ASSESSMENT OF MORPHOLOGICAL ASPECTS AND BANK PROTECTION WORKS OF THE RIVER SURMA

Project by

MD. TAUHID-UR-RAHMAN

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(Water Resources)

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Department of Water Resources Engineering

Bangladesh University of Engineering and Technology, Dhaka

#99616#

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We hereby recommend that the project prepared by Md. Tauhid-Ur-Rahman entitled "Assessment of Morphological Aspects and Bank Protection Works of the River Surma" be accepted in partial fulfillment of the requirement for the degree of Master of Engineering in Water Resources.

Professor Dr. M. Abdul Matin
(Dept. of Water Resources Engg.)
Chairman
(Supervisor)

Professor Dr. Md. Khorshed Alam
(Dean, Faculty of Civil Engg.)
Member

Professor Dr. M. Monowar Hossain
(Dept. of Water Resources Engg.)
Member

August, 2004

CERTIFICATE

This is to certify that this thesis work has been done by me and neither this thesis nor any part thereof has been submitted elsewhere for the award of any degree or diploma.

Signature

_____

(Md. Tauhid-Ur-Rahman)

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ABSTRACT

Realizing the gravity of the changed hydro morphological characteristics of the hilly river, Surma, this study has been conducted to investigate the morphological characteristics, sediment transport phenomena and also to analyze the design parameters of the implemented bank protection works of this river at Sylhet. Mainly, cross sectional properties at 24 selected sections of the river Surma for the years 1970, 1989, 1991 and 1999 were analyzed. It is observed that sedimentation is portrayed in the period 1972-73 to 1981-82 whereas erosion can be illustrated in the period from 1981-82 to 1991-92. Sedimentation dominates over a period of ten years before reaching a peak of erosive activity in 1999. In addition, it has been found that the river had turned into wider and shallower up to 1989. After that, it changed into comparatively narrower and shallower for the last decade (1989 to 1999). Variation of width in successive years shows that the section no. S-18 and S-38 experienced the sudden rise and fall during the 30 years period.

In addition, the maximum rise in calculated mean bed level is happened at section no. S-42 (13.13 m) whereas the maximum fall in mean bed is found at section no. S-18 (0.82m in 1991) and S-3 (0.46m in 1989).

Due to the deposition of huge sediment load (about 3.00 MT/year), the river has lost its normal carrying capacity about 27% and flash flood visits almost every year inundating the surrounding lands and towns.

Discharge carrying capacity and sediment concentration of 14 cross sections of the river Surma starting from S-29 (Sylhet) to S-42 (Lubachara) have been estimated under bankful conditions, using a simplified resistance equation and a sediment predictor. Results indicate that the section no. S-31 has the highest discharge carrying capacity (973.22 cumecs) whereas section no. S-41 has the lowest of that (133.55 cumecs) among all the selected sections. In this regard, it can be mentioned that the bankful discharge of Surma at Sylhet is 1373.33 cumecs. Superimposition of satellite images shows that the change of planform of this river is not significant over the last five years period (1997-2002).

Sediment load of the Surma river has been computed with the help of three well known sediment predictors such as Engelund-Hansen's equation, Ackers-White's equation and van Rijn's equation for the years 1975, 1989 and 1999 at the station Sylhet and were compared with the values of the measured sediment load of those years. The observed annual sediment load at Sylhet was 2.776MT, 3.121MT and 3.0971 MT for the year 1975,1989 and 1999 respectively. However, the average annual sediment load predicted from Engelund-Hansen's equation is 0.727 MT, from Ackers White's equation is 1.818 MT and from van Rijn's formula is 0.828 MT. Comparison shows that out the three sediment predictors Ackers White's formula is found to be well suited against the observed data of the river, Surma.

The implemented bank protection works starting from Kazirbazar to Mollapara at Sylhet City has been also considered for this present study. Depending on the assembled field data and information, hydraulic design parameters of the bank protection works were evaluated in terms of effectiveness, suitability and sustainability.

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LIST OF MAIN SYMBOLS

Symbol	Description
a	Reference level
B	Average width of the channel
C	Overall Chezy coefficient
C'	Chezy coefficient related to grain
C_a	Reference concentration of suspended bed material load
C_s	Sediment concentration by weight (= Qs/Q)
C_t	Total average sediment concentration
d	Median fall diameter of the bed material
d_m	Characteristics particle diameter
d_s	Representative particle diameter of suspended bed material
D	Hydraulic Depth
D_*	Dimensionless particle parameter
d_{50}	Median grain size of bed material
d_{90}	Grain size of the bed material for which 90% is finer
F	Shape factor
F_g	Mobility number
g	Acceleration of gravity
h	Total flow depth
H	Average depth of flow
k_s	Equivalent roughness height of Nikuradse
q_b	Bed load discharge per unit width
q_s	Suspended load transport per unit width
q_t	Bed material load transport per unit width
Q	Measured water discharge
Q_c	Assessed discharge
$Q_{s\,(cal)}$	Calculated Sediment load
$Q_{s\,(obs)}$	Observed Sediment load
R	Hydraulic radius
s	Specific gravity of sediment

S	Channel bed slope
T	Transport stage parameter
u or V	Depth averaged velocity
u*	Overall bed shear velocity
U*	Bed shear velocity
w_s	Fall velocity suspended sediment
y	Water depth
Z', Za	Suspension number
β	Ratio of sediment and fluid mixing coefficient
γ	Specific weight of water
γ_s	Specific weight of sediment
Δ	Bed form height
θ	Bed shear parameter
θ_{cr}	Critical bed shear (or Shields) parameter
k	Von Karman constant (0.4)
ρ	Density of fluid
ρ_s	Density of sediment
τ_0	Bed shear stress
$\tau_{b,cr}$	Critical bed shear stress according to Shields
$\tau_b^{'}$	Bed shear stress related to grains
ψ	Bed form steepness
g_s	Sediment transport per unit time per unit width
n	the transition exponent
ν	kinematic viscosity of water
c, n, A, m	Ackers White's Coefficients
d_g	Grain size parameter
W	Weight of individual stone (lab. Wt.)
D	Diameter of stone
D_n	Dimension of cube
θ	Slope of bank (°)

Φ	Angle of repose of revetment materials (°)
H_g	Significant wave height
6	Strength coefficient, 3 for cubes, 2 for dumped cubes
E	Wave breaking parameter
T	Wave period
T	Thickness of stone riprap
D	the design scour depth
C_u	coefficient of uniformity
O_{90}	effective opening size
η	material specific reduction factor
k_g	permeability of the geo-textile (m/s)
k_s	permeability of the soil (m/s)
I_p	plasticity index
w_L	Liquid limit
w_p	Plastic limit
R	Regression Coefficient
T	Top width
S	Cross section

LIST OF ABBREVIATIONS

BRTC	Bureau of Research Testing & Consultancy
BWDB	Bangladesh Water Development Board
BUET	Bangladesh University of Engineering & Technology
CE	Civil Engineering
CEGIS	Centre for Environmental Geographic Information System
FAP	Flood Action Plan
HFL	High Flood Level
IWM	Institute of Water Modeling
JMBA	Jamuna Multipurpose Bridge Authority
LWL	Low Water Level
MBL	Mean Bed Level
MPO	Master Plan Organization
PWD	Public Works Department
SUST	Shahjalal University of Science & Technology.
IWM	Institute of Water Modeling
US	United States
WARPO	Water Resources Planning Organization

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CHAPTER ONE

INTRODUCTION

1.1 General

The major rivers of Bangladesh are the Ganges and the Brahmaputra originating in the south and north-eastern Himalaya respectively as well as the Meghna, draining the Sylhet basin in the north eastern part of Bangladesh. Together with numerous tributaries and distributaries a dense network of rivers in Bangladesh is formed representing the lowermost alluvial deltaic reach of the fluvial system, which is draining to the Bay of Bengal. One important hydrological aspect of the rivers of Bangladesh is, that the rise and fall of the river stages are only very weakly dependent on the local rainfall, because 92% of the catchment lies outside Bangladesh. The rivers have changed their courses frequently in the past, the Brahmaputra switched from its eastward course in favor of a southward course along its small former distributary of the Brahmaputra/Jamuna river itself. Previously, the Ganges used to empty into the bay through the Arial Khan river but after capture of the Brahmaputra/Jamuna river flow it shifted north-eastward joining the Upper Meghna.

The Upper Meghna, which originates in the Shillong Plateau and foothills is a relatively small river having a bankful width of about 1 km only and is representing one of the areas of highest rainfall in the world, the water yield is about 0.06 m^3/s per km^2. The annual average discharge is about 4800 m^3/s. The lower reach of the river becomes tidal during the period from December to April. The seasonal water variation is about 5m (FAP-6 '1993).

Geologically Bangladesh consists of deltaic alluvial sediments of the three great rivers and their tributaries. The basins of the three great rivers are bounded to the tectonically highly active Himalayas mountain ranges, which are subject to severe erosion contributing to the heavy sediment load in the river system. The entire country of Bangladesh is a part of the Bengal basin, filled in the tertiary-quaternary geological period and this basin is balanced by the deposition of sediments supplied

by its river system. Again, the rivers of Bangladesh are characterized by a fine sedimentary environment. The consequence is that the threshold velocity for sediment mobility is low, about 0.2 m/s. Hence, the rivers are mobile with continuous reworking and deformation of their beds and banks transporting huge quantities of sediment.

Again, bank erosion can occur in stable as well as in unstable rivers or river channels. Although the morphology of stable rivers is in a state of equilibrium with regard to the governing physical processes and is not expected to change significantly the general shape and dimensions, some local erosion and deposition is likely to occur, especially in meander bends.

Modification of flow velocity, discharge, sediment load and river morphology in unstable rivers are major factors initiating erosion and deposition. How fast the river responds to changes in boundary conditions depends on the natural stability of the subsoil and the extent of changes. Successive erosion and deposition often leads to rapid changes in the river plan-form and slope. Increased meandering reduces the channel slope, whereas straightening of the channel through cut-offs in most cases increases the local gradient. Any changes in bed elevation can also promote rapid bank erosion. Incision can destabilize a bank. Moreover, strong accumulation of sediments, followed by development of sand bars promotes rapid widening of channels.

In order to prevent or minimize the loss of valuable land, several stretches of the river banks might need suitable protection against erosion. Both river training and bank protection measures, which are strongly interrelated, have the objective to ensure a safe and efficient transport of water and sediments. Again, a safe and expeditious passage of flood discharge must be possible during high water stages with a minimum of negative effects on surrounding areas. In this context it has to be emphasized that if local protection measures are planned, the consequences must be taken into account, because a certain response of the river, i.e., morphological changes in the vicinity or even further away from a countermeasure, are to be expected. Protection of one place will possibly influence erosion and bankline shifting at other locations.

Hence, the nature of the bank erosion and channel shifting problems of the alluvial rivers demands rigorous and vigilant long-term study. Furthermore, a simplification of the planning, design and implementation as well as of the appropriate monitoring and maintenance scheme is crucial to allow for timely completion of bank protection structures within a restricted construction window and despite possible sudden changes of the river course.

1.2 Background

Mainly the hydraulic parameters control the physical characteristics of any channel. Again, the hydraulic characteristics of an alluvial river are altered by the inflow, sediment movement, water surface and bed slope, bed and bank roughness and various factors. Water resources Engineers have been intrigued of this fluvial processes come upon the alluvial rivers for long days. Appropriate comprehension of the hydrodynamics of the flow combined with the tactics of sediment transport desires to be acquainted with the different hydraulic dilemma such as the bed and suspended load movement, usual and anthropogenic alteration of river morphology etc.. Consequently, the indulgent of the prediction of morphological behavior, the design of dredging for the deposited sediment, design of irrigation and drainage channels, stabilization of rivers, the flood control, the planning of reservoirs and the control and maintenance of soil erosion are essential. With a view to working out the sediment associated intricacy plentiful pragmatic formulae have been proposed by various pollsters for the prediction and computation of sediment movement in alluvial channels.

A meticulous long-term study on the flow and sediment characteristics of the alluvial rivers is thus, crucial for the planning and designing of water recourses improvement scheme.

1.3 The Surma River System

The river Surma after commencing from the divergence of the Barak at Amalshed (Figure 1.3) runs towards west through Sylhet until it meets the Balui river and collects inflows from the 56% area of the Surma basin which occupies most of the

southern slope of Shillong Plateau and receives world's highest rainfall. The famous tributaries of Surma are the Lubha, Sarigowain, Piyain, Dhalai, Umium, Jhalukai and Jadukata. Mainly the Barak branched off the Surma and Kushiyara river at Amalshed from that they region after 300 km downstream where they flow into the Upper Surma river. The river Surma can be divided into three subdivisions such as from Amalshed to Chattak (the Upper Surma), from chhatak to old Surma off take (Lower Surma River) and the old Surma off take to Balui river junction (the Nawa river) (Table-1.1). In 1768, Rennel's survey demonstrated that the River Surma is a continuation of the Barak river and was very close to its present alignment between Amalshed and Sunamganj. The old Surma river starting from Sunamgong ends at Ajmiriganj which doesn't carry enough flood flows whereas the principle flow is now through the Nawa river towards the southward flow of the Balui river.

The Meghna sub region receives flash floods from the adjacent Indian states and gets flood affected during the wet season and further is affected by soil moisture deficit in dry season. This region faces a tropical monsoon climate. During summer air flowing from southwest direction brings moist air from Bay of Bengal and rainfall in this season increases north westwards across the region. Across the Northwest region rainfall during the southwest monsoon ranges between 1500 mm in the southwest to around 4100 mm in the northeast monsoon at the border with Meghalaya (Figure. 1.4). In spring, the rainfall ranges from around 490 mm in the southwest to around 1290 mm in the northwest (FAP-6 '1993). In a study of daily rainfall for the northeastern region of Bangladesh, a generalized rainfall Intensity-Duration-Frequency relationship for the north-eastern region was presented (Matin and Ahmed '1984).

BWDB has measured the inflows in the Surma at Sylhet and Kanairghat where discharge-measuring stations are available. It is observed from the 22 years' record of discharge at Sylhet and Kanairghat that the mean discharge per annum is 549m^3/s and 563 m^3/s respectively (Table 1.3). In this connection the hydrograph and rating curve of the Surma at Sylhet is illustrated in Figure 1.1 and 1.2.

Between the many river channels of the Meghna sub- region, there are interfluvial areas called haors. Static water found at the center of the haor in the dry season, is

termed as beel. The haors comprise an important part of the agricultural land of the region, but their seasonal inundation severely constraints the agriculture. The haors also comprise an important part of the fisheries environment. When the ground water table remains over the ground level in dry season, the beels are permanent, where it falls below the ground level, the beels are seasonal (Kamrunnessa '1994).

The upper Surma flows through flood plain deposits until a point downstream of chhatak where it enters the haor areas of the central basin. Between amalshed and Chhatak, the Surma flows in a single irregularly meandering sand bed channel. The river becomes noticeably wider in the downstream of Chhhatak. During most water level conditions there are no bars exposed and no islands are available. The river becomes narrower again in the Nawa reach, downstream of the old Surma uptake. The main geomorphic features of the Surma are given in Table no 1.1.

The Sylhet Trough is a part of the Bengal basin and consists of 13-20 km thickness of alluvial and deltaic sediments underlain by much older granite rocks. This basin is bounded by the Shilong plateau on the north, by the Indian-Myanmar ranges on the East and by the Indian shield to the west. Rapid subsidence has occurred in this basin since the Miocene times 922 million years ago as a result of encroachment of the Indo-Myanmar ranges to the east and over thrusting by shilong plateau along the dauki fault to the north (Kamrunnessa'1994). It is reported that the rates of subsidence may reach in the order of two meters per century (MPO-1980). Typical water surface slope in this region is 2-4 cm per km which could be affected by the land subsidence and this would be partly offset by long term sedimentation.

Information on seismic activity in the northeast region could be derived from FAP-21 (2001). More than 120 major earthquakes have been recorded in and around Bangladesh over the last 130 years. These earthquakes have included land sliding and slope failures in headwater catchments in the Shillong Plateau, which could greatly increase the amount of sediment supplied to the region for long term. Therefore, river processes and sedimentation patterns in the north-east region may be subjected to major disruptions following severe seismic events (Kamrunnessa '1994).

1.4 Importance of the Study

Sylhet town is situated on both of the banks of the Surma, a hilly river that faces flash flood during monsoon in almost every year. After originating from hilly river Bark at amalshed under Zakiganj upazila of Sylhet district, it flows through Sylhet City and ultimately falls into the Meghna river. Various hilly rivulets originating from India i.e. Kakra, Gomra, Boleswar, Lubachara etc. meet on the way towards Surma river. As time changes, hydro-morphological features of Barak river started changing since 1960's and hereafter major flow of the Barak river being mostly discharged by the Kushiara river. In this situation, Surma river could receive only 20% flow from the Barak river during monsoon season while in dry season no surge of water flows from Barak into the Surma river.

Because of such hydro morphological characteristics, bed level of Surma river being silted up with the resultant reduction of river depths to a large extent. Consequently, Surma river cannot accommodate hilly rain water with turbulent flow generated from upstream reach within its bed. In these circumstances, water surge overtops on both of the banks of the river and devastating erosion occurs in adjacent community, which also put threat to human lives and properties of Sylhet City.

Generally, an alluvial river changes its position and shape continually as a consequence of hydraulic forces acting on its bed and banks and related geo-morphological forces. In Bangladesh most of the morphological study of rivers includes behavior and geometric characteristics of the major rivers. Institute of Water Modeling studied the morphological behavior of the river Brahmaputra and some other rivers of Bangladesh in 2001(IWM'2001). Before that, the morphological study of the river Brahmaputra-jamuna was conducted by Mukherjee (1995). Therefore, it is also important to understand the behavior and characteristics of the medium and minor rivers. The Surma is the third largest river of the Meghna region. The most important feature of this river is that its catchment includes the southern facing slope of Shilong plateau in Meghalaya, Cherapunji, which is the wettest place on the earth. The inflows during monsoon season causes flash flood with peak flows ranging up to 30 or more times than the average flows. The massive flash flood and a large sediment load causes continual erosion and sedimentation, which affects river banks

stabilization, navigation, flood control, fisheries and agriculture. Accordingly, the Surma has been chosen as an envoy of the medium sized rivers of Bangladesh for this current study.

The current study has been intended to investigate the morphological characteristics, sediment transport phenomena and also to analyze the design parameters of the implemented bank protection works at Sylhet of the Surma river.

1.5 Objectives

The specific objectives of the present study can be set as follows:

(1) To investigate the morphological characteristics of the Surma river for the selected cross-sections.

(2) To analyze the sediment transport characteristics of the river Surma at Sylhet.

(3) To assess the plan-form characteristics at selected reach of the Surma river.

(4) To analyze the hydraulic factors with a view to evaluating the design of selected bank protection works of the Surma river implemented by BWDB at Kazirbazar, Sylhet.

(5) To compute the discharge carrying capacity of the cross sections of the selected reach (S-29 to S-42).

1.6 Scope of the Study and its Limitation

This study was concentrated on the assessment of the morphological changes of the Surma river for the time period of 30 years from 1970 to 1999. Data including cross-section, discharge, sediment, water level and the Satellite images have been analyzed to find out the probable changes. Attempt has been made to evaluate the design considerations of the bank protection works implemented by BWDB in Surma river adjacent to the Sylhet City. The shortcoming of this study has been recapitulated as follows:

1. Just after the year 1999, no cross sectional data of the Surma river is available in the BWDB's data bank. Detailed study of the available cross sections for the years 1991 and 1999 revealed that their locations were not exactly at the same place. If more data were available then better analyses could have been possible.

2. The sediment data is not up-to-date. In absence of updated data the analyses was based on old data of 1975,1989 and 1999.

3. Collected Satellite images were only for two years (1997 and 2002). Due to the absence of more images, precious analysis was not possible.

4. The study of sediment transport was performed with the analyses of grain size distributions and water surface slope taken from the specialist study (FAP'1993) for a single station (Sylhet) instead of the whole Surma river.

CHAPTER TWO

REVIEW OF LITERATURE

2.1 General

History depicts that the Northeast Regional Water Management Project is the only significant studies carried out on the river Surma. However, most of the studies concerned with the morphological changes and sediment transport had been performed for the major rivers like the Ganges, the Brahmaputra, the Meghna etc. Some of these studies are narrated in the following articles.

2.2 Morphological Study

Generally, BWDB collects the hydrological and morphological data like water level, discharge and cross sections and publishes in various reports. Morphological aspects of some major and minor rivers of Bangladesh were carried out by many researchers in many years.

A study by Khan (1975) on the roughness characteristics of four rivers in Bangladesh revealed that the roughness coefficient "n" varied significantly with the stage. The rivers were the Kumar (Lakhsmikanda), Gumti (Comilla), Halda (South Sunderpur) and Sangu (Banderban).

Rahman et al (1980) had studied the probable behaviour of the Ganges river reach for a length of sixty five miles. It was shown that the sinuosity of the selected reach was being reduced gradually. The frequent meandering of the thalweg from one place to another was due to the higher magnitude of the flood time discharge and also due to the sand bars' and mid Channel Islands' movement.

In 1980, Galay studied the river channel shifting of the major rivers in Bangladesh. This study summarized that three types of channel shifting like the gradual migration of the major flow channel, rapid shifting of the major channel during the development of cutoffs and sudden creation of new flow channels on the flood-plain outside the Bankful channel was being occurred.

Goswami (1985) undertook a study on the physiography, basin denudation and channel aggradation of the Brahmaputra river in Assam and suggested that the high rate of denudation of the Himalayas might be attributed mainly to the rapid uplift of the mountain system, recent earthquake activity, and high susceptibility of geologic formations to erosion by running water coupled with the effectiveness of the monsoon rainfall regime.

Bristow (1987) deliberated the channel migration and deposition of the Brahmaputra river. That work followed the previous research performed by Coleman (1969). Here, the deposition pattern was presented in four styles such as new mid channel bars (13%), channel abandonment (15%), lateral accretion to bank (19%) and addition to bars (53%).

In 1987, Habibullah determined the bed level variations and bank line movements between Aricha and Charnatua. This study depicted that the maximum amount of bank line erosion and deposition were 348 m/year and 335 m/year respectively during eighteen years period since 1965. Again, the mean bed level varied and the river- bed had been increased from 6.74 cm/km in 1966 to 7.99 cm/km in 1984.

Klaassen and Vermer (1988) considered the channel characteristics of the braided River Jamuna within the framework of a feasibility study for a bridge across this river. LANDSAT images were used for the Plan form characteristics study, which concluded that over the last decades any lateral shifting of the river Jamuna was not noticeable and this was in contrast with the behaviour of the river which was followed by a western movement of up to 10 km in some reaches.

Ullah (1989) summarized the findings of the application of a hydrodynamic numerical model (MIKE-11) based on full Saint Venant equations to Ganges-Brahmaputra river system of Bangladesh to study the impact of a barrage.

Nahar (1991) invented a software based on ForTran for the prediction of bed level changes in the alluvial rivers and this had been applied in the Jamuna River for a reach extending from Bahadurabad to Sirajganj.

Ashrafuzzaman undertook a research work on the geometric aspects of the Arial Khan river for a 200-km reach. He investigated and analyzed the cross sectional geometry, non-dimensional correlation, thalweg and bank line shifting, mean bed level variation and meander parameters.

Kamrunnessa carried out a study in 1994 to find out the geometric characteristics of the Surma river. This research work concluded showing the variation of mean bed level and ranges of aggradation and degradation within a selected reach.

Islam (1996) accomplished the morphology of the Jamuna River including the present responses and future morphological prediction. This research summarized that the mean size of bed material load and number of channels had significant influence on the hydraulic geometry.

2.3 Sediment Transport Study

Since 1958 Bangladesh Water Development Board has been assembling sediment data for the river Surma. Generally, BWDB uses a field suspended procedure to split finer sized sediment from the suspended load and the concentration values represent only the fraction coarser than 0.06 mm (Kamrunnessa '1994).

The North East Regional Water Management Project analyzed bed material loads at Sylhet and Kanairghat station using Acker White's sediment transport equation. This load corresponds to sand coarser than 0.12 mm, moving on bed load as well as in suspension. It was noticed that the annual load at Kanairghat is higher than that of Sylhet indicating local aggradation. The lower transport capacity at Sylhet is partly due to the reduction in flood flows at Sylhet caused by over bank spills.

Sediment transport study was carried out mainly for the great rivers. Some of these are described here.

Bari and Alam (1979) completed a research work to study the sediment transport aspect of the Ganges river, comparing five recommended formulas. This work revealed that the Colby relations and the Engelund-Hansen formula might be applicable with appropriate correction factors.

Alam and Hossain (1988) made an attempt to utilize the available suspended sediment data of the Jamuna river for a quantitative evaluation of the transport rate of the river. The testing efficiency of the well-known sediment transport formulae such as Ackers-White's, Inglis-Lacy's , Yang's and Hossain' equation were considered.

Sultana (1989) made a critical review of sediment transport on past studies based on the same data as used by Bari (1978). It was found that the sediment transport in the Jamuna river was 435 MT and this result was further compared with the sediment load predicted by the two equations such as Yang's (1976) and Hossain's (1987). She concluded that the Hossain's formula yielded higher magnitude of sediment movement whereas the Yang's formula showed very low value.

Another research works conducted by Khan (2001) concluded that the MIKE 11 sediment transport and Morphological model could be used with sufficient accuracy to simulate the transient bed profiles in a laboratory flume under a non-uniform flow using the calibrated transport formulae.

Hossain (1992) performed an analysis of the total sediment load in the lower Ganges and Jamuna. The study findings showed that total average sediment flow through the major rivers of Bangladesh was of the order of 1.2 billion tons with a maximum of 1.5 billion tons.

In 1993, Bari and Wahiduzzaman accomplished a one-dimensional numerical model to simulate the variations in sediment transport rates and concomitant bed level changes due to erosion and deposition in the Gorai-Madhumati river.

Islam (1993) utilized a one-dimensional numerical model MIKE 11 to simulate the variations in sediment transport rates and concomitant bed level changes due to erosion and deposition in the Ganges river.

Kamrunnessa (1994), the only researcher who studied the sediment movement characteristics of the Surma river. She analyzed the suspended sediment data of the Surma at Sylhet and tested the applicability of three well-known sediment transport equations, i.e. Engelund-Hansen's, Yang's and Hossain's.

Ahmed, (1996) conducted a research work to compare the shear velocity from three methods such as steady and uniform flow equation, unsteady flow equation and log law equation and finally examined the consequences of U* in predicting the sediment transport using different available empirical formulae in the Jamuna River.

Khan, (2001) conducted a research work on morphological changes due to construction of a barrage on the Teesta river. Future prediction on the Teesta river sedimentation was made using the MIKE 11 morphological module of DHI based on the channel geometry of 1997. The model results had shown that there would be 1meter bed level rise in the 10 years period after the construction of the barrage.

2.3.1 Sediment Transport Equations

Mainly stage, discharge, velocity, water surface and bed slope, shear stress, mean particle diameter and stream power control the sediment movement of any channel. Only a single equation cannot incorporate all these variables and predict the sediment load. For this reason, different equations have been put forward on the basis of different independent variables. Out of many available empirical formulas the following three well known equations have been selected for the present study.

2.3.1.1 Engelund and Hansen's Formula (1967)

Based on the shear approach and experimental data from the series of tests on a large flume this formula is developed. The sediments used in this flume had a median diameter of 0.19mm, 0.27mm, 0.45mm and 0.93mm, respectively, and geometric standard deviations of particle sizes of 1.3 for the finest sediment and 1.6 for the others (Ahmed '1996). This formula should be applied to streams with a dune bed in accordance with the similarity principle. Nonetheless, it can be applied to upper regime with particle size greater than 0.15 mm without serious error. Engelund and Hansen applied the Bagnold's stream power concept and the similarity principle to obtain a sediment transport equation:

$$g_s = 0.05\gamma_s \; v^2 \sqrt{\frac{D_{50}}{g\left(\frac{\gamma_s}{\gamma}-1\right)}}\left[\frac{\tau_0}{(\gamma_s-\gamma)D_{50}}\right]^{\frac{3}{2}} \qquad (2.1)$$

where,

g_s = Sediment transport per unit time per unit width

τ_0 = bed shear stress

V = average flow velocity

D_{50} = median diameter of bed material

γ_s = specific weight of sediment particles

γ = specific weight of water

g = acceleration due to gravity

2.3.1.2 Ackers and White's Approach (1973)

In 1973, based on Bagnold's stream power concept, Ackers and White applied dimensionless analysis technique to express the mobility and transport rate of sediment in terms of some dimensionless parameters (Ahmed '1996). They related the concentration of bed material load as a function of the mobility number F_g, and is given as:

$$C_s = c\,s\,\frac{d}{R}\left(\frac{V}{u_*}\right)\left(\frac{F_g}{A}-1\right)^m \tag{2.2}$$

Where A, c, n and m are coefficients and s, specific gravity (= γ_s/γ) of the material.

The function is applicable to grain sizes with $d_g > 1$, e.g., sand sizes in excess of 0.04 mm. The mobility number F_g is given by

$$F_g = \frac{u_*^n}{\left[gd(s-1)^{\frac{1}{2}}\right]}\left[\frac{V}{(32)^{1/2}\log\left(10R/d\right)}\right]^{(1-n)} \tag{2.3}$$

The co-efficient 'n' is the transition exponent, which depends on the sediment size; it is used when both modes of transport are present. Again, n = 0 for coarse and n = 1 for fine sediment. For intermediate or transitional sizes of sediment, n may take a value between 0 and 1. The form of the F_g parameter ensures that the fine sediment

transport depends upon the total bed shear stress and the coarse transport rate upon the effective grain shear stress. The term d_g is expressed as:

$$d_g = d\left[\frac{g(s-1)}{\nu^2}\right]^{1/3} \tag{2.4}$$

where, ν, kinematic viscosity of water (m^2/s). Coarse materials are those with d_g >60, e.g, and in excess of 2.5 mm. Fine materials are those with d_g<1, e.g., 0.04 mm silt. The coefficients are determined from the best-fit curves of almost 1000 sets of laboratory data with sediment size greater than 0.04 mm and Froude number less than 0.8. Values of these empirical coefficients are listed in Table 2.1 as follows:

Table 2.1: Values of coefficients of Ackers-White's Equation (Garde and Ranga Raju' 1985)

Coefficient	**Coarse sediments $d_g > 60$**	**Transition sediment $60 \geq d_g > 1$**
c	0.025	$\text{Log } c = 2.86 \log d_g - (\log d_g)^2 - 3.53$
n	0.0	$1 - 0.56 \log d_g$
A	0.17	$0.23/(d_g)^{1/2} + 0.14$
m	1.50	$9.66/d_g + 1.34$

2.3.1.3 van Rijn's Approach (1984)

One of the most recent and popular transport equation is proposed by van Rijn (van Rijn, 1993). This expression is simplified for the particle characteristics and transport rate both for small and large particles. The bed load transport rate (kg/m/s) for particles in the range 200 to 2000 μm, which is below the reference level a, can be computed as (Ahmed '1996) :

$$q_b = 0.053\ \rho_s\,[(s-1)g]^{0.5}\,(d_{50})^{1.5}\,(D_*)^{-0.3}\,T^{2.1} \tag{2.5}$$

Equation 2.5 was found over predict the transport rates for T≥ 3. Therefore, a modified expression is proposed for this range:

$$q_b = 0.1\ \rho_s\,[(s-1)g]^{0.5}\,(d_{50})^{1.5}\,(D_*)^{-0.3}\,T^{1.5} \tag{2.6}$$

where, $D_* = d_{50}\left[\frac{g(s-1)}{\nu^2}\right]^{1/3}$ = dimensionless grain size parameter;

$$T = \frac{\left(\tau_b^{/} - \tau_{b,cr}\right)}{\tau_{b,cr}} = \text{dimensionless bed shear parameter} \tag{2.7}$$

$\tau_{b,cr} = (\rho_s - \rho)\ g\ d_{50}\ \theta_{cr}$ = critical bed shear stress according to Shields,

$\tau_b^{/} = \rho g(\bar{u}/C')^2$

$C^{/} = 18\log\left(\frac{12h}{3d_{90}}\right)$ = Chezy coefficient related to grains ($m^{0.5}/s$).

$S = \rho_s/\rho$, relative density; ρ_s, sediment density (kg/m^3); and ρ fluid density (kg/m^3). In the van Rijn's function the reference level 'a' is related to the bed form height Δ or to the Nikuradse's roughness parameter K_s, while a minimum and maximum value are set at a_{min} = 0.01h and a_{max} = 0.05h, respectively. The Depth integrated suspended load transport rate (kg/m/s) above the reference level 'a' can be computed as (van Rijn '1992):

$$q_s = \rho_s F\ \bar{u}\ h\ C_a \tag{2.8}$$

$$\text{in which } C_a = 0.015\ \frac{d_{50}}{a}\ \frac{T^{1.5}}{D_*^{0.3}} \tag{2.9}$$

is the reference concentration (% by weight) at level z = a above the bed. Voogt et.al. (1991) showed that Equation 2.9 is valid for velocities up to 3 m/s.

$$F = \frac{\left(\left(\frac{a}{h}\right)^{Z'} - \left(\frac{a}{h}\right)^{1.2}\right)}{\left(1-\frac{a}{h}\right)^{Z'}(1.2-Z)} = \text{shape factor}$$

$Z' = Z_a + \phi$ = modified suspension number

$$\phi = 2.5\left(\frac{w_s}{U_*}\right)^{0.8}\left(\frac{C_a}{C_0}\right)^{0.4} \quad \text{for } 0.01 \le W_s/u^* \le 1 \text{ and } 0.01 \le a/h \le 0.1 \qquad (2.10)$$

the ϕ - parameter is a correction factor of suspension number which represents the turbulence effect and the hindered settling effect.

$Z_a = \frac{w_s}{\beta k U_*}$, k = Von Karman's constant = 0.4

$\beta = 1 + 2\left(\frac{Ws}{U_*}\right)^2$ is the ratio of sediment and fluid mixing coefficient ($\beta_{max} = 2$)

$$W_s = \frac{(s-1)gd_s^2}{18\nu} \qquad \text{for } 1 < d_s \le 100\ \mu m \qquad (2.11)$$

$$W_s = \frac{10\nu}{d_s}\left[\left(1+\frac{0.01(s-1)gd_s^3}{\nu^2}\right)^{0.5} - 1\right] \quad \text{for } 100 < d_s \le 1000\ \mu m \qquad (2.12)$$

$d_s = [\ 1+0.011(\sigma_s - 1)\,(T-25)]\ d_{50}$ = representative particle size of suspended bed material (m), $d_s = d_{50}$ for $T \ge 25$.

$\sigma_s = \frac{1}{2}\left(\frac{d_{84}}{d_{50}} + \frac{d_{50}}{d_{16}}\right)$ = gradation coefficient of bed material.

2.4 Bank Protection Study

The stability of unprotected riverbanks depends on a number of factors, which have to be assessed carefully in the process of selection and design of suitable protection measures. A reliable assessment of potential causes of bank failures indispensable for the success of any measures. Normally, river training measures comprise permanent and recurrent measures, which are built either on the mainland, the floodplain attached chars or which are built as floating structures (FAP-21 '2001). A large variety of traditional and low cost measures are existing, such as bandals, bamboo groynes (spurs), floating screens, cut-offs so called intelligent dredging schemes etc. that are being used in Bangladesh and surrounding countries. In general due to constraints of the natural material and hand driven equipment used, these measures are restricted to a certain range of applications and comparatively low hydraulic impacts. Some improvements have been introduced to allow for use also under moderate boundary conditions. The selection of the above measures depends mainly on the strategy followed and on the prevailing and expected hydraulic loads as well as on available materials.

Many researchers have studied the bank protection structures on different rivers in Bangladesh.

Ahmed (1989) undertook a research work to study some bank protection works in Bangladesh. He concluded that confluence of Padma and the Meghna was shifting northward and it had direct bearing on the erosion at Chandpur town.

Under a research project (BRTC-BUET '2002), the experts of WRE and CE Dept. of BUET completed the technical evaluation of some selected flood protection and river erosion control works already implemented by BWDB. In this research work, the experts had checked the design as well as the sufficiency of design parameters of the existing river bank protection projects and established design criteria and parameters.

Tanzeeba (2002) performed a physical model study on bank protection by revetment in a reach of the old Brahmaputra by placing the both hexagonal and cubical blocks

in the eroded bank keeping same condition for both of the blocks in different scenarios. It has been revealed from the study that hexagonal blocks required 50% less amount of material as compared to cubical blocks of equivalent weight for the selected bank protection area though it experienced less damage and more stability than the cubical shapes.

Nandi (2002) analyzed the stability of cement concrete blocks as revetment material against wave attack. Mainly this study was done to check the validity of the formula widely used for design of cement concrete block against wave erosion. Comparing the laboratory results with the Pilarczyk (1990) formula the agreement was found satisfactory.

2.4.1. Revetment

Passive bank protection measures are primarily armored structures or armour layers preventing a bank line from erosion but which do not create significant interference with the passing fluid. The hydraulic influence on the local flow condition is limited to changes in bed roughness. Typical passive measures of revetment structures, which are built more or less parallel to the flow to form an artificial sloped or vertical river bank. Vertical structures e.g. retaining walls of stone filled gabions, sheet pile walls or similar, are not recommended for extremely mobile rivers, since these allow for high flow velocities directly at the toe of the structure (influence of water depth) followed by excessive scour, thus requiring substantial and expensive toe protection. Structures, constructed on a slope of the riverbank or an embankment must be designed with a suitably chosen gradient and an adequately sized toe protection to support the revetment and to protect against scouring. Dependent on the prevalent soil to be protected against erosion and the external hydraulic loads by current and waves, many different types of revetments regarding the cross section (berms, varying steepness) and the applied components are existent. Due to the difference between the river water level and the ground water table additional pore pressure and subsoil is limited, which may induce mass failure of bank lines, especially after rapid sinking of the river water level.

2.4.2. Hydraulic factors for Revetment design

The hydraulic factors for revetment design are narrated as follows:

2.4.2.1. General

For the design of structural element of river training works, hydraulic factors such as water level, discharge, flow velocity, wave height and anticipated scour bed level of the particular river have to be considered according to the guide line (BWDB-Design manual '1993). The criteria and considerations for selecting or determining each of these hydraulic factors are described in the following articles:

2.4.2.2. Water level

The design water levels at river training works are required for the following purposes:

a. To decide the boundary between the above water slope protection and below water slope protection,

b. To fix the highest level of protection works,

c. To compute scour depth.

The design water levels may be taken from available analyzed records or may be computed from available data. The following consideration is necessary for hydrological design purpose:

Flood levels – 1 in 100 years

1 in 50 years

1 in 20 years

Bank full level

Average year level

Low water level – Lowest during dry season

- Average lowest in various dry months

2.4.2.3. Discharge

For design of river training works, the discharge is required for following purposes:

a. To compute scour depth, which is in turn, is used to select design scoured bed level.

b. To determine average velocity of flow, which is in turn used to select local velocity at protection site.

The design data that are important are as follows:

Flood Discharge: 1 in 100 years

1 in 50 year

1 in 20 year, Average year discharge

Bank full Discharge

The design discharge for various conditions may be taken as follows:

- For major rivers: 1 in 100 year or 50 year discharge

- For minor rivers: Bank full discharge

- For flashy rivers: Dominant discharge which may be bank discharge or 70% of 1 in 20 year discharge whichever is higher.

2.4.2.4. Current

The revetment used to protect an erodable surface against erosion has to withstand the drag forces generated by the velocity.

The usual practice in design is to apply thumb rules to estimate local velocities. The local velocity at the boundary of a straight channel is assumed to be two thirds of the cross sectional mean velocity. The velocity at the outer bank of a severe bend can be up to four thirds of the cross sectional means.

The average velocity may be obtained from measured data of a discharge measurement site. Otherwise, if the discharge and corresponding water levels are

known, the average velocity may be computed from surveyed river cross section at the point of interest.

2.4.2.5. Waves

The wind waves would usually govern the design of any protection work at the slopes of river training works. With respect of protection two aspects of waves have to be considered:

(a) Run up of waves against slope which might overtop the upper limit of protection

(b) Erosive forces of breaking waves against the slope causing erosion.

To evaluate wave height the following factors that create waves in open water must be analyzed:

(a) Design wind direction

(b) Effective fetch

(c) Wind velocity and duration

The relationships are based on the Sverdrup-Muck theory as modified by Bretschneider (FAP 21 '2001) and are considered accurate and reliable enough for riprap design.

2.4.2.6. Scour

The protection of toe of any river training is of prime importance as regards to the stability of overall slope protection against scour. Lacey's regime formula is widely used to find out scour depth in constricted alluvial rivers. The empirical regime formula suggested by Lacey is given below:

$$D_m = 0.47(Q/f)^{1/3} \tag{2.13}$$

Where,

D_m = Scour depth at design discharge

Q = Discharge

f = Lacey's silt factor

$= 1.76\ (d_m)^{1/2}$

d_m = Weighted mean diameter of sediment particles in mm.

To estimate maximum natural scoured depth, a multiplying factor must be added. The Table 2.2 shown below gives coefficients recommended by the Indian Code (after Lacey) based mainly upon consideration of cross sectional shape.

Table 2.2: Empirical Multiplying Factors for Maximum Scoured Depth

Nature of Location	Factor
Straight reach of channel	1.25
Moderate bend	1.50
Severe bend	1.75
Right angle abrupt turn	2.00
Noses of piers	2.00
Alongside cliffs & walls	2.25
Noses of guide banks	2.75

2.4.3 Design principles for structural elements

The design principles for structural elements can be recapitulated as follows:

2.4.3.1 General

Whatever may be the type of structure used in river training works e.g. bank revetment, groyne or guide bund, the protection works can be divided into two main parts i.e. protection of bank itself and protection of the toe of the bank. The protection of the bank is done by revetment using selected materials and launching apron or driven piles does the protection of toe.

The following general criteria should be considered during design at any protection works:

-The revetment does not slide under frequently occurring hydraulic loads

-The revetment including filter layers subsoil must be in equilibrium as a whole

-The component of the weight of the revetment normal to its face should be greater than the uplift pressure caused by water

-The surface particles of revetment should have enough resistance against wave and current attack

-The toe of revetment shall be stable against probable maximum scour in the river- bed

The structural elements of the protection works need to be selected to fulfill the above criteria are as follows:

- Size and thickness of revetment materials in open type revetment
- Thickness of revetment in close type revetment
- Thickness and gradation of riprap
- Thickness and gradation of granular filter
- Dimension of launching apron
- Depth of pile used as toe protection

2.4.3.2 Stability of revetments under current attack

For ensuring of the stability of revetment against the current strike the possible theoretical measurements can be assembled as follows:

2.4.3.3. Loose units

A number of equations relating the size of revetment materials and the velocity impinging on it have been developed. The most of these have been presented here.

(i) Isbash (1936) $W = \dfrac{4.1 \times 10^{-5} S_g V^5}{(S_g - 1)^3 Cos\theta}$ (2.14)

(ii) California State Highways

$$W = \frac{2 \times 10^{-5} S_g V^5}{(S_g - 1)^3 Sin^3 (70 - \theta)} \quad \text{(FPS)} \qquad (2.15)$$

(iii) Neill (1972) presented an equation in the form of a design graph for spherical stones (specific gravity = 2.65) and for bank slopes between horizontal and vertical, $1(V)$: $2(H)$. The following equation has been fitted to the curve.

$$D = 0.034V^2 \text{(Metric-unit)} \tag{2.16}$$

(iv) Pilarczyk (1973)

$$D = \frac{V^2}{36g(S_g - 1)\psi(h/D)} \tag{2.17}$$

(FPS or metric unit)

(v) PIANC (1987)

$$D_n = \frac{0.7V^2}{g(S_g - 1)Cos\,\theta(1 - \tan^2\theta / \tan^2\Phi)} \tag{2.18}$$

(FPS or metric unit)

(vi) JMBA (BWDB, Design Manual '1993)

$$D_n = \frac{0.7V^2}{2(S_g - 1)g} \frac{2}{\log(6h/D)} \frac{1}{\left[1 - (Sin\,\theta / Sin\Phi)^2\right]^{0.5}} \tag{2.19}$$

(FPS or metric unit)

In these equations

W = Weight of individual stone (lab. Wt.)

D = Diameter of stone (ft or m)

D_n = Dimension of cube (ft or m)

V = Velocity (ft/s or m/s)

h = Depth of water (ft or m)

S_g = Specific gravity of stone

θ = Slope of bank (°)

Φ = Angle of repose of revetment materials (°)

ψ = Shields constant

g = Gravitational acceleration (ft/s^2 or m/s^2)

The definition of velocity is not fixed. The Neill's equation expresses the velocity against the stone, in other case it is mean velocity in the adjacent channel or the velocity at a specified distance from the bank.

The PIANC equation that is stated to be a form of Isbash equation gives much lower size of revetment materials compared to the other three equations. The equations suggested by Pilarczyk (1973) and JMBA (BWDB Design Manual'1993), considered the depth factors for computation of size of revetment materials but the former gives higher size compared to later. Neill's equation and JMBA's equation consider (taking depth factor h/D=5) nearly equal size of revetment materials. Considering all factors, it is recommended to use Neill's and JMBA's equations for computation of revetment size against velocity.

2.4.3.4 Stability of revetment under wave attack

Principal factor affecting the design of slope protection is wave action. A riprap layer must be designed to protect the individual rock particles from displacement by wave forces. Riprap protection against wave action is generally satisfactory for protecting slope from other attacks.

2.4.3.5. Loose units (Wave attack)

Various methods and equations are available to determine the size of revetment material required for resisting wave forces. Some of these formulae are (according to the Design manual of BWDB '1993) as follows:

(a) CHP
$$W = \frac{0.0231 H^2 \rho Co \sec^3(70° - \theta)}{\Delta^3} \tag{2.20}$$

(b) Hudson
$$W = \frac{H^3 \rho \tan\theta}{k\Delta^3} \tag{2.21}$$

(c) Irribarren
$$W = \frac{f H^3 \rho}{\Delta^3 (Cos\theta - Sin\theta)^3} \tag{2.22}$$

(d) Pilarczyk
$$D = \frac{H_g}{(S_g - 1)} \cdot \frac{1}{6} \cdot \frac{E^{1/2}}{Cos\theta} \tag{2.23}$$

Where,

W = Weight of revetment material

D = Cubic dimension

H_g = Significant wave height

6 = Strength coefficient, 3 for cubes, 2 for dumped cubes

θ = Bank slope angle

E = Wave breaking parameter

$$= 1.25 \frac{T}{H_g^{0.5}} \tan\theta$$

T = Wave period (sec)

f = A coefficient related to the amplitude of the depth angle of the slope

ρ = Density of revetment material

Δ = Relative density of revetment material

$$= (\rho - \rho_w) / \rho_w$$

ρ_w = Density of water

k = A coefficient varying from 3.2 for smooth quarry stone to 10 for tetra pods

S_g = Specific gravity of revetment material

2.4.3.6. Thickness and Grading of Riprap

Opinions of different authorities regarding the thickness of slope pitching are given below:

- U.S. Army Corps of Engineers (1991), recommended that thickness of protection should not be less than the spherical diameter of the upper limit W_{100} (percent finer by weight) stone or less than 1.5 times the spherical diameter of the upper limit W_{50} stone, whichever resulted in greater thickness.

- California Highway Division recommended that there should be at least two layers of overlapping stones so that slight loss of material does not cause massive failure.
- ECAFE recommends thickness of protection should be at least 1.5 D, where D is the diameter of normal size rock specified.
- Spring (1903) recommended thickness of stone in inches for covering by rough, heavy and loose stone for pitching from low water up wards as shown in Table 2.6.
- The thickness of stone pitching and soiling for permanent slopes required at head, body and tail of guide bank for river flowing in alluvial plains as recommended by Gales (1938) is tabulated in Table 2.7.
- Inglis (1949) recommended following formula to compute thickness of stone required,

$$T = 0.06\ Q^{1/3} \tag{2.24}$$

Where,

T= Thickness of stone riprap in m

Q= Discharge in cumec

The Inglis (1949) formula apparently gives excessive thickness for discharge above 1.5 million cumecs.

The thickness determined above should be increased by 50 percent when the riprap is placed under water to provide for uncertainties associated with this type of placement.

2.4.3.7. Riprap grading

Size distribution of a riprap mixture should form a smooth grading curve without a large spread between minimum and maximum sizes. Stones should be reasonably well graded. Table 2.5 shows grading specifications for three classes of riprap, which have been considered suitable for a fairly wide range of stream, flow situations.

2.4.3.8. Design of Toe protection

Different Steps involved in design of toe protection can be described as follows:

A. Toe scour estimation and protection

Lack of protection of the toe of revetment against undermining is a frequent cause of failure. Accordingly protection of the toe of revetment by suitable method is obviously needed. Again, scour is the result of several factors, the factors are mentioned below:

- Change in cross-section in meandering channel after the bank is protected: the thalweg often moves towards the riverbank when the bank is restricted. Channels with both erodible bed and banks can experience significant scour along the toe of the new revetment.
- Scour at high flows in meandering channel: bed protection measurements have shown that the bed observed at lower level is not same as that exists at high flows.
- Braided channels: scour in braided channels can realize maximum at intermediate discharges where the flow of channel braids and attacks the banks at sharp angles.

B. Toe protection methods of revetment

Followings may be provided as toe protection of revetments:

- Extension to scour depth: lower extremity of revetment placed below expected scour depth or founded on non-erodible bed materials. These are preferred methods, but can be difficult and expensive when under water excavation required.
- Placing launchable stone: launching stone is defined as stone that is placed along expected erosion prone areas at an elevation above the zone of attack. As the attack in resulting erosion occurs below the stone, the stone is undermined, rolled and slided down the slope, stopping the erosion. This method has been widely used on sand bed streams. Launch slope is less predictable if cohesive material is

present, since cohesive material may fall in large blocks. Successful applications include:

(i) window revetments: riprap placed at top of bank.

(ii) trench-fill revetments: riprap placed at low water level

(iii) weighted riprap toes: riprap placed at intersection of channel bottom and side slope.

C. Dimension of launching apron

Among the various methods, launching apron has been considered to be most economical and common method of toe protection for revetment. Launching apron has been considered to be laid horizontally along the river bed or flood plain at the foot of revetment so that when scour occurs, the materials will settle and replenish the scour hole to form a natural slope. Adequate quantity of stone for the apron has to be provided to ensure complete protection of the whole on the scoured face. This quantity will obviously depend on the apron thickness, depth of scour and slope of the launching apron, which is considered below:

(i) Thickness of launching apron

Spring (1903) recommended a minimum thickness of apron equal to 1.25 times the thickness of stone riprap of the slope revetment. He recommended further that the thickness of apron at the junction of apron and slope should be increased in the shape of that laid on the slope but should be increased in the shape of a wedge towards the river bed, where intensity of current attack is severe and hence probability of loss of stone is greater.

Since the apron stone shall have to be laid mostly under water and cannot be hand placed, thickness of the apron at junction according to Rao (1946) should be 1.5 times the thickness of riprap in slope. The thickness of river end of apron in such case shall be 2.25 times the thickness of riprap in slope.

The slope of the launching apron may be taken as 2:1 for loose stone as suggested by Spring (1903).

(ii) Size of stone

The required size of stone for launching apron may be the same as for the size in slope revetment considering steam velocity as governing factor.

(iii) Length of launching apron

The general practice as recommended by Inglis (1949) is to lay the apron over a length of 1.5 D, where D is the design scour depth below the position of laying.

(iv) Quantity of stone in apron

Knowing the thickness of apron, the depth of maximum probable scour and the slope of the launched apron, the quantity of apron stone can be assessed.

(v) Recommended shape

It is recommended to use the shape of launching apron as suggested by Rao (1946) considering the condition of stone provided at the junction of the apron and shape, which appears to be more logical.

2.4.3.9. Design of filter material

The design procedure of filter material are described as follows:

(i) Granular filter

The properties of granular filters depend significantly on the particle size. The filter criterion relates the grading of the filter to that of the subsoil. If the filter also has received drainage function, it is necessary to check for filter uniformity to ensure that internal migration of fines does not occur. Various authors have developed minimum filter requirements. Pilarczyk (1973) defined the following criteria regarding the relation between characteristic grain sizes of the subsoil D_s and the filter D_f

$D_{15f} < (4 \text{ to } 5).\ D_{85s}$ (stability criterion)

$D_{15f} > (4 \text{ to } 5).\ D_{15s}$ (permeability criterion)

$D_{50r} > (20 \text{ to } 25).\ D_{50s}$ (segregation criterion)

$$C_u = \frac{D_{50}}{D_{10}} < 10 \qquad \text{(no migration)}$$

$$C_u = \frac{D_{50}}{D_{10}} > 20 \qquad \text{(susceptible to migration)}$$

With

C_u (-) coefficient of uniformity

D_x (mm) diameter according to x % undersize by mass taken from grain size distribution

To achieve the required filter characteristics it might be necessary to use more than one granular layer. In that case the filter has to be built in successively coarser layers starting from the underlying soil. The first layer must retain the base material, whereas the outer layer must be stable against the revetment armour layer. The minimum thickness of any granular filter is normally taken as 2 to 3 times the maximum particle size for each layer, maintain a minimum 150 mm thickness of the granular filter of 150 mm. Where ever practicable, the granular, material must be carefully compacted to minimize settlements.

(ii) Geo-textile filters

The main design parameters for geo-textile filters are the retention criterion and the permeability criterion, which define the capability of the material to retain the existent sub-soil without clogging and to allow unhindered water transport through the membrane. Besides the required functional characteristics of the geo-textile in context with the existing sub-soil properties, certain stability standards must be considered, which have to be defined with respect to the planned use and which might have further implications on the construction techniques to be employed. Specific properties of geo-textiles are available from product sheets of the respective manufactures (BWDB, Design manual '1993).

(a) Determination of the range of the grain-size distribution

The grain-size distribution curve must be determined following international standard regulations, to allow for calculation of the various design parameters. The filter characteristics of geo-textile are mainly influenced by the fine compartment of

the grain-size distribution and the PIANC (1987)-method categories the soil by the screen fraction smaller than 0.06 mm grain size.

The soil categories for the geo-textile filter design are classified as follows

Range A: 40% or more of the soil particles are smaller or equal to 0.06 mm.

Range B: 15% or less of the soil particles are smaller or equal to 0.06 mm

Range C: between 15% and 40% of the soil particles are smaller or equal to 0.06

(b) Design for soil retention

The capacity of a geo-textile in terms of soil retention is characterized by the effective opening size O_{90}, which is defined by the equivalent diameter of a grain fraction, which is retained to 90% by the filter mat in a sieving test. This value is normally provided in the product information sheet provided by the manufacturer. The soil-retention is strongly influenced by the dynamics of the impact. Therefore different regulations are given for moderate stationary current and for potentially high dynamic hydraulic loads (e.g. wave impacts). The minimum requirements for the geo-textile filter to be considered for dynamic load conditions, characterized by high turbulent flow and wave attack, are specified in Table 2.3. The given retention criteria are only applicable for O_{90} values determined by the wet sieving analysis as defined by Swiss standard SN640550.

Table 2.3: Soil retention criteria (PIANC '1987)

Grain size range	Retention criteria
A (amount of fines ≤ 0.06+ mm larger than 40%)	$O_{90} < d_{90}$ $< 10\ d_{50}$ < 0.3 mm
B (amount of fines ≤ 0.06 mm smaller than15%)	$O_{90} < 1.5\ d_{90}\ \sqrt{C_u}$ $< d_{50}$ < 0.5 mm
Customary (fines ≤ 0.06 mm between 15% to 40%)	As range B

(*) if the soil exhibits long-term stable cohesion. Then $O_{90} < 2\ d_{90}$ is applicable

(c) Design for permeability

The geo-textile filter must maintain a long-term permeability equal or larger than that of the prevailing soil. Shortly after installation a reduction in the fabric permeability due to clogging and blocking will occur, which depends on the pore structure and thickness of the material as well as on the grain structure of the soil. In general, the permeability of the geo-textile material is acceptable if

$$\eta \cdot k_g \geq k_s \tag{2.25}$$

with

η (-)	material specific reduction factor
k_g (m/s)	permeability of the geo-textile
k_s (m/s)	permeability of the soil

If k_g is not available from laboratory tests, it can be approximated by the empirical relation filazen, in Tomlinson, 1996):

$$k = 0.0116 D_{10}^2 \tag{2.26}$$

The reduction factor η for needle-punched and other non-woven fabrics thicker than 2 mm measured at a normal stress of 2 kN/m^2) is defined as a constant:

$$\eta = \frac{1}{50} \tag{2.27}$$

(d) Identification of soils susceptible to down-slope migration

The migration of soil particles underneath the geo-textile filter layer by gravity induced down slope water transport (e.g. rain water or wave run-down) is apparent particularly in soils with fine, but non cohesive material (hence, mainly grading range A and B). Therefore, a distinction between soils susceptible to down-slope migration and those not susceptible can be related to grain size, permeability and cohesion of the existing soil sub-layer (revetment core). Soils susceptible to down-slope migration are in general characterized by the following condition:

Grain size : a considerable amount of fine material with d < 0.06

$C_u = d_{60}/d_{10} < 15$: coefficient of uniformity (conservation estimate based on practical experience; for larger C_u values normally a secondary filter with establish)

$I_p = w_L - w_p < 0.15$:limited value for plasticity index. The plasticity index is defined as the difference between the moisture content at liquid limit (w_L) and the moisture content at plastic limit (w_p). If I_p is not known, the following criterion, which relates the weight of the clay fraction to the weight of the silt fraction, may be used for preliminary design:

$$\frac{W_{(d<0.002mm)}}{W_{(0.002mm<d<0.06mm)}} < 0.5 \tag{2.28}$$

The above given conditions allow only for a rough estimation regarding the risk of down-slope migration processes at certain subsoil properties. For consideration of additional influencing conditions and site-specific factors, an experienced soil mechanic engineer should be consulted.

(e) Counter measures against down-slope migration

Down-slope migration of soil particles underneath a geo-textile filter can be prevented by incorporating a granular sub-layer between the geo-textile and the cover layer (thickness of approx. 300 mm), which should be fine enough to provide adequate damping effect and coarse enough to be retained by the cover layer.

Furthermore, the surface of the soil underneath a geo-textile can be stabilized by special composite geo-textiles, providing a second, relatively thick layer (minimum of about 5 mm) coarse fibers attached to the back of the geo-textile filter. The required physical properties of the synthetic coarse layer are dependent on the soil grading range (Table 2.4). As an alternatively increase the slope stability, a heavy weight cover layer, which is reducing potential uplift force caused by excess pore water pressure, can be applied.

Table 2.4: Minimum standards of the coarse layer (PIANC-1987)

Characteristics of coarse layer	Range A Grading curve	Range B Grading curve
Effective opening size O_{90}	$0.3<O_{90}<1.5$ mm	$0.5<O_{90}<2.0$ mm
Thickness of geo-textile t_{gg}	$5<t_{gg}<15$ mm	$5<t_{gg}<20$ mm

2.4.3.10 Placement of Riprap

Common methods of riprap placement are hand placing and machine placing, such as from a skip, dragline, or some form of bucket. Hand placing produces the most stable riprap revetment because the long axis of the riprap particles is oriented perpendicular to the bank. Steeper side slope can be used with hand placed riprap than with other placing methods. This reduces the required volume of hard material.

In the machine placement method, sufficiently small increments of stone should be released as close to their final positions as practical. Stone should not be dropped from an excessive height or dumped and spread, as this may cause segregation and breakage of stone.

The layer thickness and stone size may be increased somewhat to offset the shortcomings of placement method. Thickness of underwater placement should be increased by 50% to provide the uncertainties associated with the type of placement. Underwater placement is usually specified in terms of weight of stone per unit area, to be distributed uniformly and controlled by a " grid " established by shoreline survey.

Table 2.5: Suggested Stone Riprap Grading for Stream Bank Revetment (BWDB, Design Manual '1993)

Class	Description	Grading Specification
I.	Nominal 1 inch diameter or 80 lb weight Allowable local velocity up to 10 ft/ sec	100% smaller than 18 inches or 300 lb At least 20% larger than 14 inches or 150 lb At least 50% larger than 14 inches or 80 lb At least 80% larger than 8 inches or 25 lb
II	Nominal 20 inch diameter or 400 lb weight Allowable local velocity up to 13 ft/sec	100% smaller than 30 inches or 1500 lb At least 20% larger than 24 inches or 700 lb At least 50% larger than 20 inches or 400 lb At least 80% larger than 12 inches or 70 lb
III	Nominal 30 inch diameter or 1500 lb weight Allowable local velocity up to 15 ft/sec	100% smaller than 48 inches or 5000 lb At least 20% larger than 36 inches or 2500 lb At least 50% larger than 30 inches or 1500 lb At least 80% larger than 20 inches or 400 lb

Table 2.6: Spring's Table to Compute Thickness of Stone (Spring. F.J., 1903)

River bed materials as classified by Spring	Thickness in inches for river slopes in inches per mile					Remarks
	3	9	12	18	24	
Very Coarse	16	19	22	25	28	The stone pitch prevents sand underneath from being sucked out by high velocity flow. More rationally stone pitch thickness should be based on velocities.
Coarse	22	25	28	31	34	
Medium	28	31	34	37	40	
Fine	34	37	40	43	46	
Very Fine	40	43	46	49	52	

Table 2.7: Gales' Table to Compute Thickness of Stone on Slope (BWDB, Design Manual, 1993)

River	**Rivers with discharge 0.25 to 0.75 million cumec**		**Rivers with discharge 0.75 to 1.5 million cumec**		**Rivers with discharge 1.5 to 2.5 million cumec**	
Pitching Stone	3′- 6″	3′- 6″	3′- 6″	3′- 6″	3′- 6″	3′- 6″
Thickness of Soiling Ballast	7″	7″	8″	8″	9″	9″
Total Thickness	4′-1″	4′-1″	4′- 2″	4′- 2″	4′- 3″	4′- 3″

CHAPTER THREE

METHODOLOGY AND DATA COLLECTION

3.1 General

The methodological approach adopted for this study for attaining the set objectives can be organized as follows:

i. Investigation followed by Field Visit

ii. Data Collection

iii. Collection and Testing of Soil Sample

iv. Review of Design of bank Protection

v. Detailed analysis

3.2 Investigation followed by Field Visit

With a view to gathering of enough information about the river conditions, hydraulic parameters including wave conditions, type, condition and effectiveness of erosion protection and revetment works, necessary field visits of the Surma river around the Sylhet City have been performed. Design circles of Central and Local BWDB offices have been visited for collecting various documents and also for exchanging and sharing knowledge based experiences about the Surma river bank protection works. It may be mentioned that during the field visits, the present conditions of selected bank protection works has been detected and noted down. At the same time, photographs have been taken to make evidence of the circumstances of the particular protection works.

3.3 Data Collection

For this present study four types of data were collected. These are: (i) topographic data, consisting of satellite Images, (ii) river morphology, composed of cross sections, (iii) flow characteristics such as water level and discharge (iv) Sediment data.

Data utilized in this analysis are collected from BWDB, IWM and CEGIS and are presented as follows:

Type of Data	Name of River	Station	Period (year)	Source
Water Level	Surma	Sylhet, Chattak, Kanairghat, Sunamgonj	1975,1989, 1998-1999, 1990-2000, 2002-2003	BWDB, IWM
Discharge	Surma	Sylhet, Kanairghat	1975-1976, 1989-1990, 1993-1994, 1998-1999, 2002-2003	BWDB
Cross Section	Surma	Whole-River (S-1 to S-42)	1991, 1999	BWDB
Sediment Data	Surma	Sylhet	1975, 1989, 1999	BWDB
Satellite Image	Surma	Total Reach	1997, 2002	CEGIS
Cross Section Map	All Rivers	Bangladesh	1993	BWDB
Bank Protection Design	Surma	Sylhet	2002	BWDB

3.4 Collection and Testing of bank and bed material

For effective design of bank protection works consideration of geotechnical and hydrological data are mandatory. Again, the test results of the bank material at the particular site should be performed carefully since sediment characteristics differ from one site to another.

Sediment sample had been collected from the bank of the Surma river at Kazirbazar (sloping surface above water level) during dry season when the discharge is low.

Sediment finer than 75μ sizes couldn't be sieved. The particle size distribution of such sample was determined by sedimentation analysis. For experimental procedure the hydrometer method was chosen.

Again, the sediment sample collected from the bank was investigated thoroughly in the geotechnical point of view. The test procedures included the computation of

median size of sediment, uniformity co-efficient, liquid limit, plastic limit, plasticity index, and ratio of clay to silt fraction.

3.5 Review of Design of bank Protection Works

Depending on the assembled field data and information hydraulic design parameters were evaluated in terms of effectiveness, suitability and sustainability. The effectiveness was checked by whether the implemented protective works could able to stop bank erosion, to cease the slope sliding, and to protect the toe efficiently. Suitability was measured in consideration of varieties of protection works were suitable for the river size, current and waves. On the other hand sustainability is related to the life of the structural elements and sustainable with reasonable operation and maintenance with the local available construction materials.

3.6 Detailed Analysis

Detailed analysis related to the morphological and sediment transport were carried out with the help of the collected data from the BWDB considering the selected empirical equations and is presented in the following chapters.

CHAPTER FOUR

ANALYSIS

4.1. Morphological Analysis

In the present study of morphological analysis, cross-sectional data of 24 number of sections (Table 4.1 and Figure 3.1 to 3.3) starting from S-42 (Lubachara, 0.0km Chainage) to S-1 (Markuli, 250.7 km Chainage) of the river Surma for the years 1991 and 1999 have been selected and plotted to visualize the change in cross sections happened during 10 years (Table 4.1 to 4.3 and Figure 4.1, 4.8 and 4.11 to 4.15). The previous year data for the year 1970 and 1989 was collected from the previous thesis and was incorporated with the present set of data. Finally, four years data (1970, 1989, 1991 and 1999) were plotted and analyzed. Again, the cross sectional area, width, mean bed level and deepest point, width of the selected sections have been calculated for the year 1991 and 1999 (Figure 4.1 to 4.10 and Table-4.1 to 4.3). Specially, cross sectional area at 24 selected sections for the year 1991 and 1999 were plotted in Figure 4.8 to evaluate change in cross section. Variation of width at bank level has also been plotted to evaluate the change in width for the years 1991 and 1999 and is shown in Figure 4.4. Then, deepest point elevation (thalweg line) for the 24 sections for the year 1970, 1989, 1991 and 1999 also has been plotted and presented in Figure 4.6.

Mean bed level was computed for the selected 24 sections for the selected years to determine the extent of change of mean bed level (Figure 4.7). The mean bed level of an equivalent rectangular cross section having the width and area equal to the width and area of that particular section were computed such that the net erosion below and deposition above this level remain unchanged for a hydrological year (Table 4.3). This level was measured from a fixed reference line. This procedure is correct when channel is wider i.e., the width to depth ratio is greater than 20 (Das '1992).

Area-elevation relationship was developed and from that relationship different curves were drawn to see whether the bed was rising or falling. A typical presentation of area-elevation curve of section S-24 is shown in Figure 4.2.

The hydraulic, geometric and sediment transport parameters required in these analysis have been taken considering the active portion of the channel section. First of all, width of the channel has been considered as the surface width of the river. Secondly, mean depth of the flow has been determined from equivalent rectangular channel section whose top lateral dimension equals the water surface width. Hence, the cross sectional area divided by the top width gave the average depth, which was deducted from the bank level with respect to PWD datum. Consequently, mean bed level for the respective section was obtained. Thirdly, average slope of the river Surma was taken from the Specialist study, River Sedimentation and Morphology done by Northwest Hydraulic Consultants. Finally, cross-sectional area was computed from the lower of the two values both of the right and left bank (Kamrunnessa '1994).

Next, grain size distribution of the bank and bed material was performed at the laboratory of the Civil Engineering Department of Shahjalal University of Science & Technology, Sylhet for the samples collected from bed and from bank of the Surma river. From that data several grain size distribution curves were drawn and a representative grain size distribution of the bank and bed material are shown in the Figure 4.26 and 4.27 respectively. After that, D_{50} of the bank material was calculated. Finally, D_{50} of the bed material was taken from the Specialist's Report (0.20 mm) for sediment computation to perform consistent analyses in respect to the previous studies.

4.2. Prediction of Discharge Capacity

Available up-to-date (year 1999) data of twelve sections in Surma River have been collected from surface hydrology section of BWDB and used in the present analysis. Location of the present study and cross sections details is shown in Figure 3.1 to 3.3. The actual cross sections are analyzed for different flow depths, increasing from the bed level to the bank-full levels. For each cross section the hydraulic mean depth at

each water level is computed conventionally using the following relation (Alhamid and Matin '1998):

$$\frac{U}{U_*} = \frac{1}{F_f}\left(\frac{S}{\Delta\rho_s / \rho}\right)^{\left(x-\frac{1}{2}\right)} \left(\frac{R}{d}\right)^{x/3} \tag{3.1}$$

$$D_i = \frac{1}{T_i}\left(\sum A_{i-1} + \frac{1}{2}(T_{i+1} + T_i)(h_{i+1} - h_i)\right) \tag{3.2}$$

where A is the flow area, T is the top width and h is the water level at i, and i = 1,2,3,……up to number of division, from lowest bed level to bank full level.

For Surma channel reach, sediment characteristics varying significantly. Typical grain size distribution curves of bed material of the Surma river at Sylhet are shown in Figure 4.27. It can be seen that samples collecting from cross section no S-29 located at Sylhet, the median sediment size, d_{50} of the bed is 0.16 mm. Thus for bed material size $d_{50} \geq 0.16$ mm, relative sediment density, $\Delta\rho_s / \rho = 2.63$, the parameter R* found to be less than 0.01, which falls in lower regime (Alhamid and Matin '1998). Coefficients of K_1 and K_2 versus sediment size are shown in Figure 4.16. Therefore, using the F_f value as obtained from lower regime curve of Figure 4.17, and with R=D, Equation (3.1) becomes;

$$\frac{U}{U_*} = 4.44(S)^{0.05}\left(\frac{D}{d_{50}}\right)^{0.183} \tag{3.3}$$

For given bed slope, S, and sediment median size, d_{50}, equation (3.2) and (3.3) have been used to calculate the mean velocity for any given stage. Accordingly, discharge may be computed by multiplying the mean velocity with the corresponding flow area (Alhamid and Matin '1998).

4.3. Revetment Design

For assessing the design of structural element of river training works, hydraulic factors such as water level, discharge, flow velocity, wave height and anticipated

scoured bed level of the river have been evaluated. In selecting the water level, high flood level for Bankful level has been considered. And for low water level average lowest in various dry months has been considered. Again, for discharge consideration, Bankful discharge or 70% of 1 in 20 year discharge whichever is higher has been taken as the river is a flashy river (BWDB, Design manual '1993). The average velocity has been obtained from measured data. For waves consideration design wind direction, effective fetch and wind velocity and duration data have been collected from the design manual of BWDB. Besides, the protection of toe of any river training is of prime importance as regards to the stability of overall slope protection against scour. In connection to that Lacey's formula is widely used. The empirical regime formula of Lacey has been used to determine the anticipated scour depth. Then, for checking the stability of revetments under current attack JMBA formula has been analyzed (FAP 21'2001). Again, for determining the dimensions of launching apron its thickness, size of stone. Length, quantity of stone and recommended shape, design of filter have been evaluated with the help of the design manual of bank protection works. Dimensions of geotextile also have been determined (BWDB Design Manual '1993). Sediment sample collected from the bank of the Surma river at Kazirbazar has been investigated for Geotechnical aspects (Table 4.25 and 4.26). The grain size distribution of the bank material of the Surma river at Kazirbazar, Sylhet shows that the median size of sediment D_{50} is 0.016 mm. The Geotechnical investigation shows that the bank protection works at Kazirbazar is susceptible to down slope migration. An index map of bank protection works is presented in Figure 4.28. A typical design layout of the implemented bank protection works of the Surma river at Kazirbazar, Sylhet is shown in the Figure 4.29. Again, a sample calculation of bank protection works is presented in the Appendix.

4.4. Sediment Transport Computation

Three well known sediment transport equations such as Engelund-Hansen's, Acker-White's and van Rijn's empirical formula were considered and analyzed for computation of total sediment load for the year 1975,1989 and 1999 to observe the pattern of sediment transport of the river Surma (Table 4.6 to 4.20).

Graphical presentation of the calculated sediment load and discharge including trend lines and power equations are shown in Figure 4.18 to 4.20 and 4.24. Relationship between observed sediment load and discharge, between observed sediment load and computed sediment load were developed for the year 1975, 1989 and 1999. Discrepancy ratios of various equations are presented in Table 4-21 to 4.23 respectively.

In Figure 4.21 to 4.23 and 4.25, the developed relationship between the observed sediment load with discharge and the measured sediment load with velocity for the year 1975, 1989 and 1999 are presented.

4.5. Planform Change Assessment

The collected satellite images (Photograph-10 to 11) were digitized and superimposed (Photograph-12) with the help of Arc view software to see the planform changes of the river Surma considering the image 1997 as the base.

CHAPTER FIVE

RESULTS AND DISCUSSIONS

5.1 Morphological Process

5.1.1 Cross Sectional Variations

From the analysis of the selected 24 cross sections (presented in Table 4.1) for the years 1970, 1989, 1991 and 1999 maintaining the same scale for the parameters like the variations in cross sectional shape, top width, thalweg, average depth, aspect ratio (width/depth ratio) long profile and average depth (Figure 4.1 to 4.10), it has been observed that the river had turned into wider and shallower up to 1989. After that, it has changed into comparatively narrower and shallower for the next ten years period (1989 to 1999). In this regard, geometric dimensions of cross sections from section no. S-29 to S-42 are presented in Table 1.2.

The graphical presentations (Figure 4.1 and 4.8) show that the cross sectional areas at bank level in the section no. S-9 (397.3 m^2), S-14 (1643.10 m^2), S-16 (1911.20 m^2), S-18 (1873.00 m^2), S-20 (1520.00 m^2), S-38 (749.12 m^2), S-40 (843.3 m^2), S-41 (842.36 m^2) and S-42 (1017.11 m^2) decreased significantly in the year 1999 in compare to those of the previous years. Again, in 1989, the area of the section no. S-18 (146.9 km Chainage, 3856.8 sq.m) had the highest area ever computed. But during 1999, that area reached a lower value (1873.00 sq. m.). These phenomena might be the sign of sedimentation taken place in those sections during a period of time. However, the area of the section no. S-7 (1322.0 m^2), S-12 (2424.0 m^2), S-23 (913.8 m^2) and S-23 (3057.0 m^2) increased remarkably during the ten-year (1989 to 1999) period. The attention-grabbing feature is that for the section no. S-27, the cross sectional area in the year 1970 was only 1196.85 Sq.m., while that value for the year 1989 (2876.28 m^2), 1991(3456 m^2) and 1999 (3057 m^2) were augmented. This is because, severe erosion due to carrying of sediments and discharge during flash floods might have been occurred in those cross sections. Again, the cross sectional area located in the down stream of Sunamganj (S-10 to S-1) is in general a little figure in compare to rest of the areas of the rivers irrespective of years. Furthermore,

most of the areas in the year 1999 had a lower value than that of the previous years indicating that siltation have been occurred throughout the rivers. Hence, the carrying capacity of the river has reached the lowest position and flash flood has been taken place in the successive years.

The width variation curve (Figure 4.4) expresses that S-9 is the narrowest section while the section no. S-16 is the widest of all. The section no S-18 and S-38 experienced the sharp rise and fall during the 30 years time period. Mean while, remaining stable for 19 years, section no. S-23 (170.44 m in 1970, 179.51m in 1989 and 298.1 m in 1999) experienced sudden rise in the year 1999.

Deepest point (Figure 4.6) analysis of the 24 sections for the selected years shows that the noteworthy increase in the deepest point happened in the section no. S-1, S-16, S-20, S-25, S-34, S-36, S-38, S-40, S-41 and S-42. Whereas the prominent fall in thalweg line was recorded in the sections S-10, S-12 and S-14. At the same time, the section no. S-9 (1.73m), S-23 (-2.225m) and S-32 (0.31m) are remained almost stable. The mentionable characteristic of this thalweg line is that section no. S-14 (-10.625 m in 1999) experienced the deepest point while the section no. S-38 (8.95 m in 1999) received the highest rise in deepest point.

5.1.2 Superimposition of Cross-sections

The alteration of morphology of a river along transverse direction from year to year due to the consequence of erosion of the river bed and shifting in bank line can be revealed with the tool like Superimposition of a cross-section at a particular location for different years. In this regard, a momentous lifting up of river bed since 1991 can be visualized in the Figure 4.15 which plots the cross-section no. S-42 of the Surma surveyed from 1991 to 1999 at Lubachara, near its bifurcation point with the Kushiyara. Hence, the ascending of river- bed along the thalweg line is reasonably unusual, about 6.5 m, during 9 years period. It means that for a long time severe siltation has been occurring in this upstream portion of the river.

5.1.3 Area Time Curve

Considering the possible past and up to date cross sections of Surma river, time series of cross sectional area at bankful level for selected locations starting from its offtake (Lubachara) to outfall (Markuli) has been presented in Figure 4.1. Usually, morphological activity for a certain periods can be divulged through this area curves. Sedimentation is portrayed in the period 1970 to 1980 whereas erosion can be illustrated by a period from 1980 to 1991. Later sedimentation presides over a period of certain years before reaching a peak of erosive activity in 1999. Currently, sedimentation has governed the morphological process as indicated by the usual drift of decreased cross-sectional area after 1999-2000 (IWM'2001). The outcome is pronounced in the upstream reach between Lubachara and Sylhet. The declining course of the Surma river known as old-Surma river, represented by curves at Derai and Markuli also exhibit similar behaviour. In the area time curve, Sunamganj, the deepest cross sectional location of the river, reaches the climax of erosive activity in 1991-92, later sedimentation initiates harmonizing the overall morphological drift of the river. Moreover, there are exceptions to this general morphological behaviour. In addition, increase in area is indicated at Golapganj, few km upstream of Sylhet, where local erosion at a bend site has been observed recently. Similar pattern is observed for the cross section at Ramnagar just upstream of the bifurcation point of the old-Surma and Nawa Surma (the active channel of Surma) rivers. After, the year 1994, the notable increase in area at that location might be the consequence of the Nawa Surma turning into prominent shape by enlarging of the cross-section.

5.1.4 Mean Bed Level variation

To observe and evaluate the effects of erosion and deposition on mean bed level, mean bed level of the selected 24 sections for different years were computed and is presented in the Figure 4.7. It is found that the maximum rise in calculated mean bed level is happened in the Section no. S-42 whereas the maximum fall in mean bed is found at section no. S-18 and S-3. Although the exact amount of erosion and deposition occurred all over the river was not possible due to the limited data, however, an initiative was performed to get acquainted with the concept of erosion and sedimentation activities prevailing in that river.

5.1.5 Relationship Between Area and Elevation

With a view to observing of the aggradation and degradation of a specific section, area elevation relationship is established for that section. For this purpose, area elevation curve for the typical section no. S-24 for the years 1989 and 1999 was plotted (Figure 4.2). It is found that a significant aggradation has occurred over the period 1989 to 1999, which strengthens the comparison of the cross sectional areas presented in Figure 4.8.

5.1.6 Superimposition of Long Profiles

For appraising the trend in bed topography considering the erosion and sedimentation along the channel, superimposition of long profiles for a certain years for a specific river, is a nice tool. Besides, the bringing together of both superimposition of cross sections and long profiles provides a valuable insight into the morphological behaviour of the concerned river. The longitudinal profiles of the Surma river from Lubachara to its confluence with the Kushiyara river at Markuli have been presented in Figure 4.10. The peculiar characteristics of the profile is the adverse slope of river bed from Lubachara to Kanaighat which might be created due to the consequence of the bar formation at the downstream of the bifurcation point with the Kushiyara river at Amalshid (FAP-6 '1993). Furthermore, the usual trend is illustrated in the increase of river bed from Lubachara to Chatak in recent years, which is considered the valley course of the river. On the other hand, an adverse slope is noted in the old course of the Surma river through the haor area starting from the Sunamganj to Markuli which indicates the persistent decling condition of the river.

5.1.7 Variation of Conveyance

To visualize the carrying capacity of the river, conveyance for the year 1970, 1989, 1991 and 1999 were plotted against the cross sections (Figure 4.5). It is seen that in 1999, the conveyance of most of the sections were reduced notably in compare to those of other years. The lower values of conveyance are found at section no. S-9 (19,699.13 $m^{8/3}$) and S-38 (32,477.62 $m^{8/3}$). In consequence to the huge sediment

load, the river has lost its normal carrying capacity about 29% in 1999 compared to 1991 and flash floods visits in each year inundating the near by lands and towns.

5.2 Prediction of Discharge capacity

Discharge carrying capacity and sediment concentration of 14 cross sections of the river Surma starting from section no. S-29 (Sylhet) to S-42 (Lubachara) have been estimated (Figure3.2) under bankful conditions, using a simplified resistance equation and Ackers-white's sediment predictor (Alhamid and Matin '1998). Except, the section no. S-29, no other sections have discharge stations. Results are presented in Table 4.4. Results indicate that section no. S-31 has the highest discharge capacity (973.22 cumecs) whereas section no. S-41 has the lowest of that (133.55 cumecs) among all the selected sections. In this regard, it can be mentioned that the Bankful discharge of Surma at Sylhet is 1373.33 cumecs (Two third of the highest discharge, 2060 cumecs). On the other hand, maximum sediment concentration was estimated in section no. S-36 (1485.03 ppm) and minimum was found in the section no. S-41 (214.11 ppm).

5.3 Sediment predictor's Performance

Transported Sediment load for the river Surma were computed with the help of three well known sediment predictors such as Engelund-Hansen's equation, Ackers-White's equation and van Rijn's equation for the years 1975, 1989 and 1999 at Sylhet and were compared with the values of the measured sediment discharge of those years. The performance of these equations is narrated in the following paragraphs.

5.3.1 Engelund-Hansen's Equation

The predictions of Engelund-Hansen's equation was good for the year 1999 and 1975 whereas in the year 1989 the values of the sediment load is much lower than the field measurement (Table 4.6 to 4.11). Computation of sediment load in ton per day against the corresponding discharge in cumec for the year 1975, 1989, 1999 are presented in Figures no. 4.18 to 4.20 and 4.24 respectively. Best-fit lines are drawn from those computations.

Relationships between the computed sediment load and observed discharge are established for the year 1975, 1989 and 1999. The coefficients of correlation are found to be 0.831 (1975), 0.766 (1989) and 0.972 (1999). Developed regression equations are as follows:

$$Q_{s\,(cal)} = 18.463\ Q^{0.7405} \tag{5.1}$$

$$Q_{s\,(cal)} = 4.7211\ Q^{0.8511} \tag{5.2}$$

$$Q_{s\,(cal)} = 2.762\ Q^{1.1432} \tag{5.3}$$

Where $Q_{s\,(cal)}$ denotes the calculated sediment load in ton/day, Q for the water discharge in cumec and 'R' is the coefficient of correlation. This prediction of this equation for the river Surma is well. The mean discrepancy ratios ($Q_{s\,(cal)}$/ Q_s) are 1.156, 1.152, and 0.52 for the year 1975, 1989 and 1999 respectively (Table 5.21 to 5.23).

5.3.2 Ackers-White's Equation

Output of this equation for different years (Table 4.6 to 4.8 and 4.12 to 4.14) is closer to the measured sediment load in compare to the other two equations. Figure 4.18 to 4.20 and 4.24 show the relationship between the calculated sediment load using this equation in ton per day against the corresponding discharge in cumec. Best-fit lines are drawn for those data. From this relationship, equations relating to computed sediment and discharge are established for the selected years. The coefficient of correlations are found to a value of 0.919 (1975), 0.456 (1989) and 0.922 (1999). The regression equations are found as follows:

$$Q_{s\,(cal)} = 0.977\ Q^{1.383} \tag{5.4}$$

$$Q_{s\,(cal)} = 15.593\ Q^{0.675} \tag{5.5}$$

$$Q_{s\,(cal)} = 0.3948\ Q^{1.461} \tag{5.6}$$

Where $Q_{s\,(cal)}$ denotes the calculated sediment load in ton/day, Q for the water discharge in cumec and 'R' is the coefficient of correlation. It can be mentioned that

the Q_s obtained from this equation is well correlated with Q for the Surma river. The mean discrepancy ratios are 0.646 (1975), 3.152 (1989), 0.34 (1999) and are shown in Table 4.21 to 4.23 respectively.

5.3.3 van Rijn's Equation

Using this equation, computed sediment load in ton/day against the discharge in cumec for the selected years are plotted and presented in the Figure 4.18 to 4.20 and 4.24 respectively. Output of this equation for bed load and suspended loads for the years 1975, 1989 and 1999 are shown in the Table 4.15 to 4.20 respectively. Relationships are established between computed sediment load and observed discharge for the year 1975, 1989 and 1999 and coefficients of correlation are noted to vary in the range of 0.408 (1975), 0.340 (1989) and 0.922 (1999). The developed regression equations are as follows:

$$Q_{s\,(cal)} = 19.787\ Q^{0.7576} \tag{5.7}$$

$$Q_{s\,(cal)} = 21.523\ Q^{0.6328} \tag{5.8}$$

$$Q_{s\,(cal)} = 0.0006\ Q^{2.428} \tag{5.9}$$

where, $Q_{s\,(cal)}$ represents calculated sediment load in ton/day, Q expresses the water discharge in cumec and 'R' is the coefficient of correlation. The mean discrepancy ratios are 0.953 (1975), 4.032 (1989) and 0.268 (1999) and are shown in the Table 4.21 to 4.23.

5.3.4 Comparative Study of the Sediment Predictors

Investigation of the previous studies (Ahmed '1996) and (Kamrunnessa '1994) about the performance of the different sediment predictors on various rivers of Bangladesh suggests that Yang's formula gives lower values, Engelund-Hansen's equation predicts significant values, Ackers-White's and van-Rijn's formulas are found suitable for predicting sediment loads. From this consideration, in order to examine the suitability of the sediment predictors three well known equations such as Engelund-Hansen's formula, Ackers-White's formula and van Rijn's equation were selected for this study of sediment transport of Surma river.

Engelund-Hansen's formula gives significant values for the year 1975 and 1999 except the year 1989. Actually, this equation was derived using sediment size 0.93 mm on a small flume and the author recommended that this equation should not be applied for the cases where d_{50} (median size of the sediment) is lower than 0.15mm. Now, for this present study, the d_{50} of the bed material is considered as 0.20 mm from the specialist report of FAP-6. Again, the gradient of the river Surma is considered, as 4 cm per Km. Furthermore, the hydraulic radius computation might be not very accurate. These may be the probable reasons of the difference between the computed sediment load and the measured sediment load.

Ackers-White's equation gives better result closely to the measured sediment loads. Except, 1989, the computation of the other two years (1975 and 1999) gives good result. The probable reasons behind the difference between the computed and measured sediment load can be summarized as follows:

- this equation is highly dependent on particle mobility factor and sediment parameter. Again, these two parameters depend on hydraulic radius (R), d_{50} and river gradient (S).

- Erroneous computation of d_g, d_{50}, 'R' and 'S' may alter the result remarkably.

On the other hand, van Rijn's formula is a very recent formula. The application of this formula in other rivers (Ahmed '1996) was found excellent. Except, 1989, the other two years' results are found well. River flow velocity has a significant influence on this equation. The interesting feature is that when the flow velocity falls below 0.33 m/s, this formula couldn't predict sediment load. In the year 1999 and 1975, several values of the flow velocity were below 0.33 m/s and this predictor didn't show any value. Furthermore, this equation contains two parts such as bed load and suspended load computation and it needs d_{50} both for the bed load and suspended load separately. But, use of same d_{50} computed for the bed load in calculating the suspended load may be one of the source of error. Besides, values of these parameters like the d_{84} and d_{16}, d_g, d_s, W_s, K_s needs to be considered accurate data and calculation procedure.

Indeed the expressions of equivalent roughness given by the different investigators are for plane bed based on grain roughness only and practically a complete plane bed

does not exist. So they have comparatively less contribution to the sediment computation. On the contrary, van Rijn considered the bed roughness consisting of grain as well as form roughness, which is practically possible. Realistic result could be obtained from van Rijn's equation if the flow velocities are higher than 1m/s. Again, this formula consists of a number of separate functions which can be individually adapted according to different conditions. However, this formula is considered to be a reliable predictor in flows with bed material in size range of 100-500μm.

Assembling the data for the years 1975, 1989 and 1999, a broad-spectrum relationship between the observed discharge and calculated sediment load was established as follows:

Considering Engelund Hansen's Formula,

$$Q_{s\,(cal)} = 5.496\ Q^{0.936};\ R^2 = 0.854 \tag{5.10}$$

Considering Ackers White's Formula,

$$Q_{s\,(cal)} = 1.098\ Q^{1.296};\ R^2 = 0.829 \tag{5.11}$$

Considering van Rijn's Formula,

$$Q_{s\,(cal)} = 6.04\ Q^{0.9407};\ R^2 = 0.494 \tag{5.12}$$

where, $Q_{s\,(cal)}$ represents calculated sediment load in ton/day, Q expresses the water discharge in cumec and 'R' is the coefficient of correlation. Relationship between the observed sediment load and observed discharge at Sylhet was developed using the data for the year 1970 to 1989 and also for the year 1999 (Figure 4.24). The developed equations are as follows:

$$Q_{s\,(obs)} = 2.859\ Q^{1.2258};\ R^2 = 0.942\ \ (1970\text{-}1989) \tag{5.13}$$

$$Q_{s\,(obs)} = 3.108\ Q^{1.297};\ R^2 = 0.949\ (1999) \tag{5.14}$$

where, $Q_{s\,(obs)}$ represents the observed sediment load in ton/day, Q expresses the water discharge in cumec and 'R' is the coefficient of correlation.

Total sediment load moved through the station Sylhet of the river Surma per annum for the year 1975, 1989 and 1999 was computed and presented in the Table 4.5. The

annual sediment load at Sylhet station was found 2.776 MT (1975), 3.121 MT (1989) and 3.0971 MT (1999). However, annual sediment load computed from Engelund Hansen's equation was 0.699 MT, 0.784 MT and 0.697 MT in the year 1975, 1989 and 1999 respectively (Table 4.5). The average value found from that equation is 0.727 MT per annum.

Ackers White's equation gave total sediment load 1.716 MT (1975), 1.969MT (1989) and 1.768 MT (1999) per annum. The annual average sediment load computed from this equation was 1.818 MT.

The computation of van Rijn's formula gave the annual Total sediment load as 0.797 MT (1975), 0.893 MT (1989) and 0.794 MT (1999). The annual average sediment load obtained from this equation was 0.828 MT. Hence, it can be summarized that out the three sediment predictors Ackers White's formula is found to be well suited against the data of the river Surma.

5.4 Relationship Between Measured Sediment Load and Velocity

Relationship between the observed sediment load and velocity were developed for the year 1975, 1989 and 1999 at the station Sylhet of the river Surma. In logarithmic scale, the roughly fitted straight line (from power trend line) was found (Figure 4.23). The regression coefficients are 0.5616 (1975), 0.1746 (1989) 0.256 (1999) and 0.569 (1975-1999). The regression equations for these are as follows:

$$Q_{s\,(obs)} = 11649\ V^{3.491}\ (1975) \tag{5.15}$$

$$Q_{s\,(obs)} = 2797.6\ V^{3.402}\ (1989) \tag{5.16}$$

$$Q_{s\,(obs)} = 2218.3\ V^{2.527}\ (1999) \tag{5.17}$$

$$Q_{s\,(obs)} = 8486.8\ V^{3.093}\ (1975\text{-}1999) \tag{5.18}$$

From all these equation it could be predicted that with the increase of the velocity, the sediment movement would be increased.

5.5 Discharge and Velocity Relationship

Discharge in cumec against the flow velocity in m/s were plotted to develop a relationship for the year 1975, 1989 and 1999 using the data of Sylhet of the river

Surma (Figure 4.25) and the following regression equations were found:

$$Q = 538.2\ V^{2.527} \tag{5.19}$$

The coefficient of regression was found as 0.613. Here Q represents the observed discharge in cumec, V denotes the flow velocity in m/s and 'R' is the coefficient of correlation. From the relationship it was found that flow velocity would be increased with the increase of discharge.

5.6 Planform Study

In order to obtain superimposition (Photograph 12) of the Satellite images (Photograph no 10 and 11) of the Surma river for the year 1997 (30 m interval) and 2002 (6 m interval), digitization of a small reach at Kanaighat was performed with the help of the Arc View software. As a result, superimposition of Satellite images shows that the change of planform of this river is not significant over the last five years period (1997-2002). But it is visualized that the river has become comparatively narrower. Only five years' interval data (Image) is not sufficient enough to make meaningful prediction about the planform changes for the more or less stable and small river like Surma.

5.7 Bank Protection study

The implemented bank protection works starting from Kazirbazar to Mollapara (Photograph 1 to 9) was taken under study. Geotechnical investigation of the collected sediment samples from the right bank of the river Surma at Kazirbazar was performed. It was observed that the sample is silty clay and 95.6 % of the sample passed the no. 200 sieve. Again, 94 % particle is smaller than 0.06 mm. The uniformity coefficient was 17, ratio of clay to silt is 0.17 and the plasticity index was 18 (Table 4.25 and 4.26). Comparing to the (PIANC'1987) criteria, it was found that the sub soil of the protection works is susceptible to down slope migration (Table 4.26). To prevent this, a granular layer should be placed below the protective layer of the revetment (BRTC-BUET '2002).

A detailed calculation of the revetment design is presented in the Appendix. An index map of the bank protection works is shown in Figure4.28 (BRTC-BUET '2002). Again, implemented bank protection's design lay out is presented in Figure 4.29 (BRTC-BUET '2002).

As the river Surma is a minor and flashy river so 70% of the highest discharge was considered. The size of boulder should be larger than 186 mm considering against the velocity. Since the fetch of wind-generated wave is only 1 to 2 km, so, size against the wave was not considered (BRTC-BUET '2002).

According to the Inglish (1949) formula, the revetment thickness should be 678 mm. Design depth of scour below the LWL should be 4.00 m. Volume of stone required should be 7.70 m^3/m. The inside and outside thickness of the unlaunched apron should be 1000 and 1500 mm respectively.

If, Cement Concrete blocks are considered for the revetment then, the following measurements should be used:

Dimension $150mm \times 150mm \times 150mm$; required volume = 1.7 m^3/m.

The geotextile should be: effective opening size O_{90} $\langle$ 0.022 mm. And the permeability of the geotextile should be $=9.8*10^{-7}$ m/s (BWDB, Design Manual '1993). After performing several field visits to identify and evaluate the existing condition of the implemented bank protection works, the pictorial view of the findings are presented in the Photograph no 01 to 09.

The implemented design of the BWDB was checked and found that they didn't examine the grain size distribution regularly rather than considering the thumb rule. For this they used to perform over design to make factor of safety within in acceptable limit. However, the design procedure is satisfactory and the implementation was also good but the maintenance works is remarkably poor. For this reason, in spite of having sufficient suitability and effectiveness, the protection works couldn't sustain for a long time.

By arranging random field visits it was observed that the boulders were not in the right places. Some were misplaced and some might be washed out. Again, the inhabitants of the community located at the river-side took away some boulders for their personal purposes. In addition to that the compaction works done at the time of implementation of the bank protection works was probably not satisfactory. The placing and grading of the stone was not appropriate. More over, the maintenance works were not happened in time. The responsible authority may be reluctant about the timely maintenance of the protection works.

On the other hand, several road-side shops, refuse dumping places and boat and launch ghats are found on the bank protection works. These types of human activities are partly responsible for damaging the bank protection works, which should be taken care immediately by the responsible authority.

CHAPTER SIX

CONCLUSIONS & RECOMMENDATIONS

6.1 Conclusions

The following conclusions can be drawn from this study:

1. It is observed that up to 1989 the river Surma becomes wider and shallower. After that, the river was becoming comparatively narrower and shallower. Over the thirty years period, thalweg of most of the sections experienced deposition. However, section no. S-36 to S-42 suffered the remarkable rise of thalweg line in recent time. However, erosion has taken place at section no. S-18 and S-31. In general, the deposition tendency in mean bed level throughout the river was also observed.

2. Due to siltation the carrying capacity of the river Surma has been reduced about 27% in 1999 compared to that of the year 1991.

3. Superimposition of satellite images shows that the change of planform of this river is not significant over the last five years period (1997-2002).

4. The discharge capacity and sediment concentration of 14 cross sections (S-29 to S-42) have been estimated using the simplified resistance equation (equation 3.1 and 3.3) and Ackers-White's sediment predictor (equation 2.2 and 2.3) respectively. Among all of the selected cross sections, the section no. S-31 has the highest discharge carrying capacity (973.22 cumecs) whereas section no. S-41 has the lowest of that (133.55 cumecs). In this regard, it can be mentioned that the bankful discharge of Surma at Sylhet is 1373.33 cumecs. Again, maximum sediment concentration has been estimated in section S-36 (1485.03 ppm) and minimum of that (214.11 ppm) has been found in the section S-41.

5. Three selected sediment transport predictors were examined against the measured sediment data collected from the BWDB. Results shows that the output of Ackers White's formula (1.768MT) was remarkably close to the observed sediment load than other two predictors. Sediment load computed from Engelund- Hansen's (0.697 MT) and van Rijn's equation (0.794 MT) underestimated the sediment load

compared with observed values (3.097 MT). The sediment rating equation (equation 5.10 to 5.14) have been developed and found good correlation for the Surma river.

6. The geotechnical investigation of the bank materials collected from the bank of the Surma at Kazirbazar of Sylhet City, shows that the bank protection works' sub soil is susceptible to down slope migration.

7. Design of protection works implemented by BWDB has been verified with available formula and found that the size of protective layers would be more realistic if they could perform proper geotechnical investigations before designing. Moreover, field inspection during dry period revealed that the protection works were partly damaged. Also, the launching apron is found to be not properly placed.

6.2 Recommendations

The following recommendations can be made from this study:

1. The present study was performed in selecting 24 out of 42 cross sections randomly for four years. For obtaining better results it is necessary to include all 42 cross sections for a more number of years.

2. The cross sectional data were discontinuous. Continuous and consistent data are needed for better analysis.

3. For morphological assessment morphological database should include all types of morphological data, e.g., cross section, sediment data and planform data in the form of satellite images.

4. Collection of wet period cross section data and updating of cross sections during discharge measurement may be considered.

5. The present study is confined with only three equations. Similar types of work could be performed taking into consideration of other sediment predictors.

6. The sediment data collection of BWDB should be more satisfactory. The database should be updated with the regular measurement of sediment data. Again, due to

unavailability of sediment data, only the station Sylhet is considered for this research. But for conducting better work, it is necessary to consider as more data as possible.

REFERENCES

Ahmed. N.M. (1989), " A Study of Some Bank Protection Works in Bangladesh", M.Engg. Thesis, Department of Water Resources Engg., BUET, Dhaka.

Ahmed, N. (1996), " Applicability of Sediment Transport Predictors in the River Jamuna by Measured Shear Velocity", M.Sc. Engineering Thesis, Department of Water Resources Engg., BUET, Dhaka.

Alam, M.K. and Hossain, M.M. (1988), " Sediment Transport in the River Jamuna", Journal of Institution of Engineers, Bangladesh, Vol, 16, No. 20, pp. 17-26.

Alhamid, A.A. and Matin, M.A. (1998), " Fluvial Stage-discharge rating of Wadi Hanifa main Channel", Journal of King Saud University., Vol. 12 Engg. Science (1), pp. 45-63.

Ashrafuzzaman, A.K.M.,(1992), 'A Study on the Geometric Aspects of the Arial Khan River', M.Engg. Thesis, Dept. of Water Resources Engineering, BUET, 1992.

Bank Protection Pilot Project FAP 21 (2001) " Guidelines and Design Manual for Standardized Bank Protection Structures", Water Resources Planning Organization, Dhaka.

Bari, M.F. and M.K. Alam (1979), Sediment transport in the Ganges, Journal of Institution of Engineers, Bangladesh, Vol. 7(4): 13-19.

Bari, F. M. and Wahiduzzaman, (1993), Nemurical simulation of sediment transport and morphological changes in rivers, International Congress on Computational Methods in Engineering, Iran, May 2-6, 1993.

Bristow, C.S., (1987), Brahmaputra River: Channel migration and deposition, The Society of Economic Paleontologists and Mineralogists, 63-74 pp.

BRTC-BUET (2002), "Technical evaluation of some selected flood protection and river erosion control works already implemented by BWDB", Final report, BWDB.

BWDB, DESIGN Manual (December, 1993) "Guide to planning and design of river training and bank protection works".

99676

Das S.K. (1992) " Study of Hydraulic Geometry of the Ganges", M.Engg. Thesis, Dept. Dept. of Water Resources Engineering, BUET.

FAP-6 (1993), Surface Water Resources of Northeast Region, specialist Study.

FAP-6 (1993), River Sedimentation and Morphology, specialist Study.

Galay, V.J., (1980), River Channel shifting on large rivers in Bangladesh, Proc. International Symposium on River Sedimentation, Beijing, China, 543-562 pp.

Garde, R.J. and Ranga Raju, K.G. (1985), "Mechanics of Sediment Transport and Alluvial Stream problems. " Willy Eastern Ltd., 2nd Edition, New Delhi.

Goswami, D.C. (1985), Brahmaputra River, Assam, India: basin denudation and channel aggradation, Water Resources Research, vol. 21 (7): 959-978

Habibullah, M. (1987), " Computer modeling of river channel changes in alluviul condition", First Interim Report, R02/87, IWFM, BUET, Dhaka.

Hossain, M.M., (1992), Total sediment load in the lower Ganges and Jamuna, Jr. Institution of Engineers, Bangladesh, vol, 20(1-2):1-8.

Inglish, C.C., (1949), the behavior and control of rivers and canals, parts I and II, research publication No. 13, Central Water and Power Research Station, Puna, India.

Isbash, S.V., Construction of dams by depositing rock in running water Trans. 2nd Cong. Large Dams Vol.5 Comm. No. US Govt. Printing Off. Washington DC, 1936.

Islam, M.M., (1996), Morphological Behavior of Jamuna River, AIT Thesis No. WM-96

Kamrunnessa (1994), " A Study on Geometric and Sediment Transport Characteristics of the River Surma", M. Engg., Project Work, Department of water resources Engineering, BUET, Dhaka.

Khan, H.R. (1975), Roughness of Coefficient for some rivers in Bangladesh, Jr. of Institution of Engineers, Bangladesh, vol. 2(4): 105-112

Khan, S.A., (2001) " Morphological Changes due to construction of a Barrage on the Teesta River", M.Sc. Engg. Thesis, Dept. Dept. of Water Resources Engineering, BUET.

Klaassen, G.J., and K. Vermeer (1988), Channel characteristics of the braiding Jamuna River, Bangladesh, Proc. International Conference on River Regime, Wallingford, England, 173-189 pp.

Matin, M.A. and Ahmed, S.M. (1984) "Rainfall Intensity-Duration-frequency Relationship for North-Eastern region of Bangladesh", Bangladesh Journal of water Resource Research, Bangladesh, Vol. 5, No. 1, pp-7-19.

Mukherjee, P. (1995), " Morphological Study of the River Brahmaputra- Jamuna", M.Sc. Engineering thesis, Dept. of the water Resources Engineering, BUET, Dhaka.

Nahar, Q. (1991), " A Numerical approach to Study Erosion-Deposition in a River Reach", M.Sc. Engg., Thesis, Department of Water Resources Engineering, BUET, Dhaka.

Nandi. B. (2002), " A Study on the Stability of C.C. Blocks as Revetment material against wave attack.

Neill, C.R. (ed.), (1972), Guide to Bridge Hydraulics, Project Committee on Bridge Hydraulics, Roads and Transportation Association of Canada.

Permanent International Association of navigation Congress (PIANC) (1987), Guidelines for the design and construction of flexible revetments incorporating geotextile for inland waterways, Report of Working Group 4, Supplement to Bulletin No. 58, Brussels.

Pilarczyk, K.W., River Training and Bank Protection, Bureau of Flood Control and Water Resources Department, Economic Commission of Asia and the Far East, Bangkok Thailand, 1973.

Rao, T.S.N., (1946), History of the Hardinge Bridge up to 1941, railway Board, Government of India, New Delhi, Technical Paper No. 318, 42-50.

Rahman, K.S. and M.K. Alam (1980), Instability of River Padma from Goalundo to Chandpur, Jr. of Institution of Engineers, Bangladesh, vol. 8 (1): 17-21.

Spring. F.J., (1903), River training and control on the guide bank system, Manager of Government Publications, New Delhi, Railway Board technical Paper No. 153

Sultana, N. (1989), "Critical Review of Sediment Transport Studies of Jamuna River", M.Engineering Thesis, Dept. of Water Resources Engg., BUET.

IWM (2001), Morphological Assessment of Rivers of Bangladesh, Final Report Phase (I & II).

Tanzeeba. S. (2002), " A Physical Model Study on Bank Protection by Revetment in a Reach of the old Brahmaputra.", M.Sc. Engineering Thesis, Department of Water Resources Engg., BUET, Dhaka.

Ullah, M.H. (1987) " Computer Modelling of River Channel Changes in Alluvial Condition", First Interim Report, R 02/87, IFCDR, BUET, Dhaka.

U.S. Army Corps of Engineers. (1991), Hydraulic design of flood control channels, Engineering and design, EM 1110-2-1601, July,

van Rijn, L.C., "Principle of Sediment Transport in Rivers, Estuaries and Coastal Area", AQUA Publications, The Netherlands, 1993.

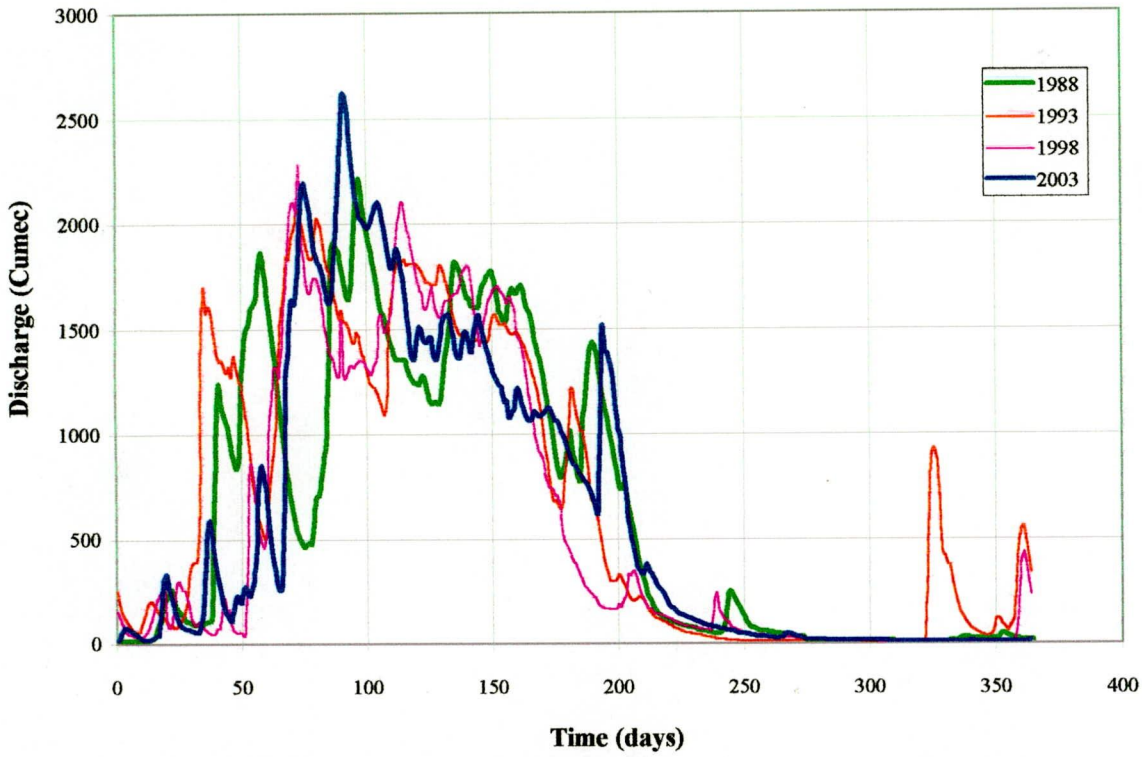


Figure 1.1: Hydrograph of the Surma river at Sylhet for Different Years

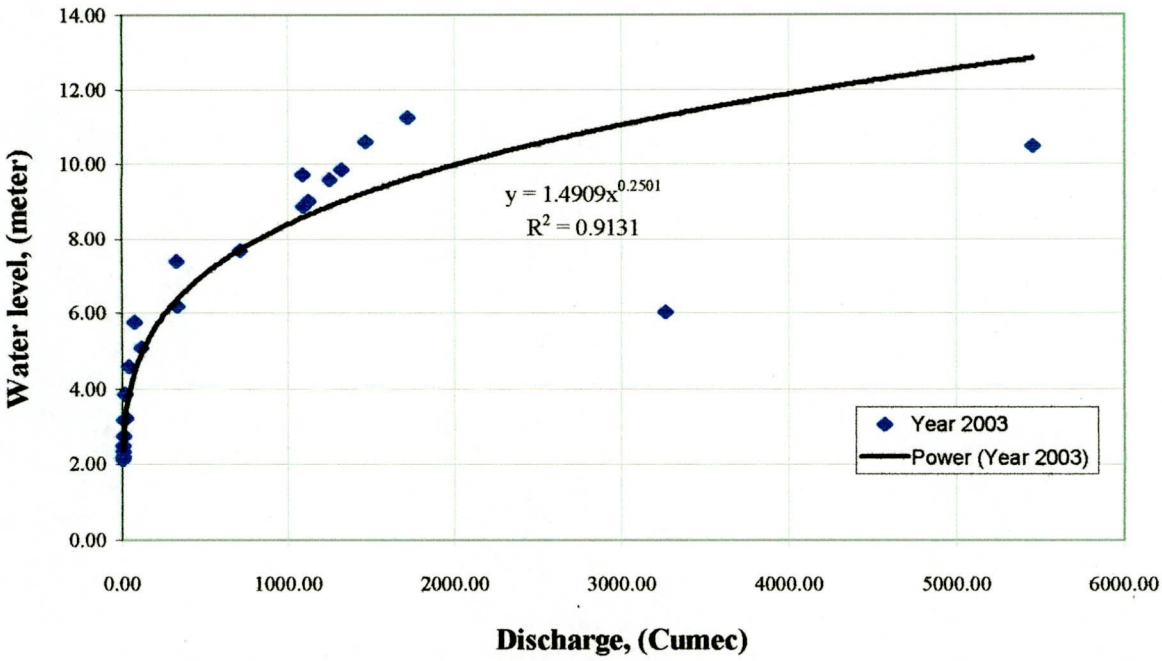


Figure 1.2: Rating Curve of Surma at Sylhet for the Year 2003

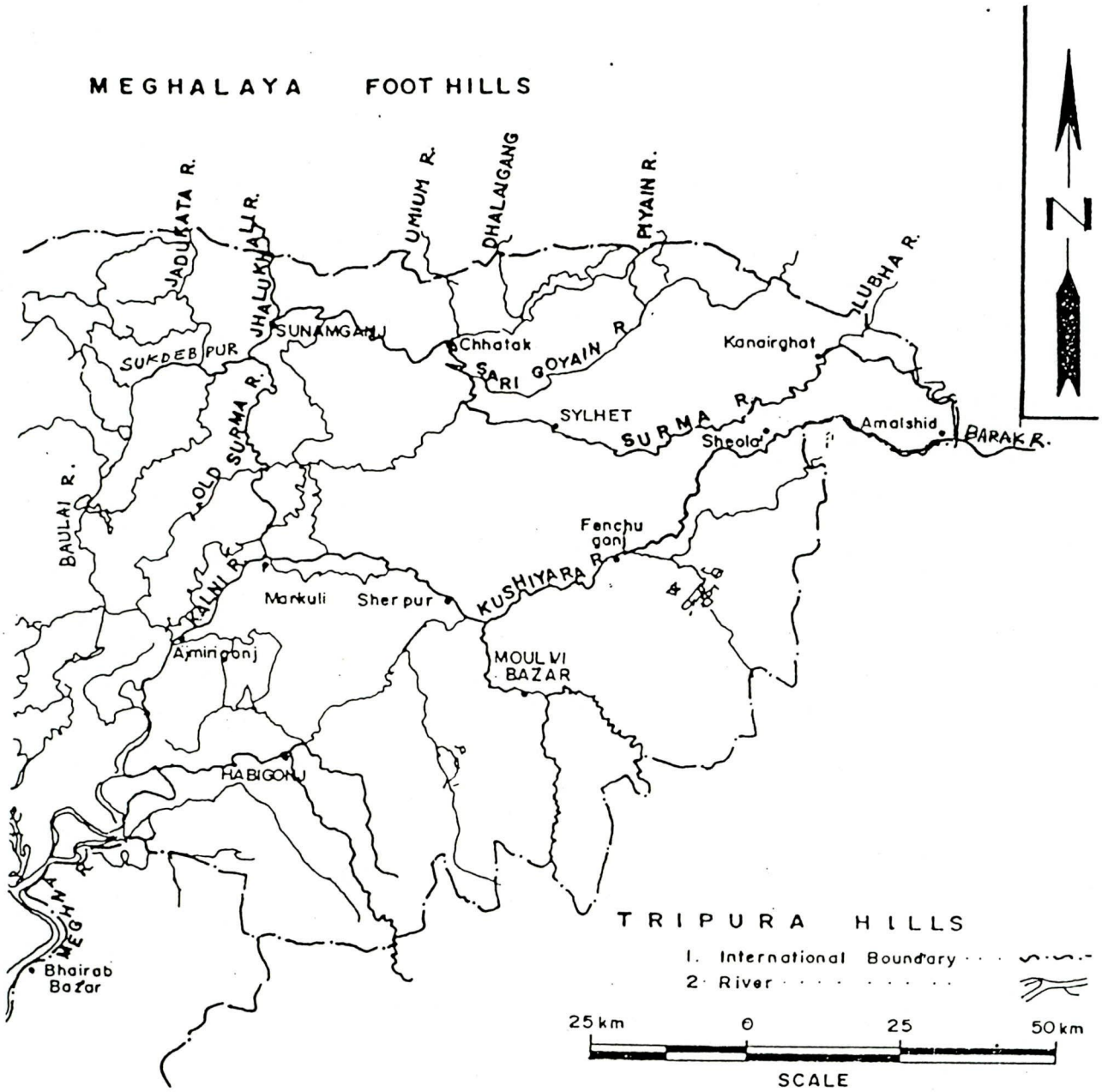


Figure No. 1.3: The Surma River System (Source: BWDB'1993)

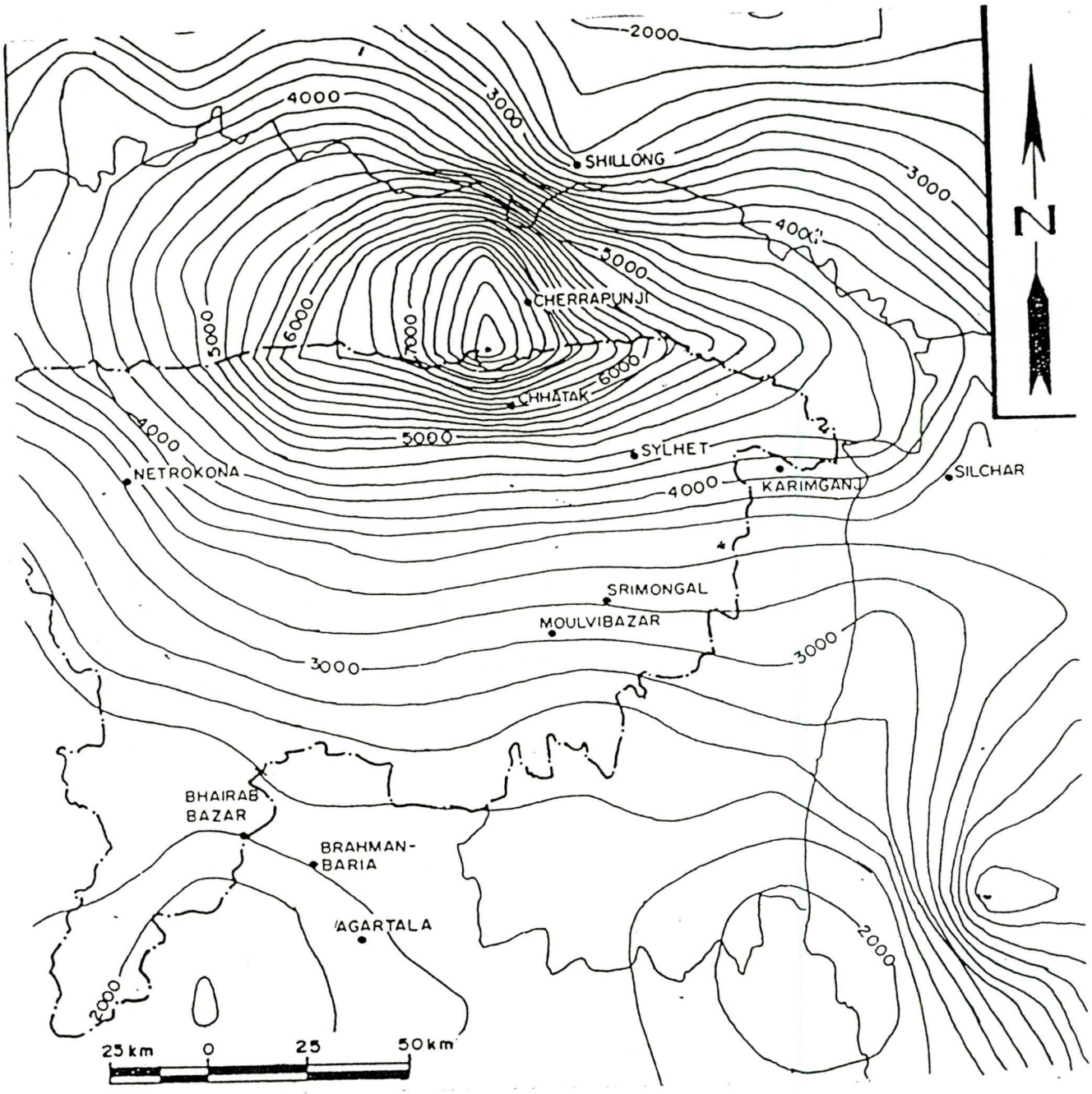


Figure No. 1.4: Annual Rainfall of Sylhet Region (Source: BWDB'1993)

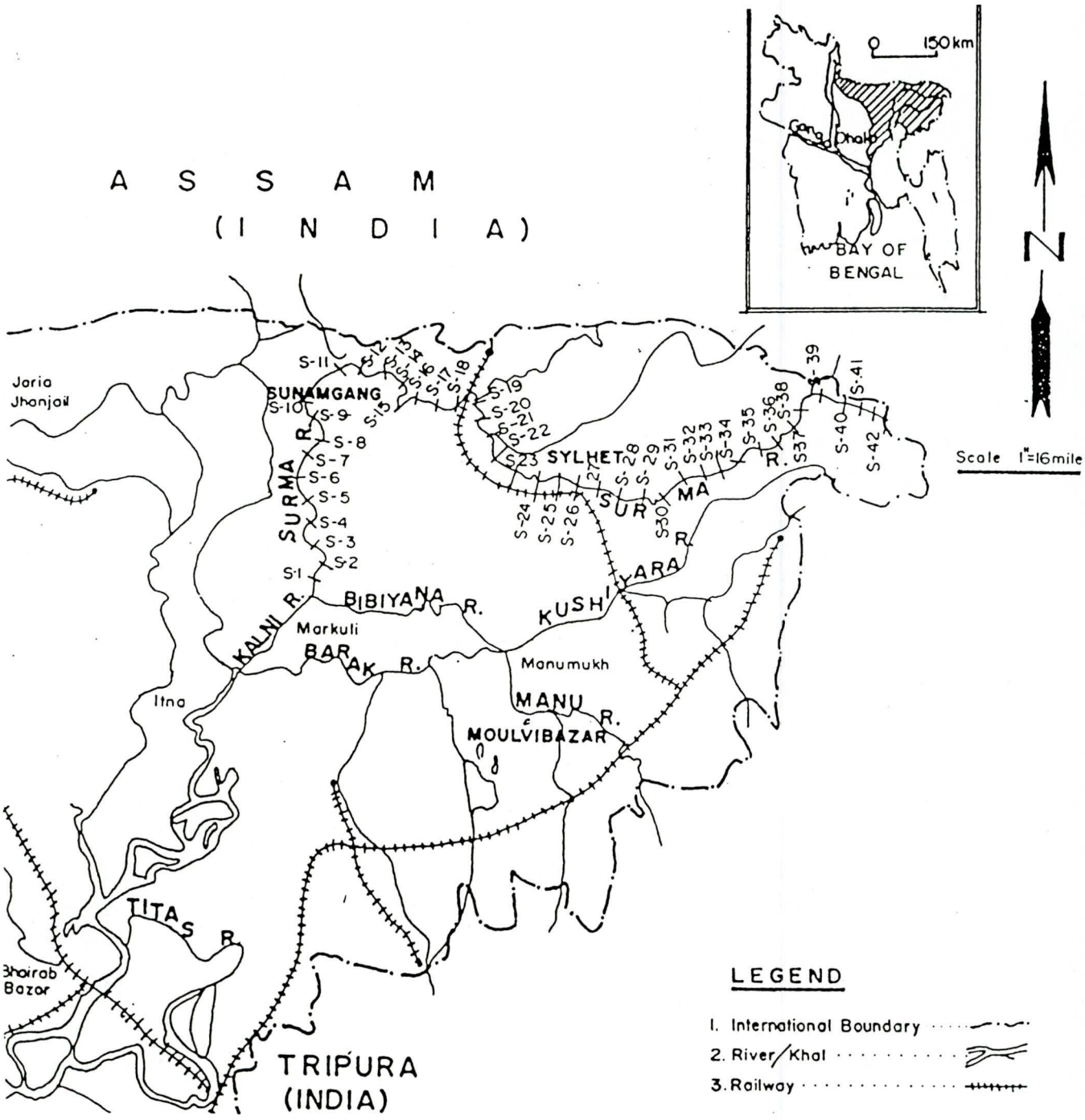


Figure No. 3.1: Cross sectional map of the Surma river (Source: BWDB'1993)

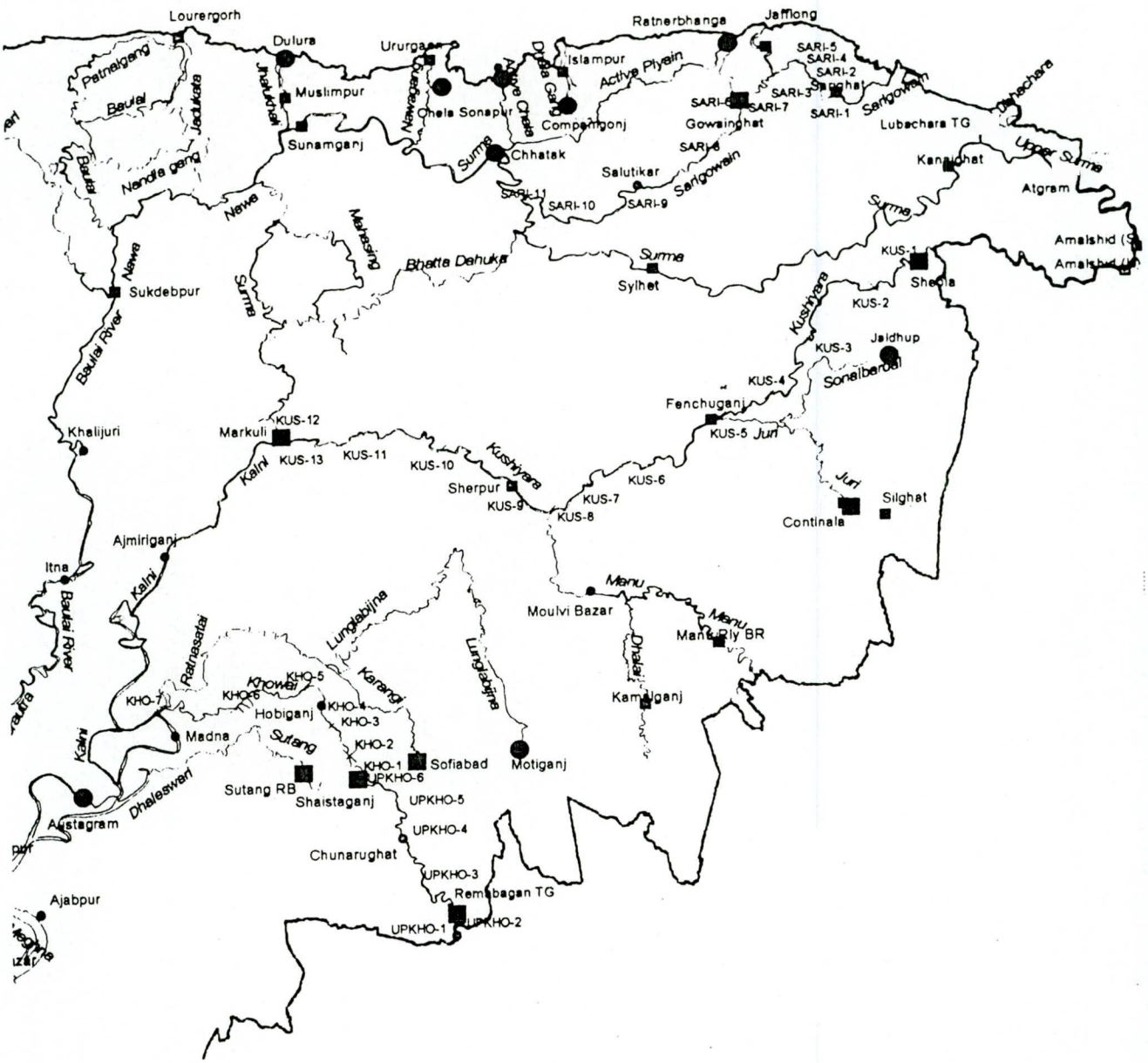


Figure 3.2: Map of the Study Area (Source: IWM '2002)

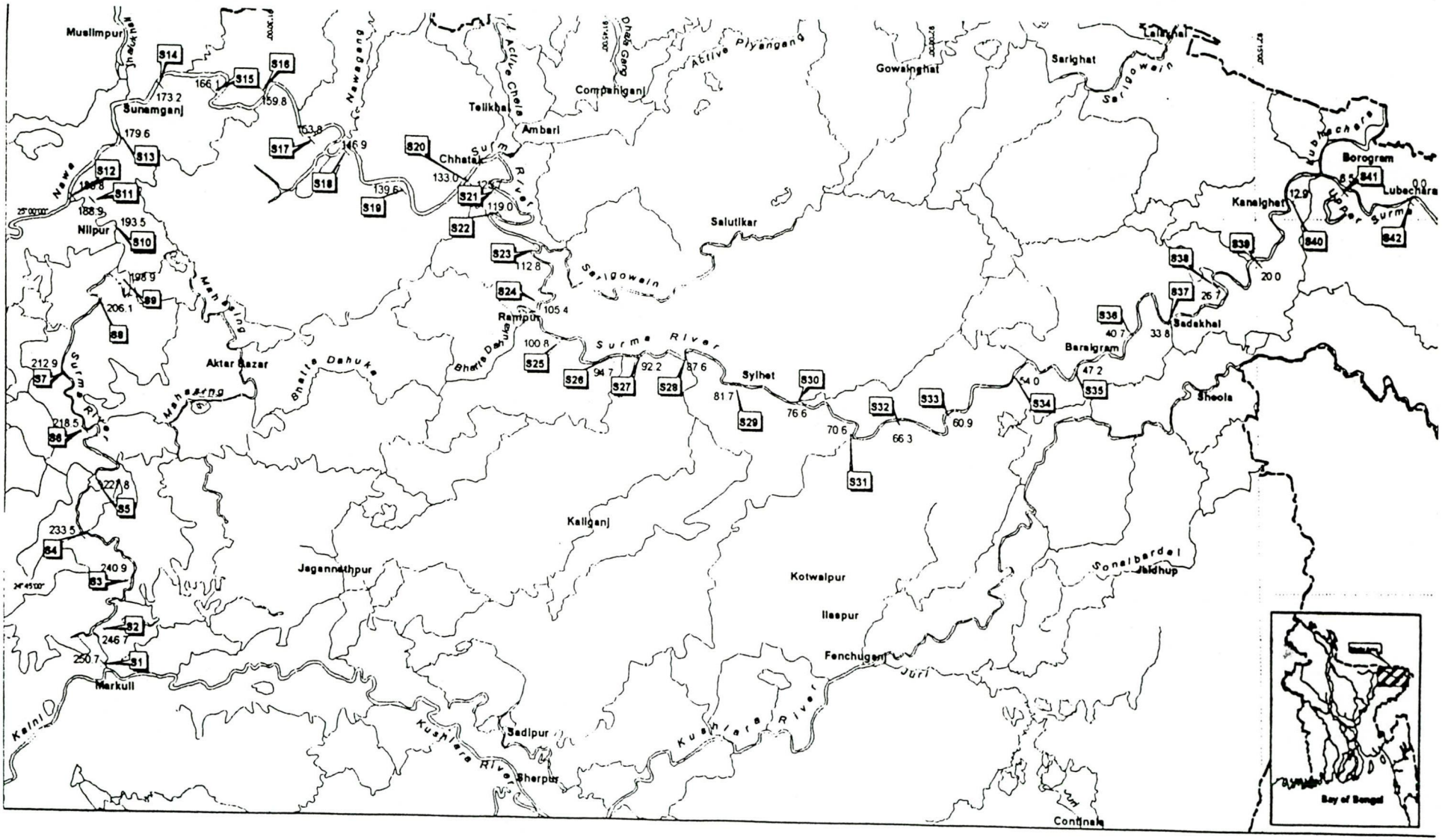


Figure No. 3.3: Index map showing cross sectional locations of Surma river (Source: IWM' 2002)

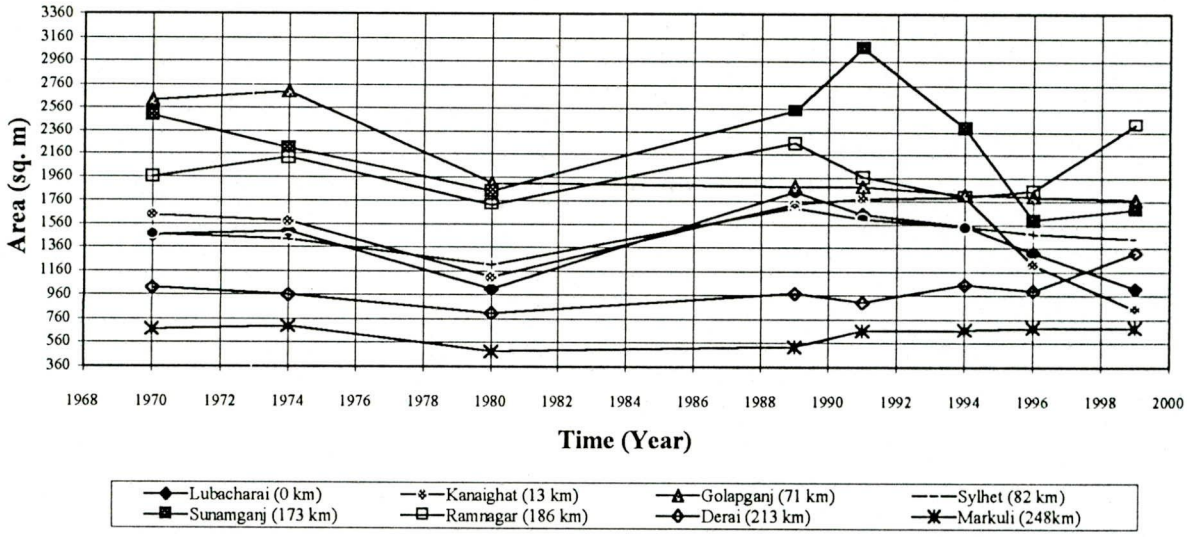


Figure. 4.1: Time Varying Cross sectional Area of Surma River at Different Locations

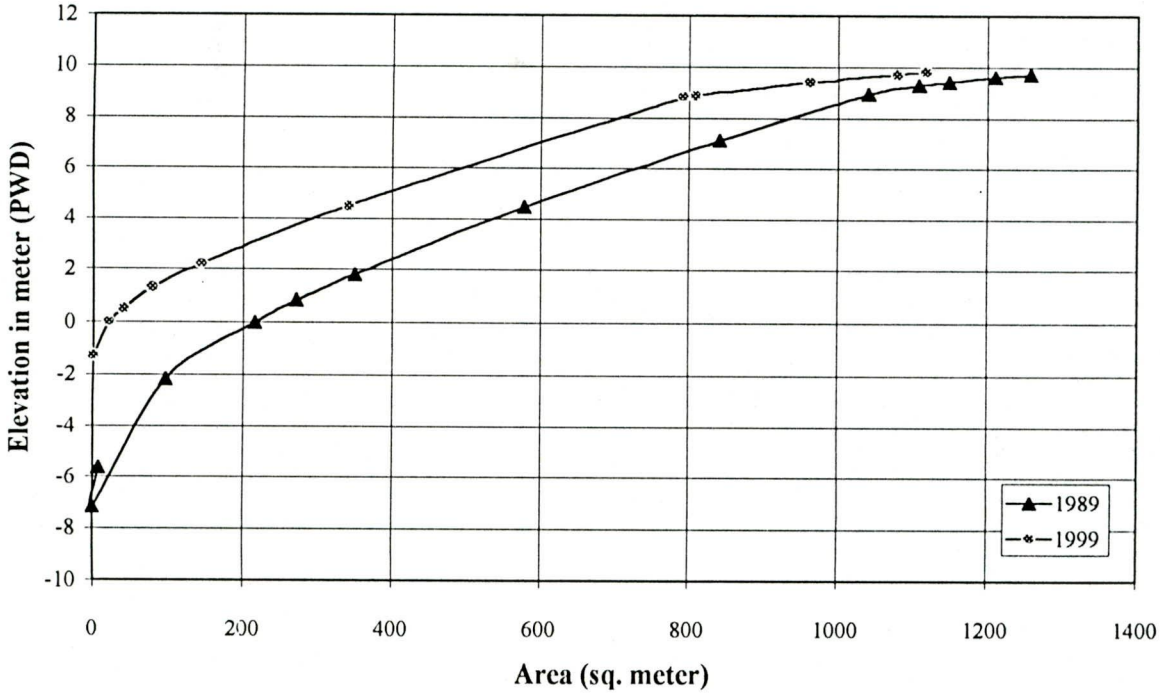


Figure 4.2: Relationship Between Area and Elevation for the Surma river at Section no. S-24

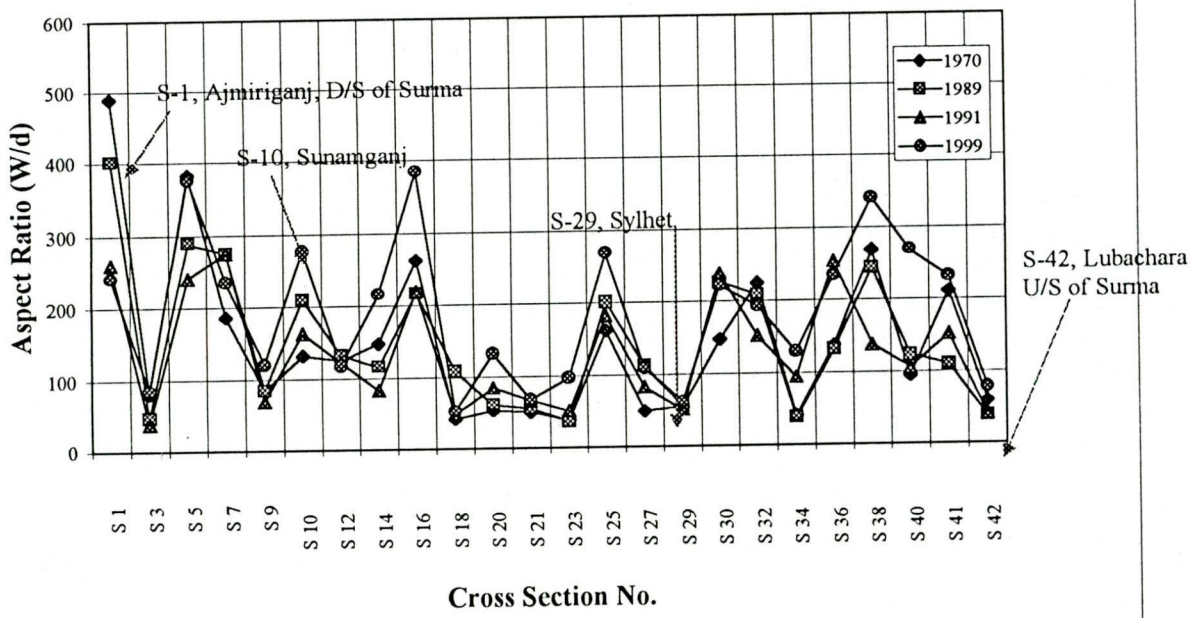


Figure 4.3: Variation of Aspect Ratio for the River Surma

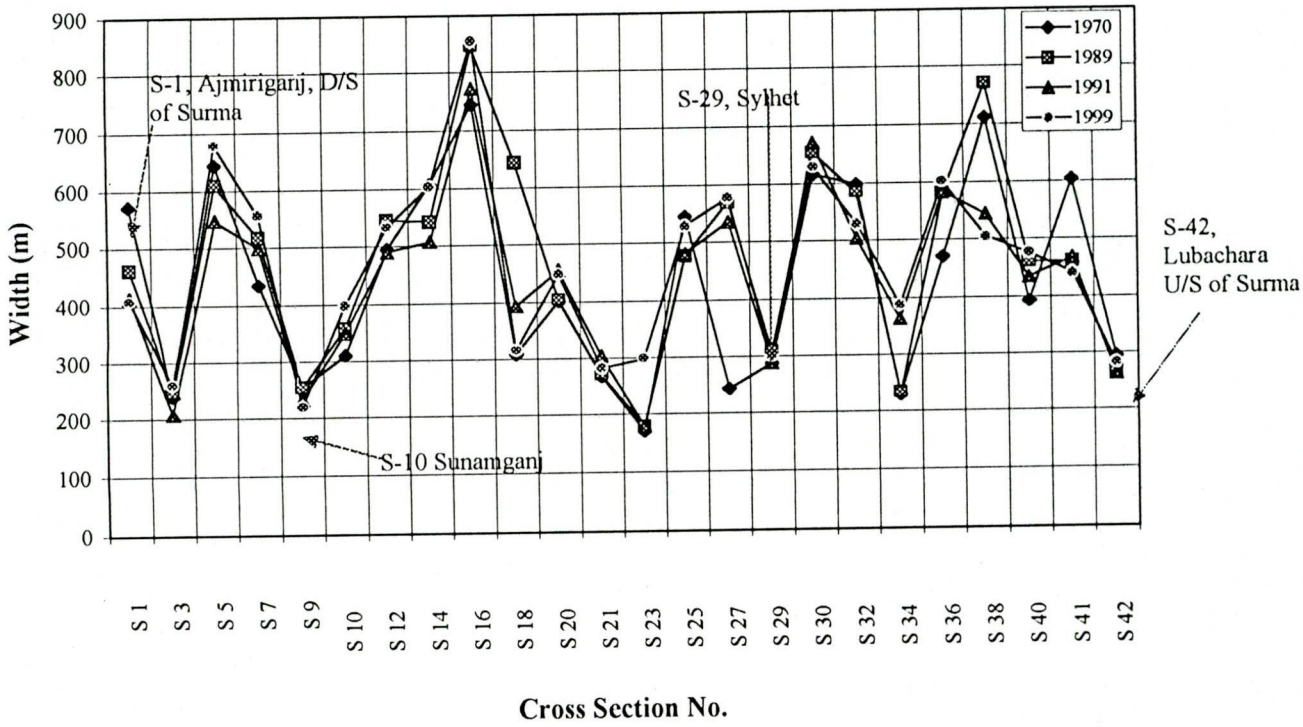


Figure 4.4 : Variation of Width of the River Surma

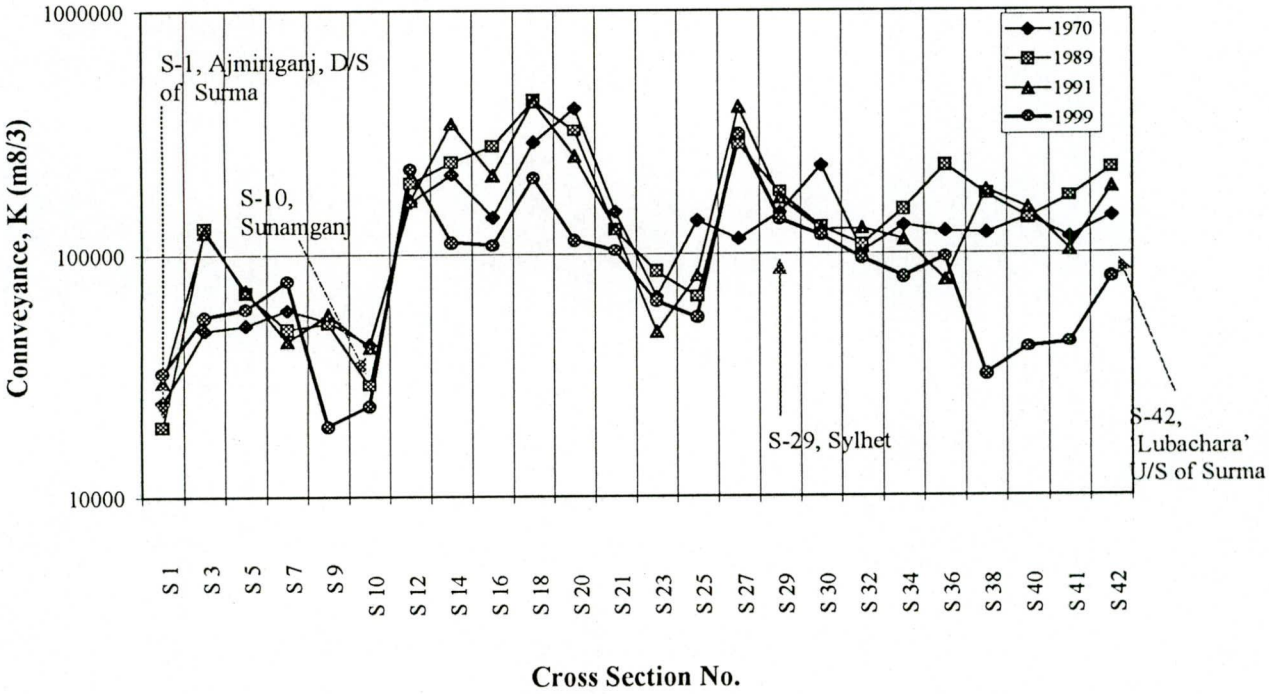


Figure 4.5: Variation of Conveyance of the River Surma

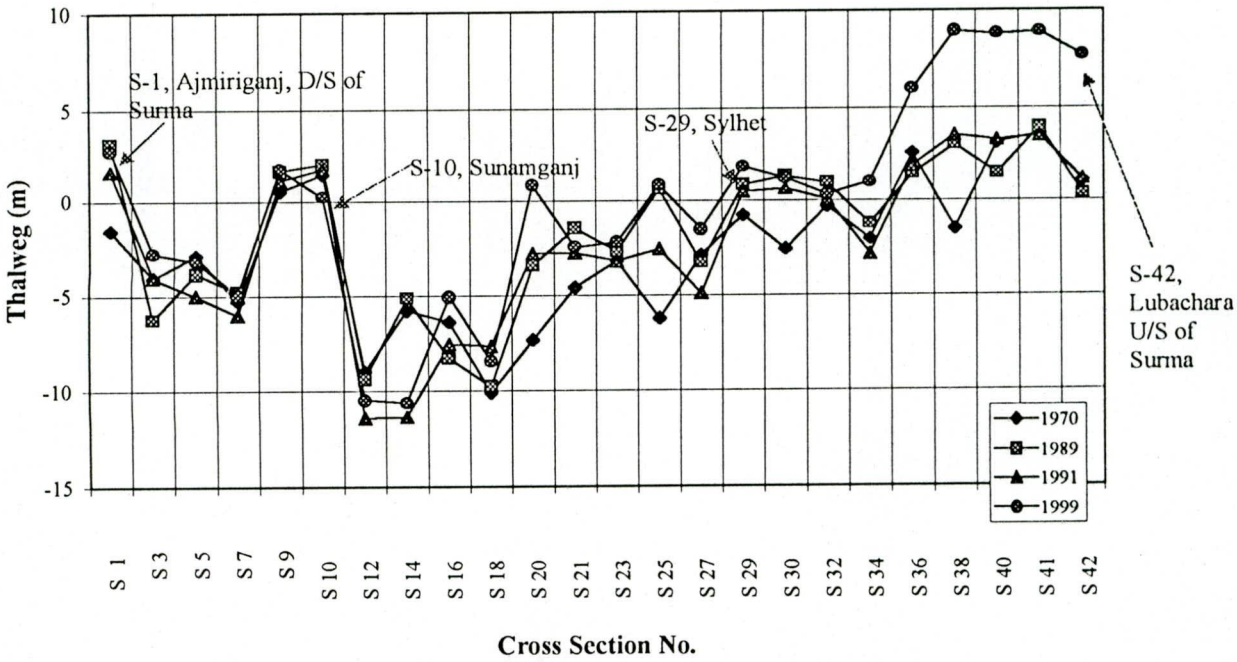


Figure 4.6 : Variation of Thalweg for the river Surma

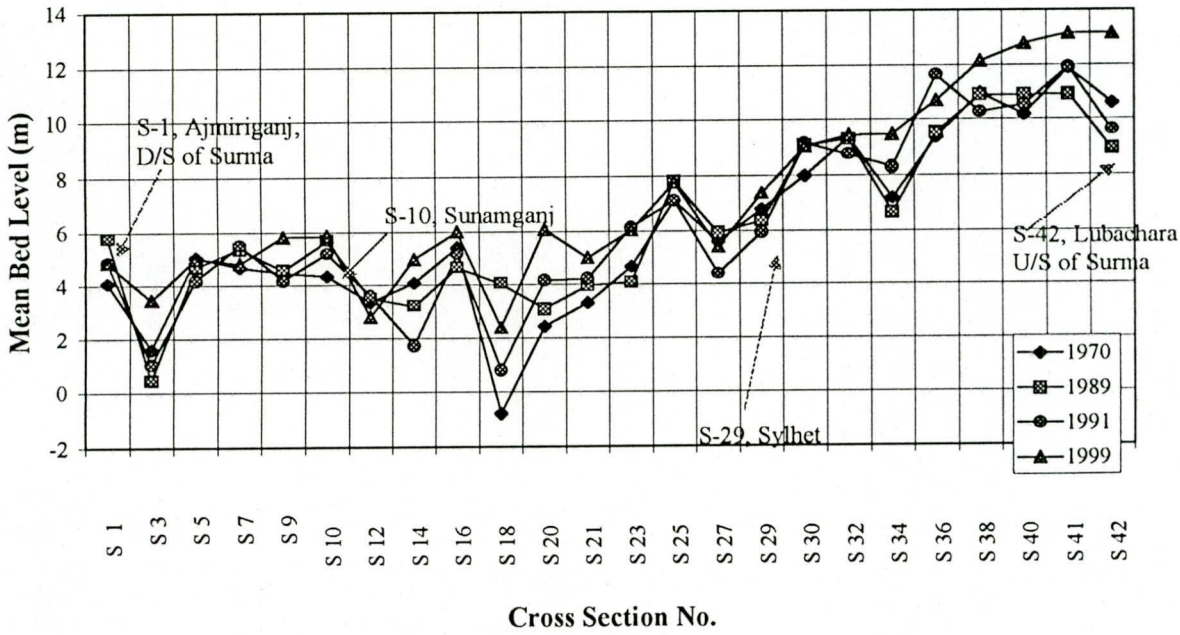


Figure 4.7 : Mean Bed Level Variation of the River Surma

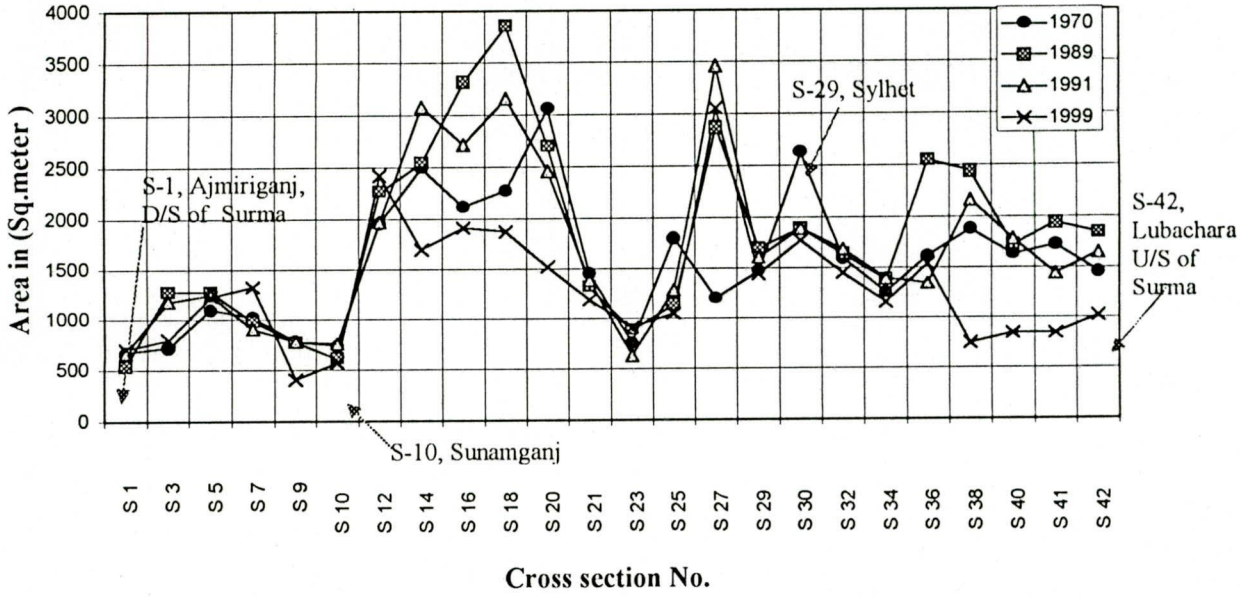


Figure 4.8 : Variation of Cross Sectional Area for the River Surma

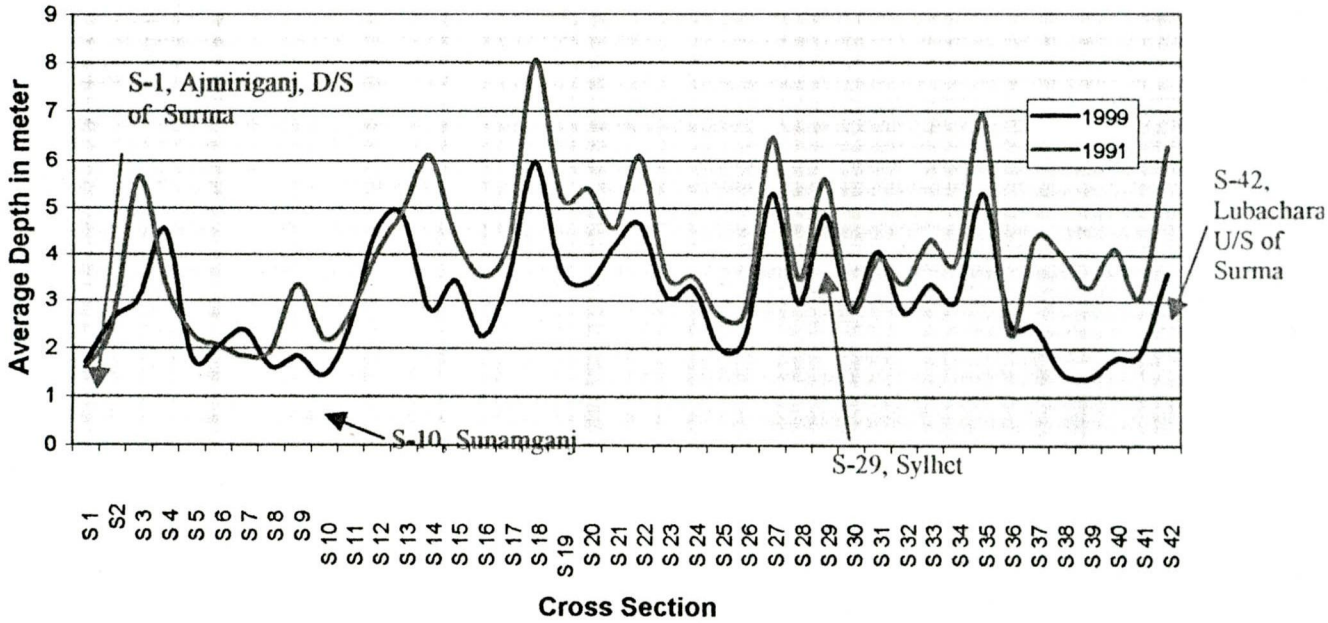


Figure 4.9 Variation in Average Depth for the river Surma

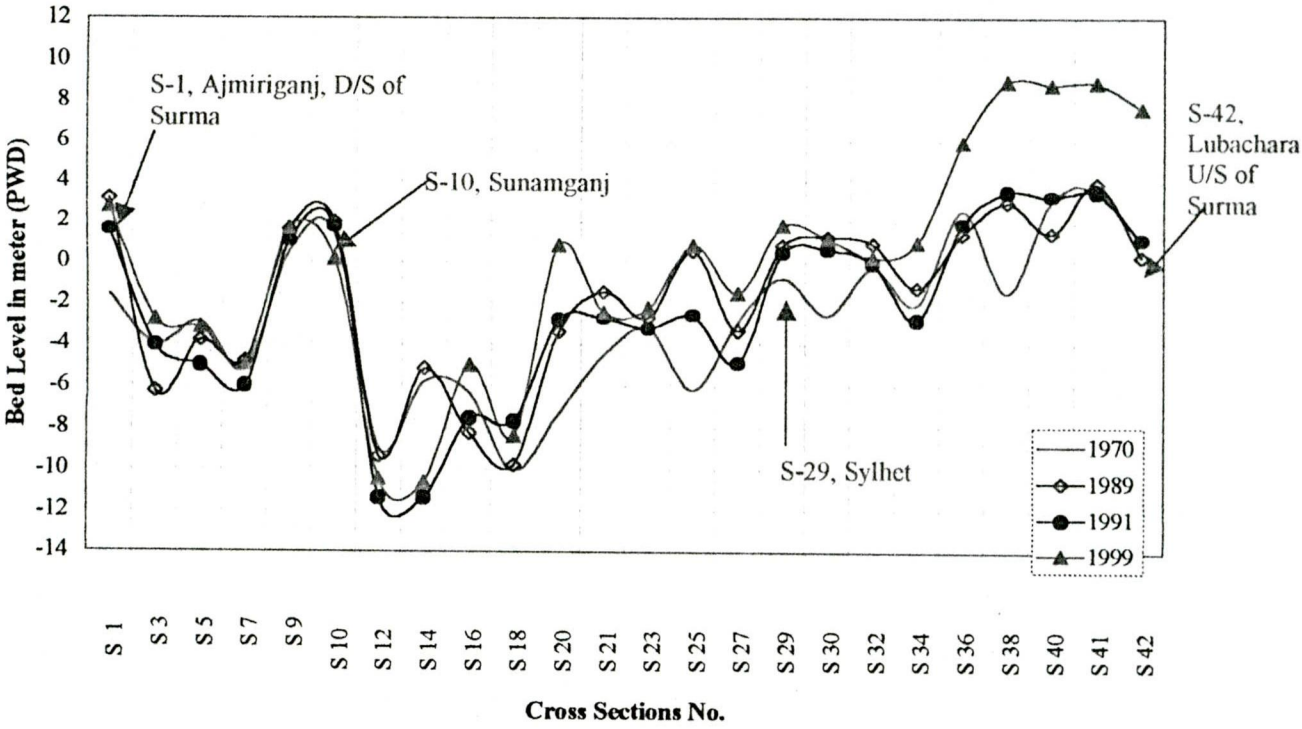


Figure 4.10: Long profile of the Surma river for different year

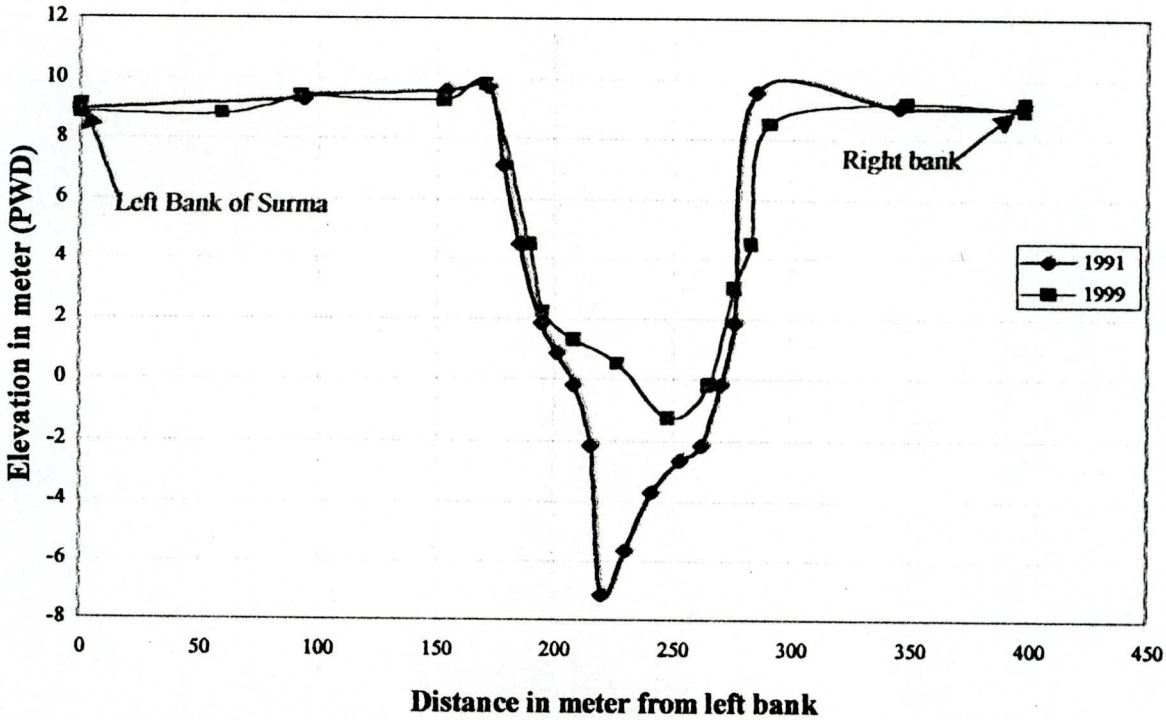


Figure 4.11: Cross sectional area of section no. S 24 of Surma river

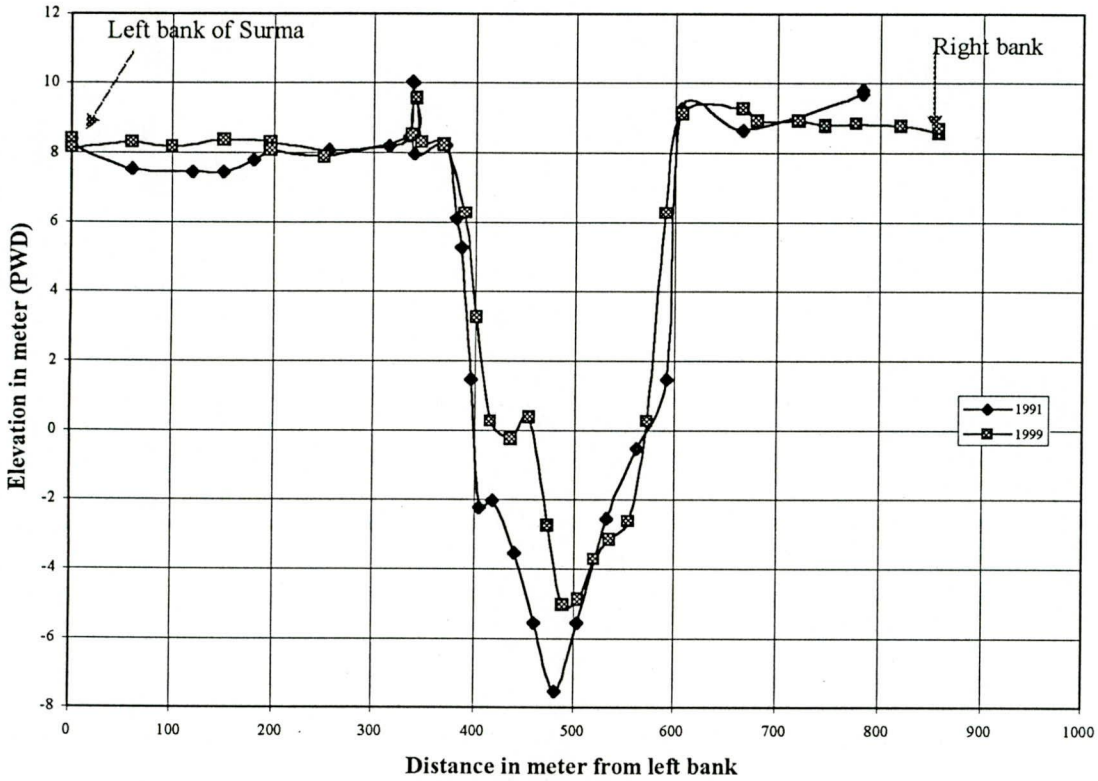


Figure 4.12: Cross sectional area of section no. S-16 of Surma river

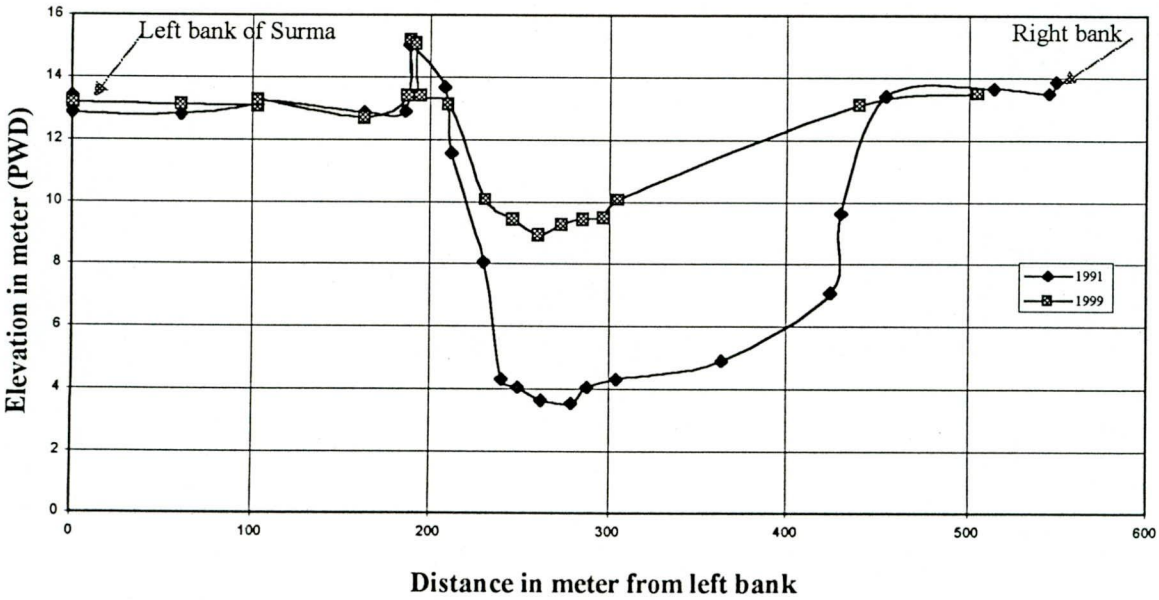


Figure 4.13: Cross sectional area of section no. S-38 of Surma river

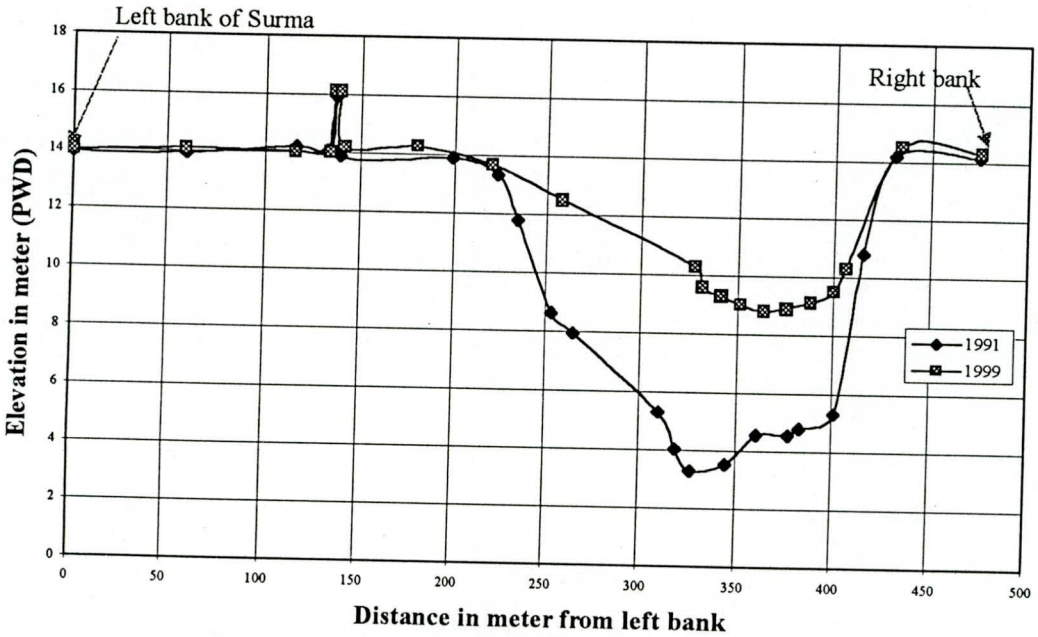


Figure 4.14: Cross sectional area of section no. S-40 of Surma river.

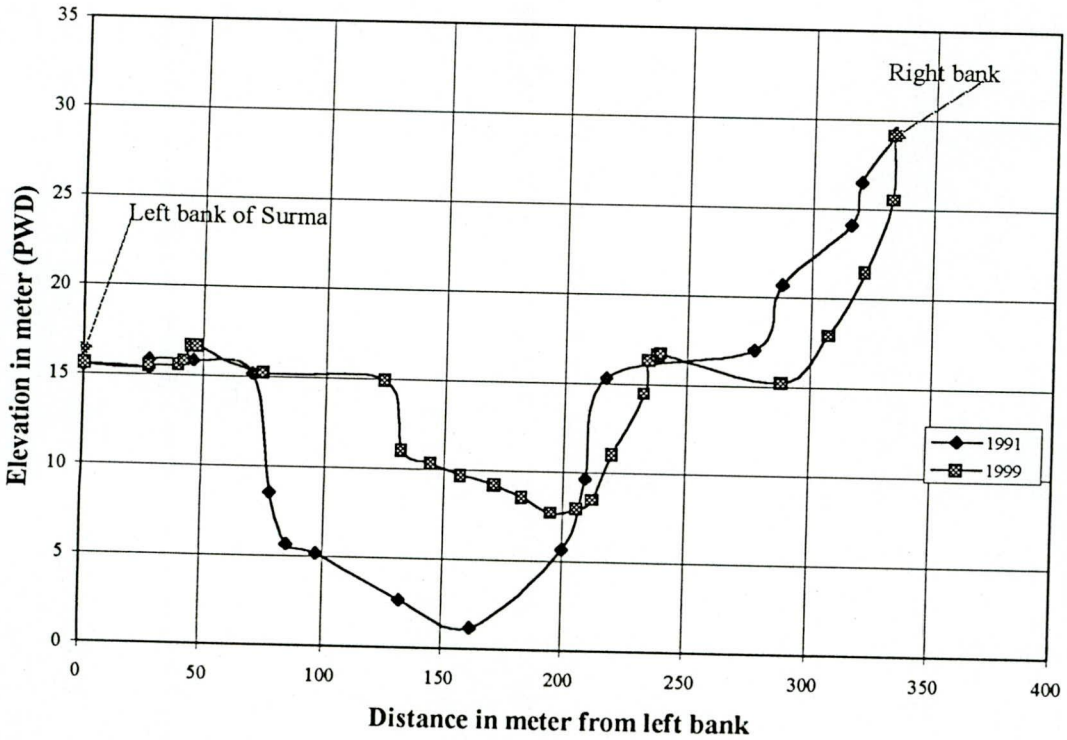


Figure 4.15: Cross sectional area of section no. S 42 of Surma river.

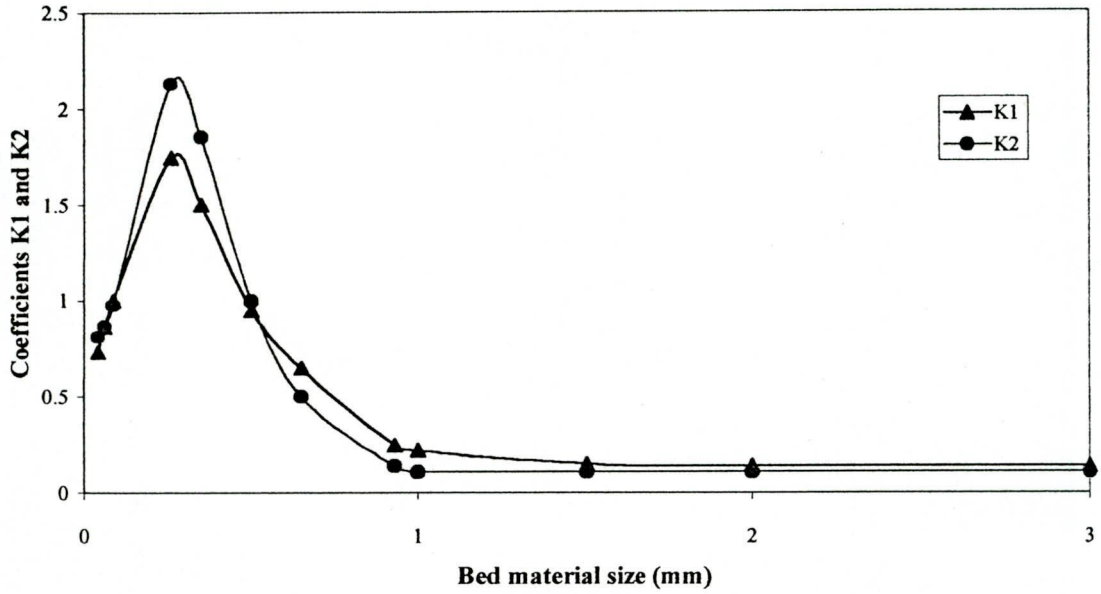


Figure 4.16 : Coefficients K1 and K2 Vs Sediment Size [Alhamid & Matin'1998]

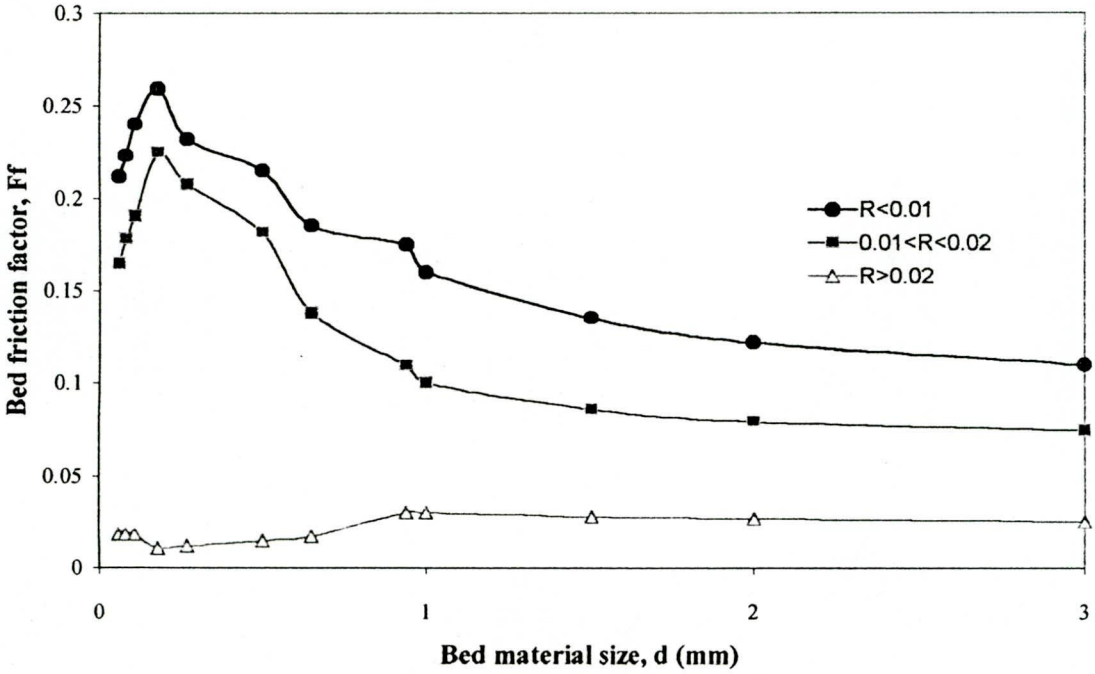


Figure 4.17 : Alluvial Resistance Factor As a Function of Sediment Size [Alhamid & Matin'1998]

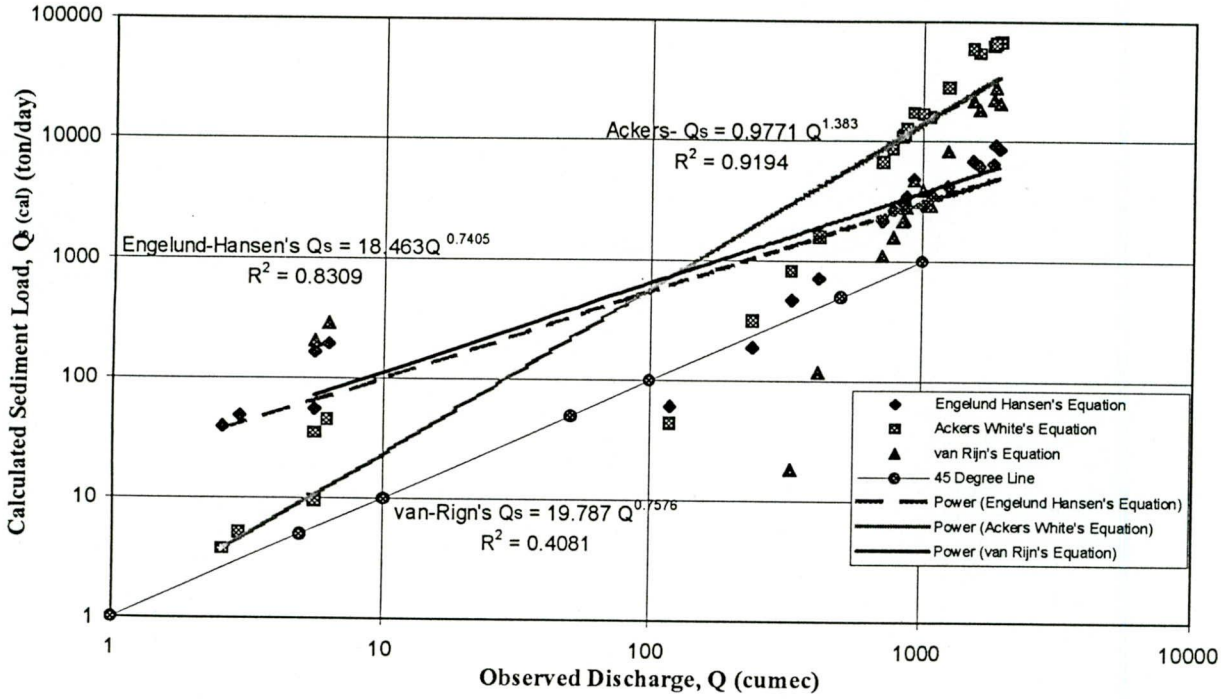


Figure 4.18: Observed Discharge Vs Calculated Sediment Load of Surma River at Sylhet in 1975

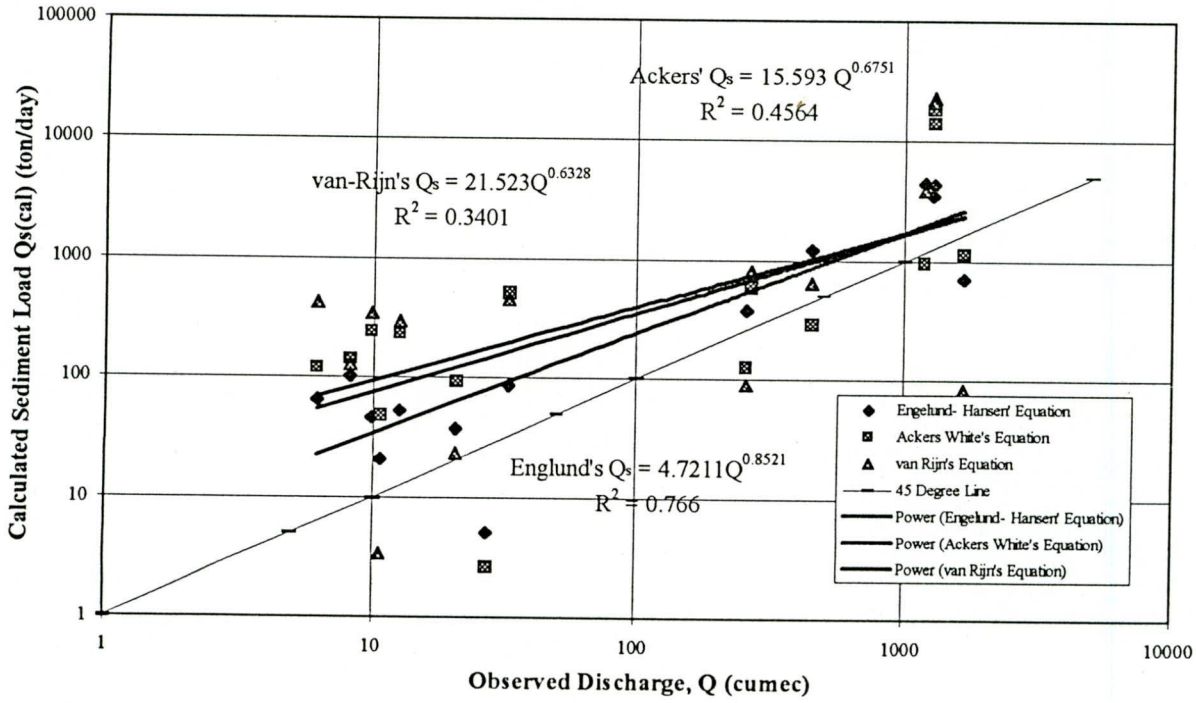


Figure 4.19: Observed Discharge Vs Calculated Sediment Load of Surma River at Sylhet in 1989

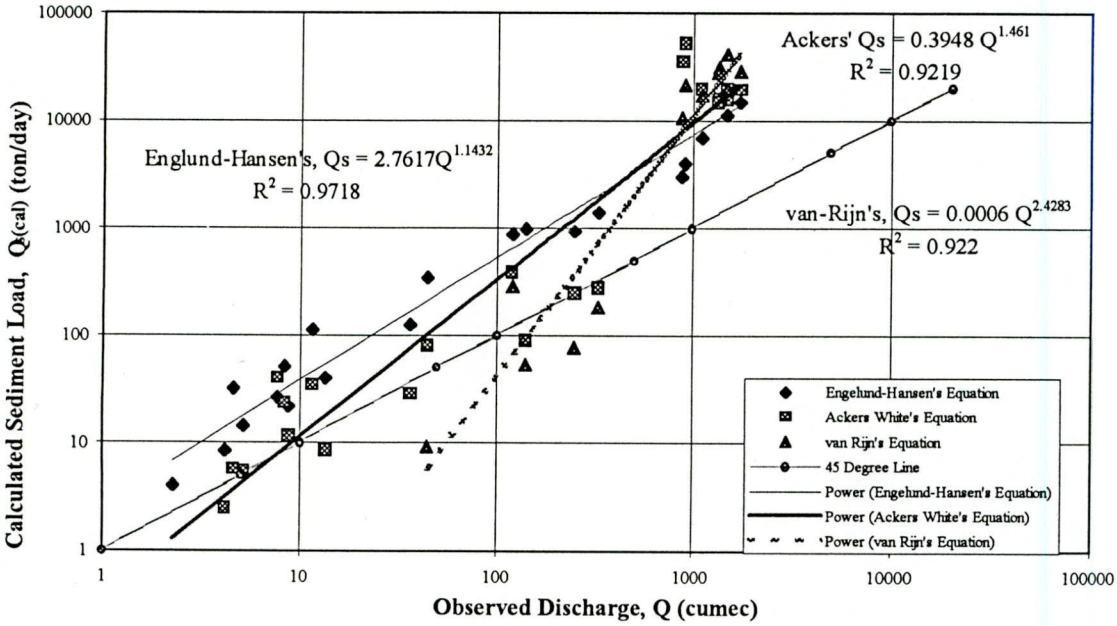


Figure No. 5.20: Observed Discharge Vs Calculated Sediment Load of Surma River at Sylhet in1999

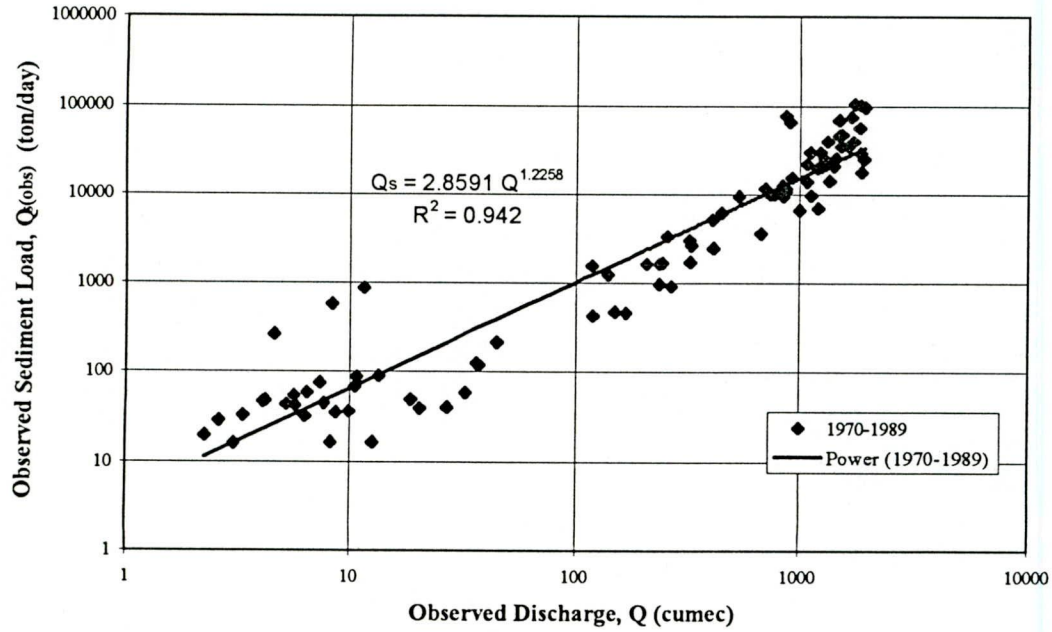


Figure No. 5.21 : Observed Discharge Vs Measured Sediment Load of Surma River at Sylhet (1970-1989)

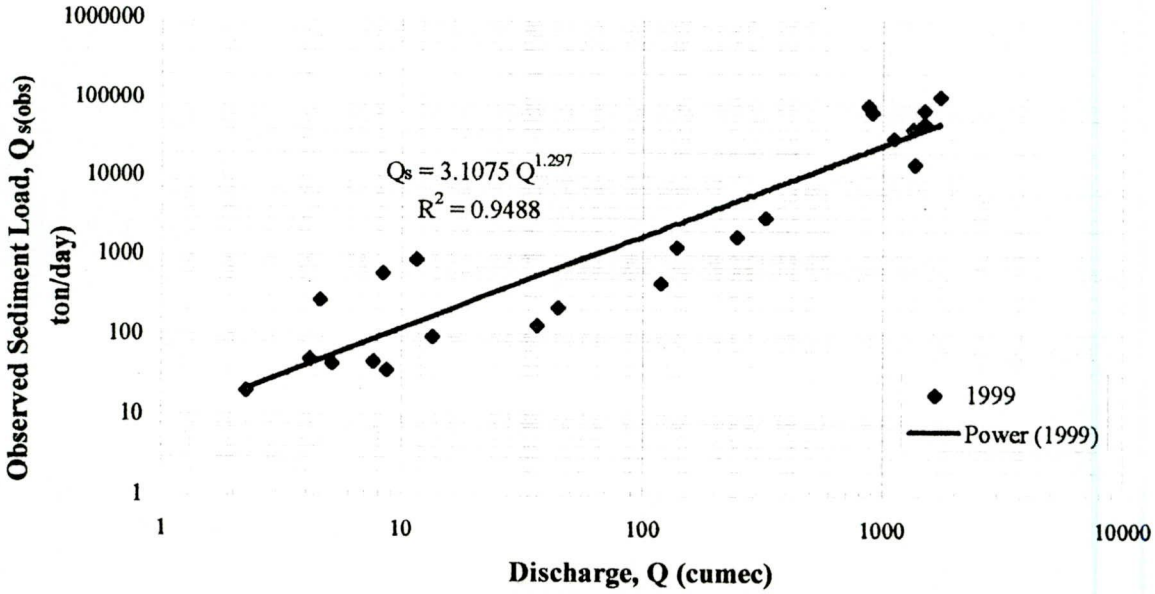


Figure 4.22 : Relationship Between Observed Sediment Load and Observed Discharge at Sylhet in 1999

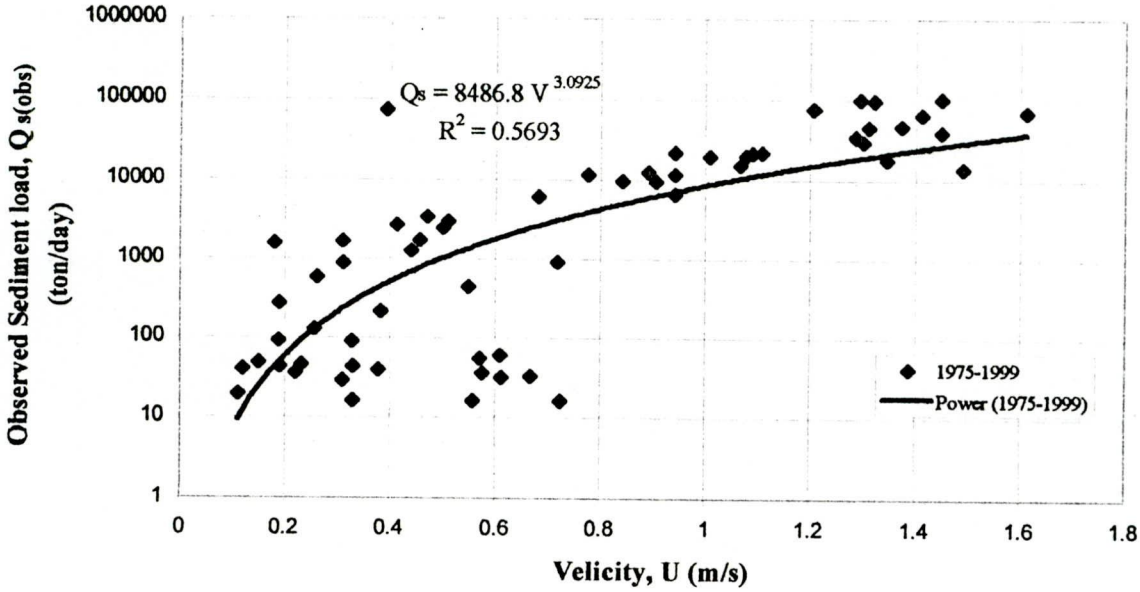


Figure 4.23 : Velocity Vs. Observed Sediment load of the Surma River at Sylhet (1975-1999)

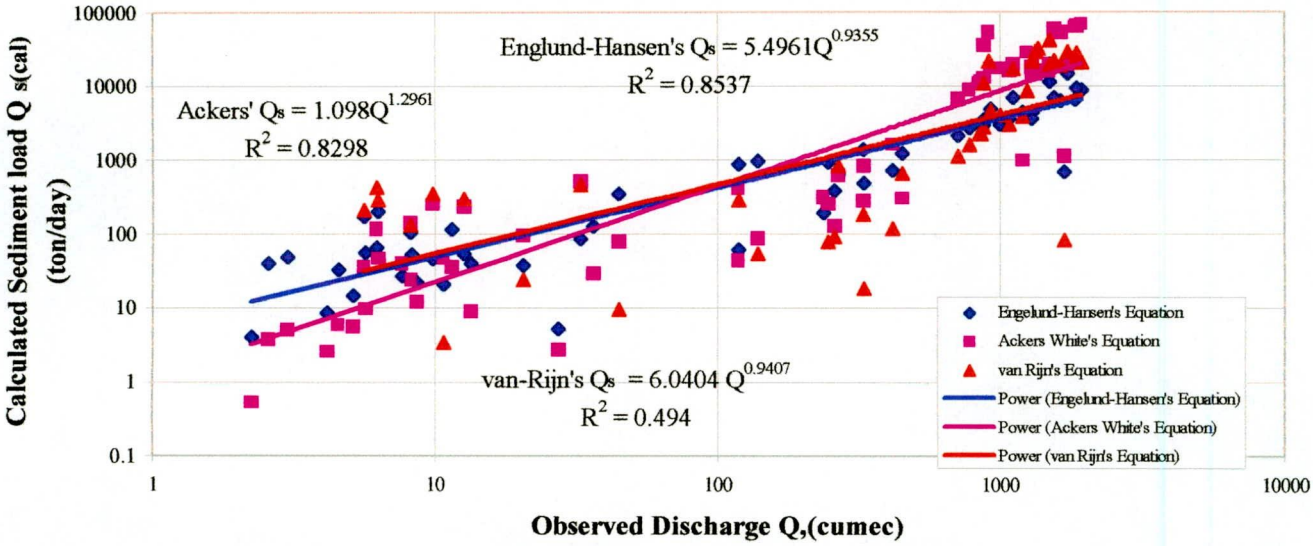


Figure 4.24: Observed Discharge Vs Calculated Sediment Load of Surma River at Sylhet (1975-1999)

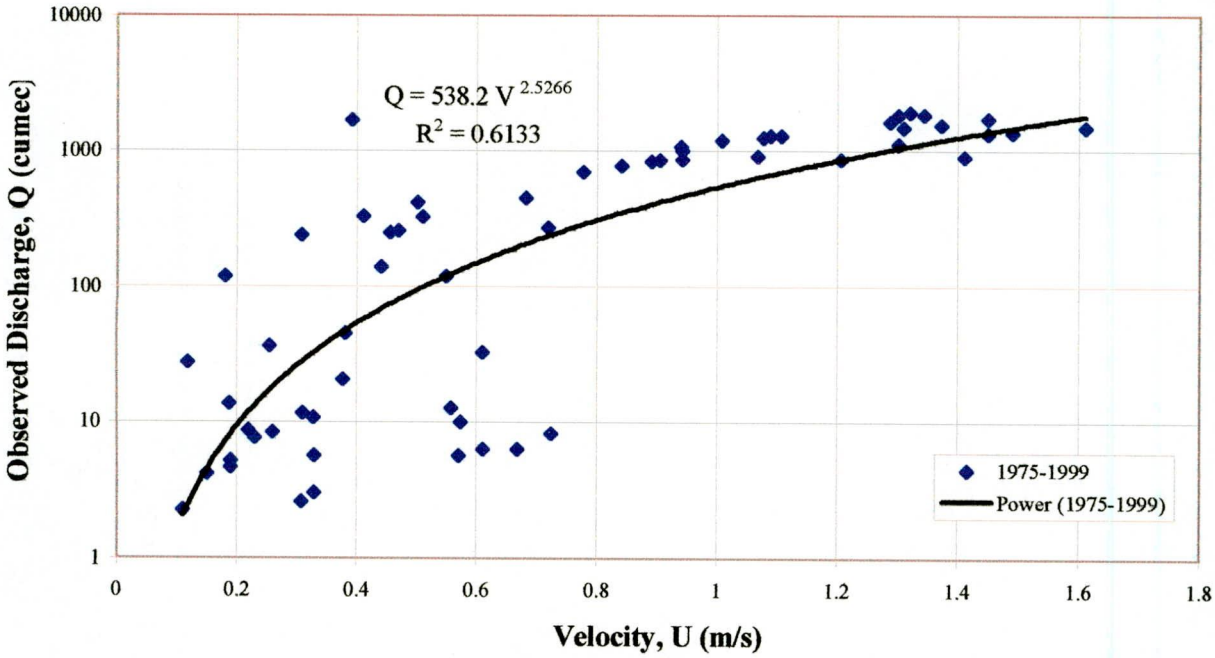


Figure 4.25 : Observed Discharge Vs Velocity of Surma River at Sylhet, (1975-1999)

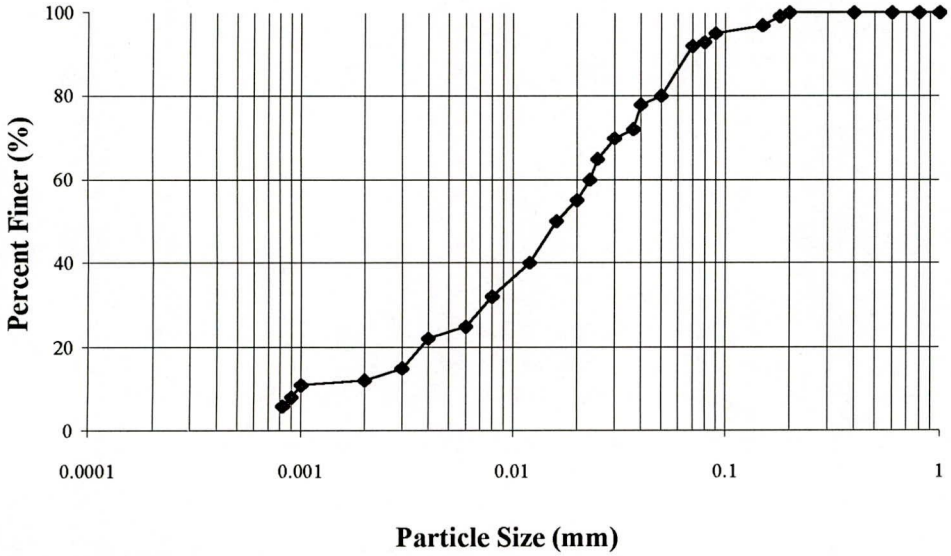


Figure 4.26: Grain size distribution curve of bank material of the right bank of Surma at Kazirbazar, Sylhet, Year 2003

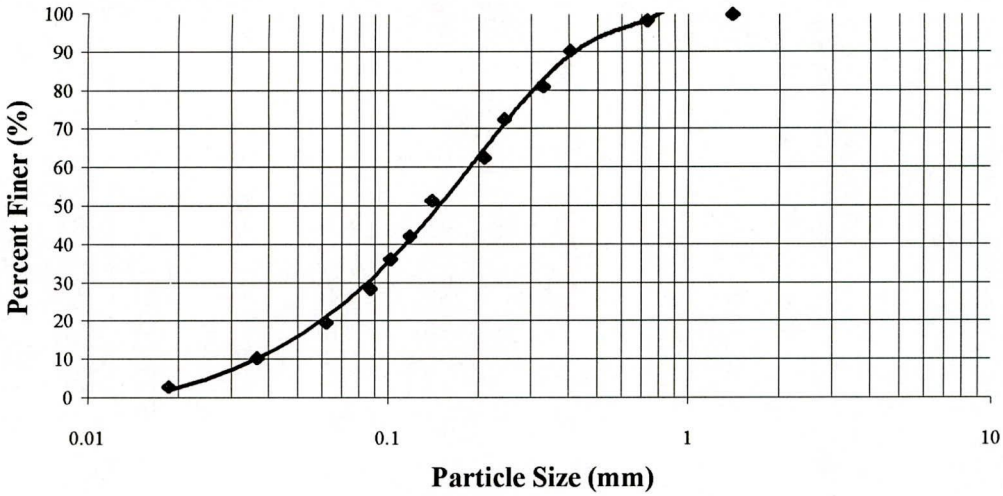


Figure 4.27: Grain size Distribution of bed material of Surma River at Sylhet ,Year 2003

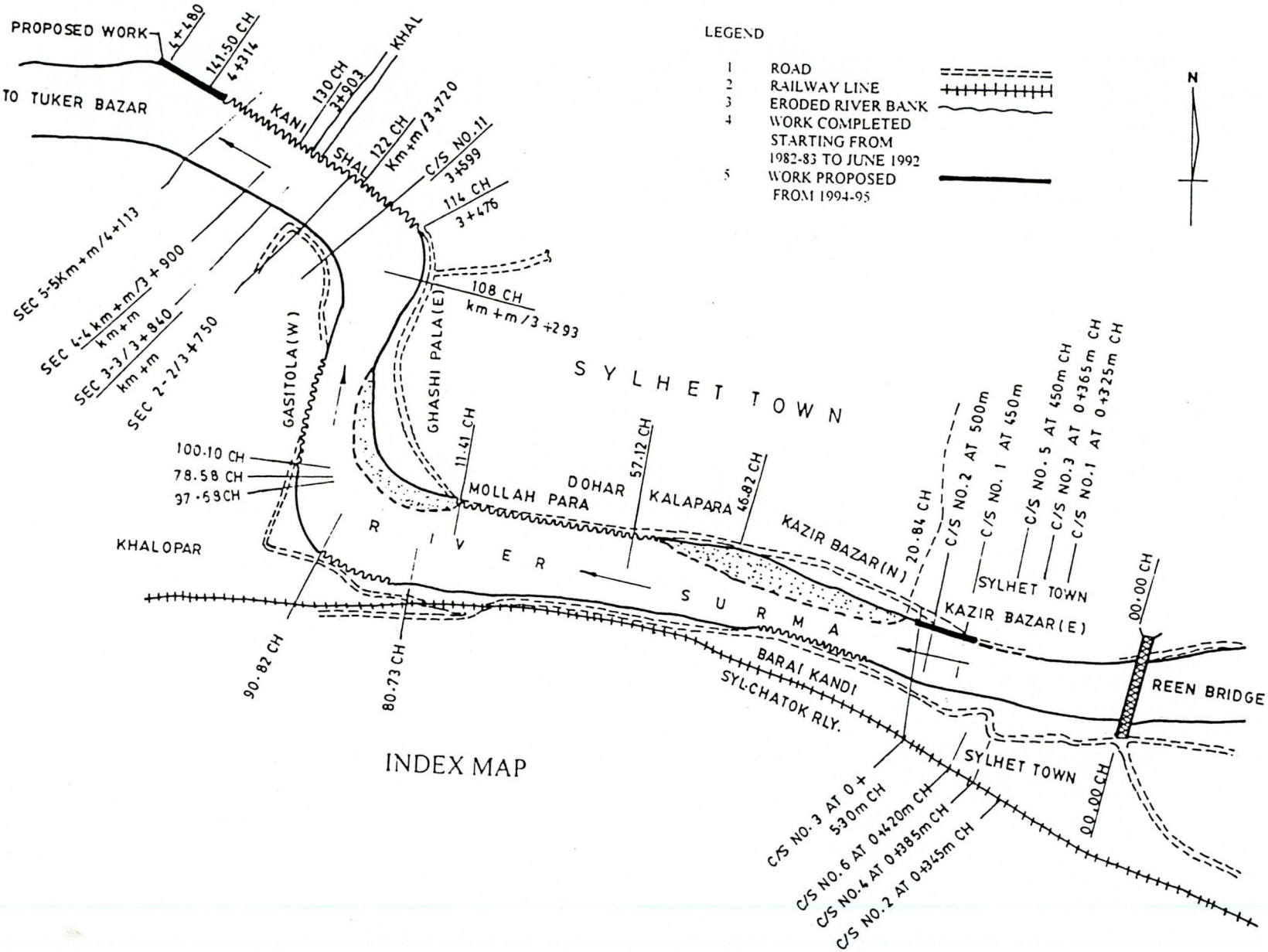
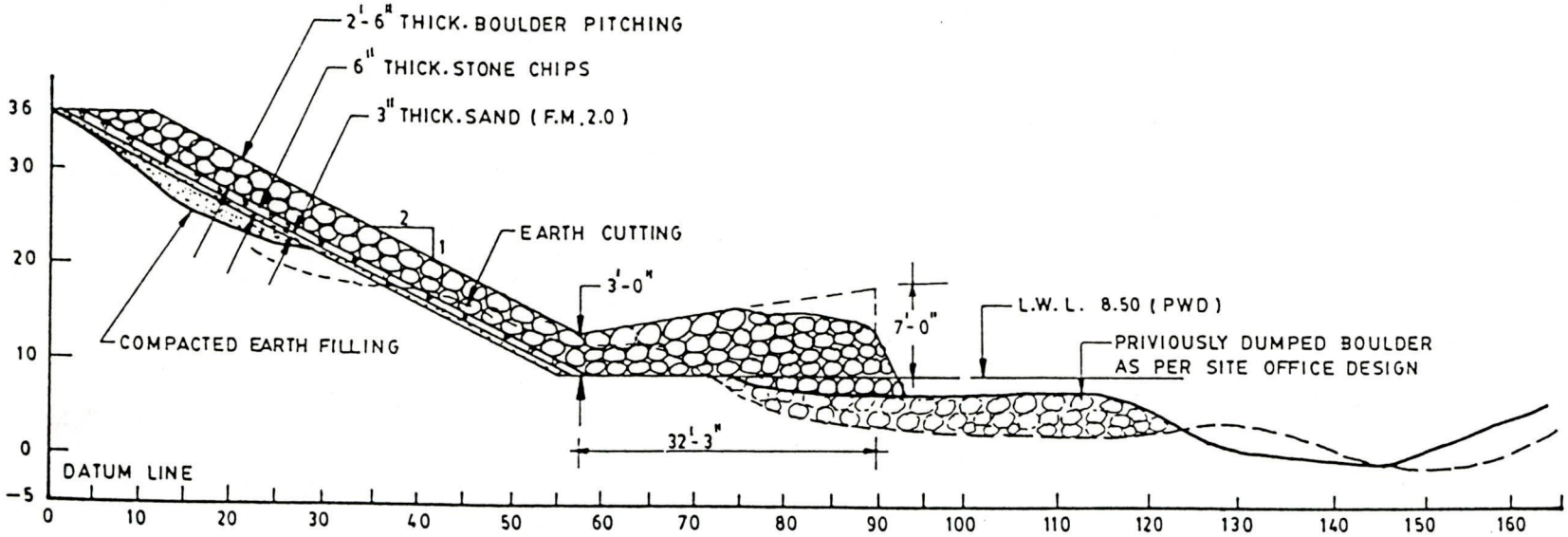


Figure 4.28: Index map of the Implemented bank Protection works of the Surma river adjacent to the Sylhet City (Source: BRTC-BUET '2002).



CROSS-SECTION NO.4 AT +385 m CH

Figure 4.29: Right Bank Protection Work of River Surma From Kazirbazar to Mollapara (Source: BRTC-BUET '2002).

Table 1.1: The Main Geomorphic Features of The Surma (FAP-6 '1993)

Extent of River Reach	Channel Pattern	Bars	Islands	Vertical Stability	Lateral Stability	Bed Material D_{50} (mm)	Sinuosity	Slope (m/km) Average Pre-monsoon Monsoon	Bankfull Dimension Top Width Mean Depth Area
Amalsh ed-Chhatak 0-164 km	Single; Irregular Meanders	Point Bars	Absent	Stable	Minor erosion due to progressi ve meander migration	0.20	1.51	0.040 0.040 0.050	172.0 8.4 1448.0
Chhatak -Old Surma 164-220 Km	Single; Sinuous Meanders	Absent	Few	Degrading	Minor widening	0.16	1.58	0.005 0.005 0.026	251.0 10.3 2583.0
Old Surma-Baulai river 220-248 Km	Single; Irregular Sinuous	Absent	Few	Degrading	Minor widening	0.095	1.24	0.008 0.030 0.014	177.0 11.3 1996.0

Table 1.2: Geometric Dimensions of Selected Cross-Sections along Surma River at Bank Full Condition

Cross Section No.	Chainage (km)	Bank Level (m)	Flow Area (sq. m)	Bank Full Width (m)	Mean Bed Level (m)	Hydraulic Mean Depth, D (m)	Average Bed Slope * 10^{-3} (m/km)
S 29	81.7	12.21	1440.11	298	7.377	3.49	0.045
S 30	76.6	11.895	1779.02	627.4	9.059	3.25	0.065
S 31	70.6	11.475	1986.16	489.17	7.4136	2.83	0.0124
S 32	66.3	12.21	1454.19	529.5	9.464	3.88	0.029
S 33	60.9	12.25	1238.3	369.16	8.895	2.896	0.058
S 34	54	12.51	1160.24	387.2	9.512	2.176	0.0365
S 35	47.2	13.36	1304.17	247.23	8.08	2.71	0.0183
S 36	40.7	13.29	1544.4	601.3	10.72	2.344	0.029
S 37	33.8	13.4	1054.22	435.04	10.977	1.527	0.0456
S 38	26.7	13.62	749.1	505.31	12.136	1.44	0.0237
S 39	20	14.63	850.7	620.14	13.257	1.855	0.019
S 40	12.9	14.51	843.3	434.1	12.567	1.92	0.0122
S 41	6.5	15.02	842.27	441.12	13.11	1.278	0.0135
S 42	0	16.72	1017.14	283.3	13.13	1.348	0.0125

Table 1.3: Highest and Lowest Discharge, Velocity and Water level of The River Surma at Sylhet.

Sl. No.	Year	Highest Discharge (cumec)	Lowest Discharge (cumec)	Highest Velocity (m/s)	Highest Velocity (m/s)	Highest water level (m)	Lowest water level (m)
01	1980	1657	5.81	1.07	0.46	10.49	2.35
02	1981	1757	5.86	1.06	0.49	11.16	2.52
03	1982	1292	4.33	1.02	0.32	11.28	2.65
04	1983	1894	4.72	0.89	0.30	11.33	1.67
05	1984	1563	2.83	1.08	0.11	11.18	2.04
06	1985	1935	4.00	1.47	0.06	11.15	2.17
07	1986	1904	2.61	1.30	0.07	10.89	1.99
08	1987	1947	4.24	1.33	0.16	11.60	2.11
09	1988	1858	3.52	1.36	0.34	11.95	2.21
10	1989	1689	4.14	1.41	0.26	11.34	2.22
11	1990	1840	4.46	1.40	0.39	10.10	2.05
12	1991	1990	5.72	1.22	0.32	11.48	1.99
13	1992	1562	5.89	1.18	0.27	11.31	2.13
14	1993	1967	5.35	1.45	0.36	11.57	2.45
15	1994	1948	4.74	1.21	0.30	11.16	2.15
16	1995	2060	2.75	1.26	0.26	11.64	2.20
17	1996	1347	5.30	1.05	0.06	11.39	2.10
18	1997	1440	7.40	1.28	0.30	11.48	2.07
19	1998	1806	5.47	1.32	0.06	11.74	2.00
20	1999	1724	2.43	1.09	0.08	11.25	2.25
21	2000	1670	2.78	1.08	0.07	11.12	2.16

Table 4.1 Morphological Dimensions of Selected Cross-sections of the Surma River, Year-1991

Cross Section No.	Chainage (km)	Bank Level (m PWD)	Area (Sq. m)	Width (m)	Average Depth (m)	Mean Bed Level (m PWD)	Deepest point (m PWD)
S 1	250.7	6.440	662.8	414.0	1.601	4.836	1.587
S 3	240.9	6.695	1175.0	208.0	5.649	1.0459	-4.070
S 5	227.8	6.474	1248.0	547.0	2.280	4.192	-5.006
S 7	212.9	7.284	902.4	498.0	1.812	5.471	-5.998
S 9	198.9	7.544	773.1	231.5	3.339	4.204	1.100
S 10	193.5	7.355	755.1	349.5	2.161	5.194	1.770
S 12	185.8	7.639	1971	490.0	4.022	3.616	-11.386
S 14	173.2	7.812	3081	507.0	6.077	1.735	-11.378
S 16	159.8	8.652	2715.0	772.2	3.516	5.136	-7.538
S 18	146.9	8.872	3156.0	392.0	8.051	0.821	-7.679
S 20	133.0	9.540	2458.0	456.0	5.390	4.149	-2.789
S 21	125.7	8.790	1382.0	304.0	4.546	4.244	-2.766
S 23	112.8	9.630	628.8	179.0	3.513	6.117	-3.214
S 25	100.8	9.768	1282.0	482.0	2.659	7.108	-2.582
S 27	92.2	10.838	3456.0	535.0	6.459	4.378	-4.892
S 29	81.7	11.520	1603.0	287.0	5.585	5.934	0.473
S 30	76.6	11.995	1888.0	670.2	2.817	9.177	0.655
S 32	66.3	12.132	1689.0	504.0	3.351	8.780	0.047
S 34	54.0	12.164	1397.0	363.0	3.848	8.315	-2.826
S 36	40.7	13.936	1347.0	584.0	2.306	11.629	1.928
S 38	26.7	14.260	2169.0	545.0	3.979	10.280	3.540
S 40	12.9	14.636	1783.0	434.0	4.108	10.528	3.298
S 41	6.5	15.015	1446.0	466.8	3.098	11.917	3.490
S 42	0.0	15.846	1646.0	263.3	6.251	9.594	1.161

Table 4.2: Morphological Dimensions of Selected Cross-sections of the Surma River, Year-1999

Cross Section No.	Chainage (km)	Bank Level (m PWD)	Area (Sq. m)	Width (m)	Average Depth (m)	Mean Bed Level (m PWD)	Deepest point (m PWD)
S 1	250.7	6.54	692.0	407.0	1.700	4.835	2.735
S 3	240.9	6.51	795.0	260.0	3.057	3.452	-2.790
S 5	227.8	6.78	1221.0	678.0	1.801	4.979	-3.190
S 7	212.9	7.20	1322.0	557.0	2.373	4.828	-4.970
S 9	198.9	7.62	397.3	219.0	1.814	5.801	1.730
S 10	193.5	7.27	568.3	397.0	1.431	5.838	0.200
S 12	185.8	7.34	2424.0	534.2	4.538	2.803	-10.480
S 14	173.2	7.76	1693.0	603.0	2.808	4.952	-10.625
S 16	159.8	8.23	1911.0	857.0	2.230	6.000	-5.040
S 18	146.9	8.35	1873.0	315.0	5.946	2.404	-8.420
S 20	133.0	9.45	1520.0	448.0	3.393	6.057	0.865
S 21	125.7	9.21	1187.0	283.0	4.194	5.016	-2.450
S 23	112.8	9.095	913.8	298.1	3.065	6.029	-2.225
S 25	100.8	9.76	1051.0	531.0	1.979	7.781	0.870
S 27	92.2	10.68	3057.0	578.0	5.289	5.391	-1.510
S 29	81.7	12.21	1440.0	298.0	4.832	7.378	1.873
S 30	76.6	11.895	1779.0	627.4	2.836	9.059	1.240
S 32	66.3	12.21	1454.0	529.5	2.746	9.464	0.310
S 34	54.0	12.51	1160.0	387.0	2.997	9.513	1.020
S 36	40.7	13.29	1544.0	601.0	2.569	10.720	5.960
S 38	26.7	13.62	749.1	505.0	1.483	12.136	8.950
S 40	12.9	14.51	843.3	476.0	1.772	12.738	8.810
S 41	6.5	15.02	842.0	441.0	1.909	13.110	8.890
S 42	0.0	16.72	1017.0	283.3	3.589	13.130	7.650

Table 4.3: Erosion and Deposition of the Surma River (1991 to 1999)

Cross Section No.	Change in Area (Sq. m)	Change in Width (m)	Change in Average Depth (m)	Change in Mean Bed Level (m PWD)	Change in Deepest point (m PWD)
S 1	+29.20	-7.00	+0.099	-0.001	+1.148
S 3	-380.00	+52.00	-2.591	+2.406	+1.280
S 5	-27.00	+131.00	-0.480	+0.786	+1.816
S 7	+419.60	+59.00	+0.561	-0.644	+1.028
S 9	-375.80	-12.50	-1.525	+1.596	+0.630
S 10	-186.80	+47.50	-0.729	+0.644	-1.570
S 12	+453.00	+44.21	+0.515	-0.813	+0.906
S 14	-1388.00	+96.00	-3.269	+3.217	+0.753
S 16	-804.00	+84.80	-1.286	+0.864	+2.498
S 18	-1283.00	-77.00	-2.105	+1.583	-0.741
S 20	-938.00	-8.00	-1.997	+1.907	+3.654
S 21	-195.00	-21.00	-0.352	+0.772	+0.316
S 23	+285.00	+119.10	-0.447	-0.088	+0.989
S 25	-231.00	+49.00	-0.680	+0.672	+3.452
S 27	-399.00	+43.00	-1.170	+1.013	+3.382
S 29	-163.00	+11.00	-0.753	+1.443	+1.400
S 30	-109.00	-42.80	+0.0184	-0.118	+0.585
S 32	-235.00	+25.50	-0.605	+0.683	+0.263
S 34	-237.00	+24.00	-0.851	+1.197	+3.846
S 36	+197.00	+17.00	+0.263	-0.908	+4.032
S 38	-1419.90	-40.00	-2.496	+1.856	+5.410
S 40	-939.70	+42.00	-2.336	+2.211	+5.512
S 41	-604.00	-25.75	-1.188	+1.194	+5.400
S 42	-629.00	+20.00	-2.661	+3.535	+6.489

* '+'ve sign indicates increase in cross sectional area/width or rise in elevation
** '-' ve sign indicates decrease in cross sectional area/width or fall in elevation

Table 4.4: Discharge Capacity, Mean Velocity of Selected Cross-Sections along Surma river at Bank full condition using Ackers-White's Sediment Predictor (Year, 2003)

Cross Section No.	Chainage (km)	Bank Level (m)	Flow Area (sq. m)	Mean Velocity, U (m/ sec)	Discharge Capacity, Q, (Cumec)	Dimensionless, Particle Mobility Factor, F_{gr}	Sediment Concentration, Cs, ppm
S 29	81.7	12.21	1440.11	0.65	936.07	1.51	734.17
S 30	76.6	11.895	1779.02	0.29	519.40	0.53	288.81
S 31	70.6	11.475	1986.16	0.49	973.22	2.32	272.20
S 32	66.3	12.21	1454.19	0.57	828.89	2.16	365.08
S 33	60.9	12.25	1238.3	0.43	526.71	0.806	633.22
S 34	54	12.51	1160.24	0.33	383.81	0.621	358.87
S 35	47.2	13.36	1304.17	0.38	498.36	0.730	386.38
S 36	40.7	13.29	1544.4	0.36	559.60	0.72	1485.04
S 37	33.8	13.4	1054.22	0.24	253.78	0.48	514.00
S 38	26.7	13.62	749.1	0.25	189.18	0.497	502.60
S 39	20	14.63	850.7	0.20	171.52	0.397	353.46
S 40	12.9	14.51	843.3	0.16	135.04	0.328	226.38
S 41	6.5	15.02	842.27	0.15	133.55	0.324	214.11
S 42	0	16.72	1017.14	0.27	278.85	0.538	325.77

Table 4.5: Annual Sediment Transport of the Surma River at Sylhet

Year	Annual Average Discharge (cumec)	Observed Sediment Load (MT)	Computed Sediment Load (MT)		
			Engelund Hansen's Equation	Ackers White's Equation	Van Rijn's Equation
1975	549.776	2.776	0.699	1.716	0.797
1989	612.24	3.121	0.784	1.969	0.893
1999	545.14	3.0971	0.697	1.768	0.794

Table 4.6: Computation of Sediment Load (Station: Sylhet, 1975)

Serial No.	Sampling date	Observed Discharge, Q (cumec)	Suspended Sediment Load Qs (ton/day)	Computed Sediment Load (ton/day)		
				Engelund-Hansen's Equ^n	Acker-White's Equ^n	Van Rijn's Equ^n
1	07.02.75	5.635	41.87	55.53	9.48	0
2	21.02.75	6.286	31.5	196.68	45.32	288.23
3	07.03.75	5.607	54.26	166.52	34.70	207.29
4	21.03.75	3.002	16.08	48.46	5.07	0
5	04.04.75	2.577	28.94	39.70	3.70	0
6	18.04.75	238.116	1625.29	190.53	317.87	0
7	02.05.75	415.635	2441.94	727.61	1589.97	118.03
8	09.05.75	118.902	1561.52	61.34	44.21	0
9	23.05.75	775.542	9917.01	2669.61	8773.83	1593.86
10	30.05.75	707.61	11738.4	2155.22	6823.91	1109.66
11	06.06.75	331.137	2660.75	477.43	823.83	18.18
12	14.06.75	854.263	9521.27	3099.70	11279.48	2194.12
13	20.06.75	921.742	15529.5	4786.44	17005.37	4760.89
14	27.06.75	842.681	12522.91	3100.55	10827.47	2187.04
15	05.07.75	867.656	11619.66	3477.36	12574.31	2809.8
16	11.07.75	1074.992	22198.16	3590.94	15775.8	2913.46
17	18.07.75	1836.574	100603.12	6547.00	61888.91	22143.1
18	26.07.75	1925.631	96663.57	8715.23	67086.52	20618.16
19	02.08.75	1854.13	17781.85	9282.84	66048.35	27816.57
20	08.08.75	1245.46	20337.86	4249.05	27951.84	8383.12
21	27.08.75	1623.745	34932.59	6266.44	53941	18644.85
22	29.08.75	1001.312	6575.02	2917.19	16827.27	3934.81
23	05.09.75	1537.605	47559.96	6956.17	58514.19	21756.1

Table 4.7: Computation of Sediment Load (Station: Sylhet, 1989)

Serial No.	Sampling date	Observed Discharge, (cumec)	Suspended Sediment Load (ton/day)	Computed Sediment Load (ton/day)		
				Engelund-Hansen's Equ^n	Acker-White's Equ^n	Van Rijn's Equ^n
1	01.01.89	27.24	40.01	5.12	2.64	0
2	11.01.89	20.5	38.97	37.48	92.42	23.43
3	25.01.89	12.63	16.37	52.82	231.75	297.08
4	07.02.89	9.87	35.82	45.84	241.30	346.77
5	22.02.89	32.63	59.2	85.76	520.03	456.54
6	08.03.89	8.18	16.25	102.98	140.71	129.11
7	22.03.89	6.23	32.84	64.96	118.20	427.83
8	05.04.89	269.21	907.13	653.10	602.62	813.05
9	19.04.89	258.37	3370.77	382.13	125.87	89.53
10	28.06.89	1198.19	19669.41	4456.98	961.40	3892.66
11	12.07.89	1297.56	21637.07	4347.72	14200.99	22726.24
12	17.07.89	450.95	6233.88	1234.41	292.68	642.95
13	26.07.89	1287.9	21921.06	3563.09	18271.49	21312.52
14	09.08.89	1680.76	74496.49	703.25	1130.56	83.19
15	27.12.89	10.71	88.85	20.87	48.034	3.36

Table No 4.8: Computation of Sediment Load (Station: Sylhet, 1999)

Serial No.	Sampling date	Observed Discharge, (cumec)	Suspended Sediment Load (ton/day)	Computed Sediment Load (ton/day)		
				Engelund-Hansen's Equ^n	Acker-White's Equ^n	Van Rijn's Equ^n
1	13/01/99	7.62	44.54	26.82	39.89	0
2	27/01/99	8.66	34.99	22.05	11.72	0
3	10.02.99	5.13	42.79	14.59	5.46	0
4	24.02.99	4.14	48.4	8.60	2.48	0
5	10.03.99	2.24	19.49	4.03	0.51	0
6	24.03.99	4.56	265.3	32.66	5.73	0
7	07.04.99	8.28	578.23	51.31	23.41	0
8	21.04.99	11.53	869.12	113.81	34.49	0
9	05.05.99	326.67	3005.99	1409.30	279.82	183.38
10	19.05.99	139.49	1245.35	978.81	88.74	53.49
11	16.07.99	1724.08	103492.9	14976.29	19325.48	28324.69
12	29.07.99	1487.8	46190.24	11278.22	15476.09	19475.16
13	12.08.99	1484.02	69300.86	19654.79	19486.75	41262.97
14	26.08.99	1358.75	14139.2	16109.63	15915.39	31220.59
15	09.09.99	1330.87	39830.19	15087.78	14748.72	28186.57
16	23.09.99	1110.12	29882.11	6965.43	19547.16	17183.87
17	07.10.99	907.64	65490.08	4019.05	52979.46	21194.35
18	22.10.99	871.02	77304.33	2996.28	35174.63	10620.86
19	04.11.99	246.51	44.54	936.38	253.55	77.59
20	18.11.99	119.36	34.99	890.26	395.24	286.21
21	02.12.99	44.88	42.79	347.47	80.63	9.26
22	16.12.99	36.41	48.4	125.60	28.53	0
23	31.12.99	13.45	19.49	39.93	8.63	0

Table 4.9: Computation of Sediment Load of The River Surma [Station: Sylhet, Year, 1975, Engelund -Hansen's Approach]

Sl No	Sampling Date	Hydraulic Radius, R (m)	Width B, (m)	Velocity, U, (m/s)	Observed Discharge, Q (cumec)	Mean Grain Size Bed Material, D_{50} (m)	Slope, S (m/km)	Bed shear Stress τ (kg/m^2)	Sediment Transport, g_s (kg/m/sec)	Sediment Transport, Qs, (ton/day)	Observed Sediment Load, (ton/day)
1	07.02.75	2.183	93.67	0.329	5.635	0.0002	0.0000	0.0873	0.00686	55.53	41.87
2	21.02.75	2.223	93.92	0.61	6.286	0.0002	0.0000	0.0889	0.02423	196.6	31.5
3	07.03.75	2.179	93.84	0.57	5.607	0.0002	0.0000	0.0871	0.02053	166.5	54.26
4	21.03.75	2.009	92.60	0.329	3.002	0.0002	0.0000	0.0803	0.00605	48.46	16.08
5	04.04.75	1.927	92.13	0.308	2.577	0.0002	0.0000	0.0770	0.00498	39.70	28.94
6	18.04.75	4.98	106.43	0.308	238.116	0.0002	0.0000	0.199	0.02071	190.5	1625.29
7	02.05.75	6.208	110.81	0.5	415.635	0.0002	0.0000	0.2483	0.07599	727.6	2441.94
8	09.05.75	4.825	105.19	0.18	118.902	0.0002	0.0000	0.19	0.00674	61.34	1561.52
9	23.05.75	7.222	114.53	0.841	775.542	0.0002	0.0000	0.2888	0.26977	2669.6	9917.01
10	30.05.75	6.993	113.68	0.777	707.61	0.0002	0.0000	0.2797	0.21941	2155.2	11738.4
11	06.06.75	6.102	110.43	0.411	331.137	0.0002	0.0000	0.2440	0.05004	477.4	2660.75
12	14.06.75	7.233	114.58	0.905	854.263	0.0002	0.0000	0.2893	0.31311	3099.7	9521.27
13	20.06.75	7.535	119.77	1.067	921.742	0.0002	0.0000	0.301	0.46278	4786.4	15529.5
14	27.06.75	7.017	124.02	0.89	842.681	0.0002	0.0000	0.2806	0.28935	3100.5	12522.91
15	05.07.75	7.002	124.56	0.942	867.656	0.0002	0.0000	0.2800	0.32311	3477.3	11619.66
16	11.07.75	6.68	138.04	0.94	1074.992	0.0002	0.0000	0.267	0.30108	3590.9	22198.16
17	18.07.75	3.679	325.81	1.30	1836.574	0.0002	0.0000	0.1471	0.23257	6547.0	100603.12
18	26.07.75	3.78	400.82	1.32	1925.631	0.0002	0.0000	0.151	0.25165	8715.2	96663.57
19	02.08.75	4.009	377.04	1.344	1854.13	0.0002	0.0000	0.1603	0.28495	9282.8	17781.85
20	08.08.75	3.856	285.45	1.076	1245.46	0.0002	0.0000	0.1542	0.17228	4249.0	20337.86
21	27.08.75	3.672	317.14	1.286	1623.745	0.0002	0.0000	0.1468	0.22869	6266.4	34932.59
22	29.08.75	3.92	249.46	0.942	1001.312	0.0002	0.0000	0.156	0.13535	2917.1	6575.02
23	05.09.75	3.688	307.28	1.372	1537.605	0.0002	0.0000	0.1475	0.26201	6956.1	47559.96

Table 4.10: Computation of Sediment Load of The River Surma [Station: Sylhet, Year, 1989, Engelund Hansen's Approach]

Sl No	Sampling Date	Hydraulic Radius R (m)	Width, B, (m)	Velocity, U, (m/s)	Observed Discharge, Q (cumec)	Mean Grain Size Bed Material, D_{50} (m) * 10^{-4}	Slope, S (m/km)* 10^{-5}	Bed shear Stress τ (kg/m^2)	Sediment Transport, g_s (kg/m/sec)	Sediment Transport, Qs, (ton/day)	Observed Sediment Load, (ton/day)
1	01.01.89	1.46	120.661	0.119	27.2	2	4	0.0584	0.00049	5.12	40.01
2	11.01.89	1.26	109.55	0.377	20.5	2	4	0.0505	0.00396	37.4	38.97
3	25.01.89	1.02	96.757	0.557	12.6	2	4	0.0410	0.00631	52.8	16.37
4	07.02.89	0.93	91.213	0.574	9.87	2	4	0.0372	0.00581	45.8	35.82
5	22.02.89	1.18	105.51	0.608	32.6	2	4	0.0475	0.00940	85.7	59.2
6	08.03.89	1.36	72.393	0.724	8.18	2	4	0.0547	0.01646	102.98	16.25
7	22.03.89	1.20	64.492	0.668	6.23	2	4	0.0484	0.01165	64.9	32.84
8	05.04.89	3.27	125.886	0.718	269.21	2	4	0.13	0.06004	653.10	907.13
9	19.04.89	3.98	128.515	0.469	258.37	2	4	0.1595	0.03441	382.13	3370.77
10	28.06.89	7.16	134.851	1.007	1198.19	2	4	0.2868	0.38253	4456.98	19669.41
11	12.07.89	2.50	545.551	1.089	1297.56	2	4	0.1001	0.09223	4347.72	21637.07
12	17.07.89	5.23	130.378	0.682	450.95	2	4	0.2095	0.10958	1234.41	6233.88
13	26.07.89	2.26	501.335	1.107	1287.9	2	4	0.0907	0.08225	3563.09	21921.06
14	09.08.89	2.89	547.177	0.392	1680.76	2	4	0.1158	0.01487	703.25	74496.49
15	27.12.89	1.09	100.45	0.327	10.7	2	4	0.0438	0.00240	20.8	88.85

Table 4.11: Computation of Sediment Load of The River Surma [Station: Sylhet, Year, 1999, Engelund Hansen's Approach]

Sl No	Sampling Date	Hydraulic Radius, R (m)	Width, B, (m)	Velocity, U, (m/s)	Observed Discharge, Q (cumec)	Mean Grain Size Bed Material, D_{50} (m)	Slope, S (m/km)	Bed shear Stress τ (kg/m^2)	Sediment Transport, g_s (kg/m/sec)	Sediment Transport, Qs, (ton/day)	Observed Sediment Load, (ton/day)
1	13.01.99	2.7	67.0	0.2	7.615	0.0002	0.00004	0.1096	0.004633	26.82	44.54
2	27.01.99	2.	67.0	0.2	8.655	0.0002	0.00004	0.104	0.003808	22.05	34.99
3	10.02.99	2.4	63.0	0.1	5.129	0.0002	0.00004	0.0984	0.002680	14.59	42.79
4	24.02.99	2.3	65.0	0.1	4.138	0.0002	0.00004	0.0932	0.00153	8.60	48.4
5	10.03.99	2.2	61.0	0.1	2.243	0.0002	0.00004	0.0904	0.000764	4.03	19.49
6	24.03.99	2.3	155.00	0.1	4.56	0.0002	0.00004	0.0924	0.002438	32.66	265.3
7	07.04.99	2.3	129.00	0.2	8.284	0.0002	0.00004	0.094	0.004603	51.31	578.23
8	21.04.99	2.8	150.0	0.3	11.525	0.0002	0.00004	0.1124	0.008781	113.81	869.12
9	05.05.99	7.9	144.00	0.5	326.667	0.0002	0.00004	0.3164	0.113272	1409.30	3005.99
10	19.05.99	7.6	140.00	0.4	139.486	0.0002	0.00004	0.3052	0.080920	978.81	1245.35
11	16.07.99	8.0	184.00	1.4	1724.07	0.0002	0.00004	0.3228	0.942047	14976.29	103492.9
12	29.07.99	7.5	186.00	1.3	1487.8	0.0002	0.00004	0.302	0.701800	11278.22	46190.24
13	12.08.99	8.3	185.00	1.6	1484.02	0.0002	0.00004	0.3352	1.22965	19654.79	69300.86
14	26.08.99	8.1	185.0	1.4	1358.75	0.0002	0.00004	0.3256	1.007859	16109.63	14139.2
15	09.09.99	8.1	184.00	1.4	1330.86	0.0002	0.00004	0.3244	0.94906	15087.78	39830.19
16	23.09.99	5.9	167.50	1.3	1110.11	0.0002	0.00004	0.238	0.481304	6965.43	29882.11
17	07.10.99	3.8	161.00	1.4	907.64	0.0002	0.00004	0.1524	0.288924	4019.05	65490.08
18	22.10.99	3.8	161.50	1.20	871.01	0.0002	0.00004	0.1536	0.21473	2996.28	77304.33
19	04.11.99	6.5	160.00	0.45	246.50	0.0002	0.00004	0.2608	0.067736	936.38	1674.76
20	18.11.99	4.9	157.00	0.54	119.35	0.0002	0.00004	0.1988	0.065630	890.26	431.12
21	02.12.99	4.3	157.00	0.38	44.88	0.0002	0.00004	0.1728	0.025615	347.47	212.31
22	16.12.99	3.8	150.00	0.25	36.41	0.0002	0.00004	0.1544	0.009691	125.60	125.27
23	31.12.99	2.9	130.0	0.18	13.44	0.0002	0.00004	0.1188	0.003555	39.93	91.37

Table 4.12: Computation of Sediment Load of The River Surma [Station: Sylhet, Year, 1975, Ackers-White's Approach]

Sampling date	Hydraulic Radius, R (m)	Width, B (m)	Observed Discharge Q,(cumec)	Velocity, U (m/s)	Median size, $D_{50\,(m)}$	Slope, (S), (m/km)	Shear stress, (U*) (m/S)	Particle Mobility Number, F_{gr}	Concentration, C_s (= Q_s/Q) % by weight	Sediment Transport, Q_s (Kg/m/s)	Sediment Transport Q_s (ton/day)	Observed Sediment Load, ton/day
07.02.75	2.183	93.675	5.635	0.329	0.0002	0.00004	0.029268	0.79702	1.95E-05	0.001172	9.48	41.87
21.02.75	2.223	93.919	6.286	0.61	0.0002	0.00004	0.029535	1.02168	8.34E-05	0.005585	45.32	31.5
07.03.75	2.179	93.838	5.607	0.57	0.0002	0.00004	0.029241	0.98939	7.16E-05	0.004281	34.70	54.26
21.03.75	2.009	92.603	3.002	0.329	0.0002	0.00004	0.028077	0.77942	1.95E-05	0.000634	5.07	16.08
04.04.75	1.927	92.132	2.577	0.308	0.0002	0.00004	0.027498	0.75096	1.66E-05	0.000465	3.70	28.94
18.04.75	4.98	106.432	238.116	0.308	0.0002	0.00004	0.044206	0.97026	1.55E-05	0.034567	317.87	1625.29
02.05.75	6.208	110.813	415.635	0.5	0.0002	0.00004	0.049356	1.24691	4.43E-05	0.166068	1589.97	2441.94
09.05.75	4.825	105.192	118.902	0.18	0.0002	0.00004	0.043512	0.77836	4.3E-06	0.004865	44.21	1561.52
23.05.75	7.222	114.533	775.542	0.841	0.0002	0.00004	0.053235	1.59492	0.000131	0.886634	8773.83	9917.01
30.05.75	6.993	113.688	707.61	0.777	0.0002	0.00004	0.052384	1.53243	0.000112	0.694712	6823.91	11738.4
06.06.75	6.102	110.428	331.137	0.411	0.0002	0.00004	0.048933	1.14878	2.88E-05	0.086347	823.83	2660.75
14.06.75	7.233	114.579	854.263	0.905	0.0002	0.00004	0.053275	1.64240	0.000153	1.139385	11279.48	9521.27
20.06.75	7.535	119.707	921.742	1.067	0.0002	0.00004	0.054376	1.772	0.000214	1.644193	17005.37	15529.5
27.06.75	7.017	124.02	842.681	0.89	0.0002	0.00004	0.052474	1.61821	0.000149	1.010465	10827.47	12522.91
05.07.75	7.002	124.559	867.656	0.942	0.0002	0.00004	0.052417	1.65389	0.000168	1.16841	12574.31	11619.66
11.07.75	6.68	138.04	1074.992	0.94	0.0002	0.00004	0.051198	1.63285	0.00017	1.322744	15775.8	22198.16
18.07.75	3.679	325.81	1836.574	1.30	0.0002	0.00004	0.037995	1.57478	0.00039	2.198521	61888.91	100603.12
26.07.75	3.78	400.824	1925.631	1.32	0.0002	0.00004	0.038513	1.59836	0.000403	1.93717	67086.52	96663.57
02.08.75	4.009	377.041	1854.13	1.344	0.0002	0.00004	0.039663	1.63557	0.000412	2.027494	66048.35	17781.85
08.08.75	3.856	285.445	1245.46	1.076	0.0002	0.00004	0.038899	1.48256	0.00026	1.133377	27951.84	20337.86
27.08.75	3.672	317.136	1623.745	1.286	0.0002	0.00004	0.037959	1.56965	0.000384	1.96861	53941	34932.59
29.08.75	3.92	249.456	1001.312	0.942	0.0002	0.00004	0.03922	1.413	0.000195	0.780739	16827.27	6575.02
05.09.75	3.688	307.281	1537.605	1.372	0.0002	0.00004	0.038042	1.61212	0.00044	2.204001	58514.19	47559.96

Table 4.13: Computation of Sediment Load of The River Surma [Station: Sylhet, Year, 1989, Ackers-White's Approach]

Sampling date	Hydraulic Radius, R (m)	Width, B (m)	Observed Discharge (cumec)	Velocity, U (m/s)	Median size, $D_{50\,(m)}$	Slope, (S), (m/km)	Shear stress, (U*) (m/S)	Particle Mobility Number, F_{gr}	Concentration, C_s (= Q_s/Q) % by weight	Sediment Transport, Q_s (Kg/m/s)	Sediment Transport Q_s (ton/day)	Observed Sediment Load, ton/day
01.01.89	1.461	120.661	27.24	0.11	0.0002	0.00004	0.023943	0.4792299	1.12079E-06	0.000253	2.64	40.01
11.01.89	1.262	109.55	20.5	0.37	0.0002	0.00004	0.022253	0.8302611	5.21804E-05	0.0097645	92.42	38.97
25.01.89	1.024	96.757	12.63	0.55	0.0002	0.00004	0.020045	1.0167544	0.000212377	0.0277223	231.75	16.37
07.02.89	0.931	91.213	9.87	0.57	0.0002	0.00004	0.019113	1.0520267	0.000282963	0.0306189	241.30	35.82
22.02.89	1.188	105.51	32.63	0.60	0.0002	0.00004	0.02159	1.0166443	0.000184458	0.0570455	520.03	59.2
08.03.89	1.367	72.393	8.18	0.72	0.0002	0.00004	0.023160	1.0540992	0.000199098	0.0224969	140.71	16.25
22.03.89	1.209	64.492	6.23	0.66	0.0002	0.00004	0.02178	1.0507809	0.000219588	0.0212124	118.20	32.84
05.04.89	3.275	125.886	269.21	0.71	0.0002	0.00004	0.035848	0.8584422	2.59084E-05	0.0554058	602.62	907.13
19.04.89	3.987	128.515	258.37	0.46	0.0002	0.00004	0.039553	0.6936782	5.63835E-06	0.0113355	125.87	3370.77
28.06.89	7.169	134.851	1198.19	1.00	0.0002	0.00004	0.053038	0.8198439	9.28677E-06	0.0825156	961.40	19669.41
12.07.89	2.502	545.551	1297.56	1.08	0.0002	0.00004	0.031333	1.0764071	0.000126671	0.3012794	14200.99	21637.07
17.07.89	5.238	130.378	450.95	0.68	0.0002	0.00004	0.045336	0.7553049	7.51205E-06	0.0259826	292.68	6233.88
26.07.89	2.268	501.335	1287.9	1.10	0.0002	0.00004	0.029832	1.1082298	0.000164202	0.4218248	18271.49	21921.06
09.08.89	2.895	547.177	1680.76	0.39	0.0002	0.00004	0.033704	0.6956679	7.78526E-06	0.0239139	1130.56	74496.49
27.12.89	1.094	100.45	10.71	0.32	0.0002	0.00004	0.020719	0.811538	5.19106E-05	0.0055347	48.034	88.85

Table 4.14 Computation of Sediment Load of The River Surma [Station: Sylhet, Year: 1999, Ackers-White's Approach]

Sampling date	Hydraulic Radius, R (m)	Width, B (m)	Observed Discharge (cumec)	Velocity, U (m/s)	Median size, $D_{50\,(m)}$	Slope, (S), (m/km)	Shear stress, (U*) (m/S)	Particle Mobility Number, F_{gr}	Concentration, C_s (= Q_s/Q) % by weight	Sediment Transport, Q_s (Kg/m/s)	Sediment Transport Q_s (ton/day)	Observed Sediment Load, ton/day
13/01/99	2.74	67.00	7.615	0.23	0.0002	0.00004	0.0327899	0.7332341	6.063E-05	0.0068912	39.89	44.54
27/01/99	2.6	67.00	8.655	0.22	0.0002	0.00004	0.0319412	0.5627398	1.568E-05	0.0020251	11.72	34.99
10.02.99	2.46	63.00	5.129	0.19	0.0002	0.00004	0.0310693	0.5405969	1.231E-05	0.0010023	5.46	42.79
24.02.99	2.33	65.00	4.138	0.15	0.0002	0.00004	0.0302373	0.4981396	6.944E-06	0.0004421	2.48	48.4
10.03.99	2.26	61.00	2.243	0.11	0.0002	0.00004	0.0297796	0.4414312	2.632E-06	9.679E-05	0.51	19.49
24.03.99	2.31	155.00	4.56	0.19	0.0002	0.00004	0.0301072	0.5485068	1.455E-05	0.000428	5.73	265.3
07.04.99	2.35	129.00	8.284	0.26	0.0002	0.00004	0.0303668	0.6161103	3.27E-05	0.0021001	23.41	578.23
21.04.99	2.81	150.00	11.525	0.31	0.0002	0.00004	0.0332061	0.6369222	3.464E-05	0.0026611	34.49	869.12
05.05.99	7.91	144.00	326.667	0.51	0.0002	0.00004	0.0557125	0.6125784	9.914E-06	0.022491	279.82	3005.99
19.05.99	7.63	140.00	139.486	0.44	0.0002	0.00004	0.0547176	0.5841954	7.363E-06	0.0073361	88.74	1245.35
16.07.99	8.07	184.00	1724.077	1.45	0.0002	0.00004	0.0562732	0.9204002	0.0001297	1.2156227	19325.48	103492.9
29.07.99	7.55	186.00	1487.8	1.31	0.0002	0.00004	0.05443	0.8993163	0.0001204	0.9630182	15476.09	46190.24
12.08.99	8.38	185.00	1484.022	1.61	0.0002	0.00004	0.0573438	0.9510887	0.000152	1.2191409	19486.75	69300.86
26.08.99	8.14	185.00	1358.754	1.49	0.0002	0.00004	0.0565167	0.9285287	0.0001356	0.9957069	15915.39	14139.2
09.09.99	8.11	184.00	1330.867	1.45	0.0002	0.00004	0.0564124	0.9193646	0.0001283	0.9277328	14748.72	39830.19
23.09.99	5.95	167.50	1110.116	1.30	0.0002	0.00004	0.0483196	0.9458105	0.0002038	1.3506885	19547.16	29882.11
07.10.99	3.81	161.00	907.643	1.41	0.0002	0.00004	0.0386658	1.0806665	0.0006756	3.8086222	52979.46	65490.08
22.10.99	3.84	161.50	871.015	1.205	0.0002	0.00004	0.0388177	1.0150614	0.0004674	2.5208284	35174.63	77304.33
04.11.99	6.52	160.00	246.505	0.455	0.0002	0.00004	0.0505811	0.6124781	1.191E-05	0.0183415	253.55	1674.76
18.11.99	4.97	157.00	119.356	0.549	0.0002	0.00004	0.0441614	0.7017683	3.833E-05	0.029137	395.24	431.12
02.12.99	4.32	157.00	44.884	0.381	0.0002	0.00004	0.0411724	0.6274558	2.079E-05	0.0059439	80.63	212.31
16.12.99	3.86	150.00	36.414	0.255	0.0002	0.00004	0.0389187	0.5495915	9.067E-06	0.0022011	28.53	125.27
31.12.99	2.97	130.00	13.448	0.188	0.0002	0.00004	0.0341384	0.5176207	7.425E-06	0.0007681	8.63	91.37

Table 4.15: Computation of Sediment Load of The River Surma [Station: Sylhet, Year, 1975, Van Rijn's Approach (Bed Load)]

Sampling date	Hydraulic Radius, R (m)	Width, B (m)	Velocity, U (m/s)	Median size, D_{50} (m)	Slope, (S), (m/km)	Critical Bed Shear Stress $\tau_{b\,cr}$ (N/m^2)	Chezy, C' ($m^{1/2}/s$)	Shear Stress (grain) τ_{b} (N/m^2)	Bed Shear Stress parameter, T	Grain Size parameter, D*	Bed load q_b, (Kg/m/s)	**Bed Load q_b** (ton/day)
07.02.75	2.183	93.675	0.329	0.0002	0.00004	0.1605	81.47052	0.159978	-0.00325	5.0591	0	0
21.02.75	2.223	93.919	0.61	0.0002	0.00004	0.1605	81.61246	0.548044	2.414607	5.0591	0.003915	31.77
07.03.75	2.179	93.838	0.57	0.0002	0.00004	0.1605	81.45618	0.480364	1.992923	5.0591	0.002616	21.21
21.03.75	2.009	92.603	0.329	0.0002	0.00004	0.1605	80.82119	0.162559	0.012827	5.0591	6.54E-08	0
04.04.75	1.927	92.132	0.308	0.0002	0.00004	0.1605	80.49542	0.143624	-0.10514	5.0591	0	0
18.04.75	4.98	106.432	0.308	0.0002	0.00004	0.1605	87.91768	0.120398	-0.24986	5.0591	0	0
02.05.75	6.208	110.813	0.5	0.0002	0.00004	0.1605	89.64068	0.30521	0.90162	5.0591	0.000926	8.87
09.05.75	4.825	105.192	0.18	0.0002	0.00004	0.1605	87.6705	0.041353	-0.74235	5.0591	0	0
23.05.75	7.222	114.533	0.841	0.0002	0.00004	0.1605	90.82339	0.841135	4.240715	5.0591	0.00945	93.52
30.05.75	6.993	113.688	0.777	0.0002	0.00004	0.1605	90.5715	0.721985	3.498347	5.0591	0.007081	69.55
06.06.75	6.102	110.428	0.411	0.0002	0.00004	0.1605	89.50605	0.206846	0.288762	5.0591	0.000168	1.60
14.06.75	7.233	114.579	0.905	0.0002	0.00004	0.1605	90.83528	0.973771	5.067111	5.0591	0.012343	122.19
20.06.75	7.535	119.707	1.067	0.0002	0.00004	0.1605	91.15505	1.344115	7.374547	5.0591	0.021672	224.14
27.06.75	7.017	124.02	0.89	0.0002	0.00004	0.1605	90.59828	0.946693	4.898398	5.0591	0.011732	125.71
05.07.75	7.002	124.559	0.942	0.0002	0.00004	0.1605	90.58155	1.060941	5.610226	5.0591	0.01438	154.76
11.07.75	6.68	138.04	0.94	0.0002	0.00004	0.1605	90.21353	1.069615	5.664268	6.0591	0.01382	164.82
18.07.75	3.679	325.81	1.30	0.0002	0.00004	0.1605	85.55069	2.24782	13.00511	7.0591	0.045926	1292.83
26.07.75	3.78	400.824	1.32	0.0002	0.00004	0.1605	85.7624	2.32393	13.47931	8.0591	0.046572	1612.86
02.08.75	4.009	377.041	1.344	0.0002	0.00004	0.1605	86.2222	2.383578	13.85095	9.0591	0.046839	1525.84
08.08.75	3.856	285.445	1.076	0.0002	0.00004	0.1605	85.91802	1.538598	8.586278	10.0591	0.022154	546.37
27.08.75	3.672	317.136	1.286	0.0002	0.00004	0.1605	85.5358	2.217456	12.81593	11.0591	0.039266	1075.92
29.08.75	3.92	249.456	0.942	0.0002	0.00004	0.1605	86.0467	1.175716	6.325332	12.0591	0.013266	285.924
05.09.75	3.688	307.281	1.372	0.0002	0.00004	0.1605	85.56979	2.521949	14.71308	13.0591	0.045951	1219.95

Table 4.16: Computation of Sediment Load of The River Surma [Station: Sylhet, Year, 1975, Van Rijn's Approach (Suspended Load)]

Selected Reference Level (a), (m)	Chezy, C ($m^{1/2}/s$)	Bed shear Velocity, U* (m/s)	Reference Concentration Ca (% by weight)	Representative particle Size, d_s, (m)	Fall Velocity, W_s, (m/s)	Ratio, β	Suspension Number, Za	Correction factor, ϕ	Corrected Suspension Nember, Z'	Shape Coefficient F	Suspended Load q_s(kg/m/s)	Suspended Load q_s (ton/day)	Total Load Q_s (= q_b+q_s) ton/day
0.0218	55.42526	0.029268	0	0.00017	0.020374	1.96913	0.88377	0	0	0	0	0	0
0.08030	45.38461	0.029535	8.62E-0	0.00017	0.020891	2.00062	0.88388	0.05328	0.937172	0.102049	0.03160	256.45	288.23
0.06796	46.53253	0.029241	7.64E-0	0.00017	0.020801	2.01202	0.88386	0.05100	0.934868	0.091321	0.02295	186.07	207.29
0.0200	55.42526	0.028077	1.33E-0	0.00017	0.020377	2.05343	0.88358	0.00408	0.887672	0.041329	9.66E-0	0.07	0
0.0192	55.42526	0.027498	0	0.00017	0.020352	2.09554	0.88296	0	0	0	0	0	0
0.0498	55.42526	0.044206	0	0.00017	0.020321	1.42263	0.80781	0	0	0	0.01102	101.34	0
0.0820	53.24212	0.049356	1.92E-0	0.00017	0.020567	1.34729	0.77323	0.01915	0.79239	0.054488	0.01140	109.16	118.03
0.0777	51.69963	0.043512	0	0.00017	0.020216	1.43170	0.81126	0	0	0	0	0	0
0.1760	48.45965	0.053235	9.15E-0	0.00017	0.021282	1.31964	0.7573	0.03457	0.791938	0.102949	0.15161	1500.34	1593.86
0.16476	48.72545	0.052384	7.33E-0	0.00017	0.021123	1.32519	0.76070	0.03185	0.79256	0.100392	0.10588	1040.10	1109.66
0.0610	55.42526	0.048933	4.69E-0	0.00017	0.020436	1.34883	0.77406	0.01091	0.784976	0.055705	0.00173	16.5	18.18
0.1776	48.40126	0.053275	0.00011	0.00017	0.021459	1.32449	0.7602	0.03857	0.79886	0.101869	0.20929	2071.92	2194.12
0.16010	49.53347	0.054376	0.00023	0.00018	0.021954	1.32603	0.76120	0.05045	0.811661	0.089232	0.43864	4536.74	4760.89
0.17554	48.25695	0.052474	0.00011	0.00017	0.021423	1.33335	0.7654	0.03838	0.803866	0.102038	0.19237	2061.32	2187.04
0.1727	48.36528	0.052417	0.00014	0.00017	0.021576	1.33885	0.76859	0.04218	0.810778	0.09948	0.24670	2655.04	2809.8
0.16887	48.17497	0.051198	0.00013	0.00017	0.021587	1.35556	0.77761	0.04271	0.820328	0.09908	0.23046	2748.64	2913.46
0.05992	51.61132	0.037995	0.00130	0.00018	0.023165	1.74342	0.87425	0.14037	1.01463	0.044909	0.74067	20850.2	22143.1
0.5626	34.31555	0.038513	0.00014	0.00018	0.023267	1.72994	0.87304	0.05721	0.930257	0.29418	0.54879	19005.3	20618.16
0.05428	53.05524	0.039663	0.00147	0.00018	0.023347	1.69298	0.86922	0.14310	1.012334	0.038433	0.80704	26290.7	27816.57
0.10683	47.4591	0.038899	0.00035	0.00018	0.022215	1.65230	0.86409	0.07897	0.943066	0.081761	0.31776	7836.75	8383.12
0.06162	51.37738	0.037959	0.00108	0.00018	0.023124	1.74222	0.87415	0.13029	1.004446	0.047179	0.64118	17568.9	18644.85
0.1291	46.10532	0.03922	0.00017	0.00017	0.021729	1.61390	0.85821	0.0582	0.916418	0.098805	0.16929	3648.88	3934.81
0.04511	53.84989	0.038042	0.00173	0.00018	0.023532	1.76532	0.87603	0.15912	1.035163	0.033227	0.77351	20536.1	21756.1

Table 4.17: Computation of Sediment Load of The River Surma [Station: Sylhet, Year, 1989, Van Rijn's Approach (Bed Load)]

Sampling date	Hydraulic Radius, R (m)	Width, B (m)	Velocity, U (m/s)	Median size, $D_{50\,(m)}$	Slope, (S), (m/km)	Critical Bed Shear Stress $\tau_{b\,cr}$ (N/m^2)	Chezy, C' $(m^{1/2}/s)$	Shear Stress (grain) $\tau_{b\,(N/m^2)}$	Bed Shear Stress parameter, T	Grain Size parameter, D*	Bed load q_b, (Kg/m/s)	**Bed Load q_b** (ton/day)
01.01.89	1.461	120.661	0.119	0.0002	0.00004	0.1605	78.331	0.02264	-0.85893	5.0591	0	0
11.01.89	1.262	109.55	0.377	0.0002	0.00004	0.1605	77.186	0.23402	0.45811	5.0591	0.0001194	1.13
25.01.89	1.024	96.757	0.557	0.0002	0.00004	0.1605	75.552	0.53318	2.32201	5.0591	0.0036066	30.15
07.02.89	0.931	91.213	0.574	0.0002	0.00004	0.1605	74.808	0.57754	2.59843	5.0591	0.0045675	36.00
22.02.89	1.188	105.51	0.608	0.0002	0.00004	0.1605	76.714	0.61620	2.83927	5.0591	0.0055019	50.16
08.03.89	1.267	72.393	0.724	0.0002	0.00004	0.1605	77.811	0.84925	4.29157	5.0591	0.0096209	60.18
22.03.89	1.209	64.492	0.668	0.0002	0.00004	0.1605	76.851	0.74113	3.61790	5.0591	0.0074469	41.50
05.04.89	3.275	125.886	0.718	0.0002	0.00004	0.1605	84.641	0.70591	3.39822	5.0591	0.0067791	73.73
19.04.89	3.987	128.515	0.469	0.0002	0.00004	0.1605	86.179	0.29054	0.81023	5.0591	0.0007892	8.76
28.06.89	5.169	134.851	1.007	0.0002	0.00004	0.1605	90.765	1.20748	6.52329	5.0591	0.0180298	210.07
12.07.89	5.602	545.551	1.089	0.0002	0.00004	0.1605	82.536	1.70777	9.64033	5.0591	0.0323913	1526.79
17.07.89	5.238	130.378	0.682	0.0002	0.00004	0.1605	88.312	0.58505	2.64517	5.0591	0.0046556	52.44
26.07.89	2.895	501.335	1.107	0.0002	0.00004	0.1605	81.769	1.79798	10.2023	5.0591	0.0352649	1527.51
09.08.89	1.094	547.177	0.392	0.0002	0.00004	0.1605	83.677	0.21529	0.34137	5.0591	0.0002158	10.20
27.12.89	6.594	100.45	0.327	0.0002	0.00004	0.1605	76.069	0.18127	0.12944	5.0591	5.04E-05	0.44

Table 4.18: Computation of Sediment Load of The River Surma [Station: Sylhet, Year, 1989, Van Rijn's Approach (Suspended Load)]

Selected Reference Level (a), (m)	Chezy, C ($m^{1/2}/s$)	Bed shear Velocity, U* (m/s)	Reference Concentration Ca (% by weight)	Representative particle Size, d_s, (m)	Fall Velocity, W_s, (m/s)	Ratio, β	Suspension Number, Za	Correction factor, ϕ	Corrected Suspension Nember, Z'	Shape Coefficient F	Suspended Load q_s(kg/m/s)	Suspended Load q_s (ton/day)	Total Load Q_s (= q_b+q_s) (ton/day)
0.0992	40.4538	0.023943	0	0.00017	0.0201909	2.4222092	0.8703523	0	0	0	0	0	0
0.03325	47.8521	0.022253	1.72E-05	0.000172	0.0204723	2.6926752	0.8541376	0.034516	0.8886537	0.0412149	0.002355	22.29	23.43
0.09481	38.0265	0.020045	6.883E-05	0.000174	0.020871	3.1681382	0.8216075	0.066361	0.8879692	0.0909315	0.031929	266.92	297.08
0.10572	36.4313	0.019113	7.308E-05	0.000174	0.0209302	3.3982628	0.8055944	0.070768	0.876363	0.0966866	0.03943	310.77	346.77
0.11481	37.6921	0.021591	7.686E-05	0.000175	0.0209817	2.8887203	0.8410142	0.065632	0.9066465	0.0925354	0.044578	406.38	456.54
0.13868	37.3123	0.023160	0.0001182	0.000176	0.0212929	2.6904548	0.8542817	0.074589	0.928871	0.0966256	0.0110	68.93	129.11
0.13806	36.3874	0.021781	9.194E-05	0.000176	0.0211485	2.8855398	0.841232	0.070459	0.9116914	0.0934223	0.069333	386.33	427.83
0.13642	44.2708	0.035848	8.47E-05	0.000175	0.0211015	1.6929714	0.8692267	0.045687	0.9149144	0.0901244	0.06797	739.31	813.05
0.0497	53.7024	0.039553	2.707E-05	0.000172	0.0205475	1.5397276	0.8434676	0.026194	0.8696625	0.0434988	0.00727	80.76	89.53
0.14591	49.8698	0.053038	0.0002106	0.000179	0.0217717	1.3369981	0.7675523	0.049296	0.8168488	0.106103	0.316071	3682.59	3892.66
0.11315	43.6285	0.031333	0.000488	0.000182	0.0224413	2.0259129	0.8838112	0.107685	0.991497	0.0562308	0.449754	21199.45	22726.24
0.11394	49.3498	0.045336	6.965E-05	0.00017	0.0209402	1.426674	0.8093723	0.034798	0.8441706	0.0984552	0.052420	590.50	642.95
0.08260	45.3206	0.029832	0.0007277	0.000183	0.0225621	2.1439811	0.8818881	0.131979	1.0138675	0.0666585	0.456766	19785.00	21312.52
0.028	55.68609	0.033704	1.314E-05	0.000172	0.0204473	1.7360802	0.8736104	0.022211	0.8958216	0.0403904	0.001543	72.98	83.19
0.0235	49.44835	0.020719	3.656E-06	0.000172	0.020402	2.9392346	0.8375407	0.019615	0.857156	0.0450856	0.000335	2.91	3.36

Table 4.19: Computation of Sediment Load of The River Surma [Station: Sylhet, Year, 1999, Van Rijn's Approach (Bed Load)]

Sampling date	Hydraulic Radius, R (m)	Width, B (m)	Velocity, U (m/s)	Median size, D_{50} (m)	Slope, (S), (m/km)	Critical Bed Shear Stress $\tau_{b\,cr}$ (N/m^2)	Chezy, C' ($m^{1/2}/s$)	Shear Stress (grain) τ_{b} (N/m^2)	Bed Shear Stress parameter, T	Grain Size parameter, D*	Bed load q_b, (Kg/m/s)	**Bed Load** q_b (ton/day)
13/01/99	2.74	67.00	0.23	0.0002	0.00004	0.1605	83.24706	0.073587	-0.541514	5.059	0	0
27/01/99	2.6	67.00	0.22	0.0002	0.00004	0.1605	82.83707	0.066084	-0.588262	5.059	0	0
10.02.99	2.46	63.00	0.19	0.0002	0.00004	0.1605	82.40438	0.0510604	-0.681867	5.059	0	0
24.02.99	2.33	65.00	0.15	0.0002	0.00004	0.1605	81.97996	0.0319725	-0.800794	5.059	0	0
10.03.99	2.26	61.00	0.11	0.0002	0.00004	0.1605	81.7415	0.0168094	-0.895269	5.059	0	0
24.03.99	2.31	155.00	0.19	0.0002	0.00004	0.1605	81.91257	0.0516754	-0.678035	5.059	0	0
07.04.99	2.35	129.00	0.26	0.0002	0.00004	0.1605	82.04677	0.0947603	-0.409593	5.059	0	0
21.04.99	2.81	150.00	0.31	0.0002	0.00004	0.1605	83.44427	0.1336526	-0.167273	5.059	0	0
05.05.99	7.91	144.00	0.51	0.0002	0.00004	0.1605	91.53473	0.3033422	0.8899823	5.059	0.00155388	19.33
19.05.99	7.63	140.00	0.44	0.0002	0.00004	0.1605	91.25299	0.2301544	0.4339839	5.059	0.00052912	6.40
16.07.99	8.07	184.00	1.45	0.0002	0.00004	0.1605	91.69128	2.4397738	14.201083	5.059	0.09904367	1574.56
29.07.99	7.55	186.00	1.31	0.0002	0.00004	0.1605	91.1706	2.031548	11.65762	5.059	0.07366469	1183.82
12.08.99	8.38	185.00	1.61	0.0002	0.00004	0.1605	91.98594	2.9903164	17.631255	5.059	0.13701539	2190.05
26.08.99	8.14	185.00	1.49	0.0002	0.00004	0.1605	91.75879	2.572831	15.0301	5.059	0.10784184	1723.74
09.09.99	8.11	184.00	1.45	0.0002	0.00004	0.1605	91.72993	2.4377182	14.188275	5.059	0.09890971	1572.43
23.09.99	5.95	167.50	1.30	0.0002	0.00004	0.1605	89.30886	2.075383	11.930735	5.059	0.17920739	2593.49
07.10.99	3.81	161.00	1.41	0.0002	0.00004	0.1605	85.8242	2.6328136	15.403823	5.059	0.30646062	4262.99
22.10.99	3.84	161.50	1.205	0.0002	0.00004	0.1605	85.88551	1.9310933	11.031734	5.059	0.06781257	946.23
04.11.99	6.52	160.00	0.455	0.0002	0.00004	0.1605	90.02401	0.2505966	0.5613493	5.059	0.00029224	4.04
18.11.99	4.97	157.00	0.549	0.0002	0.00004	0.1605	87.90197	0.382663	1.3841934	5.059	0.00194477	26.38
02.12.99	4.32	157.00	0.381	0.0002	0.00004	0.1605	86.80626	0.1889804	0.1774483	5.059	2.6026E-05	0.35
16.12.99	3.86	150.00	0.255	0.0002	0.00004	0.1605	85.92612	0.0863971	0	5.059	0	0
31.12.99	2.97	130.00	0.188	0.0002	0.00004	0.1605	83.87717	0.049283	0	5.059	0	0

Table 4.20: Computation of Sediment Load of The River Surma [Station: Sylhet, Year, 1999, Van Rijn's Approach (Suspended Load)]

Selected Reference Level (a), (m)	Chezy, C ($m^{1/2}/s$)	Bed shear Velocity, U* (m/s)	Reference Concentration Ca (% by weight)	Representative particle Size, d_s, (m)	Fall Velocity, W_s, (m/s)	Ratio, β	Suspension Number, Za	Correction factor, ϕ	Corrected Suspension Nember, Z'	Shape Coefficient F	Suspended Load q_s(kg/m/s)	Suspended Load q_s (ton/day)	Total Load Q_s (= q_b+q_s) ton/day
0.029	54.9522	0.032789	0	0.000171	0.020258	1.7634379	0.875894	0	0	0	0	0	0
0.035	53.1443	0.031941	0	0.000171	0.020248	1.8037535	0.878636	0	0	0	0	0	0
0.049	50.0207	0.031069	0	0.000171	0.020228	1.8478193	0.880880	0	0	0	0	0	0
0.073	46.5019	0.030237	0	0.000171	0.020203	1.8928769	0.882466	0	0	0	0	0	0
0.098	43.9927	0.029779	0	0.000171	0.020183	1.9186954	0.883089	0	0	0	0	0	0
0.047	49.8156	0.030107	0	0.000171	0.020229	1.9029456	0.882733	0	0	0	0	0	0
0.024	55.4252	0.030366	0	0.000172	0.020286	1.8926136	0.882459	0	0	0	0	0	0
0.028	55.4252	0.033206	0	0.000172	0.020338	1.7503057	0.874843	0	0	0	0	0	0
0.07	56.3472	0.055712	2.20301E-05	0.000173	0.020564	1.272499	0.725187	0.01835	0.743540	0.063118	0.013185	164.0468302	183.38
0.054	58.1711	0.054717	9.82054E-06	0.000172	0.020467	1.279827	0.730665	0.01342	0.744092	0.063012	0.003892	47.08107698	53.49
0.11	53.0110	0.056273	0.000898222	0.000188	0.023422	1.3464859	0.772798	0.08904	0.861839	0.044483	1.682651	26750.12586	28324.69
0.115	52.1615	0.05443	0.000640545	0.000185	0.022875	1.3532479	0.776403	0.07838	0.854785	0.048260	1.138200	18291.33342	19475.16
0.105	53.6399	0.057343	0.001296868	0.000192	0.024160	1.3550306	0.777336	0.10414	0.8814783	0.042060	2.444501	39072.91554	41262.97
0.103	53.5930	0.056516	0.001044544	0.000189	0.023600	1.3487587	0.774022	0.09482	0.868851	0.043599	1.845397	29496.83633	31220.59
0.103	53.5946	0.056412	0.000961767	0.000188	0.023419	1.3446959	0.771825	0.0913	0.863145	0.044317	1.674097	26614.13412	28186.57
0.108	50.7841	0.048319	0.000705575	0.000185	0.022933	1.450544	0.818017	0.0898	0.907817	0.041425	1.008179	14590.37948	17183.87
0.088	48.8901	0.038665	0.001268683	0.000189	0.023681	1.7502039	0.874834	0.13924	1.014078	0.02929	1.217172	16931.35547	21194.35
0.118	46.6333	0.038817	0.000571601	0.000184	0.022740	1.6863869	0.868464	0.09768	0.966149	0.040670	0.693342	9674.623115	10620.86
0.065	55.4252	0.050581	1.18988E-05	0.00017	0.020494	1.328338	0.762565	0.01545	0.778021	0.056875	0.005320	73.54718208	77.59
0.066	53.1812	0.044161	4.53599E-05	0.000174	0.020670	1.4381652	0.813645	0.02962	0.843272	0.058400	0.019154	259.8227347	286.21
0.043	55.4252	0.041172	3.19171E-06	0.000172	0.020412	1.4915872	0.830953	0.0107	0.841683	0.04714	0.000656	8.902802188	9.26
0.039	55.4252	0.038918	0	0.000172	0.020374	1.5481281	0.845394		0.845394	0.046641		0	0
0.03	55.4252	0.034138	0	0.000172	0.020374	1.712382	0.871326		0.871326	0.043292		0	0

Table 4.21: Discrepancy Ratio of Various Sediment Transport Equations (1975)

Serial No.	Sampling Date	Computed Sediment Load/ Observed Suspended load		
		Engelund Hansen's Equation	Ackers-white 's Equation	Van Rijn's Equation
1	07.02.75	1.33	0.23	0
2	21.02.75	6.25	1.44	9.16
3	07.03.75	3.07	0.64	3.83
4	21.03.75	3.02	0.32	0
5	04.04.75	1.38	0.13	0
6	18.04.75	0.12	0.2	0
7	02.05.75	0.3	0.66	0.05
8	09.05.75	0.04	0.03	0
9	23.05.75	0.27	0.89	0.17
10	30.05.75	0.19	0.59	0.1
11	06.06.75	0.18	0.31	0.01
12	14.06.75	0.33	1.19	0.24
13	20.06.75	0.31	1.1	0.31
14	27.06.75	0.25	0.87	0.18
15	05.07.75	0.3	1.09	0.25
16	11.07.75	0.17	0.72	0.14
17	18.07.75	0.07	0.62	0.23
18	26.07.75	0.1	0.7	0.22
19	02.08.75	0.53	3.72	1.57
20	08.08.75	0.21	1.38	0.42
21	27.08.75	0.18	1.55	0.54
22	29.08.75	0.45	2.56	0.6
23	05.09.75	0.15	1.24	0.46
MEAN		**1.156**	**0.646**	**0.953**

Table 4.22: Discrepancy Ratio of Various Sediment Transport Equations (1989)

Serial No.	Sampling Date	Computed Sediment Load/ Observed Suspended load		
		Engelund Hansen's Equation	Ackers-white 's Equation	Van Rijn's Equation
1	01.01.89	0.13	0.07	0
2	11.01.89	0.97	2.38	0.61
3	25.01.89	3.23	14.16	18.15
4	07.02.89	1.28	6.74	9.69
5	22.02.89	1.45	8.79	7.72
6	08.03.89	6.34	8.66	7.95
7	22.03.89	1.98	3.6	13.03
8	05.04.89	0.72	0.67	0.9
9	19.04.89	0.12	0.04	0.03
10	28.06.89	0.23	0.05	0.2
11	12.07.89	0.21	0.66	1.06
12	17.07.89	0.2	0.05	0.11
13	26.07.89	0.17	0.84	0.98
14	09.08.89	0.01	0.02	0.01
15	27.12.89	0.24	0.55	0.04
MEAN		**1.152**	**3.152**	**4.032**

Table 4.23: Discrepancy Ratio of Various Sediment Transport Equations (1999)

Serial No.	Sampling Date	Computed Sediment Load/ Observed Suspended load		
		Engelund Hansen's Equation	Ackers-white 's Equation	Van Rijn's Equation
1	13.01.99	0.61	0.9	0
2	27.01.99	0.64	0.34	0
3	10.02.99	0.35	0.13	0
4	24.02.99	0.18	0.06	0
5	10.03.99	0.21	0.03	0
6	24.03.99	0.13	0.03	0
7	07.04.99	0.09	0.05	0
8	21.04.99	0.14	0.04	0
9	05.05.99	0.47	0.1	0.07
10	19.05.99	0.79	0.08	0.05
11	16.07.99	0.15	0.19	0.28
12	29.07.99	0.25	0.34	0.43
13	12.08.99	0.29	0.29	0.6
14	26.08.99	1.14	1.13	2.21
15	09.09.99	0.38	0.38	0.71
16	23.09.99	0.24	0.66	0.58
17	07.10.99	0.07	0.81	0.33
18	22.10.99	0.04	0.46	0.14
19	04.11.99	0.56	0.16	0.05
20	18.11.99	2.07	0.92	0.67
21	02.12.99	1.64	0.38	0.05
22	16.12.99	1.01	0.23	0
23	31.12.99	0.44	0.1	0
MEAN		**0.52**	**0.34**	**0.268**

Table 4.24: Summary of Implemented Bank Protection Works of the Surma River at Sylhet.

Location	Types of work	Length of work, m	Construction year	Geometry of the sight (from u/s to d/s)	Present condition
Tukerbazar	Revetment	154.6	1999-01	Partly concave and right bank	Boulders are not in right place
Kanishail to Ghashitula	Revetment	981	1993-01	Concave and right bank	Boulders are displaced and slope is reduced
Khalopar	Revetment	900	1984-87	Concave and left bank	Partly failed in downstream portion
Kazirbazar to Mollapara	Revetment	1226	1993-01	Straight reach of the river and right bank	Human interference is too much here and structures are build on the bank protection works
Technical Cellege to Mistri Mosque	Revetment	780	1998-01	Straight reach of the river and left bank	Boulders are found irregularly and the protection works getting eroded continuously
Jhalopar	Revetment	160	1991-01	Convex and left bank	Road beside the protection works getting damaged due to river bank failure
Mendibagh	Revetment	45	1991-01	Straight reach of the river and right bank	Protection works is about to fail
Kushighat to Burhanabad	Revetment	382	1998-01	Concave and right bank	Total sites seems getting damaged

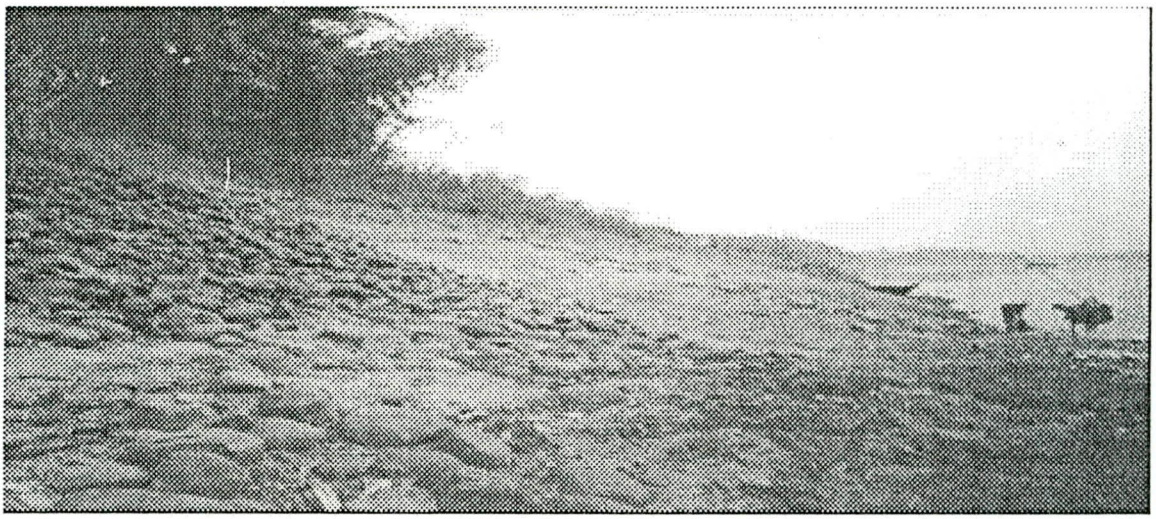
Table 4.25: Geotechnical Properties of the Right Bank of the River Surma at Kazirbazar, Sylhet.

Index properties of Soil samples (September'2003)					
Sample Location	Specific Gravity	Liquid Limit	Plastic Limit	Plasticity Index	USCS Symbol
Kazirbazar, Sylhet City	2.68	39	21	18	CL

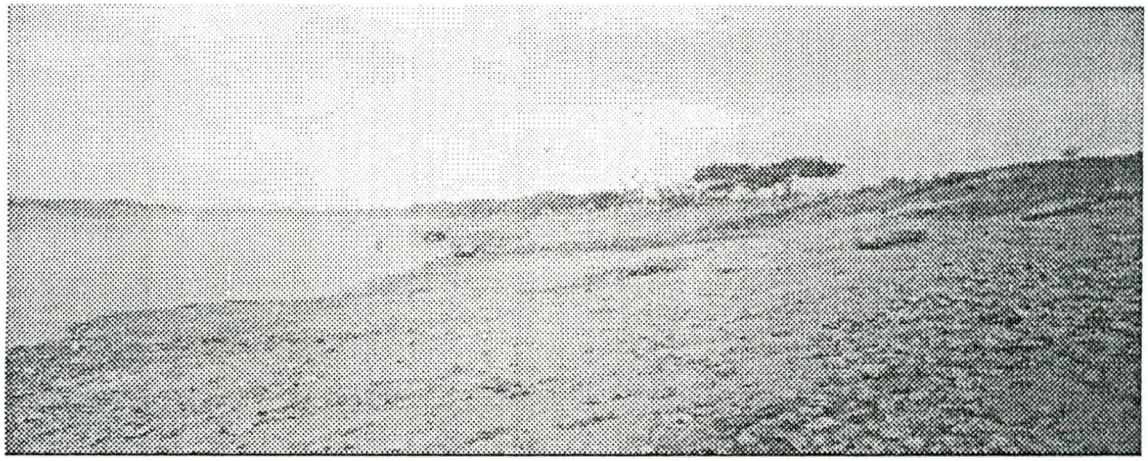
Grain Size Distribution of Soil Samples (September'2003)							
Sample Location	% Finer, # 200 Sieve (0.074 mm)	Sand (%)	Silt (%)	Clay (%)	D_{60} (mm)	D_{50} (mm)	D_{10} (mm)
Kazirbazar, Sylhet City	95.6	7.0	79.7	13.3	0.022	0.016	0.0013

Table 4.26: Parameters for assessment of susceptibility to down slope migration (September'2003)

Sample Location	% of Particles ($\leq$ 0.06 mm)	Uniformity Coefficient, $Cu = D_{60}/D_{10}$	% of Particles between (0.02-0.1 mm)	Ratio of clay to silt fraction	Plasticity Index	Remark
Kazirbazar, Sylhet City	93	17	38	0.17	18	Susceptible to down slope migration

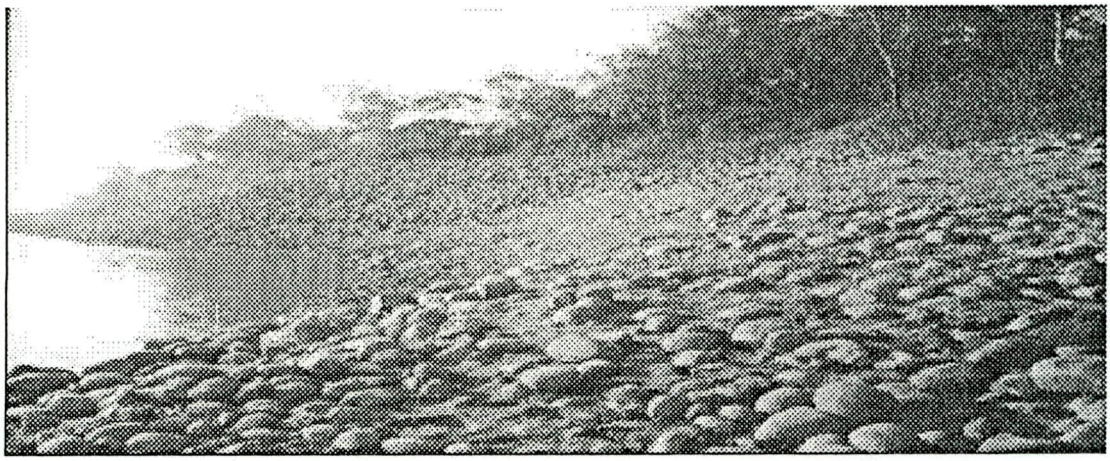


Photograph 01: Tukerbazar bank protection works (Date: 07-02-2003)

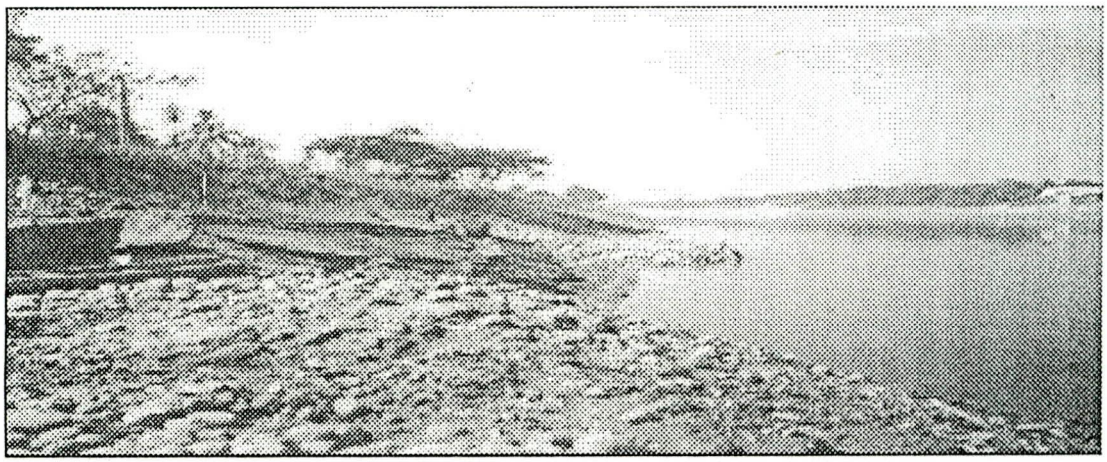


Photograph 02: Kanishail to Ghashitula bank protection works (Date: 07-02-2003)

Photograph 03: Khalopar bank protection works (Date: 07-02-2003)

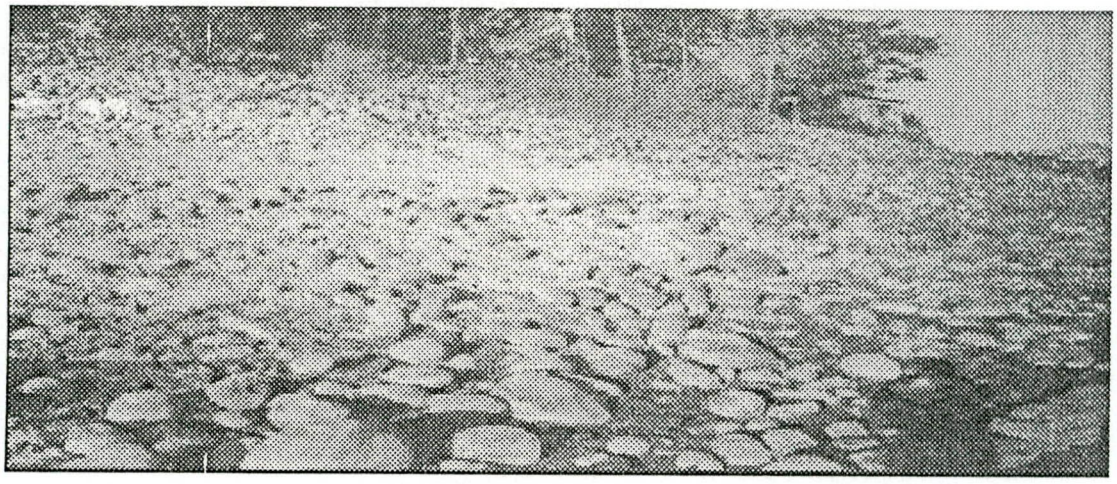


Photograph 04: Kazirbazar to Mollapara bank protection works (Date: 07-02-2003)

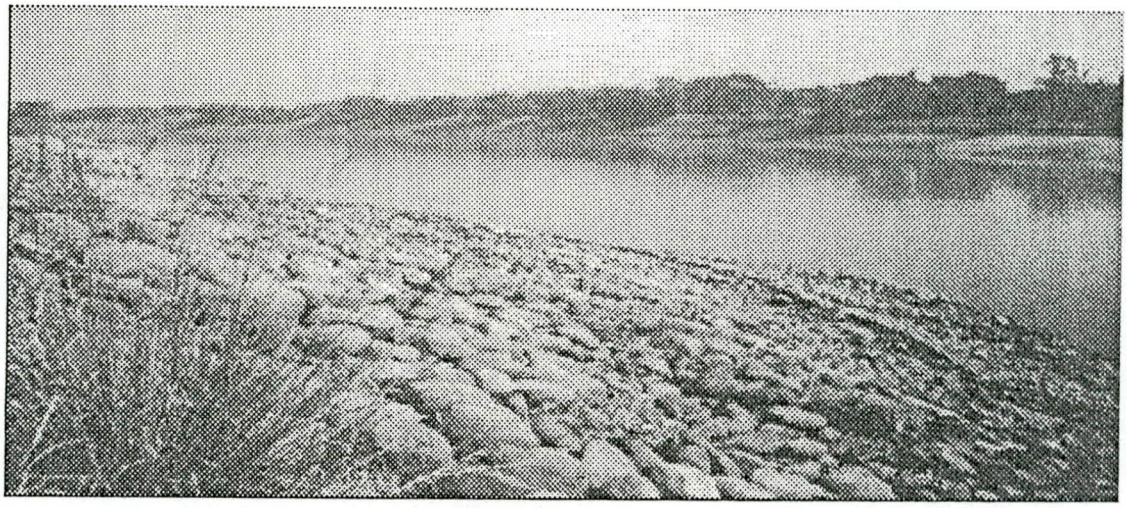


Photograph 05: Technical College to Mistri Mosque bank protection works (Date: 07-02-2003)

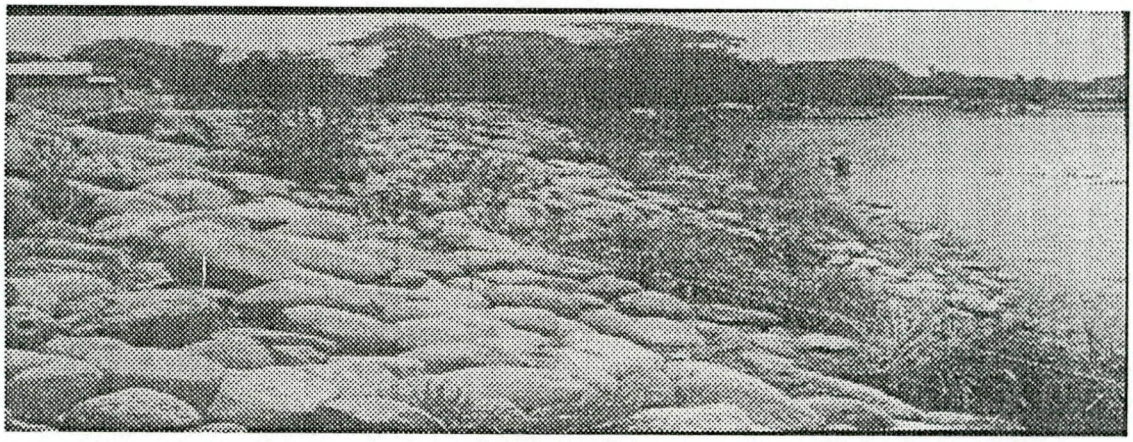
Photograph 06: Jhalopar bank protection works (Date: 07-02-2003)



Photograph 07: Mendibagh bank protection works (Date: 07-02-2003)

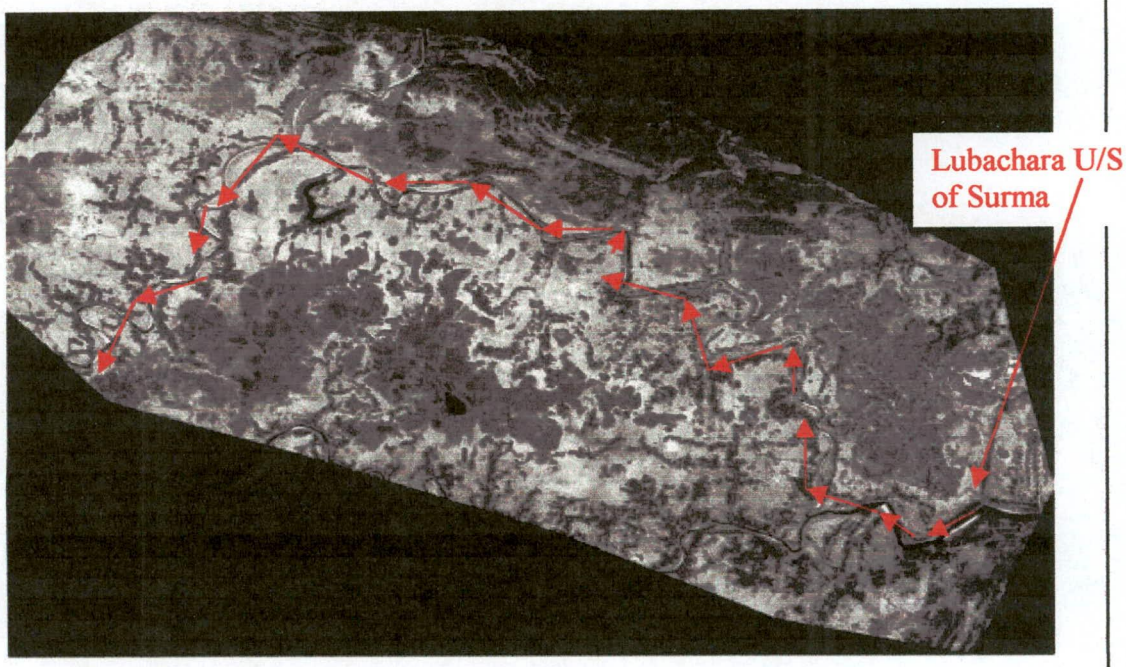


Photograph 08: Kushighat to Burhanabad bank protection works (Date: 07-02-2003)

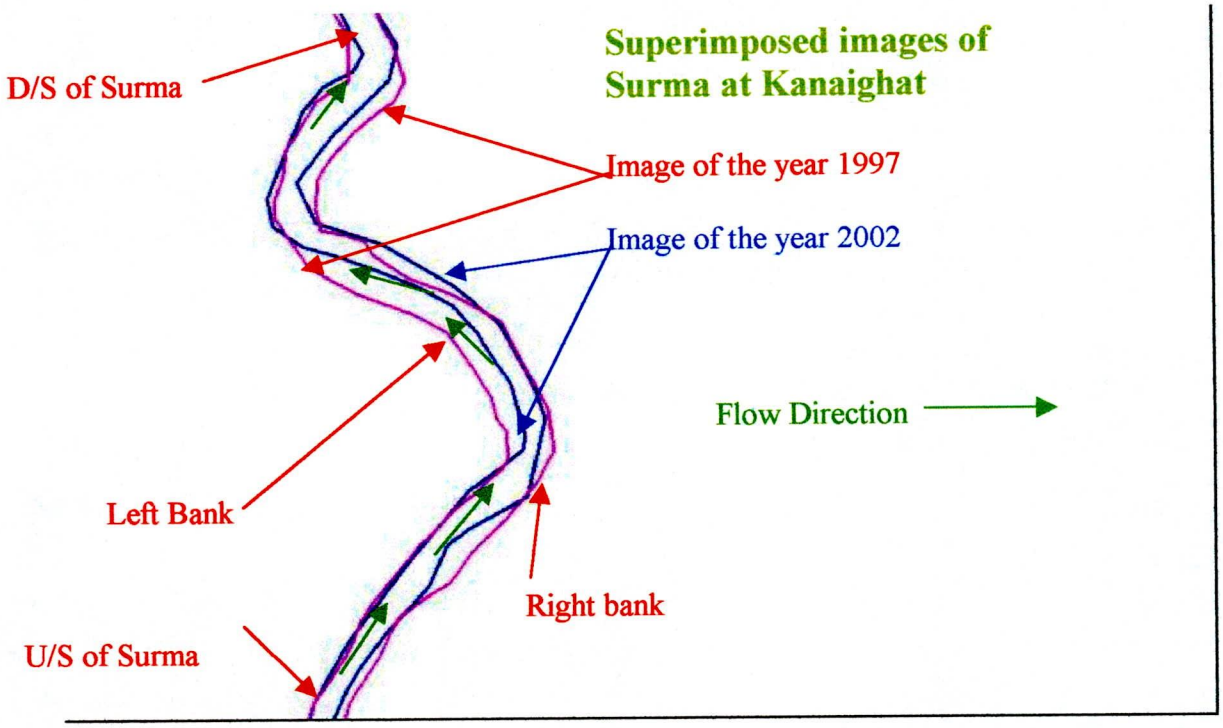


Photograph 09: Bank Protection Works at Kola para, Sylhet (Date: 07-02-2003)

Photograph 10: Satellite image of Surma river system in 1997 (30 m interval) (Source: CEGIS)



Photograph 11: IRS image (6m interval) of Surma river system, 2002 (Source: CEGIS)



Photograph 12: Superimposition of images (Photograph 10 and 11) of the River Surma for a small reach at Kanairghat (Source: CEGIS)

Appendix-X
(Sample Calculation)

Bank Protection Study:

Sample calculation of Design of Bank Protection Works

Location: Kazirbazar to Molla para

Design Data:

1. Discharge – Bank full : 2060 cumec
2. High Water Level – Bank full : 11.74 m PWD
3. Average Low Water Level : 1.87 m PWD
4. Average Flow Velocity : 1.17 m/sec
5. Average Size of Bed Material : 0.034 mm
6. d_{10} : 0.0013 mm
7. d_{50} : 0.016 mm
8. d_{60} : 0.022mm
9. Average River Bed Level : 10.8 m PWD
10. Revetment Material : Boulder
11. Specific Gravity, S_g : 2.65 (stone), 2.2 (C.C.)
12. Ratio of Water Depth & Revetment Size, h/D : 5
13. Slope of Bank, θ : 26.5°
14. Angle of Repose, Φ : 40°

Design Computation

Design for Size of Revetment Material

Against Velocity

a) Using Neill's method

$$D = 0.034V^2$$

$$= 0.034 * (2*1.17)^2$$

$$= 0.186 \text{ m}$$

$$= 186 \text{ mm}$$

b) Using JMBA Equation

$$D_n = \frac{0.7V^2}{2(S_g - 1)g} \frac{2}{\log(6 * h/D)} \frac{1}{\left[1 - (Sin\theta / Sin\Phi)^2\right]^{0.5}}$$

$$= \frac{0.7 \times 2.34^2}{2(2.65-1)9.81} \times \frac{2}{\left[\log(6 \times 5)^2\right]} \times \frac{1}{\left[1 - (Sin26.5° / Sin40°)^2\right]^{0.5}}$$

$= 0.145$ m $= 145$ mm

$$D = \frac{D_n}{0.81} = \frac{145}{0.81}$$

$$= 179 \text{ mm} \approx 180 \text{ mm}$$

Against Wave

Since, the wind fetch for wave is about 1-2 km, therefore no severe wind induced wave is directly attacking towards the river banks. And, so, the calculation against wave is insignificant.

Design for Thickness of Riprap

a) Using Inglish Formula

Revetment Thickness, $T = 0.06Q^{1/3}$

$$= 0.06(2060 \times 0.7)^{1/3}$$

$$= 0.678 \text{ m} = 678 \text{ mm}$$

b) Based on stone size:

According to ESCAPE, Thickness of Protection

$$= 1.5D = 1.5 \times 47 = 70.5 \text{ mm}$$

Design of Launching Apron

--The apron is assumed to launch in 1:2 slope.

-- Length of Apron equal to 1.5 times scour depth below bed level.

-- Scour multiplying factor is 1.5 (for minor river bend)

Silt Factor, $f = 1.76(d_{50})^{1/2}$

$$= 1.76(0.016)^{1/2}$$

$$= 0.223$$

Scour Depth, $R = 0.47(Q/f)^{1/3}$

$$= 0.47(1442/0.223)^{1/3}$$

$$= 8.76 \text{ m}$$

Design Scour Depth $= 1.5R = 1.5 \times 8.76$

= 13.14 m

Depth of Scour, Y = (Design Water Level) – (Design Scour Depth)

= 10.8 – 13.14

= (-) 2.32 m

Design Depth of Scour from LWL, D = (1.67+2.32) = 3.99 ≈ 4.00 m

Average Thickness of launching apron = 1.25T =678*1.25 = 847.5 mm≈ 850 mm

Length of Launched Apron, = 2.25D =2.25* 4.00 =10.00 m

Volume of Stone Required = 2.82 DT = 2.25*4.00*0.678 = 7.64 ≈ 7.70 m^3/m.

Inside thickness of un-launched apron = 1.5T = 1.5* 678 = 1017 mm ≈ 1000 mm

Outside thickness of un-launched apron = 2.25 T = 2.25 * 678 = 1525mm ≈ 1500 mm

For C.C. Blocks

$$\frac{4}{3}\pi r^3 = L^3$$

$$L = \left(\sqrt[3]{\frac{4}{3}\pi}\right).\ r = 1.61 * 93 = 149.73 = 150 \text{ mm. } (d = 186 \text{ mm})$$

Dimension of CC Blocks, $150mm \times 150mm \times 150mm$

Required volume = 2.25 D * 1.25 T* 1= 2.25*4*1.25*0.150*1 = 1.687 m^3/m≈ 1.7 m^3/m

Design for Grading of Riprap Materials

Gradation of Stone is recommended as follows:

250 mm to 300 mm	30%
300 mm to 350 mm	50%
350 mm to 400 mm	20%

Design of Geotextile

From the Grain Size analysis of the selected site the following findings were found:

d_{10} : 0.0013 mm

d_{50} : 0.016 mm

d_{60} : 0.022 mm

C_u : 17

A. Design for soil retention

According to **PIANC-method**, grain size range is-group A, which implies amount of fines ≤0.06 mm is more than 40% and the retention criteria, is

$$O_{90} < d_{90}$$

$$< 10d_{50}$$

$$< 0.3\,\text{mm}$$

Now, putting the data,

$$O_{90} < 0.022$$

$$< 0.16\,\text{mm}$$

$$< 0.3\ \text{mm}$$

$$< 0.3$$

Therefore, effective opening size O_{90} should be less than 0.022 mm

B. Design for permeability

In general, the permeability of the geotextile material is acceptable if

$$\eta \cdot k_g \geq k_s \text{ , where,}$$

η (-) material specific reduction factor

k_g (m/s) permeability of the geotextile

k_s (m/s) permeability of the soil

If k_s is not available from laboratory tests, it can be approximated by the empirical relation (Hazen, in Tomlinson, 1996):

$$k = 0.0116 \cdot d_{10}^{\ 2}$$

$$= 0.0116 \times 0.0013^2$$

$$= 1.9604 \times 10^{-8}\ \text{m/s}$$

The reduction factor η for needle punched and other non-woven fabrics thicker than 2 mm (measured at a normal stress of 2 KN/m^2) is defined as a constant: $\eta = \frac{1}{50}$

The permeability of the geotextile should be = 9.8*10^{-7} m/s

The gradation of the boulder is

250 mm to 300 mm	30%
300 mm to 350 mm	50%
350 mm to 400 mm	20%

The geotextile specification,

Permeability is 9.8*10^{-7}

Effective opening size O_{90} is 0.022mm

To prevent the down slope migration, stabilization of the soil surface may be adopted. The requirement of the coarse layer may be as follows:

O90 $= 0.3 \langle O_{90} \langle 1.5mm$ (for range A grading curve)

Thickness (t) = $5 \langle t \langle 15mm$

Appendix-Z

(Data)

District	Station ID	Station Name	Date	Discharge (m^3/S)
Sylhet	SW266	Kanairghat	1/12/98	7.01
Sylhet	SW266	Kanairghat	1/26/98	7.67
Sylhet	SW266	Kanairghat	2/9/98	4.36
Sylhet	SW266	Kanairghat	2/23/98	8.15
Sylhet	SW266	Kanairghat	3/1/98	5.81
Sylhet	SW266	Kanairghat	3/2/98	5.56
Sylhet	SW266	Kanairghat	3/3/98	5.54
Sylhet	SW266	Kanairghat	3/4/98	5.54
Sylhet	SW266	Kanairghat	3/5/98	5.15
Sylhet	SW266	Kanairghat	3/6/98	4.53
Sylhet	SW266	Kanairghat	3/7/98	4.46
Sylhet	SW266	Kanairghat	3/8/98	5.86
Sylhet	SW266	Kanairghat	3/9/98	7.35
Sylhet	SW266	Kanairghat	3/10/98	7.08
Sylhet	SW266	Kanairghat	3/11/98	5.78
Sylhet	SW266	Kanairghat	3/12/98	5.70
Sylhet	SW266	Kanairghat	3/13/98	4.66
Sylhet	SW266	Kanairghat	3/14/98	4.67
Sylhet	SW266	Kanairghat	3/15/98	5.01
Sylhet	SW266	Kanairghat	3/16/98	5.76
Sylhet	SW266	Kanairghat	3/17/98	4.86
Sylhet	SW266	Kanairghat	3/18/98	4.72
Sylhet	SW266	Kanairghat	3/19/98	4.55
Sylhet	SW266	Kanairghat	3/20/98	4.66
Sylhet	SW266	Kanairghat	3/21/98	4.48
Sylhet	SW266	Kanairghat	3/22/98	4.28
Sylhet	SW266	Kanairghat	3/23/98	10.18
Sylhet	SW266	Kanairghat	3/24/98	69.65
Sylhet	SW266	Kanairghat	3/25/98	276.22
Sylhet	SW266	Kanairghat	3/26/98	477.60
Sylhet	SW266	Kanairghat	3/27/98	626.35
Sylhet	SW266	Kanairghat	3/28/98	583.44
Sylhet	SW266	Kanairghat	3/29/98	488.63
Sylhet	SW266	Kanairghat	3/30/98	371.81
Sylhet	SW266	Kanairghat	3/31/98	265.49
Sylhet	SW266	Kanairghat	4/1/98	210.24
Sylhet	SW266	Kanairghat	4/2/98	165.77
Sylhet	SW266	Kanairghat	4/3/98	96.05
Sylhet	SW266	Kanairghat	4/4/98	75.41
Sylhet	SW266	Kanairghat	4/5/98	64.15
Sylhet	SW266	Kanairghat	4/6/98	52.49
Sylhet	SW266	Kanairghat	4/11/98	42.66
Sylhet	SW266	Kanairghat	4/12/98	74.26
Sylhet	SW266	Kanairghat	4/13/98	134.09
Sylhet	SW266	Kanairghat	4/14/98	181.44
Sylhet	SW266	Kanairghat	4/15/98	201.53
Sylhet	SW266	Kanairghat	4/16/98	165.59
Sylhet	SW266	Kanairghat	4/17/98	135.24
Sylhet	SW266	Kanairghat	4/18/98	83.22
Sylhet	SW266	Kanairghat	4/19/98	75.48
Sylhet	SW266	Kanairghat	4/20/98	66.05

District	Station ID	Station Name	Date	Discharge (m^3/S)
Sylhet	SW266	Kanairghat	4/21/98	77.85
Sylhet	SW266	Kanairghat	4/22/98	132.64
Sylhet	SW266	Kanairghat	4/24/98	441.24
Sylhet	SW266	Kanairghat	4/25/98	522.87
Sylhet	SW266	Kanairghat	4/26/98	432.16
Sylhet	SW266	Kanairghat	4/27/98	349.19
Sylhet	SW266	Kanairghat	4/28/98	274.75
Sylhet	SW266	Kanairghat	4/29/98	207.59
Sylhet	SW266	Kanairghat	4/30/98	173.21
Sylhet	SW266	Kanairghat	5/1/98	142.89
Sylhet	SW266	Kanairghat	5/2/98	178.72
Sylhet	SW266	Kanairghat	5/3/98	132.16
Sylhet	SW266	Kanairghat	5/4/98	72.94
Sylhet	SW266	Kanairghat	5/5/98	72.94
Sylhet	SW266	Kanairghat	5/6/98	60.85
Sylhet	SW266	Kanairghat	5/7/98	53.22
Sylhet	SW266	Kanairghat	5/8/98	43.64
Sylhet	SW266	Kanairghat	5/9/98	136.54
Sylhet	SW266	Kanairghat	5/10/98	182.56
Sylhet	SW266	Kanairghat	5/11/98	199.23
Sylhet	SW266	Kanairghat	5/12/98	161.02
Sylhet	SW266	Kanairghat	5/13/98	135.37
Sylhet	SW266	Kanairghat	5/14/98	106.12
Sylhet	SW266	Kanairghat	5/15/98	82.61
Sylhet	SW266	Kanairghat	5/16/98	61.87
Sylhet	SW266	Kanairghat	5/17/98	42.26
Sylhet	SW266	Kanairghat	5/18/98	35.38
Sylhet	SW266	Kanairghat	5/19/98	24.69
Sylhet	SW266	Kanairghat	5/20/98	21.46
Sylhet	SW266	Kanairghat	5/21/98	18.71
Sylhet	SW266	Kanairghat	5/22/98	322.63
Sylhet	SW266	Kanairghat	5/23/98	1276.06
Sylhet	SW266	Kanairghat	5/24/98	1210.93
Sylhet	SW266	Kanairghat	5/25/98	861.56
Sylhet	SW266	Kanairghat	5/26/98	671.94
Sylhet	SW266	Kanairghat	5/27/98	578.93
Sylhet	SW266	Kanairghat	5/28/98	470.34
Sylhet	SW266	Kanairghat	5/29/98	416.81
Sylhet	SW266	Kanairghat	5/30/98	681.05
Sylhet	SW266	Kanairghat	5/31/98	1666.85
Sylhet	SW266	Kanairghat	6/1/98	1416.86
Sylhet	SW266	Kanairghat	6/15/98	1802.22
Sylhet	SW266	Kanairghat	6/29/98	1453.92
Sylhet	SW266	Kanairghat	7/13/98	1563.29
Sylhet	SW266	Kanairghat	7/27/98	1988.51
Sylhet	SW266	Kanairghat	8/10/98	2013.27
Sylhet	SW266	Kanairghat	8/24/98	1154.41
Sylhet	SW266	Kanairghat	9/7/98	1363.25
Sylhet	SW266	Kanairghat	9/21/98	1030.93
Sylhet	SW266	Kanairghat	10/5/98	197.56
Sylhet	SW266	Kanairghat	10/19/98	244.58

District	Station ID	Station Name	Date	Discharge
Sylhet	SW266	Kanairghat	11/2/98	164.48
Sylhet	SW266	Kanairghat	11/30/98	142.14
Sylhet	SW266	Kanairghat	12/14/98	89.80
Sylhet	SW266	Kanairghat	12/28/98	37.03
Sylhet	SW266	Kanairghat	1/10/03	11.69
Sylhet	SW266	Kanairghat	1/14/03	10.96
Sylhet	SW266	Kanairghat	1/18/03	10.55
Sylhet	SW266	Kanairghat	1/28/03	8.97
Sylhet	SW266	Kanairghat	1/30/03	8.62
Sylhet	SW266	Kanairghat	2/9/03	6.72
Sylhet	SW266	Kanairghat	2/19/03	5.79
Sylhet	SW266	Kanairghat	2/25/03	4.76
Sylhet	SW266	Kanairghat	2/27/03	4.40
Sylhet	SW266	Kanairghat	3/1/03	5.14
Sylhet	SW266	Kanairghat	3/11/03	5.29
Sylhet	SW266	Kanairghat	3/15/03	6.09
Sylhet	SW266	Kanairghat	3/25/03	5.24
Sylhet	SW266	Kanairghat	7/13/03	1676.35
Sylhet	SW266	Kanairghat	7/28/03	1058.20
Sylhet	SW266	Kanairghat	8/12/03	1429.94
Sylhet	SW266	Kanairghat	8/25/03	1359.49
Sylhet	SW266	Kanairghat	9/8/03	1136.86
Sylhet	SW266	Kanairghat	9/22/03	1132.55
Sylhet	SW266	Kanairghat	10/6/03	743.62
Sylhet	SW266	Kanairghat	10/20/03	801.73
Sylhet	SW266	Kanairghat	11/3/03	313.13
Sylhet	SW266	Kanairghat	11/17/03	96.69
Sylhet	SW266	Kanairghat	12/1/03	38.13
Sylhet	SW266	Kanairghat	12/15/03	17.05
Sylhet	SW266	Kanairghat	12/29/03	21.30

Station ID	Station Name	Date	Discharge (m^3/S)
SW267	Sylhet	1/14/98	7.81
SW267	Sylhet	1/28/98	8.08
SW267	Sylhet	2/11/98	6.13
SW267	Sylhet	2/25/98	13.83
SW267	Sylhet	3/11/98	5.48
SW267	Sylhet	3/25/98	143.06
SW267	Sylhet	4/11/98	48.64
SW267	Sylhet	4/22/98	73.70
SW267	Sylhet	5/6/98	56.47
SW267	Sylhet	5/20/98	53.30
SW267	Sylhet	6/3/98	1359.00
SW267	Sylhet	6/17/98	1574.12
SW267	Sylhet	7/1/98	1306.01
SW267	Sylhet	7/15/98	1502.96
SW267	Sylhet	7/29/98	1806.21
SW267	Sylhet	8/12/98	1713.23
SW267	Sylhet	8/26/98	1621.33
SW267	Sylhet	9/9/98	1462.38
SW267	Sylhet	9/23/98	899.97
SW267	Sylhet	10/7/98	243.91
SW267	Sylhet	10/21/98	241.38
SW267	Sylhet	11/4/98	135.52
SW267	Sylhet	11/18/98	43.32
SW267	Sylhet	12/2/98	38.33
SW267	Sylhet	12/16/98	31.27
SW267	Sylhet	12/30/98	15.55
SW267	Sylhet	1/14/98	7.81
SW267	Sylhet	1/28/98	8.08
SW267	Sylhet	2/11/98	6.13
SW267	Sylhet	2/25/98	13.83
SW267	Sylhet	3/11/98	5.48
SW267	Sylhet	3/25/98	143.06
SW267	Sylhet	4/11/98	48.64
SW267	Sylhet	4/22/98	73.70
SW267	Sylhet	5/6/98	56.47
SW267	Sylhet	5/20/98	53.30
SW267	Sylhet	6/3/98	1359.00
SW267	Sylhet	6/17/98	1574.12
SW267	Sylhet	7/1/98	1306.01
SW267	Sylhet	7/15/98	1502.96
SW267	Sylhet	7/29/98	1806.21
SW267	Sylhet	8/12/98	1713.23
SW267	Sylhet	8/26/98	1621.33
SW267	Sylhet	9/9/98	1462.38
Sylhet	SW267	9/23/98	899.97
Sylhet	SW267	10/7/98	243.91
Sylhet	SW267	10/21/98	241.38
Sylhet	SW267	11/4/98	135.52
Sylhet	SW267	11/18/98	43.32

Station ID	Station Name	Date	Discharge (m^3/S)
Sylhet	SW267	12/2/98	38.33
Sylhet	SW267	12/16/98	31.27
Sylhet	SW267	1/3/03	12.22
Sylhet	SW267	1/16/03	9.67
Sylhet	SW267	1/30/03	9.14
Sylhet	SW267	2/13/03	8.37
Sylhet	SW267	2/27/03	6.92
Sylhet	SW267	3/13/03	6.44
Sylhet	SW267	3/27/03	8.37
Sylhet	SW267	4/10/03	26.31
Sylhet	SW267	4/25/03	117.22
Sylhet	SW267	5/8/03	708.40
Sylhet	SW267	5/22/03	335.53
Sylhet	SW267	6/5/03	3263.32
Sylhet	SW267	6/19/03	5457.08
Sylhet	SW267	7/3/03	1714.25
Sylhet	SW267	7/17/03	1463.06
Sylhet	SW267	7/31/03	1316.82
Sylhet	SW267	8/14/03	1084.63
Sylhet	SW267	8/28/03	1249.04
Sylhet	SW267	9/11/03	1121.50
Sylhet	SW267	9/25/03	1088.24
Sylhet	SW267	10/23/03	330.62
Sylhet	SW267	11/6/03	77.98
Sylhet	SW267	11/20/03	42.90
Sylhet	SW267	12/4/03	19.73
Sylhet	SW267	12/18/03	14.10

District	Station ID	Station Name	Date	Water Level	Discharge	Cross Section Area	River Width	Maximum Depth	Maximum Velocity
Sylhet	SW267	Sylhet	1/14/98	2.26	7.81	22.60	67.00	0.60	0.47
Sylhet	SW267	Sylhet	1/28/98	2.25	8.08	23.55	67.00	0.55	0.48
Sylhet	SW267	Sylhet	2/11/98	2.17	6.13	20.42	63.00	0.47	0.45
Sylhet	SW267	Sylhet	2/25/98	2.36	13.83	27.47	65.00	1.00	0.71
Sylhet	SW267	Sylhet	3/11/98	2.11	5.48	16.83	61.00	0.70	0.44
Sylhet	SW267	Sylhet	3/25/98	4.15	143.06	310.36	155.00	4.00	0.67
Sylhet	SW267	Sylhet	4/11/98	3.54	48.64	217.35	129.00	3.60	0.34
Sylhet	SW267	Sylhet	4/22/98	4.50	73.70	364.70	150.00	5.00	0.34
Sylhet	SW267	Sylhet	5/6/98	4.18	56.47	322.36	144.00	4.65	0.32
Sylhet	SW267	Sylhet	5/20/98	4.01	53.30	302.88	140.00	4.55	0.31
Sylhet	SW267	Sylhet	6/3/98	10.20	1359.00	433.88	184.00	11.16	1.35
Sylhet	SW267	Sylhet	6/17/98	10.94	1574.12	1534.34	194.00	11.43	1.43
Sylhet	SW267	Sylhet	7/1/98	10.08	1306.01	1403.76	184.00	11.00	1.34
Sylhet	SW267	Sylhet	7/15/98	10.74	1502.96	1500.46	186.00	11.25	1.41
Sylhet	SW267	Sylhet	7/29/98	11.19	1806.21	1577.55	209.00	11.58	1.59
Sylhet	SW267	Sylhet	8/12/98	10.87	1713.23	1549.64	185.00	11.16	1.55
Sylhet	SW267	Sylhet	8/26/98	10.70	1621.33	1505.10	185.00	10.97	1.47
Sylhet	SW267	Sylhet	9/9/98	10.46	1462.38	1471.49	184.00	11.06	1.31
Sylhet	SW267	Sylhet	9/23/98	8.51	899.97	997.46	167.50	9.14	1.21
Sylhet	SW267	Sylhet	10/7/98	6.18	243.91	611.25	161.00	7.00	0.52
Sylhet	SW267	Sylhet	10/21/98	6.34	241.38	620.80	161.50	7.10	0.51
Sylhet	SW267	Sylhet	11/4/98	5.24	135.52	481.86	160.00	5.86	0.39
Sylhet	SW267	Sylhet	11/18/98	4.37	43.32	378.30	157.00	5.40	0.20
Sylhet	SW267	Sylhet	12/2/98	4.43	38.33	379.73	157.00	5.45	0.19
Sylhet	SW267	Sylhet	12/16/98	3.46	31.27	345.73	150.00	5.00	0.16
Sylhet	SW267	Sylhet	12/30/98	3.02	15.55	253.40	130.00	3.60	0.12
Sylhet	SW267	Sylhet	1/3/03	2.74	12.22	34.50	64.00	0.98	0.66
Sylhet	SW267	Sylhet	1/16/03	2.49	9.67	27.66	63.00	0.95	0.63
Sylhet	SW267	Sylhet	1/30/03	2.34	9.14	27.01	62.00	0.72	0.62
Sylhet	SW267	Sylhet	2/13/03	2.21	8.37	25.50	61.00	0.90	0.60
Sylhet	SW267	Sylhet	2/27/03	2.12	6.92	22.08	59.00	0.80	0.50
Sylhet	SW267	Sylhet	3/13/03	2.13	6.44	16.10	40.00	1.00	0.54
Sylhet	SW267	Sylhet	3/27/03	2.18	8.37	24.23	60.00	0.88	0.58
Sylhet	SW267	Sylhet	4/10/03	3.23	26.31	188.80	128.00	3.60	0.24
Sylhet	SW267	Sylhet	4/25/03	5.08	117.22	563.71	165.00	5.97	0.33
Sylhet	SW267	Sylhet	5/8/03	7.68	708.40	959.26	180.00	8.38	1.04
Sylhet	SW267	Sylhet	5/22/03	6.19	335.53	757.38	170.00	6.71	0.60
Sylhet	SW267	Sylhet	6/5/03	6.05	3263.32	715.01	171.00	7.01	0.62
Sylhet	SW267	Sylhet	6/19/03	10.48	5457.08	1482.46	184.00	10.55	1.21
Sylhet	SW267	Sylhet	7/3/03	11.26	1714.25	1675.39	186.00	11.22	1.47
Sylhet	SW267	Sylhet	7/17/03	10.60	1463.06	1476.22	184.00	10.21	1.42
Sylhet	SW267	Sylhet	7/31/03	9.88	1316.82	1368.67	182.00	9.72	1.33
Sylhet	SW267	Sylhet	8/14/03	9.73	1084.63	1287.54	185.00	9.45	1.17
Sylhet	SW267	Sylhet	8/28/03	9.59	1249.04	1492.92	184.50	9.39	1.15
Sylhet	SW267	Sylhet	9/11/03	9.03	1121.50	1121.50	182.00	9.24	1.11
Sylhet	SW267	Sylhet	9/25/03	8.87	1088.24	1397.29	182.00	8.99	1.10
Sylhet	SW267	Sylhet	10/23/03	7.41	330.62	898.86	175.50	6.89	0.52
Sylhet	SW267	Sylhet	11/6/03	5.75	77.98	551.81	160.00	5.94	0.24
Sylhet	SW267	Sylhet	11/20/03	4.61	42.90	377.93	142.00	3.63	0.19
Sylhet	SW267	Sylhet	12/4/03	3.87	19.73	290.32	137.00	3.38	0.12
Sylhet	SW267	Sylhet	12/18/03	3.19	14.10	213.38	134.00	2.74	0.11

District	Station ID	Station Name	Date	Water Level	Discharge	Cross Section Area	River Width	Maximum Depth	Maximum Velocity
Sylhet	SW266	Kanairghat	1/12/98	4.86	7.01	23.40	41.00	1.04	0.43
Sylhet	SW266	Kanairghat	1/26/98	4.90	7.67	24.80	42.00	1.07	0.43
Sylhet	SW266	Kanairghat	2/9/98	4.75	4.36	14.53	37.00	0.76	0.46
Sylhet	SW266	Kanairghat	2/23/98	4.98	8.15	24.08	46.00	0.98	0.48
Sylhet	SW266	Kanairghat	3/1/98	4.81	5.81	19.11	39.00	0.73	0.46
Sylhet	SW266	Kanairghat	3/2/98	4.80	5.56	18.81	39.00	0.72	0.45
Sylhet	SW266	Kanairghat	3/3/98	4.78	5.54	18.79	38.00	0.72	0.44
Sylhet	SW266	Kanairghat	3/4/98	4.78	5.54	18.75	38.00	0.70	0.43
Sylhet	SW266	Kanairghat	3/5/98	4.77	5.15	17.84	39.00	0.69	0.44
Sylhet	SW266	Kanairghat	3/6/98	4.76	4.53	17.16	38.00	0.76	0.35
Sylhet	SW266	Kanairghat	3/7/98	4.76	4.46	16.86	38.00	0.76	0.37
Sylhet	SW266	Kanairghat	3/8/98	4.84	5.86	19.19	39.00	0.73	0.46
Sylhet	SW266	Kanairghat	3/9/98	4.89	7.35	22.31	40.00	0.87	0.46
Sylhet	SW266	Kanairghat	3/10/98	4.88	7.08	21.40	40.00	0.86	0.48
Sylhet	SW266	Kanairghat	3/11/98	4.82	5.78	19.40	38.00	0.93	0.40
Sylhet	SW266	Kanairghat	3/12/98	4.78	5.70	19.36	39.00	0.94	0.37
Sylhet	SW266	Kanairghat	3/13/98	4.78	4.66	16.75	38.00	0.73	0.40
Sylhet	SW266	Kanairghat	3/14/98	4.74	4.67	16.91	38.00	0.74	0.37
Sylhet	SW266	Kanairghat	3/15/98	4.75	5.01	16.57	38.00	0.71	0.44
Sylhet	SW266	Kanairghat	3/16/98	4.74	5.76	16.39	37.00	0.71	0.40
Sylhet	SW266	Kanairghat	3/17/98	4.73	4.86	16.32	36.00	0.71	0.40
Sylhet	SW266	Kanairghat	3/18/98	4.73	4.72	15.82	36.00	0.70	0.39
Sylhet	SW266	Kanairghat	3/19/98	4.72	4.55	15.22	35.00	0.68	0.40
Sylhet	SW266	Kanairghat	3/20/98	4.71	4.66	15.53	35.00	0.68	0.39
Sylhet	SW266	Kanairghat	3/21/98	4.70	4.48	15.12	35.00	0.67	0.39
Sylhet	SW266	Kanairghat	3/22/98	4.69	4.28	14.74	35.00	0.66	0.36
Sylhet	SW266	Kanairghat	3/23/98	5.02	10.18	30.15	52.00	0.92	0.52
Sylhet	SW266	Kanairghat	3/24/98	5.90	69.65	249.74	145.00	3.26	0.37
Sylhet	SW266	Kanairghat	3/25/98	8.06	276.22	572.04	159.00	5.33	0.66
Sylhet	SW266	Kanairghat	3/26/98	9.50	477.60	783.38	163.00	6.64	0.86
Sylhet	SW266	Kanairghat	3/27/98	10.32	626.35	913.36	166.00	7.68	0.92
Sylhet	SW266	Kanairghat	3/28/98	10.20	583.44	896.84	165.00	7.59	0.89
Sylhet	SW266	Kanairghat	3/29/98	9.65	488.63	815.92	164.00	7.04	0.81
Sylhet	SW266	Kanairghat	3/30/98	8.91	371.81	645.60	160.00	6.31	0.68
Sylhet	SW266	Kanairghat	3/31/98	8.19	265.49	580.67	157.00	5.64	0.61
Sylhet	SW266	Kanairghat	4/1/98	7.53	210.24	486.52	156.00	4.91	0.57
Sylhet	SW266	Kanairghat	4/2/98	7.02	165.77	412.79	153.50	4.39	0.52
Sylhet	SW266	Kanairghat	4/3/98	6.57	96.05	322.93	149.00	3.90	0.40
Sylhet	SW266	Kanairghat	4/4/98	6.23	75.41	278.15	146.00	3.60	0.38
Sylhet	SW266	Kanairghat	4/5/98	5.98	64.15	242.15	145.00	3.35	0.38
Sylhet	SW266	Kanairghat	4/6/98	5.80	52.49	217.39	144.00	3.14	0.35
Sylhet	SW266	Kanairghat	4/11/98	5.71	42.66	192.78	142.50	2.93	0.31
Sylhet	SW266	Kanairghat	4/12/98	6.22	74.26	275.69	146.00	3.54	0.38
Sylhet	SW266	Kanairghat	4/13/98	6.66	134.09	353.36	147.00	4.15	0.63
Sylhet	SW266	Kanairghat	4/14/98	7.06	181.44	417.50	153.50	4.45	0.56
Sylhet	SW266	Kanairghat	4/15/98	7.40	201.53	470.77	155.00	4.79	0.59
Sylhet	SW266	Kanairghat	4/16/98	7.02	165.59	412.70	153.50	4.36	0.51
Sylhet	SW266	Kanairghat	4/17/98	6.61	135.24	48.15	147.50	4.15	0.62
Sylhet	SW266	Kanairghat	4/18/98	6.35	83.22	303.79	146.00	3.96	0.40
Sylhet	SW266	Kanairghat	4/19/98	6.20	75.48	285.06	145.50	3.81	0.42
Sylhet	SW266	Kanairghat	4/20/98	6.04	66.05	262.46	145.30	3.54	0.33
Sylhet	SW266	Kanairghat	4/21/98	6.12	77.85	274.11	145.50	3.63	0.38
Sylhet	SW266	Kanairghat	4/22/98	6.64	132.64	350.76	149.50	4.11	0.52
Sylhet	SW266	Kanairghat	4/24/98	8.87	441.24	683.93	159.50	6.19	0.93

District	Station ID	Station Name	Date	Water Level	Discharge	Cross Section Area	River Width	Maximum Depth	Maximum Velocity
Sylhet	SW266	Kanairghat	4/25/98	9.12	522.87	726.46	161.50	6.58	0.98
Sylhet	SW266	Kanairghat	4/26/98	8.83	432.16	677.68	159.50	6.16	0.91
Sylhet	SW266	Kanairghat	4/27/98	8.36	349.19	605.60	158.00	5.70	0.74
Sylhet	SW266	Kanairghat	4/28/98	7.89	274.75	538.73	157.30	5.43	0.67
Sylhet	SW266	Kanairghat	4/29/98	7.39	207.59	458.63	154.30	4.85	0.59
Sylhet	SW266	Kanairghat	4/30/98	7.01	173.21	399.38	151.80	4.69	0.57
Sylhet	SW266	Kanairghat	5/1/98	6.76	142.89	362.21	150.50	4.45	0.55
Sylhet	SW266	Kanairghat	5/2/98	6.72	178.72	364.10	149.50	4.27	0.69
Sylhet	SW266	Kanairghat	5/3/98	6.66	132.16	348.68	148.00	4.15	0.50
Sylhet	SW266	Kanairghat	5/4/98	6.40	72.94	266.06	146.00	3.63	0.36
Sylhet	SW266	Kanairghat	5/5/98	6.07	72.94	266.06	146.00	3.63	0.36
Sylhet	SW266	Kanairghat	5/6/98	5.90	60.85	241.97	145.00	3.47	0.34
Sylhet	SW266	Kanairghat	5/7/98	5.74	53.22	218.87	143.50	3.63	0.33
Sylhet	SW266	Kanairghat	5/8/98	5.61	43.64	200.04	142.50	3.20	0.31
Sylhet	SW266	Kanairghat	5/9/98	6.10	136.54	289.15	147.00	3.84	0.60
Sylhet	SW266	Kanairghat	5/10/98	7.03	182.56	407.99	153.00	4.54	0.60
Sylhet	SW266	Kanairghat	5/11/98	7.21	199.23	435.99	153.50	4.75	0.60
Sylhet	SW266	Kanairghat	5/12/98	7.06	161.02	407.51	153.00	4.54	0.56
Sylhet	SW266	Kanairghat	5/13/98	6.76	135.37	363.37	151.00	4.24	0.48
Sylhet	SW266	Kanairghat	5/14/98	6.43	106.12	319.60	147.50	3.87	0.44
Sylhet	SW266	Kanairghat	5/15/98	6.09	82.61	270.08	146.00	3.51	0.41
Sylhet	SW266	Kanairghat	5/16/98	5.80	61.87	228.65	144.00	3.11	0.38
Sylhet	SW266	Kanairghat	5/17/98	5.58	42.26	192.14	142.00	2.85	0.32
Sylhet	SW266	Kanairghat	5/18/98	5.50	35.38	179.51	140.50	2.75	0.31
Sylhet	SW266	Kanairghat	5/19/98	5.35	24.69	149.64	137.50	2.45	0.26
Sylhet	SW266	Kanairghat	5/20/98	5.24	21.46	135.48	136.00	2.35	0.26
Sylhet	SW266	Kanairghat	5/21/98	5.15	18.71	124.30	135.00	2.20	0.25
Sylhet	SW266	Kanairghat	5/22/98	7.91	322.63	534.11	157.30	4.69	0.76
Sylhet	SW266	Kanairghat	5/23/98	11.24	1276.06	1068.46	169.00	8.05	1.50
Sylhet	SW266	Kanairghat	5/24/98	11.78	1210.93	1158.81	173.00	8.99	1.27
Sylhet	SW266	Kanairghat	5/25/98	11.15	861.56	1024.54	168.00	8.11	1.07
Sylhet	SW266	Kanairghat	5/26/98	10.41	671.94	902.62	166.00	7.38	0.95
Sylhet	SW266	Kanairghat	5/27/98	10.03	578.93	828.14	163.50	7.07	0.90
Sylhet	SW266	Kanairghat	5/28/98	9.54	470.34	739.78	161.50	6.52	0.83
Sylhet	SW266	Kanairghat	5/29/98	9.13	416.81	628.62	160.00	6.19	0.80
Sylhet	SW266	Kanairghat	5/30/98	9.94	681.05	816.88	163.50	7.13	1.07
Sylhet	SW266	Kanairghat	5/31/98	12.69	1666.85	1329.67	175.00	9.88	1.56
Sylhet	SW266	Kanairghat	6/1/98	12.53	1416.86	1303.85	174.50	9.66	1.43
Sylhet	SW266	Kanairghat	6/15/98	13.60	1802.22	1493.77	178.50	10.79	1.52
Sylhet	SW266	Kanairghat	6/29/98	12.69	1453.92	1322.82	175.00	9.95	1.43
Sylhet	SW266	Kanairghat	7/13/98	12.83	1563.29	1420.77	175.00	10.27	1.35
Sylhet	SW266	Kanairghat	7/27/98	14.31	1988.51	1688.70	180.00	11.86	1.41
Sylhet	SW266	Kanairghat	8/10/98	13.85	2013.27	1622.68	180.00	11.67	1.68
Sylhet	SW266	Kanairghat	8/24/98	12.89	1154.41	1446.57	178.50	10.91	1.03
Sylhet	SW266	Kanairghat	9/7/98	13.38	1363.25	1518.94	179.30	11.06	1.11
Sylhet	SW266	Kanairghat	9/21/98	10.25	1030.93	1341.80	166.70	10.08	1.03
Sylhet	SW266	Kanairghat	10/5/98	7.39	197.56	1078.39	155.30	8.05	0.45
Sylhet	SW266	Kanairghat	10/19/98	6.99	244.58	1013.41	152.50	7.68	0.42
Sylhet	SW266	Kanairghat	11/2/98	6.22	164.48	794.31	147.90	6.50	0.40
Sylhet	SW266	Kanairghat	11/30/98	6.22	142.14	664.61	146.80	5.65	0.40
Sylhet	SW266	Kanairghat	12/14/98	5.11	89.80	469.80	137.50	4.40	0.33
Sylhet	SW266	Kanairghat	12/28/98	4.93	37.03	360.78	136.20	3.90	0.17
Sylhet	SW266	Kanairghat	1/10/03	4.79	11.69	26.13	70.00	0.58	0.70
Sylhet	SW266	Kanairghat	1/14/03	4.77	10.96	24.90	69.00	0.58	0.69

District	Station ID	Station Name	Date	Water Level	Discharge	Cross Section Area	River Width	Maximum Depth	Maximum Velocity
Sylhet	SW266	Kanairghat	1/18/03	4.73	10.55	23.87	68.00	0.56	0.69
Sylhet	SW266	Kanairghat	1/28/03	4.69	8.97	20.86	66.00	0.53	0.66
Sylhet	SW266	Kanairghat	1/30/03	4.68	8.62	20.19	65.00	0.51	0.65
Sylhet	SW266	Kanairghat	2/9/03	4.64	6.72	16.98	64.00	0.46	0.57
Sylhet	SW266	Kanairghat	2/19/03	4.61	5.79	15.35	62.00	0.43	0.57
Sylhet	SW266	Kanairghat	2/25/03	4.57	4.76	13.40	60.00	0.38	0.54
Sylhet	SW266	Kanairghat	2/27/03	4.55	4.40	12.70	59.00	0.35	0.53
Sylhet	SW266	Kanairghat	3/1/03	4.58	5.14	14.14	60.00	0.41	0.55
Sylhet	SW266	Kanairghat	3/11/03	4.58	5.29	14.22	60.00	0.41	0.57
Sylhet	SW266	Kanairghat	3/15/03	4.60	6.09	15.31	60.00	0.46	0.57
Sylhet	SW266	Kanairghat	3/25/03	4.56	5.24	13.98	60.00	0.41	0.57
Sylhet	SW266	Kanairghat	7/13/03	13.38	1676.35	1350.87	178.00	10.42	1.60
Sylhet	SW266	Kanairghat	7/28/03	11.54	1058.20	1052.25	171.00	8.90	1.30
Sylhet	SW266	Kanairghat	8/12/03	12.68	1429.94	1230.49	174.00	9.94	1.44
Sylhet	SW266	Kanairghat	8/25/03	12.34	1359.49	1171.17	173.00	9.57	1.40
Sylhet	SW266	Kanairghat	9/8/03	11.60	1136.86	1069.58	172.00	8.93	1.34
Sylhet	SW266	Kanairghat	9/22/03	11.56	1132.55	1058.62	171.00	8.93	1.36
Sylhet	SW266	Kanairghat	10/6/03	9.41	743.62	730.64	162.00	6.77	1.22
Sylhet	SW266	Kanairghat	10/20/03	9.81	801.73	789.75	162.00	7.13	1.25
Sylhet	SW266	Kanairghat	11/3/03	7.58	313.13	501.80	155.00	5.10	0.83
Sylhet	SW266	Kanairghat	11/17/03	5.80	96.69	242.23	147.00	3.40	0.61
Sylhet	SW266	Kanairghat	12/1/03	5.26	38.13	156.03	138.00	2.45	0.42
Sylhet	SW266	Kanairghat	12/15/03	4.98	17.05	114.60	127.00	2.13	0.28
Sylhet	SW266	Kanairghat	12/29/03	5.09	21.30	131.55	133.00	2.25	0.33

বাংলাদেশ প্রকৌশল বিশ্ববিদ্যালয়
নং 99616
তাং 21.9.04
লাইব্রেরী, ঢাকা