HYDROLOGY AND SUSPENDED SEDIMENT YIELD IN SUNGAI KINABATANGAN

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FACULTY OF SCIENCE AND NATURAL RESOURCES
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ACKNOWLEDGED BY

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Prof. Dr. Kawi Bidin

DECLARATION

I hereby declare that the material in this thesis is my own except for quotations, excerpts, equations, summaries and references, which have been duly acknowledged.

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ABSTRACT

The quality of many rivers today is affected by anthropogenic factors such as land use conversions and industrial developments. These activities have altered the pattern of runoff, increased the sediment loads delivered into river channels, and inadvertently affect the quality of river water. This study was carried out to (a) analyse the hydrology characteristics of Sungai Kinabatangan Catchment; (b) determine the sediment yield in the Sungai Kinabatangan Catchment; (c) develop baseline hydro-geometry data of Sungai Kinabatangan and its tributaries; and (d) design flow duration curves (FDC) for ungauged rivers in the Sungai Kinabatangan Catchment. The four objectives were determined by field measurements of river geometrics as well as analysis of long-term gauging station data. For the first objective, this study found that the Sungai Kinabatangan Catchment portrays hydrologic characteristics of a large catchment. It is mainly dominated by baseflow and less responsive to rainfall. The second objective determined that the sediment yield in the Sungai Kinabatangan Catchment averages about 250 to 1,250 ton/km^2/year. The amount is deemed tolerable and the yield has been relatively the same since previous studies carried out 20 years ago. Hydro-geometry measurements (width and depth of a channel) were obtained for 17 tributaries within the Sungai Kinabatangan Catchment as well as the main river stem itself. These measurements are useful in establishing a baseline of hydro-geometry data for Sungai Kinabatangan. For the final objective, the design FDC for all the tributaries in the Sg. Kinabatangan basin was established based on the data from five existing gauging stations in the basin. Flow regime for each tributary could be extracted from the design FDC. This method is useful in the estimation of flow for small tributaries within a big catchment. It is especially practical where numerous high-order streams drain into the catchment and these streams are less accessible or are without a gauging record.

ABSTRAK

HIDROLOGI SUNGAI KINABATANGAN: KESAN GUNA TANAH TERHADAP GEOMETRIK SALIRAN DAN INTERAKSI KAWASAN TADAHAN

Kualiti air kebanyakan sungai dipengaruhi oleh kegiatan manusia seperti penukaran gunatanah dan perkembangan industri. Aktiviti-aktiviti ini telah menyebabkan perubahan corak air larian, peningkatan beban sedimen yang mengalir ke dalam sungai, dan secara langsung menjejaskan kualiti air sungai. Kajian ini dijalankan untuk (a) menganalisis ciri-ciri hidrologi Lembangan Sungai Kinabatangan; (b) menentukan hasil enapan di Lembangan Sungai Kinabatangan; (c) menyediakan data asas hidro-geometri Sungai Kinabatangan serta anak-anak sungai; dan (d) mereka bentuk flow duration curve (FDC) *untuk kawasan tadahan sungai yang tidak diukur. Semua objektif kajian telah ditentukan dengan kerja-kerja mengukur keratan rentas sungai di Lembangan Sungai Kinabatangann, serta menganalisis data jangka panjang daripada stesen pengukuran. Bagi objektif pertama, kajian ini mendapati bahawa Lembangan Sungai Kinabatangan menggambarkan ciri-ciri hidrologi kawasan tadahan yang besar. Sebahagian besar lembangan sungai ini didominasi oleh aliran dasar* (baseflow) *dan kurang responsif kepada hujan. Objektif kedua telah menentukan bahawa purata hasil enapan di Lembangan Sungai Kinabatangan kira-kira 250 hingga 1,250 tan/km*^{2}*/tahun. Jumlah ini dianggap boleh diterima dan juga agak sama apabila dibandingkan dengan kajian yang telah dijalankan 20 tahun yang lalu. Ukuran lebar dan kedalaman telah diperolehi untuk 17 anak sungai serta batang sungai utama Sungai Kinabatangan. Penyediaan data asas ini berguna dan boleh membantu dalam kajian-kajian akan datang di Lembangan Sungai Kinabatangan. Bagi objektif yang terakhir, reka bentuk FDC untuk semua anak sungai di lembangan Sg. Kinabatangan telah dihasilkan berdasarkan data daripada lima stesen pengukuranyang berada di lembangan itu. Rejim aliran bagi setiap anak sungai boleh diperolehi daripada FDC. Kaedah ini boleh digunakan untuk menganggar aliran sungai kecil di kawasan tadahan yang besar. Ia amat praktikal terutamanya untuk sungai-sungai di tempat yang sukar ditembusi ataupun tidak mempunyai rekod pengukuran.*

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LIST OF ABBREVIATIONS

ASCE	American Society of Civil Engineers
DID	Drainage and Irrigation Department, Sabah
DOE	Department of Environment Malaysia
FDC	flow duration curves
GIS	Geographical Information System
GPS	Global Positioning System
IRBM	Integrated River Basin Management
JICA	Japan International Cooperation Agency
POP	persistent organic pollutants
Sg.	Sungai *(River)*
WWF	World Wide Fund for Nature

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

The dynamics of river systems today, either within the catchment or directly in the river corridor, reflect human intervention. In developing countries, the exponential population growth implies an urgent need for water security in agriculture as well as increasing water supply for domestic and industrial uses. The sound understanding of hydrology and fluvial geomorphology is important in developing decisions and approaches to river management that conserve biodiversity and ecology as well as the restoration of ecosystems degraded by the rapid development process.

Many of the problems for river management today are related to anthropogenic factors such as land use conversions, water resource developments, and industrial expansion. These activities have altered the pattern of runoff, the quality of river water, and the load of sediment delivered to river channels (Petts and Calow, 1996). Catchment-wide changes have severe impacts not only on river ecosystems but also biodiversity at the landscape scale (Petts *et al*. 1989; Naiman & Decamps 1990; Petts & Amoros, 1996).

Comprehending the change of river channel patterns through time may be imperative for sensible management of the environment. For instance, in conservation works, it may aid in the restoration of a river channel to a condition that existed prior to development. It is also essential for environmental impact assessments to determine the magnitude and rate of change arising from a variety of impacts. The changes in river channel pattern and mobility influences in-stream and floodplain habitats significantly.

1.2 Objectives

The general aims of the study presented in this thesis are:

a) To analyse the hydrology characteristics of Sungai Kinabatangan Catchment;
b) To determine the sediment yield of Sungai Kinabatangan;
c) To develop baseline hydro-geometry data of Sungai Kinabatangan and its tributaries;
d) To design flow duration curves for ungauged rivers in the Sungai Kinabatangan Catchment.

1.3 Importance of Study

This study may be significant to the field of hydrology as not many recent researches have studied the hydrological characteristics of Sungai Kinabatangan and its catchment area. The findings from this study can contribute to the scientific information available for the Sungai Kinabatangan catchment. The data can be utilised by related institutions such as government agencies and non-profit organisations as a baseline to aid sustainable planning, management and development of the catchment area.

1.4 Structure of Thesis

This sub-chapter explains the framework underlying the structure in which this study is to be viewed. The structure of this study is based on the content of the individual chapters.

Chapter One introduces the gist of this study's topic and highlights the objectives and importance of this study.

Chapter Two includes a collection of literature review defining terms such as "channels", "catchment areas", and the classification of channels. The morphology and geometry of channel hydrology was also highlighted. The impacts of anthropogenic activities and land use to channels and catchments were discussed with examples from previous studies. These are linked to water resources and land use planning in Sabah, Malaysia.

Chapter Three details the study area, including the geology, geomorphology, and the many roles of Sg. Kinabatangan. The land use in the catchment is also documented and further elaborated in this chapter.

Chapter Four explains the methodology used in this study where data analysis can be separated into three parts. The first part describing the fieldwork carried out to obtain hydro-geometry measurements. The second and third parts are the hydrological analysis and sediment yield analysis, respectively, of long term data. Long term daily rainfall, flow, and suspended sediment data were acquired from the Drainage and Irrigation Department, Sabah (DID).

Chapter Five presents the results and discussions of the hydrological analysis of Sg. Kinabatangan Catchment. The rainfall, runoff and sediment yield results are presented and discussed. A flow frequency analysis of the catchment is also carried out and the flow duration curve procured was used to design the flow of the ungauged basins.

Chapter Six discusses the results of the channel size – catchment area interaction analysis. The interactions were also correlated with land use to determine if any significant relationship exists. The results were discussed in this chapter.

Chapter Seven is where the outcome of this study and the conclusions are stated. Not many studies of this kind have been carried out, especially in areas with tropical climate. Thus, the findings from this study could be used as a baseline or be further looked into for further exploration in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 Channel Hydrology

Channel, by definition, is a naturally or artificially created open conduit which either periodically or continuously contains moving water. It can also be a connecting link between two water bodies. Natural channels are synonymous with terms such as river, creek, branch, and tributary, while canal and floodway are terms used to describe artificial channels (Langbein and Iseri, 1983).

Natural channels are classified based on its relation to time, space, and ground water (Meinzer, 1923; Svec et al., 2005) and the classifications are as follow:

a. Relation to time:

Perennial rivers are channels that contain water and flows throughout the year. Intermittent channels are those that flow only certain times of the year, especially during wet seasons, when it receives water from some source such as a spring, rain or snow melt. Ephemeral channels are formed during or immediately after a rainfall event and is at all times above the water table.

b. Relation to space:

Channels are classified as interrupted when they contain alternating reaches that are perennial, intermittent, or ephemeral. A continuous channel does not have interruptions in space.

c. Relation to ground water:

Gaining channels are those which ground water source is from the zone of saturation as opposed to losing channels which contribute to the zone of saturation. An insulated channel is separated from the zone of saturation by an impermeable bed thus does not source nor contributes to it. A perched channel is either a losing river or an insulated stream that is separated from the underlying groundwater by a zone of aeration.

Large and Petts (1996) described the river corridor as a zone which encompasses active and abandoned channels, the riparian zones along the channel banks, and floodplains. Rivers are characterised by their changing flows and channel forms, variable water quality conditions, and hydraulic and morphological attributes. Although a natural river channel is formed and maintained by its flow, Brookes (1996) observed that it is never of sufficient size to contain all discharge. On average about once each year, larger floods will overflow the normal channel banks on to the adjacent floodplains. This is an important process as it builds a floodplain through deposition of sediment. Alluvial channels with sufficient powerful streams also naturally erode at various rates laterally across their floodplains. The changes in discharge and sediment load rarely produce an immediate response in a channel's fluvial regime, but instead initiate a sequence of changes which may extend over a long period of time.

2.1.1 Channel Morphology

The morphology of a channel is formed by the movement of water and sediment (Brookes, 1996) while the size of a channel is determined by the amount of water flowing through it, especially flood peak flows which causes erosion and channel-shaping sediment transport (Fitzpatrick *et al.*, 1999). Physical processes in rivers are governed by both primary and secondary factors. Primary factors are volume and time distribution of water supplied from upstream; volume, timing and the character of delivered sediment; the nature of materials which a river flows through; and the local geological history of the riverine landscape. The secondary factors listed are local climate, vegetation along the river banks, and the land use within the drainage basin (Church, 1996).

A channel transports both water and sediment and the flow is typically non-uniform, unsteady and turbulent. Channels change in a myriad of ways to achieve equilibrium through processes that are affected by the catchment's characteristics such as erosion and deposition. In theory, channels that are in equilibrium tend to be morphologically stable. They are able to transport water and sediment load imposed from the upstream parts of the catchment without enlarging or aggrading (Stockwell, 2000). However, a channel that is described as stable may also face bed and bank erosions that occur naturally. Brookes (1996) mentioned that sediment load and surface runoff can be expected to change in response to deforestation, urbanisation, agriculture, and other land use alterations.

2.1.2 Channel Geometry

The shape of a river channel cross-section at any location is a function of the flow, the character and quantity of sediment moving through the section, the composition of bed and bank materials, and riparian vegetation (Stockwell, 2000). In 1922, Schaffernak (cited in Tilleard, 1999) first proposed the observation that the size and shape of a river channel reflects the discharge which corresponds to the stage at which the bulk of the river's bed load is carried. Subsequently, Wolman and Miller (1960) demonstrated that the largest proportion of total sediment load in a channel is carried by flows that occur once or twice each year instead of the more extreme but less frequent events. They also observed that the flows at or near the bankfull stage determine the channel shape which led to the conclusion that frequently recurring events of moderate intensity are the effective events in forming significant landforms rather than rare floods of unusual magnitudes.

According to Leopold *et al.* (1964), a natural channel not only transports sediment downstream, but carries it laterally from one bank to the other via erosion. The erosion of one bank and deposition at the opposite bank maintain an average constant channel cross section. Bank erosion and sediment transport are directly produced by hydraulic factors such as depth, slope and velocity of flow which determine the cross-sectional shape, the pool-riffle formation, and the meander shape of alluvial river channels.

The bend in a watercourse is called a meander, and it is formed when the outer bank of a stream erodes and its valley widens. Meanders appear at the point which a river does the least work turning, thus they are the most probable form a river can take and possesses a striking geometric regularity (Leopold and Langbein, 1966). Meanders are characterised as irregular waveforms because the bankfull width of a stream has to be taken into account in contrast to ideal waveforms which are one line thick. The bankfull width is the distance across a cross-section at the full-stream level, usually estimated by the lowest line of vegetation (Gordon *et al.*, 2005).

The meander depends on the flow characteristics and its length is empirically related to the dominant discharge. However the parameters of the waveform are independent of the flow and are said to be caused by geological factors. In 1964, Leopold *et. al* proposed that there is a relation between width and meander length in alluvial rivers. Generally, the meander length is 10 to 14 times, with an average of 11 times, the bankfull width, and a large number of bends having a range of 2 to 3, with a median value of 4.7, ratio of radius of curvature to bankfull width. Newbury and Garboury (1993) added that for rivers ranging from 0.3 to 300m wide, a full meander length occurs between 7 to 15 times the bankfull width (Figure 2.1).

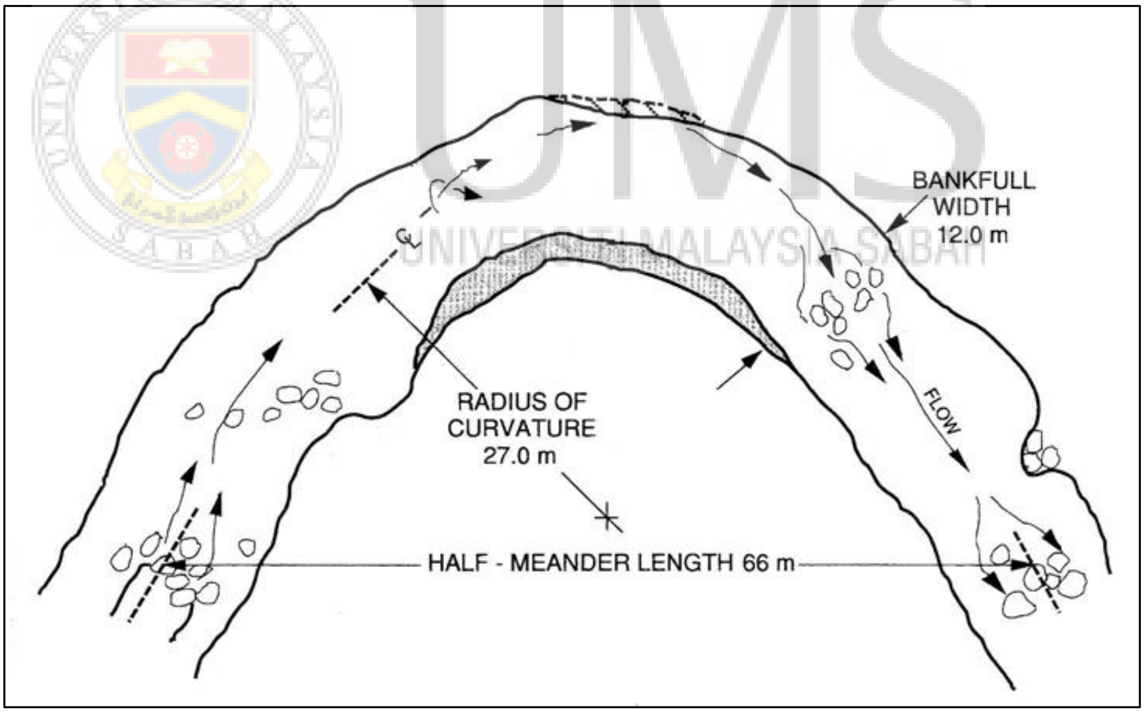

Figure 2.1: Stream geometry of a meander bend on the North Pine River.

Source : Newbury and Garboury, 1993.

The interaction of flowing water and mobile sediments results in pools and riffles, which illustrates the depth pattern of a meander. Pools are created where the flow at very high discharges tends to converge and is characterised by relatively deep, slow-moving water which causes scouring. At riffles, the flow is divergent, corresponds to deposition, and the cross-section is often symmetrical (Brookes, 1996). According to Newbury and Gaboury (1993) the profile of pools and riffles for all river patterns in erodible materials are related to the bankfull width. Pools are spaced, in average, half the meander length, or about 5.6 to 6.7 times the bankfull width for alluvial and bedrock channels (Figure 2.2).

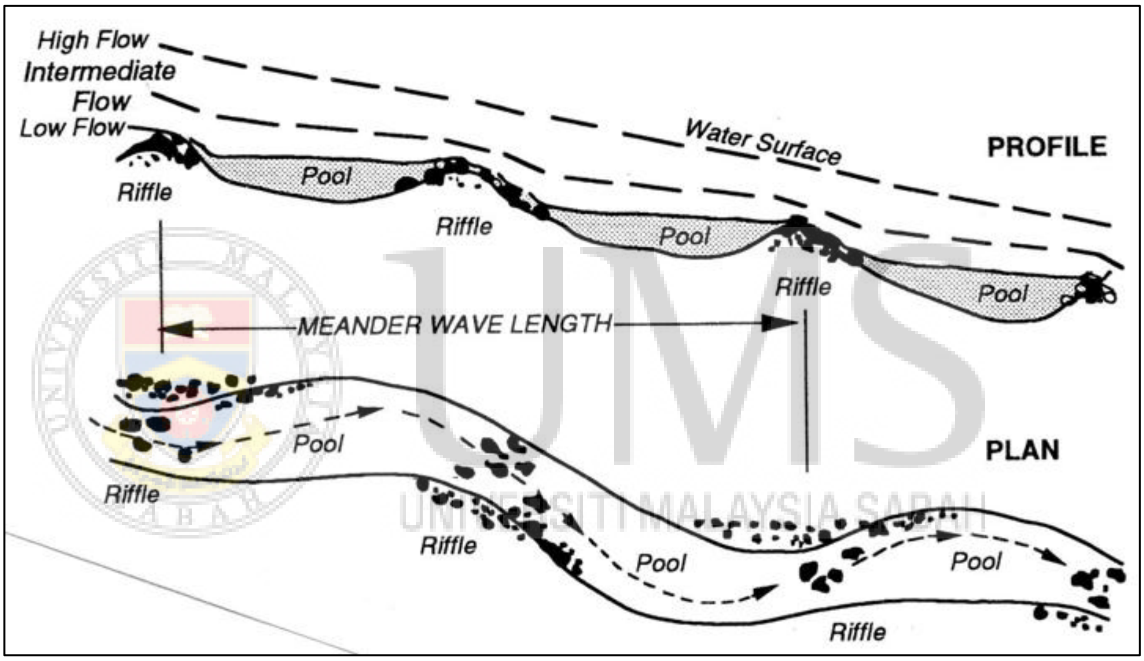

Figure 2.2 : Schematic of a long profile and pool-riffle sequences.

Source : Newbury and Garboury, 1993.

2.2 Catchment Management

A catchment area, or drainage basin, is an area bounded by the watershed line and drains all water that precipitates within that boundary (Huggett & Cheesman, 2002). The watershed line is the elevation contour that extends along the crests of hills to delimit the area draining into a river (Stanford & Ward, 1992). The catchment area is also a measure of surface or shallow subsurface runoff at a given point in a landscape and is used as a fundamental unit for hydrology and fluvial