlson (1953): $n = \frac{1}{21.14} d_{75}^{1/6}$ (2.3)

Category 2: Equations based on the ratio of flow depth (y_o) or hydraulic radius (R) over sediment size

Limerinos (1970): $n = \frac{0.113R^{1/6}}{0.35 + 2.0\log_{10}\left(\frac{R}{d_{50}}\right)}$ (2.4)

Bray (1979): $n = \frac{0.113y_o^{1/6}}{1.09 + 2.2\log_{10}\left(\frac{y_o}{d_{50}}\right)}$ (2.5)

Category 3: Equations include water-surface slope (S_o) besides bed sediment size and hydraulic radius or flow depth

Bruschin (1985): $n = \frac{d_{50}^{1/6}}{12.38} \times \left(\frac{R}{d_{50}} \times S_o\right)^{1/7.3}$ (2.6)

Category 1 was developed from data of large, wide rivers with gental slopes (Rahmeyer, 2006) and bed material is the primary source of resistance. Limerinos (1970)'s equation was developed using 50 data from California rivers where d_{50} ranges from 6 mm to 253 mm. The river channels are relatively wide stream of simple trapezoidal shapes with inbank flow (Lang et al. 2004). Bray (1979)'s equation was calibrated against data from 67 gravel-bed reaches in Alberta, Canada with d_{50} range from 18 mm to 147 mm and channel width between 14 m to 546 m (Lang et al. 2004). Equation by Bruschin (1985) was based mainly on flume and sandy river data (Raudkivi, 1993).

The existing equations (Strickler, 1923; Meyer-Peter & Muller, 1948; Lane & Carlson 1953; Limerinos, 1970; Bray, 1979 and Bruschin, 1985) were evaluated for their suitability in predicting discharge for several streams along the Sungai Kinta catchment. However, the evaluation of the existing equations for the six study sites at Sungai Kinta catchment resulted in an unsatisfactory prediction of discharge, as shown in Figure 2.6 (Abdul Ghaffar, 2003).

Two new equations (Equations 2.7 and 2.8) were proposed by Abdul Ghaffar (2003) for determining Manning's n for rivers in Malaysia for moderate-size channels in Malaysia with a correlation coefficient $R^2 = 0.61$. Figures 2.7 and 2.8 plot Manning's n against both y_o/d_{50}, and R/d_{50}, respectively. These equations were evaluated for their suitability in predicting discharge for several streams along the Sungai Kinta catchment.

Abdul Ghaffar (2003):

$$n = 2\times10^{-8}\left(\frac{y_o}{d_{50}}\right)^2 - 3\times10^{-5}\left(\frac{y_o}{d_{50}}\right)^2 + 0.0511 \qquad (2.7)$$

$$n = 3\times10^{-8}\left(\frac{R}{d_{50}}\right)^2 - 4\times10^{-5}\left(\frac{R}{d_{50}}\right) + 0.0537 \qquad (2.8)$$

Table 2.2 gives a summary of discrepancy (ratio of computed discharge over measured discharge) by using Equations 2.7 and 2.8 for all the 122 data. The results show that all the computed discharges are within the 0.5 to 2.0 range of discrepancy ratio suggesting the viability of using these new equations for predicting discharge of the rivers with similar characteristics as studied (Table 2.1).

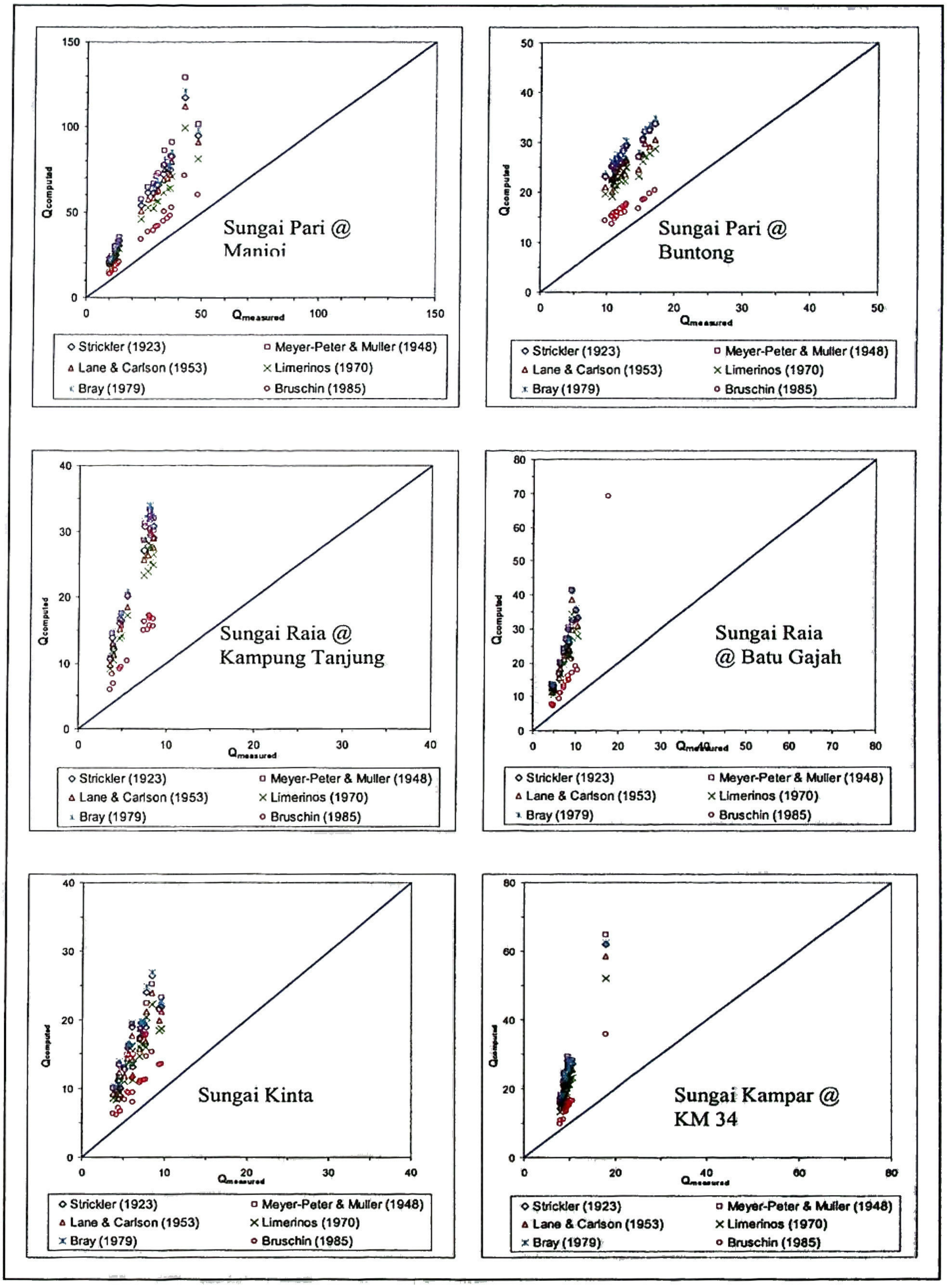


Figure 2.6: Evaluation of Manning's Equations using Equations 2.1 to 2.6 (Abdul Ghaffar, 2003)

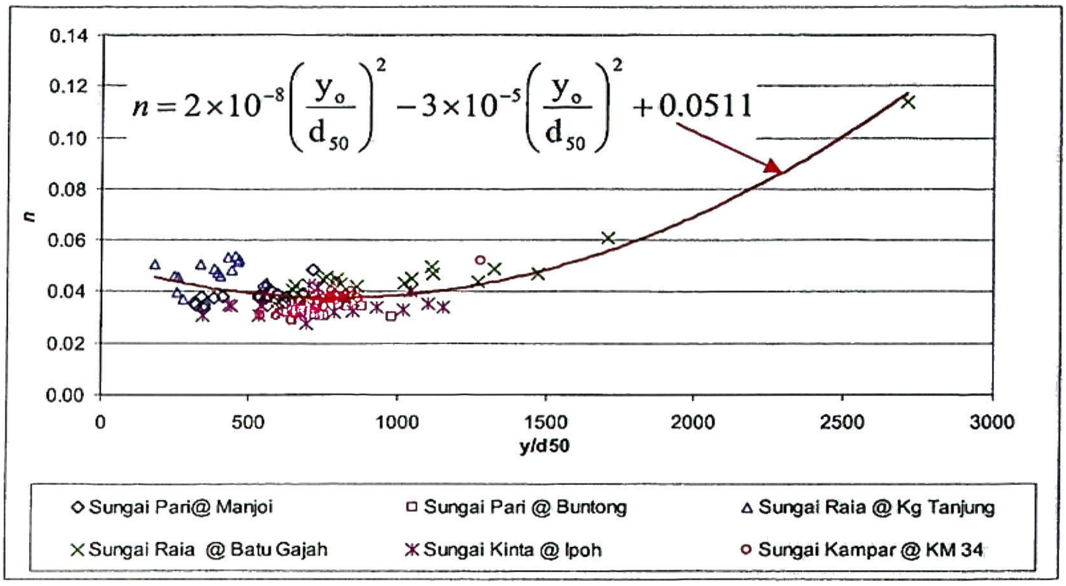


Figure 2.7: Development of Equation 2.7 to determine the Value of *n* based on y_o/d_{50} (Abdul Ghaffar, 2003)

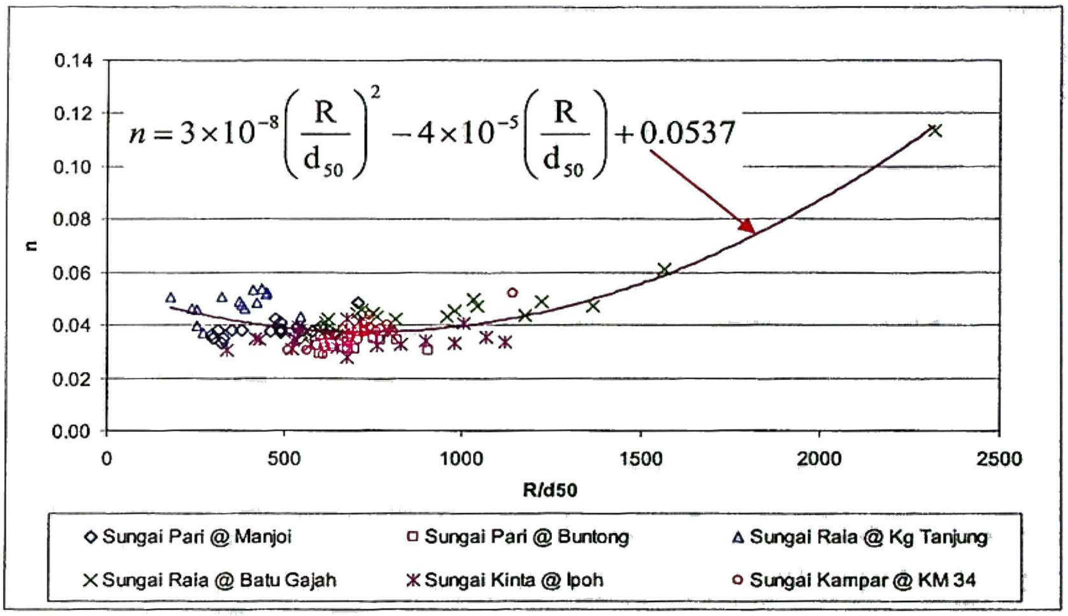


Figure 2.8: Development of Equation 2.8 to determine the value of *n* based on R/d_{50} (Abdul Ghaffar, 2003)

Table 2.2: Summary of Discrepancy Ratio using Equations 2.7 and 2.8 for Sungai Kinta Catchment (Abdul Ghaffar, 2003)

River	Study Site	Equation 2.7			Equation 2.8		
		Discrepancy Ratio			Discrepancy Ratio		
		0.5-2.0 (%)	0.75-1.50 (%)	Average	0.5-2.0 (%)	0.75-1.50 (%)	Average
Sungai Pari	Manjoi	100	100	0.92	100	100	0.91
	Buntong	100	90	0.84	100	90	0.82
Sungai Raia	K. Tanjung	100	100	1.32	100	100	1.31
	Bt. Gajah	100	100	1.03	100	100	1.00
Sungai Kinta	Ipoh	100	95	0.88	100	90	0.87
Sungai Kampar	KM 34	100	90.48	0.92	100	85.71	0.91

Sediment Transport Equation Assessment

The analysis for a total of 122 set of data was also carried out by applying four sediment transport equations namely Yang's equation (1972), Engelund-Hansen's equation (1967), Ackers-White's equation (1973) and Graf's equation (1971). The performances of the equations were measured using the discrepancy ratio value, which is the ratio of the predicted load to measured load. A discrepancy ratio of 0.5 to 2.0 was used in the evaluation of sediment assessment. From the results of sediment transport assessment for total load (Table 2.3), it can be concluded that Yang and Engelund & Hansen equations gave the best performance to predict the sediment load, and it can be used to predict sediment transport rate for sand-bed rivers in Malaysia (Ab. Ghani et al., 2003).

Table 2.3: Summary of Sediment Transport Equation Assessment for Sungai Kinta Catchment (Ab. Ghani, 2003)

River	Study Site	Total of Data	Discrepancy Ratio (0.5 to 2.0)							
			Yang		Engelund & Hansen		Ackers & White		Graf	
			No. of data	(%)	No. of data	(%)	No. of data	(%)	No. of data	(%)
Sungai Pari	Manjoi	20	6	30.0	19	95.0	2	10.0	4	20.0
	Buntong	20	1	5.0	1	5.0	0	0	0	0
Sungai Raia	Kg. Tanjung	20	1	5.0	0	0	1	5.0	0	0
	Bt. Gajah	21	1	4.8	0	0	0	0	0	0
Sungai Kinta	Ipoh	20	6	30.0	3	15.0	4	20.0	6	30.0
Sungai Kampar	KM 34	21	7	33.3	7	33.3	0	0	0	0

2.2.2 Sungai Langat Catchment

A total of 165 sediment data were obtained at Sungai Langat Catchment from 2000 until 2002 by Ariffin (2004). Data collection including flow discharge, water-surface width, flow depth, water-surface slope, bed load, suspended load and bed material has been carried out by refering to Ab. Ghani et al. (2003). The tributaries Sungai Lui and Sungai Semenyih flow into the main river, Sungai Langat. In contrast, the lower region of Sungai Langat has yet to be fully developed. There are rubber and oil palm plantations within the catchment. Four study sites (Figure 2.9) were chosen in this study.

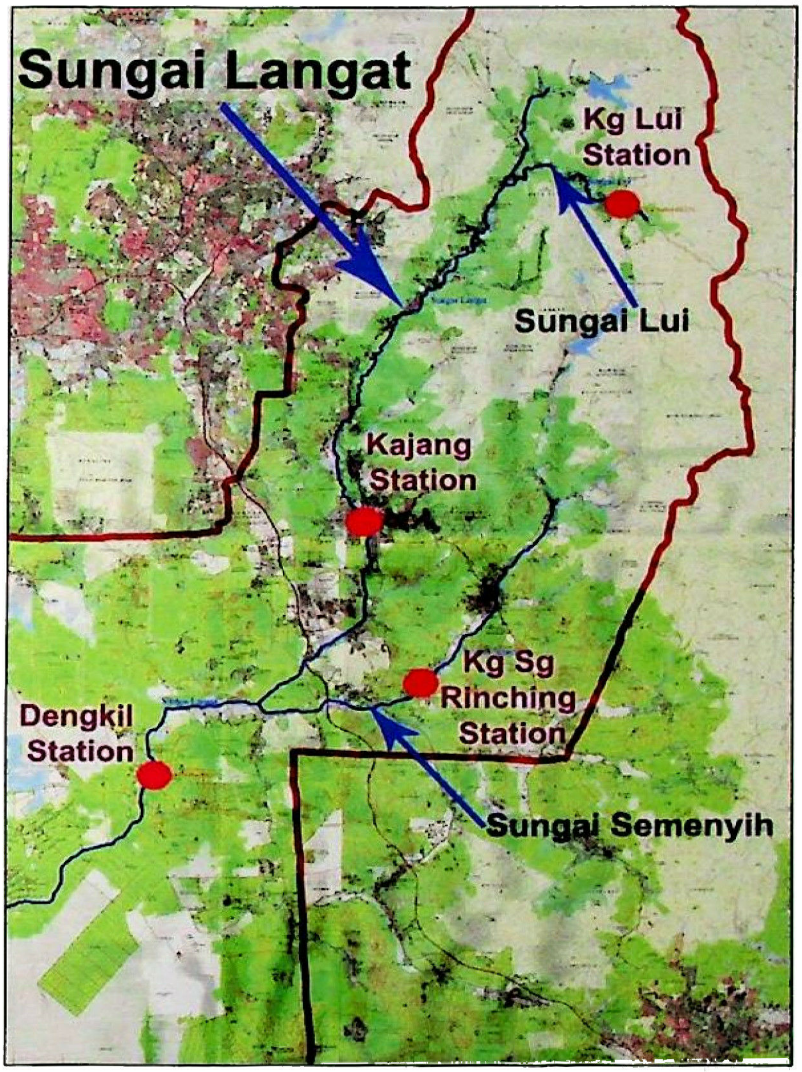


Figure 2.9: Study Sites at Sungai Langat Catchment

Range of Data

Table 2.4 shows a summary of the data collected at the four study sites. The mean sediment sizes for all sites show that the study reaches are sand-bed streams where d_{50} range from 0.37 to 2.30 mm. The aspect ratios for the three rivers (Sungai Langat, Sungai Lui and Sungai Semenyih) are between 9 and 66 indicating that they are moderate-size channels. For all study sites the water-surface slopes were found to be mild with values range in between 0.0003 and 0.017.

Table 2.4: Range of Field Data for Sungai Langat Catchment (Ariffin, 2004)

Study Site	Sungai Langat @ Kajang	Sungai Langat @ Dengkil	Sungai Lui @ Kg Lui	Sungai Semenyih @ Kg Sg Rinching
No. of Sample	20	3	92	50
Discharge, Q (m^3/s)	3.75 – 39.56	33.49 – 87.79	0.74 – 17.17	2.60 – 8.04
Water surface width, B (m)	15.0-20.0	30.0-33.0	15.0 – 17.0	13.5 – 15.0
Flow depth, y_o (m)	0.45-1.39	1.90-3.23	0.23 – 0.99	0.36 – 0.82
Hydraulic radius, R (m)	0.42-1.22	1.70-2.66	0.22 – 0.89	0.34 – 0.73
Water surface slope, S_o	0.0043 – 0.0051	0.0167	0.0003 – 0.009	0.0023 – 0.015
Mean sediment size, d_{50} (mm)	0.37 – 2.13	0.52 – 0.95	0.50 – 1.74	0.88 – 2.29
B/y_o	14.4 – 33.5	9.30 – 17.4	17.2 – 65.8	17.1 – 41.5
Bed load, T_b (kg/s)	0.02 – 1.29	0.27 – 0.65	0.04 – 1.55	0.65 – 3.16
Suspended load, T_s (kg/s)	0.66 – 77.51	18.69 – 118.31	0.05 - 5.77	0.24 - 10.77
Total load, T_j (kg/s)	0.78 – 77.86	18.96 – 118.93	0.27 - 6.16	1.08 - 12.08

Sediment Transport Analysis

The observed flows range in between 0.74 m^3/s to 87.8 m^3/s carrying total sediment load between 0.27 kg/s to 118.9 kg/s. The sediment concentration for Sungai Langat as the main tributary exceeded those from the two tributaries. Figures 2.10 and 2.11 show the bed load rating curve and total load rating curve, which the sediment ratings show that the points scatter widely, although the transport rate is sensitive to discharge.

Sediment Transport Equation Assessment

The analysis for a total of 165 set of data was also carried out using four sediment transport equations namely Yang's equation (1972), Engelund & Hansen's equation (1967), Ackers-White's equation (1973) and Graf's equation (1971). From the results of total load transport assessment (Table 2.5), it can be concluded that applications of Yang and Engelund & Hansen equations yielded highest percentage of discrepancy ratio in predicting sediment transport in sand-bed rivers.

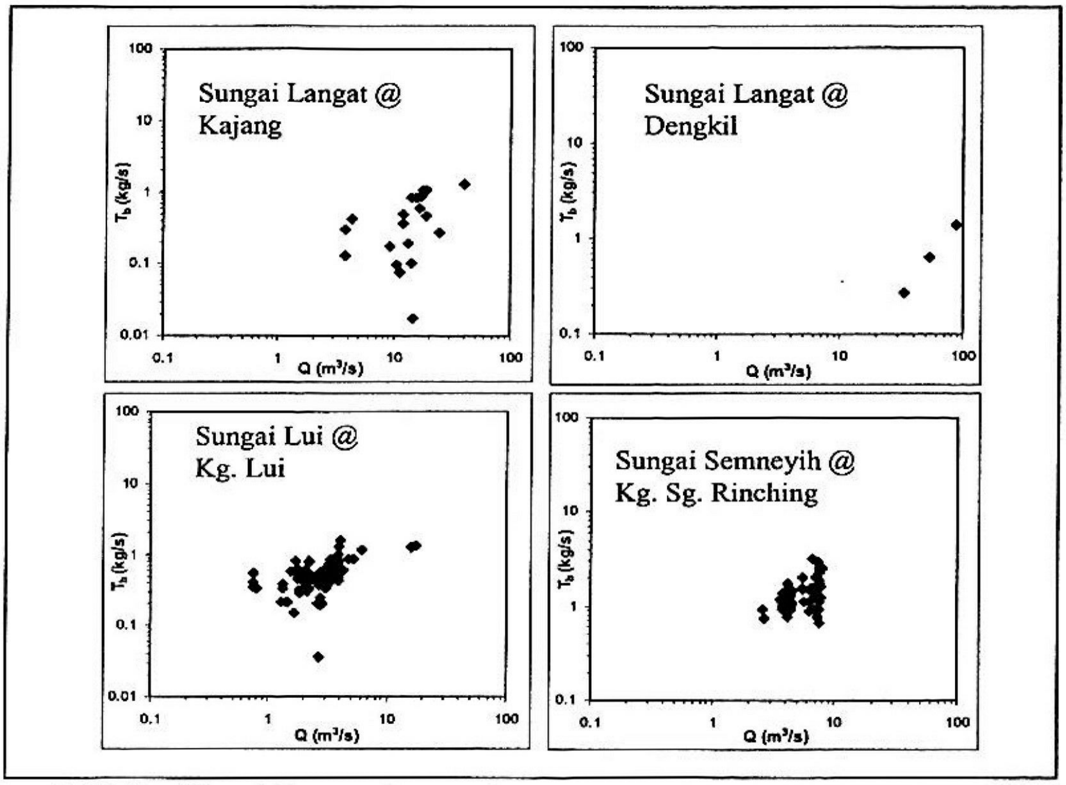


Figure 2.10: Bed Load Rating Curves for Sungai Langat Catchment (Ariffin, 2004)

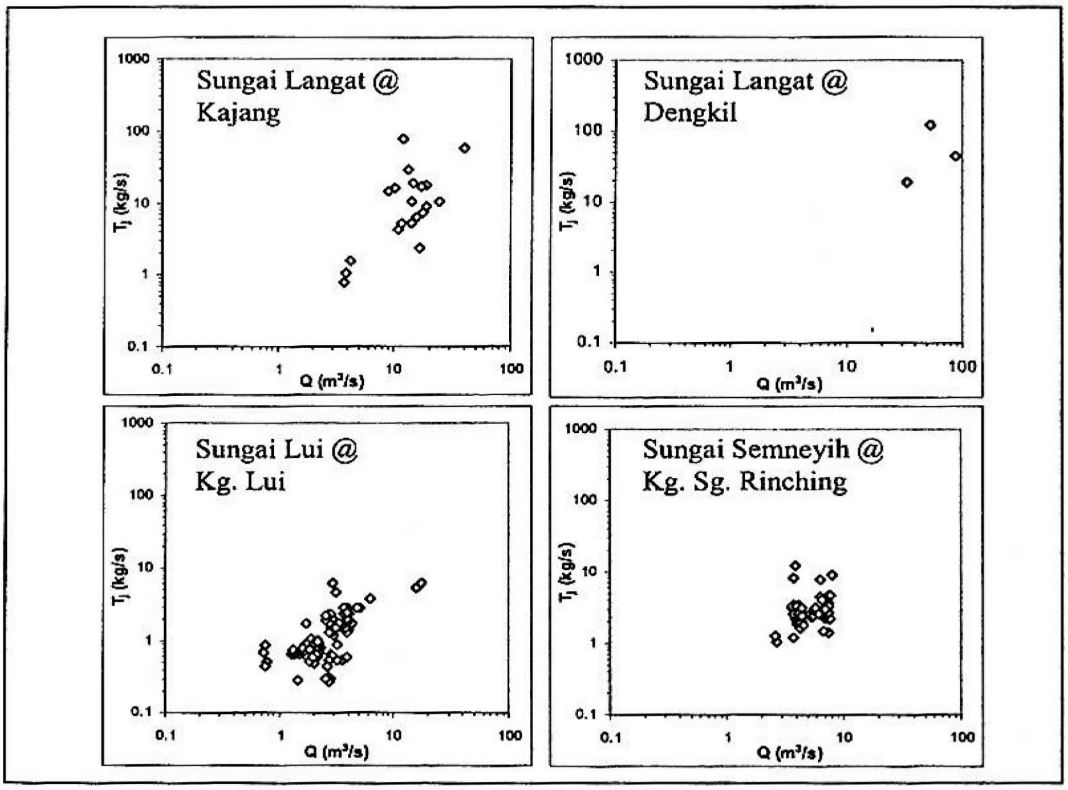


Figure 2.11: Total Load Rating Curves for Sungai Langat Catchment (Ariffin, 2004)

Table 2.5: Summary of Sediment Transport Equation Assessment for Sungai Langat Catchment (Ariffin, 2004)

River	Study Site	Total of Data	Discrepancy Ratio (0.5 – 2.0)							
			Yang		Engelund & Hansen		Ackers & White		Graf	
			No. of data	(%)	No. of data	(%)	No. of data	(%)	No. of data	(%)
Sungai Langat	Kajang	20	4	20.0	5	25.0	0	0	0	0
	Dengkil	3	0	0	0	0	0	0	0	0
Sungai Lui	Kg. Lui	92	27	29.3	14	15.2	21	22.8	2	2.2
Sungai Semenyih	Kg. Sg. Rinching	50	18	36.0	15	30.0	12	24.0	4	8.0

2.2.3 Nile River Catchment

Measurements of bed-load and suspended-load transport rates were carried out at four study sites of the Nile River, Egypt by Abdel-Fattah ($1997^{a,b,c,d}$) along the entire length from Aswan to Cairo (Figure 2.12) using a mechanical sampler called the Delft Nile Sampler.

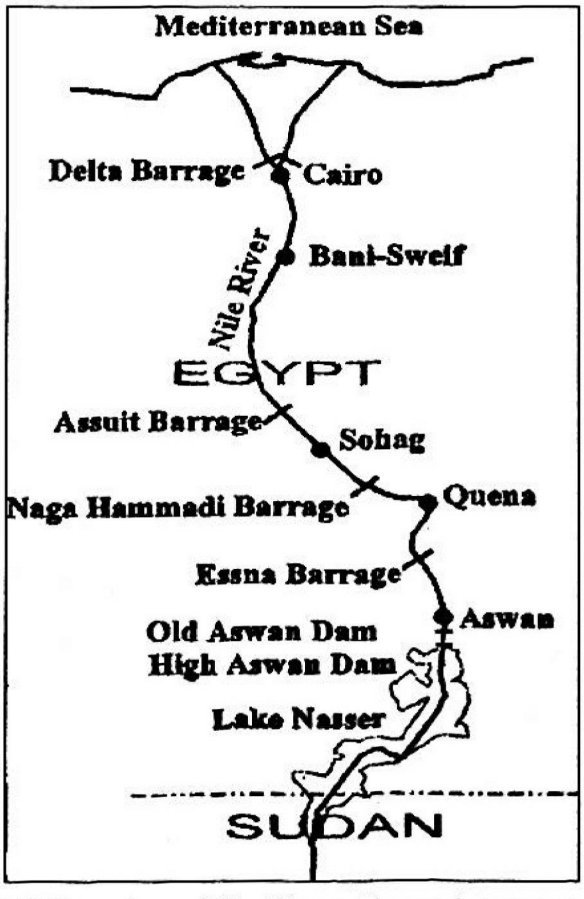


Figure 2.12: Study Sites along Nile River, Egypt (Abdel-Fattah et al., 2004)

The sediment load transport was measured using the Delft-Nile Sampler (Van Rijn and Gaweesh, 1992; Van Rijn, 1993), which was operated from an anchored boat. This mechanical sampler was designed to measure, in contact to the bed, the bed load and the suspended load up to 0.5 m above the bed (the sampler height). A separate device (Delft fish) equipped with a small nozzle connected to a suction pump, a propeller meter, and an echo sounder for depth determination was used to measure suspended load at different water depths above the bed and near the water surface (Figure 2.13).

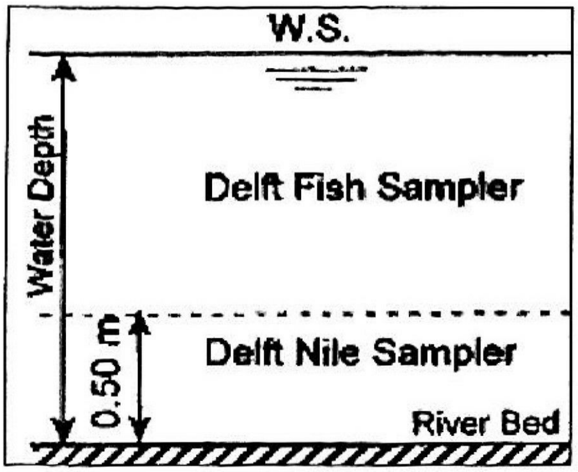


Figure 2.13: Sketch of Measuring Technique (Abdel-Fattah et al., 2004)

The locations of the measurement cross sections were selected in a stable reach to avoid unsteady bed conditions during the measurements. The measurements of bed, suspended load, and velocity profiles were conducted at the six measurement stations (St1 to St6, Figure 2.14). At each station, measurements were performed at five locations (L1, L2, L3, L4, and L5) distributed over the length of the longitudinal section, which is almost equal to the mean bed form length. Figure 2.14 shows the layout of the measurement stations and locations.

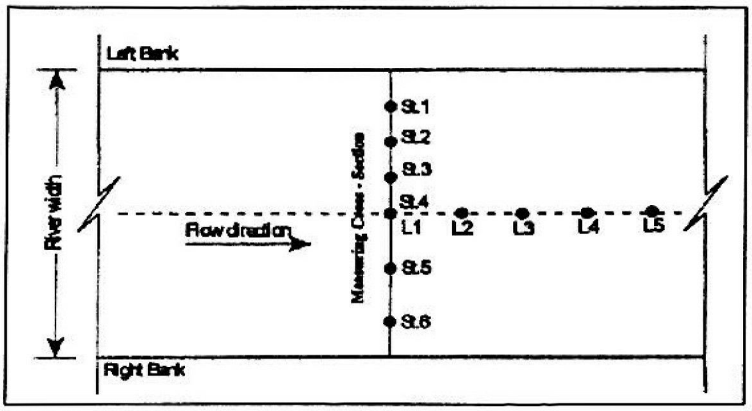


Figure 2.14: Layout of Measurement Stations and Locations (Abdel-Fattah et al., 2004)

The measurements were performed at 30 locations, and at each station the following measurements were performed for the five locations:

- Ten instantaneous samplings using the Delft Nile Sampler with a bag of mesh size 250 mm; the sampler was lowered to the bed and immediately raised up after the nozzle had touched the bed.
- Eight bed load samplings of 3 minutes each using the Delft Nile Sampler with the same bag size.
- Suspended load samplings over the water depth using the Delft Nile and the Delft Fish Samplers. The suction of the samples was driven by a set of pulsation pumps. The samples were collected (volume = 5 L) in plastic buckets.
- Velocity profiles over the water depth using propeller current meters installed on the Delft Nile and the Delft Fish Samplers. The flow velocity measurements were carried out as follows:
  - At 0.18, 0.37 and 0.50 m above the bed level by using three propeller-type current meters attached to the Delft Nile Sampler
  - From 0.50 m above the bed level to the water surface by using a propeller-type current meter attached to the Delft Fish.
- One bed material sample at the end of each measurement using a grab sampler.

- Water temperature was measured.
- At each station, a longitudinal bed profile for the five locations was sounded.

The main topographic and hydraulic characteristics of the four study sites were summarized in Table 2.6 and measured data were presented in Tables 2.7.

Table 2.6: Main Characteristics of the Study Sites (Abdel-Fattah et al., 2004)

Location	Aswan	Quena	Sohag	Bani-Sweif
River width	517	578	481	400
Local slope	3.5	4.2	5.7	8.5
Flow discharge	1,331	1,250	1,560	1,040
Average bed form length	44	22	24	28
Average bed form height	1.6	0.8	0.7	0.75

Table 2.7: Measured Data at Four Study Sites, Nile River (Abdel-Fattah et al., 2004)

Station	Distance from left bank	Mean depth (m)	d_{10} (μm)	d_{50} (μm)	d_{90} (μm)	Standard deviation of bed material, σ_g	Velocity (m/s) Mean	Suspended Load (kg/m/s) Mean	Bed Load (kg/m/s) Mean
Aswan									
1	60	4.98	207	313	493	2.0	0.482	0.0078	0.0056
2	140	5.72	187	322	580	1.8	0.487	0.0081	0.0012
3	220	4.78	215	359	577	1.7	0.587	0.0089	0.0038
4	300	5.02	234	389	635	2.0	0.618	0.0098	0.0058
5	380	4.82	266	542	1197	1.9	0.591	0.0092	0.0113
6	460	5.70	186	345	735	2.5	0.415	0.0077	0.0005
Quena									
1	81	4.34	231	378	556	1.2	0.66	0.034	0.0167
2	164	4.65	141	282	429	2.0	0.67	0.033	0.0120
3	252	4.40	166	267	389	1.5	0.60	0.010	0.0064
4	338	3.55	161	277	354	1.5	0.49	0.006	0.0015
5	414	4.03	135	239	315	1.6	0.31	0.003	0.0001
6	517	3.88	184	267	344	1.4	0.36	0.003	0.0009
Sohaj									
1	55	4.54	352	586	1155	2.0	0.82	0.0396	0.0117
2	124	4.58	177	453	594	1.4	0.77	0.1118	0.0313
3	183	4.13	236	472	987	1.8	0.88	0.1236	0.0291
4	274	4.19	160	258	412	1.1	0.78	0.2199	0.0259
5	355	4.12	176	251	330	1.7	0.75	0.0979	0.01
6	425	4.27	204	314	591	1.5	0.61	0.0175	0.002
Bani-Sweif									
1	344	2.82	306	603	1661	1.77	0.81	0.0163	0.0191
2	282	2.76	415	490	1,216	1.64	0.74	0.0272	0.0152
3	221	2.76	359	409	700	1.43	0.72	0.0422	0.0178
4	179	3.40	305	343	543	1.39	0.66	0.0416	0.0126
5	120	4.28	295	350	697	1.56	0.71	0.0482	0.0057
6	60	5.04	251	296	619	1.63	0.73	0.0623	0.0040

Three equations including Meyer-Peter-Muller (1948), Bagnold (1966), and Van Rijn (1984[a]) equations were tested for the prediction of bed-load transport using the Nile data. Table 2.8 shows the comparison between the measured and predicted bed load transport rates at the four study sites; Ratio of computed and measured transport rate is given between brackets. From the results, the prediction of bed load transport rate using Van Rijn's equation gives significantly better results than the Bagnold's equation and slightly better results than the Meyer-Peter-Muller's equation.

Table 2.8: Measured and Predicted Bed Load Transport Rates at the Four Study Sites (Abdel-Fattah et al., 2004)

Site	Measured	Predicted Bed-load transport rates (Kg/s)		
		Bagnold	Meyer-Peter-Muller	Van Rijn
Aswan	1.73	8.2 (4.7)	2.9 (1.7)	1.6 (0.93)
Quena	3.21	12.8 (4.0)	5.8 (1.8)	2.7 (0.86)
Sohag	7.21	31.2 (4.3)	19.1 (2.7)	14.0 (1.9)
Bani-Sweif	3.92	22.3 (5.7)	14.4 (3.7)	11.5 (2.9)

Note: Ratio of Computed and Measured Transport Rate is Given between Brackets

The suspended-load transport rates were computed using Bagnold (1966) and Van Rijn (1984[b]) equations. Table 2.9 shows the comparison between the measured and predicted suspended-load transport rates at the four study sites. These results show that the predicted suspended transport rates of both equations are in good agreement with the measured values.

Table 2.9: Measured and Predicted Suspended Load Transport Rates at the Four Study Sites (Abdel-Fattah et al., 2004)

Site	Measured	Predicted Bed-load transport rates (Kg/s)	
		Bagnold (1996)	Van Rijn (1984[a,b])
Aswan	4.4	4.9 (1.1)	1.8 (0.4)
Quena	8.9	10.1 (1.1)	6.6 (0.7)
Sohag	47.9	26.3 (0.6)	34 (0.7)
Bani-Sweif	15.8	18.5 (1.2)	25 (1.6)

Note: Ratio of Computed and Measured Transport Rate is Given between Brackets