FAP24

Government of the People's Republic of Bangladesh

Water Resources Planning Organization

European Commission

Delft Hydraulics

Danish Hydraulic Institute

Hydroland

Approtech

Osiris

RIVER SURVEY PROJECT

Special Report No.8

Bed material sampling in Ganges, Padma Old Brahmaputra and Jamuna

October 1996

Special Report 8

Bed material sampling in
Ganges, Old Brahmaputra and Jamuna

October 1996

6

Contents

1 Bed material sampling 1
- 1.1 Introduction 1
- 1.2 Background 1
- 1.3 Objectives and scope of the study 1

2 Bed material sampling in Ganges River 3
- 2.1 Introduction 3
- 2.2 Previous sampling 3
- 2.3 Present set-up of bed material sampling 3
- 2.4 Analysis 6
  - 2.4.1 General 6
  - 2.4.2 Location of the samples: The sand and silt fraction 6
  - 2.4.3 Grain size variation (coarse sediment) 8
  - 2.4.4 Grain size distribution 9

3 Bed material sampling in Old Brahmaputra River 10
- 3.1 Introduction 10
- 3.2 River characteristics 10
- 3.3 Bed material sampling 11
- 3.4 Data analysis and results 15
  - 3.4.1 Location of the bed material samples 15
  - 3.4.2 Relating the bed material sizes with the slope and planform of the river 16
  - 3.4.3 Characteristics of the bed materials 16
  - 3.4.4 Grain size variation in a downstream direction 17

4 Bed material sampling in Jamuna River 18
- 4.1 Introduction 18
- 4.2 Previous bed material sampling 18
- 4.3 Present bed material sampling 19
  - 4.3.1 Bed material samples 19
  - 4.3.1 Sampling procedure 19
  - 4.3.2 Sampling locations 19
  - 4.3.3 Instruments 19
- 4.4 Data analysis and results 24
  - 4.4.1 Location of the samples 24
  - 4.4.2 Characteristic grain sizes 24
  - 4.4.3 Relating D_{50} to velocity and depth 25
  - 4.4.4 Relation between the flow velocity and silt and clay percentages 25
  - 4.4.5 Relation to erosion of the river bed 25
  - 4.4.6 Seasonal variation of average grain sizes 26
  - 4.4.7 Skewness of the grain size distribution 26

5 Discussion 27
- 5.1 General 27
- 5.2 The presence of silt and clay in the samples 27
- 5.3 Characteristics of grain sizes and downstream fining rate 27
- 5.4 Spatial variation of grain sizes 28

6 Conclusions 29

7 Recommendations 29

References 30

Figures

2.1 : Grain size distribution of the bed samples of the Ganges
2.2 : Location of bed material samples in the Ganges River (traced SPOT image , 1994)
2.3 : Water-level hydrograph 1994, Ganges River
2.4 : Variation of D50 across and along the river
2.5 : Position of bed material samples (block a)
2.6 : Position of bed material samples (block b)
2.7 : Position of bed material samples (block c)
2.8 : Position of bed material samples (block d)
2.9 : Variation of D_{50} with the percentage of silt content of the samples
2.10 : Variation of geometric standard deviation with the percentage of silt content
2.11 : Bathymetric survey, October 1994 and location of three sections of samples
2.12 : Position of bed material samples on the bathymetric sections
2.13 : Relation between D_{50} of the bed material samples and water depth
2.14 : Variation of grain size in a meandering bend
2.15 : Grain size versus radius of curvature along the chainage of the Ganges River
2.16 : Characteristic grain sizes variation along the chainage of the Ganges River
2.17 : Grain size distribution
2.18 : Dimensionless grain size distribution of the 40 samples
2.19 : Average bed material size and gradation, Jamuna and Padma Rivers

3.1 : Off-take of the Old Brahmaputra River
3.2 : The Old Brahmaputra River
3.3 : Bed material sample locations on the Brahmaputra River (block a)
3.4 : Bed material sample locations on the Brahmaputra River (block b)
3.5 : Bed material sample locations on the Brahmaputra River (block c)
3.6 : Bed material sample locations on the Brahmaputra River (block d)
3.7 : Bed material sample locations on the Brahmaputra River (block e)
3.8 : Bed material sample locations on the Brahmaputra River (block f)
3.9 : Bed material sample locations on the Brahmaputra River (block g)
3.10 : Bed material sample locations on the Brahmaputra River (block h)
3.11 : A part of the discharge hydrograph (1994) for the Jamuna River at Bahadurabad
3.12 : A part of the discharge hydrograph (1994) for the Old Brahmaputra River at Mymensingh
3.13 : The variation of D_{50} with the planform and the average water surface slope of the river
3.14 : Typical grain size distribution curve of samples of the Old Brahmaputra River
3.15 : Variation of D_{50} and geometric standard deviation with the percentage of silt and clay
3.16 : Variation of characteristic grain sizes in a downstream direction
3.17 : Variation of 5-point moving average of D_{50} in a downstream direction

4.1 : Jamuna River, indicating the location of Bahadurabad and Sirajganj
4.2 : Position of the routine gauging transects at Bahadurabad, March, 1993
4.3 : Position of the routine gauging transects at Sirajganj, March, 1993
4.4 : Location and D_{50} of samples at Bahadurabad, Channel 2, surveyed on 13 February 1993
4.5 : Location and D_{50} of samples at Bahadurabad, Channel 1, surveyed on 15 February 1993
4.6 : Location and D_{50} of samples at Bahadurabad, Channel 1, surveyed on 15 March 1993
4.7 : Location and D_{50} of samples at Bahadurabad, Channel 1, surveyed on 6 June 1993
4.8 : Location and D_{50} of samples at Bahadurabad, Channel 3, surveyed on 6 June 1993
4.9 : Location and D_{50} of samples at Bahadurabad, Channel 2, surveyed on 9 June 1993

4.10 : Location and D_{50} of samples at Bahadurabad, Channel 1, surveyed on 12 July 1993
4.11 : Location and D_{50} of samples at Bahadurabad, Channel 2, surveyed on 15 July 1993
4.12 : Location and D_{50} of samples at Bahadurabad, Channel 1, surveyed on 20 August 1993
4.13 : Location and D_{50} of samples at Bahadurabad, Channel 3, surveyed on 9 September 1993
4.14 : Location and D_{50} of samples at Bahadurabad, Channel 2, surveyed on 11 September 1993
4.15 : Location and D_{50} of samples at Bahadurabad, Channel 1, surveyed on 31 October 1993
4.16 : Location and D_{50} of samples at Bahadurabad, Channel 2, surveyed on 3 November 1993
4.17 : Location and D_{50} of samples at Sirajganj, Channel 1, surveyed on 23 July 1993
4.18 : Location and D_{50} of samples at Sirajganj, Channel 2, surveyed on 23 July 1993
4.19 : Location and D_{50} of samples at Sirajganj, Channel 1, surveyed on 24 October 1993
4.20 : Location and D_{50} of samples at Sirajganj, Channel 2, surveyed on 27 October 1993
4.21 : Bed material samples collected on 20/8/1993 located on the bathymetric survey August - September 1993 at Bahadurabad
4.22 : Bed material samples collected on 31/10/1993 located on the bathymetric survey November 1993 at Bahadurabad
4.23 : Relation between D_{50} and percentage of silt and clay, Bahadurabad
4.24 : Relation between D_{50} and percentage of silt and clay, Sirajgang
4.25 : Relation between geometric standard deviation and percentage of silt and clay, Bahadurabad
4.26 : Relation between geometric standard deviation and percentage of silt and clay, Sirajganj
4.27 : Relation between depth average velocity and D_{50}, Bahadurabad
4.28 : Relation between depth average velocity and D_{50}, Sirajganj
4.29 : Relation between water depth and D_{50}, Bahadurabad
4.30 : Relation between water depth and D_{50}, Sirajganj
4.31 : Relation between depth average velocity and D_{50}, for the bed material sample collected during February and March, 1993 at Bahadurabad
4.32 : Relation between percentage of silt and clay and depth average velocity, Bahadurabad and Sirajganj
4.33 : Comparison of cross-sections measured on 20/8 and 6/9/1993 and samples collected on 20/8/1993 at Bahadurabad Left Channel
4.34 : Variation of D_{50} of bed material and Helley-Smith samples with river stage, collected from the left channel at Bahadurabad
4.35 : Stage variation of average D_{50} of bed material and Helley-Smith samples collected from the Left Channel at Bahadurabad
4.36 : Relation between skewness and D_{50} of the bed material samples at Bahadurabad and Sirajganj

Tables

2.1 : Findings of D_{50} of the Ganges River by different studies
2.2 : Bed material samples, their locations and characteristic sizes, Ganges River
2.3 : Instruments used in bed material sampling
2.4 : Average silt contents, grain sizes, and standard deviation of 50 samples

3.1 : Grain size of Old Brahmaputra River bed materials
3.2 : Characteristics of the bed materials of the Old Brahmaputra River
3.3 : Slope and sinuosity of the Old Brahmaputra River
3.4 : Average characteristics grain sizes of the bed material samples

4.1 : Average characteristic grain sizes of the bed material of the Jamuna River 1965-1977
4.2 : Characteristics of bed materials and additional information during sampling at Bahadurabad
4.3 : Characteristics of bed materials and additional information during sampling at Sirajganj
4.4 : Characteristic grain sizes of bed material samples from the Jamuna River

5.1 : Average D_{50}, geometric standard deviation and downstream fining rate of bed material

1 Bed material sampling

1.1 Introduction

The River Survey Project (RSP) was initiated on 9 June 1992. The project is being executed by the Water Resources Planning Organization (WARPO) under the Ministry of Water resources. Funding for the project is provided by the European Commission. The consultants for the project are from the DELFT-DHI joint venture in association with Osiris, Hydroland, and Approtech. The project is supervised by a Project Management Unit with participation by FPCO, a Project Advisor, and a Resident Project Advisor.

The objective of the project is to provide detailed and accurate field data to FAP projects, as well as to provide base data for any other planning, impact evaluation, and design activities within national water resources and river engineering activities.

This study report describes the analysis of bed material sampling of the Ganges, Old Brahmaputra, and Jamuna Rivers. The study was executed and reported by Maminul Haque Sarker; much of the data analysis was performed by Mr. Krishna Chandra Dey.

1.2 Background

The characteristics of the bed materials are important in studying the morphological processes of a river. For example to study the planform development, bank erosion, scour holes development, formation and movement of bars etc. it is required to know the characteristics of the bed material. Moreover, the characteristic sizes of bed material are used for roughness and sediment predictors.

Two bed material sampling campaigns were conducted by RSP, one on the Ganges River on 6 August 1994, and one on the Old Brahmaputra River from 10 to 19 August 1994. During the Ganges River project, 33 bed material samples were collected. The sampling campaign in the Ganges River started approximately 12 km downstream of the Hardinge Bridge and ended near the confluence with the Jamuna River. The bed material sampling campaign in the Old Brahmaputra River covered the entire reach between the off-take of the river and the confluence with the Upper Meghna River. In addition, a number of bed material samples were collected from the Ganges, Jamuna, Padma, Arial Khan, and Dhaleswari Rivers during routine gauging and study surveys. However, the present study analyzes the samples from the Ganges, Old Brahmaputra, and Jamuna Rivers only.

In addition to the present bed material sampling and analysis a number of previous studies were performed on these rivers. The results of such previous studies have been compared with the present findings.

1.3 Objectives and scope of the study

RSP collected bed materials samples from different environment of the river bed. When collecting and analysing bed material samples, it is important to consider the purposes and the location of the collection. In this study, the main purposes are to determine the characteristics, grain sizes, gradation, and grain sorting processes that are relevant for morphological studies such as roughness and sediment transport prediction and modelling. In general, the total sediment transport volume is divided into two categories, bed material transport and wash load transport. For sand bed rivers, the two categories are demarcated at a sediment size of 0.063 mm. The sediment predictors are used to predict the bed material transport. After determining the purposes of collection, a definition of environment and the sampling location is needed. The term "environment" is used here to describe the flow intensity and areas of river bank erosion or river bed deposition in a river system.

The sediments that pass through the main rivers of Bangladesh have grain sizes of fine sand to silt and clay. The average ratio of sand to silt is approximately 1:2 in the Ganges and Jamuna Rivers (see RSP Study Report 19, 1995). In the river bed samples, however, the ratio of sand to silt depends on the position and hydraulic environment of the river bed during the bed material sampling. Moreover, the characteristic sizes of the bed materials also vary from point to point.

Simons et al. (1977) suggested that the bed material samples for sediment transport predictors should be collected from an abandoned part of a channel if the water is flowing in the river. This criterion probably does not apply to rivers in Bangladesh, because the percentage of silt fraction in an average transport volume is quite high. The abandoned part of a channel will facilitate deposition of silt on the river bed. Thus silt will dominate the constituents of the bed samples. The energy required to transport silt, however, is very small. Thus the transport of silt is not relevant for coarse sediment predictors.

The analyses of bed material samples from different rivers are presented in individual chapters. The analyses are presented in sequential order.

The extent of analysis of the bed material samples depends on the sampling procedure. In the Ganges River, for example, the bed material samples were collected along with the position and water depth of the samples. In the Old Brahmaputra River, however, only the positions of the samples were recorded; the water depths of the samples were not measured. Bed material samples collected during routine gauging provided data on the water depth and position of the samples, as well as the flow velocity of that vertical. In addition, planform data such as SPOT images and bathymetric surveys play an important role in assessing the environment of the samples with respect to the channel shape and channel planform.

The collection of the bed material samples in the Ganges River covered a certain stretch of the river from a few kilometres upstream of the Hardinge Bridge to near the confluence with the Jamuna River. In the case of the Old Brahmaputra River the collection of bed material samples covered the whole stretch of the river from the off-take of the river to the confluence with the Meghna River. The bed material sample analysis of the Ganges and Old Brahmaputra River are presented in Chapters 2 and 3. Most of the bed material samples from the Jamuna River were collected during routine gauging in Bahadurabad and Sirajganj. Since these samples were collected during routine gauging, data on the flow velocity and the water depth of the samples were available. A number of bathymetric surveys carried out at Bahadurabad created an opportunity to identify the position of the samples with respect to channel features. Therefore, the extent of bed material sample analysis on the Jamuna River differs from the analysis on the Ganges and Old Brahmaputra Rivers. The results of the Jamuna River bed material sample analysis are presented in Chapter 4. The discussion, conclusions and recommendations are presented in Chapters 5, 6 and 7 respectively.

2 Bed material sampling in Ganges River

2.1 Introduction

A bed material sampling campaign was conducted by FAP 24 on the Ganges River on 6 August, 1994. In addition, a number of bed material samples were collected during routine gauging and study surveys in 1993 and 1994. All the bed material samples collected during bed material sampling campaign (6/8/1994) and routine gauging and study surveys up to October 1994 have been analysed.

River bed grain size determination is routinely done in morphological studies and in river behaviour modelling. The grain size variation in a transverse direction and grain sorting in a downstream direction were studied. Sections 2.2 and 2.3 discuss methods of previous bed material sampling and methods of present bed material sampling respectively and the analysis presented in sections 2.4.

2.2 Previous sampling

In large surveys of the rivers of Bangladesh to improve inland navigation NEDECO (1963-1967) collected bed material samples from most of the rivers of Bangladesh. Ten bed material samples were collected from the Ganges River, the result of which is presented in Figure 2.1. In an other project NEDECO (1983) describes the results of analyses of 180 bed material samples collected from August to December 1970. That project also collected and analyzed 5 bed material samples in April 1982. The D_{50} found in these previous studies is shown in Table 2.1.

Previous study	Year of sampling	No. of samples	D_{50} (mm)
Surveys of inland water and ports NEDECO, 1967	1963-1967	10	0.01-0.20
Ganges-Kobadak project, NEDECO, 1983	1970	180	0.12
	1982	5	0.18

Table 2.1: Findings of D_{50} of the Ganges River by different studies

The results of the 1967 survey show that the variation of D_{50} ranges from 0.01 mm to 0.20 mm. The results also show that samples from the Ganges River fit into two distinct groups, one finer than the other (5 samples were taken for each group), see Figure 2.1. The average D_{50} differs considerably when samples from 1970 are compared with samples from 1982 (NEDECO, 1983). The 1982 samples were biased by the sample size, and thus are not representative of the Ganges River. There are no other known bed material studies for the Ganges River.

2.3 Present set-up of bed material sampling

Different aspects of bed material sampling methods used by RSP are discussed below:

Bed material samples

In the Ganges River, three bed samples were collected from 26 to 28 September 1993 during routine gauging. On 6 August 1994 sampling began 12 km downstream of the Hardinge Bridge and ended near the confluence of the Jamuna River (Figure 2.2). A total of 33 samples were collected in 11 cross-sections of the river. The position and depth of water were noted during the sampling. At each cross-section, three samples were collected, two samples were collected near the right and left bank and one in the middle of the river (Table 2.2). During surveys on 2 August 1994 and 19 October 1994 a total of 14 bed samples were collected. These samples were collected on the Ganges River between Hardinge Bridge and 8.50 km upstream. A total of 50 samples were collected by RSP from September 1993 through October 1994.

Hydraulic environment

A water level hydrograph for July to November 1994 (during the sampling period) is shown in Figure 2.3. It is based on FAP 24 water level gauge data at Hardinge Bridge. This figure shows that bed material sampling on 2 and 6 August 1994 was done during the rising limb of the hydrograph, and sampling on 19 October 1994 was done during the falling limb of the hydrograph. Discharge measured on 1 August 1994 near the Hardinge Bridge was 26,000 m^3/s. The discharge on 6 August 1994 was approximately 30,000 m^3/s. The discharge during the bed material sampling is shown in Table 2.3.

In addition to the hydrological data, a SPOT image from March 1994 and a bathymetric survey of October 1994 were utilized to assess the morphological condition of the river during the bed material sampling.

Sample No	Date	Chainage Km	Location L/M/R of sec.	Distance from bank, 'm'	Depth (m)	Weight percent <0.063(mm	>0.063(mm)	D10 (mm)	D16 (mm)	D35 (mm)	D50 (mm)	D65 (mm)	D84 (mm)	D90 (mm)	Standard Deviation
D-1	26/9/93	1	R		-	-	100	-	0.132	0.154	0.173	0.195	0.228	0.243	1.314
D-2	27/9/93	1	M		-	-	100	-	0.135	0.159	0.18	0.204	0.24	0.253	1.333
D-3	28/9/93	1	L		-	-	100	-	0.134	0.157	0.179	0.203	0.238	0.251	1.333
D-4*	02/08/94	-4	R		6.20	47.930	52.070	0.034	0.040	0.055	0.065	0.080	0.105	0.114	1.620
D-5	02/08/94	-4	M		16.20	6.805	93.195	0.066	0.071	0.090	0.108	0.134	0.188	0.209	1.631
D-6	02/08/94	-4	M		16.90	9.663	90.337	0.063	0.072	0.105	0.135	0.164	0.208	0.225	1.708
D-7	02/08/94	-4	M		17.60	2.165	97.835	0.126	0.132	0.155	0.176	0.200	0.234	0.246	1.331
D-8	02/08/94	-4	M		13.60	0.499	99.501	0.131	0.137	0.159	0.179	0.201	0.233	0.245	1.304
D-9	02/08/94	-4	M		7.20	0.973	99.027	0.125	0.131	0.152	0.171	0.193	0.224	0.235	1.308
D-10*	02/08/94	-4	L		4.00	42.980	57.020	0.030	0.038	0.056	0.072	0.096	0.149	0.183	1.982
G-1*	06/08/94	12	R	15	3.60	99.840	0.160	0.003	0.005	0.012	0.017	0.022	0.030	0.034	2.582
G-2	06/08/94	12	M		6.80	6.290	93.710	0.066	0.072	0.094	0.116	0.146	0.197	0.216	1.655
G-3	06/08/94	12	L	300	1.60	2.486	97.514	0.091	0.122	0.147	0.168	0.191	0.226	0.238	1.361
G-4	06/08/94	18.8	L	700	3.10	2.664	97.336	0.088	0.115	0.145	0.164	0.187	0.220	0.231	1.384
G-5	06/08/94	18.8	M		6.20	0.597	99.403	0.133	0.142	0.173	0.204	0.239	0.349	0.400	1.574
G-6	06/08/94	18.8	R	700	6.00	2.130	97.870	0.072	0.080	0.110	0.137	0.164	0.207	0.222	1.612
G-7*	06/08/94	26.6	R	30	7.20	51.700	48.300	0.013	0.022	0.043	0.061	0.087	0.156	0.209	2.665
G-8	06/08/94	26.6	M		9.40	3.747	96.253	0.075	0.088	0.133	0.155	0.182	0.222	0.236	1.597
G-9*	06/08/94	26.6	L	30	2.10	90.908	9.092	0.009	0.013	0.022	0.030	0.039	0.064	0.083	2.221
G-10	06/08/94	33.8	L	900	1.40	6.012	93.988	0.067	0.073	0.098	0.124	0.154	0.202	0.221	1.664
G-11	06/08/94	33.8	M		5.20	0.902	99.098	0.129	0.135	0.157	0.177	0.200	0.232	0.244	1.311
G-12	06/08/94	33.8	R	30	4.20	1.652	98.348	0.130	0.137	0.160	0.181	0.204	0.239	0.257	1.321
G-13*	06/08/94	41.4	R	40	3.20	93.036	6.964	0.005	0.007	0.012	0.017	0.024	0.041	0.057	2.420
G-14	06/08/94	41.4	M		7.00	0.729	99.271	0.108	0.129	0.150	0.170	0.193	0.226	0.237	1.324
G-15	06/08/94	41.4	L	800	2.80	0.876	99.124	0.126	0.132	0.154	0.173	0.194	0.226	0.237	1.308
G-16	06/08/94	49.3	R	150	3.00	11.540	88.460	0.059	0.066	0.083	0.099	0.118	0.177	0.205	1.644
G-17	06/08/94	49.3	M		5.20	1.822	98.178	0.081	0.096	0.138	0.159	0.183	0.219	0.232	1.517
G-18*	06/08/94	49.3	L	60	5.00	89.807	10.193	0.005	0.007	0.014	0.020	0.028	0.064	0.087	3.029
G-19*	06/08/94	57.3	L	40	2.60	49.810	50.190	0.025	0.030	0.049	0.063	0.087	0.135	0.171	2.121
G-20	06/08/94	57.3	M		2.10	16.100	83.900	0.053	0.063	0.075	0.087	0.100	0.120	0.136	1.380
G-21	06/08/94	57.3	R	50	5.40	0.725	99.275	0.131	0.138	0.163	0.185	0.211	0.248	0.318	1.341
G-22*	06/08/94	65.8	R	10	4.80	82.410	17.590	0.017	0.020	0.028	0.034	0.043	0.068	0.090	1.850
G-23	06/08/94	65.8	M		4.30	4.074	95.926	0.073	0.084	0.129	0.150	0.176	0.214	0.228	1.606
G-24	06/08/94	65.8	L	400	2.70	28.120	71.880	0.044	0.051	0.067	0.078	0.091	0.110	0.117	1.470
G-25	06/08/94	72.8	L	200	2.60	6.833	93.167	0.065	0.069	0.083	0.097	0.112	0.158	0.188	1.517
G-26	06/08/94	72.8	M		5.70	1.978	98.022	0.100	0.127	0.149	0.168	0.190	0.222	0.233	1.322
G-27	06/08/94	72.8	R	50	3.80	4.504	95.496	0.068	0.074	0.096	0.119	0.149	0.198	0.216	1.636
G-28	06/08/94	80	R	100	3.70	2.759	97.241	0.070	0.076	0.100	0.124	0.154	0.202	0.221	1.630
G-29	06/08/94	80	M		4.40	1.839	98.161	0.100	0.127	0.150	0.171	0.194	0.229	0.241	1.343
G-30	06/08/94	80	L	750	2.30	2.969	97.031	0.072	0.080	0.114	0.140	0.167	0.208	0.223	1.618
G-31	06/08/94	83	R	40	2.70	9.778	90.222	0.063	0.067	0.083	0.098	0.116	0.169	0.196	1.594
G-32	06/08/94	83	M		6.00	1.104	98.896	0.080	0.094	0.135	0.156	0.180	0.216	0.228	1.522
G-33*	06/08/94	83	L	250	3.70	98.780	1.220		0.004	0.010	0.014	0.019	0.029	0.035	2.786
D-11	19/10/94	-8.5	L		23.20	16.087	83.913	0.054	0.063	0.075	0.087	0.100	0.120	0.139	1.380
D-12	19/10/94	-8.5	M		4.00	0.268	99.732	0.132	0.138	0.159	0.177	0.198	0.228	0.239	1.285
D13	19/10/94	-8.5	R		6.00	8.844	91.156	0.064	0.067	0.078	0.089	0.101	0.118	0.124	1.327
D-14	19/10/94	-6	M		-	26.816	73.184	0.045	0.053	0.068	0.079	0.092	0.111	0.118	1.448
D-15	19/10/94	-4	M		-	29.847	70.154	0.042	0.051	0.067	0.082	0.099	0.135	0.199	1.627
D-16	19/10/94	-2.5	M		-	0.980	99.020	0.131	0.137	0.158	0.176	0.198	0.228	0.239	1.290
D-17	19/10/94	0	M		-	5.498	94.502	0.096	0.129	0.157	0.183	0.213	0.281	0.349	1.477

Table 2.2 : Bed material samples, their locations and characteristic sizes, Ganges River

Instruments

The sample locations were determined using a Differential Global Positioning System (DGPS). Both USBM 54 and Van Veen grab samplers were used to collect the samples (Table 2.3).

Date	Discharge (m^3/s)	No. of samples	Instrument	Status
26/9/93	43,000	3	Van Veen	Routine gauging
2/8/94	26,000	7	USBM 54	Study survey
6/8/94	30,000	33	USBM 54	Sampling campaign
19/10/94	8,000	7	Van Veen	Study survey

Table 2.3 : Instrument used in bed material sampling

The grain size analysis was performed in the RSP sediment laboratory. The characteristic grain sizes were determined by sieve analysis when $D_{10}>0.063$ mm. When $D_{10}<0.063$ mm, both sieves and Andreasen tubes were used to determine the grin size distribution. The standard sieve size used in the RSP sediment laboratory for sediment size analysis was series 2.

2.4 Analysis

2.4.1 General

Sediments in a river are classified as either bed material load or wash load. Bed material is the sand fraction and usually has a diameter larger than 0.063 mm. This material is transported in the form of bed load and suspended load. Bed material load makes an important contribution to forming and shaping the channel. In contrast, wash load is the silt and clay fraction that has a diameter smaller than 0.063 mm. It is transported as suspended load which generally has a constant concentration at different depths. The wash load helps develop the floodplain, estuaries, and deltas. In addition, the wash load probably alters the channel morphology by forming relatively high resistant banks and over time it helps forming the floodplain.

During the analysis, an attempt was made to locate the environment of the river bed from where these sand and silt samples were collected. The grain size distribution of the samples, variation of grain sizes in transverse and in downstream direction are analysed.

2.4.2 Location of the samples: The sand and silt fraction

The sample locations on traced Spot images from March 1994 are shown in Figure 2.2 and the characteristic sizes, geometric standard deviations, and percentages of silt are shown in Table 2.2. This table also identifies the sample position in the river section including the chainage of each section. A number of samples (marked with an asterix) contained 40 to 99.8 % silt. The fine samples are either from the left or the right bank (Figures 2.5 to 2.8). The D_{50} and the geometric standard deviation of all of the samples are plotted against a logarithmic scale of the silt percentage (Figure 2.9 and 2.10 respectively). Figure 2.9 shows that the D_{50} decreases as the silt content increases. The silt content has little influence on the geometric standard deviation if the silt content is less than 40 %. The geometric standard deviation varies from 1.25 to 1.75 which indicates a rather uniform grain size distribution. However, samples with more than 40 % silt show a distinct increase in the geometric standard deviation (Figure 2.10) from 1.6 to 3 indicating a wide grain size distribution. In total, 10 samples were found that contain more than 40 % silt and clay. The average silt percentage for these 10 samples was approximately 75 %, see Table 2.4.

No. of samples	Percent by weight		D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	Standard deviation
	Silt	Sand				
50	19.56	80.44	0.084	0.123	0.182	1.47
40	5.77	94.23	0.10	0.144	0.206	1.43
10	74.72	25.28	0.019	0.03	0.084	2.13

Table 2.4: Average silt contents, grain sizes, and standard deviation of 50 samples

Nine of the ten samples with a high percentage of silt were close to the banks (Figures 2.5 to 2.8). Of these samples, D-4 was not only close to the bank, but was also on the leeward side of a point bar. Sample G-33 was on the leeward side of a bar where the possibility for prevailing slack water is high. It is noted here that not all of the near bank samples did contain a high percentage of silt. The plan-form, bed topography, and velocity distribution probably determines the grain size and percentage of silt in a sample. While Spot images of the lean period can provide a good view of the river, they might not be representative of the channel during the sampling period (i.e., in the monsoon).

Three bed material sampling sections were selected (Figure 2.11) and the corresponding cross-sections from bathymetric survey are shown with the sampling position in Figure 2.8. In October 1994, RSP did a bathymetric survey covering the 16 locations on the Ganges River where samples were taken (Figure 2.11). At one sampling section there was no fine bed material sample; this section is not included in the figure. In between the time of sampling (2 to 6 August 1994) and the bathymetric survey (October 1994), the topography of the channel bed may have changed; this survey, however, could still provide an estimate of the sampling position in the river.

The positions of samples D-4 through D-10 on the cross-section profile which was based on the bathymetric survey are shown in Figure 2.12. The samples D-4 and D-10 had high silt contents. Figure 2.5 suggests that the position of sample D-4 was on the leeward side of a point bar. This is probably why this sample contained a high percentage of silt. Sample D-10 was probably sampled near the eroding bank because it contained a high silt percentage (Figure 2.12). Sample G-1 contained 99.8 % silt and was sampled on the outer bend at a relatively shallow depth (3.6 m) (Figures 2.6 and 2.12). Considering the flow regime during the sampling, it is possible that sample G-1 did not come from the river bed but from the immobile sloping part of a silty bank. This may also be true for sample G-9 which contained 90.9 % silt (Figure 2.12). The reason why sample G-7 contained 51.7 % silt cannot be explained in the same way. The sample depth for G-7 was up to 7.20 m below the actual water depth. Neither bank erosion nor prevailing slack water were noticed during sampling (Figures 2.6 and 2.12).

The October 1994 RSP bathymetric survey did not extend beyond the location of sample G-9. The aforementioned explanation is thought to be responsible for the high silt content of the other five samples.

As mentioned earlier, flow through the Ganges River during bed material sampling on 2 and 6 August 1994 was on a rising limb. The average flow velocity was approximately 1.5 m/s. Non-cohesive fine grained materials cannot sustain such high velocities on the active flow bed except in special river environments. The course material in the river bed near the eroding bank (basal location) is deposited as bed material, and the fine material is transported as wash load. On the other hand, fine grained materials are deposited in the river bed in an area with very low flow velocities, for example on the leeward side of the bar where there is slack water.

It appears that three different temporary environments are present in a river bed. The first is the area near the eroding banks; the second is the area of silt deposition where slack water prevails; and the third is the active river bed where there is active transport of bed material. The characteristic grain sizes and silt percentages from the three environments were different. The samples with the ten highest silt percentages could only be from the first two environments or the river bank itself. For the application of sediment transport or roughness prediction, only the samples from the active river bed environment (i.e., the samples containing less than 40 % silt) are relevant. Hence only these samples were analyzed further.

2.4.3 Grain size variation (coarse sediment)

The grain size varies in the channel in both the transverse direction and along the river. The variation has been examined with results as follows:

Variation with depth

The relation between grain size and water depth is shown in Figure 2.13. The water depth is a relative factor, changing with the discharge. For this reason the bed material samples collected on 6 August, 1993 are only shown in this figure. Though the plotted data are scattered, the graph shows a trend of coarser materials at higher depths. This trend may not exist for all depths. A few of the Ganges' channel stretches are much deeper than 10 m. The deepest part may even be up to 40 m during the monsoon. It is not expected that grains at those river depths are proportionately coarser.

Variation in the transverse direction

In a given section, the bed material size varies widely, see Figure 2.4. The grain size variation in the transverse direction may be the result of the primary flow distribution and secondary or helical flow in the bend. The transverse variation of grain size is chiefly due to secondary flow induced by the bed topography (Peters, 1978; Parker, 1991). However, the variation of grain size in secondary flow cells cannot be examined using the present bed material data. The grain size variation in a meander bend is mainly due to the helical flow which transports the bed and suspended sediments in different directions. Figure 2.14 shows a meander bend grain size sorting model (Parker, 1991). The D_{50} of the samples (whose cross-section positions are marked) and the inverse radius of curvature of the river bend are plotted against the chainage (Figure 2.15). The positive radius of curvature indicates the left bank convex bend, and a negative value indicates the right bank convex bend. For negative 1/R value, 'L' represents the outer bend samples. For positive 1/R values 'R' represents outer bend samples. Most of the mid-channel samples (marked 'M') were coarse. It is observed that there is no relation between the concave or convex bend samples and grain size. The sample positions were probably not in a position on the bend where grain sorting could be found. Moreover, the bends in the Ganges River are formed by more complex processes than merely meandering.

Variation in the downstream direction

Following Hack (1957), Leopold et al. (1964) described the exponential decrease of grain size along rivers (after the head waters) that is due mainly to abrasion and to a less extent due to selective transport. The general form of this type of empirical equation is:

$$(D_{50})_x = (D_{50})_0 * e^{-\beta x} \tag{2.1}$$

where,
$(D_{50})_x$ = characteristic grain size at a distance x (mm),
$(D_{50})_0$ = Characteristic grain size at the origin (mm),
x = Distance from the origin in a downstream direction (km),
β = a coefficient (km^{-1})

The average characteristic grain sizes D_{16}, D_{50}, and D_{84} of coarse sediment for each section are plotted against the chainage (Figure 2.16). Though the average grain sizes of the sections vary, there is a clear trend of finer grain sizes in a downstream direction. The exponential regression line of characteristic grain size (following the equation 2.1) was straight because the sampling stretch of the Ganges is at the downstream end of the river (Figure 2.12). The β value of the regression equation was 0.0018 km^{-1} for D_{50}. The regression line shows that at the upstream end of sampled stretch the D_{50} was 0.155 mm; at the downstream end it was 0.132 mm within a 92 km stretch of the river. Grain sizes become more fine in a downstream direction at a rate of approximately 0.025 mm per 100 km.

The downstream variation of grain sizes and geometric standard deviation for the Jamuna River was studied by RPT et al. (1987) during the Jamuna Bridge Study, see Figure 2.15. This study found a downstream fining rate of 0.04 mm per 100 km for the Jamuna River, which is higher than the downstream fining rate of the Ganges River.

2.4.4 Grain size distribution

The typical grain size distribution curves for the bed material of the Ganges River are shown in Figure 2.17. Variation of D_{50} ranges from 0.8 to 0.20 mm. The fine sand grains of the Ganges are almost uniform in distribution. Dimensionless grain sizes (D/D_{50}) are plotted against percent finer of the forty samples in Figure 2.14. Figure 2.18 also shows the range of variation of other characteristic sizes of the samples for a single value of D_{50} (the function of the geometric standard deviation of the samples). The average geometric standard deviation of the forty samples is 1.43 (Table 2.4). The average geometric standard deviation of the bed material samples of the Jamuna River is 1.40 (RPT et al., 1987), which is quite similar to the geometric standard deviation found by present analysis for the Ganges River.

3 Bed material sampling in Old Brahmaputra River

3.1 Introduction

Bed material samples were collected on the Old Brahmaputra River from 10 to 19 August, 1994. The sampling started at the confluence with the Upper Meghna River and ended at the off-take of the Old Brahmaputra River from the Jamuna River. A total of 129 bed material samples were collected. Analysis of these samples was done mainly on the basis of the findings on the Ganges River described in the previous chapter. Unlike the Ganges River, the Old Brahmaputra River is a left bank distributary of the Jamuna River. The discharge and sediment transport through the river were dependent on opening the off-take on the Jamuna River. Moreover, the discharge through the river was not the same on all the stretches of the river because of the presence of distributaries. The distributaries downstream from Toke divert the main flow of the river through the Lakhya River. The average water surface slope and planform of the river also vary from reach to reach. During the analysis of the river bed material all of the above issues were considered.

Key river characteristics are briefly discussed in Chapter 3.2 followed by a discussion of bed material sampling (Chapter 3.3) and data analysis and results (Chapter 3.4).

3.2 River characteristics

Approximately 200 years ago, the main flow of the Jamuna River passed through the present course of the Old Brahmaputra River. At present, the Old Brahmaputra is a left bank distributary of the Jamuna River. The off-take of the river is approximately 10 km upstream from Bahadurabad. This off-take is not stable and changes when the left bank anabranch of the Jamuna River change in importance (RSP Study Report 3, 1994). Figure 3.1 shows the opening of the river off-take in September, 1994. At present the Jinjaram River, which is a left tributary of the Jamuna River, is the main source of dry season flow. When the off-take of the Jamuna River is closed, the main source of Old Brahmaputra flow is spilling water from the Jamuna River.

The mean annual flow gradually decreased from 1964 to 1991. The reduction was approximately 30 % during this period (RSP Study Report 3, 1994). The mean annual peak flow at Mymensingh was approximately 3,100 m^3/s; during 1988 the peak flow was approximately 4800 m^3/s (BCEOM et al., 1993).

The river length between the off-take of the Jamuna River and the confluence with the Upper Meghna River was approximately 215 km. There were several small left bank distributaries. One of the main distributaries, Jhenai River, takes off approximately at chainage 38 km downstream from the off-take. This river flood water drained approximately 25 % of the Old Brahmaputra River flow during the 1988 flood (BCEOM et al., 1993). The outflowing discharge of the other small distributaries, such as the Banar River or Bariara River, is not known. Another main distributary of the river is the Lakhya River. Near Toke, the river bifurcates and main flow diverts through the Lakhya River. The remaining 45 km of the Old Brahmaputra River carries a small fraction of the total discharge and discharges into the Upper Meghna River downstream of Bhairab Bazar.

The slope of the river varies in the downstream direction from 8.4 cm/km near Jamalpur to 5.8 cm/km near Toke (BCEOM et al., 1993). The river meanders and has sinuous point bars. However, upstream from the Jhenai River off-take there is active shifting in the channel bends (BCEOM et al., 1993).

3.3 Bed material sampling

Several bed material samples were collected by NEDECO (1967). The results of their analysis are presented in Table 3.1. There is no other information regarding the previous Old Brahmaputra River bed material samples.

Date of sample collection	Grain size of bed material averaged over width			
	D_{16} (mm)	D_{35} (mm)	D_{50} (mm)	D_{90} (mm)
20-02-1967	-	0.102	0.162	0.358
26-10-1967	0.079	0.109	0.144	0.307

Table 3.1 Grain size of Old Brahmaputra River bed materials (NEDECO, 1967)

RSP sampled bed materials of the river. The sampling procedures, instruments used, and the hydraulic environment during the field work are presented below.

RSP bed material sampling

As mentioned earlier, 129 bed material samples were collected from the Old Brahmaputra River. The sampling began on 10 August 1994 at the confluence of the Meghna River, downstream of Bhairab Bazar, and ended on 19 August 1994 at the off-take of the river. Three bed material samples were collected on each section of the river, one from the middle of a cross-section and the other two from near the left and right banks, see Figures 3.3 to 3.10. The section interval was approximately 5 km. The date, sample position, and grain size characteristics are presented in Table 3.2. Unlike the bed material sampling in the Ganges River, the water depth at the location of the samples was not measured.

Instruments

All of the samples were collected using a USBM 54 bed material sampler. A Global Positioning System (GPS) was used to determine the sample locations. The accuracy of the GPS is about ±100 m. The procedure of the grain size analysis is the same as mentioned in Chapter 2.

Sample No.	Date	Chainage (km)	Location L/M/R of sec.	Weight Percent <0.063(mm)	Weight Percent >0.063(mm)	D10	D16 (mm)	D35 (mm)	D50 (mm)	D65 (mm)	D84	D90 (mm)	G. std. Deviation
Alu-115	19/08/94	0	L	59.00	41.00	0.019	0.024	0.038	0.051	0.073	0.118	0.154	2.22
Alu-116	19/08/94	0	M	6.94	93.06	0.080	0.125	0.148	0.168	0.191	0.225	0.237	1.34
Alu-117	19/08/94	0	R	1.21	98.79	0.127	0.134	0.157	0.178	0.202	0.237	0.249	1.33
Alu-118	19/08/94	5	L	13.95	86.05	-	0.064	0.075	0.086	0.098	0.115	0.121	1.34
Alu-119	19/08/94	5	M	0.92	99.08	0.085	0.103	0.150	0.186	0.229	0.341	0.396	1.82
Alu-120	19/08/94	5	R	2.45	97.55	0.070	0.076	0.098	0.121	0.150	0.199	0.217	1.62
Alu-121	19/08/94	10	L	7.51	92.49	0.065	0.069	0.083	0.097	0.113	0.162	0.192	1.54
Alu-122	19/08/94	10	M	9.03	90.97	0.064	0.067	0.078	0.088	0.100	0.117	0.123	1.32
Alu-123	19/08/94	10	R	8.43	91.57	0.064	0.068	0.080	0.092	0.106	0.132	0.223	1.39
Alu-124	19/08/94	15	L	11.48	88.52	0.059	0.066	0.078	0.089	0.102	0.121	0.142	1.35
Alu-125	19/08/94	15	M	12.81	87.19	-	0.065	0.077	0.089	0.102	0.122	0.150	1.37
Alu-126	19/08/94	15	R	1.28	98.72	0.128	0.135	0.157	0.178	0.201	0.235	0.247	1.32
Alu-127	19/08/94	20	L	8.87	91.13	0.065	0.076	0.126	0.150	0.178	0.223	0.239	1.73
Alu-128	19/08/94	20	M	0.67	99.33	0.127	0.134	0.157	0.178	0.202	0.237	0.249	1.33
Alu-129	19/08/94	20	R	0.41	99.59	0.133	0.140	0.164	0.187	0.212	0.248	0.318	1.33
Alu-106	18/08/94	25	L	3.55	96.45	0.083	0.107	0.145	0.167	0.192	0.231	0.244	1.47
Alu-107	18/08/94	25	M	6.84	93.16	0.065	0.069	0.084	0.099	0.115	0.173	0.205	1.59
Alu-108	18/08/94	25	R	54.03	45.97	0.027	0.034	0.046	0.059	0.075	0.100	0.109	1.72
Alu-109	18/08/94	30	L	21.90	78.10	0.046	0.055	0.071	0.082	0.095	0.114	0.121	1.44
Alu-110	18/08/94	30	M	1.17	98.83	0.128	0.136	0.163	0.188	0.217	0.291	0.356	1.47
Alu-111	18/08/94	30	R	0.69	99.31	0.129	0.135	0.157	0.177	0.199	0.232	0.243	1.31
Alu-112	18/08/94	35	L	6.97	93.03	0.066	0.073	0.102	0.130	0.159	0.205	0.222	1.68
Alu-113	18/08/94	35	M	21.34	78.66	0.045	0.055	0.072	0.083	0.096	0.116	0.122	1.45
Alu-114	18/08/94	35	R	1.83	98.17	0.087	0.111	0.149	0.174	0.205	0.255	0.330	1.52
Alu-103	18/08/94	41	L	5.03	94.97	0.072	0.084	0.130	0.152	0.177	0.216	0.230	1.62
Alu-104	18/08/94	41	M	96.22	3.78	0.009	0.012	0.020	0.025	0.031	0.044	0.050	1.92
Alu-105	18/08/94	41	R	50.49	49.51	0.032	0.038	0.053	0.063	0.078	0.103	0.112	1.65
Alu-100	18/08/94	46	L	69.03	30.97	0.021	0.026	0.036	0.045	0.058	0.089	0.102	1.85
Alu-101	18/08/94	46	M	3.37	96.63	0.074	0.086	0.131	0.156	0.186	0.232	0.248	1.65
Alu-102	18/08/94	46	R	0.51	99.49	0.140	0.153	0.203	0.253	0.312	0.407	0.442	1.63
Alu-97	17/08/94	51	L	0.32	99.68	0.157	0.184	0.269	0.315	0.367	0.447	0.476	1.57
Alu-98	17/08/94	51	M	7.45	92.55	0.072	0.097	0.150	0.183	0.223	0.331	0.390	1.85
Alu-99	17/08/94	51	R	9.19	90.81	0.064	0.070	0.094	0.119	0.155	0.219	0.244	1.77
Alu-94	17/08/94	56	L	97.58	2.42	0.008	0.012	0.020	0.025	0.031	0.041	0.046	1.86
Alu-95	17/08/94	56	M	6.19	93.81	0.065	0.068	0.078	0.088	0.098	0.113	0.118	1.29
Alu-96	17/08/94	56	R	4.12	95.88	0.067	0.072	0.090	0.107	0.130	0.190	0.215	1.63
Alu-91	17/08/94	61	L	0.34	99.66	0.145	0.162	0.229	0.285	0.345	0.438	0.473	1.65
Alu-92	17/08/94	61	M	4.36	95.64	0.076	0.092	0.147	0.188	0.241	0.364	0.416	1.99
Alu-93	17/08/94	61	R	35.66	64.34	0.028	0.035	0.061	0.106	0.154	0.223	0.254	2.57
Alu-88	17/08/94	66	L	3.01	96.99	0.071	0.079	0.110	0.138	0.165	0.208	0.224	1.63
Alu-89	17/08/94	66	M	3.16	96.84	0.069	0.075	0.098	0.121	0.150	0.199	0.218	1.63
Alu-90	17/08/94	66	R	4.23	95.77	0.068	0.074	0.096	0.118	0.147	0.196	0.215	1.63
Alu-85	17/08/94	70	L	0.31	99.69	0.163	0.198	0.278	0.319	0.367	0.436	0.461	1.49

Table 3.2.a: Characteristics of the bed materials of the Old Brahmaputra River

Sample No.	Date	Chainage (km)	Location L/M/R of sec.	Weight Percent <0.063(mm)	Weight Percent >0.063(mm)	D10	D16 (mm)	D35 (mm)	D50 (mm)	D65 (mm)	D84	D90 (mm)	G. std. Deviation
Alu-86	17/08/94	70	M	0.74	99.26	0.126	0.133	0.158	0.180	0.207	0.245	0.304	1.36
Alu-87	17/08/94	70	R	1.00	99.00	0.137	0.157	0.245	0.293	0.346	0.427	0.457	1.66
Alu-82	17/08/94	75	L	47.47	52.53	0.021	0.027	0.043	0.065	0.080	0.105	0.114	2.01
Alu-83	17/08/94	75	M	14.12	85.88	-	0.064	0.076	0.087	0.099	0.117	0.124	1.35
Alu-84	17/08/94	75	R	1.19	98.81	0.134	0.146	0.189	0.231	0.290	0.392	0.432	1.64
Alu-79	17/08/94	81	L	0.27	99.73	0.132	0.139	0.163	0.185	0.211	0.248	0.318	1.34
Alu-80	17/08/94	81	M	1.56	98.44	0.085	0.105	0.142	0.162	0.186	0.220	0.233	1.45
Alu-81	17/08/94	81	R	28.81	71.19	0.022	0.034	0.074	0.112	0.151	0.212	0.236	2.59
Alu-76	16/08/94	87	L	92.48	7.52	-	0.004	0.013	0.019	0.026	0.037	0.048	3.35
Alu-77	16/08/94	87	M	96.51	3.49	-	-	0.002	0.006	0.013	0.028	0.038	-
Alu-78	16/08/94	87	R	11.88	88.12	-	0.066	0.084	0.102	0.123	0.182	0.206	1.66
Alu-73	16/08/94	92	L	0.99	99.01	0.099	0.126	0.148	0.167	0.189	0.221	0.232	1.32
Alu-74	16/08/94	92	M	0.43	99.57	0.125	0.132	0.153	0.173	0.195	0.227	0.238	1.31
Alu-75	16/08/94	92	R	97.14	2.86	0.005	0.008	0.016	0.022	0.028	0.042	0.049	2.33
Alu-70	16/08/94	97	L	22.56	77.44	0.042	0.054	0.072	0.085	0.101	0.124	0.160	1.52
Alu-71	16/08/94	97	M	5.14	94.86	0.067	0.072	0.091	0.109	0.133	0.191	0.215	1.63
Alu-72	16/08/94	97	R	88.51	11.49	0.008	0.012	0.022	0.029	0.037	0.057	0.075	2.19
Alu-67	15/08/94	102	L	0.33	99.67	0.145	0.162	0.227	0.282	0.340	0.432	0.466	1.64
Alu-68	15/08/94	102	M	11.93	88.07	-	0.065	0.077	0.088	0.100	0.119	0.125	1.35
Alu-69	15/08/94	102	R	84.18	15.82	0.017	0.024	0.029	0.033	0.040	0.062	0.082	1.63
Alu-64	15/08/94	107	L	1.67	98.33	0.129	0.137	0.165	0.192	0.222	0.310	0.372	1.51
Alu-65	15/08/94	107	M	0.81	99.19	0.132	0.142	0.177	0.211	0.251	0.366	0.412	1.61
Alu-66	15/08/94	107	R	0.35	99.65	0.134	0.143	0.175	0.207	0.244	0.364	0.417	1.60
Alu-61	15/08/94	113	L	41.76	58.24	0.016	0.021	0.045	0.073	0.095	0.143	0.179	2.72
Alu-62	15/08/94	113	M	0.24	99.76	0.228	0.260	0.306	0.348	0.395	0.465	0.489	1.34
Alu-63	15/08/94	113	R	0.72	99.28	0.165	0.206	0.290	0.341	0.400	0.491	0.634	1.55
Alu-58	15/08/94	118	L	1.90	98.10	0.076	0.086	0.128	0.150	0.176	0.215	0.229	1.59
Alu-59	15/08/94	118	M	32.73	67.27	0.036	0.043	0.065	0.076	0.089	0.109	0.116	1.60
Alu-60	15/08/94	118	R	2.26	97.74	0.184	0.254	0.307	0.356	0.412	0.497	0.651	1.40
Alu-55	13/08/94	123	L	0.31	99.69	0.133	0.144	0.185	0.226	0.284	0.391	0.433	1.65
Alu-56	13/08/94	123	M	0.50	99.50	0.138	0.150	0.195	0.240	0.300	0.399	0.436	1.63
Alu-57	13/08/94	123	R	0.13	99.87	0.138	0.148	0.187	0.224	0.277	0.385	0.428	1.62
Alu-52	13/08/94	128	L	0.09	99.91	0.186	0.238	0.292	0.332	0.378	0.446	0.470	1.37
Alu-53	13/08/94	128	M	0.96	99.04	0.148	0.165	0.236	0.286	0.339	0.420	0.449	1.60
Alu-54	13/08/94	128	R	0.57	99.43	0.149	0.171	0.257	0.300	0.350	0.427	0.454	1.59
Alu-49	13/08/94	134	L	1.01	98.99	0.109	0.130	0.161	0.190	0.224	0.322	0.381	1.58
Alu-50	13/08/94	134	M	0.34	99.66	0.145	0.167	0.254	0.298	0.349	0.428	0.456	1.61
Alu-51	13/08/94	134	R	0.01	99.99	0.200	0.254	0.303	0.349	0.402	0.481	0.562	1.38
Alu-46	13/08/94	139	L	0.42	99.58	0.126	0.133	0.160	0.184	0.213	0.274	0.345	1.44
Alu-47	13/08/94	139	M	0.16	99.84	0.140	0.153	0.199	0.246	0.305	0.401	0.437	1.62
Alu-48	13/08/94	139	R	0.23	99.77	0.137	0.148	0.189	0.229	0.285	0.388	0.428	1.62
Alu-43	12/08/94	144	L	1.03	98.97	0.127	0.137	0.176	0.213	0.263	0.381	0.428	1.67
Alu-44	12/08/94	144	M	5.44	94.56	0.070	0.080	0.125	0.155	0.192	0.258	0.331	1.80
Alu-45	12/08/94	144	R	2.17	97.83	0.082	0.101	0.146	0.175	0.210	0.294	0.360	1.71

Table 3.2.b: Characteristics of the bed materials of the Old Brahmaputra River

Sample No.	Date	Chainage (km)	Location L/M/R of sec.	Weight Percent <0.063(mm)	Weight Percent >0.063(mm)	D10	D16 (mm)	D35 (mm)	D50 (mm)	D65 (mm)	D84	D90 (mm)	G. std. Deviation
Alu-40	12/08/94	149	L	15.52	84.48	-	0.063	0.079	0.093	0.111	0.159	0.189	1.59
Alu-41	12/08/94	149	M	0.31	99.69	0.131	0.139	0.168	0.195	0.226	0.319	0.379	1.52
Alu-42	12/08/94	149	R	1.02	98.98	0.086	0.107	0.145	0.169	0.197	0.239	0.273	1.50
Alu-37	12/08/94	154	L	97.27	2.73	-	0.006	0.014	0.020	0.028	0.046	0.052	2.82
Alu-38	12/08/94	154	M	5.02	94.98	0.066	0.070	0.084	0.096	0.111	0.153	0.185	1.48
Alu-39	12/08/94	154	R	0.54	99.46	0.131	0.145	0.197	0.250	0.313	0.415	0.454	1.69
Alu-34	12/08/94	159	L	5.10	94.90	0.067	0.072	0.090	0.107	0.129	0.187	0.210	1.62
Alu-35	12/08/94	159	M	2.36	97.64	0.073	0.082	0.118	0.143	0.170	0.211	0.225	1.61
Alu-36	12/08/94	159	R	70.62	29.38	0.007	0.011	0.024	0.037	0.054	0.099	0.118	3.02
Alu-31	12/08/94	164	L	5.84	94.16	0.069	0.079	0.121	0.146	0.173	0.214	0.229	1.66
Alu-32	12/08/94	164	M	7.67	92.33	0.066	0.076	0.118	0.144	0.171	0.213	0.228	1.69
Alu-33	12/08/94	164	R	84.32	15.68	0.008	0.012	0.024	0.032	0.044	0.063	0.092	2.32
Alu-28	12/08/94	169	L	99.72	0.28	-	0.005	0.010	0.014	0.018	0.026	0.031	2.33
Alu-29	12/08/94	169	M	99.14	0.86	-	0.005	0.012	0.016	0.020	0.029	0.037	2.51
Alu-30	12/08/94	169	R	99.36	0.64	-	0.005	0.009	0.012	0.016	0.023	0.027	2.16
Alu-25	12/08/94	174	L	78.43	21.57	-	0.006	0.014	0.021	0.032	0.075	0.100	3.54
Alu-26	12/08/94	174	M	23.48	76.52	0.007	0.014	0.139	0.212	0.291	0.402	0.445	8.52
Alu-27	12/08/94	174	R	98.75	1.25	-	-	0.007	0.010	0.013	0.021	0.025	-
Alu-22	11/08/94	179	L	46.45	53.55	0.007	0.011	0.030	0.082	0.149	0.211	0.235	5.01
Alu-23	11/08/94	179	M	59.66	40.34	0.007	0.014	0.039	0.051	0.091	0.178	0.255	3.57
Alu-24	11/08/94	179	R	56.40	43.60	0.005	0.008	0.020	0.042	0.065	0.095	0.107	3.76
Alu-19	11/08/94	184	L	76.49	23.51	-	0.005	0.011	0.018	0.029	0.128	0.171	5.36
Alu-20	11/08/94	184	M	76.22	23.78	-	0.005	0.013	0.021	0.035	0.114	0.200	4.81
Alu-21	11/08/94	184	R	17.35	82.65	0.023	0.055	0.085	0.109	0.143	0.206	0.232	1.94
Alu-16	11/08/94	189	L	38.96	61.04	0.007	0.012	0.048	0.137	0.205	0.348	0.413	6.98
Alu-17	11/08/94	189	M	26.34	73.66	0.008	0.014	0.137	0.180	0.235	0.352	0.402	7.41
Alu-18	11/08/94	189	R	90.96	9.04	-	0.005	0.010	0.015	0.021	0.045	0.059	3.00
Alu-13	11/08/94	194	L	0.18	99.82	0.137	0.147	0.183	0.218	0.266	0.376	0.419	1.60
Alu-14	11/08/94	194	M	1.96	98.04	0.134	0.146	0.192	0.239	0.298	0.397	0.435	1.65
Alu-15	11/08/94	194	R	1.34	98.66	0.149	0.171	0.257	0.301	0.352	0.429	0.456	1.59
Alu-10	11/08/94	200	L	70.04	29.96	-	0.005	0.015	0.024	0.042	0.093	0.118	4.34
Alu-11	11/08/94	200	M	39.03	60.97	0.009	0.016	0.044	0.087	0.132	0.189	0.211	3.80
Alu-12	11/08/94	200	R	82.95	17.05	-	0.004	0.010	0.014	0.029	0.070	0.090	4.25
Alu-7	10/08/94	205	L	99.24	0.76	-	-	0.006	0.009	0.012	0.019	0.022	-
Alu-8	10/08/94	205	M	99.97	0.03	-	-	-	0.007	0.011	0.020	0.024	-
Alu-9	10/08/94	205	R	99.92	0.08	-	-	0.005	0.006	0.008	0.015	0.019	-
Alu-4	10/08/94	209	L	93.50	6.50	-	-	-	-	0.009	0.026	0.048	-
Alu-5	10/08/94	209	M	99.75	0.25	-	-	-	0.005	0.008	0.016	0.020	-
Alu-6	10/08/94	209	R	95.89	4.11	-	-	-	0.006	0.011	0.027	0.044	-
Alu-1	10/08/94	214	L	98.30	1.70	-	-	-	0.007	0.015	0.025	0.033	-
Alu-2	10/08/94	214	M	97.67	2.33	-	-	0.007	0.012	0.018	0.030	0.037	-
Alu-3	10/08/94	214	R	89.76	10.24	-	-	0.009	0.017	0.026	0.049	0.071	-

Table 3.2.c: Characteristics of the bed materials of the Old Brahmaputra River

Hydraulic environment

The average peak flow in the Jamuna River was approximately 67,000 m^3/s over the last 25 years. The 1994 hydrologic year was a dry year and the maximum discharge was only approximately 40,000 m^3/s (Figure 3.11). In the Jamuna River, the discharge increased from 28,000 to 37,000 m^3/s during the sampling period, while in the Old Brahmaputra River, the discharge varied from 400 to 700 m^3/s (Figure 3.12).

Flow in the Old Brahmaputra was estimated using 1993 discharge rating curves and water levels at Mymensingh during the period of survey. The average flow during the sampling period was approximately one-sixth of the average peak flow of the Old Brahmaputra River. The flow width during the sampling period varied from 100 to 350 m depending on the stage and location. The bankfull river width varied from 200 to 500 m (BCEOM et al., 1993). The flow width of the river was approximately 60 % of its bankfull width during the sampling period, because the bankfull discharge is much higher than 700 m^3/s.

Availability of maps

The locations of the samples were measured by GPS and were traced on 1990 SPOT images, except for the reach from 175 to 215 km, where no SPOT image was available. The Old Brahmaputra River is a stable meandering river. However, it is likely that there were still changes in point bars and shifts in meandering bends from 1990 to 1994 (Figure 3.3). Unlike the Ganges River, it was difficult to locate the samples with respect to channel features such as thalwegs, bars, or banks.

3.4 Data analysis and results

The grain size distribution of the samples was determined in the RSP sediment laboratory. To determine characteristics of the bed material and the spatial variation of grain sizes, the following analyses were done:

- location of the bed material samples with respect to the planform of the river,
- relating to the water level slope, chainage and planform of the river,
- characteristics of the bed materials, and
- variation of grain size in downstream direction.

Results of the analyses are presented below:

3.4.1 Location of the bed material samples

Bed material sample positions on the 1990 planform of the river are shown in Figure 3.3 to 3.10. The bed material samples were collected in closed intervals as the river narrows. The sample points are sometimes outside the flow water, because of (i) the relatively higher stage at the time of the sampling (in August), (ii) the limited accuracy of GPS, and (iii) the planform changes between 1990 and 1994. Because SPOT images were not available in the downstream stretch of the river, the last 24 sample locations are not shown. The bed material samples which contain more than 40 % silt and clay are marked with thick circles in that figure. The samples with comparatively high silt contents were located downstream of Toke, where the river bifurcates and the main flow diverts through the Lakhya

River. Here, 24 of 30 bed material samples contained more than 40 % silt and clay. This suggests that this reach was a deposition environment at the time of survey. The remaining 99 bed material samples were collected upstream from Toke. Only 14 of these samples had more than 40 % percent silt and clay. However, it was not possible to find the location of those samples due to lack of planform data; it is not known whether they were collected from the lee side of a bar or where slack water prevails.

3.4.2 Relating the bed material sizes with the slope and planform of the river

The chainage starts at the off-take from the Jamuna River. Instead of following the river course, the present chainage is the result of a cumulative addition of straight distances between two consecutive bed material sampling sections. The Jamuna River is not stable and causes erosion and deposition, resulting in yearly shifts of the chainage. The Old Brahmaputra River is a mainly meandering river. In the upstream part, a 25 km long stretch has large point bars with chute channels at the meandering bends. In this part of the river, several channels exist and its planform indicates that it is a braided river. The rest of the river can be considered as a single thread meandering river. The average slope of the upstream stretches is higher than for the rest of the river, see Table 3.3.

Location	Length of river reach (km)	Slope (cm/km)	Sinuosity
Offtake-Jamalpur	48	8.4	1.20
Jamalpur-Mymensingh	62	7.4	1.24
Mymensingh- Toke	70	5.8	1.30

Table 3.3 Slope and sinuosity of the Old Brahmaputra River (BCEOM et al., 1993)

The median grain size along the chainage in the downstream direction is shown in Figure 3.13. The planform and the slope of the river stretches are also indicated. There was a random variation in the median grain size D_{50} in the downstream direction. The median grain size D_{50} ranged from 0.005 to 0.4 mm. The grain size 38 km upstream of the Jhenai River Off-take was somewhat uniform, varying from 0.05 to 0.2 mm. Downstream from this point, the median grain size varied in a periodic manner. Downstream of Toke, the bed materials were finer. No relation between the grain size D_{50} and the planform and the slope of the river has been observed.

3.4.3 Characteristics of the bed materials

The typical grain size distribution curves for a few samples of the Old Brahmaputra River is shown in Figure 3.14. The minimum D_{50} found from the present analysis is 0.005 mm, and the maximum D_{50} is 0.356 mm. The range of variation of the bed material sizes is approximately seventy folds. The size of the Old Brahmaputra River bed material varies widely. The sample percentages of silt and clay influenced the characteristic D_{50} sizes (Figure 3.15). On the other hand, the geometric standard deviations were quite uniform in sandy samples and varied from 1.4 to 2. Beyond this range, the geometric standard deviation was random and the highest value was approximately 9.

As mentioned earlier it was not possible to locate samples relative to channel features. Like it was the case for the Ganges River, those Old Brahmaputra River samples that contained less than 40 % silt and clay can be considered as representative for sediment predictors. The average grain size characteristics of the samples are presented in Table 3.4.

Sample type	No. of sample	Avg. weight percent		D_{10} (mm)	D_{50} (mm)	D_{90} (mm)	Geometric standard deviation
		Silt & clay	sand				
All	129	28.80	71.20	0.08	0.14	0.25	2.05
<40 % silt and clay	91	6.40	93.60	0.1	0.18	0.31	1.8
>40 % silt and clay	38	82.5	17.50	0.01	0.03	0.08	2.9

Table 3.4 Average characteristics grain sizes of the bed material samples

The average D_{50} of the bed material samples with less than 40 % silt and clay was 0.18 mm, which is coarser than that of the Ganges River. The average geometric standard deviation was approximately 1.8. The samples were less uniformly distributed than those from the Ganges River.

3.4.4 Grain size variation in a downstream direction

The average D_{16}, D_{50} and D_{84} of a cross-section has been plotted against the chainage in a downstream direction (Figure 3.17). Only the samples containing less than 40 % silt and clay were selected, so that the variation of grain size (of the sand fraction) in the downstream direction could be examined. There was a trend of coarsening in the downstream direction, which was an unexpected result. Figure 3.18 is the five-point moving average D_{50} plotted in the downstream direction. The five-point average was used to lessen the uncertainties of collecting representative bed samples. The moving average shows that in the uppermost 100 km of the river, the grain size was not highly variable. However, after Mymensingh, the grains gradually coarsen from 0.15 to 0.25 mm. They then gradually return to the original size of the upstream part of the river (near the 150 km chainage). This pattern of grain size variation cannot be fully explained, and this issue demands more attention, considering aspects such as the sub soil, the aggradation trend associated with tectonic movement, and based on a repeated sampling during the lean season.

The average bed material grain size in the Jamuna River at Bahadurabad was approximately 0.20 mm. The off-take of the Old Brahmaputra is about 10 km upstream from Bahadurabad. However, the average D_{50} in the upstream most 40 km of the river was less than 0.14 mm. This indicates two possible processes: (1) the size of sediments that enter through the off-take of Brahmaputra River is controlled by opening of the off-take, (2) the bed material of the Jinjaram River has a significant influence on the bed material size of the Old Brahmaputra River. The contribution of the Jinjaram River discharge and sediment transport probably becomes significant in a dry year such as 1994 because of less spilling over the off-take.

4 Bed material sampling in Jamuna River

4.1 Introduction

RSP collected a number of bed material samples in the Jamuna River during routine gauging surveys from February to November 1993. After this time, bed material samples were no longer collected during the routine gauging surveys. The collection of bed material samples were concentrated mainly at Bahadurabad and Sirajganj. During the collection of the bed material samples, the water depth at the sampling location and the depth averaged flow velocity of the verticals near these sampling locations were measured. In addition, three bathymetric surveys were conducted at Bahadurabad during the sampling period. These surveys provided more insight about the sorting processes of bed material in the river system.

In addition to routine gauging surveys a number of bed material samples were collected during a special RSP survey to determine the mineralogical and physical properties of river sediments, and different other special surveys also included collection of a few bed material samples. The procedure of collecting bed materials during routine gauging are partly different from that of study surveys. For example, when the bed material samples were collected for analysis of physical properties, depth and velocity were not measured. In different study surveys, however, bed material samples were collected for different purposes. Thus the data collected during sampling were dependent on the purpose of the survey. Because the bed material data collection was always the same during the routine gauging in 1993, only these data were analyzed.

In the following analysis, the general tendencies in the grain sizes of the bed material are investigated, as well as the spatial variation of the grain sizes as a function of the flow velocities. In addition, some assumptions made in the analysis for the Ganges River are verified; one example is to regard the samples with more than 40 % silt and clay as a fine sample, and to define the environment of the location of those samples as a depositioning environment.

The set-up of the previous and present bed material sampling is discussed in Sections 4.2 and 4.3, respectively. The analysis and results are presented in Section 4.4.

4.2 Previous bed material sampling

During the survey of inland waterways and ports (1963-67), about 15 bed material samples from the Jamuna River were collected and analyzed (NEDECO, 1967). From the grain size distributions, D_{90} was determined; the value ranges from 0.05 to 0.33 mm. No further details were reported. During the appraisal study for the Jamuna Multipurpose Bridge (RPT et al. 1987), an inventory was prepared of existing soil sample data from Chilmari to Aricha for the period of 1965 to 1977. This inventory and the result of the analysis were also summarised in RSP Study Report 3 (1994). Average characteristic grain sizes and geometric standard deviations of those samples are presented in Table 4.1.

Location	D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	Geometric std. deviation
Chilmari	0.157	0.231	0.306	1.40
Sirajganj	0.106	0.188	0.250	
Nagarbari	0.109	0.169	0.225	1.44

Table 4.1 Average characteristic grain sizes of the bed material of the Jamuna River collected from 1965 to 1977

The information in Table 4.1 is based on data presented by RPT et al. (1987); bed material data collected by NEDECO (1967) are not included. The table shows a gradual downstream fining of the bed material in the Jamuna River and an almost constant geometric standard deviation.

In addition to the aforementioned bed material samples, the Brahmaputra Right Embankment Project collected 95 bed material samples from a test area downstream of Sirajganj in July and November 1990. The mean diameter was 0.15 mm, and the geometric standard deviation was 2.8. In comparison with the previous data D_{50} is smaller and the geometric standard deviation is larger. The reason for this variation is probably that a number of fine samples were included in the analysis. No further information on the analysis is available.

4.3 Present bed material sampling

4.3.1 Bed material samples

A total of 138 bed material samples were collected during routine gauging surveys from the Jamuna River: 104 from Bahadurabad and 34 from Sirajganj (Tables 4.2 and 4.3). These samples were collected in 1993. No bed material samples were collected during routine gauging surveys after November 1993.

4.3.1 Sampling procedure

The present analysis of the bed material samples in the Jamuna River was based exclusively on the bed material samples collected during routine gauging surveys. During these surveys, the discharge and sediment transport in a cross-section of the river were measured. The discharge was measured by the Acoustic Doppler Current Profiler (ADCP) and Electromagnetic Flow Meter (EMF) using a moving boat method. During discharge measurement, the shape of the river bed cross-section was measured using an echosounder mounted on the survey vessel. The sediment gauging was performed in a number of verticals on the cross-section where stationary ADCP and S4 flow velocity profiles were recorded. Bed material samples were often collected near the verticals of sediment gauging.

4.3.2 Sampling locations

RSP routine gauging surveys were concentrated at Bahadurabad and Sirajganj on the Jamuna River (Figure 4.1). The routine gauging survey transects were usually selected on the basis of suitability for navigation to cover the maximum part of a channel section. Therefore, the position of these transects changed with the season depending on the suitability of the discharge measurement. The positions of the transects from which the bed material samples were collected are shown on the 1993 tracing of SPOT images (Figures 4.2 and 4.3). In each transect, between 6 and 14 samples were taken in the main channels. In the smaller channels, 3 to 6 samples were taken. Sometimes 2 samples in the same vertical were collected to see the consistency of the sampler and to obtain an impression about the variation of the grain sizes within a very short variation of space and time. For each vertical, the Easting and Northing were determined to fix the location.

4.3.3 Instruments

All the Jamuna River samples were collected by the Van Veen grab sampler. The position of the bed material in a channel section was measured by the Differential Global Positioning System (DGPS). The depths at which the bed material samples were collected were measured by echosounder relative to the actual water level. The reading of a nearby water level gauge was used to determine the river bed elevation at the sampling location in m+PWD.

The analyses of the grain sizes of the bed materials were performed in the RSP sediment laboratory by the same procedure as described in previous chapters.

Date	Channel number	Vertical number	Sample number	Easting (m)	Northing (m)	Vertical depth (m)	Dist. from lt. bank (m)	Flow velocity (m/s)	D16 (mm)	D35 (mm)	D50 (mm)	D65 (mm)	D84 (mm)	Std. Dev.	Sand (%)	Silt (%)
13.02.93	2	1	1	464365	778653	4.67	286	0.54	0.106	0.144	0.166	0.191	0.227	1.47	95	5
		2	5	464481	778683	5.00	168	0.70	0.109	0.145	0.168	0.194	0.234	1.47	98	2
		2	6	464481	778683	5.00	168	0.70	0.095	0.139	0.161	0.186	0.224	1.54	96	4
		2	7	464481	778683	5.00	168	0.70	0.111	0.144	0.164	0.186	0.220	1.41	99	1
		3	4	464526	778706	5.80	117	0.76	0.111	0.145	0.167	0.191	0.228	1.43	98	2
		4	2	464555	778720	5.52	86	0.81	0.105	0.143	0.166	0.192	0.231	1.49	98	2
		4	3	464555	778720	5.52	86	0.81	0.102	0.144	0.168	0.196	0.238	1.53	97	3
15.02.93	1	1	11	470138	776275	5.00	733	0.46	0.057	0.073	0.084	0.097	0.115	1.42	81	19
		1	20	470138	776275	5.00	733	0.46	0.059	0.073	0.084	0.096	0.115	1.40	80	20
		2	19	470225	776269	5.38	646	0.72	0.072	0.090	0.107	0.129	0.186	1.61	95	5
		3	10	470315	776267	7.10	555	0.80	0.128	0.150	0.171	0.195	0.229	1.34	99	1
		3	18	470315	776267	7.10	555	0.80	0.130	0.156	0.181	0.210	0.266	1.43	99	1
		4	17	470447	776266	6.82	423	0.89	0.149	0.193	0.235	0.294	0.396	1.63	100	0
		5	9	470520	776265	7.15	350	0.90	0.146	0.213	0.276	0.340	0.445	1.75	99	1
		5	16	470520	776265	7.15	350	0.90	0.153	0.231	0.290	0.353	0.453	1.73	100	0
		6	15	470633	776263	5.30	237	0.68	0.071	0.087	0.102	0.119	0.175	1.58	95	5
		7	08	470743	776301	2.82	127	0.34	0.032	0.056	0.070	0.085	0.109	1.87	58	42
		8	13	470806	776303	5.46	64	0.26	0.008	0.016	0.021	0.026	0.036	2.17	4	96
		8	14	470806	776303	5.46	64	0.26	0.014	0.026	0.032	0.040	0.058	2.05	12	88
15.03.93	1	1	50A	470071	776253	3.60	800	0.38	0.034	0.049	0.065	0.080	0.104	1.76	52	48
		2	55A	470126	776254	4.47	745	0.53	0.044	0.068	0.079	0.092	0.111	1.60	72	28
		3	60A	470222	776281	5.08	649	0.72	0.079	0.112	0.139	0.167	0.209	1.63	96	4
		4	65A	470340	776273	6.59	531	0.88	0.117	0.148	0.170	0.196	0.234	1.41	99	1
		5	43A	470447	776269	7.85	424	0.96	0.157	0.237	0.291	0.348	0.436	1.68	100	0
		6	36A	470541	776262	7.40	330	0.83	0.183	0.275	0.323	0.380	0.467	1.61	100	0
		7	22A	470660	776256	5.14	211	0.62	0.073	0.090	0.106	0.126	0.183	1.59	97	3
		8	1	470762	776273	3.01	109	0.31	0.009	0.018	0.024	0.029	0.038	2.13	5	95
		9	3	470794	776281	4.75	77	0.16	0.010	0.018	0.025	0.030	0.039	2.03	11	89
06.06.93	1	3	09	469933	776091	2.64	1076	0.77	0.143	0.171	0.196	0.225	0.314	1.49	100	0
		6	A14	470277	776153	8.60	728	2.15	0.155	0.206	0.257	0.314	0.404	1.62	100	0
		7	A13	470367	776171	9.37	635	1.87	0.242	0.291	0.330	0.374	0.438	1.35	100	0

Table 4.2.a: The characteristics of the bed materials and additional information during sampling at Bahadurabad

Date	Channel number	Vertical number	Sample number	Easting	Northing	Vertical depth	Dist. from lt. bank	Flow velocity	D16	D35	D50	D65	D84	Std. Dev.	Sand (%)	Silt (%)
				(m)	(m)	(m)	(m)	(m/s)	(mm)	(mm)	(mm)	(mm)	(mm)			
06.06.93	1	8	A12	470442.4	776186.4	9.54	558	1.85	0.239	0.292	0.332	0.377	0.443	1.36	100	0
		8	11	470442.4	776186.4	9.54	558	1.85	0.140	0.170	0.198	0.230	0.332	1.55	99	1
		9	A11	470572.7	776214.5	10.02	425	1.54	0.234	0.293	0.335	0.384	0.455	1.39	100	0
		10	A10	470674.2	776236.2	10.01	321	1.35	0.128	0.152	0.174	0.200	0.238	1.36	99	1
		11	A9	470714.5	776244.4	9.32	280	1.32	0.133	0.156	0.177	0.201	0.235	1.33	99	1
		12	A8	470839.4	776268.8	7.19	153	0.90	0.071	0.093	0.116	0.146	0.200	1.68	92	8
		13	A7	470937.1	776297.6	6.26	51	0.77	0.069	0.081	0.091	0.104	0.122	1.33	94	6
06.06.93	3	1	1C	464285.3	778305.4	5.54	865	0.93	0.265	0.307	0.345	0.388	0.450	1.30	93	7
		2	3C	464446.5	778389.1	9.00	683	1.49	0.069	0.095	0.122	0.154	0.206	1.73	89	11
		3	5A	464607.0	778463.4	9.02	506	0.86	0.128	0.157	0.185	0.218	0.304	1.54	99	1
		4	4A	464699.6	778509.4	6.84	403	0.94	0.135	0.156	0.175	0.196	0.226	1.29	100	0
		5	03	464780.6	778548.4	7.34	313	0.68	0.138	0.160	0.181	0.204	0.237	1.31	99	1
		6	02	464894.5	778602.5	7.90	187	0.80	0.154	0.201	0.247	0.306	0.401	1.61	100	0
09.06.93	2	14	A15	468284.4	774498.3	7.50	87		0.126	0.148	0.168	0.191	0.224	1.33	98	2
		15	A16	468036.4	774619.3	3.30	360		0.132	0.154	0.174	0.196	0.228	1.31	99	1
		16	A17	467727.1	774738.3	6.20	691	1.68	0.056	0.077	0.093	0.112	0.166	1.72	81	19
		17	A18	467812.0	774713.5	3.90	602	1.59	0.085	0.125	0.147	0.173	0.211	1.58	99	1
		18	10	467898.6	774686.8	3.20	512	1.43	0.112	0.143	0.163	0.186	0.219	1.40	99	1
		19	11	467987.3	774641.9	2.60	414	1.17	0.140	0.170	0.198	0.230	0.332	1.55	99	1
12.07.93	1	2	DHA3	467986.0	777808.5	1.58	2533	0.47	0.154	0.201	0.248	0.307	0.402	1.62	100	0
		4	DHA2	468628.3	777802.9	5.96	1891	1.05	0.169	0.268	0.310	0.359	0.432	1.61	98	2
		6	DHA1	469127.0	777800.8	7.11	1392	0.77	0.136	0.164	0.191	0.222	0.311	1.52	99	1
		8	DHA4	469319.2	777802.0	12.65	1200	0.94	0.236	0.293	0.334	0.381	0.451	1.38	100	0
		10	DHA3	469507.0	777811.9	12.81	1012	0.98	0.071	0.087	0.102	0.120	0.175	1.58	95	5
		12	DHA2	469722.6	777803.3	6.83	796	2.07	0.076	0.100	0.125	0.154	0.201	1.63	97	3
		14	DHA1	469895.7	777788.3	9.25	623	2.20	0.130	0.153	0.174	0.198	0.234	1.34	99	1
		16	DHA1	470094.4	777796.4	11.90	425	2.72	0.129	0.154	0.177	0.203	0.242	1.37	99	1
		18	01A	470254.2	777777.7	10.88	265	2.89	0.134	0.173	0.212	0.264	0.388	1.71	98	2
15.07.93	2	2	DHA-2	460712.4	782556.8	6.53	1875	1.16	0.144	0.178	0.211	0.250	0.367	1.60	100	0
		4	DHA-1	460938.2	782637.5	7.44	1635	1.16	0.138	0.165	0.191	0.220	0.301	1.48	99	1
		6	DHA-5	461117.6	782711.8	4.14	1442	0.56	0.082	0.125	0.147	0.173	0.212	1.62	96	4
		8	DHA-4	461326.3	782788.6	7.32	1219	0.66	0.068	0.080	0.092	0.105	0.126	1.36	92	8

Table 4.2.b: The characteristics of the bed materials and additional information during sampling at Bahadurabad

Date	Channel number	Vertical number	Sample number	Easting	Northing	Vertical depth	Dist. from lt. bank	Flow velocity	D16	D35	D50	D65	D84	Std. Dev.	Sand (%)	Silt (%)
				(m)	(m)	(m)	(m)	(m/s)	(mm)	(mm)	(mm)	(mm)	(mm)			
15.07.93	2	10	DHA-3	461510.6	782840.9	4.04	1028	0.90	0.086	0.130	0.152	0.177	0.216	1.59	97	3
		12	DHA-2(i)	461678.6	782907.6	2.95	847	0.85	0.076	0.100	0.124	0.153	0.200	1.62	96	4
		14	DHA-1(i)	461893.6	782967.9	5.53	624	1.18	0.125	0.148	0.168	0.191	0.224	1.34	99	1
		16	DHA-2(ii)	462072.4	783040.1	8.25	432	1.68	0.105	0.142	0.163	0.187	0.221	1.45	97	3
		18	DHA-1(ii)	462251.4	783111.8	6.52	239	1.27	0.157	0.215	0.270	0.325	0.411	1.62	99	1
20.08.93		1	1	470471.6	777483.5	7.00	104	1.80	0.237	0.291	0.330	0.375	0.441	1.36	100	0
		2	2	470309.6	777499.0	9.00	266	2.00	0.149	0.195	0.240	0.299	0.397	1.63	99	1
		3	3	470157.1	777501.1	8.48	419	2.24	0.127	0.150	0.170	0.193	0.226	1.33	99	1
		4	4	470064.3	777496.9	8.05	511	2.44	0.125	0.147	0.167	0.189	0.222	1.33	99	1
		5	5	469953.0	777497.4	7.89	623	2.87	0.132	0.154	0.174	0.197	0.231	1.32	99	1
		6	6	469745.8	777501.8	6.01	830	2.86	0.133	0.158	0.181	0.207	0.245	1.36	100	0
		8	7	469601.3	777502.5	9.51	974	2.20	0.131	0.156	0.179	0.206	0.246	1.37	99	1
		9	8	469480.9	777511.2	12.84	1095	1.03	0.087	0.129	0.151	0.176	0.214	1.58	98	2
		13	9	468999.2	777498.9	6.82	1577	0.85	0.117	0.149	0.174	0.202	0.246	1.45	98	2
		14	14	468729.6	777500.2	6.80	1846	0.91	0.141	0.171	0.200	0.233	0.338	1.55	99	1
		15	15	468575.6	777499.4	5.14	2000	0.88	0.195	0.275	0.317	0.364	0.434	1.50	100	0
		16	16	468411.8	777498.1	4.36	2164	0.93	0.255	0.298	0.337	0.381	0.444	1.32	100	0
		17	17	468195.7	777502.8	4.77	2380	0.87	0.231	0.289	0.329	0.373	0.438	1.38	100	0
		18	18	467886.0	777504.5	2.00	2690	0.65	0.169	0.252	0.295	0.346	0.423	1.59	100	0
09.09.93	3	1	DHA-1	462368.6	783188.0	21.12	104	1.02	0.082	0.141	0.174	0.214	0.316	1.97	90	10
		3	DHA1	462172.2	783105.5	11.34	317	1.25	0.179	0.263	0.306	0.355	0.429	1.56	100	0
		9	P-9	461303.9	782789.1	1.12	1241	0.88	0.070	0.086	0.100	0.117	0.171	1.57	94	6
		11	P-11	460712.2	782573.6	7.90	1870	1.39	0.074	0.096	0.116	0.146	0.201	1.65	97	3
11.09.93	2	2	DHA-1	466298.0	779740.8	4.30	143	0.76	0.150	0.195	0.240	0.299	0.396	1.63	99	1
		4	DHA-2	466299.1	779899.1	3.30	301		0.135	0.166	0.196	0.231	0.336	1.58	99	1
31.10.93	1	1	DHA-1	470501.6	777500.2	3.80	85	0.85	0.079	0.107	0.133	0.161	0.205	1.61	99	1
		3	DHA-2	470295.0	777500.6	16.18	292	1.40	0.182	0.290	0.353	0.430	0.652	1.89	95	5
		5	DHA-3	470093.5	777505.0	9.74	493	0.90	0.136	0.159	0.181	0.205	0.241	1.33	99	1
		7	DHC-3	469905.4	777501.2	5.17	681	1.01	0.182	0.266	0.307	0.356	0.428	1.54	100	0
		9	DHC-2	469614.4	777502.7	3.40	972	1.05	0.143	0.172	0.199	0.230	0.330	1.52	100	0
		11	DHC-1	469338.6	777506.0	5.67	1248	0.46	0.090	0.136	0.158	0.184	0.223	1.58	95	5
		13	DHC-4	469135.6	777503.8	2.47	1451	0.32	0.126	0.197	0.266	0.322	0.410	1.83	93	7
		15	DHC-1	468944.4	777507.2	4.30	1642	0.42	0.054	0.073	0.087	0.104	0.143	1.63	78	22
		17	DHC-2	468744.8	777503.8	4.91	1842	0.79	0.274	0.317	0.355	0.397	0.459	1.29	100	0
		19	DHC-1	468359.0	777509.5	1.96	2228	0.44	0.162	0.237	0.287	0.340	0.422	1.62	99	1
01.11.93	3	2	DHA-2	460763.3	784413.2	5.48	173	0.76	0.137	0.181	0.227	0.287	0.391	1.69	99	1
		4	DHA-3	460563.0	784341.3	6.43	385	0.96	0.102	0.141	0.163	0.188	0.225	1.49	99	1
		6	DHC-2	460286.4	784247.7	3.76	676	0.92	0.065	0.077	0.089	0.102	0.121	1.36	87	13
03.11.93	2	1	DHC-1	461726.5	785095.9	1.80	289	0.23	0.087	0.129	0.151	0.176	0.214	1.58	98	2
		3	DHA-1	461845.4	785021.6	4.40	149	0.68	0.137	0.167	0.196	0.229	0.334	1.57	99	1

Table 4.2.c: The characteristics of the bed materials and additional information during sampling at Bahadurabad

Date	Channel number	Vertical number	Sample number	Easting	Northing	Vertical depth	Dist. from lt. bank	Flow velocity	D16	D35	D50	D65	D84	Std. Dev.	Sand (%)	Silt (%)
				(m)	(m)	(m)	(m)	(m/s)	(mm)	(mm)	(mm)	(mm)	(mm)			
23.07.93	2	2	DHA-1	471796.4	699001.3	7.59	2543	1.59	0.141	0.167	0.191	0.219	0.288	1.43	99	1
		4	DHA-3	471971.5	698993.9	9.85	2368	1.32	0.137	0.160	0.182	0.206	0.242	1.33	100	0
		6	DHA-4	472214.4	698990.5	8.93	2125	0.97	0.057	0.078	0.095	0.117	0.275	2.28	81	19
		9	DHC-2	472613.8	699005.0	2.00	1727	0.65	0.131	0.154	0.175	0.199	0.233	1.33	99	1
		13	DHC-1	473829.3	699018.5	2.88	513	0.44	0.083	0.120	0.145	0.171	0.212	1.60	98	2
23.07.93	1	1	DHC-1(1)	476364.7	698255.0	2.90	2622	1.30	0.076	0.101	0.125	0.154	0.201	1.63	97	3
		3	DHA-1(1)	476703.2	698288.8	6.90	2282	1.62	0.084	0.126	0.151	0.180	0.226	1.65	97	3
		4	DHA-2(1)	476809.1	698288.5	7.60	2176	1.79	0.110	0.145	0.167	0.193	0.231	1.45	98	2
		6	DHA-1(2)	477002.2	698319.0	9.04	1981	2.18	0.086	0.129	0.151	0.178	0.218	1.60	98	2
		8	DHA-3	477207.0	698326.8	12.42	1777	2.16	0.079	0.115	0.142	0.169	0.210	1.64	96	4
		10	DHA-2(2)	477381.9	698357.1	10.03	1600	1.37	0.130	0.164	0.196	0.235	0.345	1.63	99	1
		12	DHA-1(3)	477711.8	698358.6	7.82	1271	1.85	0.137	0.161	0.182	0.206	0.240	1.32	99	1
		14	DHA-2(3)	478009.6	698396.8	11.44	971	1.56	0.136	0.159	0.179	0.202	0.235	1.31	99	1
		16	DHA-1(4)	478197.6	698412.4	11.68	782	1.60	0.148	0.191	0.233	0.291	0.391	1.63	99	1
		18	DHA-2(4)	478407.5	698432.2	10.60	572	0.98	0.259	0.304	0.344	0.390	0.457	1.33	99	1
		20	DHA-1(5)	478604.4	698447.6	6.84	374	0.58	0.054	0.069	0.080	0.093	0.112	1.44	75	25
		22	DHC-1(2)	478798.2	698468.8	3.30	179	0.11	0.039	0.057	0.071	0.086	0.109	1.68	59	41
24.10.93	1	1	DHC-2	476920.6	693884.9	5.03	2936	0.84	0.148	0.188	0.227	0.284	0.391	1.63	99	1
		3	DHC-3	477108.6	693889.1	7.63	2748	0.70	0.144	0.198	0.253	0.311	0.404	1.68	99	1
		5	DHC-4	477340.9	693883.7	4.47	2515	0.90	0.152	0.196	0.241	0.299	0.396	1.61	100	0
		7	DHC-5	477538.3	693879.8	8.44	2318	1.49	0.137	0.167	0.194	0.226	0.321	1.54	100	0
		13	DHC-1	478135.0	693875.4	6.24	1721	0.73	0.089	0.131	0.152	0.176	0.213	1.55	99	1
		15	DHC-3	478306.6	693896.0	5.45	1550	0.12	0.028	0.047	0.056	0.068	0.097	1.87	39	61
		17	DHC-2	478630.2	693888.1	4.71	1226	0.21	0.036	0.055	0.068	0.084	0.110	1.75	55	45
		19	DHC-1	479052.5	693887.7	4.76	804	0.55	0.081	0.125	0.147	0.173	0.213	1.63	95	5
		21	DHA-4	479239.5	693882.2	6.00	617	0.89	0.138	0.160	0.179	0.202	0.233	1.30	99	1
		23	DHA-3	479415.7	693879.6	8.70	440	1.26	0.248	0.296	0.338	0.386	0.457	1.36	100	0
		25	DHA-2	479641.1	693882.1	6.75	215	1.26	0.177	0.260	0.303	0.353	0.428	1.56	100	0
		27	DHA-1	479829.4	693879.0	2.40	27	0.66	0.056	0.088	0.120	0.152	0.202	1.91	81	19
27.10.93	2	1	DHC-1	472603.8	695194.4	3.69	1080	0.71	0.138	0.163	0.185	0.210	0.247	1.34	99	1
		3	DHC-2	472855.7	695037.1	5.32	783	0.63	0.134	0.164	0.191	0.224	0.317	1.54	99	1
		5	DHA-3	473031.3	694931.8	5.08	578	0.56	0.165	0.253	0.296	0.347	0.424	1.61	100	0
		7	DHA-2	473199.9	694822.8	5.46	378	0.56	0.130	0.153	0.175	0.199	0.235	1.34	99	1
		9	DHA-1	473372.0	694718.6	4.36	176	0.43	0.078	0.106	0.135	0.169	0.226	1.70	97	3

Table 4.3: The characteristics of the bed materials and additional information during sampling at Sirajganj

4.4 Data analysis and results

The data analysis mainly concentrated on locating the bed material samples, the characteristics of the bed materials, and relating the grain sorting to the flow velocity, the water depth, the planform, and in the downstream direction. Results of the analysis are presented below:

4.4.1 Location of the samples

The transect locations from which the samples were collected are shown in the 1993 SPOT image tracing (Figures 4.2 and 4.3). The sites on the Jamuna River were spread across stretches of a few kilometres up and downstream of two locations. Samples were collected during routine measurements and could be located in the corresponding cross-sections with depth average flow velocity (Figures 4.4 to 4.20). The transect depth average velocity (Figures 4.4 to 4.20) was not necessarily the same as the vertical flow velocity from which the bed material samples were collected because of time and space lags between the transect measurements and the measurement at the verticals. Therefore, the flow velocity measured during vertical profiling was used to compare bed material sizes with the depth average flow velocity.

RSP performed three bathymetric surveys in the left channel of the Jamuna River at Bahadurabad from June to November 1993. The location of bed material samples collected on 20 August 1993 are shown on the August-September 1993 bathymetric survey, and the location of bed material samples collected on 31 October 1993 are shown on the bathymetric survey of November 1993 (Figures 4.21 and 4.22). It appeared that the bed material samples collected at the head and both side of bars were coarser than other samples collected during the same routine gauging survey. This may have been due to the fact that coarser bed materials more likely occur at the front part of a bar in a braided river (Parker 1991).

4.4.2 Characteristic grain sizes

Samples from the Jamuna River contained little silt in comparison with the other rivers. Of the 104 samples from Bahadurabad, only six had more than 40 percent silt and clay; of the 34 samples from Sirajganj, only three had more than 40 percent silt and clay (Table 4.4). This was probably due to the fact that routine gauging transects were usually selected in active flow sections of the river.

Location	Sample type	No. of samples	Percent by weight		D_{16} (mm)	D_{50} (mm)	D_{84} (mm)	Geometric standard deviation
			Silt	Sand				
Bahadurabad	All	104	7.3	92.7	0.122	0.187	0.277	1.55
	<40 % silt	98	3.1	96.9	0.129	0.196	0.291	1.52
	>40 % silt	6	76.4	23.6	0.016	0.035	0.054	1.95
Sirajganj	All	34	7.3	92.7	0.117	0.179	0.269	1.57
	<40 % silt	31	3.3	96.7	0.125	0.189	0.285	1.55
	>40 % silt	3	49.0	51.0	0.034	.065	0.105	1.77

Table 4.4 Characteristic grain sizes of bed material samples from the Jamuna River

The characteristic grain sizes of bed materials taken from the two locations on the Jamuna River are shown in Table 4.4. The median grain sizes D_{50} (<40 % silt and clay) found from the present analysis is very close to what was found by the Jamuna Bridge Study (RPT et al. 1987) at Sirajganj, while the geometric standard deviation is slightly higher. Unfortunately, there were no previous bed material samples from Bahadurabad with which to compare the results.

The downstream fining rate of the bed samples (<40 % silt and clay) is 0.01 mm per 100 km, which is much less than found by the Jamuna Bridge Study, 0.04 mm per 100 km. To determine the downstream fining rate RPT et al. (1987) used the sampling locations Chilmari, Sirajganj and Nagarbari, while the present results are based on the average D_{50} at Bahadurabad and Sirajganj. The deviation is probably due to measuring uncertainties and both studies choosing only a few locations.

The relation between the geometric standard deviation and D_{50}, along with silt and clay percentages, is presented in Figures 4.23 to 4.26. The variation of D_{50} and the percentages of silt shows the tendency that a silt content above 10 % implies a D_{50} below 0.1 mm. The demarcation with respect to geometric standard deviation is 10 % of the silt content (as compared with 40 % in the other rivers).

4.4.3 Relating D_{50} to velocity and depth

The relation between D_{50} and the flow velocity and depth of the samples is shown in Figures 4.27 and 4.30. Apparently there was no relation between the median grain sizes and the flow velocity and the depth of the sampling location. If the routinely-measured samples collected in February and March, 1993, are analysed separately, the median grain size shows an increasing relation with the flow velocity (Figure 4.31). Although it was difficult to determine a relation between the two, it was indicated that a type of grain sorting occurred due to mobile armouring or sediment erosion and deposition processes in the river bed. During the lean season, enough time was available to adjust the bed material to the flow field.

4.4.4 Relation between the flow velocity and silt and clay percentages

Some samples of the Ganges and Old Brahmaputra Rivers were found to contain more than 40 percent silt and clay. These high percentages are attributed to the depositioning environment in the river bed. The relation between the velocity and the silt and clay percentages of the Jamuna River are shown in Figure 4.32 for the Bahadurabad and Sirajganj locations. It is interesting to note that only when the flow velocity range fell below 0.4 m/s did the samples contain more than 40 percent silt and clay. However, some samples contained much less silt and clay in the low flow velocity ranges. This suggests that high percentages of silt and clay were possible only at low velocity ranges, but that the silt content probably depended also on other aspects, such as the upstream supply of silt and clay.

4.4.5 Relation to erosion of the river bed

Peters (1994) indicated that coarser grains were likely to occur in bed load in eroding river beds due to selective transport. An attempt was made to examine the influence of erosion on material size. On 20 August 1993 one transect with an eroding and deposition bed was selected and a number of samples was collected. The eroding area extended from 2000 to 2600 m, and the deposition area from 1400 to 2000 m, see Figure 4.33. The changes of the river bed were detected by comparing with the routine gauging transect of 9 September 1993, measured almost at the same alignment. The average D_{50} of the eroding bed material was 0.17 mm, but the average D_{50} of the four samples around the eroding bed was 0.22 mm (Figure 4.33), indicating that the bed material at the eroding bed was not coarser than the bed material from the other location.

4.4.6 Seasonal variation of average grain sizes

The characteristics of bed materials were primarily determined by the geology of the upstream basin, characteristics of the upstream tributaries, and the river itself. During the monsoon, the contribution of the different tributaries may create a time lag in the grain size variation, while during the lean period the river bed itself was probably the main source of bed material.

Samples collected from February to November 1993 in six routine gauging surveys were used to examine the seasonal variation. Helley-Smith samples were used for bed load transport measurements. The average size of Helley-Smith samples is generally a bit coarser than the bed material samples. The six surveys produced an inadequate number of samples to demonstrate the relation, so the average D_{50} of the Helley-Smith samples in a transect was used to fill in gaps (Figure 4.34 and 4.35). It was clear that the average median grain size varied from measurement to measurement, but no particular seasonal variation trend was observed from this analysis.

4.4.7 Skewness of the grain size distribution

Skewness is an indicator of the size distribution, expressing whether the distribution is normal, or skewed in the positive or negative direction. The skewness of a grain size distribution can be expressed as :

$$Skewness = \frac{(D_{90}-D_{50})-(D_{50}-D_{10})}{(D_{90}-D_{10})} \qquad (4.1)$$

Where D_{90}, D_{50}, and D_{10} are the characteristics grain sizes.

When determining the skewness, D_{84} and D_{16} were used instead of D_{90} and D_{10}, as these characteristic sizes were the only ones available in the RSP data base (PSD24). Probably because of this substitution, the value of skewness did not vary significantly.

The relation between skewness and D_{50} of the samples from Bahadurabad and Sirajganj are shown in Figure 4.36. The skewness variation shows a periodic oscillation, and both places had the same peak D_{50} values. The RSP sediment laboratory used the standard mesh '2-series' for grain size analysis. The standard sieve openings are 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm, and 0.063 mm. Characteristic grain sizes were estimated from linear interpolation of the logarithm of the sieve openings, and from the percentages of grain that passed through or were retained by the sieve. The sand fractions of most Bangladeshi rivers vary from 0.063 to 0.40 mm, and only the 0.25 mm and 0.125 mm sieves fell within this range. hereby, the estimated characteristic grain sizes were biased, and this probably accounts for the periodic skewness variation of the median grain size.

The analysis showed that the standard sieve used in the RSP laboratory was not suitable for determining the skewness of grain distribution for fine uniformly distributed sands like those found in the main rivers of Bangladesh. More densely spaced standard sieves could eliminate the inconsistency of the standard '2 series' sieve.

5 Discussion

5.1 General

Although a river is characterised by its average grain size and gradation of the bed materials, it was observed from the analysis that within a river, the characteristics of the bed material vary widely. The percentage of silt and clay in a sample, the median grain size (D_{50}), and the geometric standard deviation of the bed material sample, differs from one sample to the other within the variation of space and time. The significance of the processes of these types of variation and comparison of the characteristics of the bed material between the different rivers are discussed in this chapter.

5.2 The presence of silt and clay in the samples

For a sand bed river, a grain size of 0.063 m is considered the demarcation point between bed material transport and wash load transport. Simon et al. (1977) suggested that when choosing a bed material size, sediment finer than D_{10} could be considered the dividing size between wash load and bed load. According to Simon, if the demarcation line is 0.063 m, then a bed material sample that contains up to 10 percent silt could be considered representative for sediment predictors. During the present analysis, samples having less than 40 % silt and clay are considered as relevant for morphological studies, and for sediment and roughness predictors. This can be justified by the following rationale:

Analysis of the bed materials of the Ganges River showed that three types of river bed environments are apparent (Chapter 2). In an active river bed, generally the bed material is coarser, and samples are expected to contain less than 40 % percent of silt and clay. The analysis of the Jamuna River supports this observation, as it was found that fine bed material samples (with more than 40 % silt and clay) only occurred in a very low flow environment. As the major changes of the river occur during its higher flow stages, the bed materials that are likely to occur at such flow condition are probably the relevant ones for studying the river morphology. The particular aspects of the river morphology, such as river bed roughness, adaptation of the river bed, bank erosion, and sediment transport capacity, are related to the size and gradation of the material which is available in the active river bed.

This does not mean that the fine bed materials (>40 % silt and clay) do not have any significance in river morphology. However, the characteristics of the fine sediments, such as chemical and mineralogical properties which determine the consolidation capacity of the deposited sediment, are beyond the scope of this study.

5.3 Characteristics of grain sizes and downstream fining rate

The median grain size D_{50}, the geometric standard deviation, and the downstream fining rate of the bed material samples (<40 % silt and clay) of the Ganges, Old Brahmaputra and Jamuna Rivers are compared in Table 5.1.

River		D_{50} (mm)	Geometric standard deviation	Downstream fining rate (mm/100 km)
Ganges		0.14	1.4	0.025
Old Brahmaputra		0.18	1.8	
Jamuna	Bahadurabad	0.19	1.52	0.01
	Sirajganj	0.20	1.55	

Table 5.1 The average D_{50}, geometric standard deviation and downstream fining rate of the bed material samples (<40 % silt and clay)

The bed material samples of the Ganges River are finer and more uniformly distributed than that of the other two rivers. On the other hand, the bed material of the Old Brahmaputra River is less uniform, although the main source of the material of this river is the Jamuna River, indicating the grain sorting within the river system.

The downstream fining rate of the Ganges River is 0.025 mm/100 km, which is higher than that of the Jamuna River, 0.01 mm/100 km. This variation may be due to the mineralogical composition of the bed materials, to selective transport processes in the river or to the inconsistencies in measuring the bed materials. The grain size variation in the downstream direction of samples of the Old Brahmaputra River shows a quite different character, which is unusual and needs further studies for exploration.

5.4 Spatial variation of grain sizes

Parker (1991) studied the grain sorting processes in a gravel bed river, which involves the following processes and effects:

- Armouring: Both static armour that impedes the transport and mobile armour that temporarily coarsen the surface;
- Beds forming structures such as dunes;
- Secondary flow cells;
- Sorting in meandering bends;
- Sorting in braided streams, including accretion of coarser material at the bar head; and
- Downstream fining due to selective sorting or abrasion.

Grain sorting that occur in meandering bends and due to secondary flow cells could not be examined from the present bed material samples due lack of (secondary) flow data and sufficient bed material samples in well-defined meandering bends.

This study analyzed the grain size variation in relation to the primary flow velocity for the bed material samples of the Jamuna river. No distinct processes were observed, but still, two probable tendencies can be observed from the analysis: The grain size increased (lean season data) with an increase in velocity (Figure 4.31), and the variation range of D_{50} narrowed with an increased velocity (Figures 4.27 and 4.28). The first observation indicates that some sort of grain sorting process occurred during the lean season, where the prevailing flow direction and magnitude (0-1.2 m/s) were sustained for a long period. The second observation indicates that grains mix better during high-flow conditions than during low-flow conditions. These findings suggest that for fine sand, a grain sorting process is possible within certain limits. In addition, grain mixing occurred with higher ranges of velocity, where bedform movements extended to a considerable higher depth. These observations are based on only a few lean season samples, and further data are needed for a verification.

In a braided river, coarser grains were likely to be found at the head of a bar (Figures 4.21 and 4.22). No extra samples were taken at other locations on braided rivers, such as at the front and lee side of the bar. It would be difficult to conclude on the grain sorting processes prevailing at or on the side of the bar, because the examples presented in Figures 4.21 and 4.22 did not show a distinct pattern.

6 Conclusions

From the analysis of the bed material samples of the Ganges, Old Brahmaputra and Jamuna Rivers, the following conclusions were drawn:

- The bed material samples of these three rivers are almost uniformly distributed fine sand. The average D_{50} of the samples (with less than 40 % silt and clay) of the Ganges River is 0.14 mm, 0.18 mm in the Old Brahmaputra River, 0.20 mm in the Jamuna River at Bahadurabad, and 0.19 mm at Sirajganj. The geometric standard deviation of the samples varies from 1.4 to 1.8.
- The silt and clay content in a bed material sample varies from 0 to 100 percent. A comparison with the current velocity suggests that the presence of more than 40 % silt and clay in bed material samples is possible only in low flow velocity areas, and that in an active river bed, the presence of silt and clay in a sample is less than 40 %. The silty samples are likely in depositing areas and the average D_{50} of finer samples (with more than 40 % silt and clay) depends on the characteristics of the area.
- The downstream fining rate of bed materials of the Ganges River is 0.025 mm/100 km, and in the Jamuna River it is 0.01 mm/100 km. The difference between the two rivers is probably due to the variation of mineralogical composition of the sediments, or to selective transport processes in the rivers, or to inconsistencies in measurement.
- Neither distinct grain sorting processes in the transverse direction nor a seasonal variation of the grain size were identified.

7 Recommendations

On the basis of the analysis, the following recommendations can be made for a further understanding, especially regarding the grain sorting processes in the river system:

- The observation of increasing grain sizes with an increasing primary velocity for the lean season data needs further elaboration with inclusion of more lean season data.
- Instead of fining in the downstream direction, the bed material samples of the Old Brahmaputra River was showing a coarsening trend at certain stretches of the river, which demands further investigation on the sub-soil, the river bed aggradation associated with tectonic movements, and additional bed material sampling in that river.
- The presently used standard '2 series' sieve is not suitable for fine, uniformly distributed sand, like the bed materials of the main rivers of Bangladesh. Therefore, more densely spaced standard sieves should be used for grain size analysis.

References

BCEOM/Compagnie Nationale du Rhone/Euroconsult/Mott MacDonald International/Satec Development/Desh Upodesh Ltd./BETS Ltd., 1993, 'North Central Regional Study', (FAP3), Flood Plan Coordination Organisation, Government of Bangladesh

Delft Hydraulics/DHI, 1994, River Survey Project , Morphological studies phase 1, Available data and characteristics, 'Study Report 3'

Delft Hydraulics/DHI, 1995, River Survey Project, Sediment Rating Curves and Balances, 'Study Report 19'

Hack, J. T., 1957, 'Studies of longitudinal stream profiles in Virginia and Maryland', U. S. Geol. Survey Prof. Paper 294-B, pp 97

Leopold, L. B., Wolman, M. G., Miller, P. J., 1964, ' Fluvial Processes in Geomorphology', W. H. Freeman and Company, San Francisco

NEDECO, 1967, 'Surveys of Inland Water and Ports', Hydrology and Morphology, Vol. III, Part B Hydrological and Morphological Phenomena, East Pakistan Inland Water Transport Authority

NEDECO, 1983, 'Feasibility Study of Ganges-Kobadak Rehabilitation and Improvement Project', Final Report, Vol. II, Technical Annexes A-D

RPT/NEDECO/BCL, 1987, 'Jamuna Bridge Appraisal Study', Phase 1, Final Report, Appendix C-Hydrology, Morphology and River Engineering

Parker, G., 1991, 'Some Random Notes on Grain Sorting', Grain sorting Seminar, Ascona, Switzerland

Peters, J. J., 1978, Discharge and Sand Transport in the Braided Zone of the Zaire Estuary', Netherlands Journal of Sea Research, Vol. 12, no. 2/3, pp. 273-292

Peters, J. J., 1994, 'Report on Mission Project Advisor', Seventh Mission, River Survey Project (FAP24), Flood Plan Coordination Organisation, Government of Bangladesh

Simons, D. B. and Fuat, S., 1977, 'Sediment Transport Technology', Water Resources Publications, Fort Collins, USA

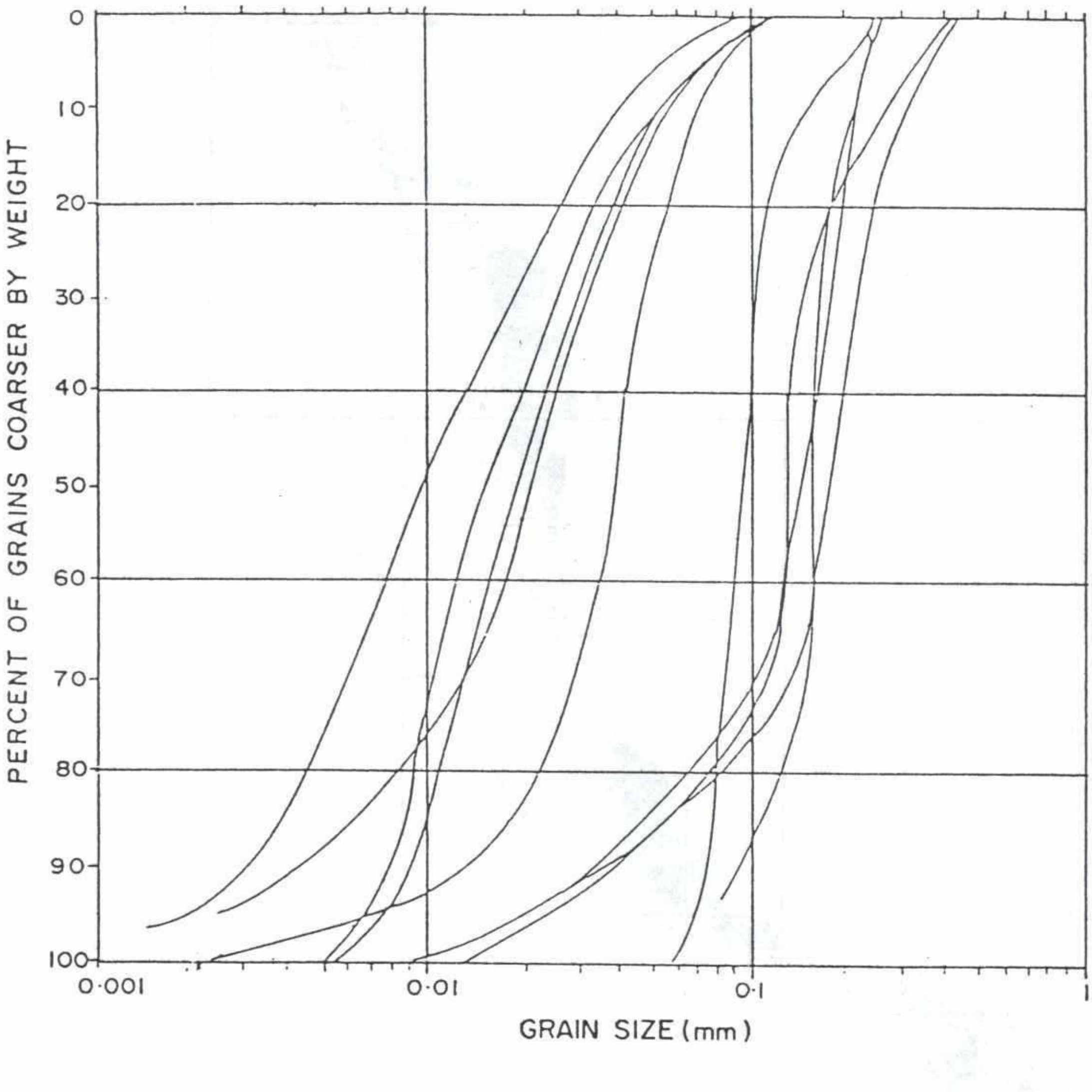


Figure 2.1 : Grain size distribution of the bed samples of the Ganges; after NEDECO, 1967

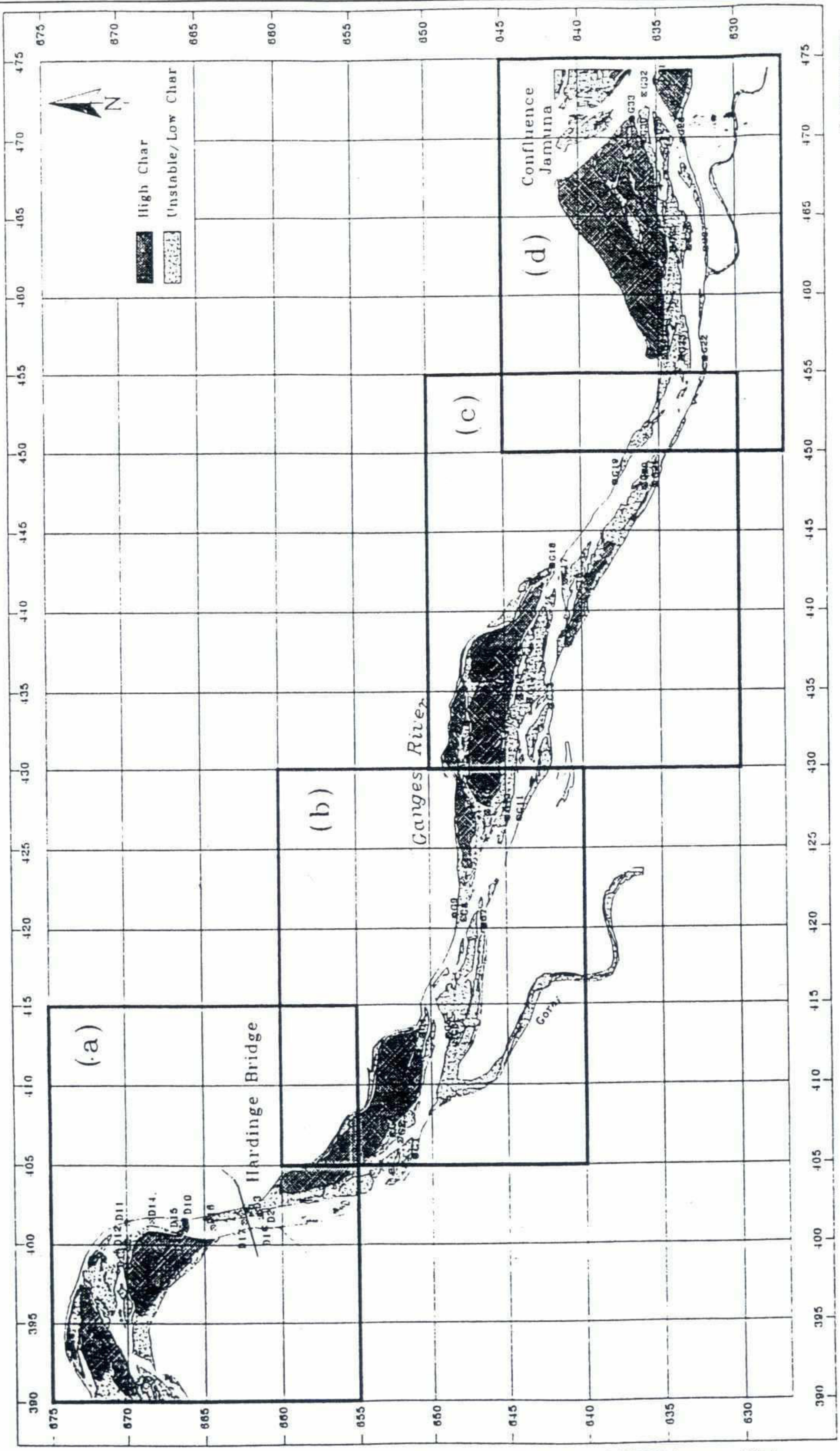


Figure 2.2 : Location of bed material samples in the Ganges River (traced SPOT image , 1994)

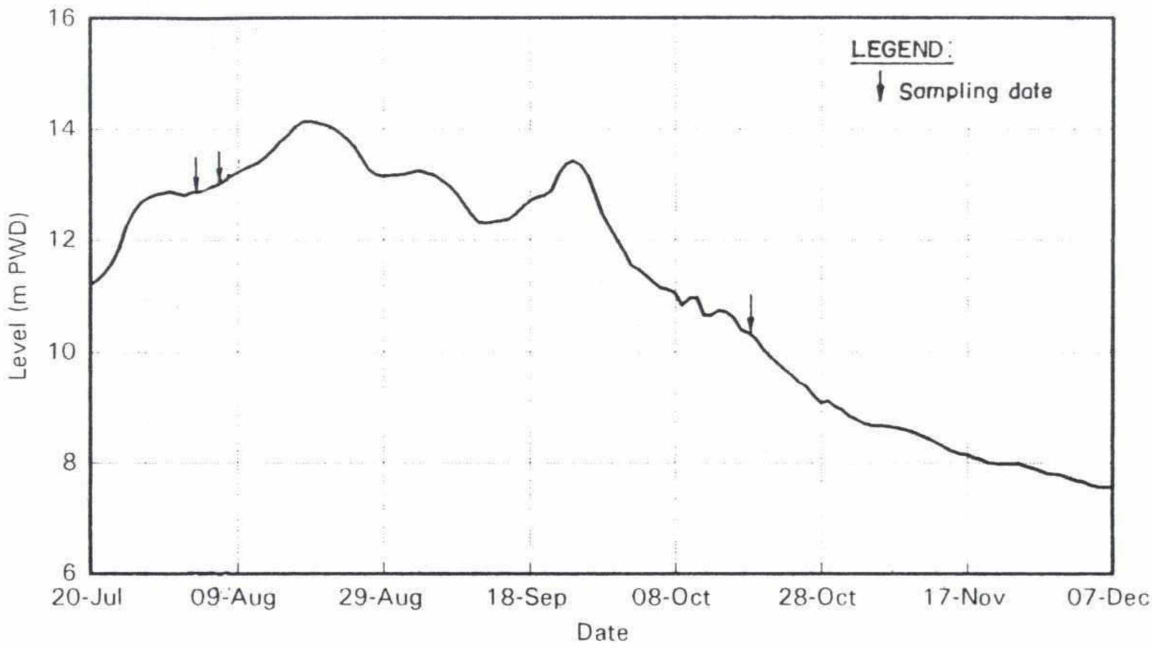


Figure 2.3 : Water-level hydrograph 1994, Ganges River

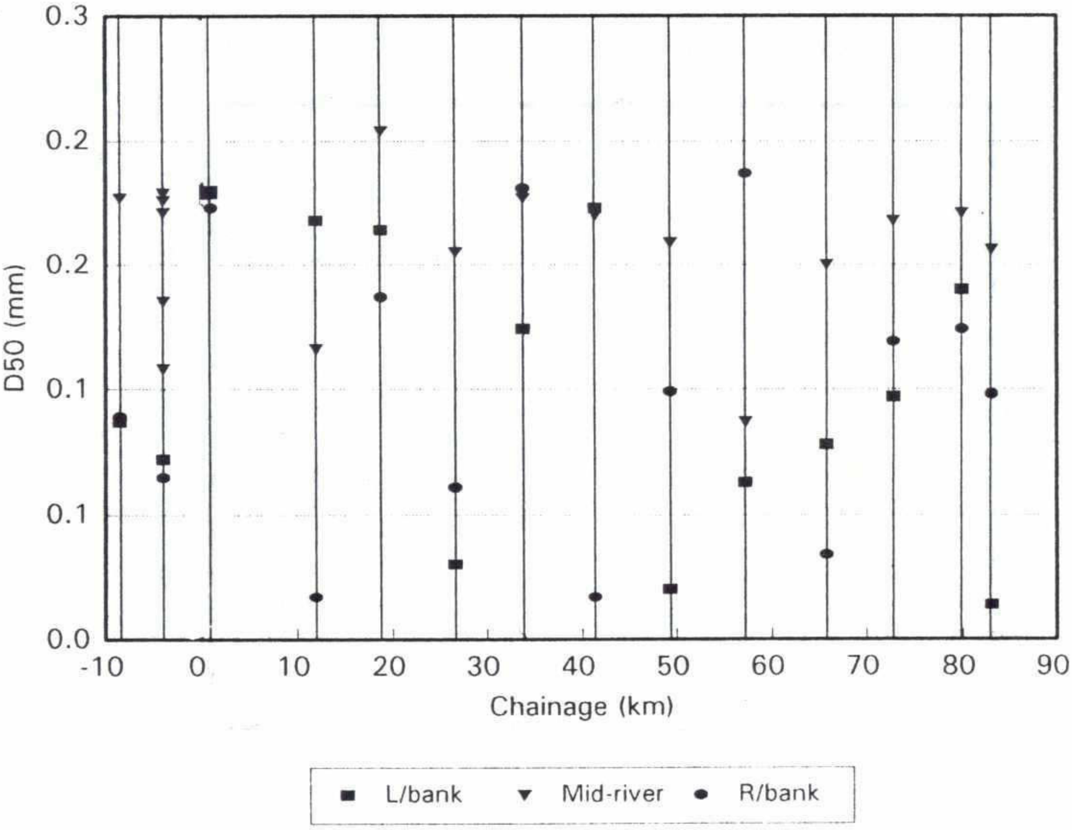


Figure 2.4 : Variation of D50 across and along the river

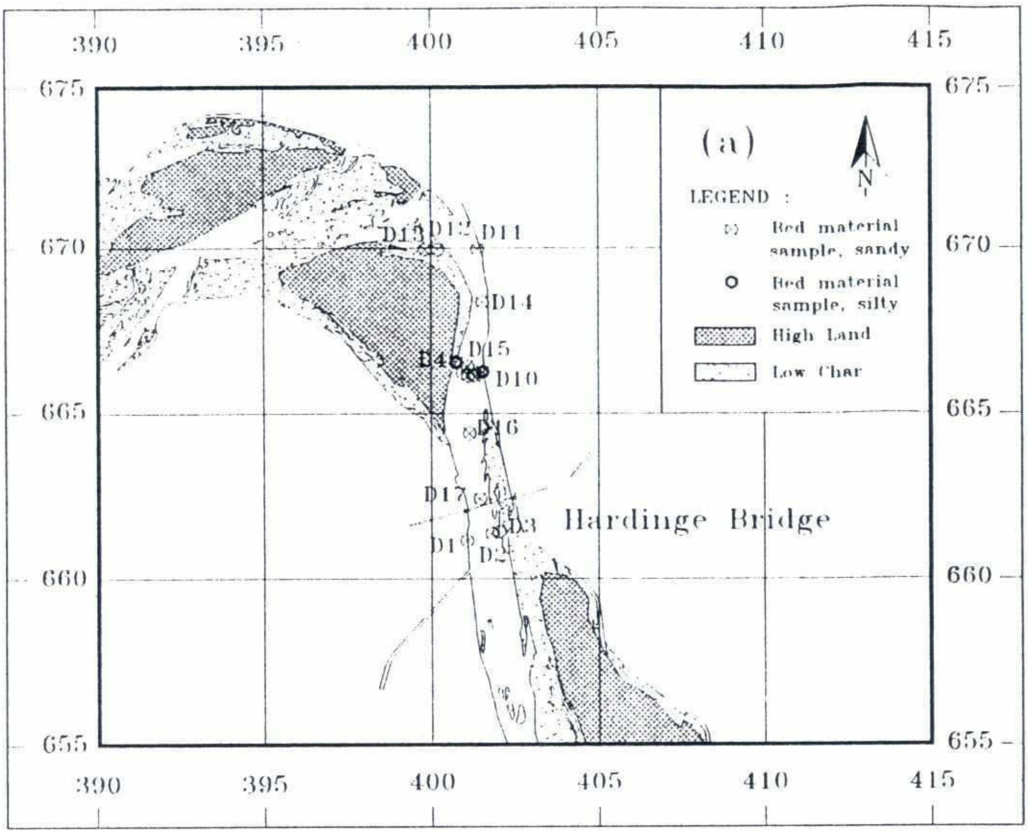


Figure 2.5 : Position of bed material samples (block a)

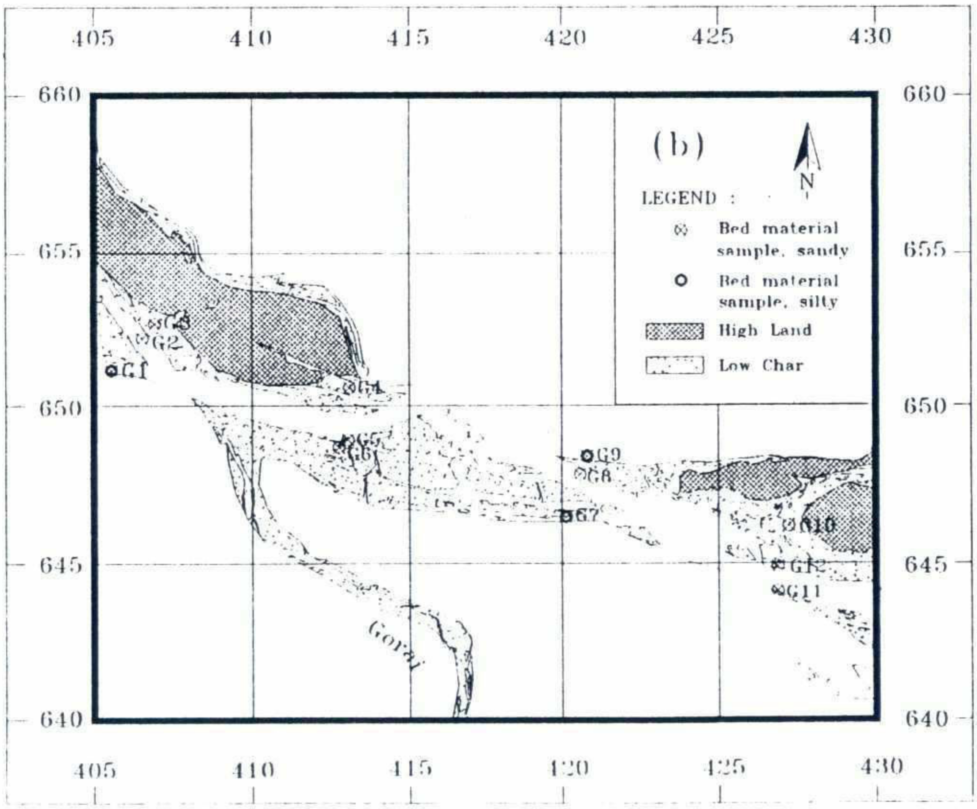


Figure 2.6 : Position of bed material samples (block b)

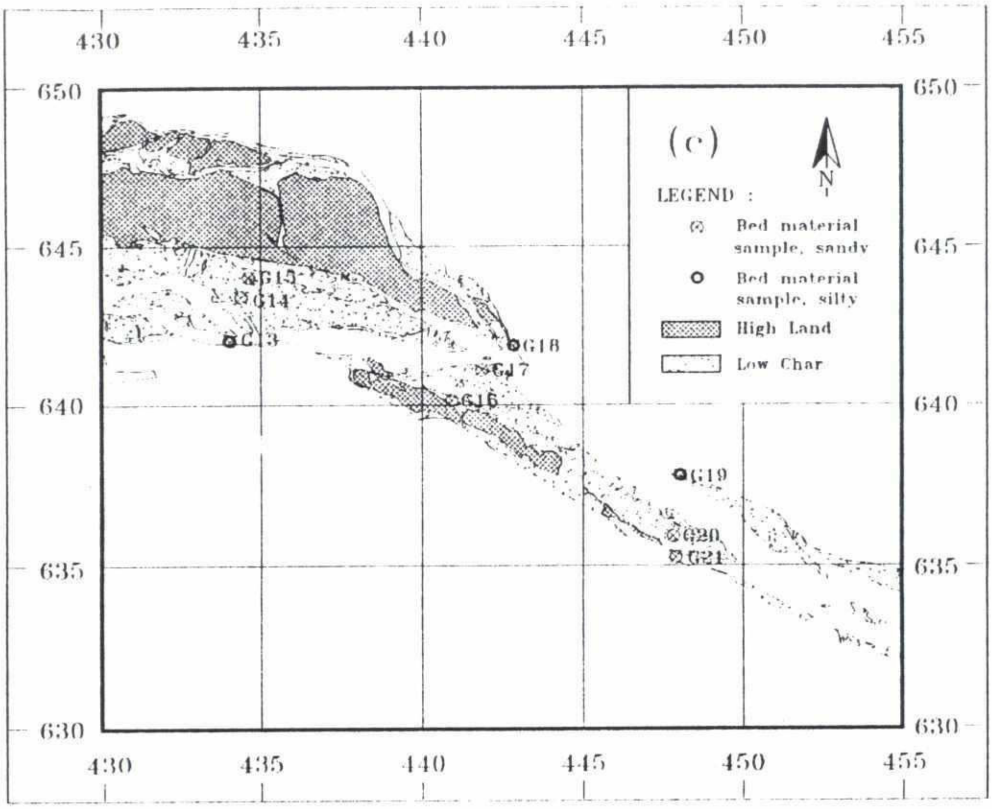


Figure 2.7 : Position of bed material samples (block c)

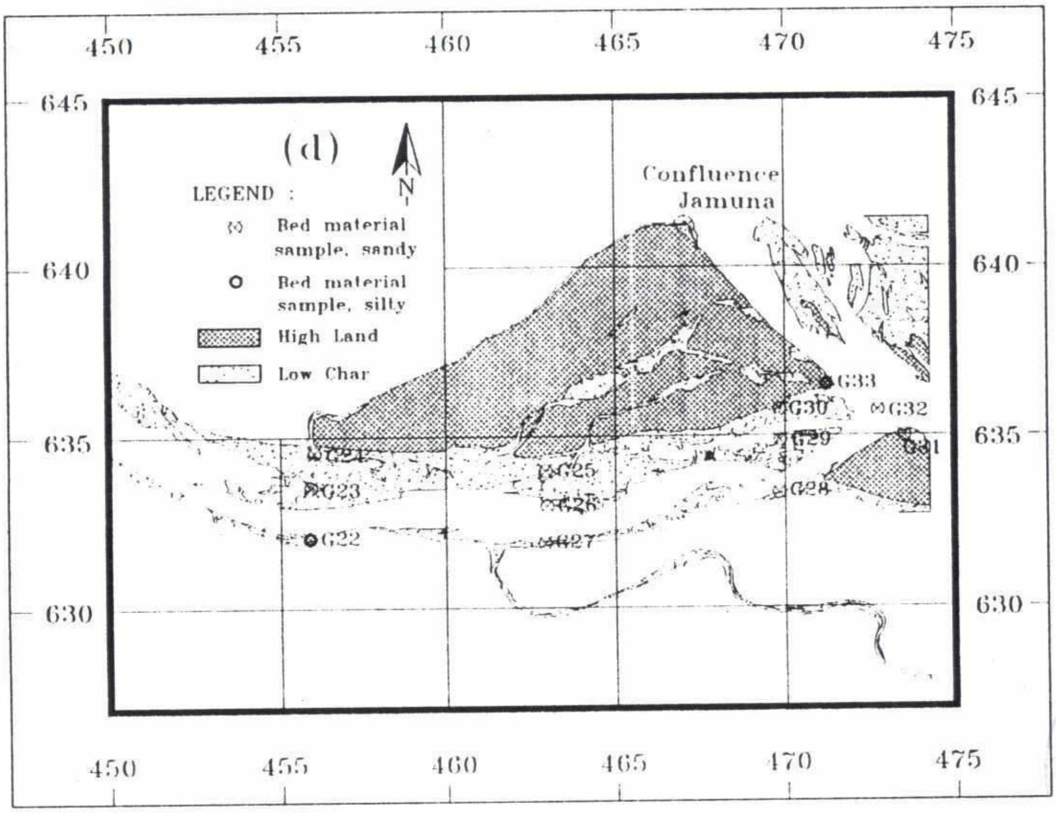


Figure 2.8 : Position of bed material samples (block d)

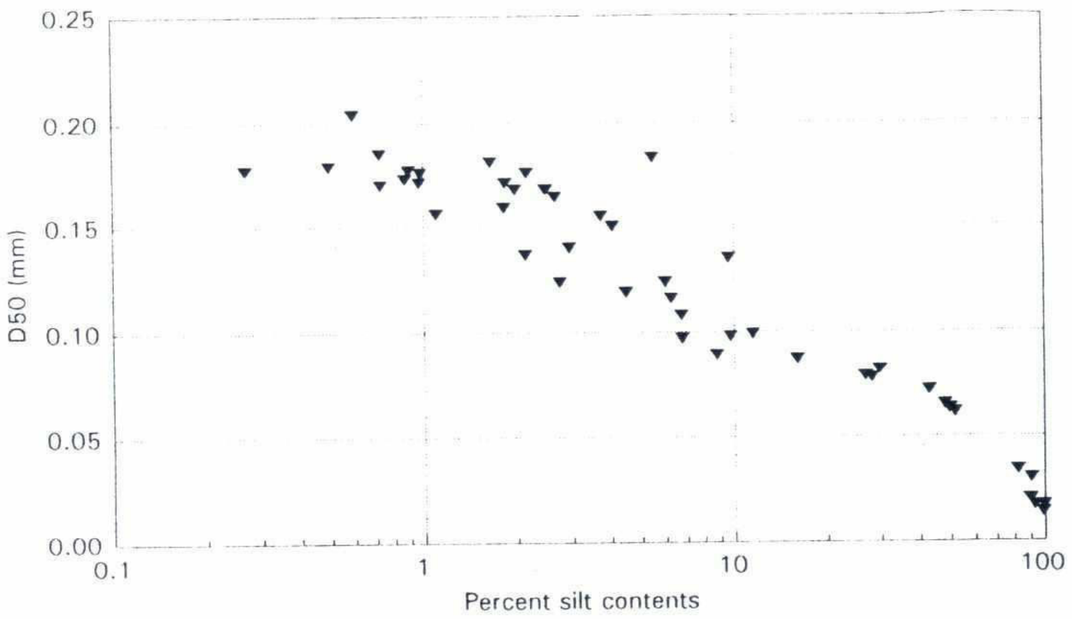


Figure 2.9 : Variation of D_{50} with the percentage of silt content of the samples

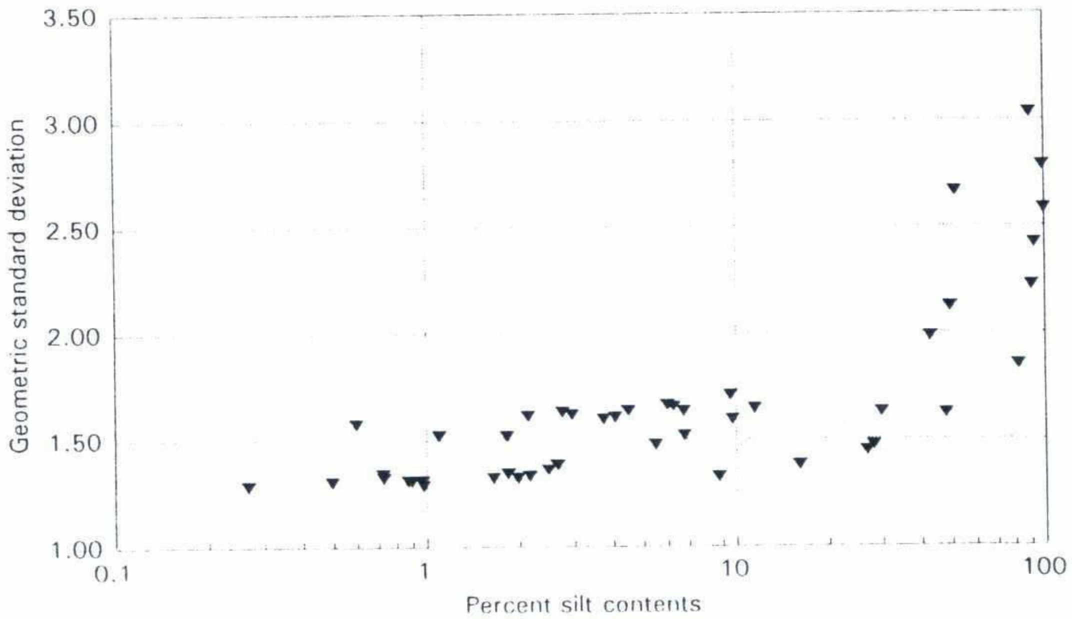


Figure 2.10 : Variation of geometric standard deviation with the percentage of silt content of the samples

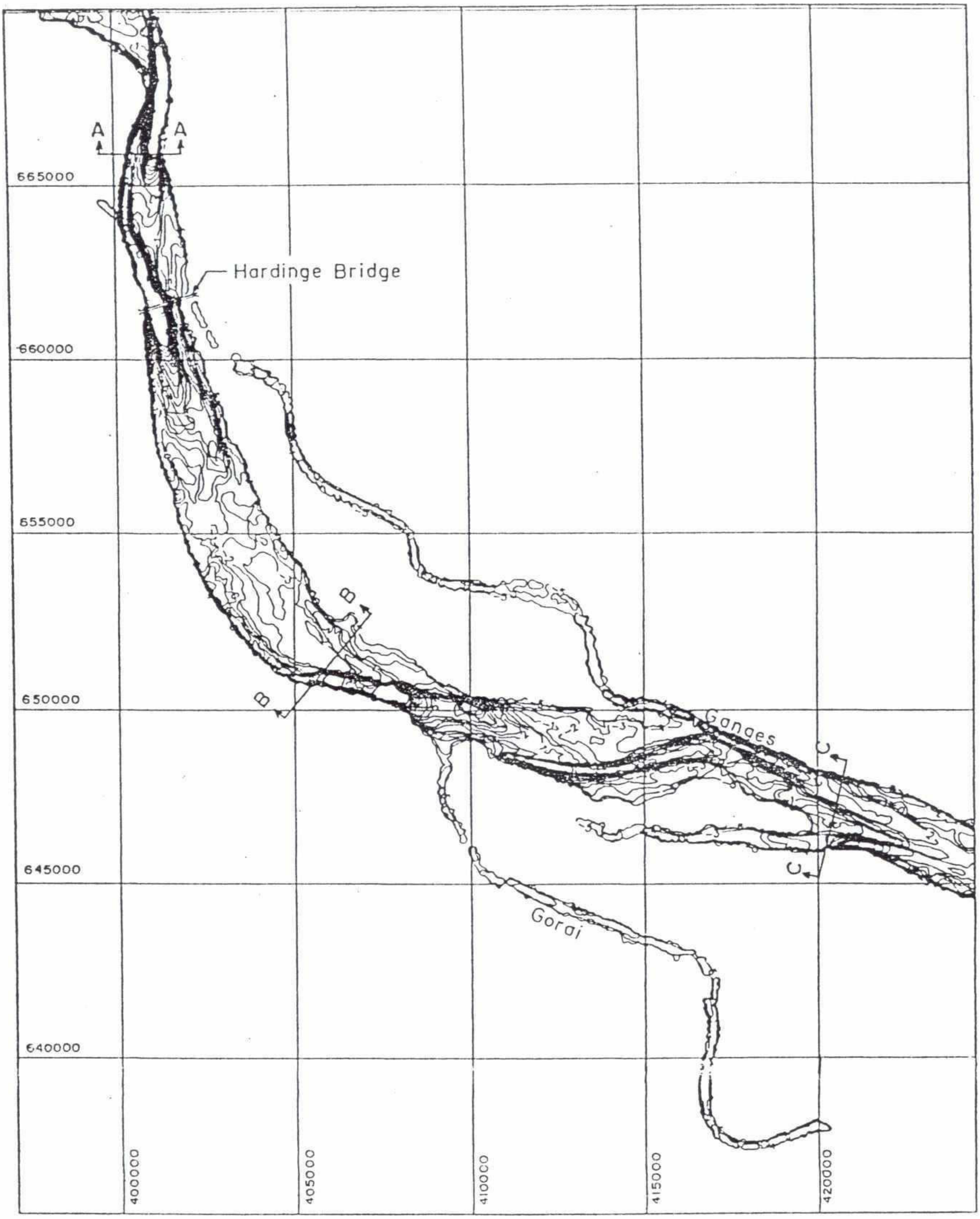


Figure 2.11 : Bathymetric survey, October 1994 and location of three sections of bed material samples

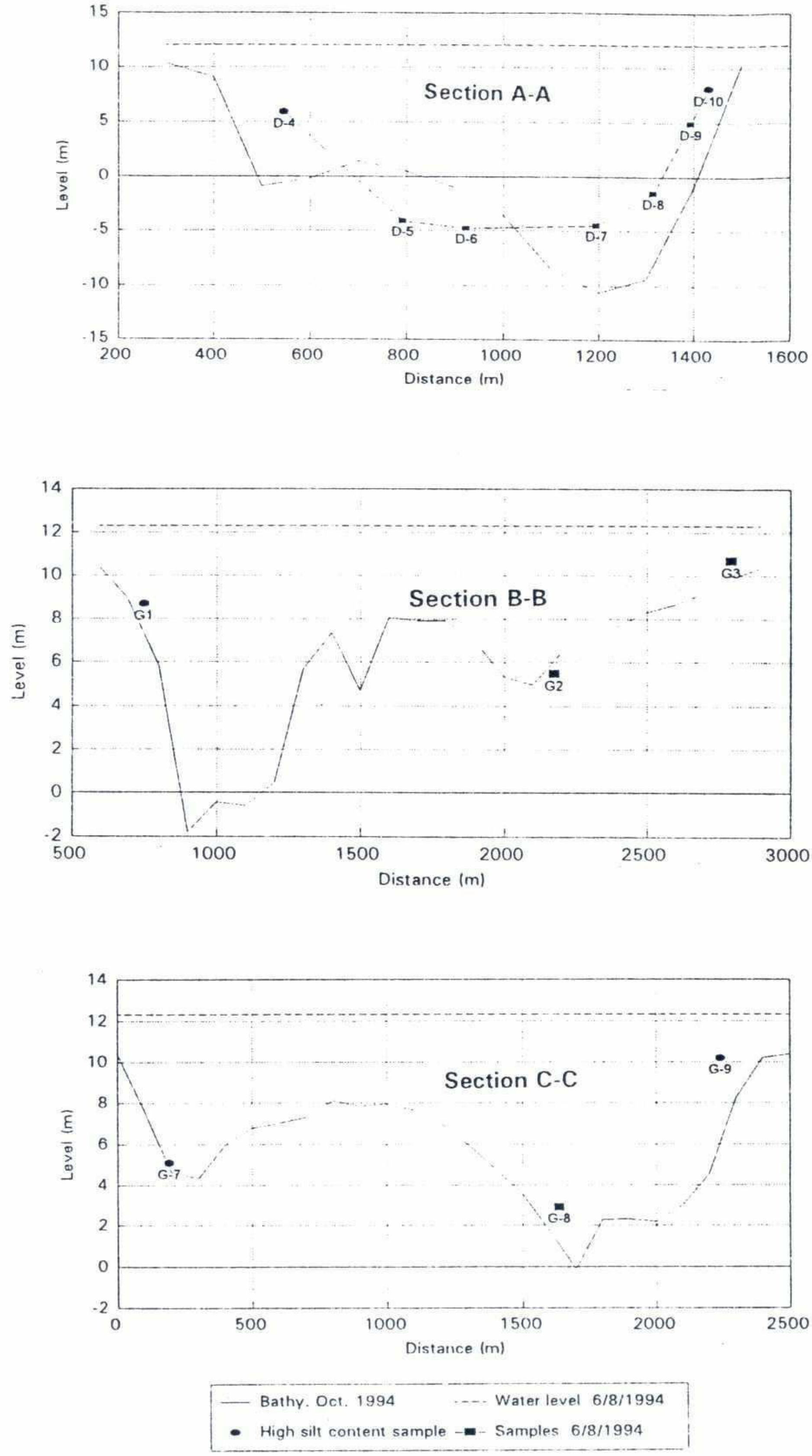


Figure 2.12 : Position of bed material samples on the bathymetric sections

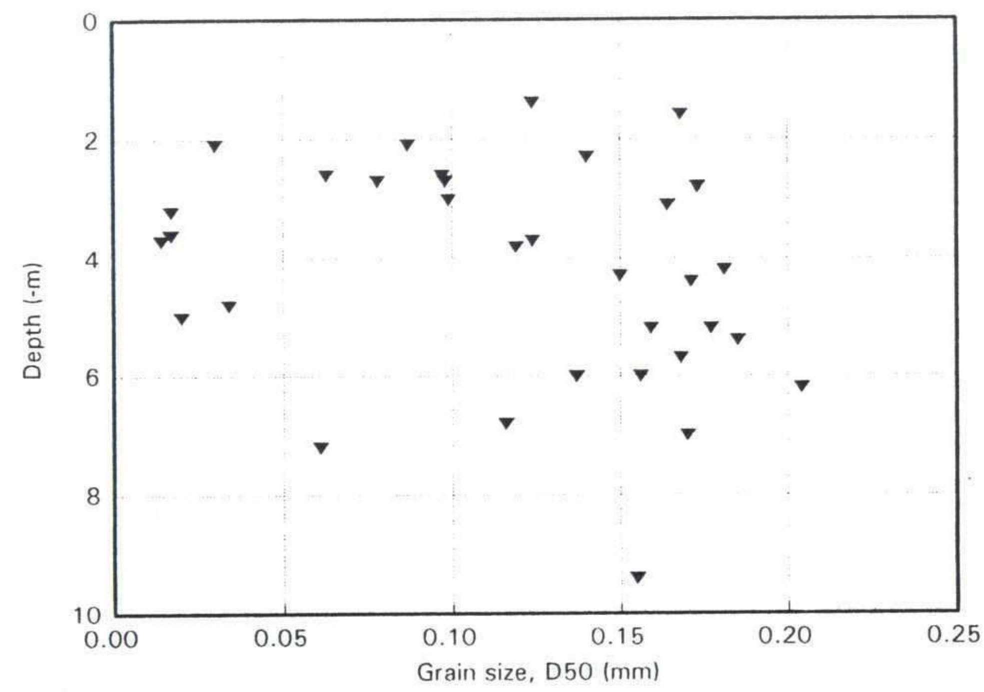
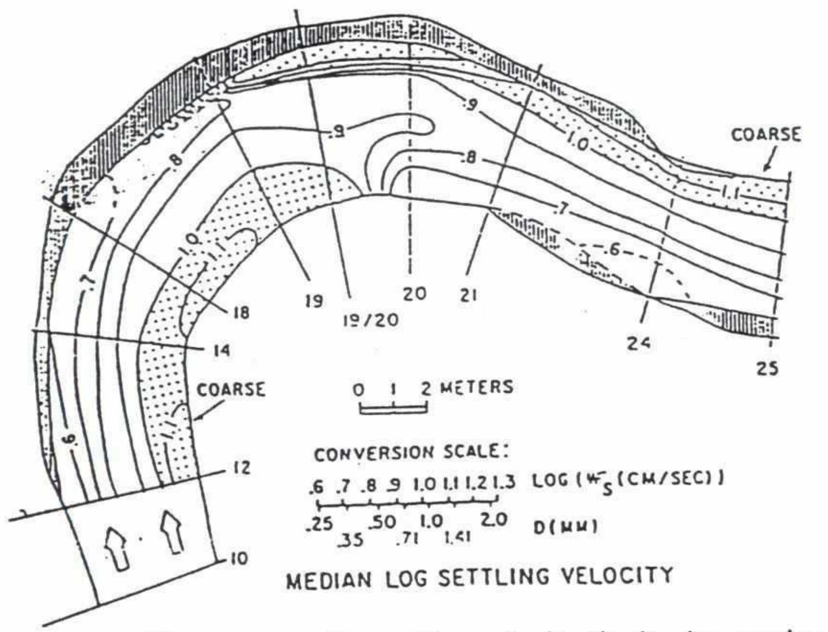


Figure 2.13 : Relation between D_{50} of the bed material samples and water depth



Map of the median settling velocity distribution moving as bed load. The contour interval is 0.1 W_{10}. Open circles represents immobile gravel in the pool, and diagonal lines indicate submerged sloping banks with immobile sediment.

Figure 2.14 : Variation of grain size in a meandering bend, (Parker, 1991)

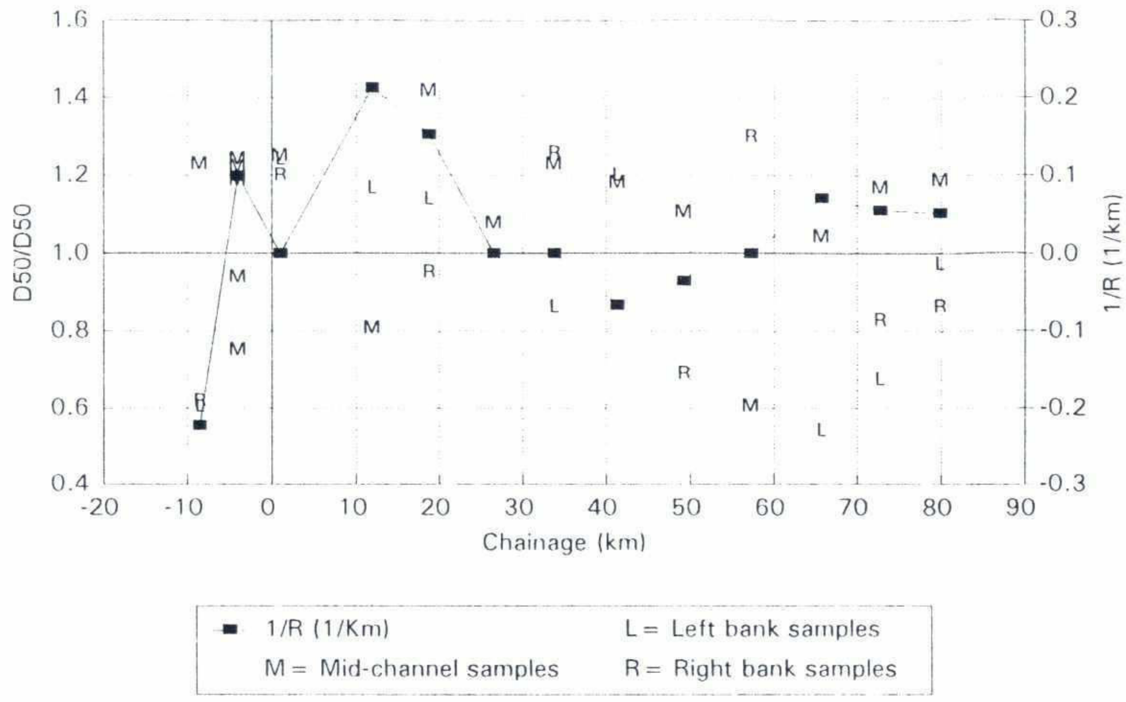


Figure 2.15 : Grain size versus radius of curvature along the chainage of the Ganges River

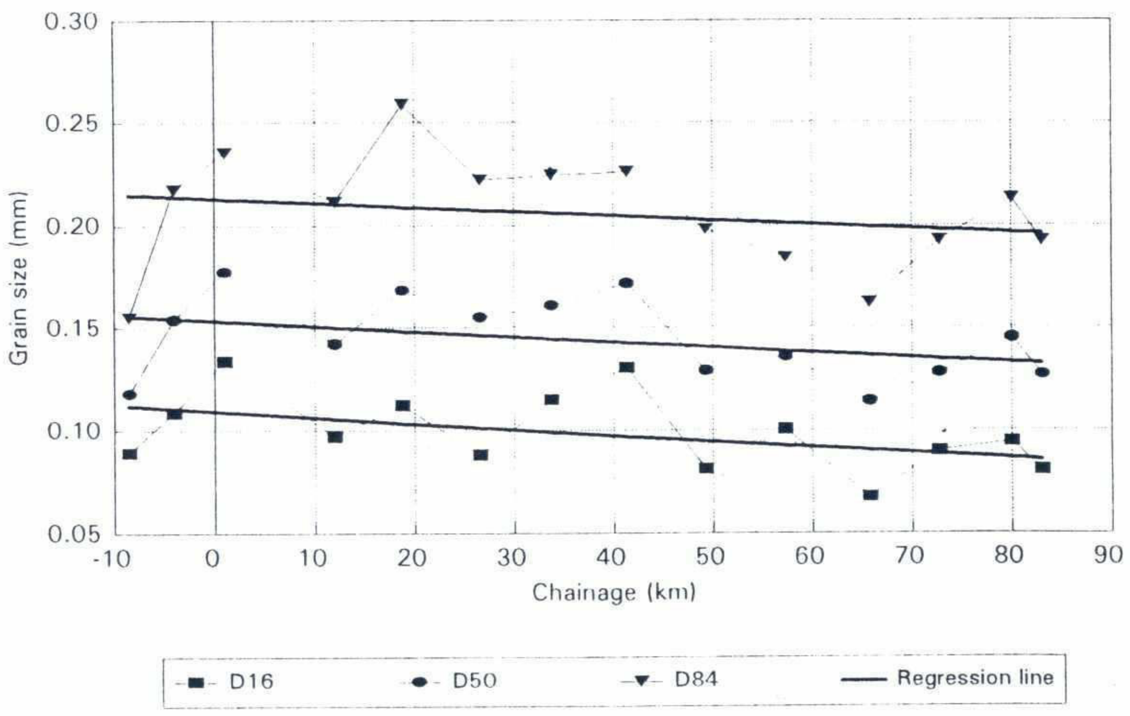


Figure 2.16 : Characteristic grain sizes variation along the chainage of the Ganges River

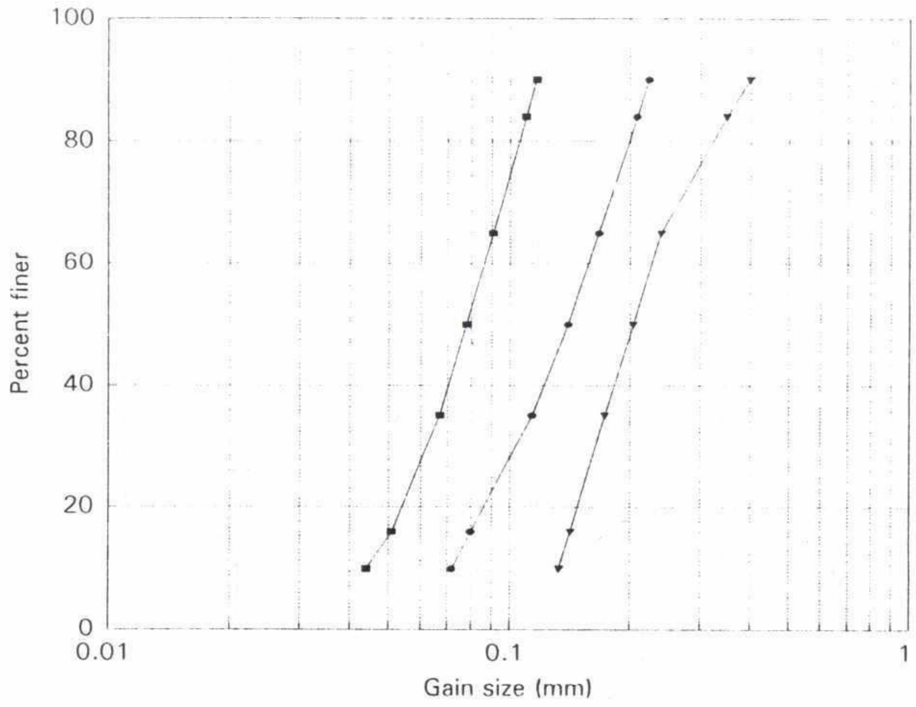


Figure 2.17 : Grain size distribution

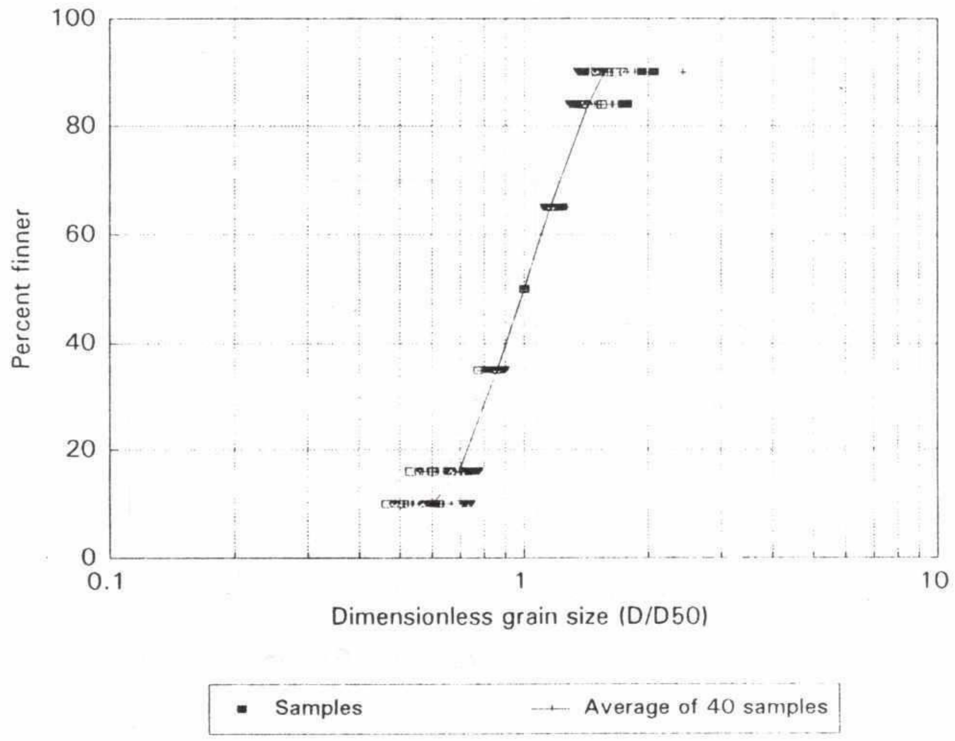


Figure 2.18: Dimensionless grain size distribution of the 40 samples

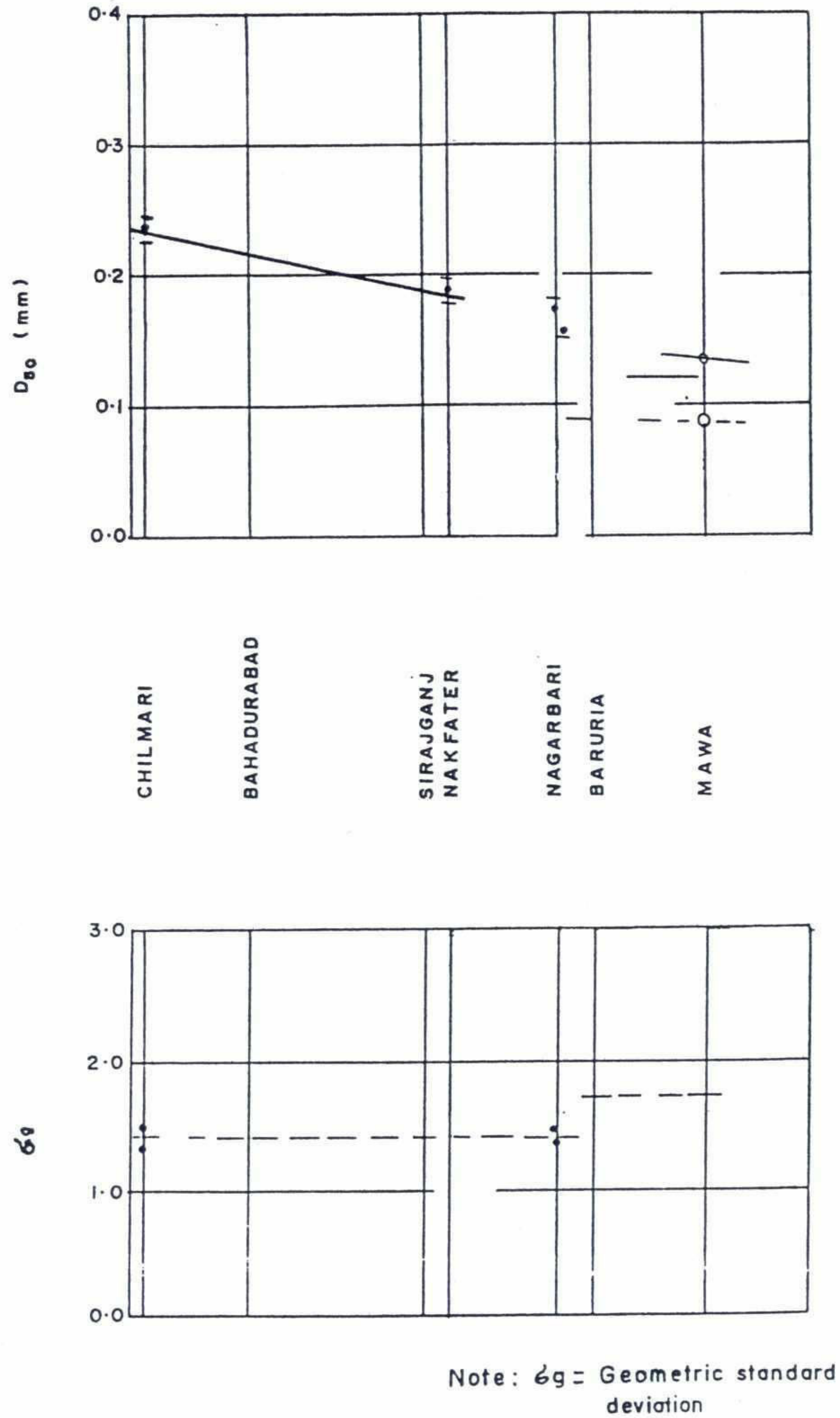


Figure 2.19: Average bed material size and gradation, Jamuna and Padma Rivers, RPT/NEDECO/BCL (1987)

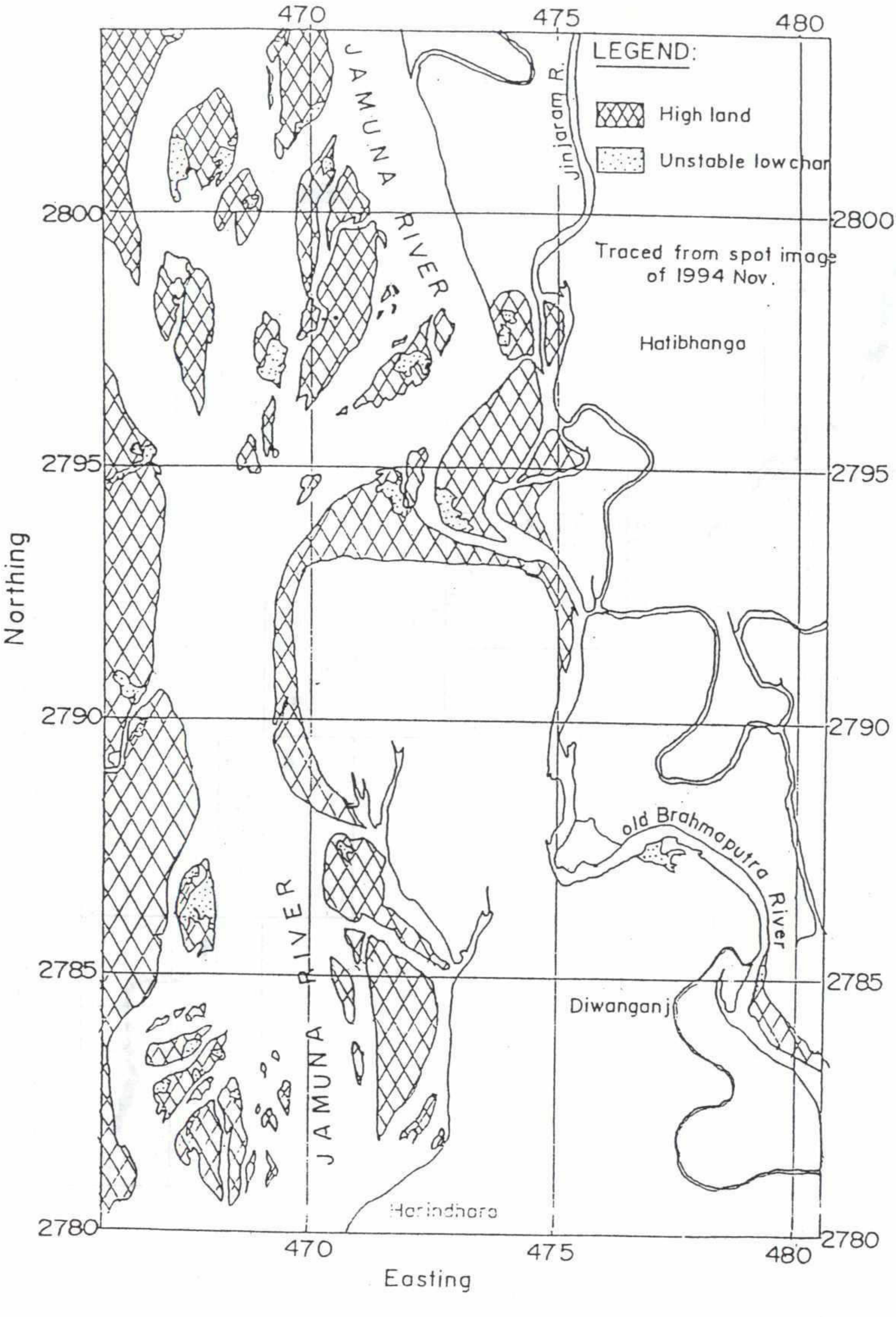


Figure 3.1: Off-take of the Old Brahmaputra River (traced SPOT images, September, 1994)

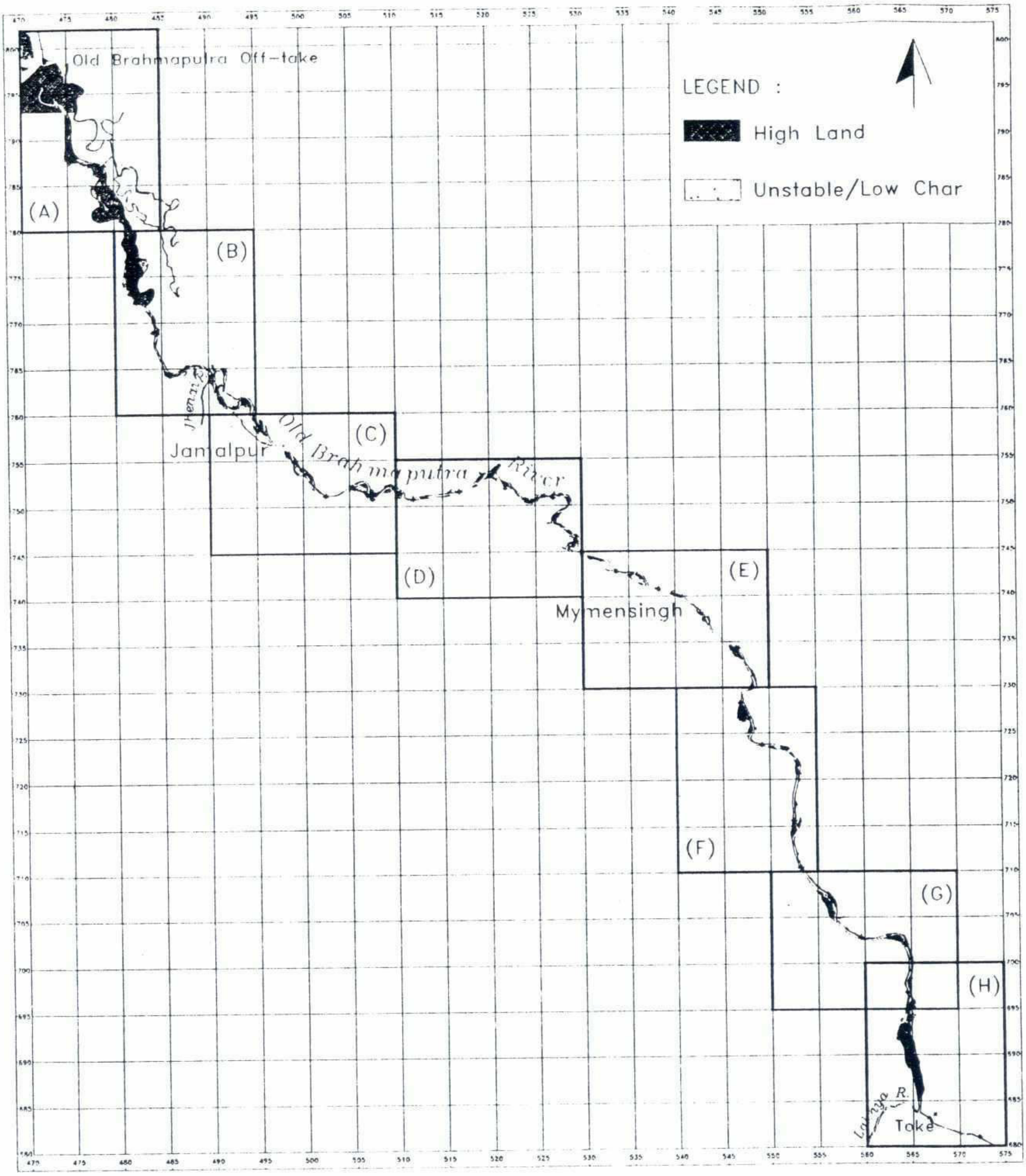


Figure 3.2: The Old Brahmaputra River, (traced SPOT images, March, 1990)

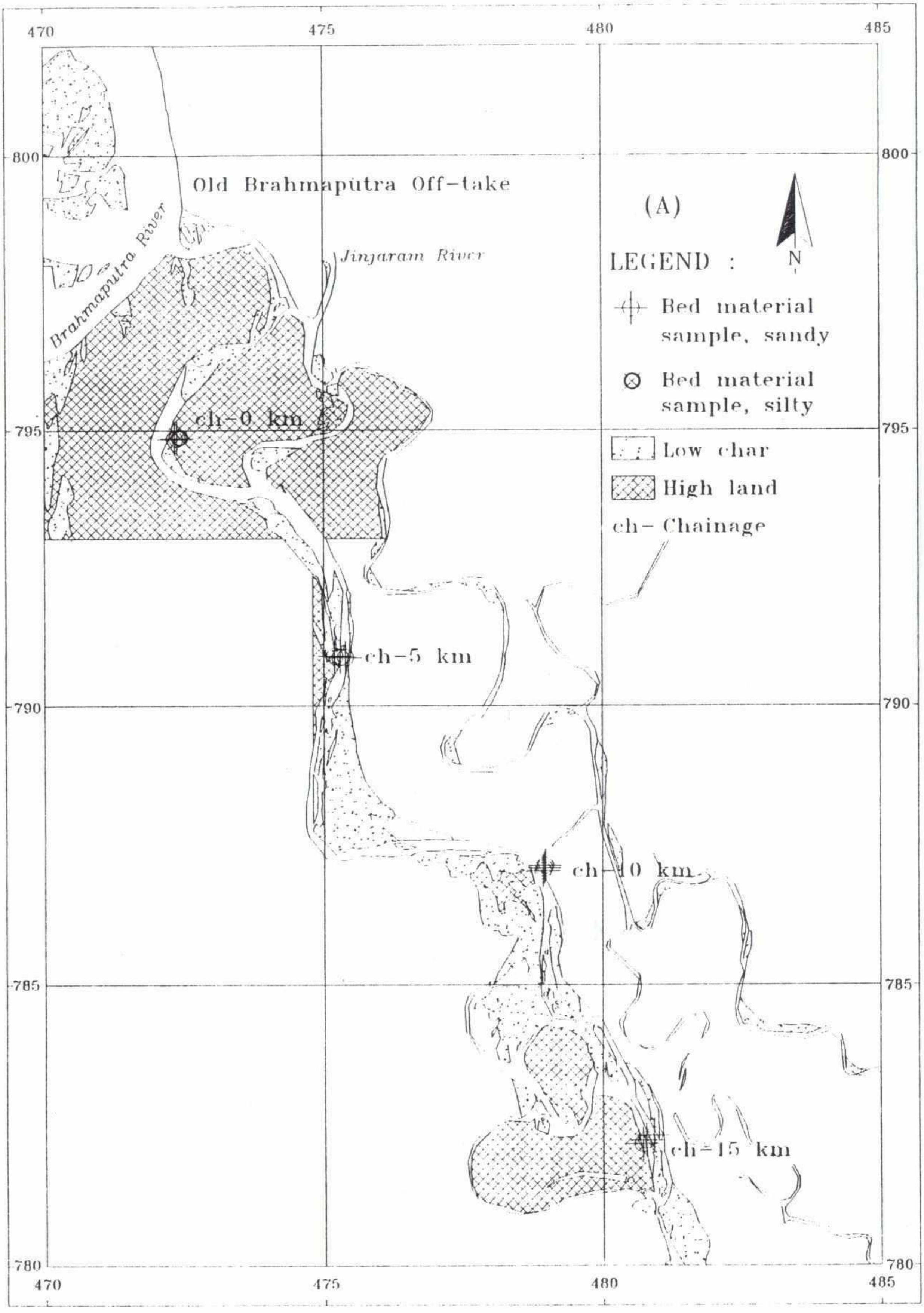


Figure 3.3: Bed material sample locations on the Brahmaputra River (block a)

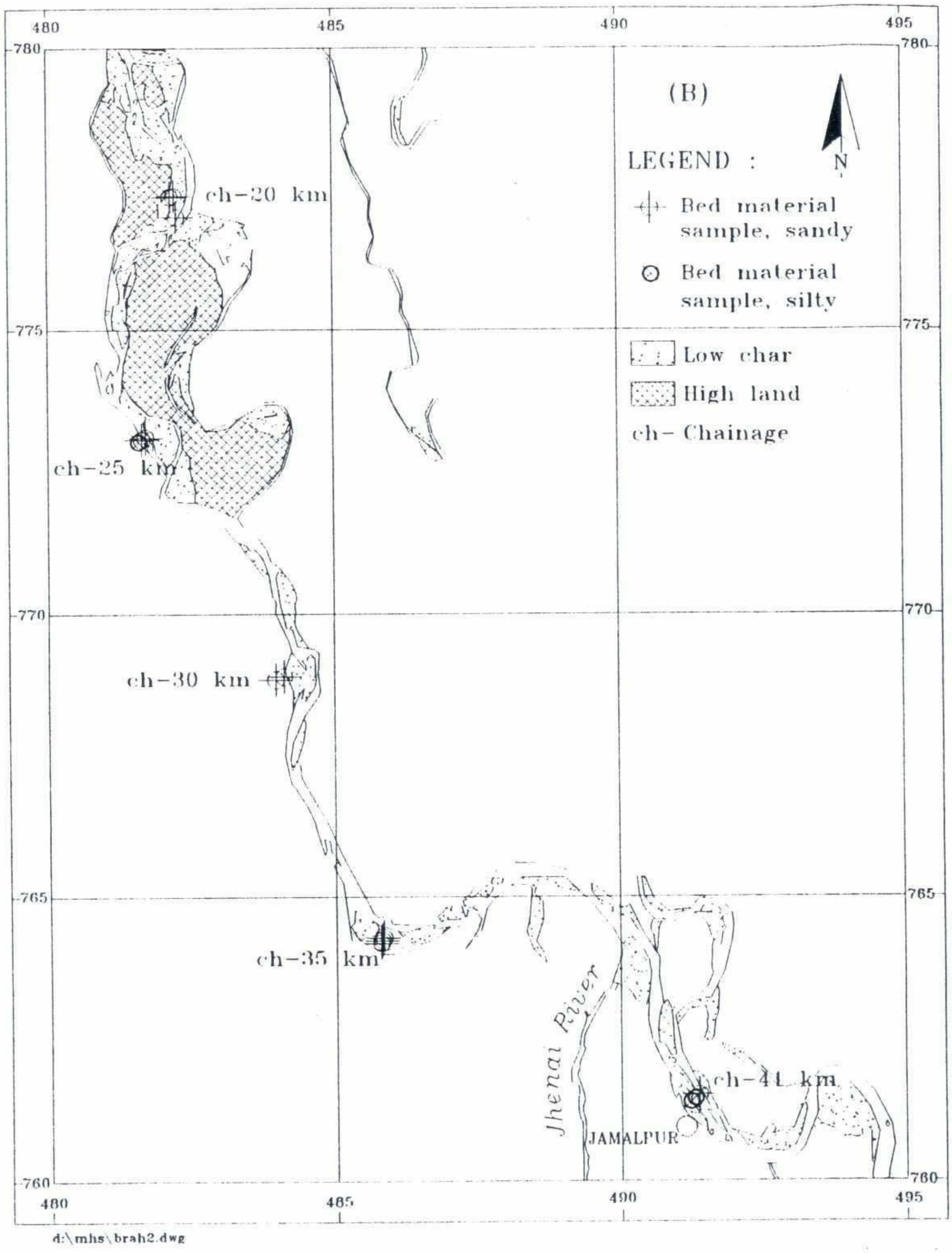


Figure 3.4: Bed material sample locations on the Brahmaputra River (block b)

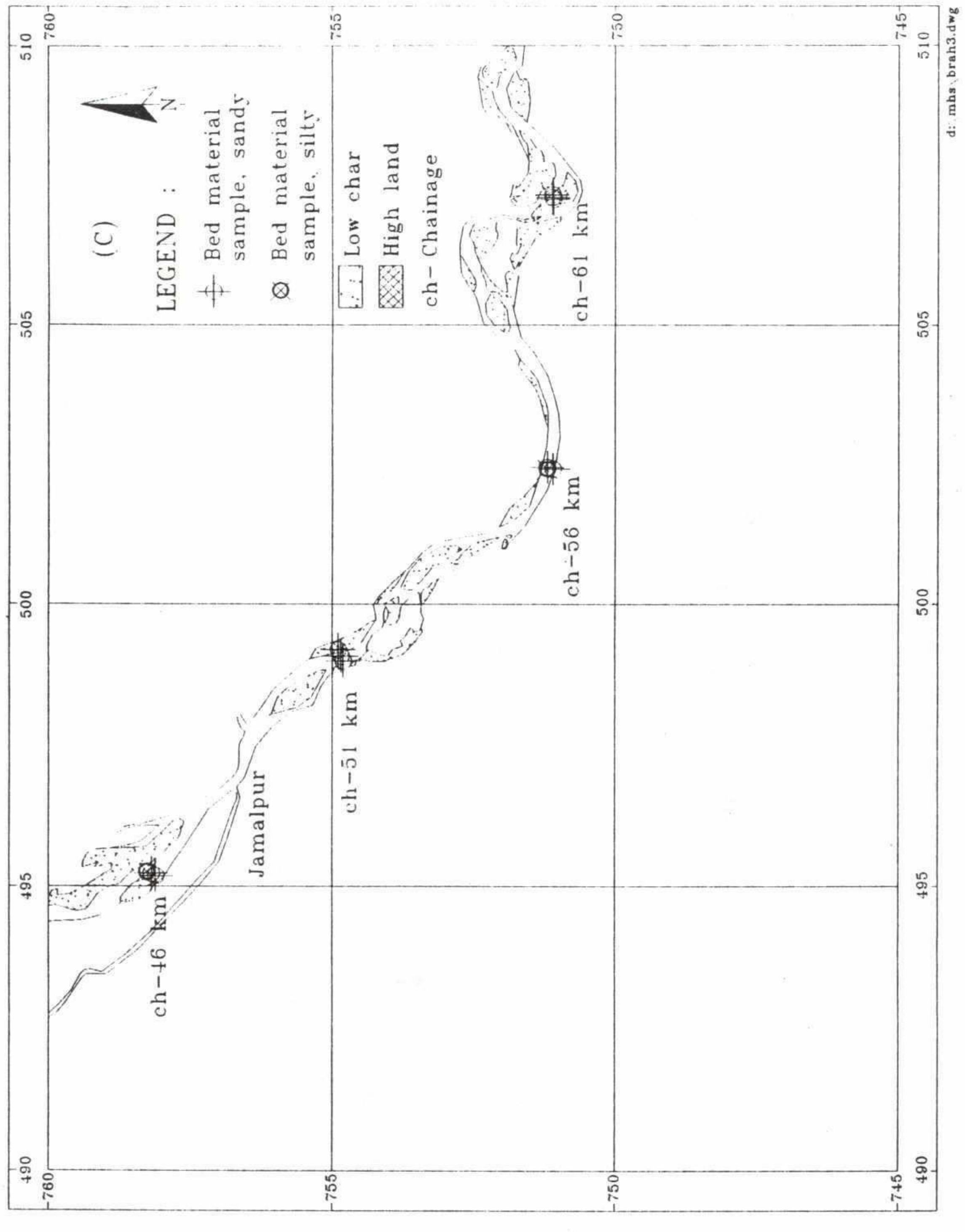


Figure 3.5: Bed material sample locations on the Brahmaputra River (block c)

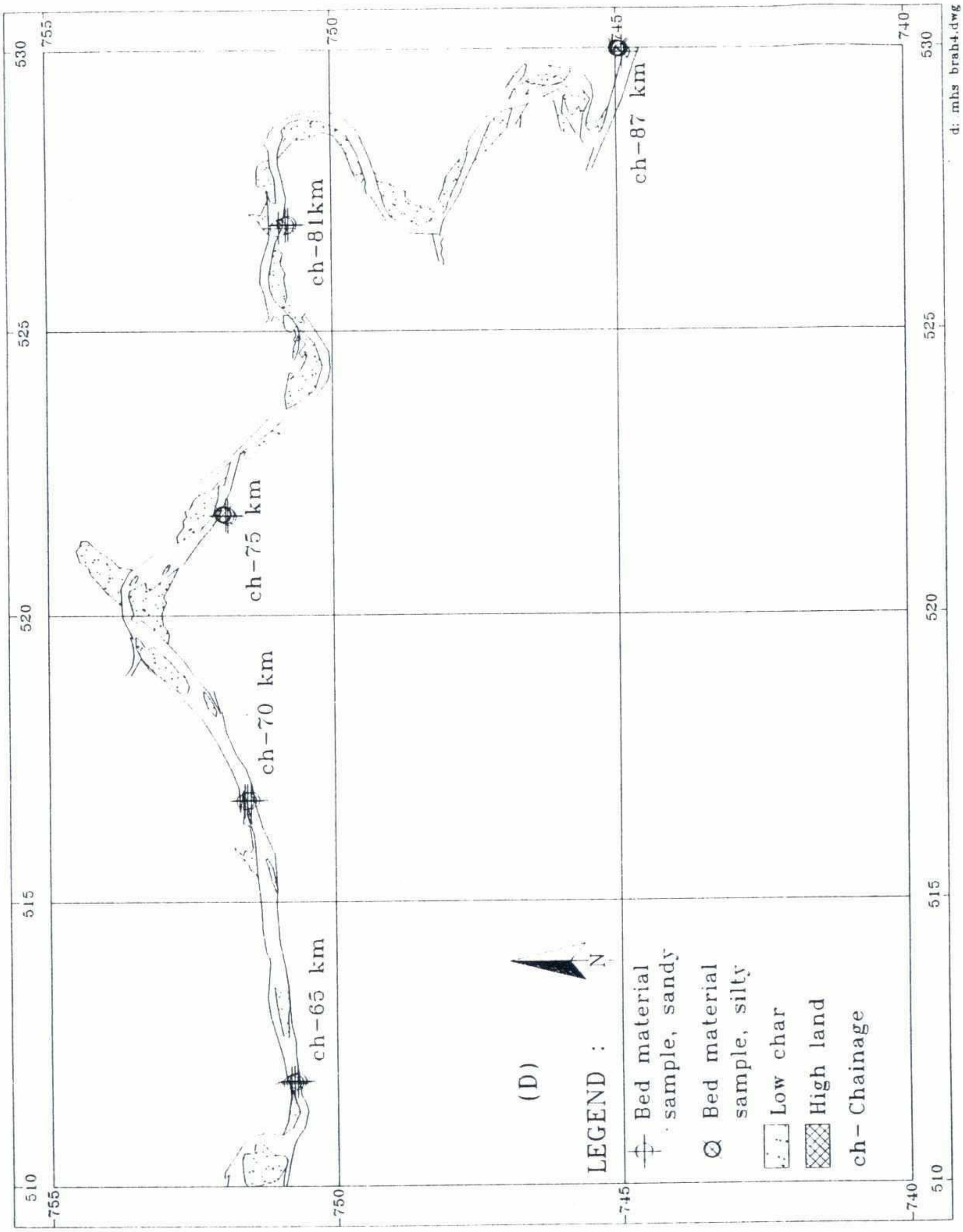


Figure 3.6: Bed material sample locations on the Brahmaputra River (block d)

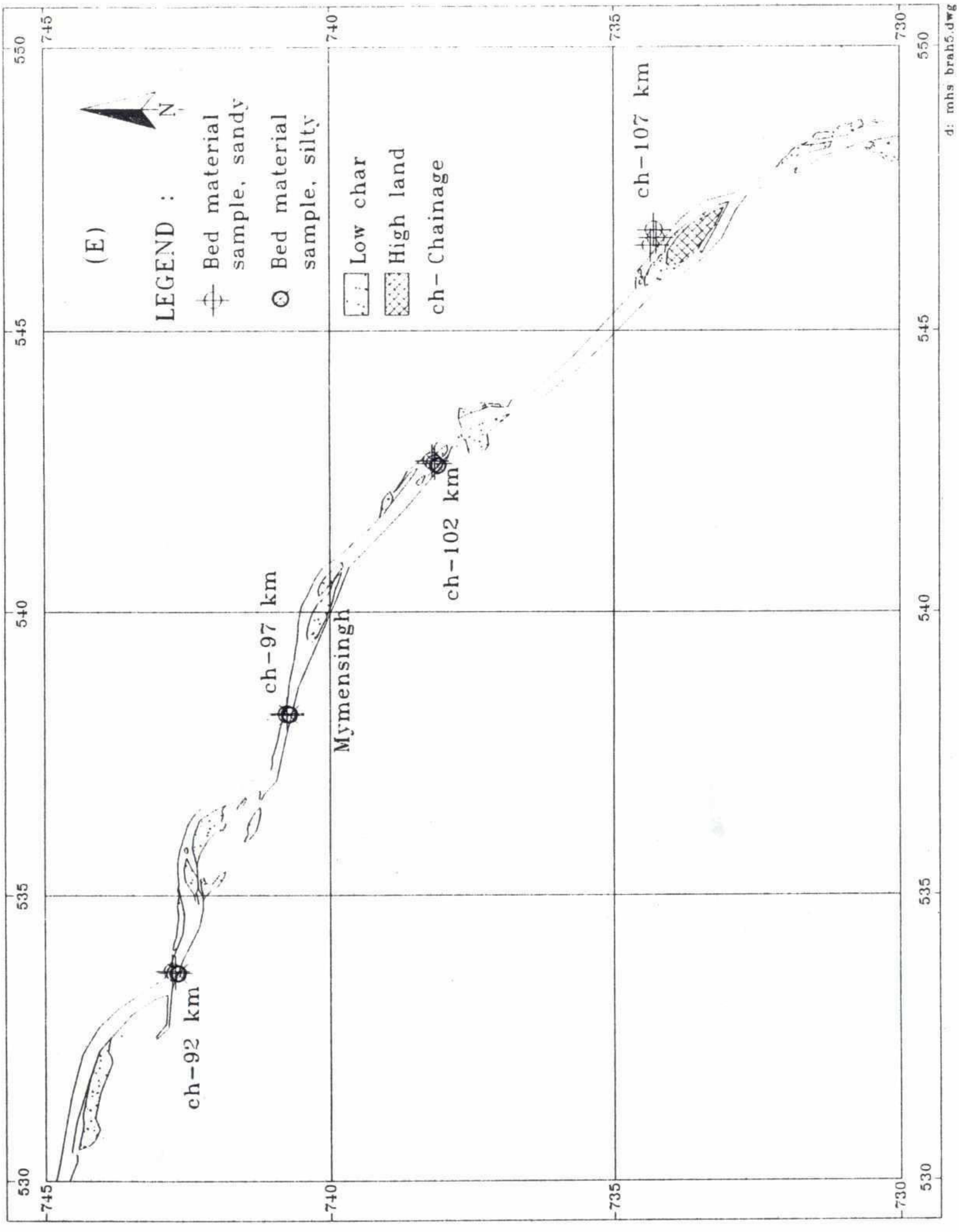


Figure 3.7: Bed material sample locations on the Brahmaputra River (block e)

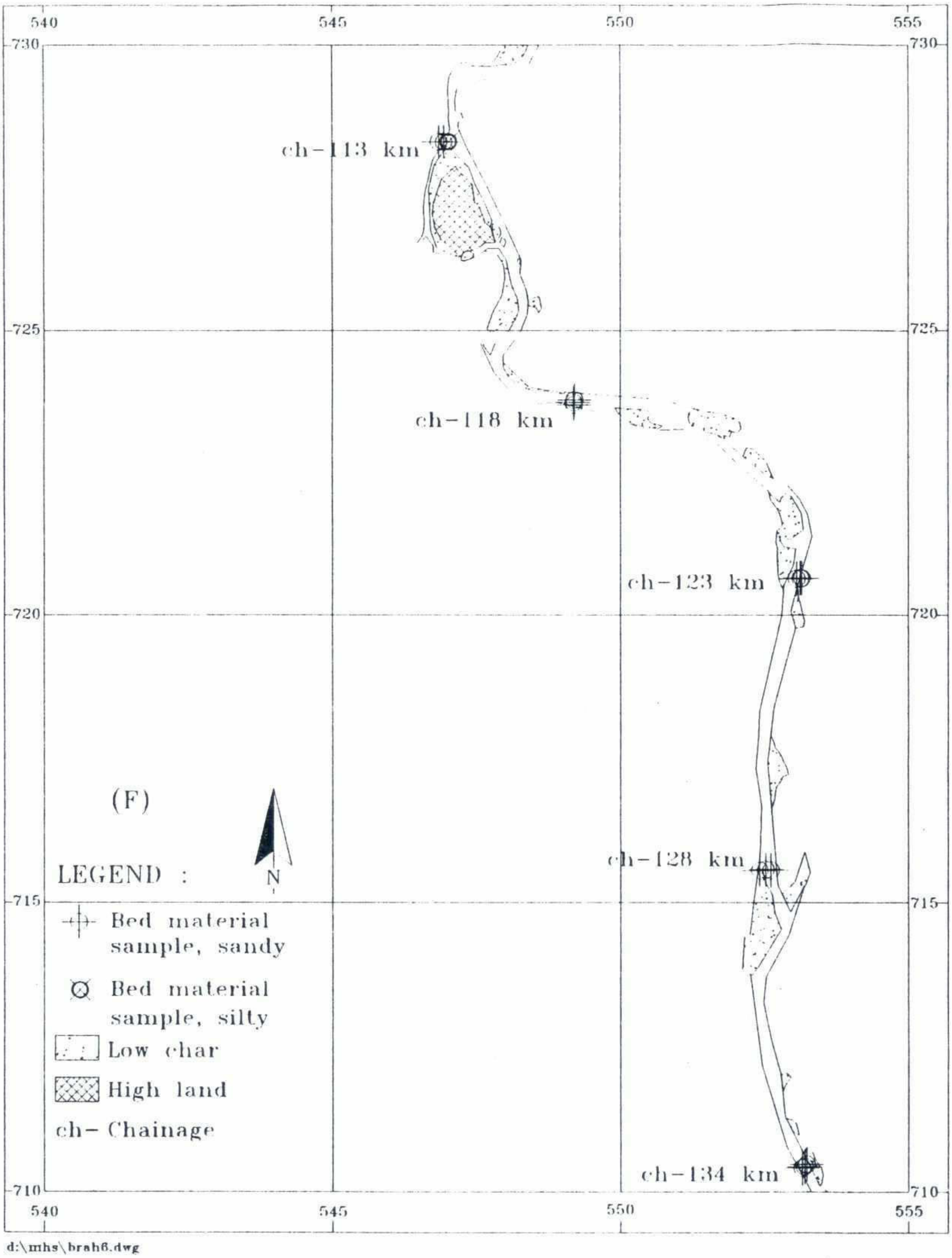


Figure 3.8: Bed material sample locations on the Brahmaputra River (block f)

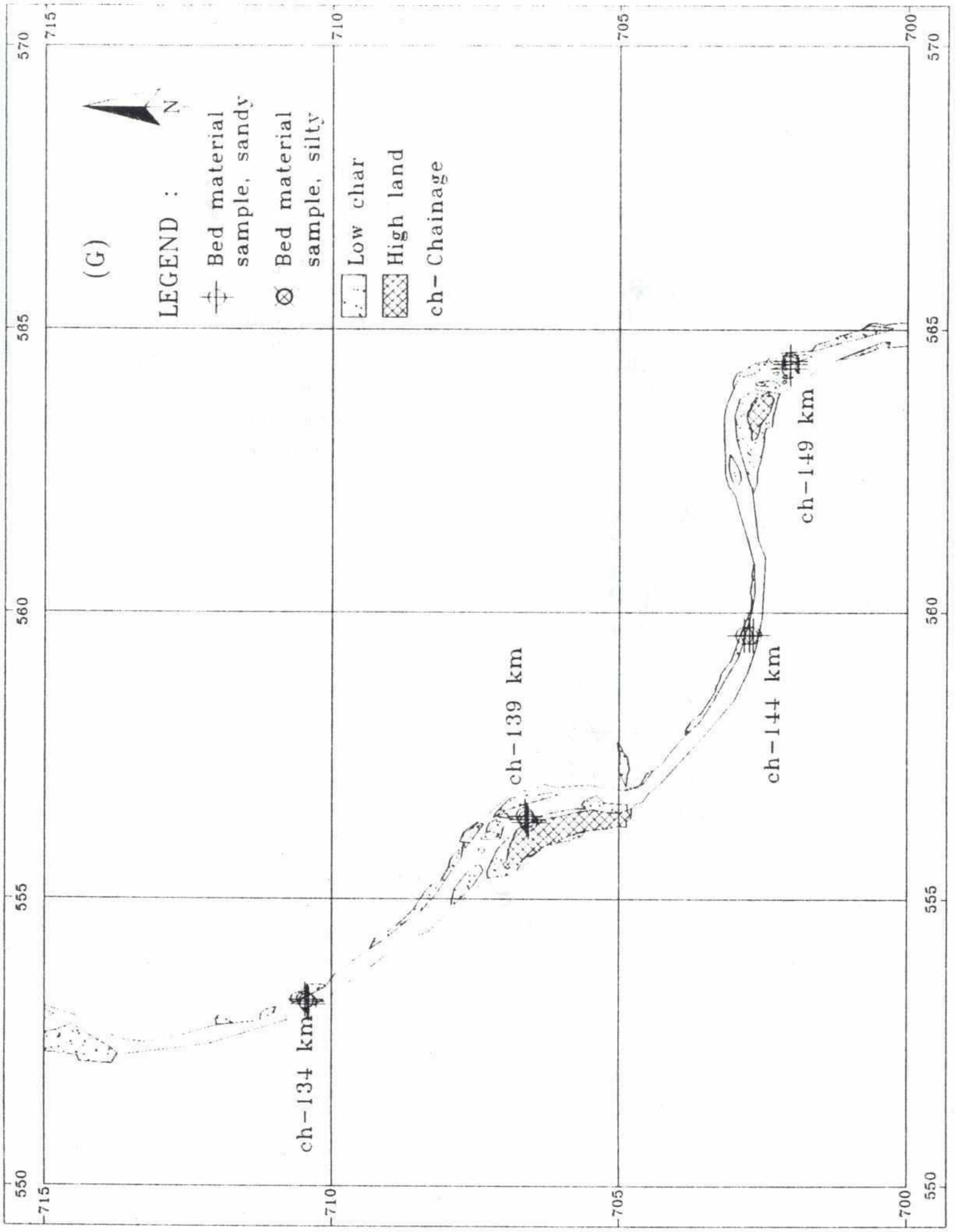


Figure 3.9: Bed material sample locations on the Brahmaputra River (block g)

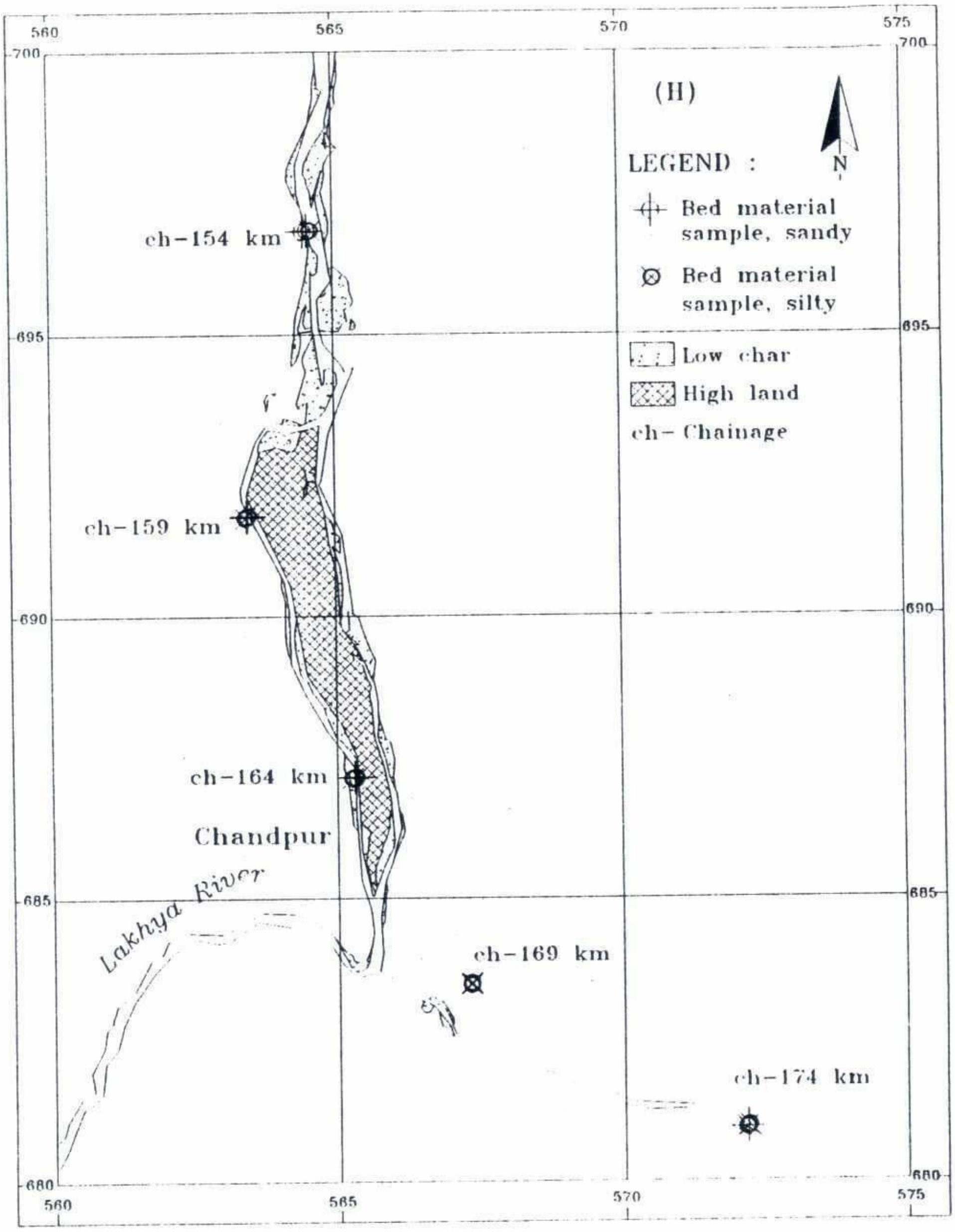


Figure 3.10: Bed material sample locations on the Brahmaputra River (block h)

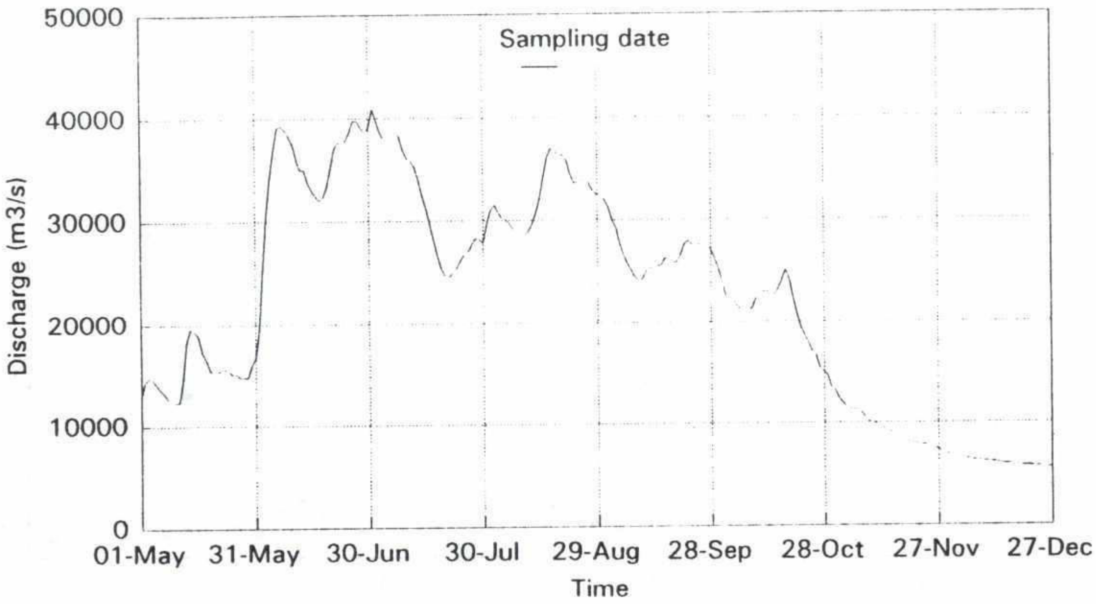


Figure 3.11: A part of the discharge hydrograph (1994) for the Jamuna River at Bahadurabad

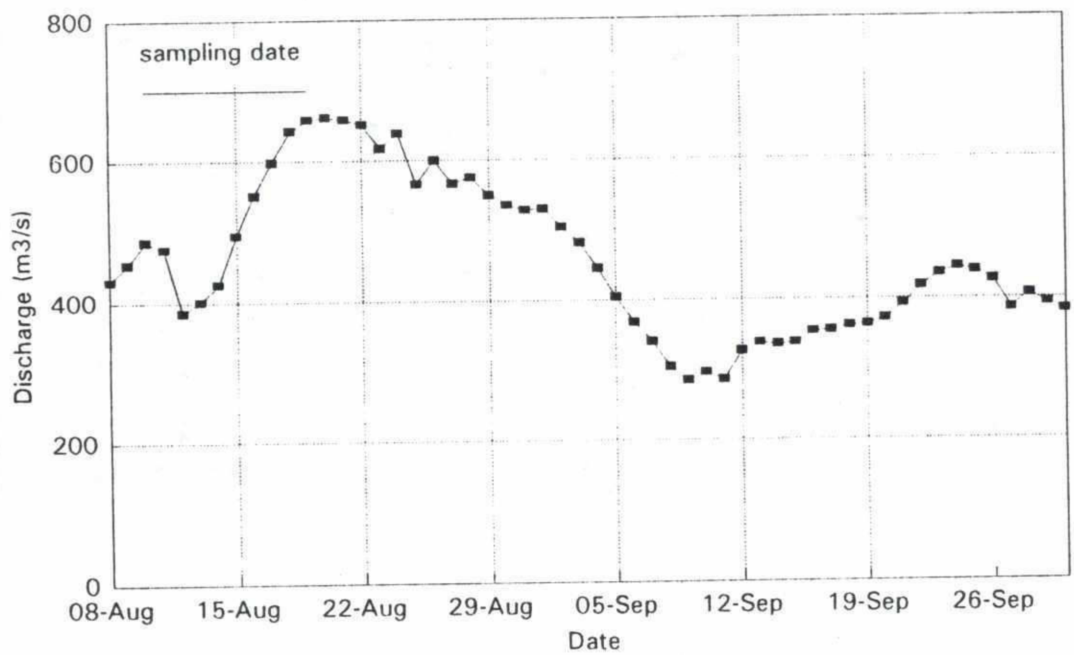
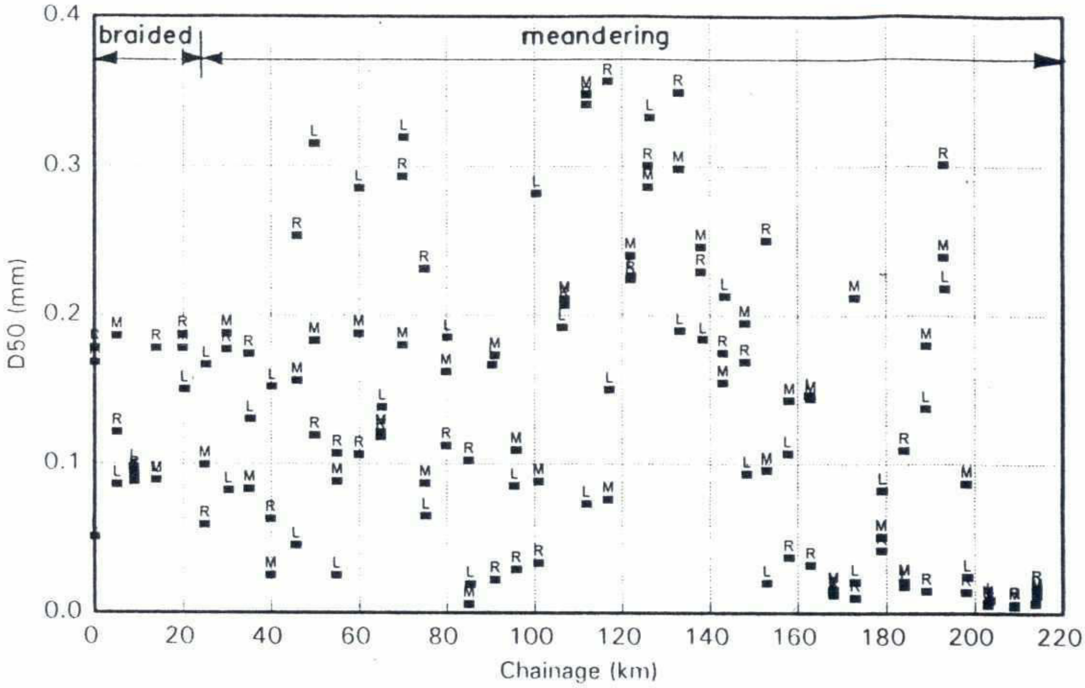


Figure 3.12: A part of the discharge hydrograph (1994) for the Old Brahmaputra River at Mymensingh, showing the period of bed material sampling



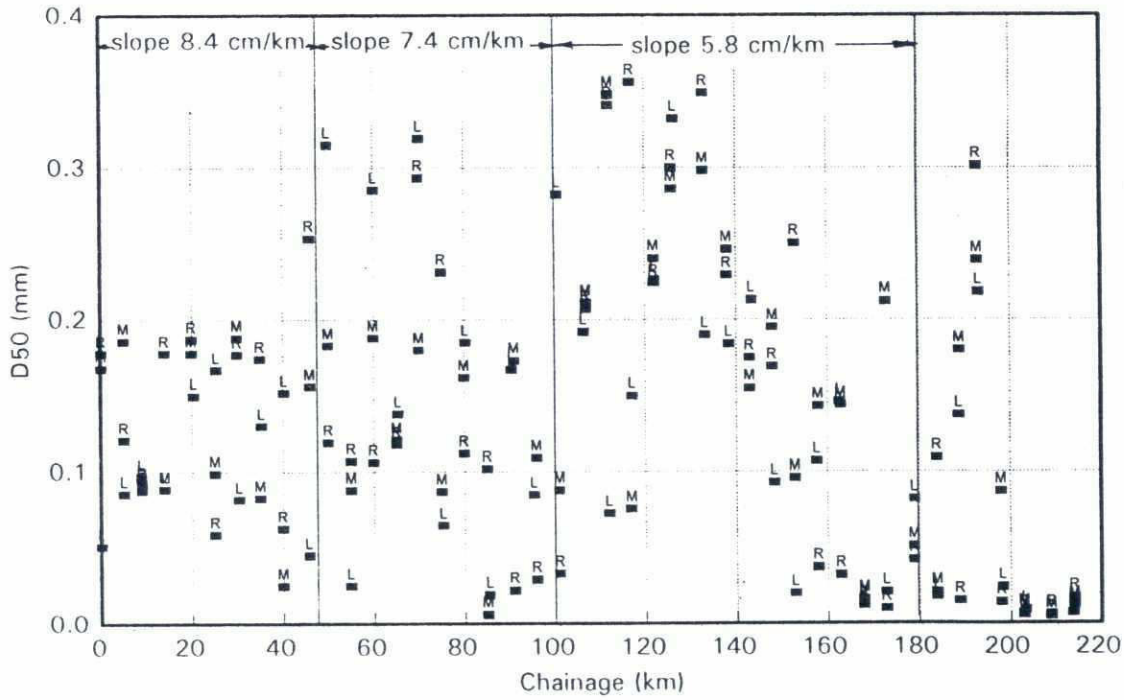


Figure 3.13: The variation of D_{50} with the planform and the average water surface slope of the river

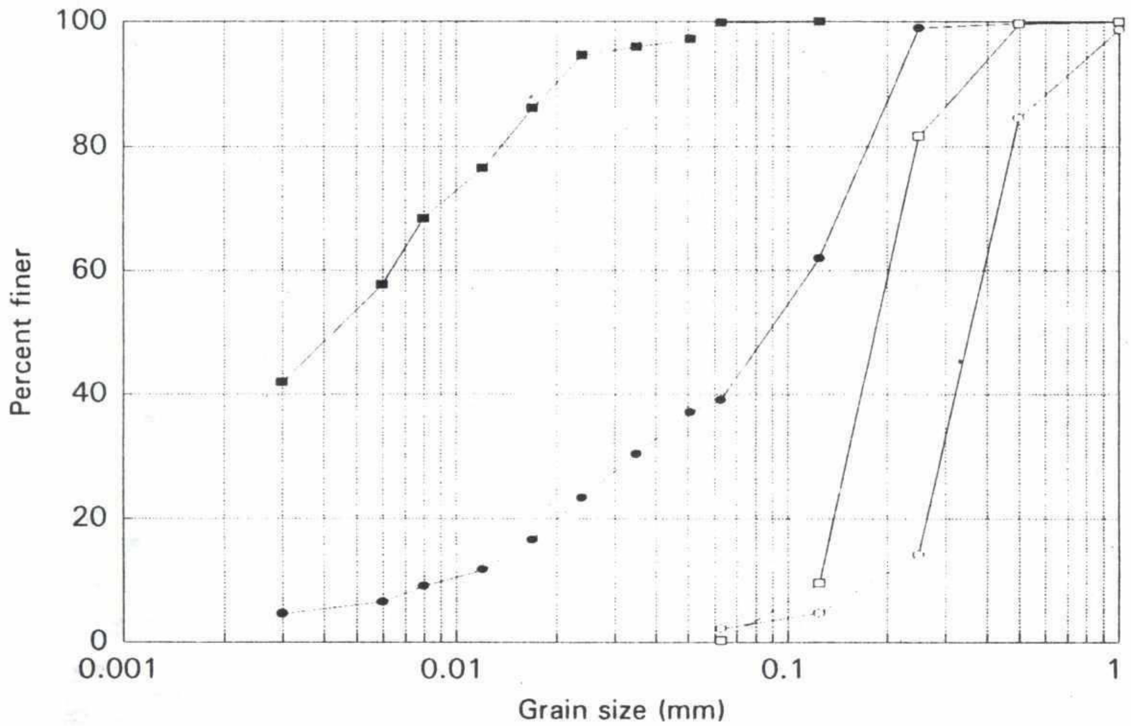


Figure 3.14: Typical grain size distribution curve of the bed material samples of the Old Brahmaputra River

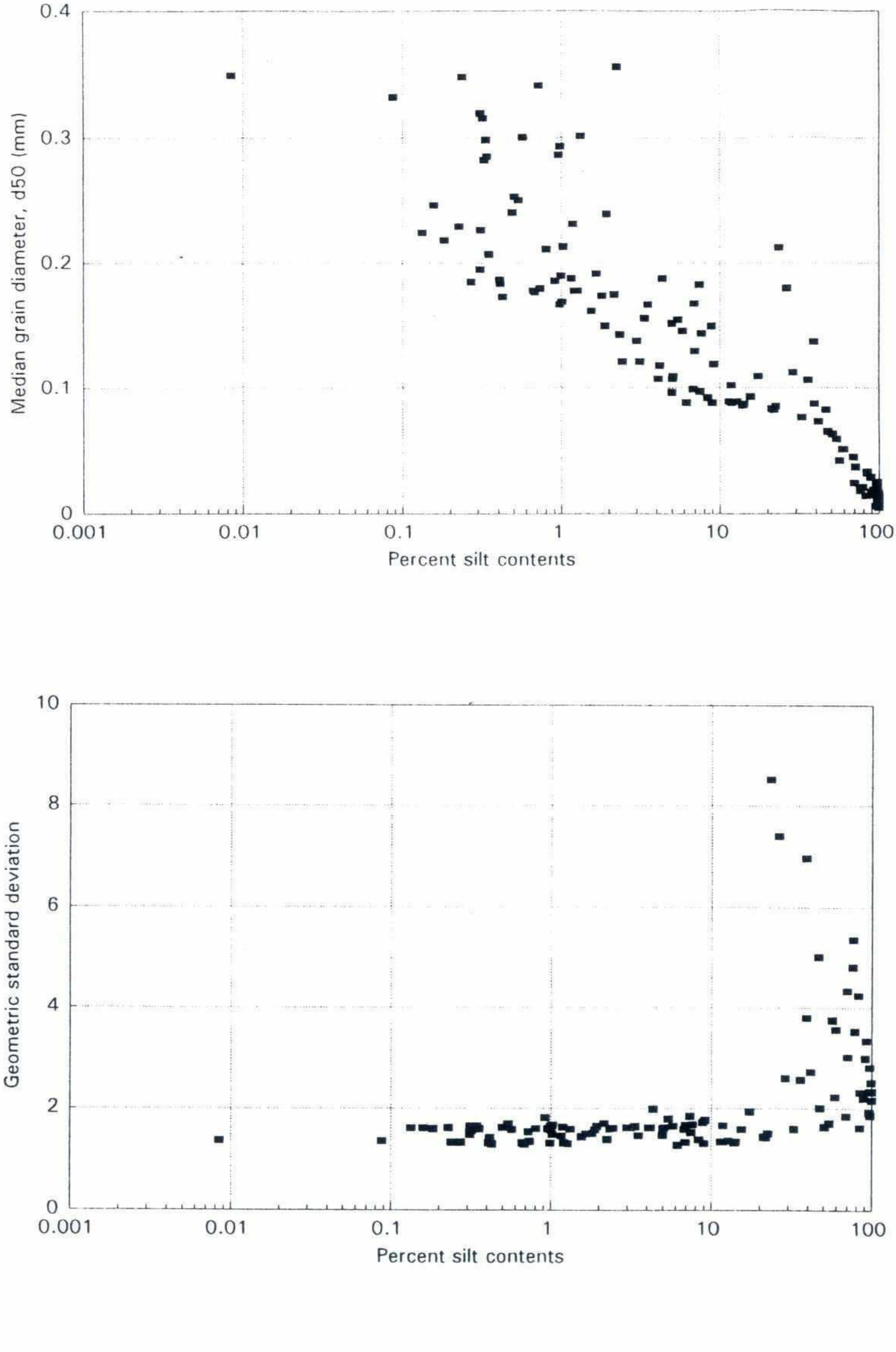


Figure 3.15: Variation of D_{50} and geometric standard deviation with the percentage of silt and clay in the samples

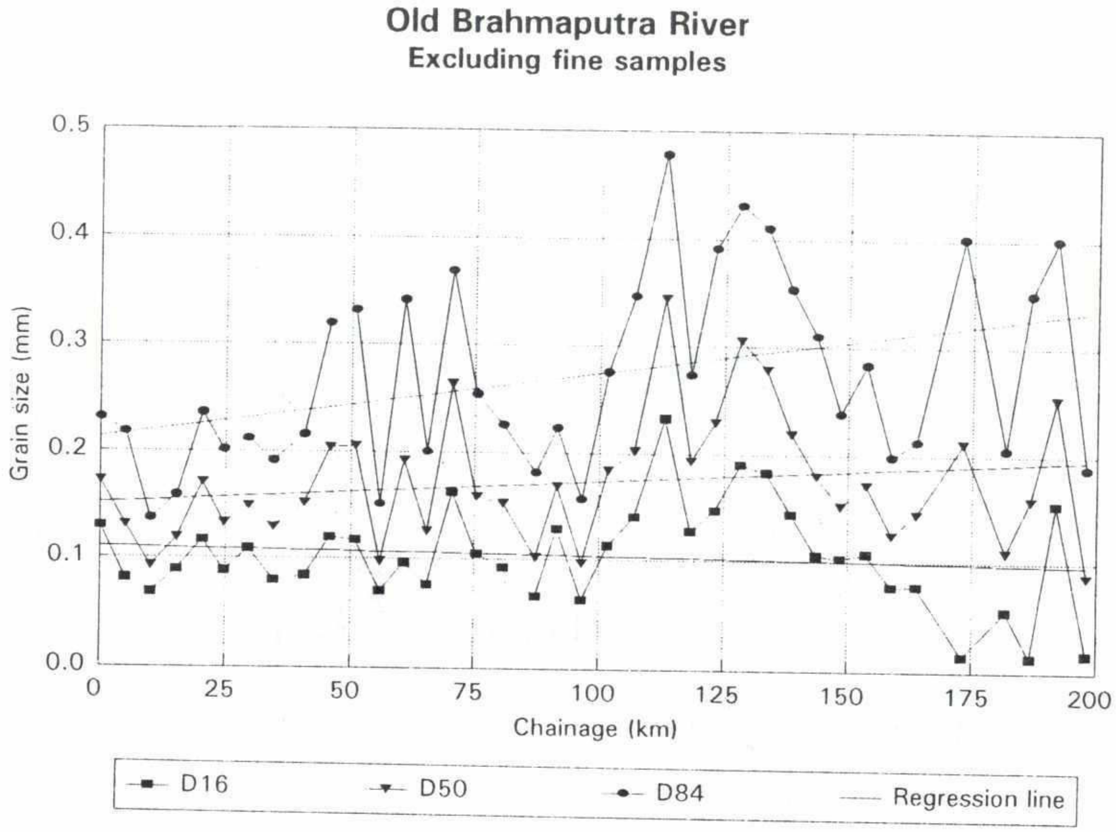


Figure 3.16: Variation of characteristic grain sizes in a downstream direction

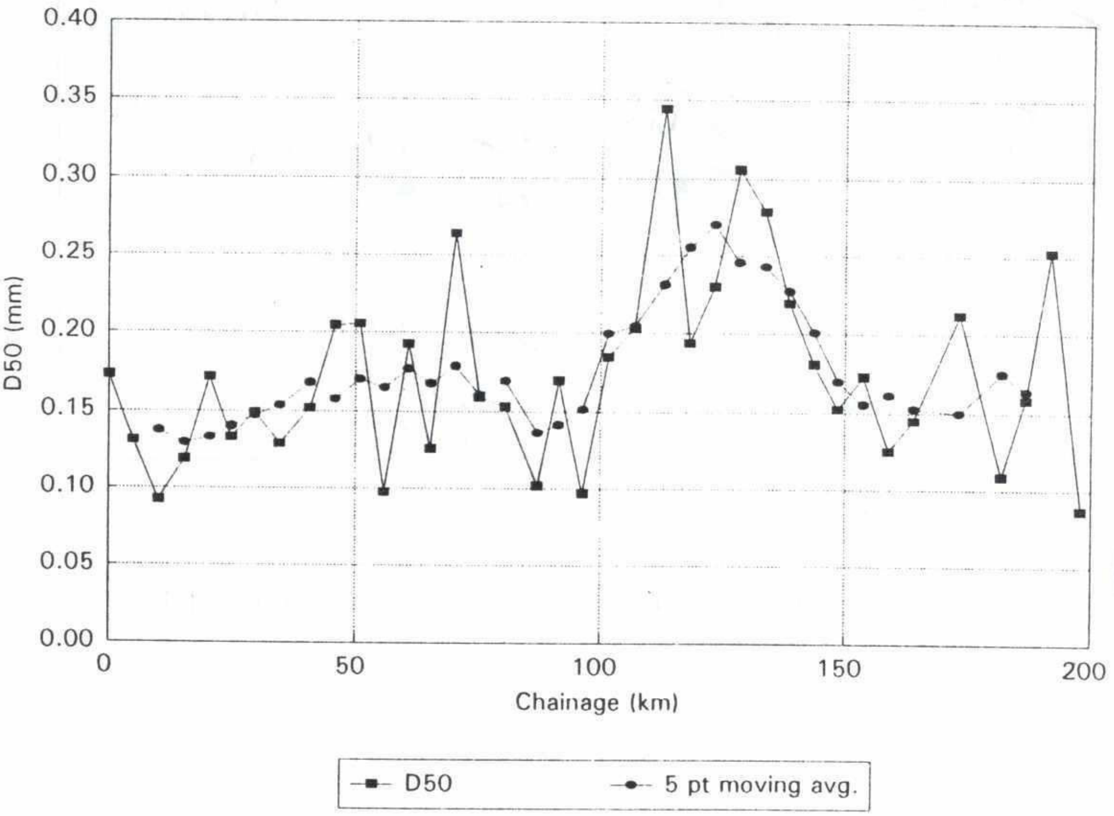
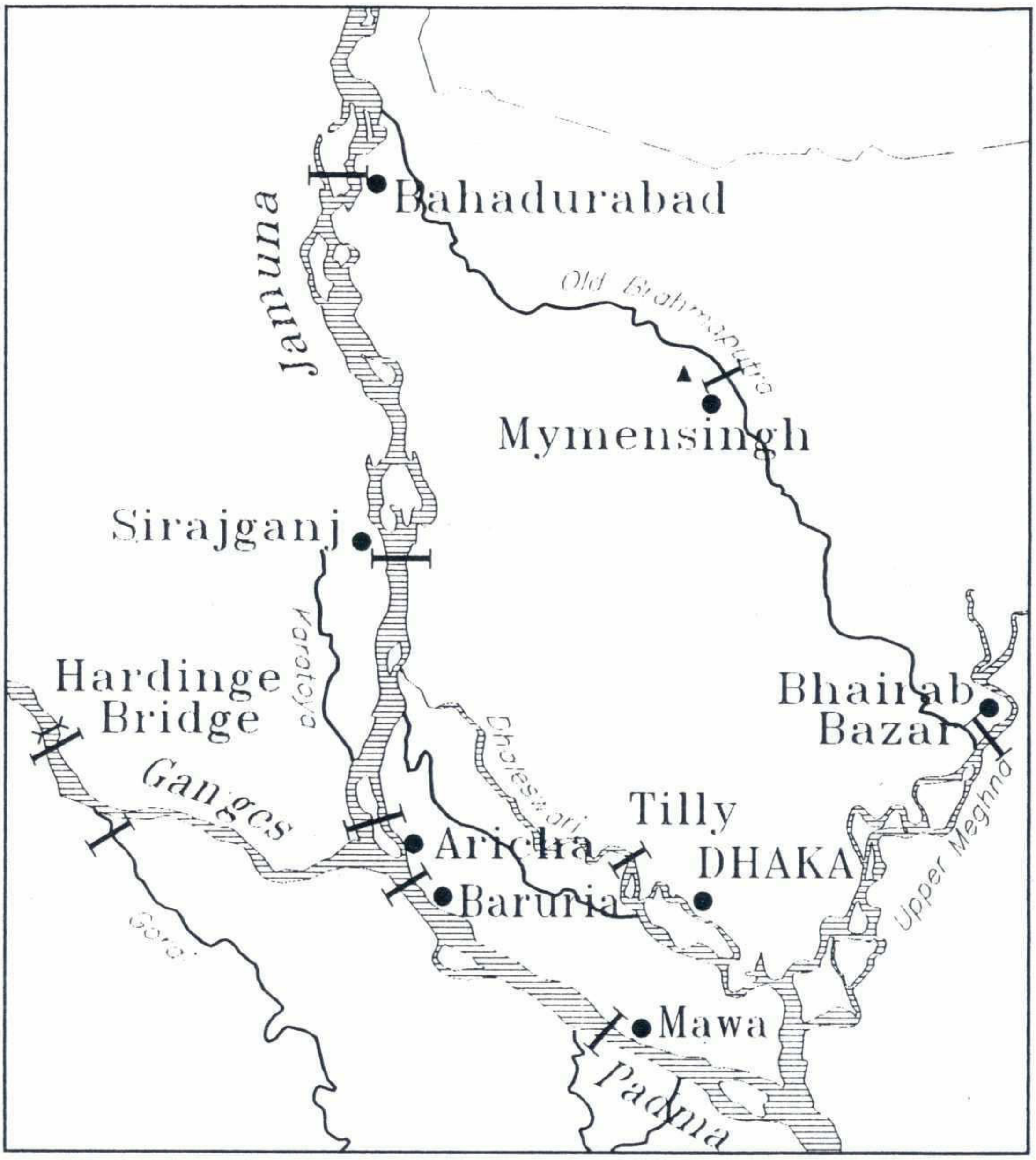


Figure 3.17: Variation of 5-point moving average of D_{50} in a downstream direction



LEGEND

⊢⊣ Transect for discharge and sediment measurements

Figure 4.1: Jamuna River, indicating the location of Bahadurabad and Sirajganj

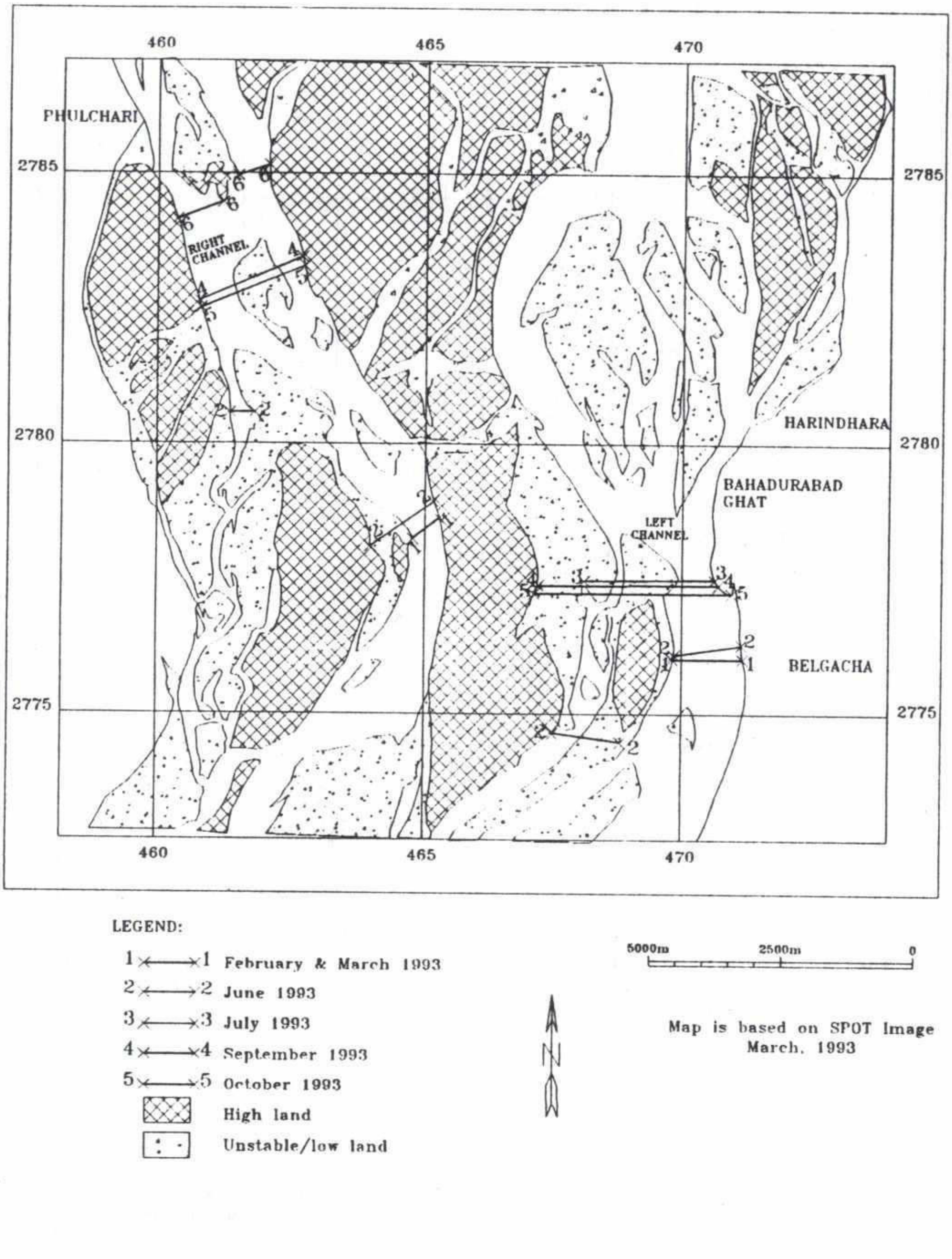


Figure 4.2: Position of the routine gauging transects at Bahadurabad on the tracing of SPOT imagery, March, 1993

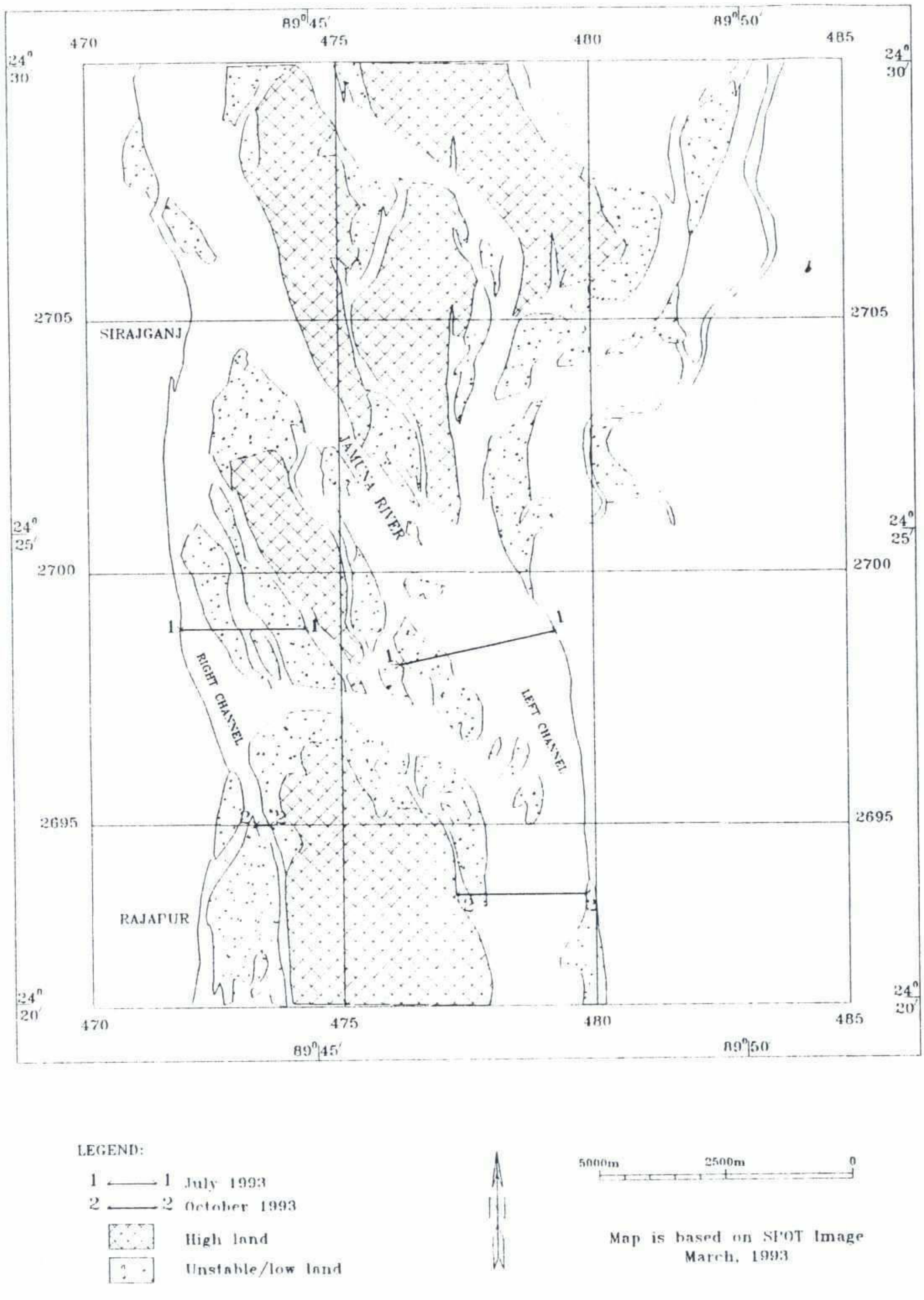


Figure 4.3: Position of the routine gauging transects at Sirajganj on the tracing of SPOT imagery, March, 1993

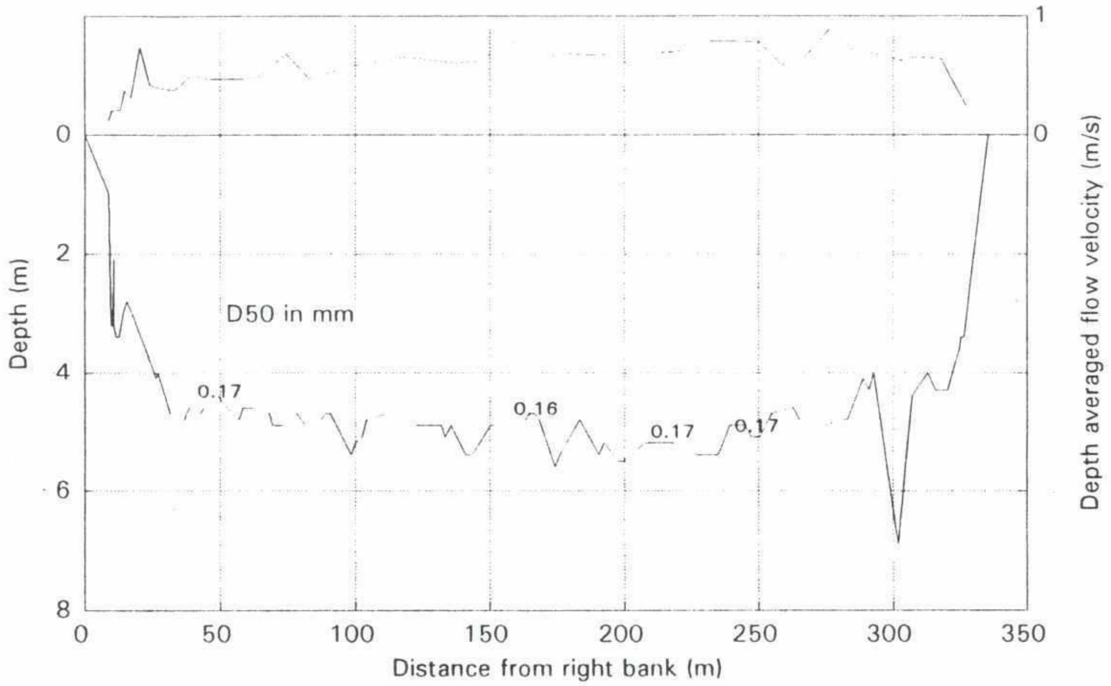


Figure 4.4: Location and D_{50} (mm) of samples at Bahadurabad, Channel 2, surveyed on 13 February 1993

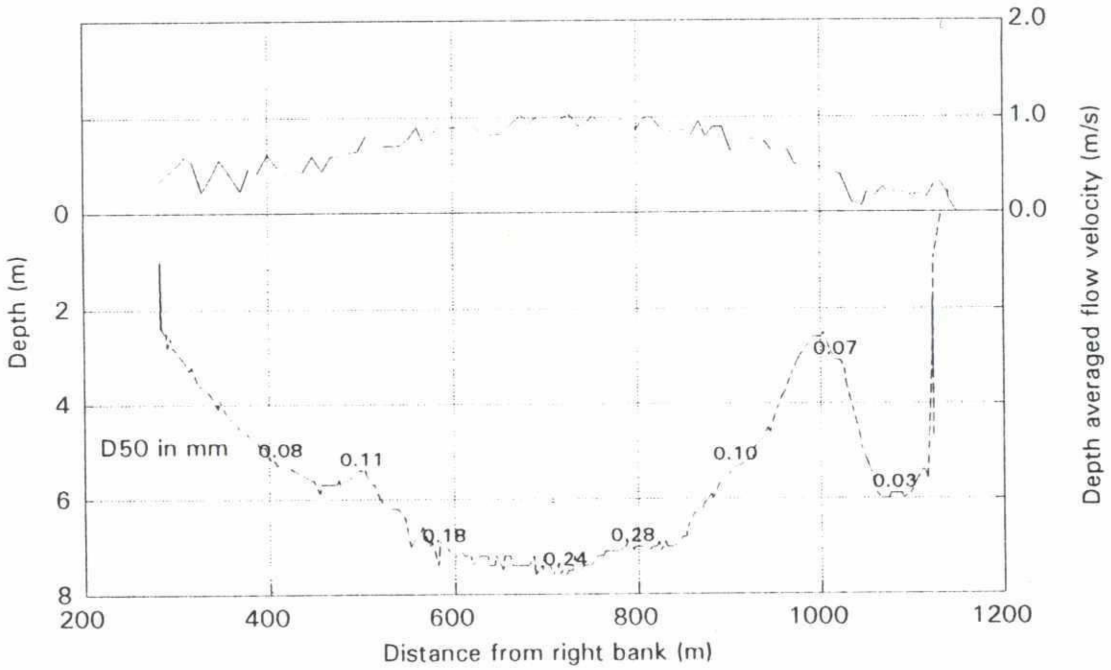


Figure 4.5: Location and D_{50} (mm) of samples at Bahadurabad, Channel 1, surveyed on 15 February 1993

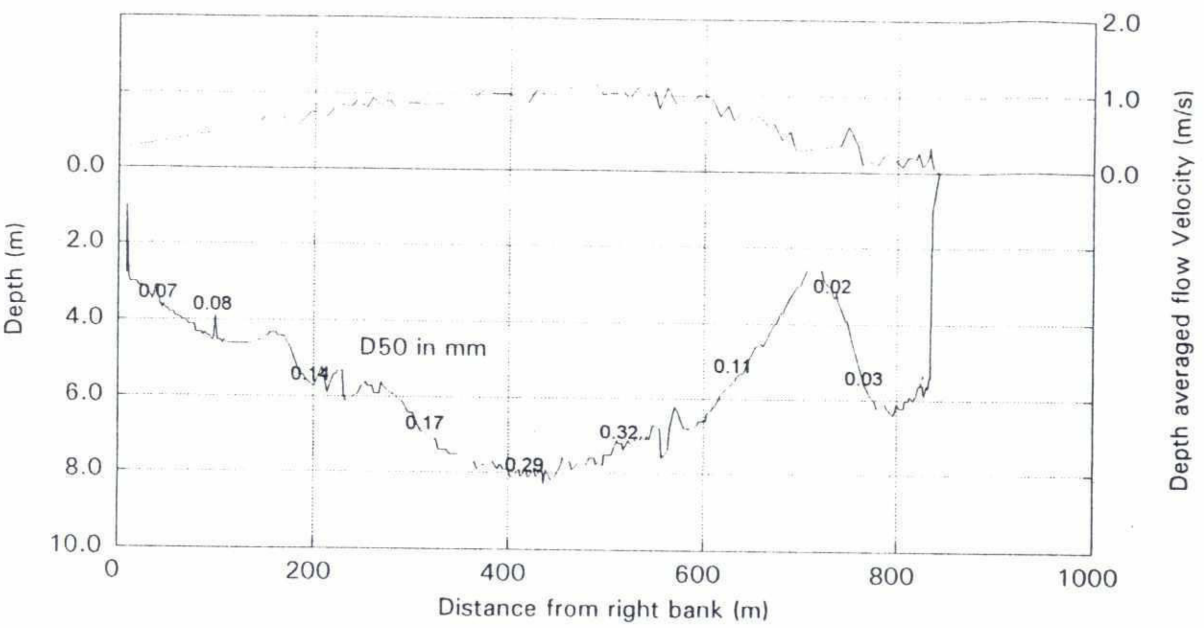


Figure 4.6: Location and D_{50} (mm) of samples at Bahadurabad, Channel 1, surveyed on 15 March 1993

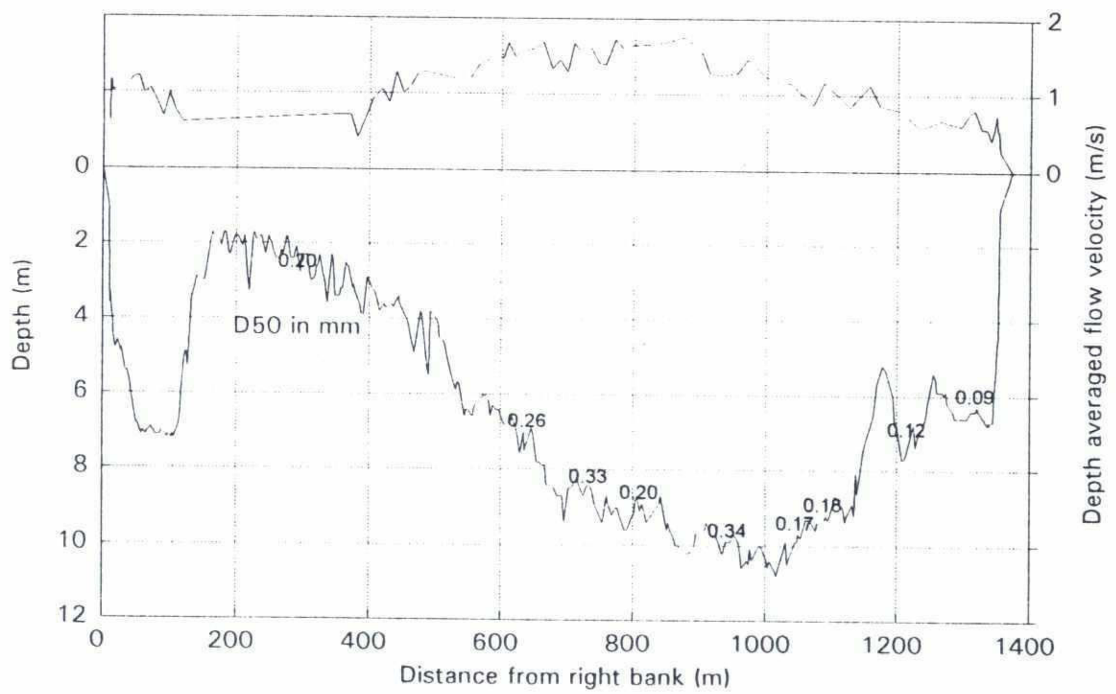


Figure 4.7: Location and D_{50} (mm) of samples at Bahadurabad, Channel 1, surveyed on 6 June 1993

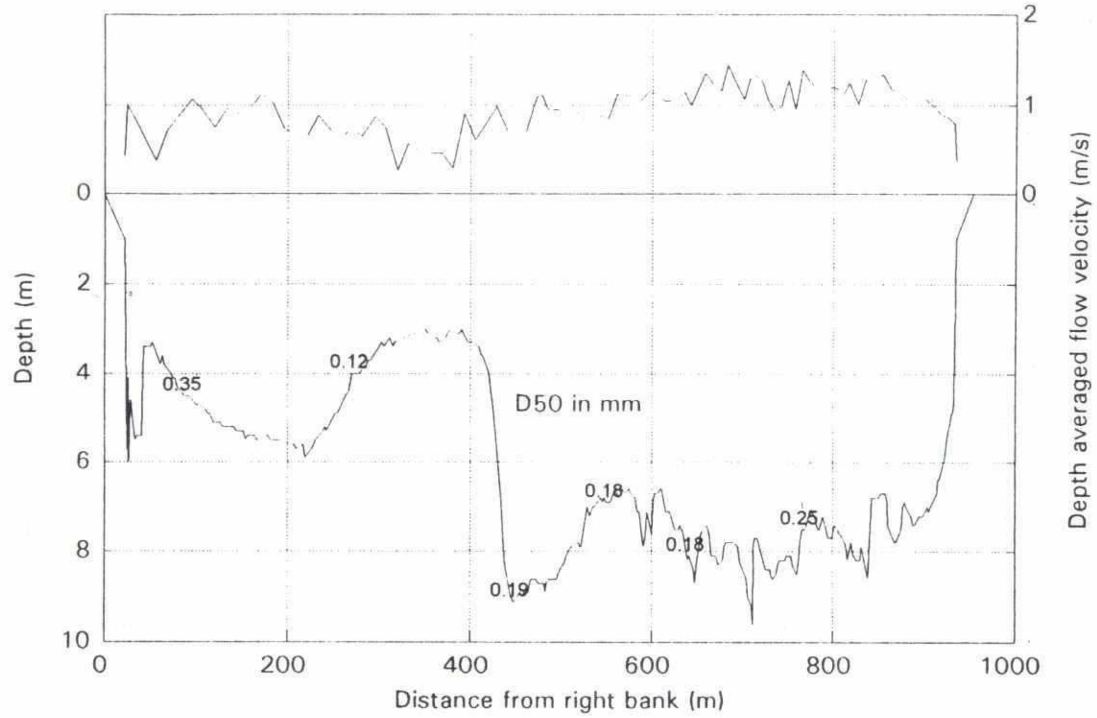


Figure 4.8: Location and D_{50} (mm) of samples at Bahadurabad, Channel 3, surveyed on 6 June 1993

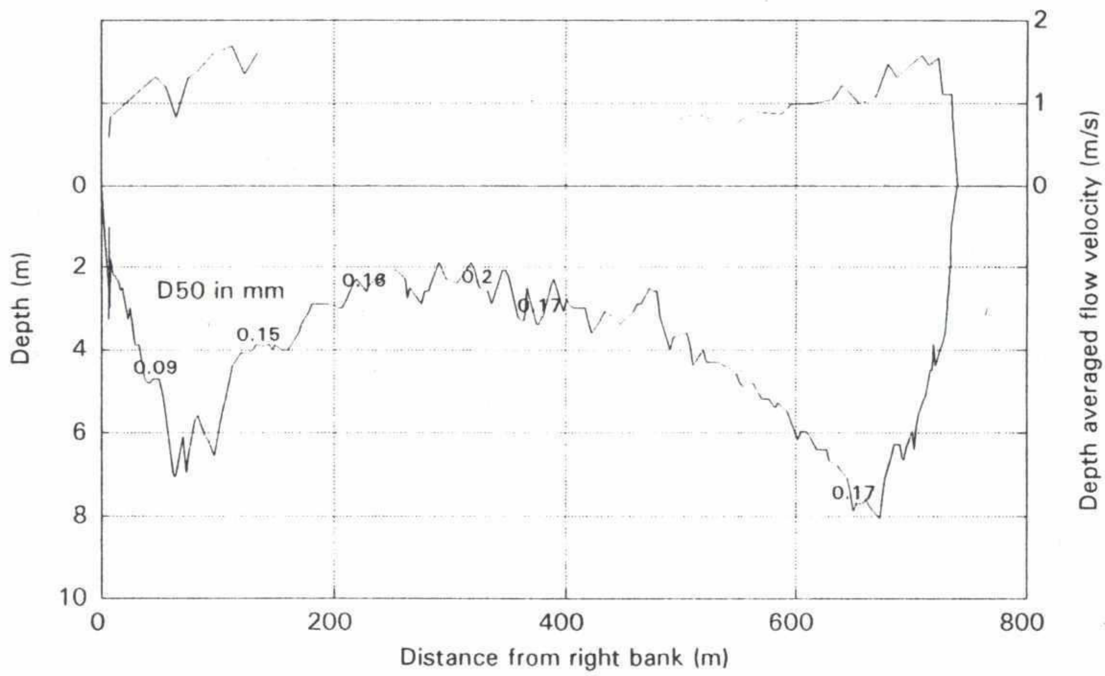


Figure 4.9: Location and D_{50} (mm) of samples at Bahadurabad, Channel 2, surveyed on 9 June 1993

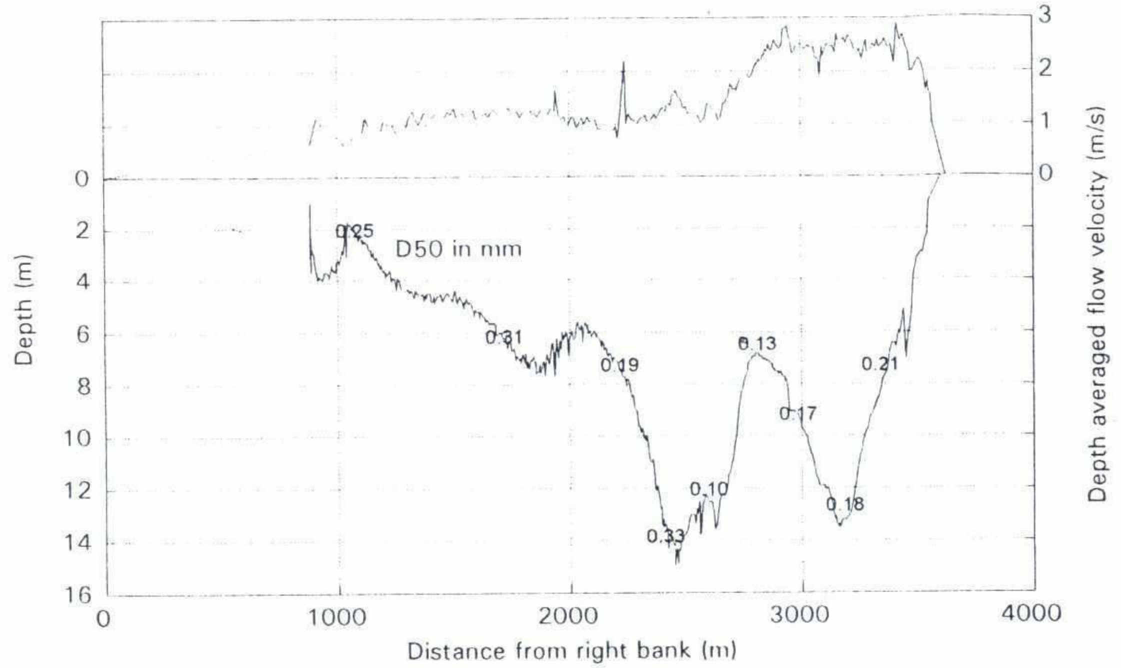


Figure 4.10: Location and D_{50} (mm) of samples at Bahadurabad, Channel 1, surveyed on 12 July 1993

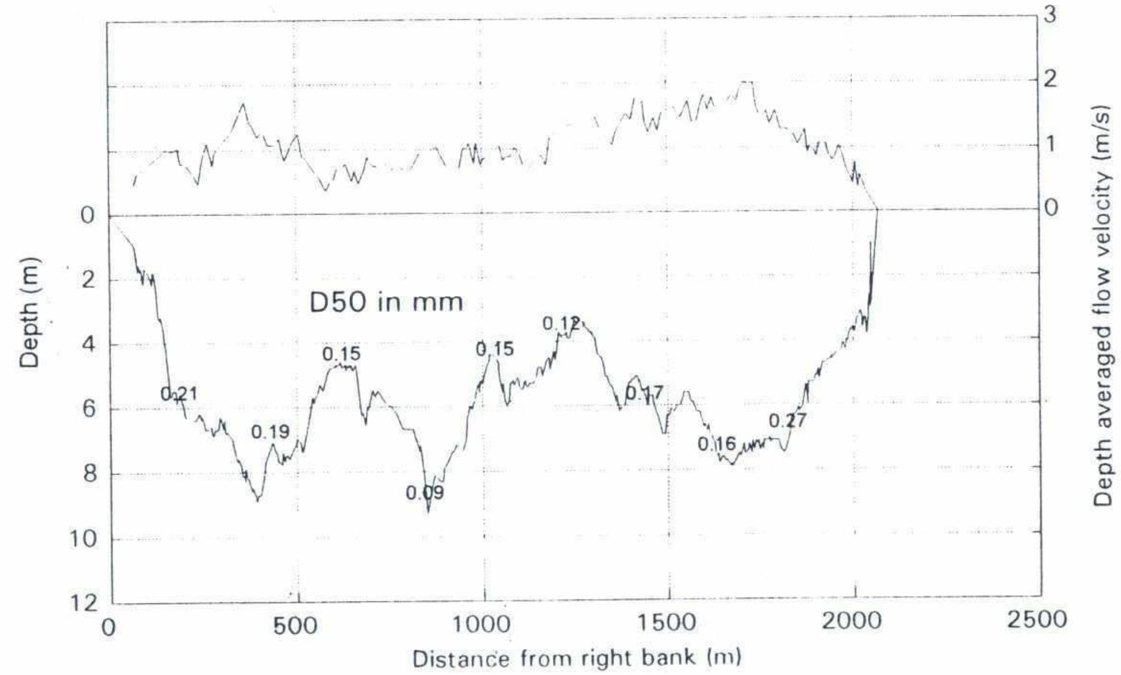


Figure 4.11: Location and D_{50} (mm) of samples at Bahadurabad, Channel 2, surveyed on 15 July 1993

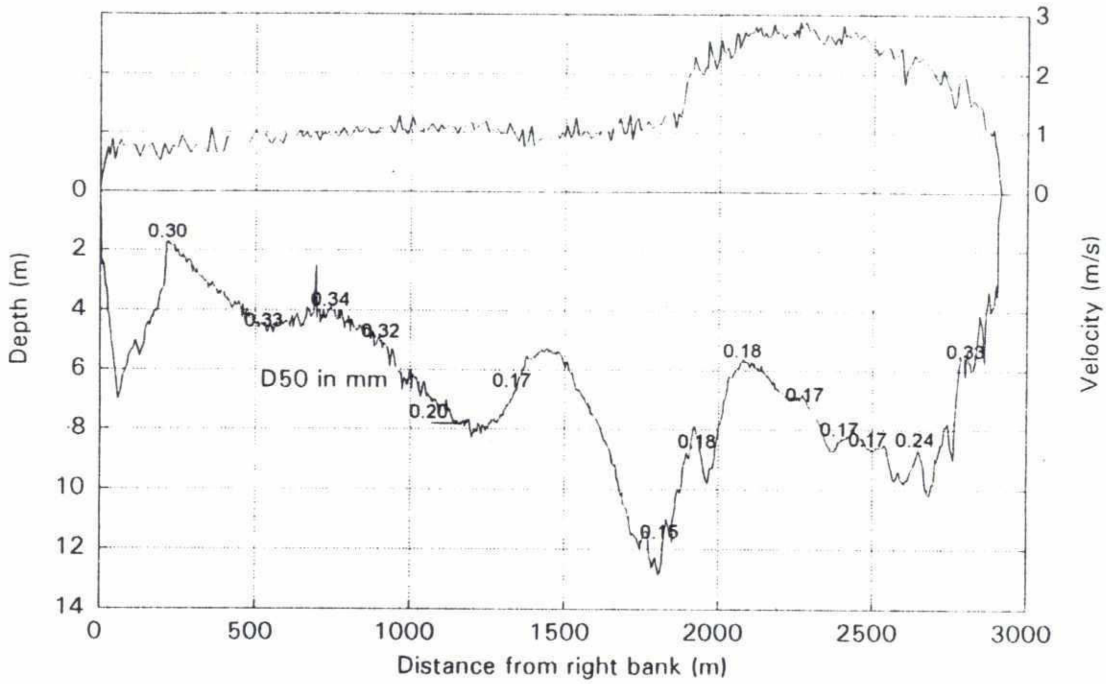


Figure 4.12: Location and D_{50} (mm) of samples at Bahadurabad, Channel 1, surveyed on 20 August 1993

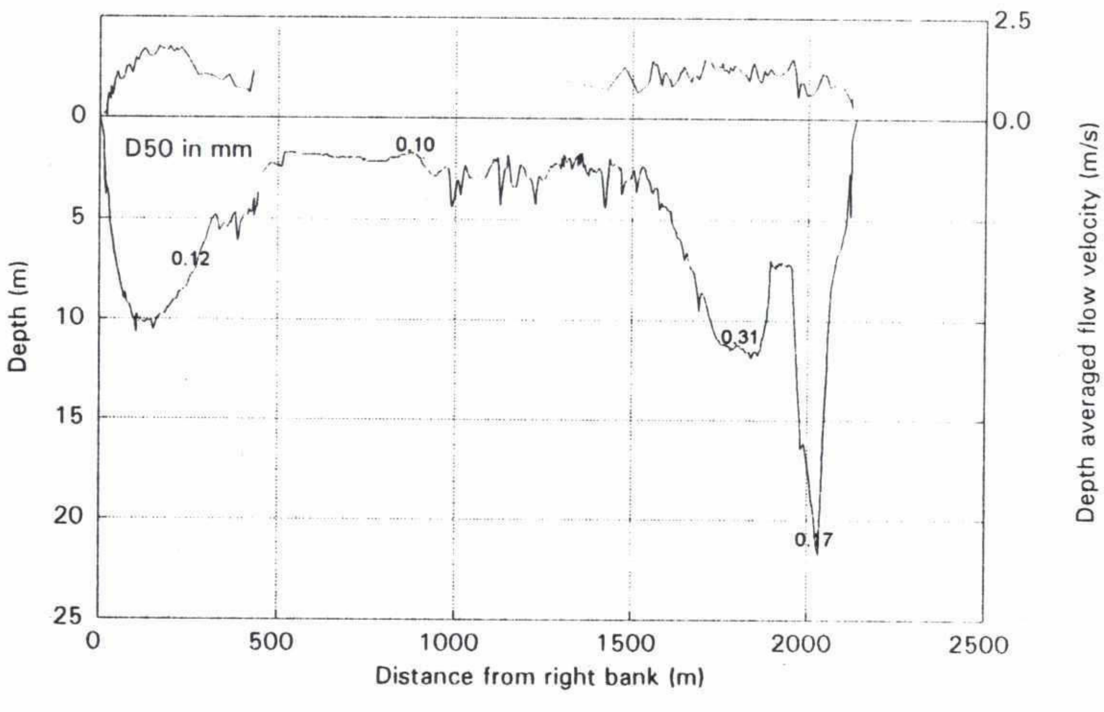


Figure 4.13: Location and D_{50} (mm) of samples at Bahadurabad, Channel 3, surveyed on 9 September 1993

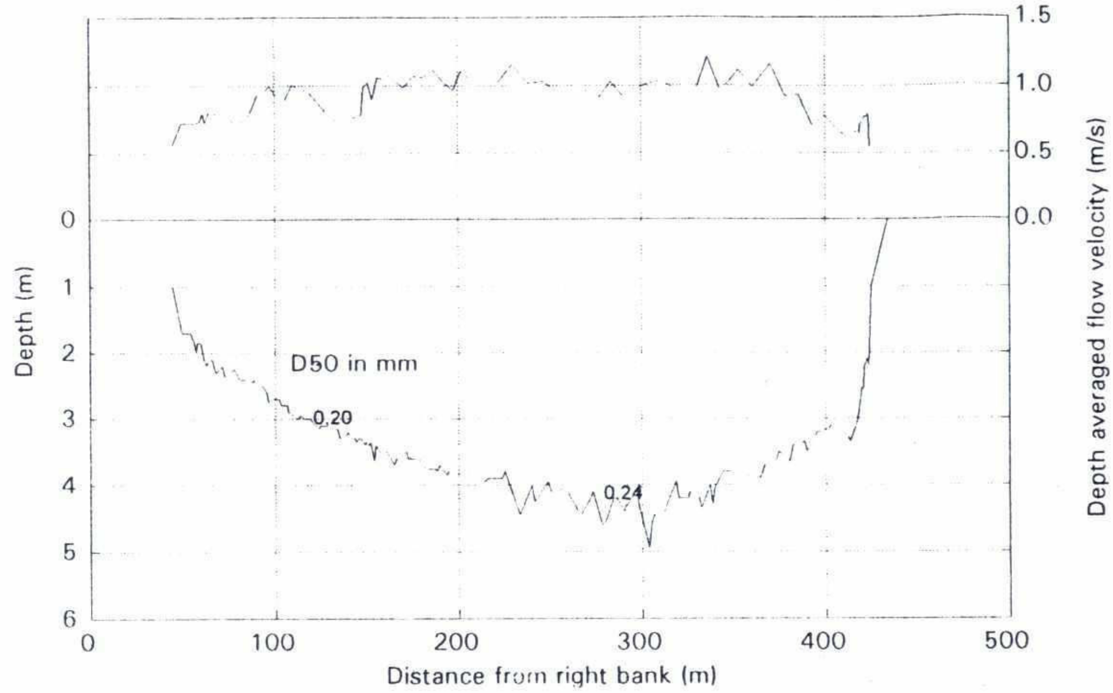


Figure 4.14: Location and D_{50} (mm) of samples at Bahadurabad, Channel 2, surveyed on 11 September 1993

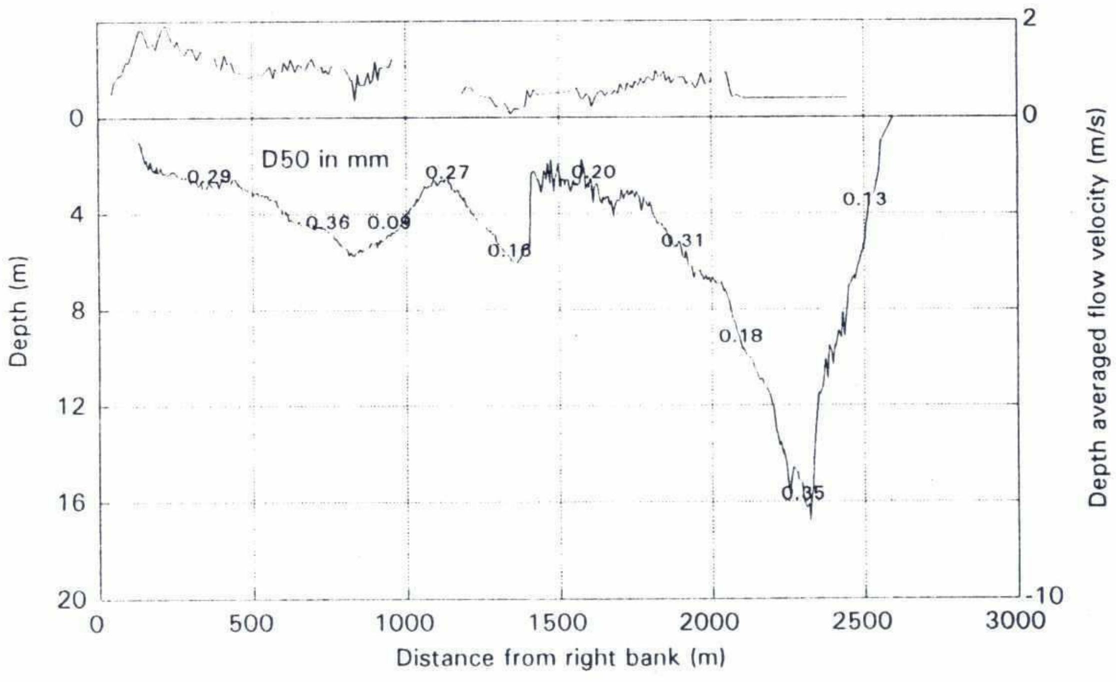


Figure 4.15: Location and D_{50} (mm) of samples at Bahadurabad, Channel 1, surveyed on 31 October 1993

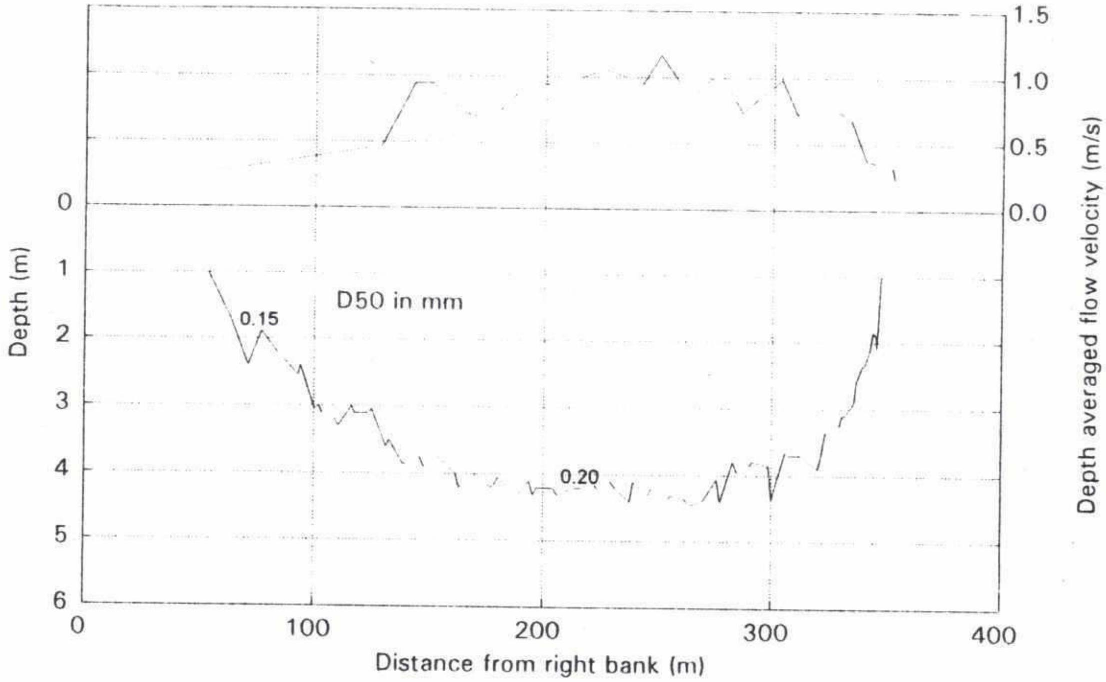


Figure 4.16: Location and D_{50} (mm) of samples at Bahadurabad, Channel 2, surveyed on 3 November 1993

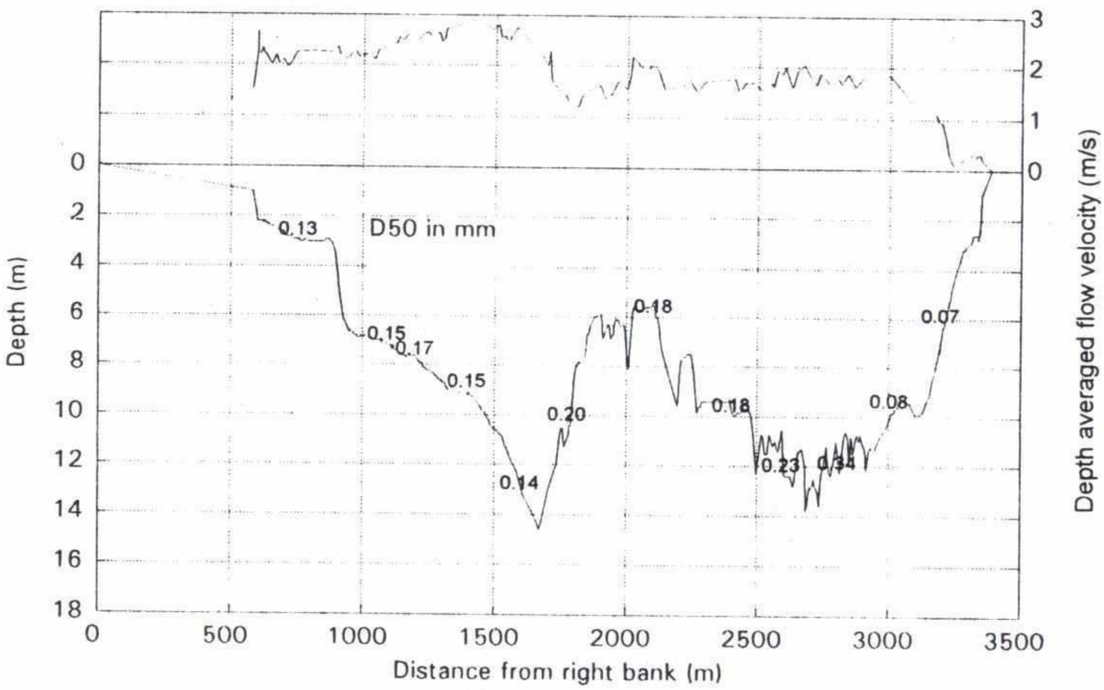


Figure 4.17: Location and D_{50} (mm) of samples at Sirajganj, Channel 1, surveyed on 23 July 1993

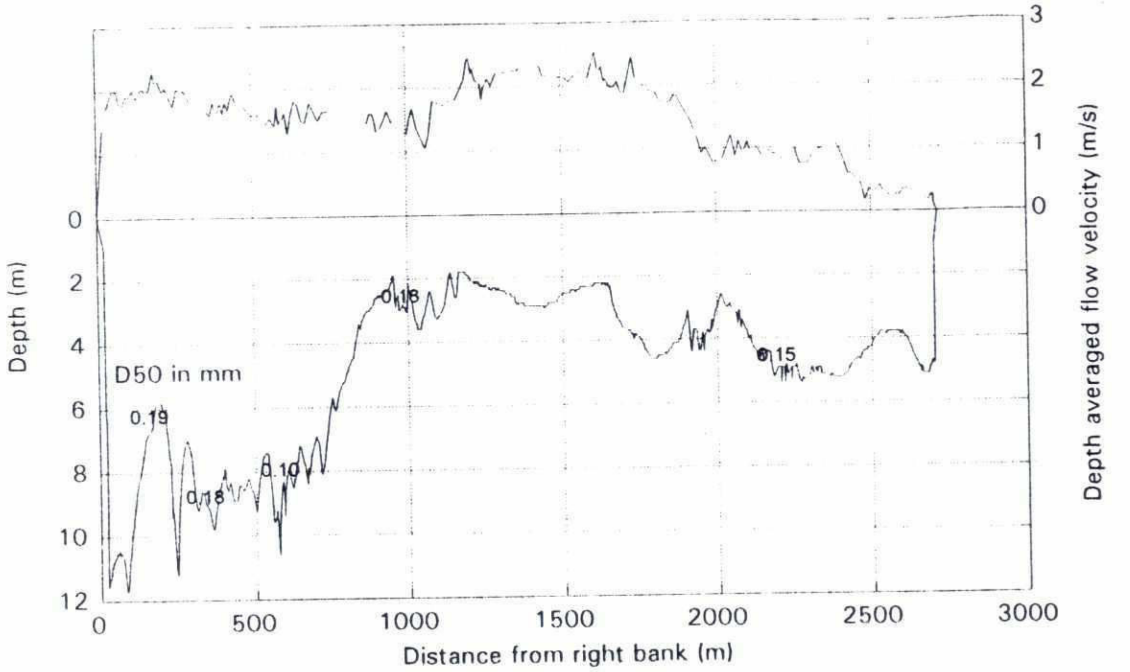


Figure 4.18: Location and D_{50} (mm) of samples at Sirajganj, Channel 2, surveyed on 23 July 1993

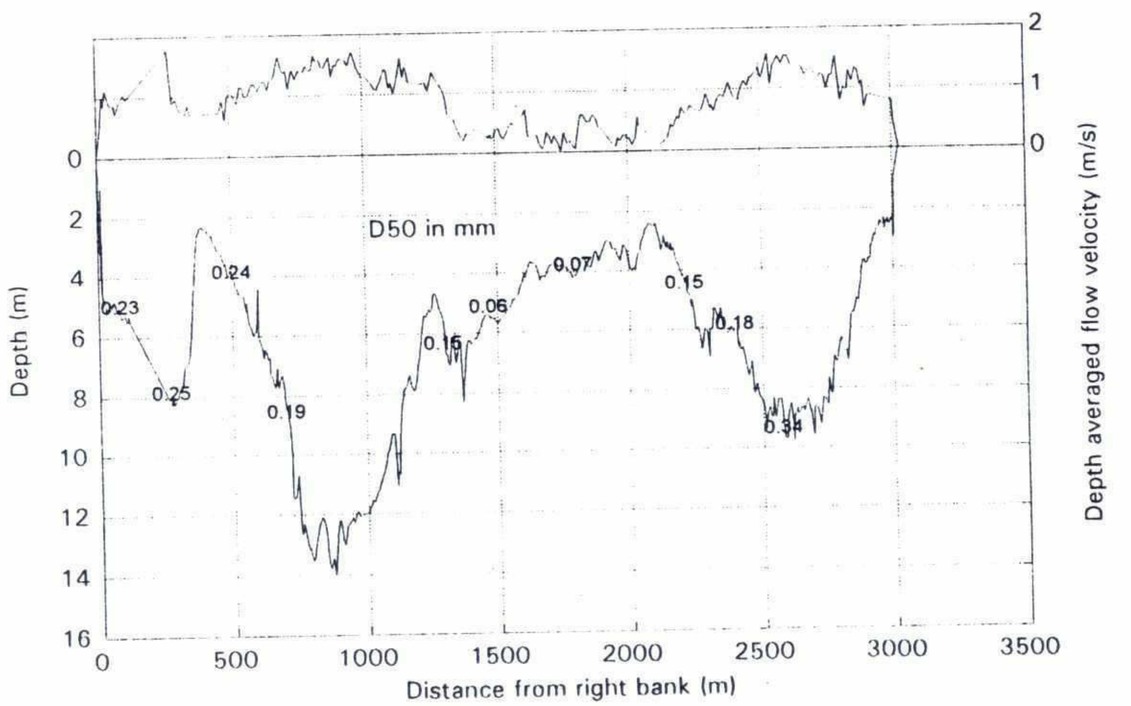


Figure 4.19: Location and D_{50} (mm) of samples at Sirajganj, Channel 1, surveyed on 24 October 1993

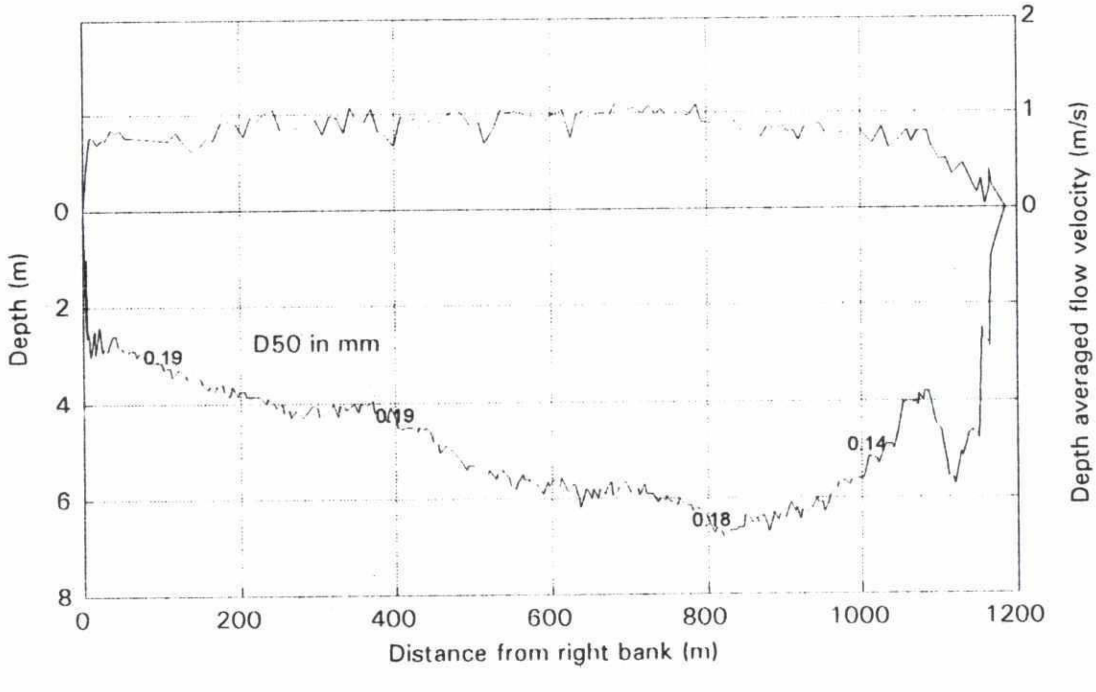


Figure 4.20: Location and D_{50} (mm) of samples at Sirajganj, Channel 2, surveyed on 27 October 1993

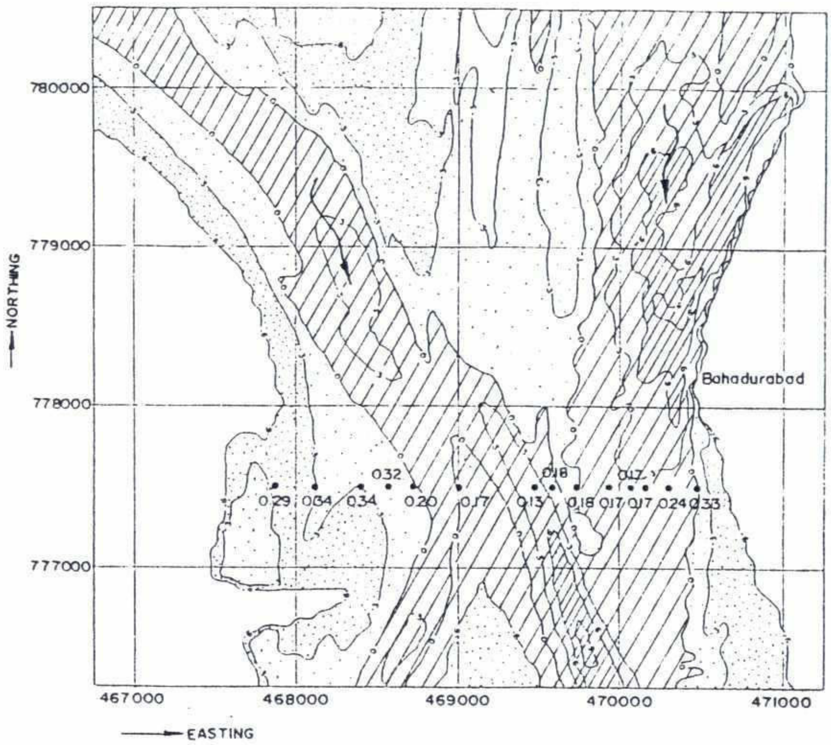


Figure 4.21: Bed material samples collected on 20/8/1993 located on the bathymetric survey August-September 1993 at Bahadurabad

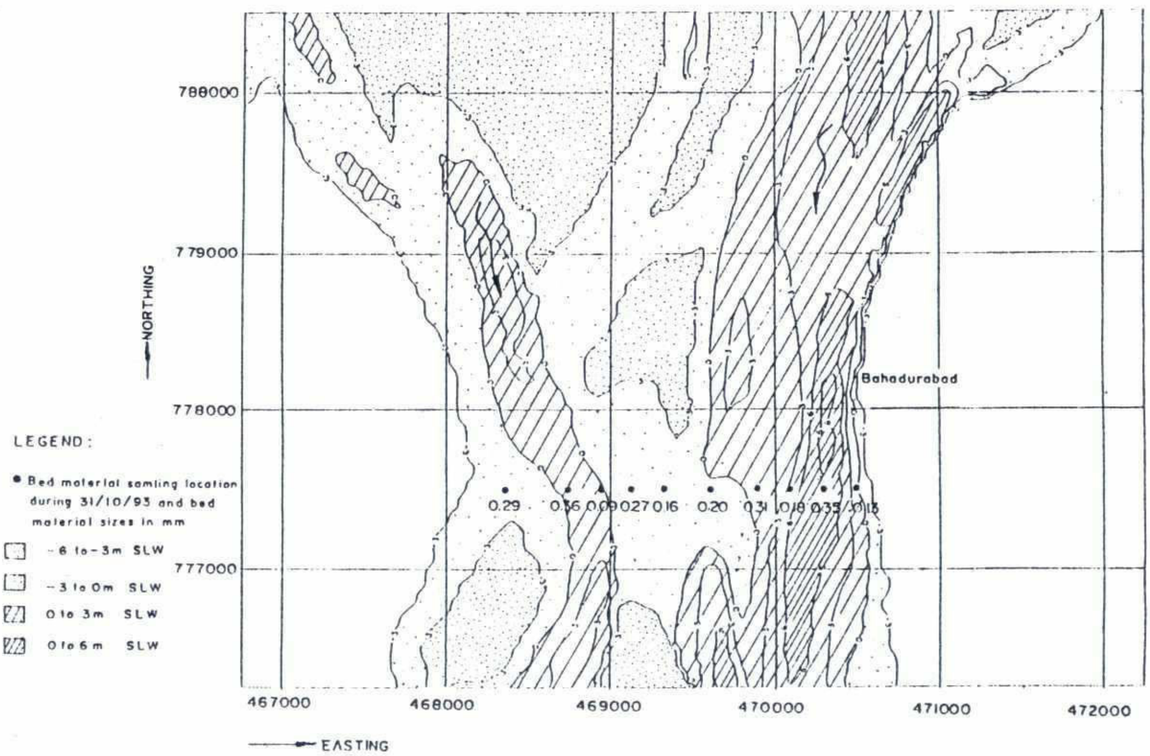


Figure 4.22: Bed material samples collected on 31/10/93 located on the bathymetric survey November 1993 at Bahadurabad

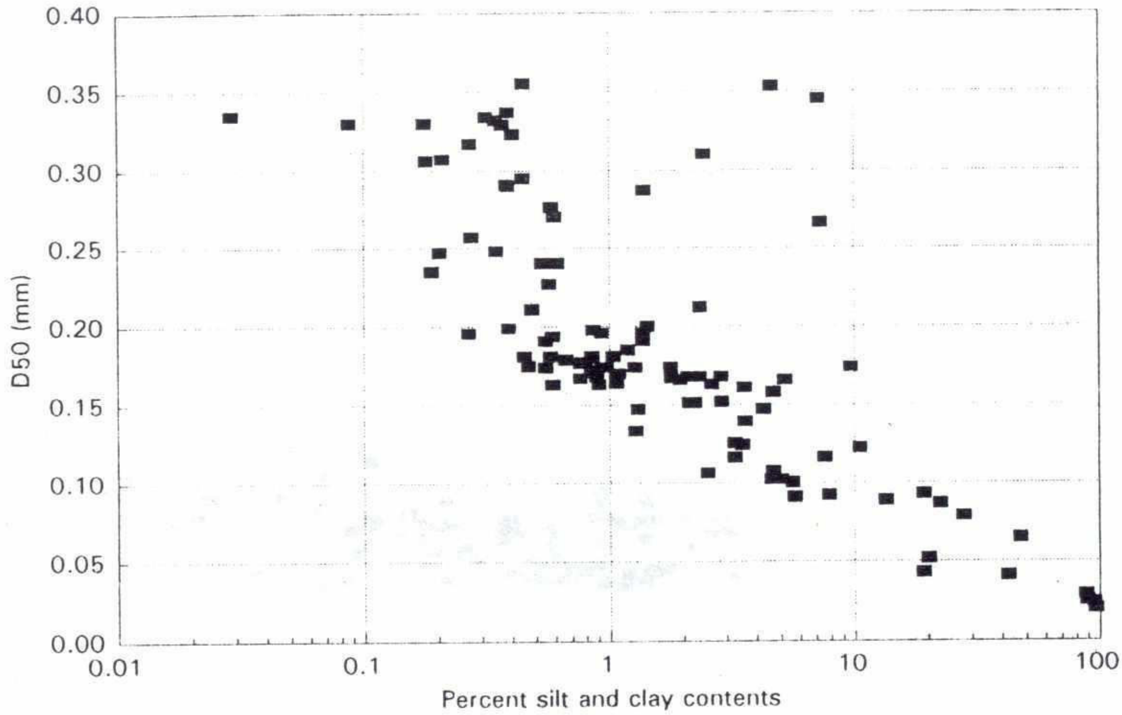


Figure 4.23: Relation between D_{50} and percentage of silt and clay, Bahadurabad

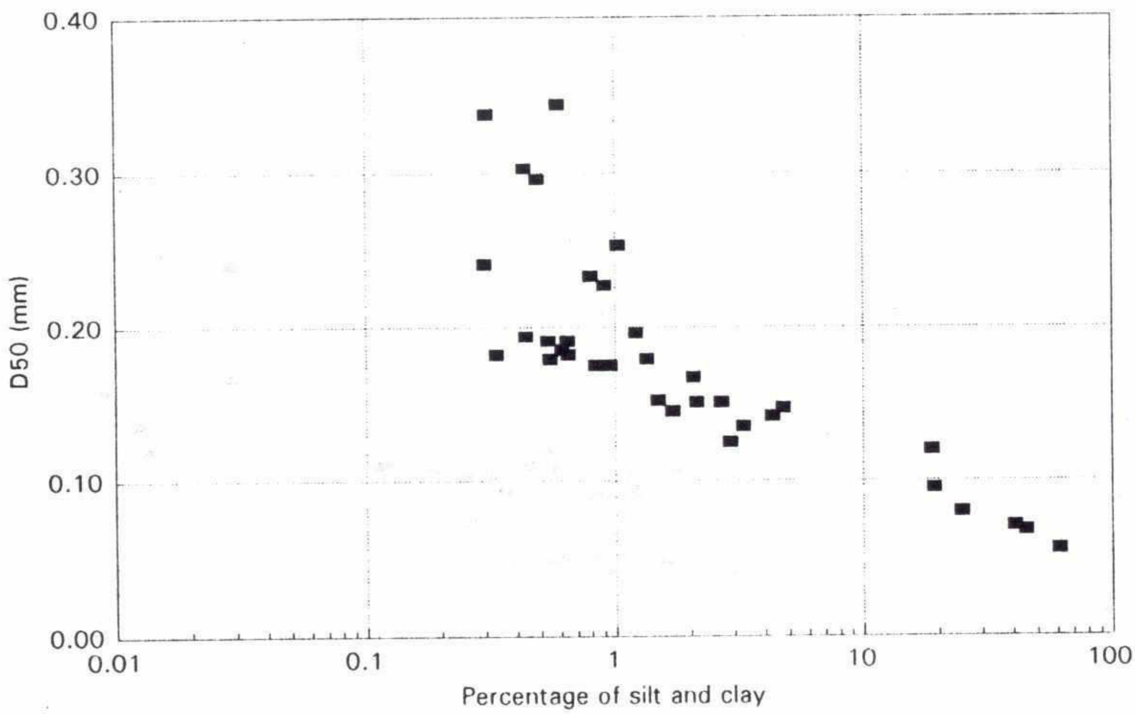


Figure 4.24: Relation between D_{50} and percentage of silt and clay, Sirajgang

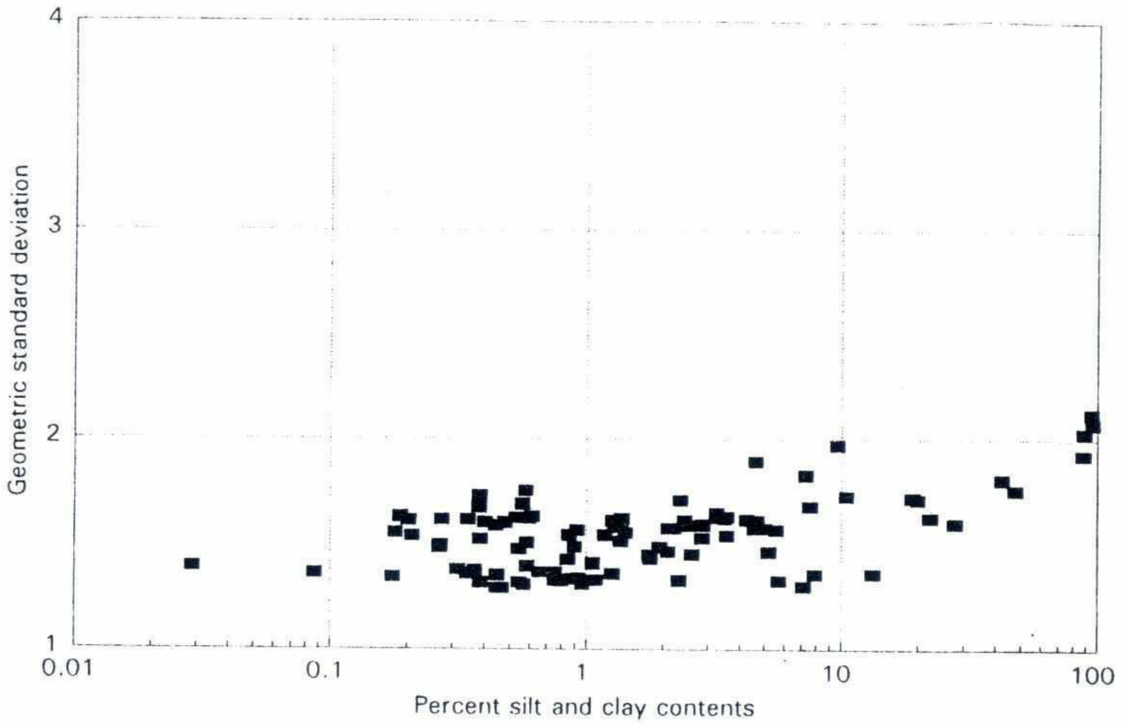


Figure 4.25: Relation between geometric standard deviation and percentage of silt and clay, Bahadurabad

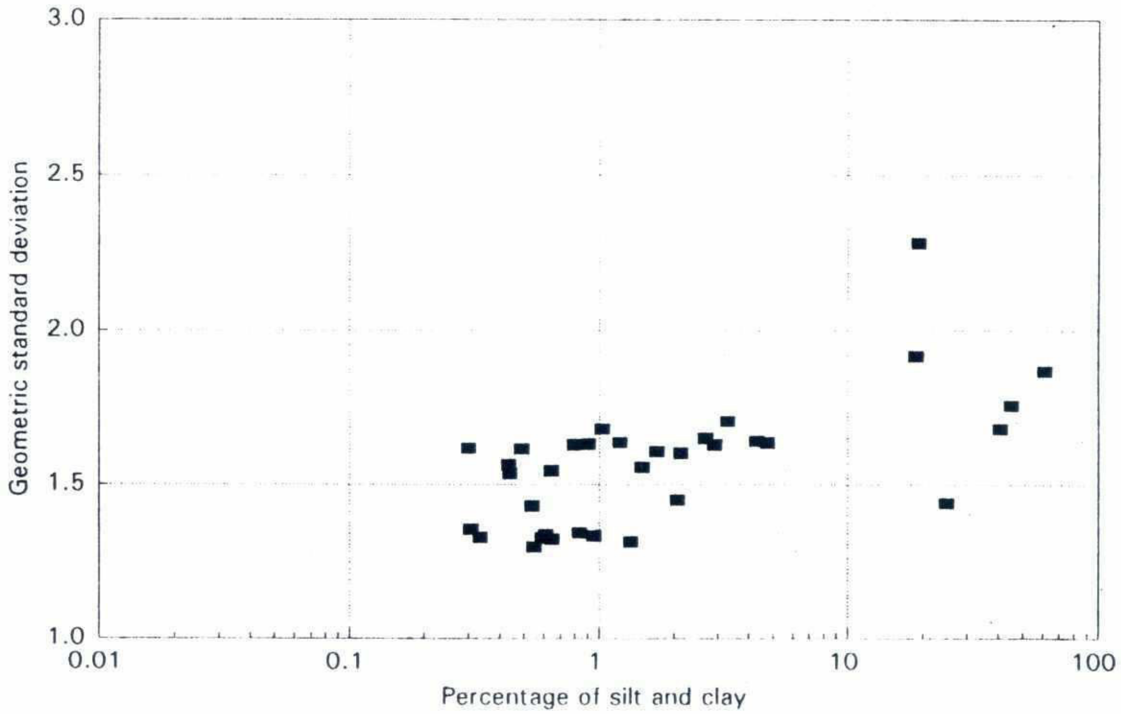


Figure 4.26: Relation between geometric standard deviation and percentage of silt and clay, Sirajganj

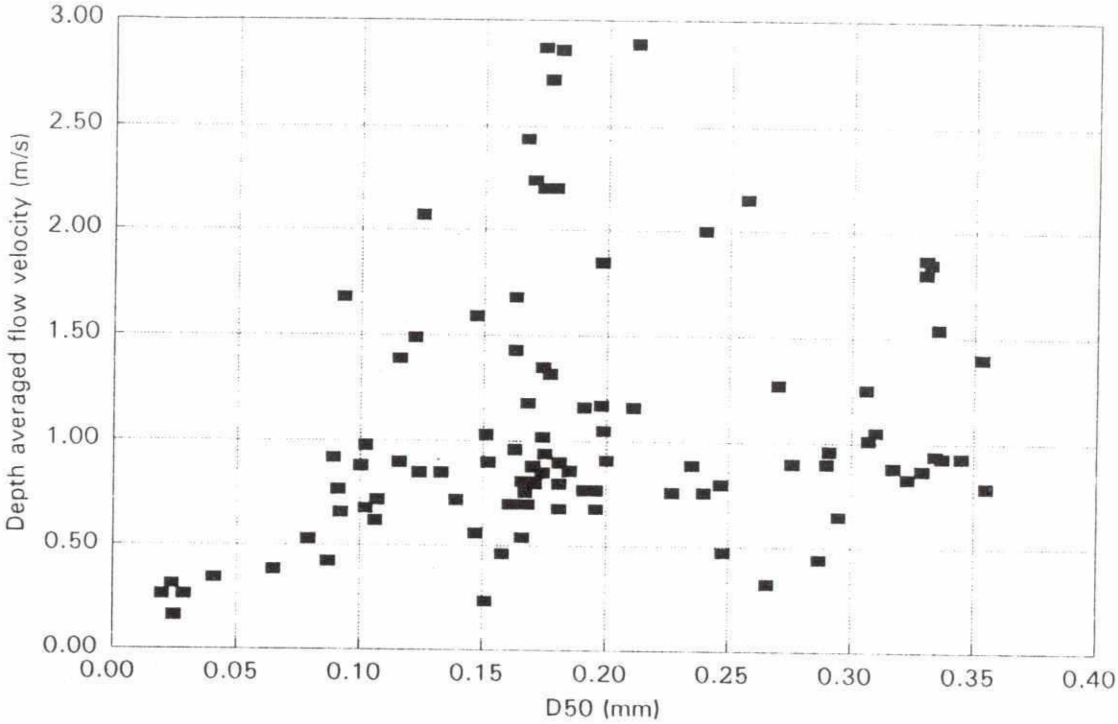


Figure 4.27: Relation between depth average velocity and D_{50}, Bahadurabad

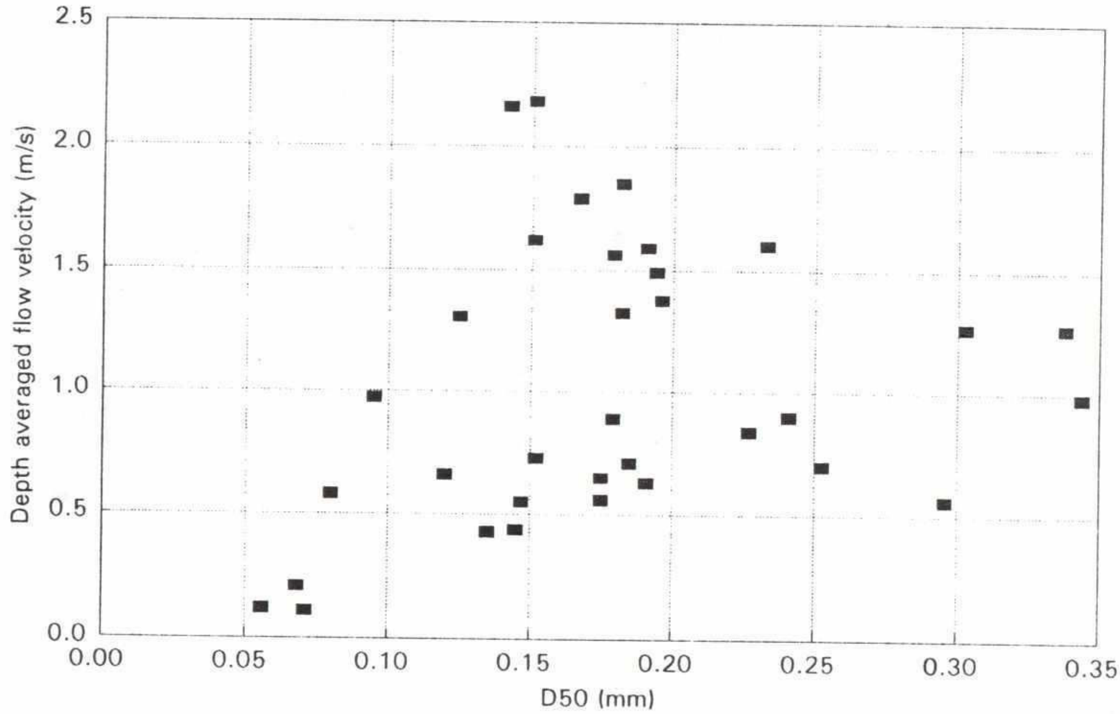


Figure 4.28: Relation between depth average velocity and D_{50}, Sirajganj

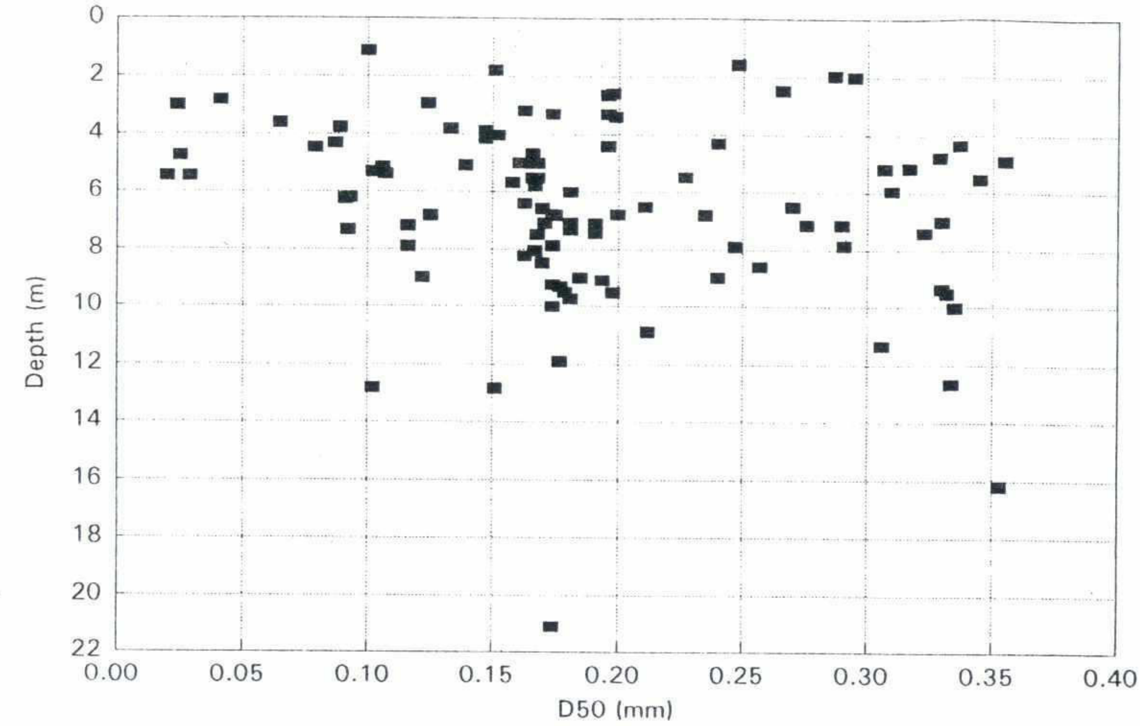


Figure 4.29: Relation between water depth and D_{50}, Bahadurabad

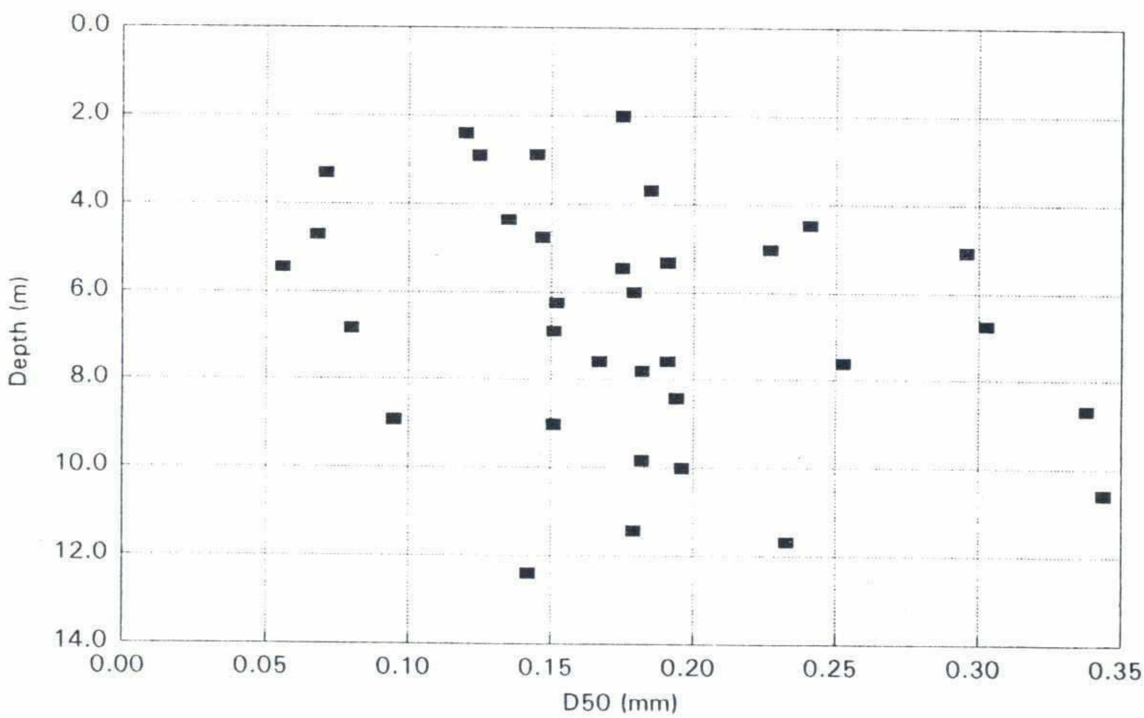


Figure 4.30: Relation between water depth and D_{50}, Sirajganj

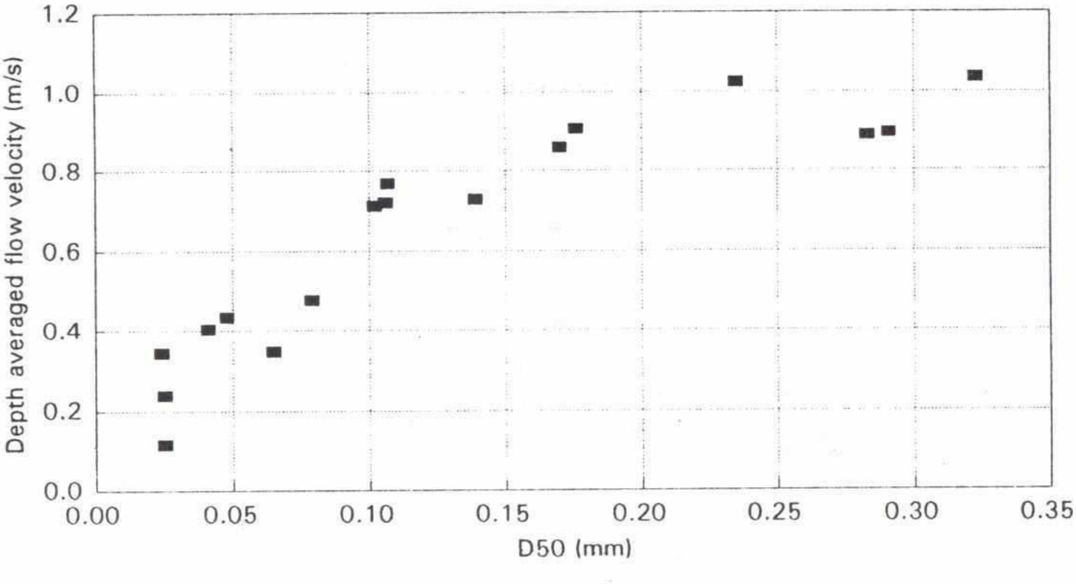
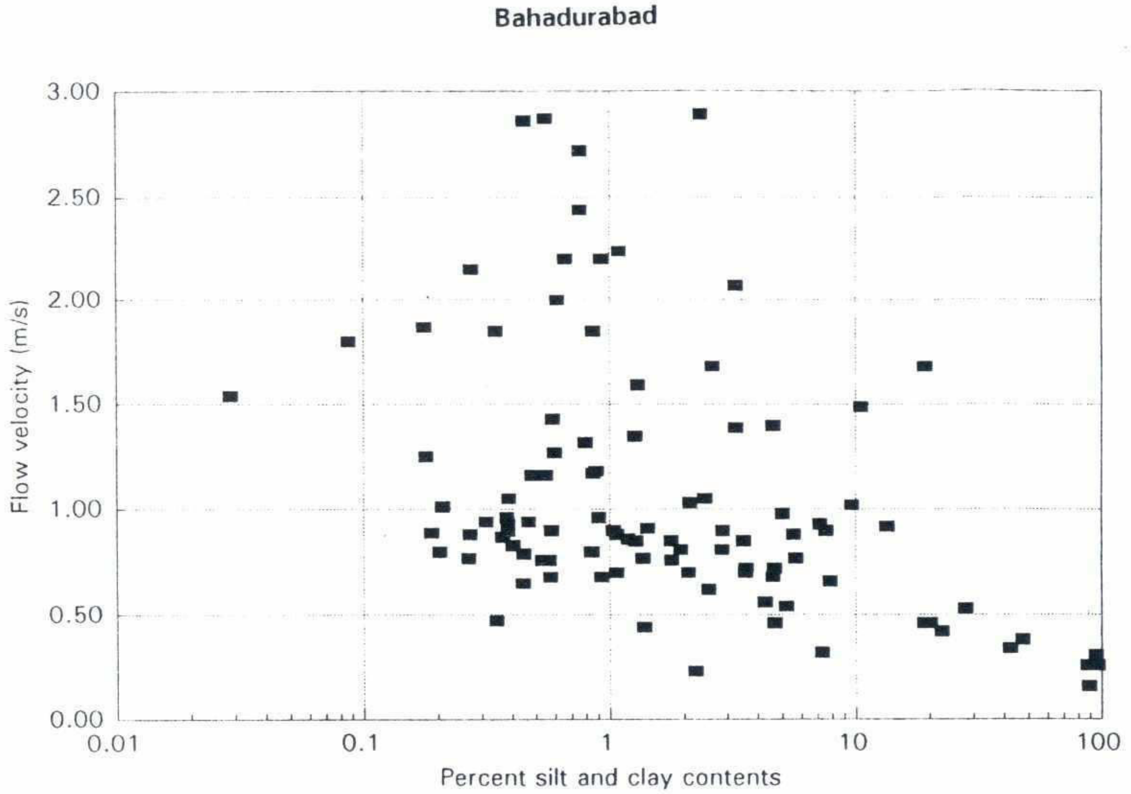


Figure 4.31: Relation between depth average velocity and D_{50} for the bed material sample collected during February and March, 1993 at Bahadurabad



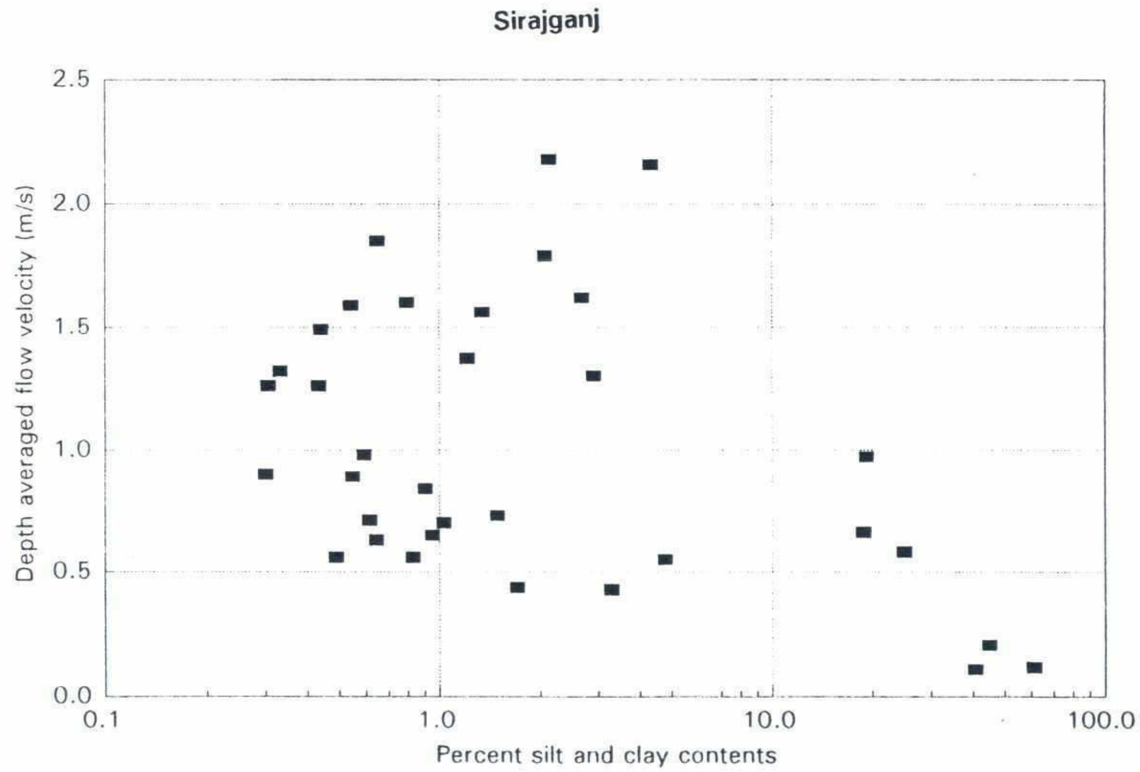


Figure 4.32: Relation between percentage of silt and clay with depth average velocity, Bahadurabad and Sirajganj

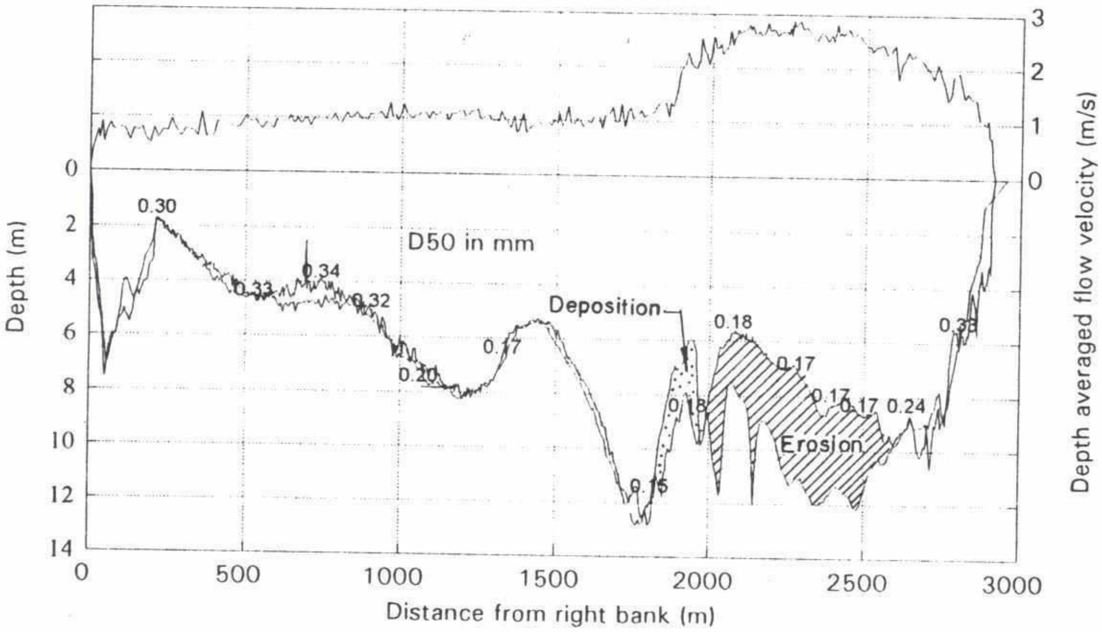


Figure 4.33: Comparison of cross-sections measured on 20/8/1993 and 6/9/1993 and the bed material samples collected on 20/8/1993 at Bahadurabad Left Channel

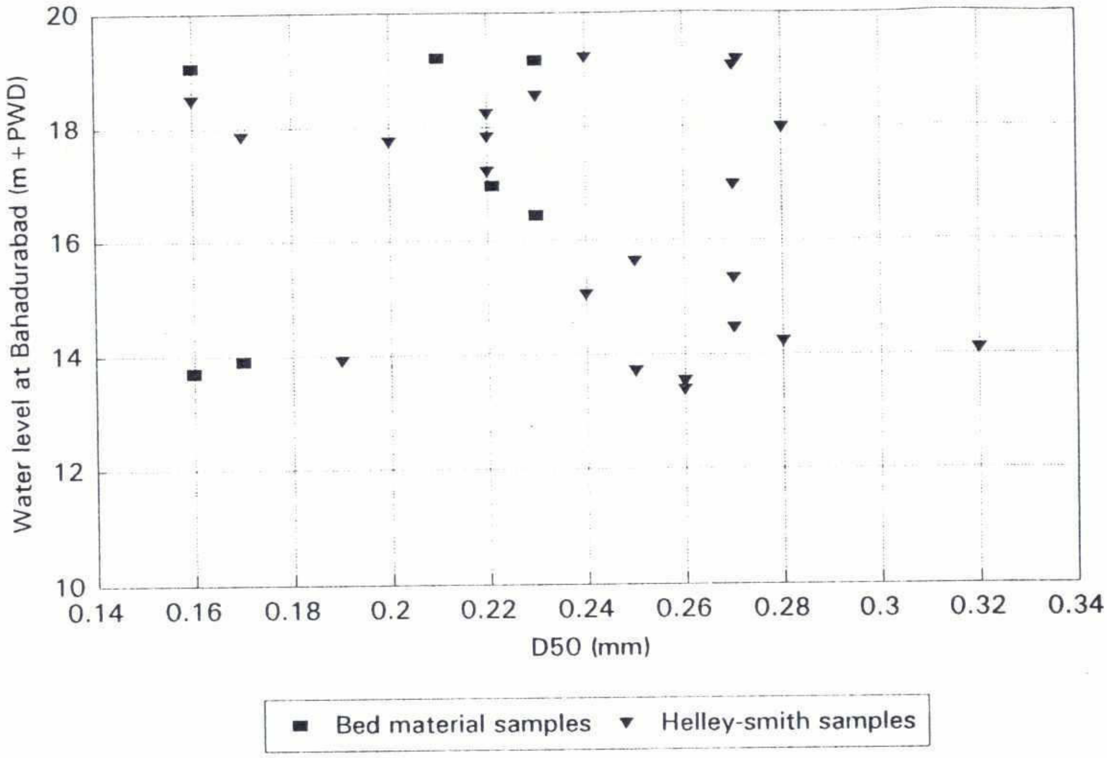


Figure 4.34: Variation of D_{50} of bed material and Helley-Smith samples with river stage, collected from the left channel at Bahadurabad

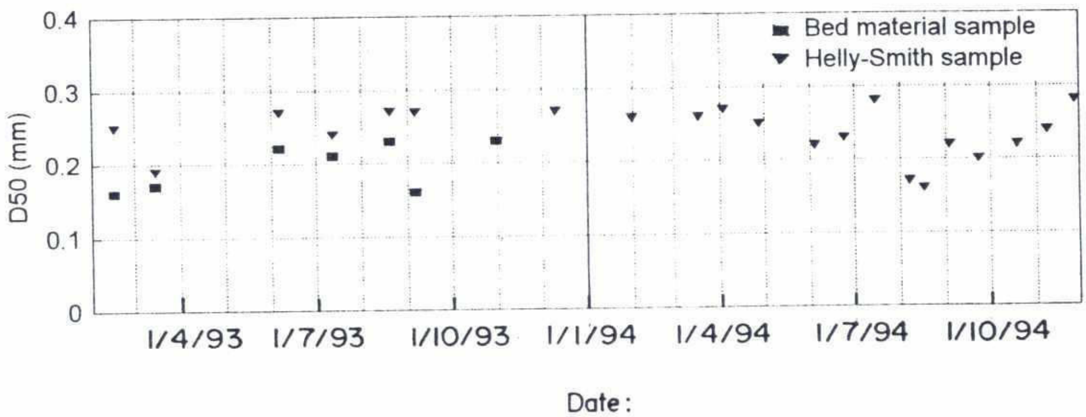
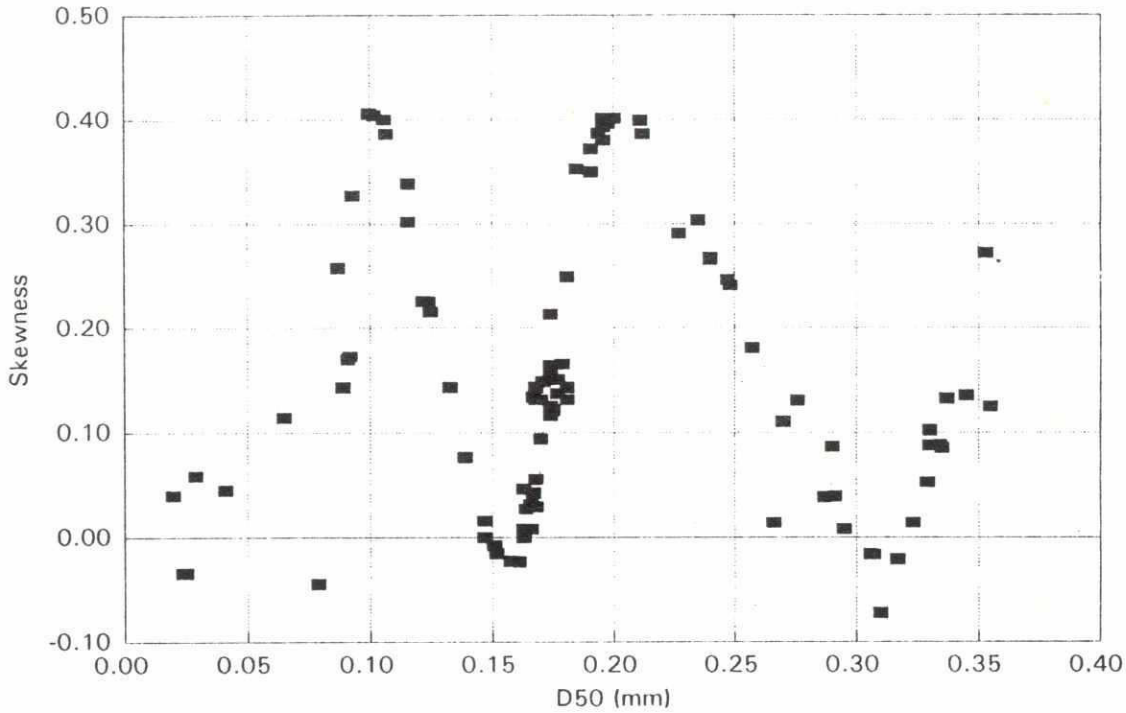


Figure 4.35: Time variation of average D_{50} of bed material and Helley-smith samples collected from the Left Channel at Bahadurabad

Jamuna River, Bahadurabad



Jamuna River, Sirajganj

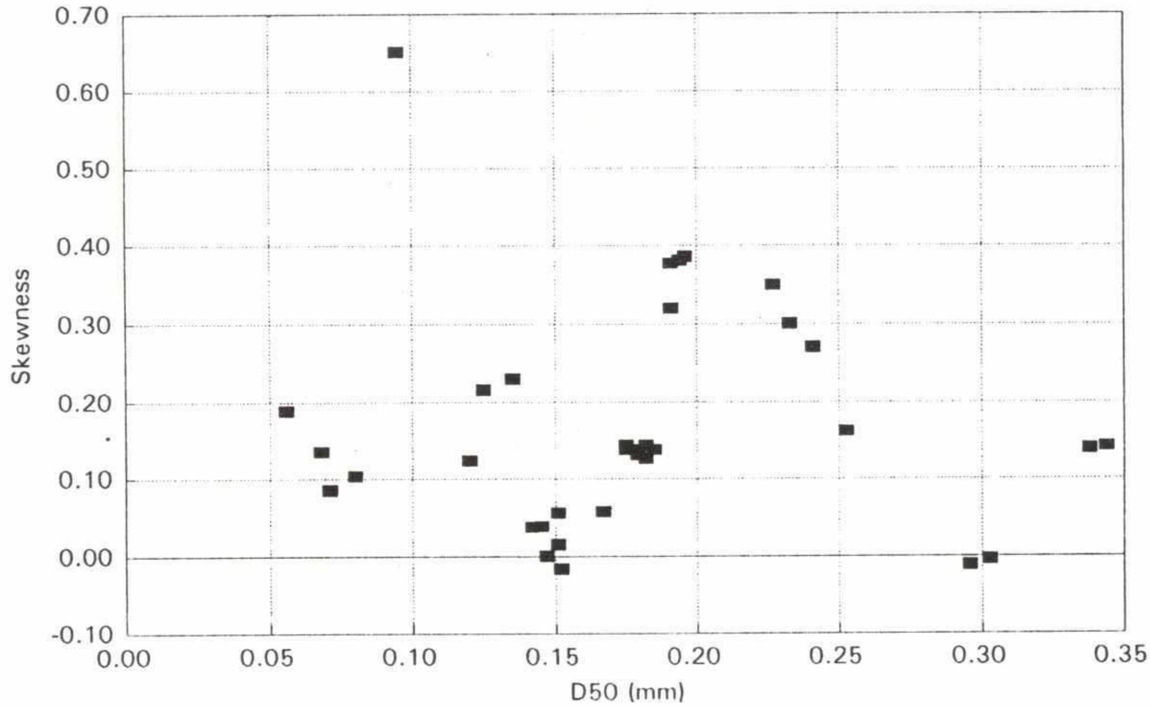


Figure 4.36: Relation between skewness and D_{50} of the bed material samples at Bahadurabad and Sirajganj