DEVELOPMENT OF SEDIMENT TRANSPORT EQUATION FOR RIVERS IN MALAYSIA

By

CHEW TECK YEOW

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ABSTRACT

River! A valuable asset of the Mother Nature. Its contribution are uncountable, not only that it provide us with the source of water, food and transportation, it's also harvest life form within it. However, river is like a double edge swords. Past through the centuries, nature disaster such as flood cause by river had taken always many life and cause unimaginable damage to our asset. Even small particle such as sediment inside the river had its own way of affecting our way of life. Due to that, the transportation factor of sediment has to be identified and represent in equation formation so that people can predict and counter attack the foe that is coming. The present study evaluates several existing equations using data of selected rivers in Malaysia (Ghani, 2003). New data were also collected from several sites along Kulim River, Kedah. These data were later used to modified the existing equations for application of the rivers in Malaysia. The modified equations are used to predict the natural phenomena and characteristic of the sediment transport in rivers to secure human life and fortune.

ABSTRAK

Sungai! Suatu harta tak ternilai alam sekitar. Penyumbangannya adalah tak terkira, bukan sahaja ia memberikan kita sumber air, makanan dan pengangkutan, ia juga mengandungkan hidupan di dalamnya. Walaubagaimanapun, sungai adalah macam pisau dua mata. Dari masa dulu lagi, bencana alam seperti banjir yang disebabkan oleh sungai telah meragut banyak nyawa dan mengakibatkan kerugian yang teruk pada harta benda kita. Sekecil seperti pasir dalam sunagi pun ada cara sendirinya dalam mempengaruhi kehidupan manusia. Oleh yang demikian, faktor pengangkutan pasir perlu dikenalpasti dan dipersembahkan dalam bentuk persamaan supaya orang ramai boleh menganggar dan mengambil tindakan ke atas apa-apa ancaman yang bakal tiba. Secara tegasnya, penyelidikan terperinci persamaan pengangkutan pasir untuk sungai di Malaysia perlu dijalankan untuk tujuan keuntungan semua Malaysian. Penyelidikan masa kini menilai beberapa persamaan sedia ada dengan menggunakan data daripada sungai terpilih di Malaysia (Ghani, 2003). Data baru juga dikumpul daripada beberapa tempat kajian di Sungai Kulim, Kedah. Data ini kemudiannya digunakan untuk memperbaharui persamaan-persamaan sedia ada untuk sungai di Malaysia. Persamaan baru yang dibentuk akan digunakan untuk menganalisis fenomena sungai yang berkait dengan pengangkutan pasir dengan tujuan melindungi harta benda dan nyawa manusia.

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CHAPTER 1
INTRODUCTION

1.1 Introduction

From the point of view of hydraulic, a river channel is a media carries both water and sediment. This system is dynamic and over time, it adjusts to changes in inputs and other condition. These chances can be due to natural processes (e.g., precipitation), or the result of human activities (e.g., narrowing if the flood plain with levees) (Koay, 2004).

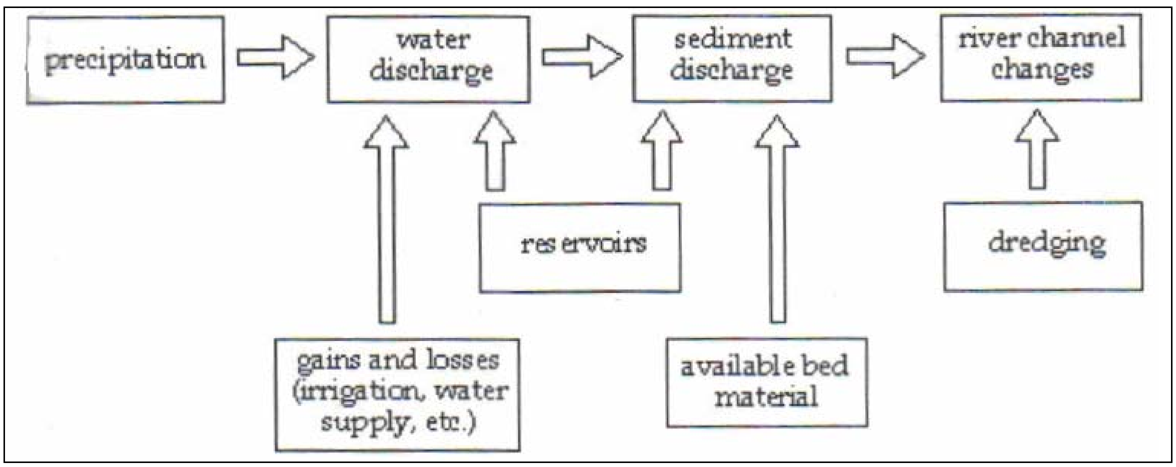


Figure 1.1: Processes affecting sediment transport in a river channel (Koay, 2004)

However, adequate knowledge of the sediment transport phenomenon (Figure 1.1) in rivers are needed for studies of reservoir sedimentation, river morphology, soil and water conservation planning, water quality modeling and design of efficient erosion control structures for the benefit of all (Shang and Kamae, 2005).

1.2 Problem Statement

Sediment transportation may create severe problem due to the movement of the sediment. The nature of movement depends on the particle size, shape and specific gravity with respect to the associated velocity and turbulence. Sediment transportation is being carried intermittently in suspension for high velocity and turbulence. Conversely, in low velocity and gradient, sediment transportation may move as bed load. The sediment particle has the tendency to remain in suspension for days or even month for relatively quiet water whether as bed load or in suspension (Vanoni, 1975). However, impingement of sediment particles are also not to be taken lightly, damages cause by the shrinking of objects by sediment particle are most likely to occur if proper measure have not been apply (Vanoni, 1975). Muddy streams that have fine-grained sediment carried in suspension have an effect on the size, population and species of fish in a stream. Suspended sediment effects the light penetration in water, thus reduces the growth of microscopic organisms on which insects and fish feed and may injure the gill and breathing structure of certain kind of fish (Vanoni, 1975).

1.3 Objectives

The objectives of this study are as follows:

1. Data collection and analysis at Kulim River, Kedah.
2. Identify and analysis of the sediment transportation factor.
3. Create the sediment transport equations that represent the rivers in Malaysia.
4. Utilization of the sediment transport equation for solving sediment problem such as geomorphic, hydrologic and environmental nature.

1.4 Scope of Research

For this research of the sediment transport, data collection at rivers are being carried out with various kinds of equipment such as Helle Smith sampler, DH-48 sampler and grab sampler to obtain the bed load and total load of the rivers. With these data, preliminary data processing can be done and the results will be used to develop the sediment transport equations. Sediment transport equations are being developed by graph, sediment transportation data for the identified parameters are being input into the graph and the original sediment transport equation is adjusted to match the Malaysian rivers data. Later on, new modify sediment transport equations that represent the rivers in Malaysia will be developed (Yahaya, 1999).

CHAPTER 2
LITERATURE REVIEW

2.1 Introduction

In actual flows, the flow, sediments and bottom shape have to be predicted (Eidsvik, 2004). In this case, the developments of sediment transport equation are crucial to predict the outcome of the flow, sediments and bottom shape.

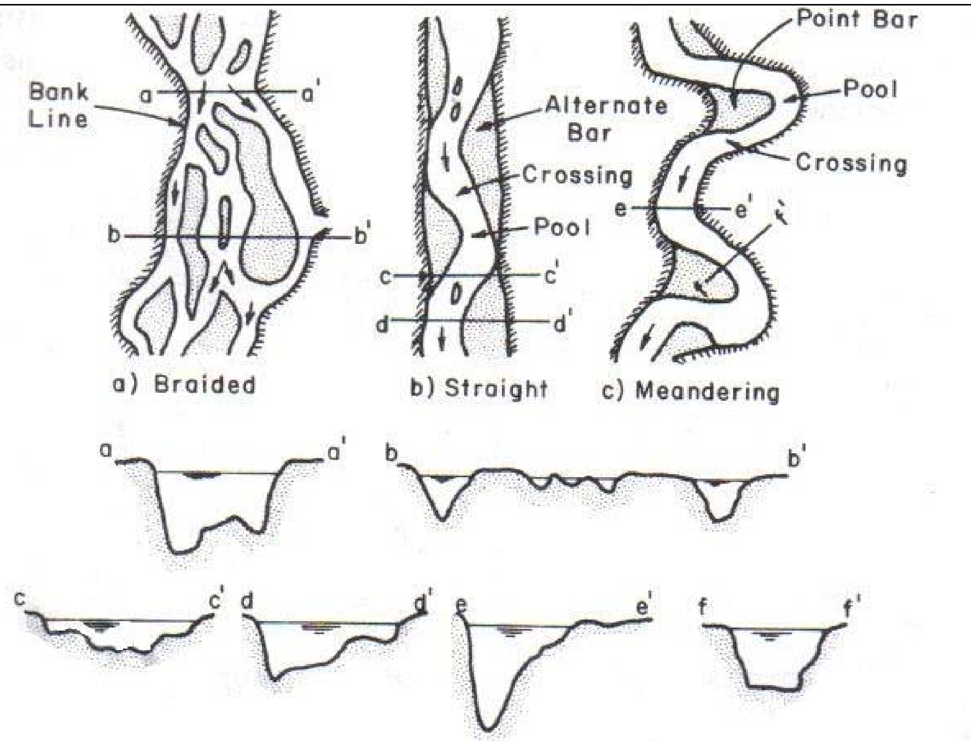
Improvements of the accuracy of sediment transport estimation have been a main theme for many studies. Yet it appears that different scientists have different opinions. Some scientists give the impression that they consider the relative uncertainty to be comparable to a factor of 10^{-1} or so, while other scientists give the impression that they consider it to be larger than a factor of 10^{3} (Eidsvik, 2004).

For all component of sediment transport, there exists a great variety of formulas and every year new formulas are added (Yang, 2005). The objective of presenting them is to make them conveniently available to those who may need to employ them and to give some information that may help in evaluating them. (Vanoni, 1975).

Engineers engaged in river regulation and design and operation of canal systems have great need for methods of computing sediment discharge. Unfortunately, available methods or relation for computing sediment discharge are far from completely satisfactory with the result that plans for works involving sediment movement by water cannot be based strongly on such relations (Vanoni, 1975).

2.2 River Profile

Rivers can briefly classify in terms of channel pattern based upon configuration as view on a map or from the air (Figure 2.1). Patterns include straight, meandering and braided or some combination of these.



Definition:

Straight channel -	One that does not follow a sinuous course.
Braided river -	Generally wide with poorly defined and unsafe banks, and is characterized by a steep, shallow water course with multiple channel divisions around alluvial islands.
Meandering channel -	One that consists of alternating bends, giving an S-shape appearance to the plan view of the river.

Figure 2.1: River Channel Patterns

(Simon and Senturk, 1992)

As we all know, sediment transportation are carried by flow velocity, when the flow velocity reached zero, sediment particles that are being carried it will settle and create the bar or island (Sivakumar and Jayawardena, 2003). Below are some of the different types and patterns of the product of sediment transportation along the river bank (Figure 2.2 and Figure 2.3).

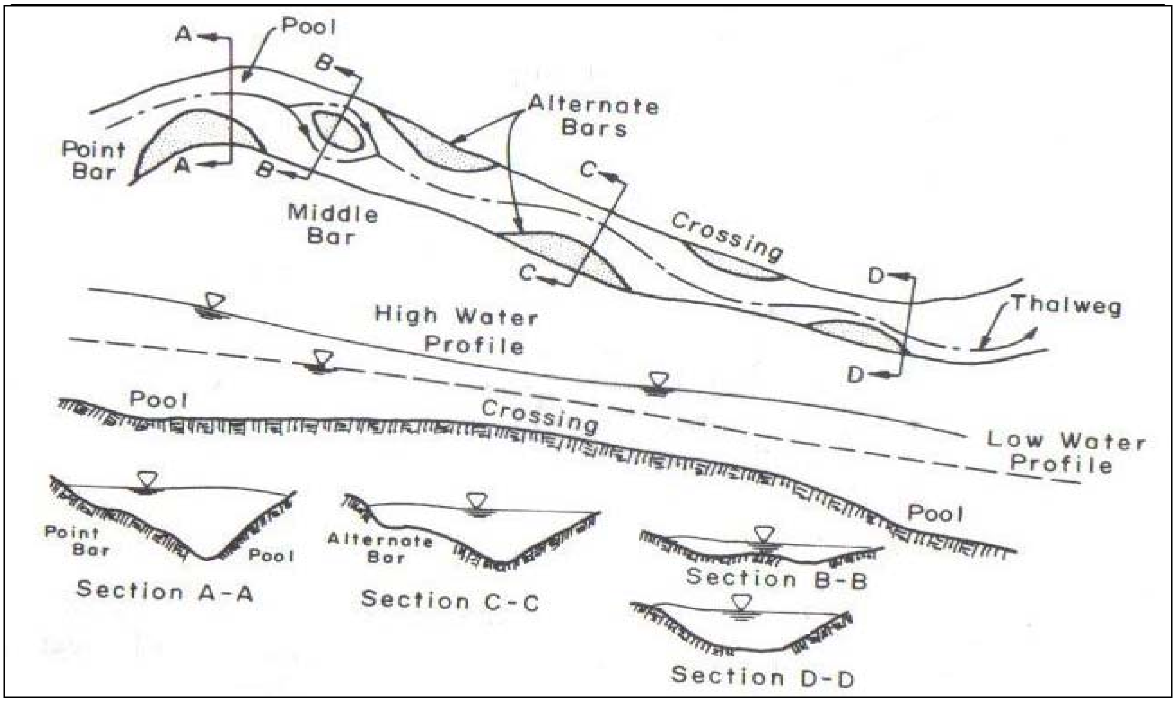


Figure 2.2: Plan View and Cross Section of a meandering stream

(Simon and Senturk, 1992)

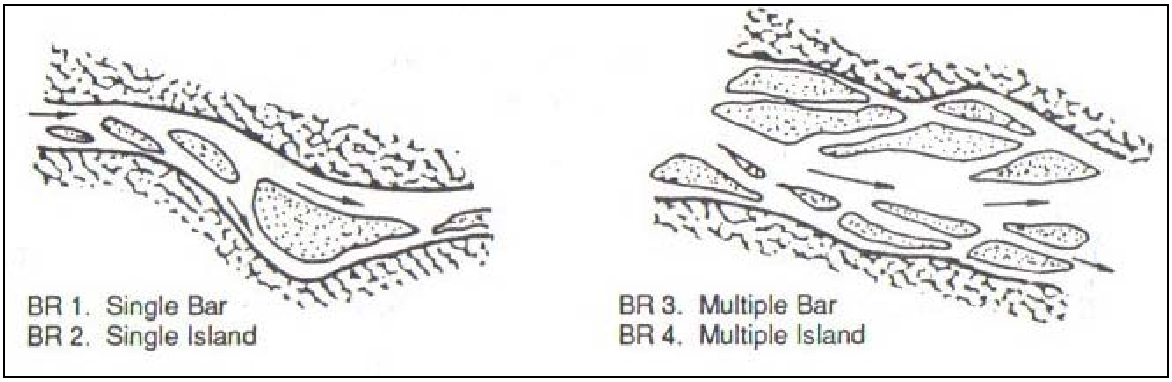


Figure 2.3: Braiding Patterns

(Simon and Senturk, 1992)

However, for further explaination on the bed forms that creates by the settlement of sediment transportation as given in Table 2.1.

Table 2.1: Summary Description of Bed Forms (Vanoni, 1975)

Bed form or configuration (1)	Dimensions (2)	Shape (3)	Behavior and occurrence (4)
Ripples	Wavelength less than approx 1 ft; height less than approx 0.1 ft.	Roughly triangular in profile, with gentle, slightly convex upstream slopes and downstream slopes nearly equal to the angle of repose. Generally short-crested and three-dimensional	Move downstream with velocity much less than that of the flow. Generally do not occur in sediments coarser than about 0.6 mm
Bars	Lengths comparable to the channel width. Height comparable to mean flow depth	Profile similar to ripples. Plan form variable	Four types of bars are distinguished: (1) Point; (2) alternating; (3) Transverse; and (4) Tributary. Ripples may occur on upstream slopes
Dunes	Wavelength and height greater than ripples but less than bars	Similar to ripples	Upstream slopes of dunes may be covered with ripples. Dunes migrate downstream in manner similar to ripples
Transition	Vary widely	Vary widely	A configuration consisting of a heterogeneous array of bed forms, primarily low-amplitude ripples and dunes interspersed with flat regions
Flat bed	—	—	A bed surface devoid of bed forms. May not occur for some ranges of depth and sand size
Antidunes	Wave length = $2\pi V^2/g$ (approx)[a] Height depends on depth and velocity of flow	Nearly sinusoidal in profile. Crest length comparable to wave-length	In phase with and strongly interact with gravity water-surface waves. May move upstream, downstream, or remain stationary, depending on properties of flow and sediment.

Figure 2.4 below show the types of multi channel streams and its branch, we can tell from the figure below that rivers have different types. Figure 2.5 show the types of bank heights available and how to differentiate them.

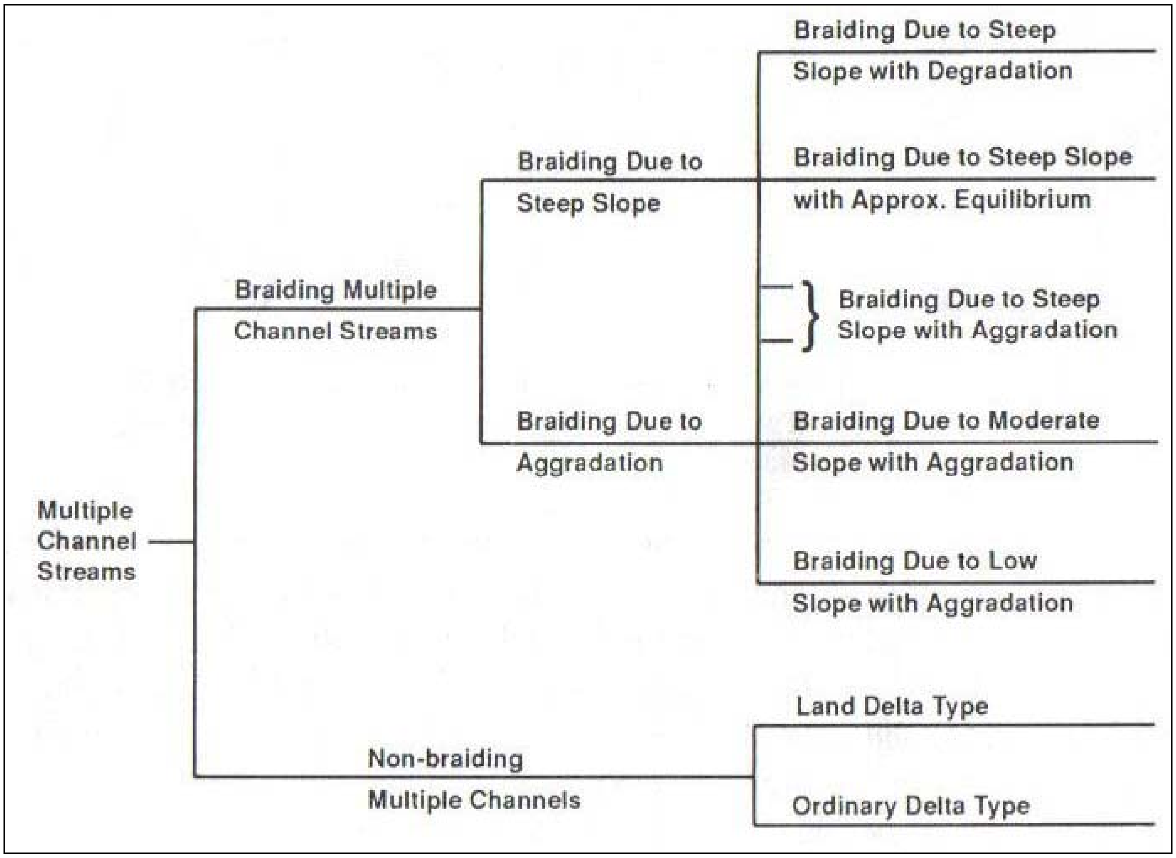


Figure 2.4: Types of multi-channel streams

(Simon and Senturk, 1992)

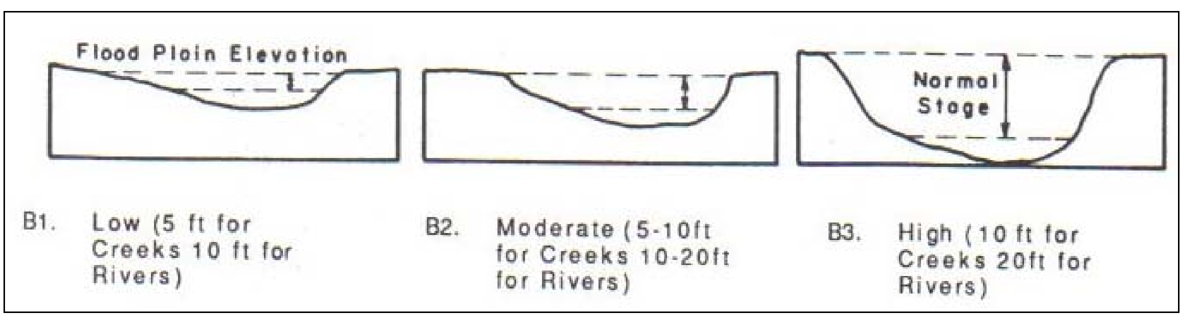


Figure 2.5: Types of Bank Heights

(Simon and Senturk, 1992)

2.3 Morphology of Rivers

From Figure 2.6, sediment are being transport along the river by the flow way and “Delta” is the place for collection of sediment where sediment is carry from up stream by the flow. However, the erosion, gravity and velocities of the flow are effecting the sediment transportation along the river (Jensen, 1999).

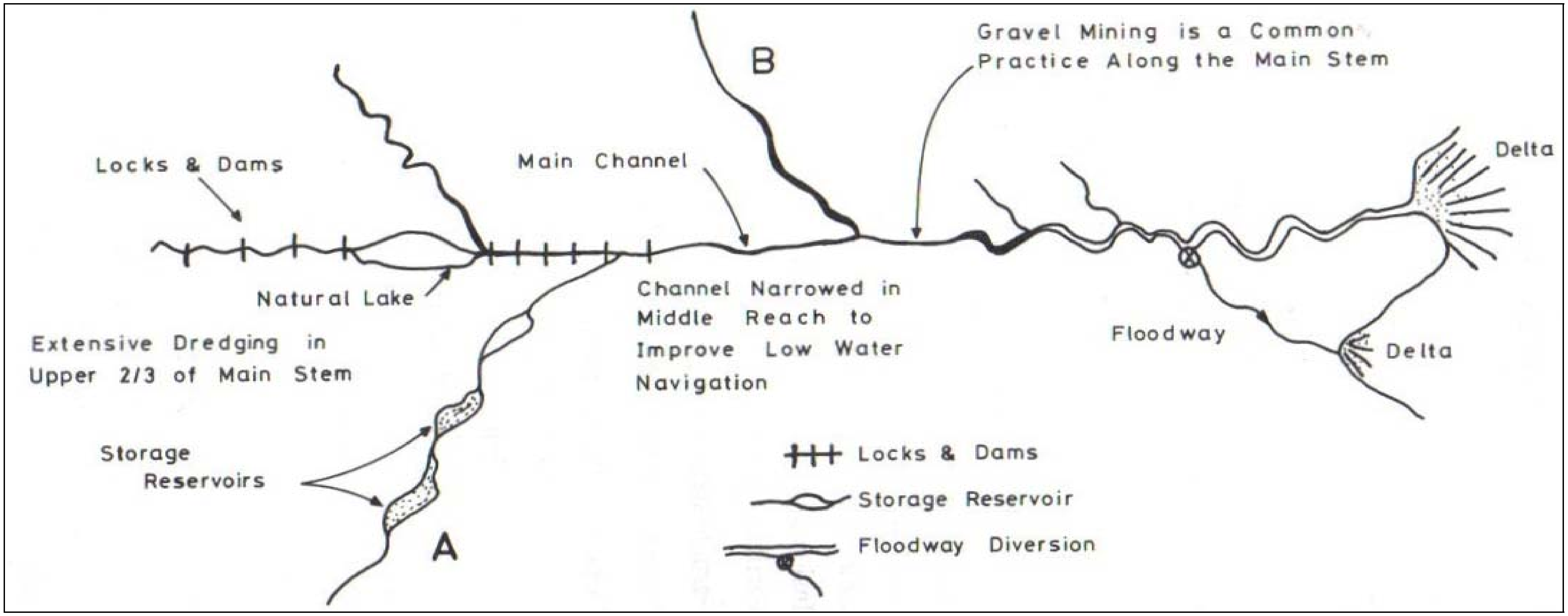


Figure 2.6: Plan View of Major River System

(Simon and Senturk, 1992)

2.4 Properties of Sediment

The entrainment, transportation, and subsequent deposition of sediment depend not only on the characteristics of the flow involved but also on the properties of the sediment itself (Table 2.2). Those properties of most importance in the sedimentation process can be divided into properties of the particles and of the sediment as a whole. The most important property of the sediment particle is its size (Vanoni, 1975).

Table 2.2: Sediment Grade Scale

(Vanoni, 1975)

Class name (1)	Size Range: Millimeters (2)	Size Range: Millimeters (3)	Size Range: Microns (4)	Size Range: Inches (5)	Approximate Sieve Mesh Openings per inch: Tyler (6)	Approximate Sieve Mesh Openings per inch: United States standard (7)
Very large boulders		4,096-2,048		160-80		
Large boulders		2,048-1,024		80-40		
Medium boulders		1,024-512		40-20		
Small boulders		512-256		20-10		
Large cobbles		256-128		10-5		
Small cobbles		128-64		5-2.5		
Very coarse gravel		64-32		2.5-1.3		
Coarse gravel		32-16		1.3-0.6		
Medium gravel		16-8		0.6-0.3	2-1/2	
Fine gravel		8-4		0.3-0.16	5	5
Very fine gravel		4-2		0.16-0.08	9	10
Very coarse sand	2-1	2.000-1.000	2,000-1,000		16	18
Coarse sand	1-1/2	1.000-0.500	1,000-500		32	35
Medium sand	1/2-1/4	0.500-0.250	500-250		60	60
Fine sand	1/4-1/8	0.250-0.125	250-125		115	120
Very fine sand	1/8-1/16	0.125-0.062	125-62		250	230
Coarse silt	1/16-1/32	0.062-0.031	62-31			
Medium silt	1/32-1/64	0.031-0.016	31-16			
Fine silt	1/64-1/128	0.016-0.008	16-8			
Very fine silt	1/128-1/256	0.008-0.004	8-4			
Coarse clay	1/256-1/512	0.004-0.0020	4-2			
Medium clay	1/512-1/1,024	0.0020-0.0010	2-1			
Fine clay	1/1,024-1/2,048	0.0010-0.0005	1-0.5			
Very fine clay	1/2,048-1/4,096	0.0005-0.00024	0.5-0.24			

2.4.1 Size of Sediment Particles

Due to the size and shape of grains making up a sediment vary over wide ranges, it is meaningless to consider in detail the properties of an individual particles, and it is necessary to determine averages or statistical values. For this reason, it has been convenient to group sediments into different size classed or grades that can be referred to Table 2.1: Sediment Grade Scale, which has been proposed by the subcommittee on Sediment Terminology of the American Geophysical Union (Vanoni, 1975).

This Sediment Grade Scale has proven advantageous in sediment work because the size are arranged in a geometric series with a ratio of two, and because the sizes correspond closely to mesh opening in sieves (Vanoni, 1975).

2.4.2 Shape of Sediment Particles

Shape refers to the form or configuration of a particle regardless of its size or composition. However, the shape of cross-section is also of considerable interest in river regulation. Cross-section shape is preferably described by the ratio of surface width and the depth of flow (Bogardi, 1974).

2.4.3 Density of Sediment Particles

The density of a sediment particle refers to its mineral composition. Usually, specific gravity, which is defined as the ratio of density of sediment to the density of water, is used as an indicator of density (Yang, 1996).

2.4.4 Fall Velocity

The fall velocity or the terminal fall velocity (Figure 2.7) that a particle attains in a quiescent column of water is directly related to relative flow conditions between the sediment particle and water during conditions of sediment entrainment, transportation and deposition. The fall velocity reflects the integrated result of size, shape, surface roughness, specific gravity and viscosity of fluid (Yang, 1996).

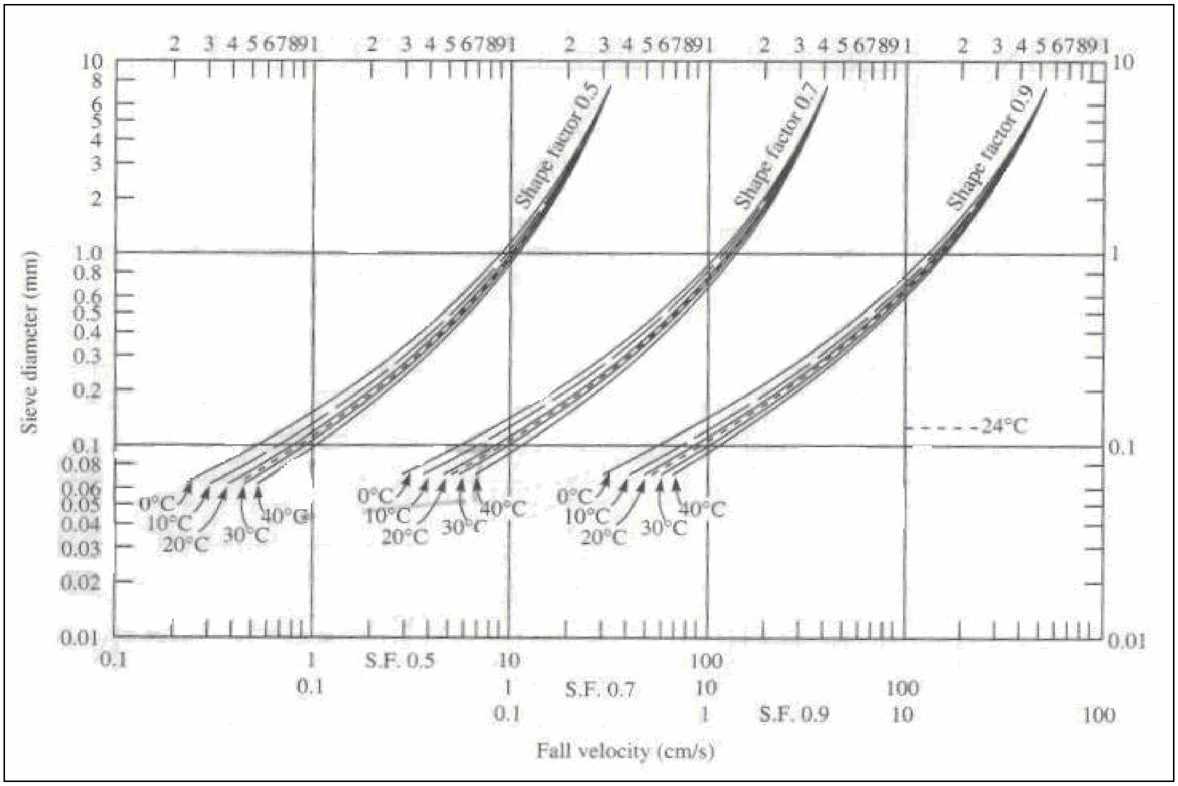


Figure 2.7: Relation between sieve diameter and fall velocity (Yang, 1996)

2.5 Bulk Properties of Sediment

In the studies of sediment transport, the three important bulk properties are (Yang, 1996):

1) Particle size distribution
2) Specific weight
3) Porosity of bed material.

2.5.1 Particle Size Distribution

Various sediment particles moving at different time may have different sizes, shapes, specific gravity and fall velocities. The characteristic properties of the sediment are determined by taking a number of samples and making a statistical analysis of the samples to determine the mean, distribution, and standard deviation of the sample such as given in Figures 2.8 to 2.10 (John, 2001).

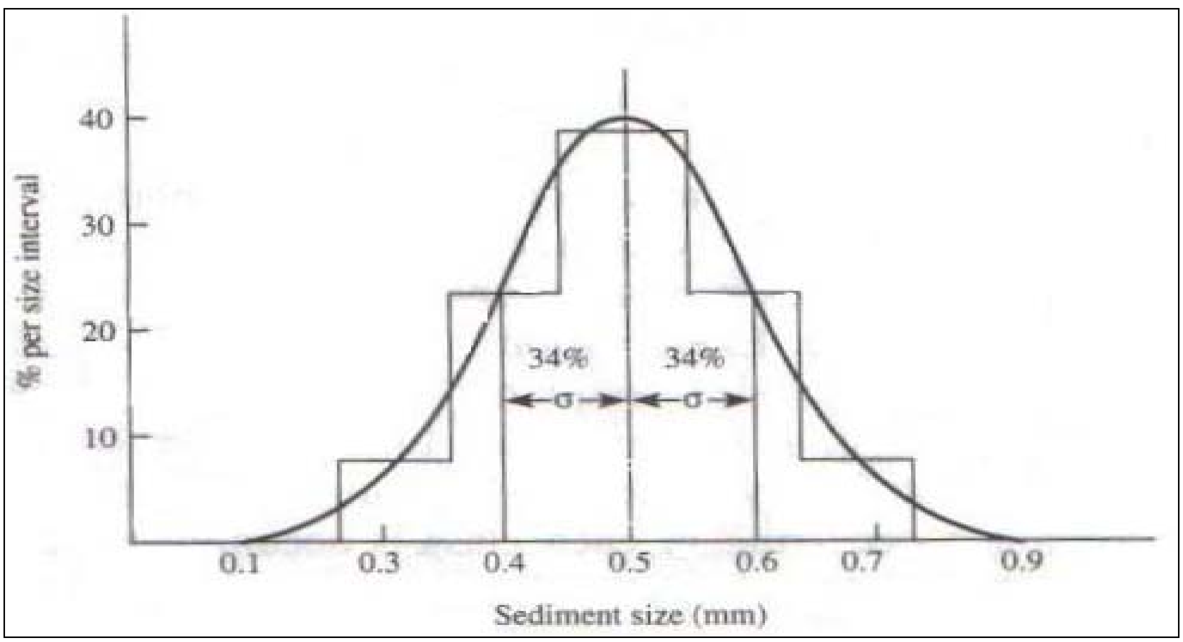


Figure 2.8: Normal Size-Frequency Distribution Curve (Yang, 1996)

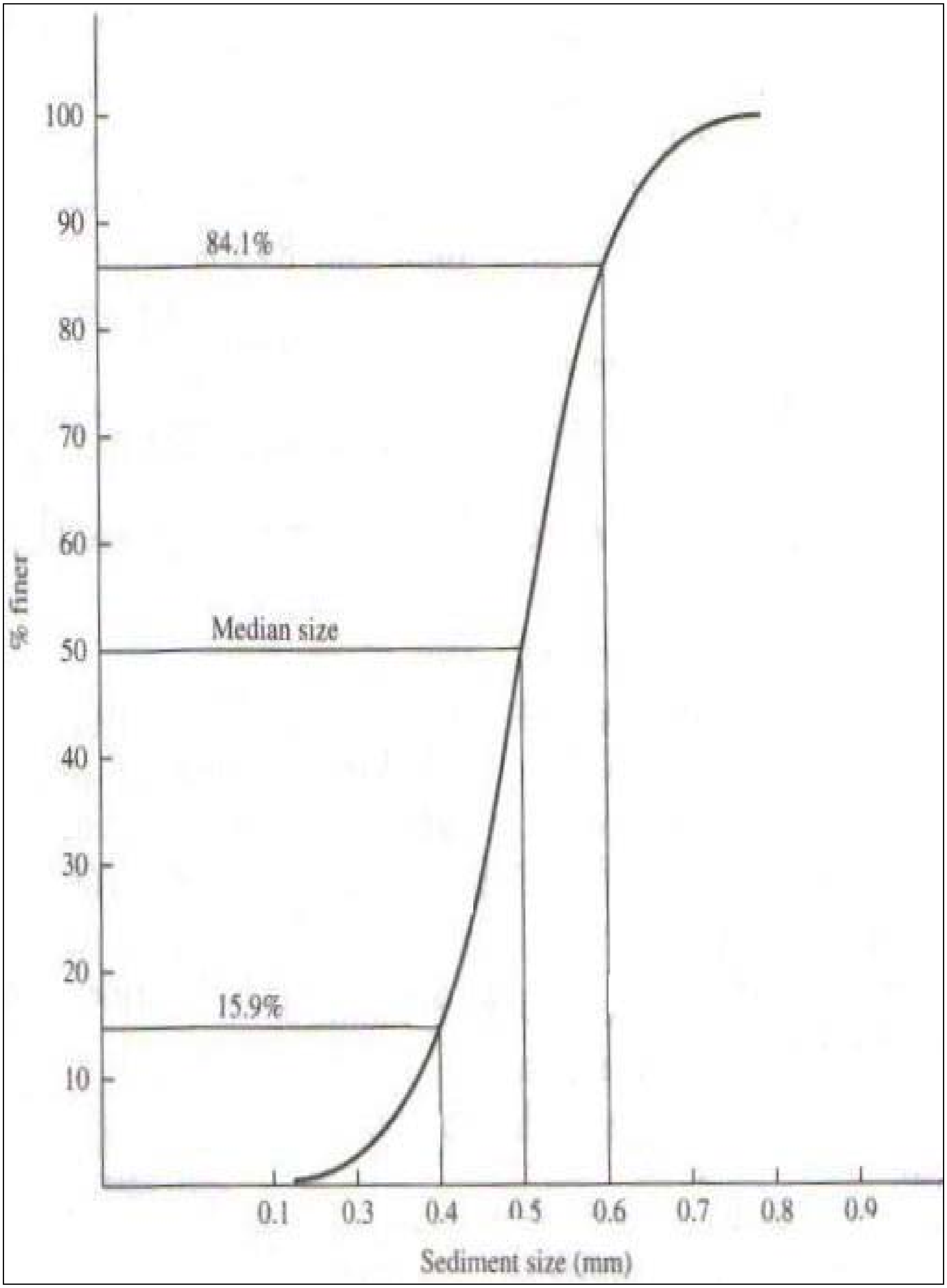


Figure 2.9: Cumulative frequency of normal distribution

(Yang, 1996)

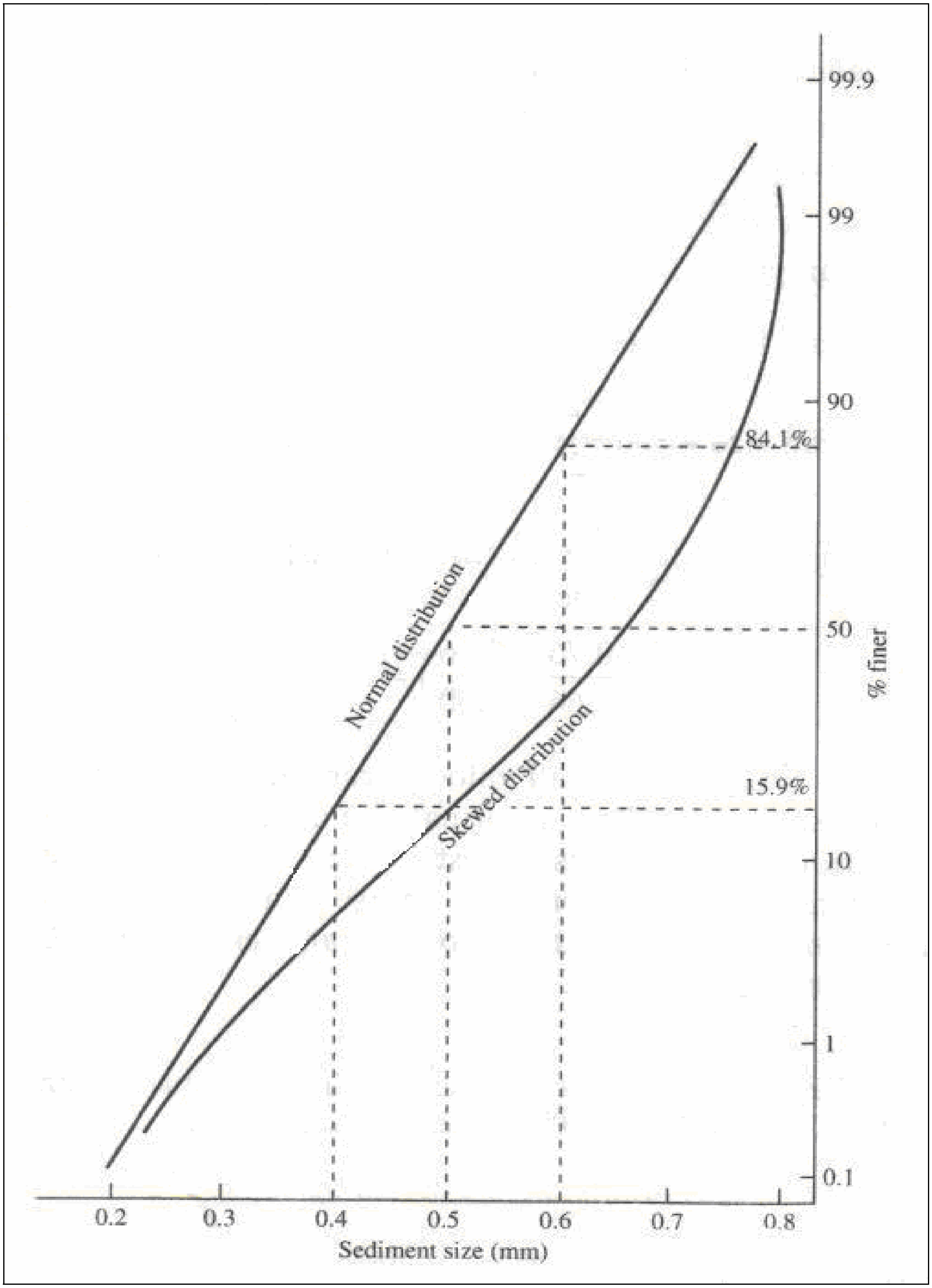


Figure 2.10: Cumulative frequency of normal and skewed distributions (Yang, 1996)

2.5.2 Specific Weight

The specific weight of deposited sediment depends on the extent of consolidation of the sediment. It increases with time after initial deposition. It also depends on the composition of the sediment mixture (Yang, 1996).

2.5.3 Porosity

Porosity is important in the determination of the volume of sediment deposition. It is also important in the conversion from sediment volume to sediment discharge (Yang, 1996).

2.6 Types of Sediment Transport

Sediment transport is very important to river hydraulics, the dynamic adjustments of river systems resulting from natural causes and the implementation of various water resources development activities has caused the change of sedimentation (Simon and Senturk, 1992).

Sediment can be transported by flow in one or combination of ways (Steven, 2000):

1) Rolling or sliding on the bed
2) Jumping into the flow and the resting on the bed, surface creep
3) Supported by the surrounding fluid during a significant part of its motion, suspension

This serves under the laws of motion (Ibad-Zade, 1992):

1) Traction
2) Suspension

2.7 Equations

Sediment transport equations involved a complex interaction between numerous interrelated variables. However, understanding the parameters that control sediment transport in rivers is a fundamental importance to the fields of hydraulics, hydrology, and water resources (Sumre and Muller, 1983).

2.7.1 Bed Load Transport

When the flow conditions satisfy or exceed the criteria for incipient motion, sediment particles is rolling, sliding, or sometimes jumping along the bed, it is called bed load transport.

1) Einstein Method

Einstein formula does not have any standard equation to be referred to due to the Einstein equation is being derived from the plotted graph (Ibrahim, 2002). However, Einstein formula is suitable for data at the range of 0.785mm to 28.65mm for d_{50}. Figure 2.11 show the example of plotted graph of the Einstein equation:

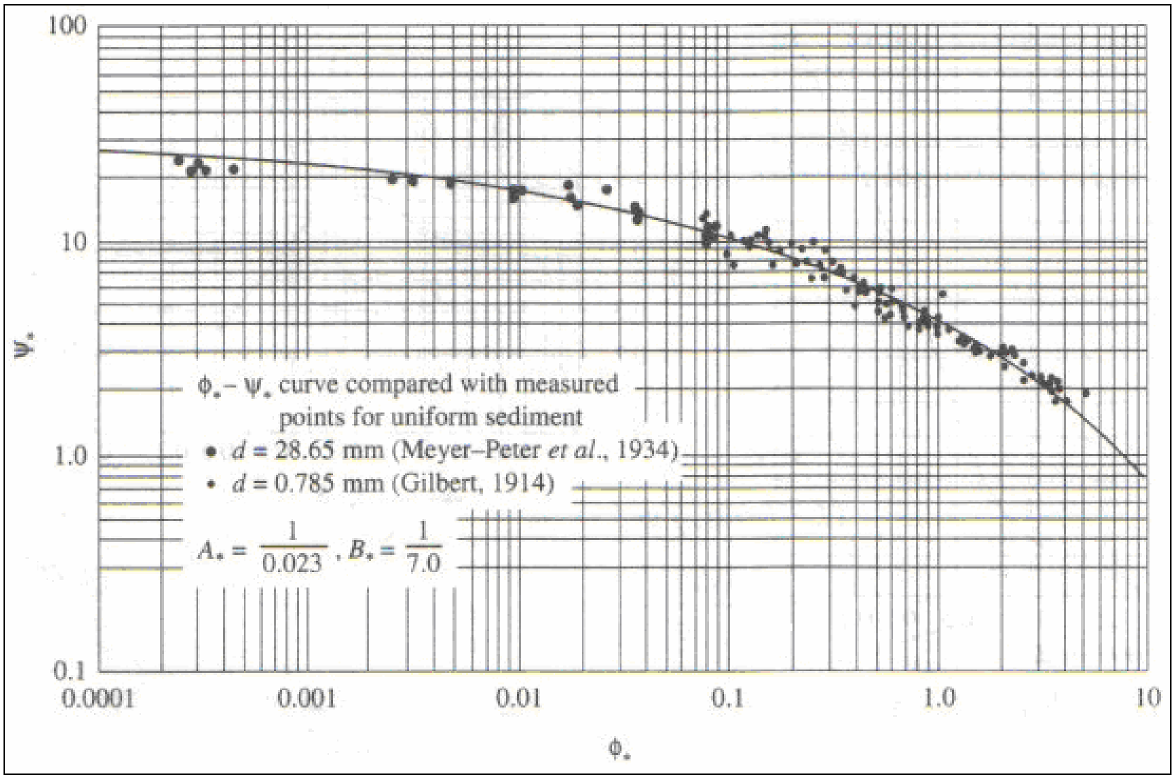


Figure 2.11: Einstein formula (Einstein, 1950)

(Yang, 1996)

2) Einstein-Brown Method

Einstein-Brown formula was presented in Chapter XII of Rouse, 1950. It is a modification developed by Hunter Rouse, M. C. Boyer and E. M. Laursen of a formula by Einstein (1942). Its name derives from the name of the original author and the author of the chapter where the formula first appeared (Vanoni, 1975).

$$\phi = 40\left(\frac{1}{\psi}\right)^3 \tag{2.1}$$

ϕ - *Sediment transport parameter*

ψ - *Flow parameter*

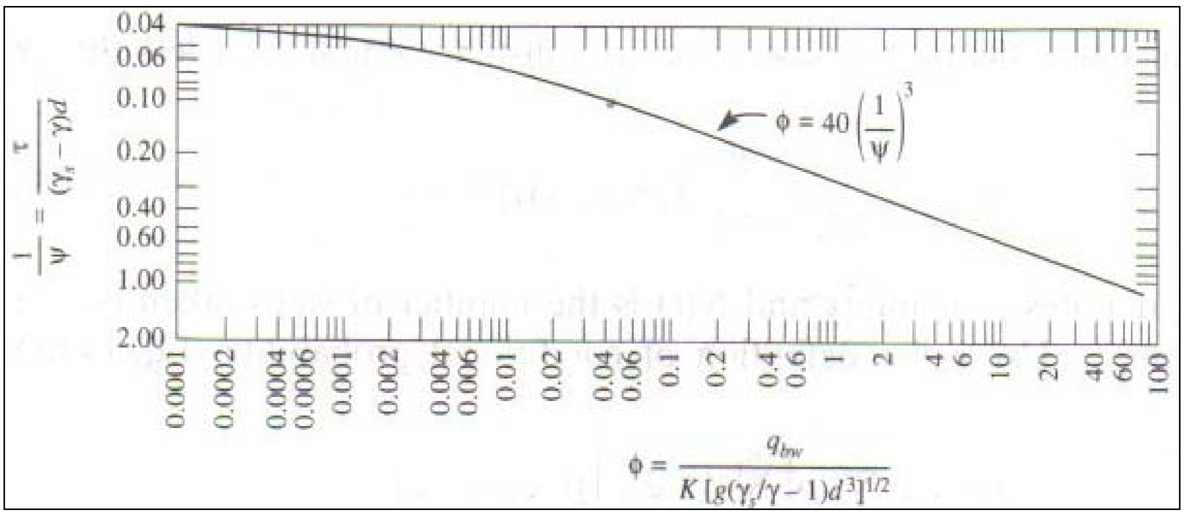


Figure 2.12: Einstein-Brown formula (Brown, 1950)
(Yang, 1996)

3) Meyer-Peter Muller (MPM) Method

Meyer-Peter conducted extensive laboratory studies on sediment transport. After 14 years of research and analysis, Meyer-Peter and Muller (1948) transformed the Meyer-Peter formula into Meyer-Peter-Muller formula (Ghani, 2003).

$$\phi = \left[\left(\frac{4}{\psi}\right) - 0.188\right]^{3/2} \quad (2.2a)$$

$$\phi = 8\left[\frac{1}{\psi} - 0.047\right]^{3/2} \quad (2.2b)$$

Sediment transport parameter:

$$\phi = \frac{C_V V R}{\sqrt{g(S_S - 1){d_{50}}^3}}$$

Flow parameter:

$$\psi = \frac{(S_S - 1)d_{50}}{RS_O}$$

S_S = *2.65*

ϕ - *Sediment transport parameter*

ψ - *Flow parameter*

S_S - *Relative density of the sand*

S_O - *Energy slope of clear water*

d_{50} - *Mean grain diameter*

C_V - *Volumetric sedimentation concentration*

V - *Flow velocity*

g - *Acceleration of gravity*

4) Shields Method

In Shields (1936) study of incipient motion, flow conditions was measured with sediment transport greater than zero, and then extended the relationship to obtain the flow condition corresponding to incipient motion. Thus, a semi-empirical equation for bed load is obtained (Ghani, 2003).

$$\frac{q_b\Delta}{qS_o} = \frac{10(\tau_o - \tau_c)}{\rho g \Delta d_{50}} \tag{2.3}$$

q - *Unit of flow rate*

q_b - *Bed load per width*

ρ - *Fluid density*

ρ_S - *Sediment density*

g - *Acceleration of gravity*

τ_O - *Tractive force on channel bottom*

τ_C - *Critical tractive force*

d_{50} - *Mean grain diameter*

Δ = $S_S - 1$

S_S - *Relative density of the sand*

5) **Chang et al. Method**

Chang, Simons and Richardson (1967) suggested that the bed load discharge by weight can be determined by Chang et al. equation (Yang, 1996).

$$q_b = \frac{K_b \gamma_S V(\tau - \tau_C)}{(\gamma_S - \gamma)\tan\phi} \qquad (2.4a)$$

$$q_b = K_t V(\tau - \tau_C) \qquad (2.4b)$$

K_b - *Constant*

ϕ - *Angle of repose of submerge bed material*

6) **Bagnold Method**

Bagnold stated that the rate of doing work is the product of available stream power and efficiency. The bed-load transport rate, expressed as submerged weight per unit width per unit time and tan α (Cheng, 2002).

$$\Phi = \Theta\left(\sqrt{\Theta} - \sqrt{\Theta_C}\right)\frac{1}{k}\left[5.75\log\left(30.2\frac{mD}{K_S}\right) - \frac{w}{U_*}\right] = (13.2 - 19.3)\Omega \qquad (2.5)$$

k = 0.63

K_S / D = *1*

$m = 1.4\left(\theta / \theta_C\right)^{0.3}$

$\frac{w}{U_*} = 4.5\left(\theta_C / \theta\right)^{0.5}$ *for* $D > 0.7mm$

$\Phi = C\Omega$

$\Theta = U_*^2 / [(S-1)gD]$

Θ - *Dimensionless shear stress*