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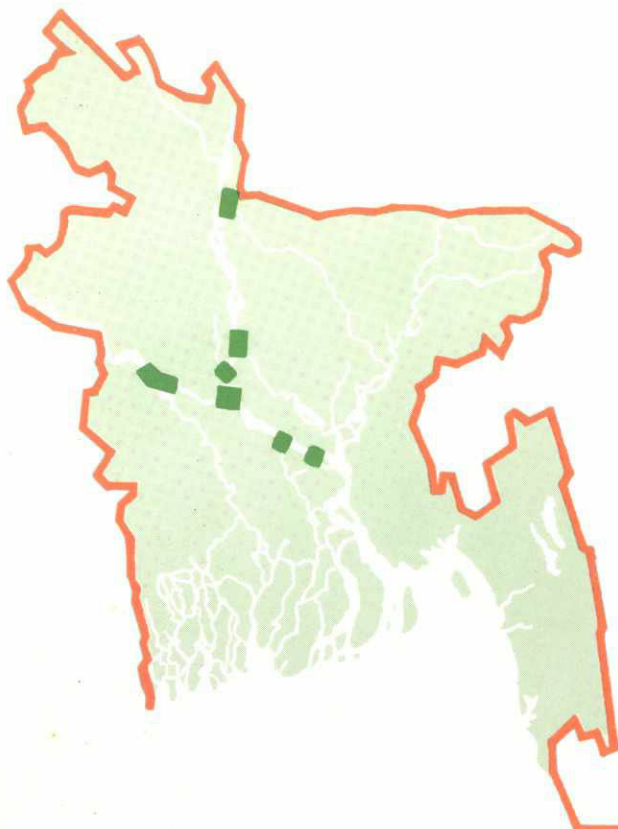
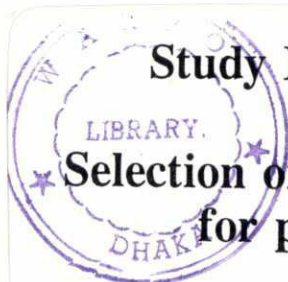


GOVERNMENT OF BANGLADESH FLOOD PLAN COORDINATION ORGANIZATION

FAP 24 RIVER SURVEY PROJECT

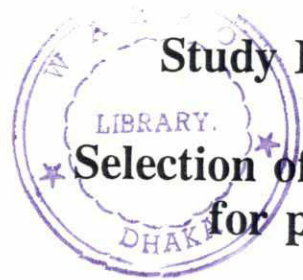
Study Report 1.

Selection of study topics
for phase 2



DELFT HYDRAULICS
DANISH HYDRAULIC INSTITUTE
OSIRIS
HYDROLAND
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Project ALA/90/04 — Commission of the European Communities



Study Report 1.
Selection of study topics
for phase 2

September 1993

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October 23, 1993

Chief Engineer
Flood Plan Coordination Organization (FPCO)
7 Green Road, Dhaka

Subject : Selection of study topics for phase 2

Our ref : RSP/9.1/615

Dear Sir,

We are pleased to submit herewith Study Report No. 1 of the River Survey Project titled: "Selection of study topics for phase 2".

The report is describing the key problems of the main river system of Bangladesh and which studies are required to tackle these problems. Part of the studies can be taken up by the River Survey Project in phase 2. A study programme is proposed. The report may be used as a background paper for the closed part of the International Workshop of November 9, 1993.

Thanking you.

Yours sincerely

Pieter van Groen
Team Leader

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Preface

To assist in the selection of study topics for the study programme of phase 2 of the River Survey Project a report has been prepared titled

"Selection of study topics for phase 2"

The studies aim at helping in finding answers to the key problems of the main river system of Bangladesh. In the report these key problems are identified and the required studies (topics) are outlined. Finally it is proposed which topics can be taken up in the study programme of phase 2 of the River Survey Project.

The Executive Summary of this report is presented hereafter.

20 October, 1993

Executive Summary

General

The River Survey Project is one of the supporting activities of the Flood Action Plan. The main components of the project are survey, study and training.

The surveys aims at collecting reliable all season hydrological and morphological data at key locations in the main river system of Bangladesh, applying improved or new technologies where possible and appropriate.

The studies aim at a better understanding of the river behaviour using both existing data and fresh data collected by the project.

The training consists of on-the-job training both in the field of surveys and studies.

The project is related to the main river system in Bangladesh, consisting of:

- (1) main rivers: the Brahmaputra/Jamuna River, the Ganges River, the Padma River, the Upper and Lower Meghna Rivers, and
- (2) distributaries (rivers carrying major flows only during the flood season): Old Brahmaputra River and Dhaleswari River taking off from the Jamuna River, the Gorai River from the Ganges River, and the Arial Khan/Dubaldia from the Padma River.

The River Survey Project started in June 1992 and it will cover a period of four years.

The Project is divided in two phases. Initially phase 1 was supposed to last one year and it would be finalized with an International Workshop on the Morphological Behaviour of Alluvial Rivers in Bangladesh. In phase 1 already some studies had to be done based on existing data. These studies were specified in the Terms of Reference. Phase 2 will take another three years and in this period the bulk of the studies has to be carried out. Which study topics have to be taken up is not specified in the Terms of Reference but it is implicitly indicated that these study topics should address the key problems experienced with the main river system in Bangladesh. Which topics should be taken up was to be decided only after the workshop referred to above. Due to some reasons phase 1 has been extended to the end of 1993, and the Workshop will only materialize in November of this year.

The present report has been prepared to assist in the selection of study topics for Phase 2. Because the aim of the studies should be to help in finding answers to the key problems of the main Bangladeshi river system, it specifically attempts to identify these key problems. In a next step study topics are identified that should be taken up to provide answers for these key problems.

Key problems

As frame-work for analysis rivers are discussed here in terms of input-output systems. The characteristics of a river (like its planform, width, depth, etc.) as output are dependent on inputs which ultimately are the climate and the geology of the basin, but at the level of a particular river reach come back to the flow hydrograph, the amounts of sediment a river has to carry over a longer time span, the characteristics of the sediment that has to be transported, and, on a geologically speaking short term (but for engineers on the long term) the valley slope. After a very long time, and for constant input parameters, a river is approaching equilibrium conditions, characterised by a dynamic equilibrium (hence fluctuations around a constant average value of a particular characteristic). This approach provides a frame-work for analysis of the main river system in Bangladesh. A review of the characteristics of the main rivers and their recent history (over last few centuries) shows that this river system is definitely not in equilibrium. Both the Brahmaputra River in its present Jamuna course and the Upper Meghna River are still in a process of adjusting to their new (only two centuries old) conditions. Furthermore there is a tendency for at least some of the distributaries to slowly loose their importance. Hence, uncertainties as to the natural development that the rivers are undergoing is one type of key problems.

Making predictions of the future conditions in the main river system of Bangladesh is only possible if a good knowledge exists of the present conditions. This condition is definitely not fulfilled. First of all only scarce data exist from the period before 1965. Secondly the data available, even those for the later period, are not sufficient for a full understanding. This is of course due to the fact that it is impossible to measure all parameters of a river at all places and at all times, but in the case of Bangladesh this is even aggravated due to the sheer size of the rivers. The width of the Jamuna River varies between 7 and 17 km, and any major systematic measuring campaign is an enormous undertaking. In this respect it is in itself already amazing how many data have been collected over the last decades. Still however the limited knowledge of the main river system definitely belongs to the key problems.

Another aspect is that the independent variables in the river system changes in time. For the main rivers in Bangladesh this relates in particular to local tectonics. Bangladesh is located in one of the tectonically speaking most active regions in the world, as it lies in the region where the Indian continental plate is sliding under the Eurasian continent. There is some evidence that some of the river courses are affected by this, in particular by faults which delineate units having differential rates of subsidence or upheaval. This may be the cause for the gradual shift to the west of the Jamuna river upstream of Sirajganj and for the gradual movement to the east of the upper reach of Lower Meghna River (and the Ganges mouth in the further past). The lack of understanding of these changes and their effect on the main river system in Bangladesh is another type of key problems in Bangladesh.

The River Survey Project is part of the Flood Action Plan and this means that part of the studies have a direct relation with this plan. Key problems in this respect are two-fold. One type of key problems is related to boundary conditions for the different structural elements that have been proposed as part of the Flood Action Plan. In particular for the embankments and the bank protection works. These boundary conditions comprise both hydraulic boundary conditions like design discharges, flood levels and flow velocities, and to boundary conditions related to morphology, sedimentation and erosion, like the safe distance of embankments from present river banks, and scour depths and their probability of occurrence for groynes and other type of bank protection works.

The second type of key problems in direct relation to the Flood Action Plan is the assessment of the impact of the different plans proposed under the various components of the plan. Predictions of this impact require an understanding of the behaviour of alluvial rivers in general and the effect of human interference in particular. Human interference usually leads to a system with a smaller number of freedoms, but still the present understanding is too limited to really predict the effects. Also because the knowledge of the present state of the river, the future adjustment and the changes in the outward controls are only very limited.

The different types of key problems are indicated in Figure ES.1, which schematically indicates which factors influence the transition of the present state of the river system to the future.

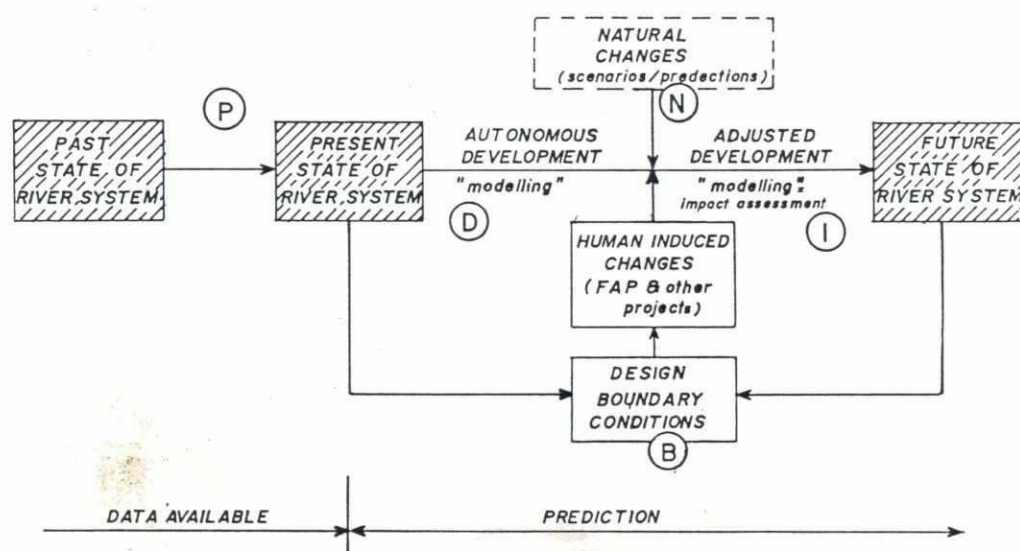


Figure ES.1 Identification and classification of key problems.

These considerations have led to the identification of a number of key problems. These are listed hereafter:

- (i) Limited understanding of the Present behaviour of the river system:
 - (P1) Limited data on present state
 - (P2) Dynamic fluctuations around equilibrium
 - (P3) Difficulties in measuring in large rivers
- (ii) Autonomous development of the river system:
 - (A1) Widening of the Jamuna River
 - (A2) Adaptation of the Upper Meghna River
 - (A3) Fate of distributaries
 - (A4) Bank erosion over 2 to 3 years
- (iii) Natural changes in independent variables
 - (N1) Shifting of river courses
 - (N2) Major changes possible?
- (iv) Boundary conditions for design
 - (B1) Design boundary conditions embankments (discharges, stages, safe distance)
 - (B2) Design conditions for groynes and revetments (stages, magnitude and direction of velocities, bed levels)
- (v) Impact assessment
 - (I1) Impact of Regional plans on river characteristics
 - (I2) Effect of narrowing/bank protection works/AFPM measures
 - (I3) Effect of embankments on sediment flux towards fields and on siltation in floodplains outside embankments
 - (I4) Impact of developments upstream
 - (I5) Influence climatic changes

Study topics

In the next step these key problems have been dissected in a number of study topics. In this context study topics are fairly well described investigations for which the rationale for carrying out the investigation, the approach, the required input in manmonths, the required field data and the expected output can be defined properly. The study topics have been derived by analyzing the different aspects of relevance for each of the key problems. Examples of such dissections are given in the main text of the report.

Subsequently a list of possible study topics was prepared and this list is given here as Table ES.1, together with the key problems. The study topics are grouped into the following categories:

- Hydrology and water balances (5 topics)
- Sediment transport and river aggradation and degradation (6 topics)
- Planform characteristics and channel dimensions (10 topics)
- Offtakes and bifurcations (4 topics)
- Confluences (3 topics)

- Bars (2 topics)
- Bedforms (4 topics)
- Local scour (4 topics)
- Measuring techniques (6 topics)
- FAP impact on the river system (4 topics)

In Appendix 2 these topics are described in some detail. There furthermore per topic the possible approach and the required study tools, a tentative ranking, the expected results and the required input are listed.

Table ES.1 was especially prepared to illustrate the relation between the key problems and the study topics. As can be observed different study topics have to be tackled for finding answers to specific key problems. It should be stressed that the study topics as they are visualised here are definitely not meant to solve the tackled problem in a universal way. Rather the idea is to address the specific topic for Bangladeshi conditions, often combining theoretical frame-works derived from mathematical-physical analyses with specific data from Bangladeshi rivers.

Selection of study topics

As indicated above for all study topics estimates were made of the required input in both expatriate manmonths and local manmonths, plus specialized expertise if any. Furthermore the requirements as to additional field measurements were evaluated. Adding up the manmonths for all study topics and comparing the result with the number of manmonths available for studies in phase 2, clearly showed that the available number of manmonths was not sufficient. Hence there is a need for selection of a more limited number of study topics.

This selection was made on the basis of a number of criteria, like (i) of interest for the impact assessment of the combined FAP's ("impact criterion"), (ii) of interest for the feasibility but more often the detailed design phase of the regional FAP's ("regional plan criterion"), (iii) required for the FAP components that are dealing with bank protection and river training works ("river training criterion"), (iv) can be studied in much more detail with the up-to-date surveying possibilities of the FAP 24 survey spread ("availability criterion"), (v) can be done with fairly low investment in manmonth ("investment criterion"), (vi) is of academic interest ("research criterion"), or (vii) is emphasizing the overall behaviour over local phenomena ("aggregation criterion"). In addition there is of course a criterion related to internal cohesiveness of the study programme: it is no use to take up one study topic if other study topics needed for finding a solution to a certain key problem are not tackled. To secure this, Table ES.1, the key problem - study topic matrix was used. The proposed selection of study topics is indicated in Table ES.1 by shaded boxes.

Num ber	Category	Sub num ber	Topic	Key problems																
				Present state			Autonomous de- velopment				Natural changes			Design Conditions		Impact assessment				
				P1	P2	P3	A1	A2	A3	A4	N1	N2	B1	B2	I1	I2	I3	I4	I5	
1	Hydrology	1.1	Improved Bahadurabad discharges and rating curves	•	•								•	•	•					
		1.2	Improvement historical Bhairab Bazar discharges	•	•								•	•	•					
		1.3	Water balances and overland flow	•					•				•	•	•		•			
		1.4	Water level profiles and water level slopes	•									•	•	•		/			
		1.5	Phase 2 updating	•	•								•	•	•					
2	Sediment transport and river aggra- dation and degra- dation	2.1	Rating curves and balances	•	•		•										•			
		2.2	Sediment transport predictors	•	•				•								•			
		2.3	Integration of existing knowledge via 1-d morphological model	•					•						•	•				
		2.4	Long-term development of distribution	•	•		•													
		2.5	Floodplain sedimentation and subsidence	•																
3	Planform charac- teristics and channel dimensions	2.6	Phase 2 updating	•	•												•			
		3.1	Planform classification and meandering and braiding characteristics	•	•		•													
		3.2	Channel dimensions		•								•	•	•	•				
		3.3	Bank erosion rates		•								•	•	•	•				
		3.4	Outer bend scour																	
4	Offtakes and bifur- cations	3.5	Channel cutoffs		•															
		3.6	Effect of tectonics on planform characteristics						•				•	•						
		3.7	Influence of cohesive material on planform characteristics		•										•					
		3.8	Local slope changes and their importance for planform changes												•					
		3.9	Prediction of medium-term planform changes		•										•					
5	Conflu- ences	3.10	Long-term changes of the location of the rivers											•						
		4.1	Discharge and sediment transport distribution				•													
		4.2	Seasonal variation of erosion and deposition																	
		4.3	Influence of bars				•													
		4.4	Influence of bed-forms																	
6	Sand bars	5.1	Erosion and deposition of out-of-phase floods		•															
		5.2	Influence of bars and bed-forms		•															
		5.3	Confluence scour																	
		6.1	Occurrence, dimensions and dynamics of bars													•				
		6.2	Time-dependence of bars													•				
7	Bed-forms	7.1	Occurrence, dimensions and dynamics		•															
		7.2	Time-dependence of bed-forms		•															
		7.3	Three-dimensionality of bed-forms																	
		7.4	Roughness and bed-forms		•												•			
		8.1	Dimensions of local scour around structures																	
8	Local scour	8.2	Time-dependence of local scour		•															
		8.3	Influence of bed-forms																	
		8.4	Combination with other types of scour																	
		9.1	Selection of measurement sites																	
		9.2	Optimization of hydraulic measurements																	
9	Measuring techniques	9.3	Optimization of sediment measurements																	
		9.4	Bed load transport via dune-tracking																	
		9.5	Bathymetry and remote sensing																	
		9.6	Sustainable survey techniques																	
		10.1	Formulation of scenario's																	
10	FAP impact on river system	10.2	Simulation of ultimate river response via analytical modelling																	
		10.3	Quantitative assessment of FAP impact with 1-d morphological model																	
		10.4	Morphological model river system including changes in braiding and meandering characteristics																	

Table ES.1 Key problem - study topic matrix

Selected topic

The tentative selection of study topics, still to be confirmed during the Workshop mentioned before, is to concentrate on a limited number of topics. These topics are hydrology and water balances, sediment transport and river aggradation and degradation, offtakes and bifurcations, bedforms but only in relationship to hydraulic roughness, measuring techniques, and the FAP impact on the river system.

An important aspect is to what extent mathematical modelling can be used in the project. Mathematical modelling is a way of combining physical phenomena in one overall tool. It allows to study the behaviour of a system as is simulated in the model. Modelling can be used as a test as to the physical understanding that has been gathered until now is sufficient for the understanding of the conditions in the field. Hence, within FAP 24 mathematical modelling is felt to be indispensable in testing present and future knowledge. In addition modelling will be used for assessing the impact of the present proposals under the different FAP projects.

As only a limited number of study topics can be tackled by the FAP 24 team, already in an early stage attempts were made to interest Universities and other institutions into taking part in some elements of the FAP 24 studies. It was considered that the unique measuring opportunities would be of interest to the scientific community and that this would be an asset to do some studies in relation to key problems in Bangladesh. This was confirmed several times. It has resulted in research proposals from a number of universities, notably:

- (1) IHE DELFT (International Institute for Infrastructural, Hydraulic and Environmental Engineering), The Netherlands, for a study into the fate of distributaries,
- (2) University of South Carolina, USA, for a study into subsidence and floodplain sedimentation;
- (3) University of Amsterdam, The Netherlands, for a study into the effect of local tectonics on planforms and planform changes;
- (4) University of Leeds, England, for two studies, one into sand bars and another one into bedforms and their hydraulic roughness;
- (5) ISVA (Technical University of Denmark), Denmark, for a study into the influence of suspended sediments on the dune tracking method.

Timing and staffing schedule

Based on the tentative selection of the study topics a division of the different activities (as far as the studies are concerned) over the different staff members, both expatriate and local, was made. Based on this a time schedule for the different study topics was made. This time schedule is presented here as Figure ES.2. It is subject to change as a consequence of possibly other study topics being put higher on the "priority list" after the Workshop. Also it is tentative as during the project the priorities may shift based on outcomes of studies and surveys for other developments.

Towards an integrated study and survey programme

For a number of study topics additional surveys will be needed. In particular there is a need for frequent measurements in a river reach with bars and bedforms, and possibly this cannot be done in one of the river reaches where the standard measurements are being done. Consultants will prepare a revised survey schedule taking into account these additional measurement requirement, investigating at the same time to what extent this can be combined with the programme of standard measurements. This may lead to (slight) revisions of both the survey and the study programme as presented in Figure ES.2. After completion of both the reports, this one on selection of the study topics and the one on selection of survey techniques, consultants intend to propose to the Client an overall programme with well-integrated study and survey components to be presented at the workshop. It should be realized, however, that also this integrated programme will be subject to changes in the next years as a consequence of results obtained over the coming years.

Concluding remark

Unfortunately only a part of the required study topics can be taken up by the River Survey Project. However, it is felt that the package of study topics proposed here by consultants, supported by the unique possibilities for collecting field data on a scale and with a combination of instruments unprecedented anywhere in the world, and together with the investigations proposed by the different universities, will result in a step forward in the understanding of the morphological behaviour of alluvial rivers in Bangladesh. This will allow to better address the key problems in Bangladesh as far as they are related to the morphological behaviour of the rivers.

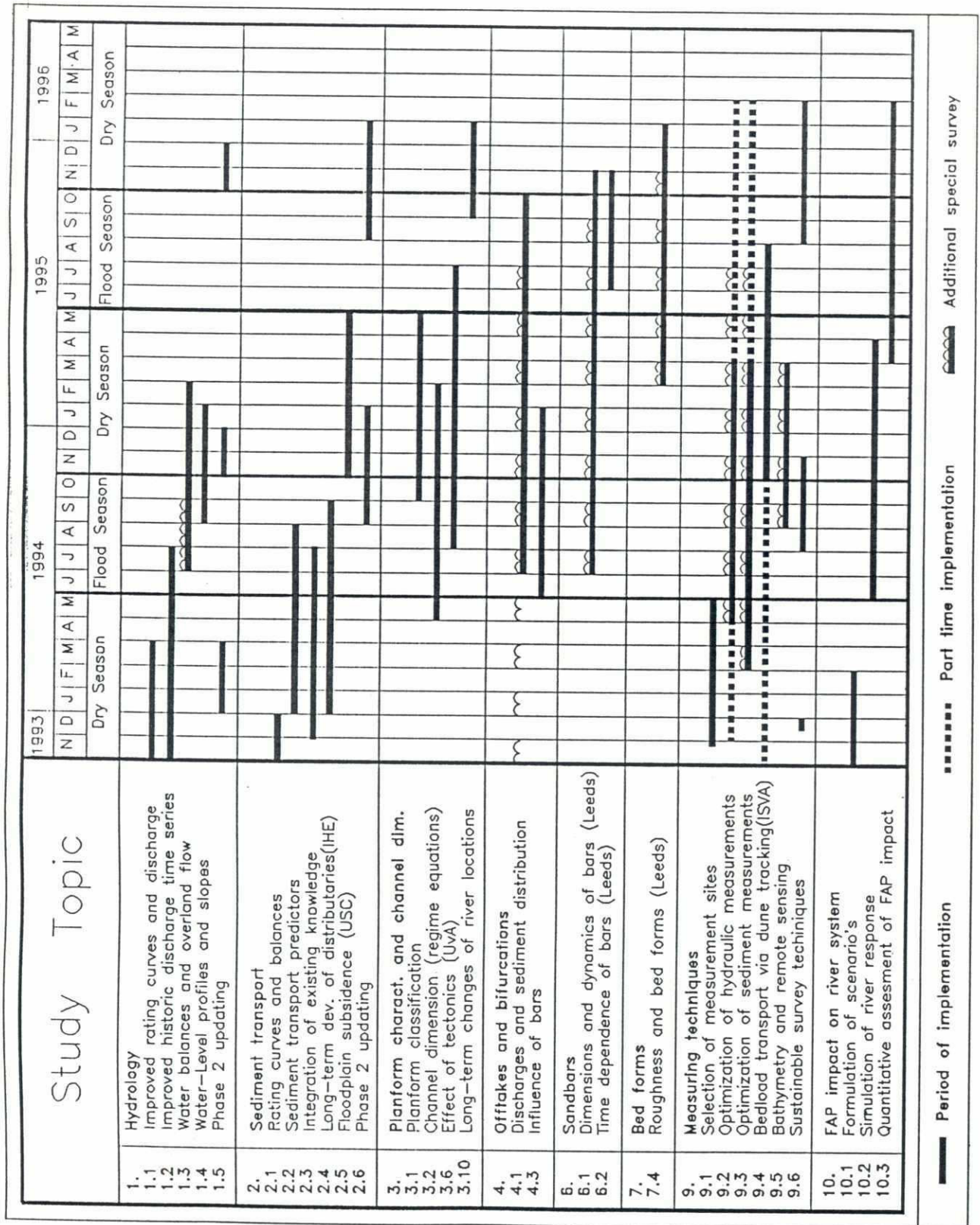


Figure ES.2 Tentative time schedule for studies and related surveys.

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List of Abbreviations

ADCP	-	Acoustic Doppler Current Profiler
AFPM	-	Active Flood Plain Management
BIWTA	-	Bangladesh Inland Water Transport Authority
BRE	-	Brahmaputra Right Embankment
BRTS	-	Brahmaputra River Training Studies
BUET	-	Bangladesh University of Engineering and Technology
BWDB	-	Bangladesh Water Development Board
CAT	-	Coordination Advisory Team
CEC	-	Commission of the European Communities
CEP	-	Coastal Embankment Project
FAP	-	Flood Action Plan
FCD	-	Flood Control and Drainage
FCDI	-	Flood Control, Drainage and Irrigation
FFW	-	Food For Works
FPCO	-	Flood Plan Coordination Organization
GIS	-	Geographical Information System
GK	-	Ganges Kobadak
GLE	-	Ganges Left Embankment
GM	-	General Model
GoB	-	Government of Bangladesh
IDA	-	International Development Agency
IHE	-	International Institute for Hydraulic and Environmental Engineering
IRD	-	Integrated Rural Development
ISVA	-	Technical University of Denmark
LRP	-	Land Reclamation Project
MPO	-	Master Plan Organization
MSL	-	Mean Sea Level
NCRS	-	Northcentral Regional Study
NEDECO	-	Netherlands Engineering Consultants
NERWMP	-	Northeast Regional Water Management Program
NWRS	-	Northwest Regional Study
PA	-	Project Adviser
PoE	-	Panel of Experts
RRI	-	River Research Institute
RSP	-	River Survey Project (FAP 24)
SERWRDP	-	Southeast Region Water Resources Development Program
SWMC	-	Surface Water Modelling Centre

SWRMP	-	Southwest Area Water Resources Management Project
ToR	-	Terms of Reference
UoL	-	University of Leeds
USA	-	United States of America
USC	-	University of South Carolina
UvA	-	University of Amsterdam

List of symbols

Symbol	Meaning	Unit
B	Channel width	(m)
B_b	Bankful width	(m)
B_t	Total width of the braided system	(m)
C	Chezy's roughness coefficient	($m^{1/2}/s$)
D	Bed material size	(mm)
E	Yearly bank erosion	(m/year)
g	Acceleration due to gravity	(m/s^2)
h	Average water depth	(m)
h_b	Bankful water depth	(m)
i	River slope	(-)
i_b	River slope at bankful stage	(-)
i_v	Valley slope	(-)
L	Meander length	(km)
n,k	Number of channels	(-)
P	Sinuosity	(-)
Q	River discharge	(m^3/s)
Q_b	Bankful discharge	(m^3/s)
R	Radius of curvature	(m)
S	Sediment transport	(m^3/s)
S_b	Sediment transport at bankful stage	(m^3/s)
u	Flow velocity	(m/s)
u_b	Flow velocity at bankful stage	(m/s)
u_*	Shear velocity	(m/s)
V	Sediment transport integrated over the year	(m^3)
W	Meander belt width	(km)
x	Longitudinal coordinate	(km)
α	Angle of attack	(degree)
α_Q	Coefficient to incorporate the influence of hydrograph	(-)
ϵ	Porosity	(-)
Δ	Relative density	(-)
λ	Cutoff ratio	(-)

1 Introduction

1.1 General

The Flood Action Plan (FAP) was formulated after Bangladesh experienced in 1987 and 1988 the two most severe floods on record. The FAP started in December 1989 with the objective to coordinate all individual approaches and major projects on water resources, drainage, flood protection and river training works. The Government of Bangladesh established the Flood Plan Coordination Organization (FPCO) to coordinate the action plan in Bangladesh. The FAP consists of 11 main components and 15 supporting activities. The River Survey Project (FAP 24) started in June 1992 as one of the supporting activities.

The River Survey Project will constitute the first phase of a longer term effort aimed at expanding and strengthening the collection of hydrological and morphological data and further developing understanding of the behaviour of the main rivers in Bangladesh. The main objectives of the project are to collect reliable all season data on the hydrology and morphology of the main river system, to undertake special studies regarding the behaviour of the river system, to provide specialised on the job training to bangladesh professionals, and to provide benchmarks against which to assess changes in the river morphology and hydrology. As such the River Survey Project has to play a major role in supplying basic data required by policy makers for the development of long term flood control and river training strategies. In other words the River Survey Project consists of three main components: survey, study and training.

The River Survey Project is planned to cover a period of four years split up in two phases. phase 1 with a duration of one year and phase 2 for the remaining three years. The present report gives an outline of the study programme for phase 2.

1.2 Rationale

One of the objectives of the River Survey Project is to undertake special studies of the behavior of the river systems in Bangladesh based on (1) the new data that will be collected during the surveys under the project, (2) existing data and (3) through supplementary surveys.

As is written in the ToR: "This programme of river studies will be undertaken to investigate key characteristics of the behaviour of the river systems. The river studies will address aspects of the main river systems which will not be covered under the various regional studies. Study topics will be finalised

during the phase 1 and the study programme will have strong bearing on the details of the hydrological and morphological data collection programme", being one of the other two components of the project. Furthermore, it is stated that under phase 1 it is required to "Review the results of the surveys and studies carried out so far, and prepare a proposal for studies to be carried out during the next phase."

The present report is Consultants' response to these requirements as stated in the ToR.

1.3 Phase 1 and phase 2 study topics

In the ToR a distinction is made between the study topics to be taken up under phase 1 and those for phase 2. The study topics for phase 1 are clearly outlined and the relevant paragraphs of the ToR are quoted hereafter:

"Phase 1 studies :

- (...) Collect, analyse and adjust as necessary , in consultation with FPCO and the PA, historical water levels and discharges of selected stations and present them both in tabular form and as frequency curves. Using these records prepare rating curves extended for extreme flood conditions and profiles of the water surface at different discharges for main rivers at different times of the year.
- (...) Assess, analyse and report on available data on river morphology (BWDB cross-sections, air photos, satellite imageries, BIWTA surveys etc) of the Brahmaputra, Ganges, Padma, Old Brahmaputra, Dhaleshwari and the upper reaches of the Meghna, Gorai and Arial Khan, which is to be used for the definition of the programme under phase 2. This study will make a preliminary assessment of the morphological characteristics of the rivers, their shifting characteristics and expected response in qualitative terms as different components of the FAP are implemented."

The studies to be undertaken under the above description are under progress: a technical report regarding the hydrological studies was issued recently, and a technical report with the phase 1 morphological studies is expected to be issued by the end of 1993.

For the Phase 2 study the following is stated:

"Phase 2 studies

- (...) Undertake a programme of studies to investigate key characteristics of the behavior of the river system. The river studies would address aspects of the main river system that are essential for the planning of projects under the Flood Action Plan. (...). The studies will be undertaken in response both to the demands of ongoing FAP studies and to the possible effects of planned Action Plan projects on river regimes.
- (...) The following will give an indication of the possible studies that the Consultants may be requested to undertake :
- Further refinement of the rating curves and estimation of peak flood flows at different flooding conditions.
 - Further refinement of the profiles of the water surfaces at different discharges for the main river at different times of the year as well as at different stages of implementation of various components of FAP.
 - quantitative assessment and evaluation of river response with respect to implementation of various FAP projects.
 - behaviour at the confluence of the Ganges and the Brahmaputra and the effect on the outlet of the Hurasagar.
 - the characteristics of overland flow during flood stages.
 - resistance and bed forms at various times of the year."

In this report the above list is reviewed and updated based on the results of the phase 1 studies and other input.

1.4 FAP 24 in relation to other developments in Bangladesh

The Terms of Reference for FAP 24 were drafted already some years ago, and since then different developments have taken place that may have a bearing on the selection of study topics. First of all there are experiences and insights gained during the execution of FAP 24 phase 1. Besides that there are the developments in several other projects which have been carried out over the last years (within the frame-work of the FAP), and some institutional developments. Hereafter some comments are made regarding these developments and their impact on the selection of the study components is indicated.

Projects which are related to FAP 24 are FAP 1, FAP 3, FAP 3.1, FAP 9B,

FAP 19, FAP 21/22, and FAP 25. Under the FAP 1 through FAP 21/22 projects several aspects of the main rivers in Bangladesh were studied, and the insight into the main river system has increased. At the same time, however, it has become more clear that answers to some fundamental questions are missing, answers that are urgently needed for drafting an appropriate Flood Action Plan, aiming at sustainable development of the country.

Under FAP 25 the CAT mission is operating. Over the last year this CAT mission has raised a number of questions related to the morphology of the main river system, and it was proposed to incorporate in FAP 25 a component dealing with the overall impact of the FAP on the main river system. As indicated in Section 1.3, however, this impact assessment is included in the FAP 24 Terms of Reference, and hence in principle there is no need for an additional study. As will become apparent from this report the number of manmonths available for the present study is too limited to allow for a major improvement of the understanding of the main river system and its response to measures proposed under the FAP. Hence it is agreed that additional funding is required to strengthen the present effort to increase the understanding of the morphological characteristics of the main rivers in Bangladesh, their shifting behaviour and their response to any imposed river training works. For more details see Chapter 5 of this report.

1.5 Methodology used

Here a summary is given of the methodology used to determine the study topics for phase 2.

During the preparation of their proposal Consultants had already prepared a tentative list of study topics based on the requirements of the project and Consultants' extensive experience with the rivers in Bangladesh. This tentative list was slightly extended further on the basis of recent studies in which Consultants was involved, and upon screening recent reports prepared by other Consultants.

This list was sent to the different FAP projects who could be interested in additional studies, notably FAP1 through FAP6, FAP16, FAP17, FAP18, FAP20, FAP21/22 and FAP25, with the request to reflect on these topics. Next most of the Team Leaders of the FAP projects and also SWMC were interviewed regarding their ideas about the key problems, the possible study topics and related surveys needed for these topics. Some of the results of these interviews were already presented in the 1st Interim Report.

Also FPCO and its Project Adviser were interviewed formally and the same holds for the local and expatriate members of the Panel of Experts of FPCO.

Based on the results of these discussions on the one hand, and Consultants own experience in a number of projects in Bangladesh and the experience obtained during the phase 1 studies on the other hand, a tentative ranking of the possible study topics was made. Next estimates were made of the manpower input needed for the various study topics, and this was compared with the available manmonths for studies.

This resulted in the "tentatively selected" study topics, the results of which were felt to be urgently required and which could be tackled with the manmonths available. In addition various Universities and other institutions were approached and where possible preliminary arrangements were made as to their possible input into phase 2 of the studies. Finally a tentative time schedule was prepared, taking into account the requirements from the study component of the project.

It should be stressed here that no manmonths were held in reserve for future studies. This implies that in further stages of the project (see also Section 1.6) some updating may have as consequence that study topics that have been selected in this report have to be removed from the list. The alternative, leaving some study topics not defined, was rejected. This was done in particular to prevent that later on no studies would have to be added and that surveys that would have been required for these lower ranked study topics would not have been done.

1.6 Need for updating

As has been stressed also in the ToR ("The first of these (studies) will be identified during the Preliminary phase of the project; others will be identified during the surveys and studies phase"), there is a need for regular updating the list of study topics. The first occasion will be after "an International Workshop at Dhaka on "Morphological characteristics of alluvial rivers and their behaviour with special reference to Bangladesh rivers" (that) will be organized at the end of phase 1 in order to provide useful input in finalizing the study programme" (quoted from the ToR). It is understood that this Workshop is planned for November of this year, where this study report will be reviewed.

Updating may also be needed during phase 2 of the report. During this phase results of both surveys and studies will become available. These results may indicate that it is preferable to change some of the study topics, or to adjust the manpower estimates required. In appropriate cases adjustments will be proposed by Consultants.

1.7 Structure of the report

This report aims at determining the study topics for phase 2. This should be based on an assessment of the characteristics of the main rivers in Bangladesh and key problems in (1) understanding their behaviour and future developments and (2) the assessment of the response of the river system to the different components of the FAP.

It is essential to discuss the possible study topics versus the general background of processes in rivers, which are characterized by (1) the river as a system with independent and dependent variables, (2) a delayed response to changes in the independent variables, and (3) both 1, 2 and 3-dimensional processes playing a role. The general framework is sketched in Chapter 2.

Considering the objectives of the present report, in Chapter 3 of this report an overview of the key characteristics of the main rivers in Bangladesh is given. Chapter 4 provides a review of different FAP components that prepared plans that may have an impact on the river system, which will have to be addressed by FAP 24, or of components that could cooperate with FAP 24 in reaching its objectives. The need to solve the presently experienced problems, caused by flooding, erosion and siltation together with the requirement to assess the response of the river system to the various FAP proposals leads to a number of key problems to be addressed under the FAP 24 project. These are described in Chapter 5.

From these key problems a list of possible study topics is derived (in Chapter 6), according to the procedure described in Section 1.5. In Chapter 7 it is explored to what extent some of the research needed can be done by various Universities and other interested parties. In Chapter 8 the tentative selection of the study topics is described. The time and staffing schedules required for the implementation of the selected study topics are presented in Chapter 9.

Finally in Chapter 10 the implications for the FAP 24 survey programme are discussed in order to come to a work programme integrating studies and surveys.

2. Frame-work for analysis

2.1 Introduction

This Chapter sets the scene for the subsequent Chapters by describing in general terms the specific characteristics of rivers.

Key issues for this description are a systems approach to rivers as typical input-output-systems, dynamic equilibrium (long-time equilibrium with short term fluctuations imposed on it), adaptation of a river system to changes in its independent inputs and continuous changes of the river characteristics in time as a result of discharge variation. Models of the system are to be used to improve the understanding of these river characteristics and to assess possible impacts of natural and human interventions. A clarification is given on: the aim of modelling, types of models, deterministic, stochastic and statistical approaches to the description of the river behaviour, 1- and 2-d approaches, and either channel or bar approach for different types of rivers. All these aspects are covered in this Chapter in general terms.

In the subsequent Chapters the conditions in the main river system in Bangladesh are discussed within this frame-work and study items are proposed keeping this frame-work of analysis as a basis for identifying research needs.

2.2 River characteristics

2.2.1 Systems approach

Rivers are dynamic systems. Here as frame-work for analysis of the main river system in Bangladesh, typically an input-output-system is used. An input-output system is a system where the output (read river characteristics) are completely determined by the inputs (read basin characteristics and human interference).

Every river can be described as a system that is responding to a number of independent inputs, the river characteristics being the resulting dependent outputs. For the subsequent discussion of the input and output parameters in a river basin reference is made to Figure 2-1, where these parameters are indicated schematically. A difference is made between the independent variables on catchment level, and the independent variables in a certain river reach.



2.2.2 Independent and dependent variables in a river system

On a very generalized level the independent inputs on the **catchment level** are the climate and the geology of the basin. The climate determines the (average) precipitation and the (average) temperature. The geological history is responsible for the rocks that in the present era are subject to weathering and hence ultimately the quantities and characteristics of the sediment that has to be transported by the river draining the catchment. In addition the geological history is determining the level differences in the catchment, and hence the energy available in the river system.

Geology and climate, however, do not in a straightforward way determine the discharges and the sediment transport rates in a river system. The picture is complicated by the role of the vegetation and the weathering processes.

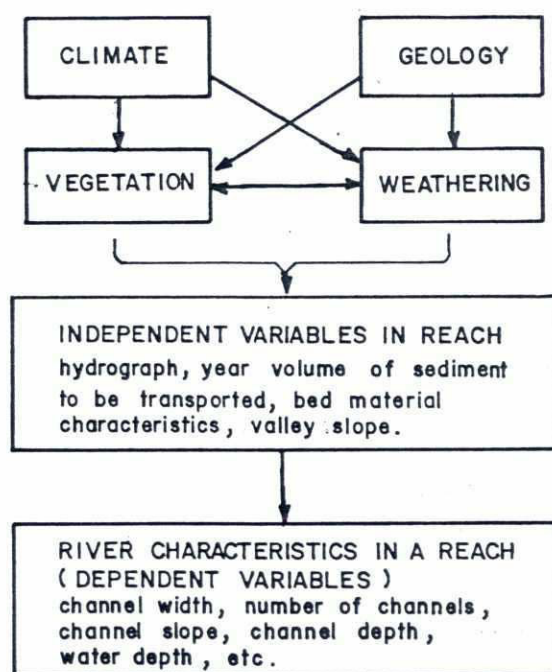


Figure 2.1 Input and output parameters in a river basin
(adapted from Morisawa, 1985)

Vegetation is largely influenced by on the one hand the climate (generally high precipitation rates and moderate temperatures are favourable for the development of vegetation), but also the geology is

important. The geology, in combination with the climate, determines the rate of weathering and this, again, has a significant influence on the growth of the vegetative cover. For more extensive discussions regarding the close interaction between geology, climate, vegetative cover and weathering reference is made to handbooks like Morisawa (1985), Richards (1987), etc.

The above close interaction, as illustrated in Figure 2.1, yields the independent inputs for the **river reach level**. In a particular river reach the inputs are:

- the discharge hydrograph (Q in m^3/s as function of t),
- the volume of sediment that has to be transported through the river reach, on say an annual basis (V in m^3);
- the characteristics of the sediment, consisting of coarse sediments (usually transported as bed material load, both as bed load and as suspended load) and fine sediments (transported as wash load, always in suspension);
- the slope of the valley.

The following observations are made regarding these independent variables:

- o Each of them is different for different river reaches: e.g. a more downstream reach usually has to carry more sediment. Hence for all independent variables at the river reach level it holds that they are a function of the longitudinal coordinate x .
- o A differentiation is made between bed material load and wash load. See also Figure 2.2, where the sediments transported in a river are distinguished as far as their origin and their mode of transport is concerned. In line with this the total volume of sediment that has to be transported is divided in V_b (bed material) and V_w (wash load).

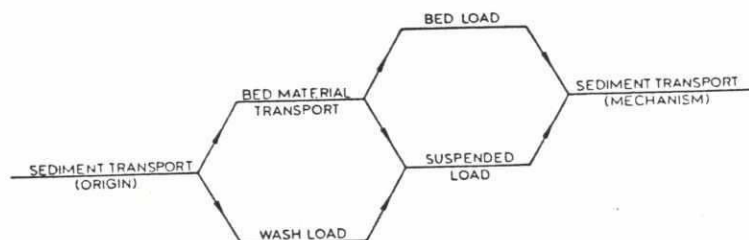


Figure 2.2 Different modes and origin of sediment transport (Jansen, 1979)

The dependent variables in a particular river reach are the river characteristics, which are listed hereafter. A distinction is made between the morphological characteristics and the hydraulic characteristics:

- o Dependent morphological characteristics:
 - number of channels n
 - average width of the channel(s) B_b , where the index b stands for bankfull conditions
 - sinuosity p of the river channel(s)
 - typical wave length of the curved channels L
 - total width B_t occupied by the river channel(s)
 - bankfull depth h_b of the river channel(s)
 - slope of the river i_b
- o Dependent hydraulic characteristics:
 - average water depth in the main channel;
 - "wet" width either in the main channel or including the floodplain;
 - inundation depth of the floodplain;
 - the roughness coefficient of the main channel and of the floodplains;
 - the average velocity.

It is obvious that the dependent hydraulic characteristics are directly affected by the morphological characteristics, while the overall morphological characteristics are affected by the hydraulic characteristics only on a longer time span.

The independent and dependent variables in a river system are illustrated in Figure 2.3.

Often the concept of the "graded river" (Mackin, 1948) is used. For such a river the independent variables have been constant over a very long period. Hence equilibrium exists, implying that there is no overall aggradation and/or degradation. On a yearly basis on the average all sediment is transported through the river reach considered. Rivers being graded are also said to be "in regime". It may be assumed that for graded rivers all dependent variables have a fairly constant value in a particular river reach. See also the Section 2.3 and 2.4.

Ideally all the dependent variables should be linked to the independent variables via relations well founded in river mechanics. The problem, however, is that for many of dependent variables no undisputed

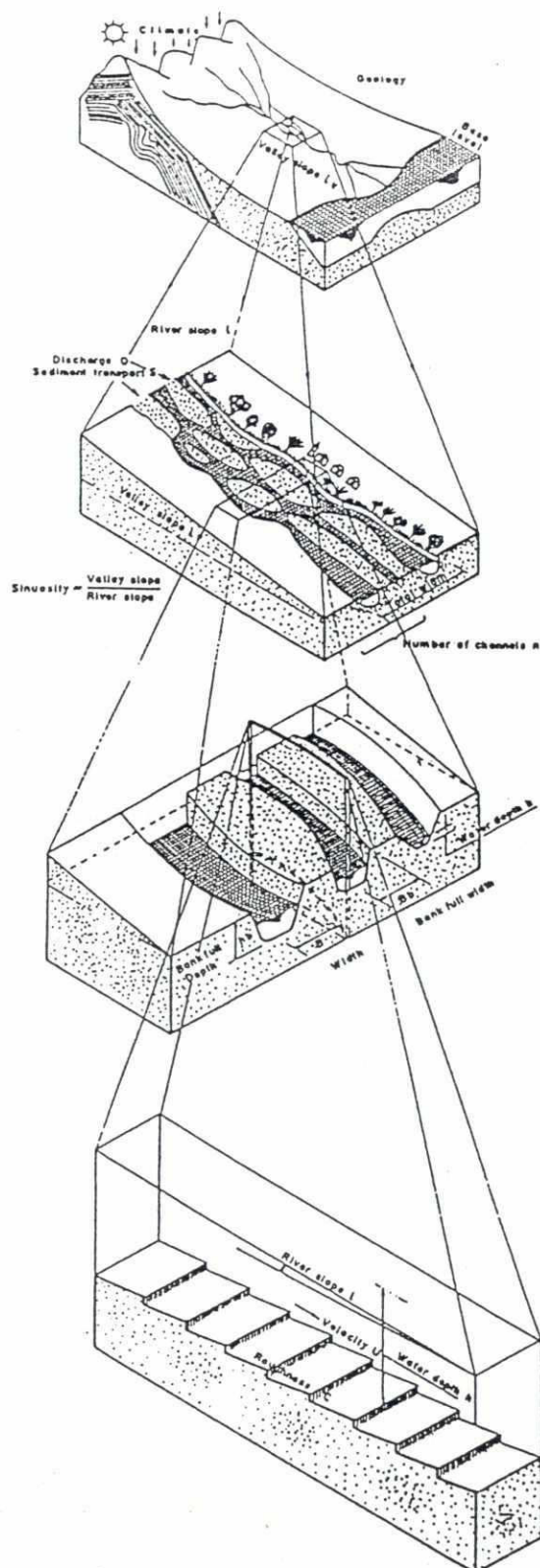


Figure 2.3 Independent and dependent variables in a river system.
(FAP 21/22 Final Report)

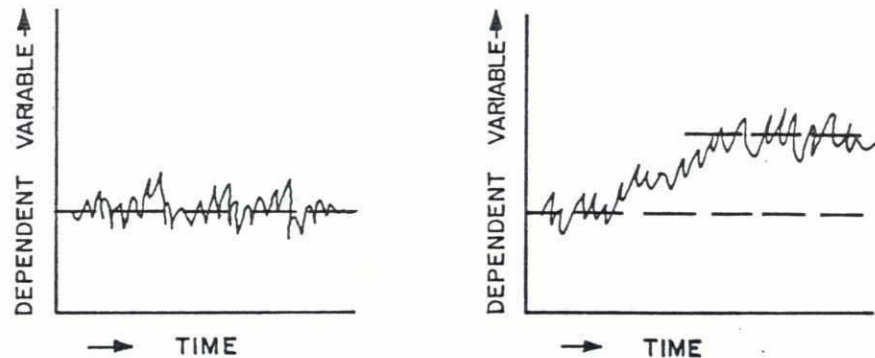
relations are available. Partly this is solved by the use of empirical relations, which may be different from one river to another, but when properly calibrated and verified can be of great help. For some other relations one has to rely on more speculative proposals like extremal hypotheses (e.g. "the river tends to maximise its sediment transport capability"). A state-of-the-art review of methods in use is provided in the Final Report of FAP 22 (Volume 2, Annex 1, Chapter 7). Annex 1 provides a complete set of equations, partly "sound", partly empirical and partly more speculative ones, that were used for impact assessment under FAP 22. It allows to determine the dependent variables. Also the impact of human interventions can be assessed using this frame-work. It provides insight into which relations have to be improved to arrive at better assessment of the physical impact of human interventions like FAP.

2.2.3 Dynamic equilibrium

In the previous section river characteristics like braiding index, river width, roughness, etc. are described as if they are constants. This, however, is definitely not the case. Even for a river system for which the independent variables have been constant over a very long time, still variations are taking place constantly. This is caused by two reasons.

First of all the discharge in the river is not constant but it is usually varying in time. This means that, even if the morphological characteristics do not change significantly over a short period, the hydraulic variables may change rapidly as a reaction to the changes in discharge in time.

Secondly also the morphological characteristics are changing in time. This type of changes can be distinguished in (1) a direct response to variation in discharge, and (2) processes that continue in time and can be regarded as the integrated effect of the discharge hydrograph. An example of the first group are changes in channel dimensions due to the effect of major floods. Dramatic examples are given in Graf (1987) for ephemeral rivers, but similar behaviour is present in perennial rivers. The second group is related to processes like outer bend erosion and cutoffs. Outer bend erosion tends to increase the length of the river and hence increases its sinuosity. Cutoffs in meandering rivers reduce the length of the river, and hence result in a reduction of the sinuosity. Hence 'the' sinuosity of a river does not exist and only an average sinuosity can be defined.



(a) Dynamic equilibrium (b) Adaptation to new (dynamic) equilibrium

Figure 2.4 Behaviour of river characteristics in time

In other words: a real equilibrium does not occur in rivers, and it is better to speak of a "**dynamic equilibrium**". This is indicated schematically in Figure 2.4(a), where the vertical axis stands for the river characteristic considered.

This indicates that many river characteristics are fluctuating around an average value, the average value being the value that is determined by the "average" value of the independent parameters.

Even the independent variables, however, will usually fluctuate around a certain value and this in itself may cause some fluctuation in the dependent variables. As an example an earthquake can be mentioned, which will induce many landslides and hence increase temporarily the input of sediment in a river. As a consequence the bed levels in the river may rise locally. The hump of sediment in the river will travel in downstream direction, and remaining noticeable over a long distance.

The above also has consequences for field measurements and their interpretation. In analyzing field data always it should be kept in mind that results of measurements may not correspond to equilibrium conditions. A good example of this are the regime equations derived by Klaassen et al (1988a) for the Jamuna River. In the derivation a substantial scatter was observed when plotting bankfull width versus

bankfull discharge. One explanation of this is that it might be due to the fact that many of the studied channels might have been either aggrading or degrading.

2.2.4 Adaptation to changes in independent variables

As all river characteristics depend on independent variables, any change in these independent variables will result in changes in the river characteristics. These changes will not take place immediately, but they will adjust in time to the new conditions.

In the interpretation of river behaviour it is often assumed that the independent variables have been constant for a long time. In reality this might not have been the case. Hence the observed river characteristics may be related to a transition phase rather than an equilibrium phase. This holds especially for the rivers in Bangladesh, being located in a tectonically speaking very active area.

As an example the Brahmaputra River can be cited. Between 1780 and 1830 the river shifted its course from its former Old Brahmaputra course to its present Jamuna course. Before 1780 the Brahmaputra River (in its Old Brahmaputra course) was clearly braided (as is shown in the famous Rennell maps). In 1830 the planform of the river (known from maps by Wilcox) was meandering. Nowadays the river is again braiding with a braiding index of 2 to 3. It seems however that the Northern reach is more braiding (higher braiding index) than the Southern reach (Klaassen et al, 1988b). This may well be due to the fact that the river is still "underway" in establishing a new equilibrium in its new course.

The same holds for the Upper Meghna River. Previously this river carried the combined discharges and sediment transport of the Brahmaputra and the upper reaches of the present Meghna River (the Kushiara and the Surma Rivers).

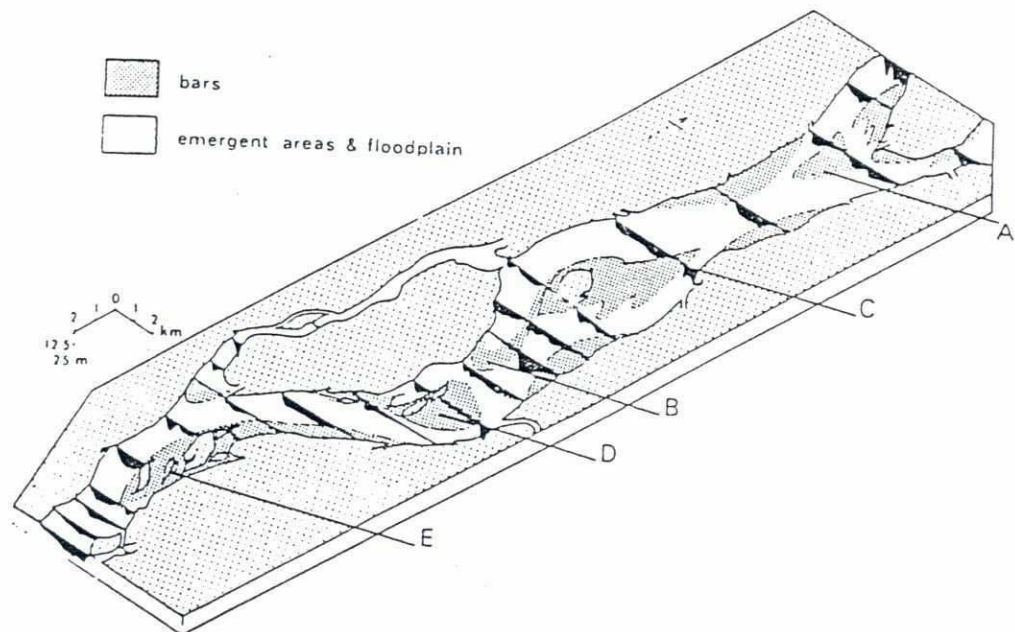
Nowadays it is fed mainly by these upper reaches with only a small input from the Old Brahmaputra. Considering the small quantities of sediment that have to be transported under the new conditions, the equilibrium state of the Upper Meghna will be a meandering river. The Upper Meghna River is adapting to its new conditions: it is transiting from a braided system to a more meandering one. This adaptation, however, is taking place very slowly, because nowadays the sediment transport in the Meghna River is very small (for more details see FAP 9B, Final Report, Volume B).

The adaptation towards a new equilibrium may take a substantial time. In the case of the Jamuna River the river is probably still adapting in its new course hence indicating that the adaptation time is several centuries. This is probably due to the fact that the adaptation takes place via bank erosion at selected reaches and that it is not a continuous process (see later). The adaptation of the Upper Meghna may take even longer: the transition to a meandering river takes place by deposition of sediment in the parallel channels and the deposition rate in the Upper Meghna appears to be fairly low. Hence the adaptation time varies per river considered and to have insight in this adaptation time is very important to conclude whether or not the characteristics of the river can be interpreted as fluctuating around an equilibrium (Figure 2.4(a)) or adaptation towards a new equilibrium. The latter is schematically illustrated in Figure 2.4(b). In this Figure it is also indicated that the adaptation takes place not at a continuous pace but that e.g. major flood events may demonstrate an accelerated drive towards the new (dynamic) equilibrium conditions.

2.2.5 Effect of variable discharges

One of the independent variables as identified in Section 2.2.2 is the hydrograph of a river. This should be understood as the average hydrograph of the river, may be obtained by averaging over a number of years. This average hydrograph, together with the other independent variables, determines the river characteristics like the number of channels and the width of the channels. In the geomorphological literature (see e.g. Bristow, 1987) these river variables are often referred to as the first and second order channels. The first order channel is then the river in totality, while the second order refers to the individual channels of the system.

In the river system there are however also higher order channels and phenomena. An example are the bars which very often can be observed in the 1st and 2nd order channels. These bars are divided in mid-channel bars, attached bars, etc. (see Figure 2.5). Also deep pools in outer bends, point bars in inner bends, crossings between two river bends, bars downstream of a confluencing tributary and deep pools downstream of confluences belong to these categories, although these are often referred to as fixed bars and pools. Figure 2.6 provides an overview of different types of bars and pools. Over the last decade many of these phenomena have been explained as instabilities (see e.g. Parker and Ikeda, 1989).



A first-order tributary bar, B second-order tributary bar, C first-order medial bar, D and E first-order point bars with subsidiary scroll bars and chute channels.

Figure 2.5 Bars of different orders in the Jamuna River (Bristow, 1987)

An interesting aspect is that (given the channel dimensions, the characteristics of the bed material, etc.), the higher order phenomena are very much affected by the discharge itself. There appears to be a close relationship between the discharge on the one hand and the dimensions of these pools and bars. Large discharges allow for deeper holes, and longer and higher bars. The discharge in a natural river, however, is usually changing. This means that in many river systems the bars and pools are never in equilibrium with the momentaneous discharge but that there is delayed adaptation.

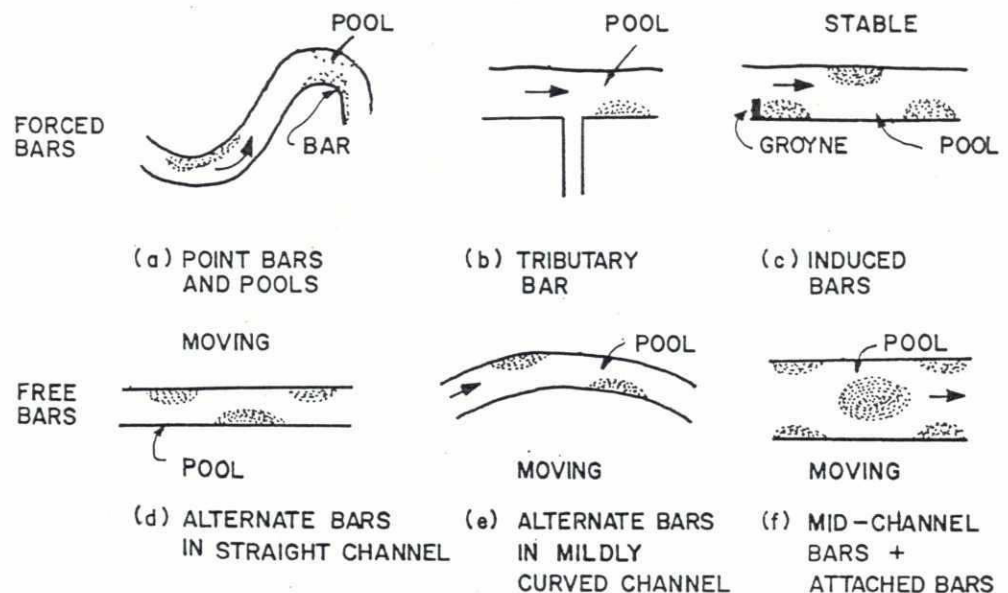


Figure 2.6 Overview of bars and pools in river systems

A similar phenomenon takes place at the still more detailed scale of the bedforms. The bedform dimensions are influenced by the local hydraulic conditions and these are affected by the discharge in the river channel. Also bedforms exhibit the typical delayed response behaviour, but here it is not certain whether the bedform dimensions are positively correlated with the discharge for all stages (see Klaassen et al, 1988b).

It is obvious that also this delayed response as discussed here should be taken into account when analyzing the river behaviour and the dimensions of phenomena like bars and bedforms, and observing of deep pools in rivers.

2.2.6 Human interventions

In the previous sections the behaviour of natural river systems was discussed and it was found that it can be considered as an input-output system with a delayed response time. Human interventions in the river system tend to affect both the independent and the dependent variables in the system. This is schematically shown in Figures 2.7 and 2.8. If the interference can be quantified, its effect can also be assessed if the response of the system is understood sufficiently.

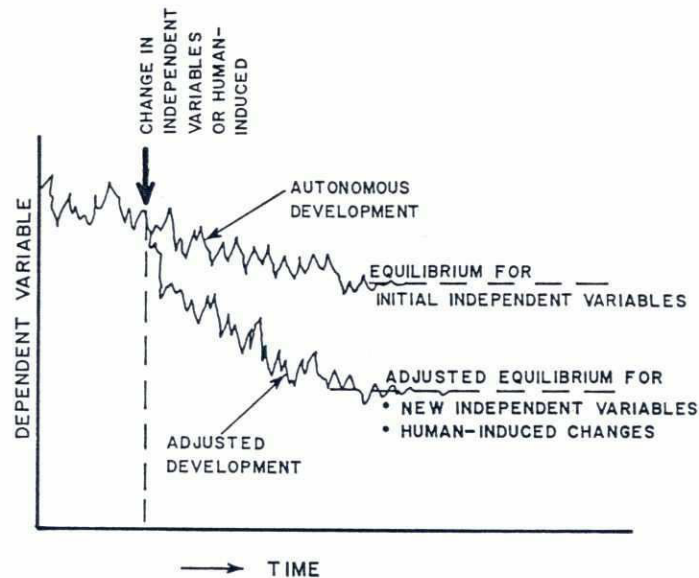


Figure 2.7 Autonomous and adjusted development.

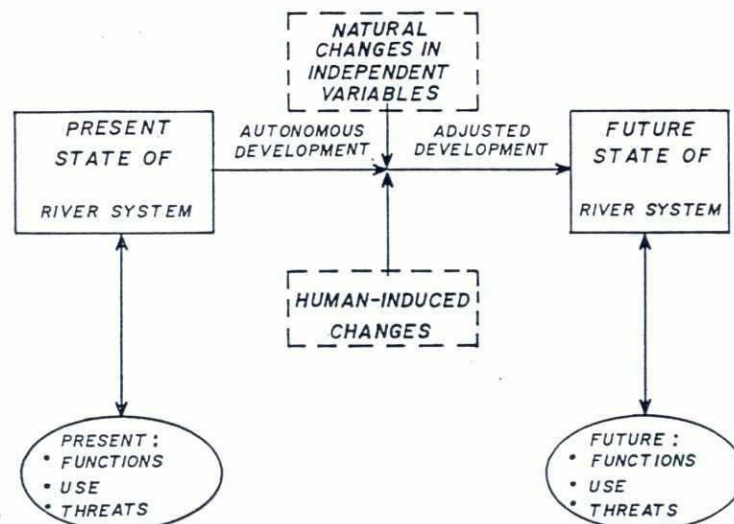


Figure 2.8 Influences on the development of a river system.

Human interference can be at different levels and can affect either the independent and/or the dependent variables. Affecting the climate and the geology is not (yet) done at a large scale. Vegetation has been affected on a large scale by deforestation and sometimes afforestation. Also the hydrograph of many rivers is very much affected by e.g. reservoirs, embankments, flood diversions, irrigation withdrawals, inter-basin transfers etc. The quantities of sediment to be carried is subject to human interference via reservoirs and siltation in them, mining, increased sedimentation due to embankments and less bank erosion by river training works. Also the dependent variables are affected very much by river training works.

If human intervention affects the dependent variables it usually results in a system with less degrees of freedom. As an example the Rhine River in Germany and The Netherlands can be cited. Due to river training works the number of channels has been reduced to 1, the width has been fixed and the sinuosity of the river has been stabilized. Hence the river system is now fully determined and its response can be predicted with fairly simple models (no change in sinuosity, constant width, etc.).

2.3 Modelling

2.3.1 Importance of modelling

The ultimate aim of the River Survey Project is to improve the understanding of the behaviour of the alluvial rivers in Bangladesh. In due time this improved understanding should lead to models in which this improved understanding is incorporated and which can be used to predict the response of the river system to e.g. natural developments and human interference. These models are not necessarily numerical models. Sometimes analytical models provide already a sufficiently detailed answer, while in other cases the conditions are so complicated that only physical models of sufficient large scale can provide the required answers.

Models are important for at least two reasons. One is the prediction of future behaviour. The second reason is the need for testing of understanding of river processes in an integrated way. It is not enough to derive relations for the width of a river or for the number of channels either empirical or more theoretical. It is essential to develop models in which the available information on the Bangladeshi rivers is included in a condensed way, and to study the behaviour of these models versus the actual behaviour of the rivers.

As an example the Old Brahmaputra can be considered. According to the present information this may be a "dying river". To study this it is possible to study the discharge and sediment distribution at its offtake. This however should be done in combination with considering the transport of sediment in the Old Brahmaputra itself. When it is shown that the observed reductions is in line with aggradation in the upstream reach, and that these bed level rises are in line with the supply of sediment at the offtake minus the transport of sediment in the river, it can be concluded that a fair understanding has been obtained in what is happening in the Old Brahmaputra River. In a second step possibilities can be studied to increase the discharge in the Old Brahmaputra and at the same time to reduce the ingress of sediment. This may result in proposals for how to re-activate this river again.

2.3.2 Types of models

Ultimately models should be based on physical processes and their mathematical description in (partial, non-linear differential) equations. For a number of reasons these models cannot be solved for general cases. For finding solutions integration over larger time and space scales is required, while often empirical relations are needed for "closing" and simplifications have to be made.

The types of models that can be used can be divided in:

- o analytical models
- o numerical models and
- o physical models

They are discussed hereafter briefly.

Analytical models are derived by (substantial) simplifications of the underlying mathematical description. Often it is required to linearize and also other simplifying assumptions as to initial and boundary conditions have to be made. Analytical "models" can also be derived on the basis of empiry, when observed behaviour is described in algebraic equations. Typical examples of analytical models as used in the Bangladeshi environment are the approach used in the Jamuna Bridge Study to assess time-dependent constriction scour (Klaassen & Struiksmā, 1988), and the empirical relation between confluence scour and the angle and depth of the confluencing channels (Klaassen & Vermeer, 1988).

Numerical models are based on differential equations, but to solve them, first of all substantial simplifications are needed (e.g. by assuming

that the width remains constant) and next these equations have to be transformed into difference equations. These are solved for the appropriate initial and boundary conditions. Numerical models have less limitations than analytical models, but (like analytical models) they are only as good as the mathematical equations describe the physical processes. Hence physical processes that are not yet sufficiently understood (like bank erosion and the process of widening or narrowing of channels) cannot yet be simulated adequately with mathematical models. In addition the numerical solution may introduce inaccuracies, but these are often minor compared to the effect of the processes not accounted for in the mathematical description. Examples of numerical models used in Bangladesh are e.g. the General Model of SWMC (a 1-d simulation of the water flow in the main river system in Bangladesh), the regional models, the (2-d) water flow and the (1-d and 2-d) morphological models used under the Jamuna Bridge Study, FAP 1 and FAP 21/22.

Scale models are reproductions of the real river at a (much) smaller scale. In principle all physical phenomena are active in these models, and in this respect they are better than mathematical models. Scale models, however, are subject to scale effects because it is not possible to reproduce all physical phenomena at the same scale. Examples of scale models used for problems in Bangladesh are the flow models in RRI, the scour models applied under the Jamuna Bridge Study and under FAP 1, FAP 9B and FAP 21/22, and models with movable bed and banks used under both the Jamuna Bridge Study and FAP 21/22.

Nowadays often a combination of analytical, numerical and scale models is used in combination with "sound engineering judgement" to find solutions for complicated cases like in the Jamuna River. See e.g. Figure 2.9 for the approach used under the Jamuna Bridge Study.

Increased understanding will lead to improved models that allow for safer and less expensive solutions for engineering problems. They can also assist in reducing maintenance costs.

2.3.3 One- and two-dimensional approaches

Models can be differentiated as to their complexity. The most simple models are 1-dimensional models where only depth-averaged and width-averaged characteristics are considered. More complicated models are either 2-d (depth averaged or width averaged) or fully 3-d models. As in-between case also 2-d models but with some 3-d aspects included exist (so-called quasi 3-d models), like depth averaged models with

spiral flow and suspended load verticals "added" to it.

What type of model can be used depends completely on the problem studied. If the problem to be tackled is again the "dying" of the Old Brahmaputra River, then it may be sufficient to use a 1-d model. Averaged cross-sections of the Old Brahmaputra should be used. Also part of the Brahmaputra River has to be included to include the influence of the aggradation in the Old Brahmaputra on the water-levels in the upstream reach. At the offtake of the Old Brahmaputra assumptions as to how much sediment is entering into it have to be incorporated in the model. These can be based on experience from elsewhere or from measurements e.g. under FAP 24. This approach is very useful for first estimates and also for investigating the internal consistency of available data and the present understanding.

If the interest is to simulate in detail the quantities of water and sediment entering into the Old Brahmaputra in the past and in the future, then a more complex 2-d or even 3-d model should be used. Such a model should allow for the simulation of the 2-d water flow, spiral flow, bed load movement and suspended load movements. Also the movement of bars through the system should probably be included.

2.3.4 Limitations and possibilities in modelling

A general problem with all models is that the processes in the rivers in Bangladesh are so complex, that they sometimes seem to be almost random. Therefore, it is important to reflect upon the predictability of these processes. Predictions with mathematical models are based on initial conditions, boundary conditions and the formulation of the predictive model. Physical models are also dependent on boundary and initial conditions. First it is discussed how all these factors put limits to the predictability and in the next section it is discussed how considerations of predictability lead to a choice of the approach to be used.

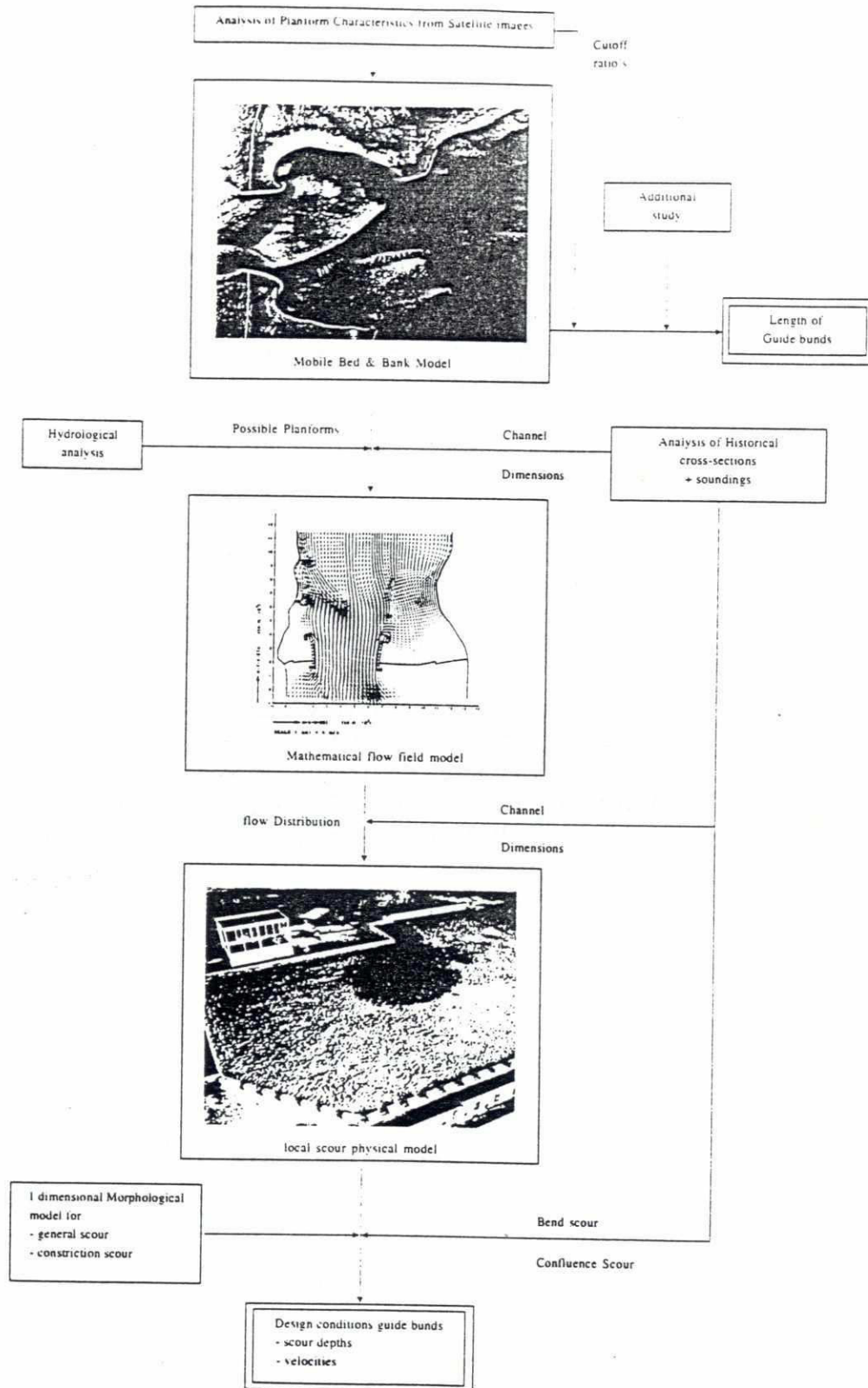


Figure 2.9 Approach Jamuna Bridge Study as example of the use of a combination of numerical and scale models.

The initial conditions are determined from observations, which usually have limited accuracy and do not provide complete information. In particular, the following problems can be mentioned:

- o The limited coverage of the field data (cross-sections, etc.)
- o Cross-sections are not available for every channel
- o Even when a cross-section is available for a certain channel, it is not necessarily representative because of the strong non-uniformity of the channels. Moreover most cross-sections are measured in the dry season only
- o Accuracy and different dates of topographic maps
- o The resolution (pixel size) of satellite images
- o Inundated banks cannot be distinguished from eroded banks on satellite images (hence, higher stages produce spurious bank erosion on the images)
- o No data on the morphological changes during a flood (only the net end result can be observed from cross-sections soundings or satellite images taken in the dry season)
- o Large scatter in available sediment transport data

The boundary conditions usually include the upstream input of water and sediment, the downstream water-levels and the properties of the surrounding terrain. Here, the problems are partly related to shortcomings in observations. The very detailed data to be collected as part of the FAP 24 river survey will to some extent alleviate these problems. In particular

- the repeated detailed surveys will make it possible to define accurate initial conditions, and to detect the changes taking place during the monsoon period
- the detailed 3D flow field obtained from the ADCP measurements will provide an excellent basis for calibration of numerical and physical models

Problems also arise because the boundary conditions are affected by complex dynamical systems with their own limited predictability, in particular by meteorology and geology. The meteorological processes determine the discharges. As long-term meteorological predictions are not possible, discharges must be treated as stochastic inputs. The planform changes are very sensitive to the discharges. Magnitude and duration of a flood determine the travel distances of wandering bars during one year, and hence whether or not such a bar arrives at a bifurcation. The arrival at a bifurcation may induce the rapid silting up of one of the bifurcated channels, which would have remained open otherwise. This represents one of the main thresholds in the system.

Another influence of meteorology is that, on larger time scales, climate changes may affect the downstream boundary through sea level rise. The influence of tectonics, both locally and via earthquakes, is also fairly unpredictable.

Bangladesh lies in one of the most active tectonic zones of the world (Figure 8.2 and Coleman, 1969) and the influence of tectonics on the rivers of Bangladesh is unusually high (Baker, 1986). It is generally recognized that major avulsions are controlled by tectonic movements (e.g. Coleman, 1969), but there are indications that also the channel patterns within the present river course are influenced in this way. This might explain why channels in the river seem to have preferred certain courses. The influence of tectonics is currently also being studied on the basis of satellite images.

Predictions covering a long period are also made difficult by the possible occurrence of exceptional events. A major earthquake could completely alter the present-day trends and result in a completely new orientation of the river courses (cf Coleman, 1969).

Mathematical models are a strong tool when dealing with systems with stochastic input. When a mathematical model first is set-up and calibrated a large number of different scenarios can easily be tested. This opens the possibilities for carrying out sensitivity analysis on the boundary conditions (e.g. the discharge), and in this way determine a possible range (and even the associated probability) for the future development.

Theoretically, a feasible predictive model can be derived from fundamental laws for the motion of water and sediment by a formal integration over time and space. This is not a direct integration from a small to a large scale, but a series of integration steps to ever higher levels in a cascade of scales. Due to the non-linearity of the system, each step requires the introduction of empirical closure relationships. This implies that even 'theoretical' models become to a large extent empirical, and hence inaccurate.

Another problem is that models may be very sensitive to initial conditions, thus producing chaotic behaviour. Phillips (1992a and 1992b) discusses general arguments of why chaotic behaviour is likely to be very common in geomorphic systems. In river morphology this is still a hardly explored subject, but the sensitivity of channel abandonment to discharge as well as the non-periodicity of the meanders in the numerical simulations by Howard & Knutson (1984)

and Crosato (1990) do suggest chaos. Furbish (1991) explains explicitly that bend shape variations can be ascribed to the sensitive dependence of meander planforms on initial conditions and entrance conditions.

2.3.5 Deterministic, stochastic and statistical approaches

Different approaches to modelling are possible. Here three types are distinguished: deterministic, stochastic and statistical approaches.

A **deterministic approach** results in an (accurate) prediction of the development of a certain river characteristic in time. Such an approach is possible if there is a direct causal relationship between the determining factors and the item of interest and if there is no uncertainty in either boundary conditions, both external and internal ones. A **stochastic approach** has to be followed if stochastic processes are also of influence in the river behaviour. Initially this effect may be minor but gradually the effect of the stochastic boundary conditions and the internal stochastic processes may take over, allowing a prediction only with a limited accuracy. This accuracy reduces if the time span of the prediction becomes larger. A **statistical approach** is appropriate when the relationships are known only approximate and empirical relations are derived giving averages and standard deviations, but not dependent on the initial stage.

Considerations on predictability for the period of interest prescribe the approach to be used. Table 2.1 gives an overview. This is illustrated by discussing models for planform changes, where first meandering rivers are considered. The boundary conditions are the discharges and the properties of the surrounding terrain. The discharge hydrograph can be more or less predictable, for instance in rivers with regular monsoon flood waves, or to a large extent irregular and unpredictable.

Planform changes are very difficult to predict if the period is short. Banks erode by mass failure during discrete events when a critical stability criterion is exceeded. This does not happen uniformly along the whole bank, but each time in small zones only, seemingly at random. This means that the surrounding terrain properties are stochastic boundary conditions and that the only modelling approach possible is a stochastic one.

For intermediate periods and relatively regular discharge hydrographs, a good prediction of river meandering is possible. The modelling can be described as deterministic. However, the sensitivity of the model to initial and boundary conditions and the possible occurrence of cut-offs

make that the model should contain stochastic elements as well.

boundary conditions	model sensitivity to boundary conditions	duration of simulation period relative to characteristic time scale of morphological processes		
		short	intermediate	long
predictable	low	deterministic	deterministic	deterministic
	high	deterministic	deterministic / stochastic	statistical
unpredictable	low	stochastic	deterministic for time averages	statistical
	high	stochastic	deterministic / stochastic	statistical

Table 2.1 Selection of type of model to be used

For longer periods, the question whether a certain place at a certain time is attacked is determined by the statistical distribution of water and land over a long period. Hence a statistical model can be applied, in which the spatial distribution of frequencies of water occurrence reflects patterns of soil properties, geology, terrain elevation and local human interference. This approach was used for determining the design conditions for a bridge over the Jamuna River (with an economic life time of 50 years and the river completely changing its planform in 5 to 10 years) (Klaassen, 1992).

The above also hold for the choice of a model for planform prediction for a braided river like the Jamuna River. For intermediate simulation periods (one to three years), however, the greater complexity and the greater importance of thresholds cause the stochastic elements to be more important here than for meandering rivers.

Similar considerations are valid for other types of models.

2.3.6 Channel and bar approach

If the interest is in the prediction of planform changes in braided and meandering rivers, principally two types of approaches are possible for the description of the processes involved. One is related to a "channel

approach" and the other one related to a "bar approach" (see Figure 2.10).

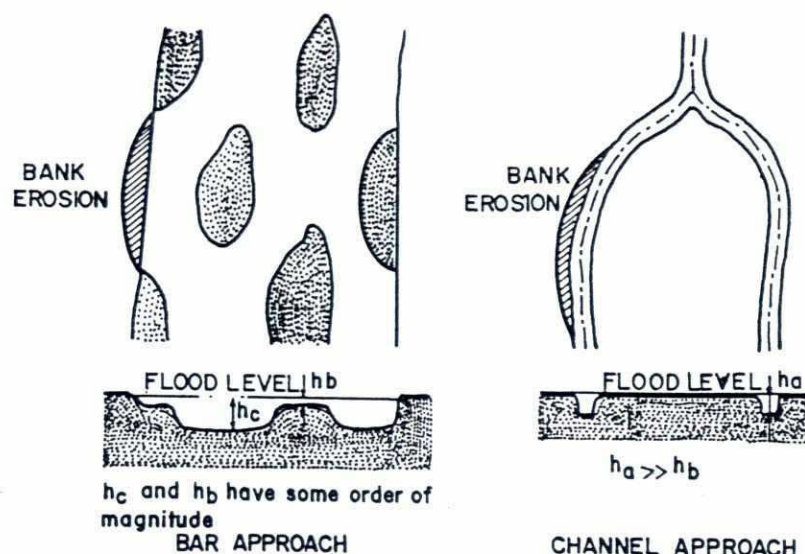


Figure 2.10 Channel approach and bar approach

The channel approach can be used for both meandering and braided rivers. In the most complicated case of a braided river, the planform patterns are schematized as a network of migrating bends, interconnected at bifurcations and confluences that are also migrating. Within this network, new channels can be created and existing channels can be abandoned. Meandering rivers are schematized similarly, although bifurcations and confluences only appear when a cutoff occurs.

The bar approach is typical for braided rivers. The pattern changes are supposed to be determined primarily by changes of a submerged bed topography consisting of attached and, for wider channels, mid-channel bars travelling through the river (see the Figures 2.5 and 2.6). These bars cause local constrictions and this may result in local bank erosion. The bar approach seems more appropriate when a braided river is in full flood with substantial sediment movement over the submerged bars. During lower stages when the bars are not submerged any more, also here the channel approach appears to be more appropriate for the prediction of planform changes (Klaassen et al, 1993).

When discussing possible study topics a differentiation can be made as to topics related to the bar approach and topics related to the channel approach.

3. Key characteristics of the main river system (of Bangladesh)

3.1 General

In this chapter the key characteristics of the main river system are discussed, as far as they are known on the basis of the data available until now. This means that it is a state-of-the-art review, meant to be updated in due time by new findings under the FAP 24 project and from other ongoing and future investigations. The present review intends to provide a bench-mark description highlighting the present understanding but also the present lacks in understanding of the river system. Together with the insight needed to assess the impact of the different FAP projects on the main river system (the latter being discussed in Chapter 4) the observations in this chapter provide sufficient material to identify (in Chapter 5) key problems in the understanding of the behaviour of the system of main alluvial rivers in Bangladesh and its response to possible future FAP projects.

The present chapter is structured as follows. First the main river system in Bangladesh is described. Next the geological and historical setting is reviewed. Then the present behaviour of these main rivers is discussed, attempting to understand this behaviour as a response to changes in its independent boundary conditions. These main rivers are partly braided systems and partly meandering ones. In the same frame-work the behaviour of the distributaries, the rivers that branch off from the main rivers, is reviewed. The interaction between the different rivers is described in a next section, while subsequently the potential role of overland flow and resulting sedimentation in the floodplain of the rivers is discussed. Finally some ideas regarding the autonomous development of the main river system in Bangladesh and human-induced changes, are presented.

3.2 Main river system in Bangladesh

The main river system in Bangladesh consists of the lower reaches of the three large rivers that enter into the Bay of Bengal via Bangladesh, notably the Brahmaputra River, the Ganges River and the Meghna River. More specifically the following rivers belonging to the main river system in Bangladesh (see Figure 3.1) were indicated by the ToR to be considered:

- | | |
|----------------------------|------------------------------|
| o Brahmaputra/Jamuna River | o Old Brahmaputra River |
| o Ganges River | o Dhaleswari River |
| o Upper Meghna River | o Gorai River |
| o Padma River | o Dubaldia/Arial Khan Rivers |
| o Lower Meghna River | |

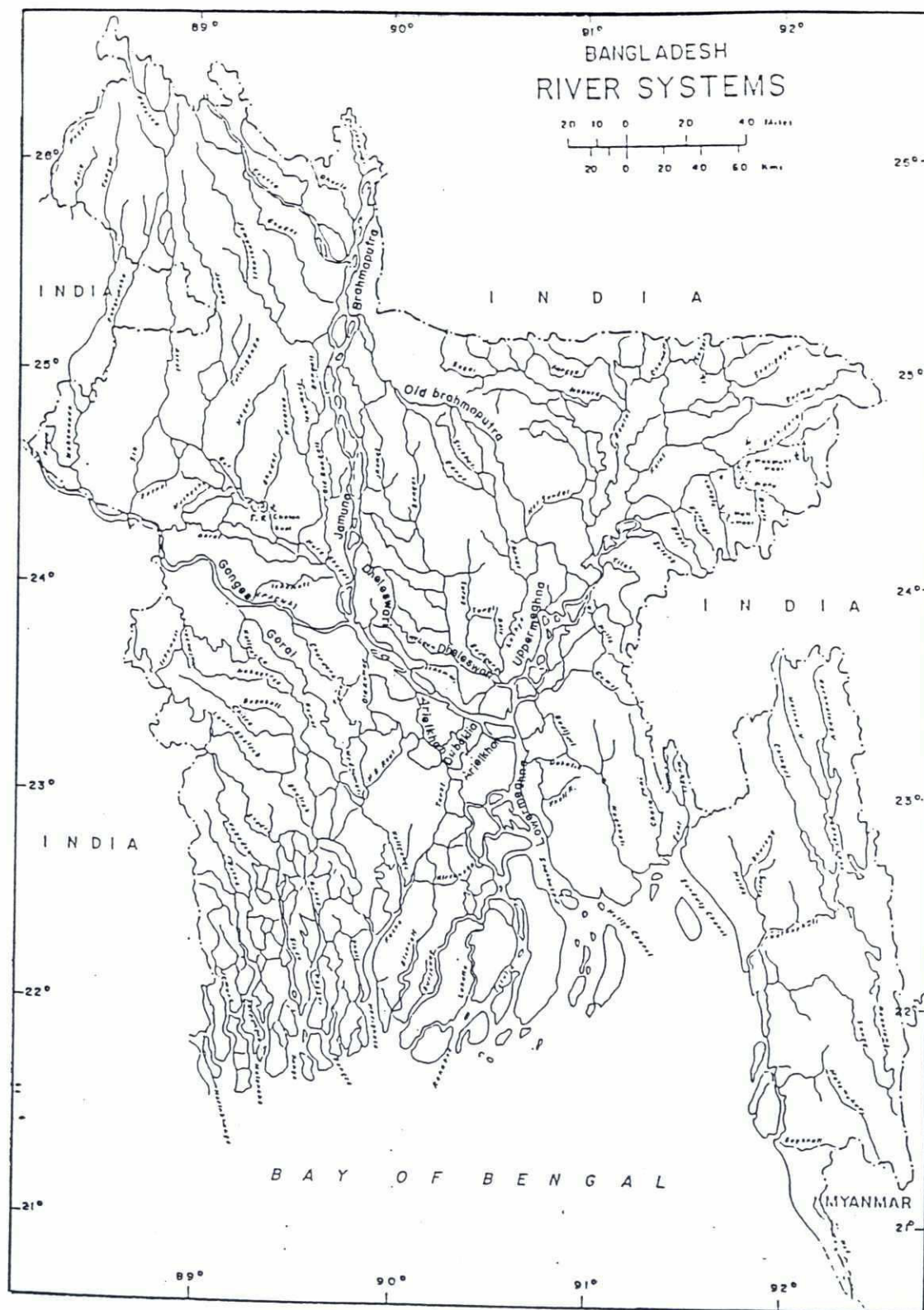


Figure 3.1 Main river system in Bangladesh

The catchment of the Brahmaputra River is shown in Figure 3.2, together with the catchments of both the Ganges river, (which joins the Jamuna River near Aricha) and the Upper Meghna River (which joins slightly upstream of Chandpur the Padma River, which is the continuation of the combined Jamuna/Ganges flow.

Hereafter the main river system is divided into:

- o main rivers, and
- o distributaries.

The distributaries branch off from the main rivers and hence depend for their discharge and sediment mainly on these main rivers. Apart from that they also have other functions such as local drainage of excess rainfall in the areas adjacent to the main rivers and local irrigation in other periods.

The main rivers are the first five rivers of the above listing (Brahmaputra/Jamuna River, Ganges River, Upper Meghna River, Padma River and Lower Meghna River) and the distributaries are the remaining four (Old Brahmaputra River, Dhaleswari River, Gorai River and the Dubaldia/Arial Khan Rivers). In addition the Padma and the Lower Meghna River are considered here as one river system, conform what was done by FAP 9B (HASKONING et al, 1990). The reasoning behind this is that the Lower Meghna is nowadays more the continuation of the Padma River than the lower reach of the Upper Meghna River. See also Section 3.3.

3.3 Geological and historical setting

Bangladesh consists primarily of Quaternary alluvial deposits. Geologically speaking the Bengal basin is bordered on the west and northwest by lower Jurassic trap rock in hills averaging 150-250 m above sea level. On the northeast lies Shillong Hills, which is predominantly composed of Eocene sand stones and Numilitic limestones. Elevations of the plateau approach 1400-1800 m above sea level. The eastern boundary is formed by the Tripura and Chittagong Hills. The southern boundary is formed by the Bay of Bengal.

According to Coleman (1969) the largest part of the basin is formed by Quaternary sediments deposited by the Ganges, the Brahmaputra and the Meghna rivers and their numerous tributaries and distributaries. In this region the relief is very low measuring a few tens of a feet. The Pleistocene alluvial terraces are restricted to four major regions. Coleman has shown their distribution in the following Figure 3.3.

Of the four areas, two flank the basin on the east and west and the other two lie within the basin. These latter two areas are known as the Barind and Madhupur

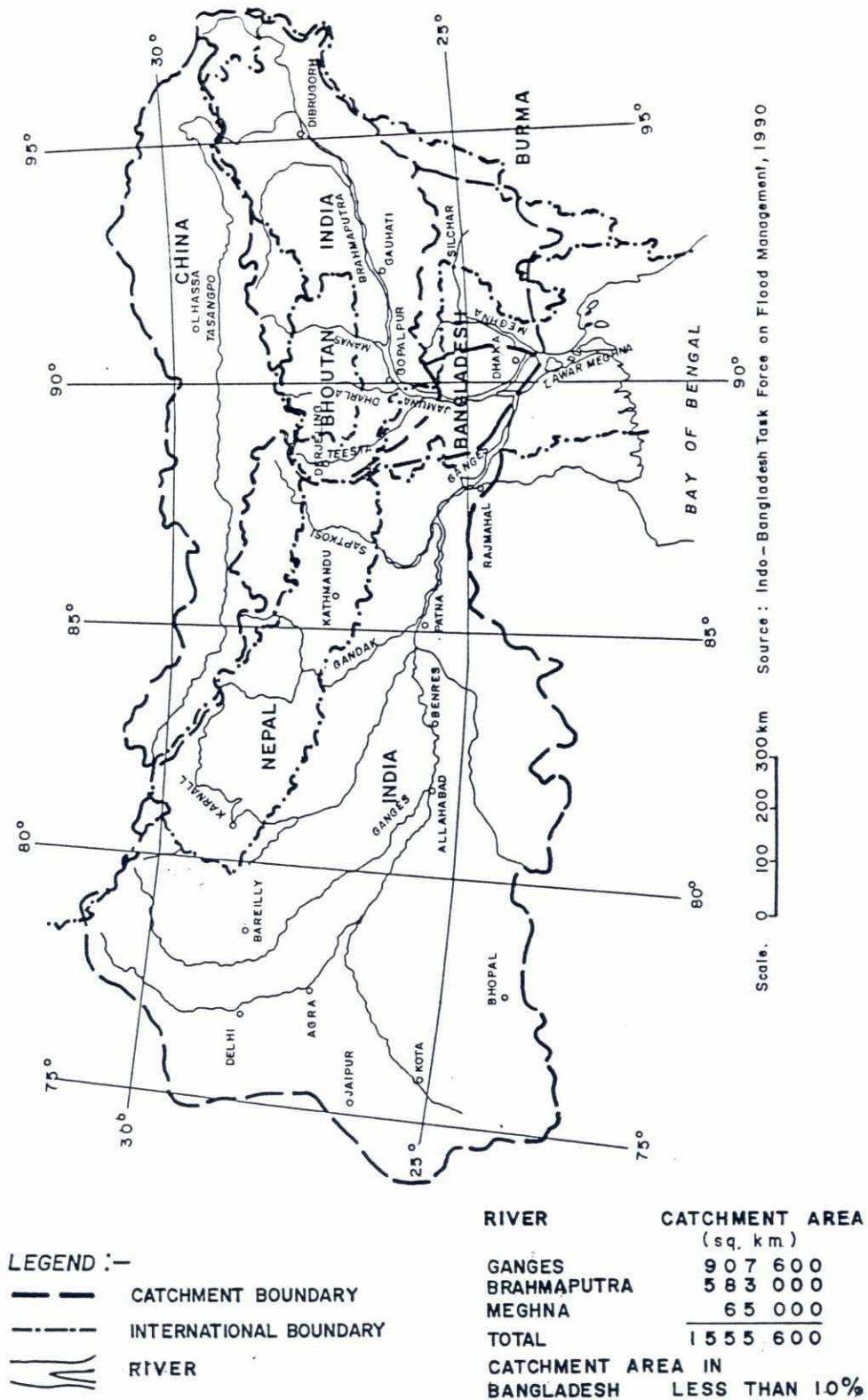


Figure 3.2 Brahmaputra, Ganges and Meghna river basins

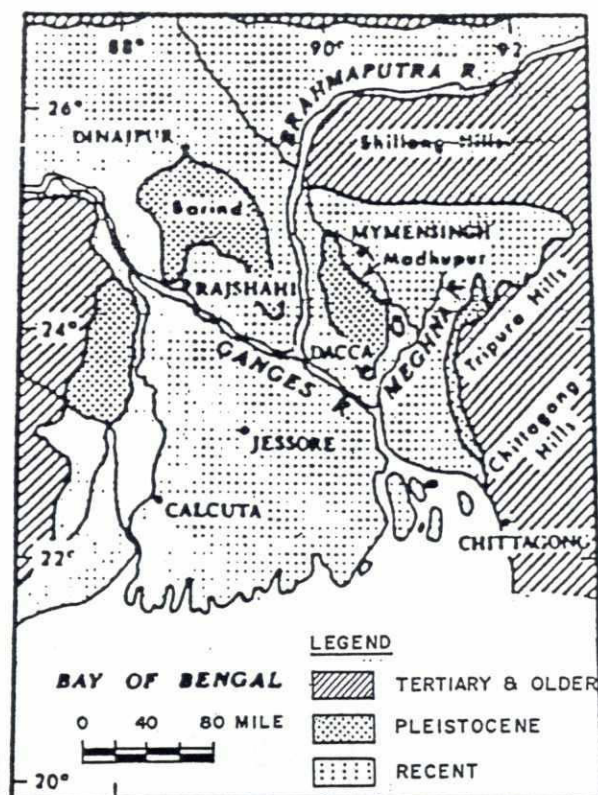


Figure 3.3 Generalised geological map of Bangladesh (Coleman, 1969)

jungle. The Pleistocene sediments were deposited as floodplain of the former Ganges-Brahmaputra river systems. The sediments are highly oxidized and are typically reddish-brown or tan. Because of their antiquity and long periods of exposure, they are characteristically more compacted and weathered than the more recent Holocene floodplain sediments. In many areas, the boundary separating the recent and pleistocene sediments is sharp and quite straight. These boundaries are the result of recent tectonic activity.

The remaining region of the Bengal basin consists predominantly of recent alluvial and deltaic sediments. In the upper valley (land above tidal inundation) these deposits are composed primarily of silts and sands; in the lower delta they are principally silts, clays, and peats. Because they were recently deposited, they contain a high water content, are commonly loosely compacted, and are generally grey. The shifting nature of the Ganges and the Brahmaputra rivers makes the geographic relationships of various sedimentary units highly complex.

According to the CBJET (1991) the Bengal basin is a tectonic basin that has undergone the co-action of two tectonic forces, notably the northward thrust

caused by the northward movement of Indian Plate and the vertical pressure by the weight of the deposits. The vertical pressure promotes subsidence as well as further sedimentation.

In Bangladesh the alluvial plain deposits are sorted in horizontal direction. The grain size gradually becomes smaller and the thickness of deposits gets larger in downstream direction going south eastwards. This can be observed in Figure 3.4. The conclusion can be that all rivers in Bangladesh are real alluvial rivers and that they are not limited in vertical erosion by the presence of any bed rock. Horizontal movements may be limited due to the presence of Pleistocene deposits.

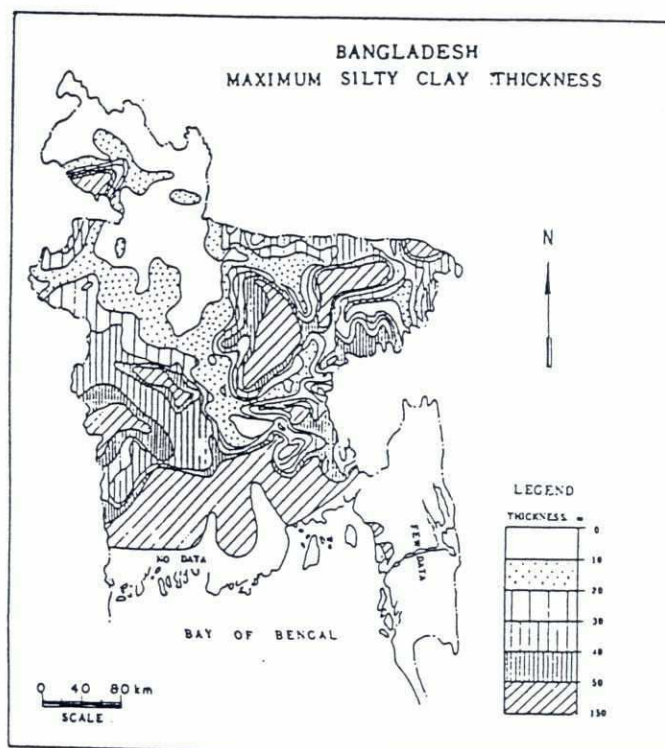


Figure 3.4 Thickness of recent alluvial deposits (CBJET, 1991)

In the recorded past substantial changes in the course of the main rivers in Bangladesh have taken place, as can be seen in Figure 3.5. The maps show that the Brahmaputra River had followed at least four different courses over the last 2000 years.

Rennell's map published in 1778 provides the first reliable information on the planform of the Brahmaputra River. It shows a braided river taking a south-easterly alignment after flowing past the Shillong hills in India and thereafter

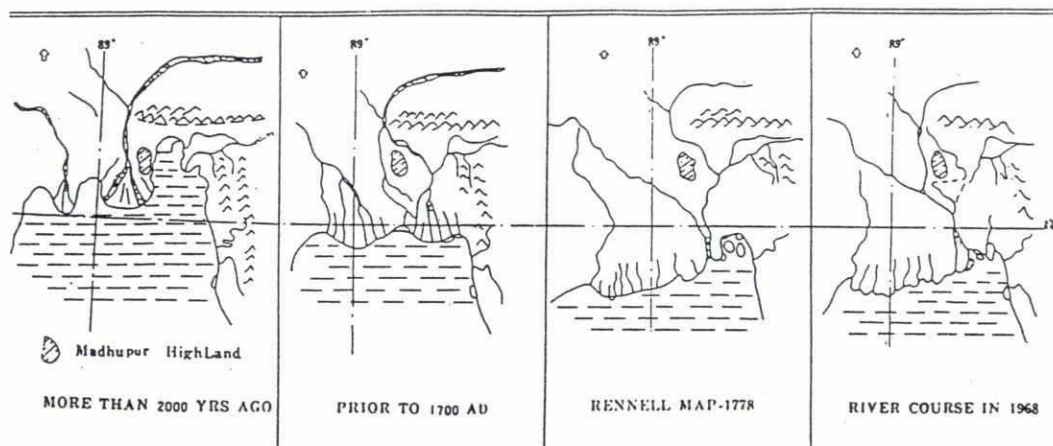


Figure 3.5 Main river courses in Bangladesh over the last 2000 years (Source: CBJET, 1991)

follows the eastern edge of the Madhupur tract. At that time the Upper Meghna River carried also the flow of the Brahmaputra River. The Ganges River occupied approximately the present Padma course and discharged into the Bay of Bengal via a river mouth separately from the Lower Meghna River. Over the previous centuries the Ganges River had gradually moved in eastern direction.

A map published in 1830 by Wilcox is considered to provide a reliable picture of the planform of the river a few years after its avulsion between 1780 to 1830 (FAP 1, Main Report). The Brahmaputra river channel has changed back to west of Madhupur high land and flowed along approximately the present course since 1830 (CBJET, 1991).

Quite different interpretations exist for the reason or period of avulsion of the Brahmaputra River from east to west of Madhupur highland prior to 1830. Though many historic documents relate to the time of this change in river course (La Touche, 1910), little agreement exists among them as to exact date and cause. In all probability the diversion of the Brahmaputra was gradual, as most major river diversions are. The changes in river course, however, stress the importance of tectonics in this part of the world.

The consequence of the shift is that the Brahmaputra now is occupying the present Jamuna course. It joins the Ganges River and continues as the Padma River. Hence the Old Brahmaputra River and also the Upper Meghna River carry substantially less water and sediment than they used to do. It seems reasonable to assume that these rivers are still in the process of adapting to these new

conditions. The same may be true for the Jamuna and Padma Rivers, as these carry much more water and sediment than they used to do before.

Hence all main rivers in Bangladesh are in a transition rather than in an equilibrium. Similarly also the distributaries are probably in transition as they are dependent upon the spill from the main rivers.

3.4 Main rivers

3.4.1 General

In the following Subsections the river characteristics of the four main rivers in Bangladesh are described. Subsequently the following rivers are reviewed:

- o Brahmaputra/Jamuna River
- o Ganges River
- o Upper Meghna River
- o Padma/Lower Meghna River

The following aspects are considered if and when sufficient data are available:

- o general aspects
- o hydrology
- o river characteristics
- o planform characteristics
- o shifting characteristics
- o bends, bank erosion, cutoffs and widening
- o mega-chars and attached chars
- o scour

3.4.2 Brahmaputra/Jamuna River system

General aspects

In this section a review is given of the morphological conditions in the Brahmaputra/Jamuna river system. It is possibly not really necessary to stress here that the Jamuna river is part of one of the largest river systems in the world and that its dimensions alone make it difficult to understand its behaviour and morphological changes. Also because the river is highly mobile due to its fine sediments and the large floods it is experiencing every year, its planform is changing completely in a few years only. Generally it can be stated that rivers of this magnitude and with these characteristics have hardly been studied in the past and therefore our

theoretical understanding is still fairly limited. Hence most information as available nowadays in the different project reports is in the form of mostly empirical relationships.

The first comprehensive description of the Jamuna river was given by Coleman (1969). Since then much more data on the river have been collected, partly by field measurements often under difficult circumstances, and, more recently, also via satellite images, which are more and more proving to be an indispensable tool for deepening the insight into the morphological processes in this largest braided sand bed river system in the world. In the period since 1986 much of these additionally collected informations has been brought together and studied in an integrated manner in the following projects:

- o Jamuna Bridge Study, Phases 1 and 2
- o Brahmaputra River Training Studies (FAP 1)
- o China-Bangladesh Joint Expert Team for training of the Brahmaputra River, and
- o Char Study (FAP 3.1)
- o River Bank Protection Pilot and AFPM Study (FAP 21/22)

Here only a summary of what is presently known on the Brahmaputra/-Jamuna river system can be presented. The emphasis is on highlighting the dynamics of the system. More information is provided in the reports of the above projects, notably in Annex 11 of the Final Report of FAP 21/22.

The river basin of the Brahmaputra/Jamuna River extends over China, Bhutan, Nepal, India and Bangladesh and it measures about 560,000 km². The length of the alluvial reach between the Indo-Chinese border and the confluence with the Ganges river is about 1,100 km. The length of the river in Bangladesh is about 240 km. The last major tributary joining the Brahmaputra in Bangladesh is the Teesta river. Other major tributaries draining the southern part of the Himalayas join the river more upstream.

Hydrology

The mean annual rainfall of some selected stations varies from 2,372 mm to 1,440 mm with a well defined seasonal variation. Table 3.1 gives the average pattern. The mean estimates represent the drainage characteristics of the Brahmaputra basin in Bangladesh; the monsoon season rainfall is significant and it is about 75% of the annual rainfall whereas the dry season rainfall is a small fraction of the annual rainfall.

Station	Mean annual rainfall (mm)	Mean rainfall June-September (mm)
Jamalpur (R-67)	2372	1723
Rangpur (R-206)	2215	1636
Bogra(R-6)	1771	1260
Nachol(R-190)	1440	1065
Pabna (R-25)	1522	1051

Table 3.1 Seasonal rainfall distribution on the Brahmaputra catchment area in Bangladesh

Maximum discharge of the Brahmaputra River at Bahadurabad is 100,244 m³/s whereas minimum and average flows are 2,427 m³/s and 20,177 m³/s respectively. Figure 3.6 shows that the average water surface slope is approximately 7.6 cm per km for the upper reach of the Jamuna River and 6.5 cm per km for the lower reach.

The variation of water-levels and discharges through the year for the Brahmaputra River at Bahadurabad are shown by means of frequency curves, where each frequency curve indicates the magnitude of the water-level/discharge for a selected specific probability of non-exceedence. Figure 3.7 illustrates that the water-level during the months of July, August and September are generally high. The lowest water-level generally occurs in February.

Figure 3.8 shows that the discharge starts increasing in April and the first peak flood generally occurs in June-July and is characterised by a rapid rise, the major peak occurs in August.

The maximum flood of the Jamuna River is generally earlier than the one in the Ganges River. The flows in these two rivers are not in phase.

River Characteristics

Here some of the characteristics of the Brahmaputra/Jamuna river system in Bangladesh are summarized in general terms, giving information on e.g. slope, width, particle size, sediment transport, etc. Other aspects of the river like braiding characteristics, the dynamics of the system, including bend development and char formation are discussed in subsequent paragraphs.

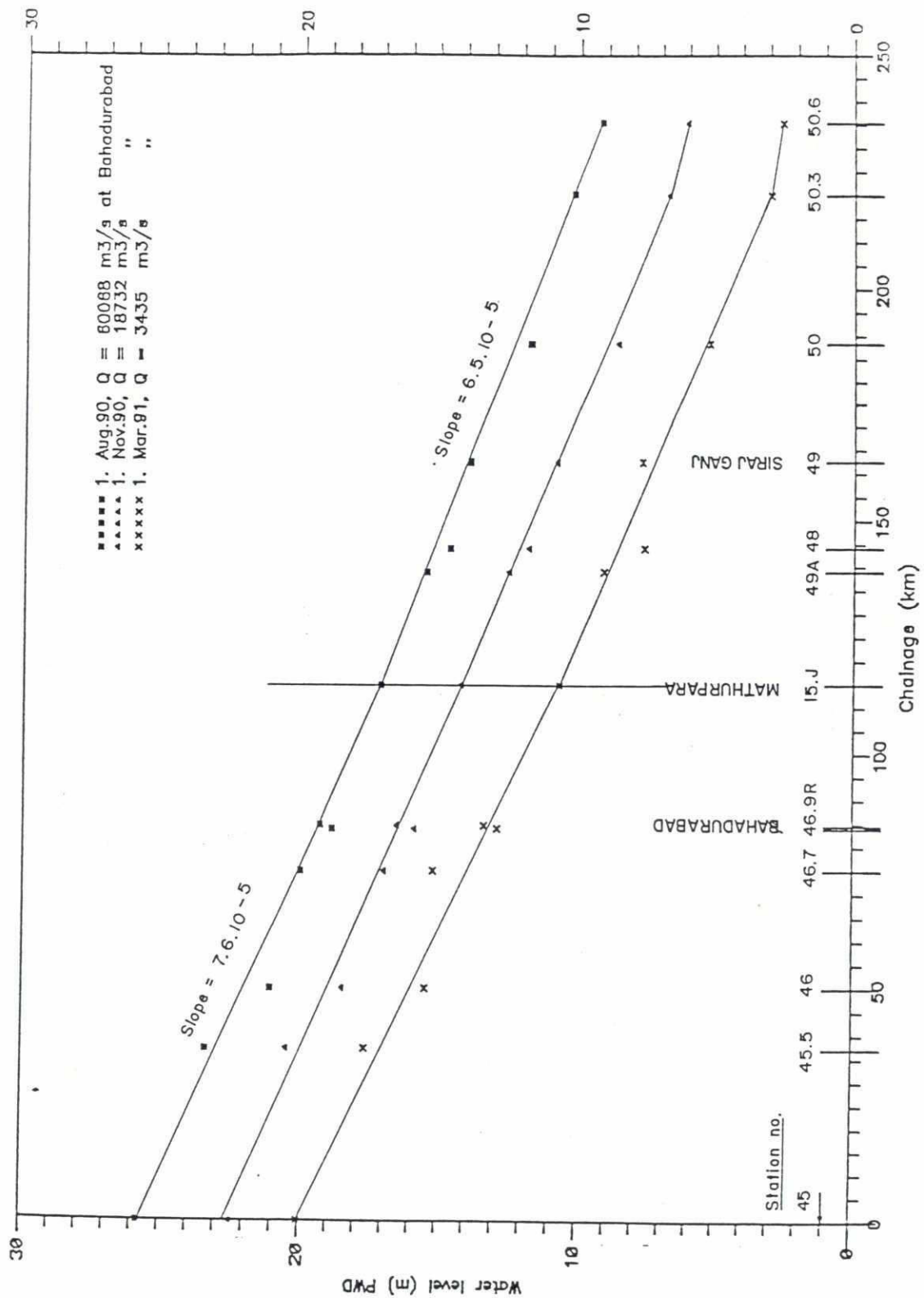


Figure 3.6 Jamuna River, water-level profiles

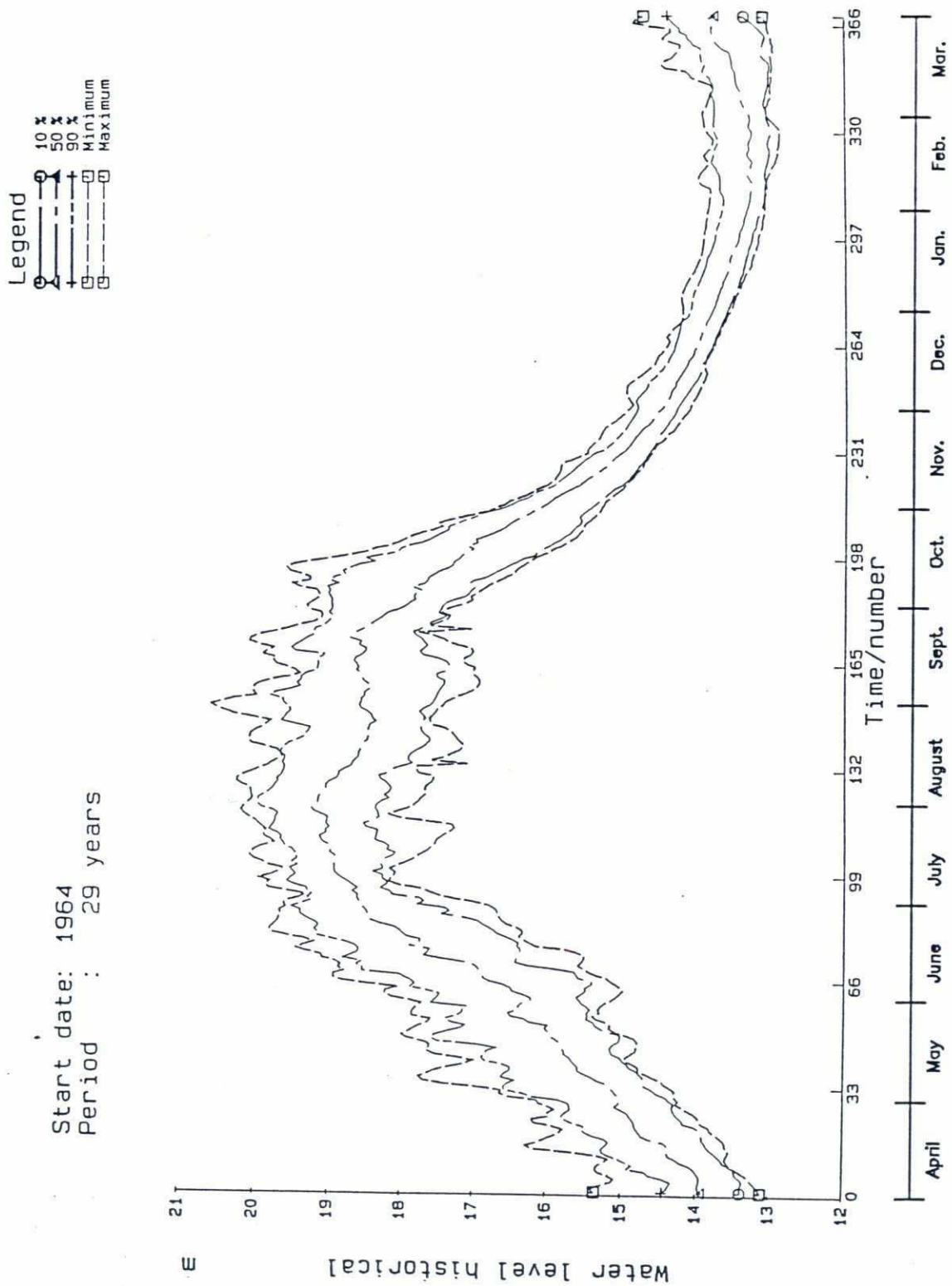


Figure 3.7 Bahadurabad, frequency curves for water-levels

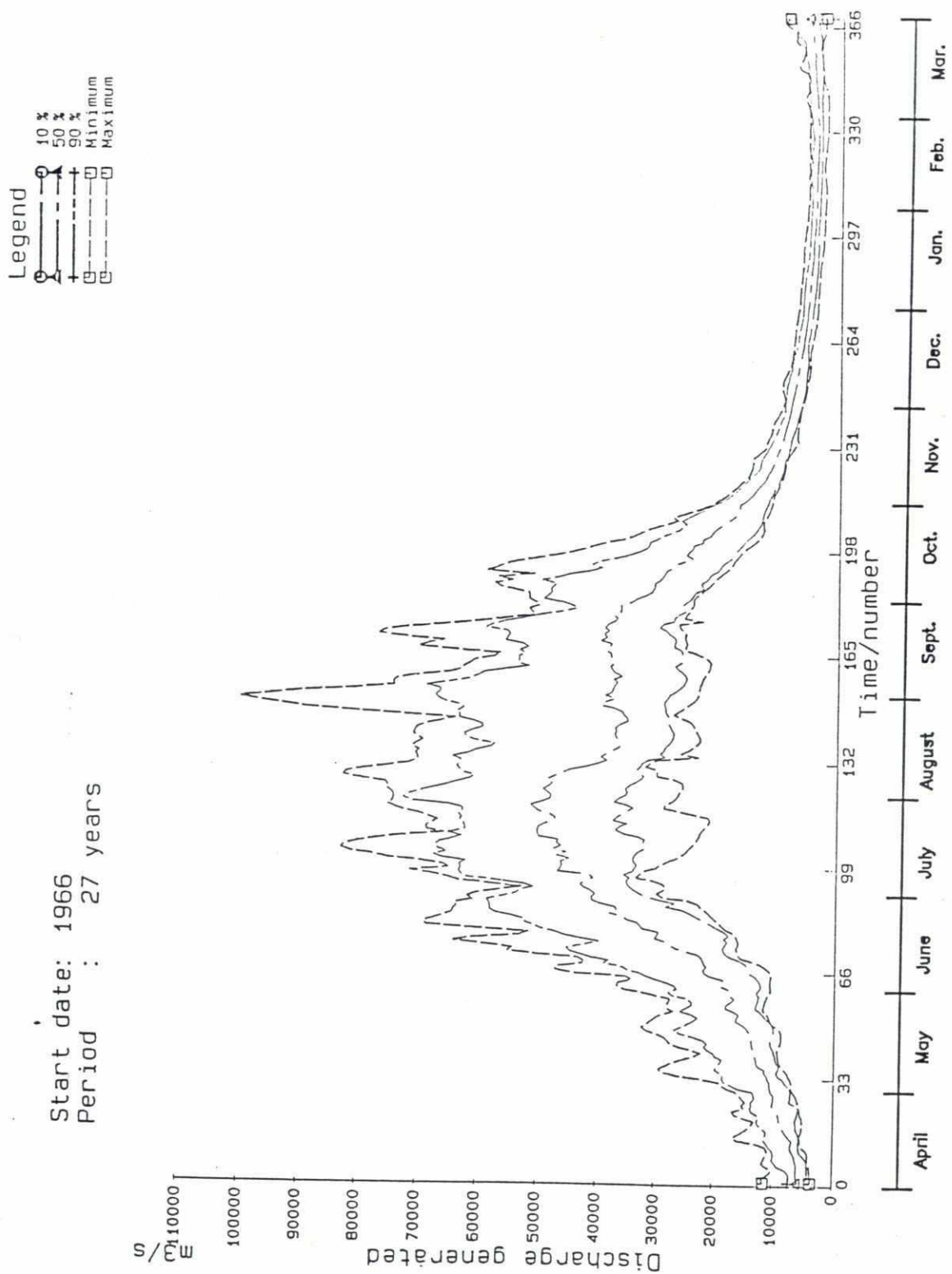


Figure 3.8 Bahadurabad, frequency curves for discharges

The valley slope of the river decreases in downstream direction. Near Bahadurabad it is about 8 cm per km, while near the confluence with the Ganges river it is about 6 cm per km, hence varying between 0.000085 and 0.00006. The bed material of the river is fine sand, with D_{50} varying between 0.22 mm at Chilmari and 0.165 mm near Aricha. The gradation is about 1.3, hence fairly uniform sediments. There is some vertical sorting also, the finer particles on the average being deposited at the higher char levels. According to an extensive sampling campaign carried out by FAP 1 (Halcrow, 1991), bank material seems to be quite uniform also and consists of fine sand too, the highest chars being covered by a layer of 1 to 2 m thickness of deposition with more clayey particles. The little variation in bank material composition in downstream direction is different from what was suggested by Coleman, notably that the existence of nodal points is due to old clayey deposits.

The Jamuna river is a braided system, with several parallel channels in each cross-section. The dimensions of these individual channels were studied in the Jamuna Bridge Study, Phase 2 (Klaassen and Vermeer, 1988), and it was found that in first approximation regime equations could be derived for these channels as well. The bankfull discharge of the Jamuna river near Bahadurabad is about 44,000 m³/s, and can be slightly smaller downstream from the offtake of the Dhaleswari river. The direction of the individual channels is varying between +90 and -90 degrees, the larger channels showing smaller deviations from the river axis (see Klaassen and Vermeer, 1988).

Considering the depth and the slope of the Jamuna river in view of the fine particle size, the so-called Shields parameter is quite high. This parameter characterizes the mobility of the sand (which in the Jamuna river is always moving, even during low flow conditions). High Shields numbers also cause the resistance of the flow to decrease. This is achieved through the bedforms that are present on the bed of the channels. Several types of bedforms have been identified (Coleman, 1969; Klaassen et al, 1988), but the sand waves are probably the most important one for the resistance to flow of the river bed. These sand waves have a length in the order of 100 m and a height of 0.1 to 0.2 times the water depth (and can hence reach heights of 5 m and more!). According to the investigations carried out in the flood season of 1987 (see Klaassen and Vermeer, 1988a) the lee-side of the bedforms is fairly gentle, which explains the high Chézy coefficients of 70 m^{0.5}/s and higher that have been observed. The sand waves move with a celerity of about 100 m/day during floods. During low flows their dimensions and their celerity will be less. Also the Chézy coefficient is less during low flow conditions.

Suspended sediment transport rates are being measured at Bahadurabad on a regular basis, although there is some doubt on the accuracy of the measurements, because of the direction of the flow and hence the sediment flux is not perpendicular to the cross-section. At Bahadurabad, with FAP 24, coarse (coarser than 63 microns) suspended sediment data are available for the period 1966-1970 and 1976-1988 and fine (finer than 63 microns) suspended sediment data are for the period 1967-1988. A closer analysis reveals that the data from the period 1966-70 suggest a significant (2-2.5 times) higher sediment transport than suggested by the 1976-1988. Analysis of these data will be presented in the Morphological Report of FAP 24. It is necessary to mention here that data for the period 1966-1970 gives reliable sediment balances for the Ganges-Padma-Brahmaputra system.

FAP 24 has derived equations for the coarse and fine suspended material load in the Brahmaputra which read as:

Coarse sediment:

$$S = 0.349 * Q^{1.42} \text{ for the period 1966-1970}$$

$$S = 0.393 * Q^{1.407} \text{ for the period 1976-1988}$$

Fine sediment:

$$S = 0.44 * Q^{1.46} \text{ for the period 1966-1970}$$

Where S is the transport rate of coarse suspended sediment in tons/day and Q is the water discharge in m³/s.

The average yearly coarse suspended sediment transport is approximately 200 million ton and fine suspended sediment transport is approximately 390 million ton.

Planform Characteristics

As stated above the Brahmaputra/Jamuna river is a braided system, implying that in one cross-section there are more channels. The number of channels is variable in space and in time. It appears that the number of channels in the upstream reaches is about 3 and in the downstream reaches often only 2 major channels are present which tend to behave as meandering channels.

Within FAP 21/22 it was investigated whether the number of channels is related to the total width of the river. This was done by plotting the number of channels versus the total width, both determined from satellite



images. The results are plotted in Figure 3.9. There indeed seems to be a relationship, but it cannot be determined whether the number of channels is a function of the total width or the other way around.

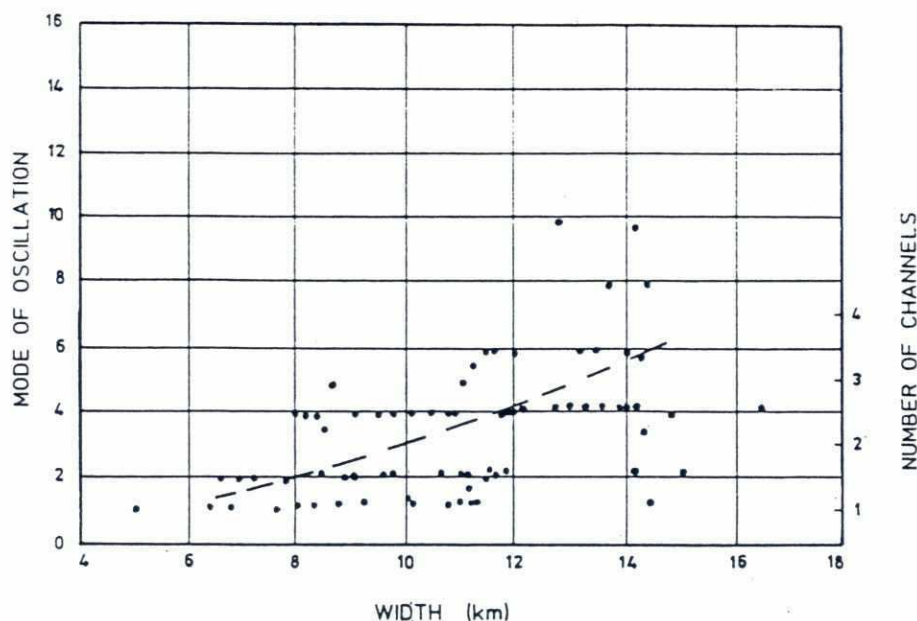


Figure 3.9 Number of channels versus the total width of the channel and bar system in the Jamuna river

In between the channels islands and sand bars are present. These are locally called chars. Nowadays a distinction is made between so-called **stable chars** (also called megachars) and **moving chars**, the position of which is changing every year. In addition so-called **attached chars** are differentiated, essentially being moving chars but connected to one of the river banks. Bristow (1987) makes a difference between 1st order, 2nd order and 3rd order bars. Figure 2.5 in the previous chapter outlines the concept he introduced in this respect. Comparable terms are used in this report; the 1st order channel being the river system in total, the 2nd order channels being the channels for which regime equations were derived, and the 3rd order being the channels in between the moving chars.

The total width of the channel pattern, comprising both the channels and the sand bars in between, is varying considerably both in space and in time. This is illustrated in Figure 3.10, yielding results from an analysis of satellite images for the years 1977 and 1989, and providing the total width of the river system, the total width of the channels and the remaining width of all islands. It can be observed that the total width varies between 3 and 15 km, while the total channel width varies between

3 and 10 km.

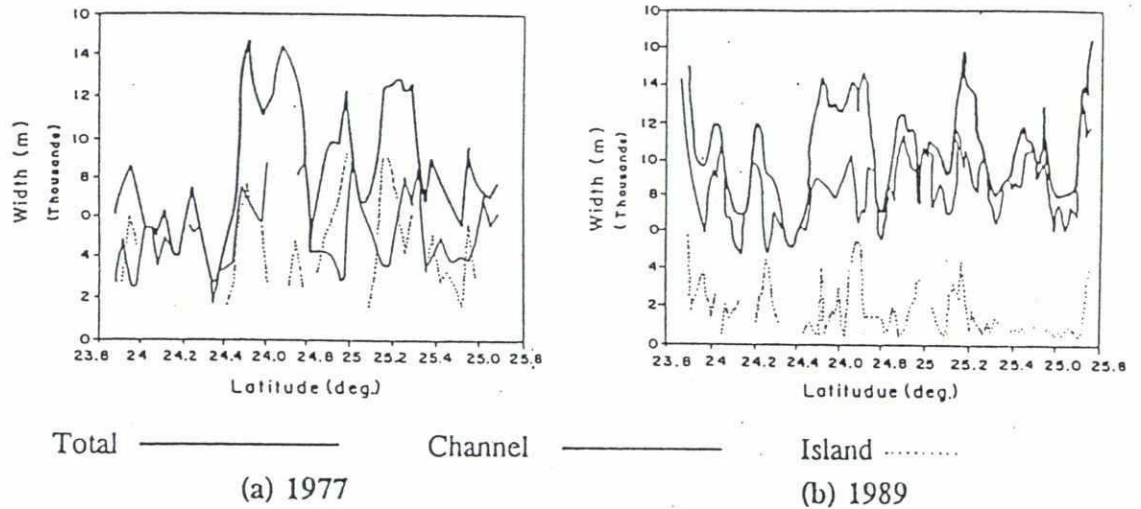


Figure 3.10 Total width, total width of channels and remaining width of islands.

Finally some observations have to be made as to nodal points. According to Coleman (1969) a number of nodal points occur along the Brahmaputra/Jamuna river, and he relates them to the possible presence of old and possibly more clayey deposits of rivers that have occupied the plains in historic times. The latest studies seem to suggest that these nodal points are not as stable as previously suggested. It could well be that they are related to fluvial morphological processes such as confluences rather than more stable reaches. This can also be deduced from the bank material data obtained under the FAP 1 study.

Shifting characteristics

The Brahmaputra/Jamuna river is an extremely dynamic system. These dynamics can be divided into the dynamics of the 2nd and 3rd order channels and related bars and the changes in the location and the width of the 1st order channel. The latter is discussed in subsequent paragraphs. Here the emphasis is on the changes of the smaller channels (still having width up to 1 to 4 km!).

The dynamics of the lower order channels can best be illustrated by stating that the channel pattern usually has changed completely in some 3 years. In this period bends have eroded often more than 300 m/year, channels have widened and others have narrowed or even completely disappeared, while many cutoffs are taking place every year. Figure 3.11 shows the planform of the same reach in the Jamuna river in the years

1973, 1980, 1986 and 1992, and the differences are amazingly large. The colour code is as follows: blue = water, yellow = sand (moving chars), grey = bare soil/cultivated land, and green = vegetation. The overall picture obtained from the detailed information now available, also owing to the satellite studies done within the framework of FAP 21/22 and within FAP 19, is indeed of an extremely dynamic river system.

In addition to the dynamic behaviour of the 2nd and 3rd order channels also the 1st order channel is subject to substantial changes, even over the limited period over which detailed information on the river system is available. According to the insight available now:

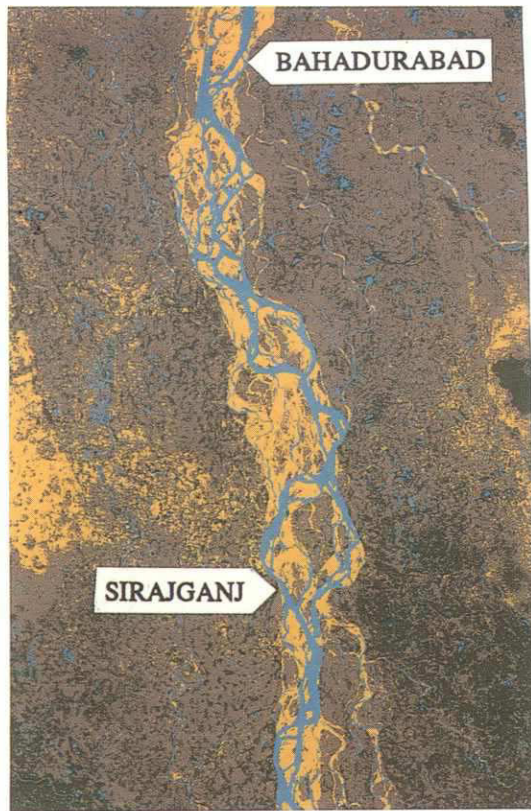
- 1) some reaches of the river are moving in a western direction (according to the FAP 1 report with a celerity of some 50 m/year),
- 2) the upper reaches of the Jamuna River are widening over the last decades.

Although in the report on the Jamuna Bridge Study, Phase 2 (1989) it is still stated that no significant changes can be observed based on an analysis of the BWDB cross-sections which are surveyed every year, in the mean time the evidence is piling up that suggests that the 1st order channel is subject to major changes. Especially the studies done by FAP 1 and FAP 3.1 have been material in this respect.

The evidence quoted comes from the comparison of older maps with newer ones and from studies based on the satellite images covering the period 1973-1992. Although there is some doubt as to whether the coordinate system of the Wilcox map can be used for comparison with other maps, this comparison seems to support the movement in western

direction. Also the satellite images appear to suggest that most of the erosion is along the western bank. This is nicely illustrated by Figure 3.11, providing the overall erosion between 1973 and 1992 in the reach between Bahadurabad and Sirajganj. This figure clearly suggests that the river has an overall tendency to move towards the West, but at the same time is widening substantially. For other reaches of the river this tendency is less pronounced. Evidence provided by FAP 21/22 shows that in the more downstream reaches the trend is possibly even in eastern direction.

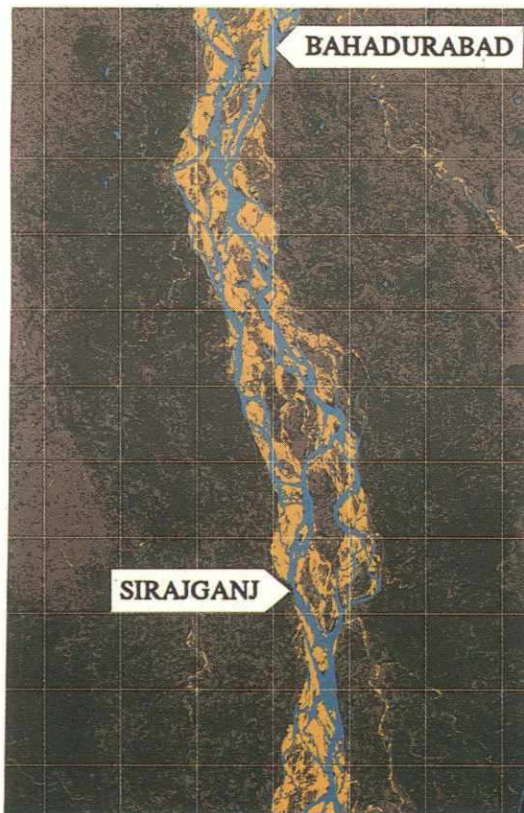
The cause for the supposed trend in either direction and the widening is not known. The overall movement could possibly be related to tectonic activities. As discussed in Section 3.3 the Brahmaputra/Jamuna river has a record of avulsive behaviour, and it may well be that this overall



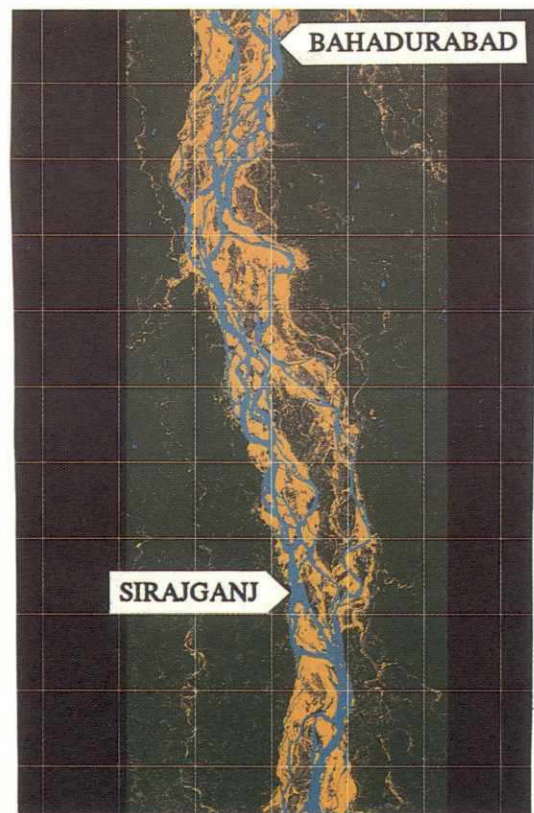
1973



1980



1986



1992

Fig. 3.11 Planforms of the Jamuna river in the years 1973, 1980, 1986 and 1992 illustrating the rapid changes in planform over the years

movement has a similar background. The widening can be attributed to an advancing alluvial fan or to the fact that the river has not fully adapted itself after the shift to its new course around 1800. In this respect it is interesting to remark here that in 1830 the river showed, according to the Wilcox map, a clear meandering behaviour also in the upstream reach.

Finally it is good to underline that the trends described here have not been established beyond doubt: the available information is too scarce and there is doubt as to reference levels and co-ordinate system. Yet, putting all the evidence available now together, the described behaviour of average movement in either direction and the widening seems likely.

Bends, bank erosion, cutoffs and widening

Until now the changes in planform of the Jamuna river were discussed without going into details as to how these channel changes are taking place. In this subsection some more details will be given as to the "agents" of these changes, notably bends, cutoffs and widening of the individual channels. Over the last years the understanding of these phenomena is increasing due to the use of satellite images firstly under the Jamuna Bridge Study (Klaassen and Masselink, 1992) and later via FAP 19 in combination with FAP 1, and in FAP 21/22. Especially in the latter study much effort has been put into understanding the changes of the river system over the years. Here only some highlights are presented; for more details reference is made to Annex 11 of FAP 21/22 Final Report.

The location of bank erosion along the Jamuna River is very difficult to predict over a longer period than a few years. From studies under FAP 1 it was found that major bank erosion is related to the presence of large bends that have a life cycle of between 3 and 7 years. In fact these bends are the most stable phenomena in the Jamuna river. Bank erosion along these bends was studied on the basis of satellite images and preliminary results were presented by Klaassen and Masselink (1992) and Thorne (1983). They observed erosion rates along outer banks of major bends varying between 200 to 700 m (and exceptionally even to 1 km) in one year.

Attempts to plot the yearly bank erosion (E) versus the relative local radius of curvature (R/W), where E = erosion rate in m/year, R = radius of curvature and W = width of the channel, resulted in graphs with considerable scatter. Still it was observed that maximum bank erosion rates occur for R/W values of about 2.5. This is in line with findings of Hickin and Nanson (1984) for Canadian rivers.

The balancing mechanism for increased bend formation is the occurrence

of cutoffs. Results of a study into the occurrence of cutoffs was also reported upon by Klaassen and Masselink (1992) and they suggest that the relative length of the two reaches downstream of the potential bifurcation is an important parameter. In the more recent FAP 21/22 it was found, however, that the angle a channel makes with the upstream (un-bifurcated) channel (reflecting the geometry of the bifurcation and hence the sediment distribution) is by far the most important parameter. If the offtake angle is less than 30 degrees then a cutoff does not occur. Increasing the angle leads to an increased probability of the bend being cut off. An even more powerful predictor can be found by plotting both downstream angles and to indicate whether or not a cutoff occurs. See Figure 3.12, being based on the study of 124 bifurcations. It can be concluded that if one angle is much larger than the other one, the first channel is quickly vanishing. This appears to occur via shallowing rather than narrowing (Mosselman et al, 1993).

In the FAP 21/22 study it was furthermore found that :

- o Bifurcations disappear in as a maximum three years
- o Abandoned channels downstream of a bifurcation are most often situated in an inner bend

Chars

A distinction is made between mega-chars, attached chars and moving chars.

As was discussed previously, in the braiding belt of the Brahmaputra/Jamuna mega-chars are present. These are also referred to as stable chars, because they have been present for a very long time already. No detailed information is available that can shed information on the age of these islands. It could be that they are related to the widening of the river.

According to the FAP 21/22 satellite study the mega-chars are much smaller than previously indicated by FAP1. Little is known about the formation and growth of mega-chars. Once they are above a certain level, and assuming that they are not eaten away by eroding bends, vertical accretion will take place. The higher the char level is, the finer will the particles be that will settle on the char surface. Hence it may be expected that gradually also finer silt and clay particles will be deposited. This will attract vegetation on the chars, and this in return will accelerate the process of vertical accretion. At present some of the mega-chars are at approximately the same level as the floodplain, and hence they are submerged only during floods above bankfull stage.

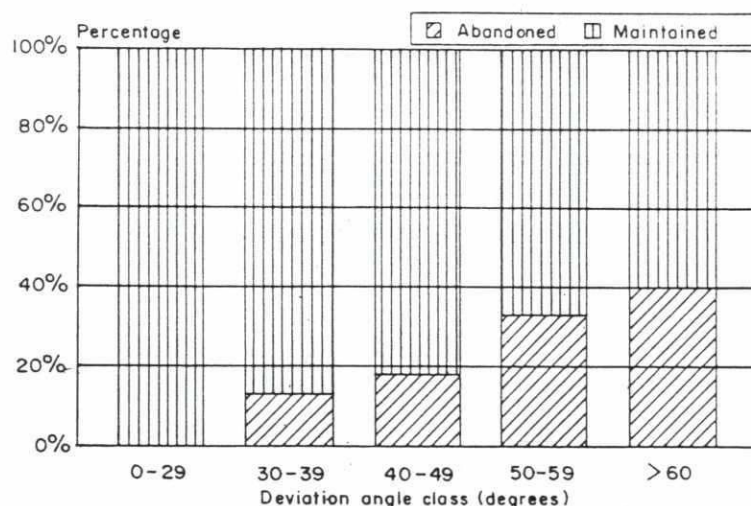


Figure 3.12 Abandonment as related to the angles of the downstream channels

Under FAP 21/22 it was attempted to determine the celerity of this vertical accretion process. It was concluded that it takes about 4 to 5 years for the chars to develop from fairly low chars to mega-chars. It should be stressed here that this is not the typical history of chars in the Jamuna river. Most of the chars have already been eroded after a few years only. It is assumed that a similar process of vertical accretion is applicable to attached bars. Hence it takes quite some time before these mega-chars and attached chars can be used for more permanent housing and cultivation.

Scour

Deep scour holes have been observed in the Brahmaputra/Jamuna river. The first overview of maximum scour depths in the Jamuna river was presented in the Jamuna Bridge Study, Phase 1. Different types of scour are present, notably bend scour, confluence scour and what is called protrusion scour (not discussed here separately). Maximum scour depths are related to either protrusion scour or confluence scour, and scour depths of 20 to 30 m have been observed. It is interesting to note that bend scour is not so pronounced in this river, probably due to the very large input of bank material due to the excessive erosion rates.

The ultimate scour depth is often a combination of the different types of scour identified here and depends on the momentary stage of the different types of scour. This aspect is discussed extensively in the FAP 21/22 reports and there recommendations are given for the combination of bend scour and local scour. How other types of scour have to be combined is not so obvious.

3.4.3 Ganges River

General aspects

The Ganges river rises west of the Nanda Devi Range west of Nepal and down to Goalundo in Bangladesh, where it joins the Jamuna River, it has a length of 2200 km. It has a drainage area of 977,500 km².

Hydrology

India has built a dam at Farakka on the river for diverting its winter flow. Pre-diversion average discharge in winter was 2,265 m³/s, while the average discharge in the monsoon period is 18,150 m³/s. After the diversion the minimum recorded discharge is 660 m³/s (1976). Figure 3.13 shows some stages at the Ganges river for some selected years.

Total flow per year is estimated to be 3.62×10^{11} m³. Its important distributaries in Bangladesh are Bhagirathi, Boral, Gorai, Bhairab and Mathabhanga. Mohananda is one of its main tributaries. The average grain size (D_{50}) of the bed material is 0.12 mm.

River characteristics

The Ganges is a wide meandering river. Its width may at places be as large as 5 km. The shape of the cross-sections is quite variable (see Figure 3.14)

According to NEDECO (1967) the water-level slope near the Hardinge Bridge is approximately 5×10^{-5} . The Darcy-Weisbach resistance coefficient of the Ganges varies between 0.08 for low flood condition to 0.01 for flood situation.

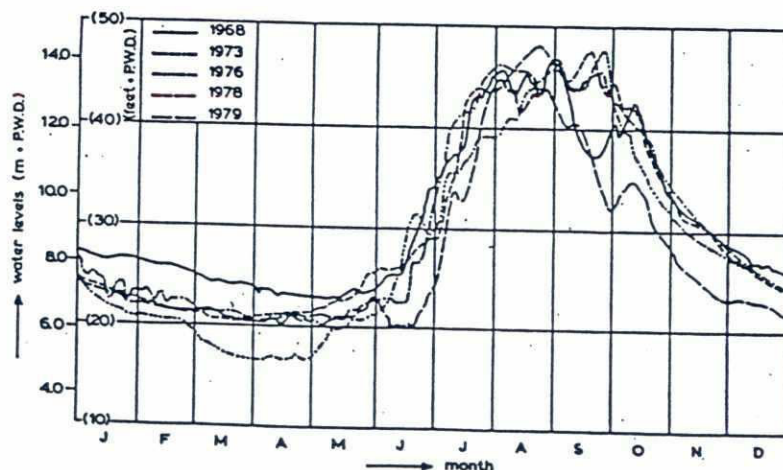


Figure 3.13 Stages of Ganges river at Hardinge Bridge for some selected years (Baset Sarker et al, 1984)

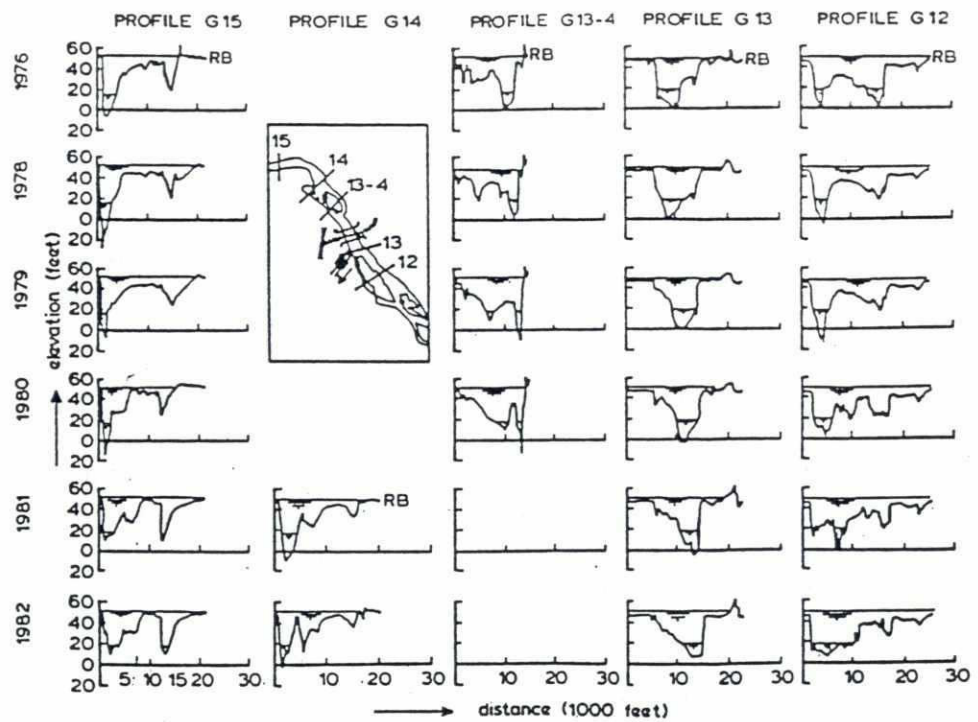


Figure 3.14 Cross-sections of Ganges river near Hardinge Bridge (Baset Sarker et al, 1984)

NEDECO (1983) estimated that suspended sediment transport is the main mode of transport in the river. NEDECO (1983) processed the suspended sediment load data for the period 1963-1977. The result is shown in Figure 3.15 along with a comparison of earlier published data of van der Veen (1962).

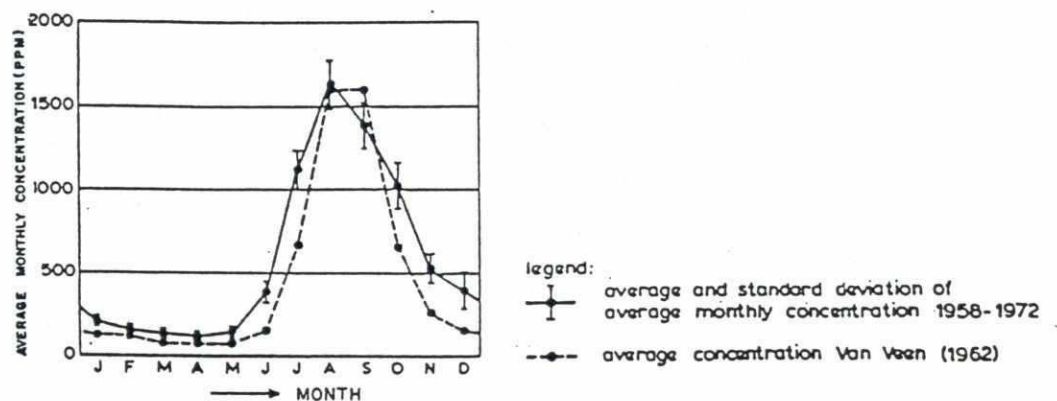


Figure 3.15 Average and standard deviation of average monthly concentration of suspended sediment load in the Ganges river near Hardinge Bridge (Baset Sarker et al, 1984)

Suspended sediment transport rates are being measured in the Ganges river at Hardinge Bridge on a regular basis. With FAP 24, coarse (coarser than 63 microns) suspended sediment data are available for the period 1966-1970 and 1976-1989 and fine (finer than 63 microns) suspended sediment data for the period 1967-1988. A closer analysis reveals that the data from the period 1966-70 suggest a significant (2 times) higher sediment transport than suggested by the 1976-1989 data. Analysis of these data will be presented in the Morphological Report of FAP 24. It should be mentioned here that data for the period 1966-1970 gives a reliable sediment balance for the Ganges-Padma-Brahmaputra system.

FAP 24 has derived equations for the coarse and fine suspended material transport in the Ganges River at Hardinge Bridge which read as:

Coarse sediment:

$$S = 7.013 * 10^{-6} * Q^{2.516} \text{ for the period 1966-1970}$$

$$S = 7.358 * 10^{-6} * Q^{2.44} \text{ for the period 1976-1989}$$

Fine sediment:

$$S = 0.157 * Q^{1.62} \text{ for the period 1967-1970}$$

Where S is in tons/day and Q is in m³/s

The average yearly (25 years) coarse sediment transport is approximately 190 million ton and fine sediment is approximately 350 million ton.

Planform Characteristics

It has been observed that morphological conditions of the river are changing continuously. This can be seen from the Figures 3.16 and 3.17.

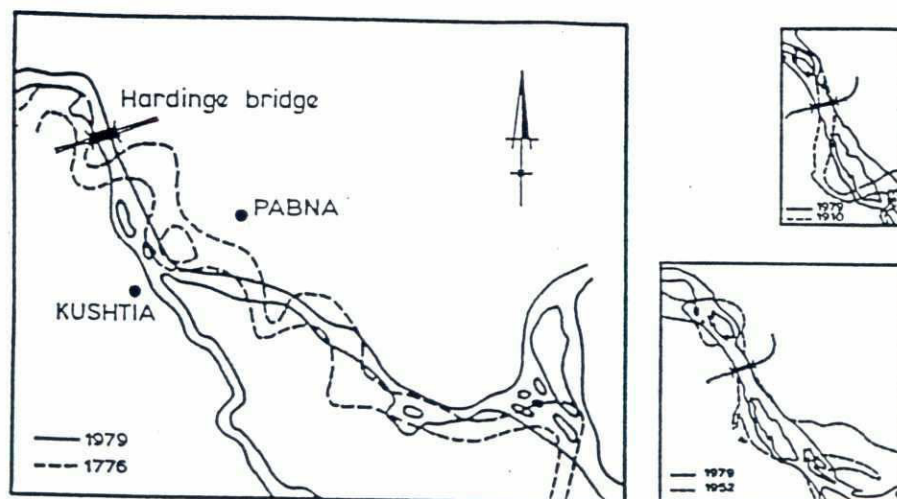


Figure 3.16 Changes in the course of the Ganges river between 1776 and 1979 (Source: IECO, 1980)

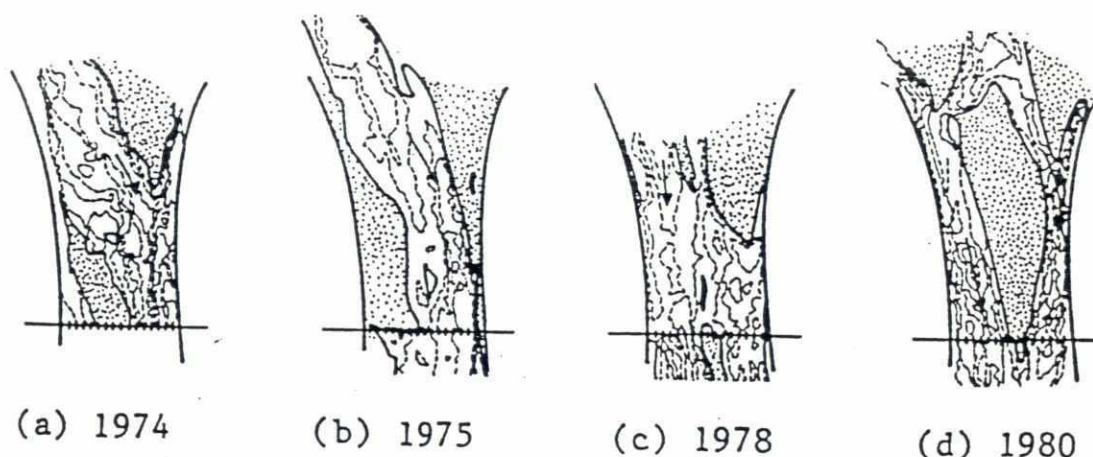


Figure 3.17 Pattern of channels and bars upstream of Hardinge Bridge according to soundings of Bangladesh Railways (Source: Baset Sarker et al, 1984)

Shifting Characteristics

As with any alluvial river system, the Ganges River shifting can be discussed in short and long-term migration trends. The short-term migration trend deals with shifting of the river channel within a meander belt while the long-term trend involves a general shifting of the meander belt. Historical evidence indicate that the Ganges River abandoned several of its distributaries in the past with a preference to migrate eastward (Morgan and McIntire, 1959). The latest active course of the river is along the Padma River which is a combined course of the Ganges and the Brahmaputra Rivers. Figure 3.18 shows the shifting of the river course from 1776 to 1979. It indicates that in the last two hundred years, the Ganges River has a northward shift near the Hardinge Bridge and Gorai River, and a general southward shift more downstream. In the lower course, it made a eastward migration toward the present course of the Padma River.

The Ganges River has a predominantly meandering form with eroding outer bends and depositing inner bends. The meander belt of the river varies between 5 and 15 kilometers (SWRMP, 1992). Twenty years (1956-1976) of BWDB cross-sectional data compilation by Hossain (1989) indicate that the meander migration rate is of the order of some 150 m/year. However, at the Hardinge Bridge, the meander migration stopped since the railway bridge was built in 1910 (Figure 3.18). The bridge introduced cyclic erosion and deposition of the river bed, with erosion during the monsoon flood stage and siltation during the low river stage (Inglis, 1949).

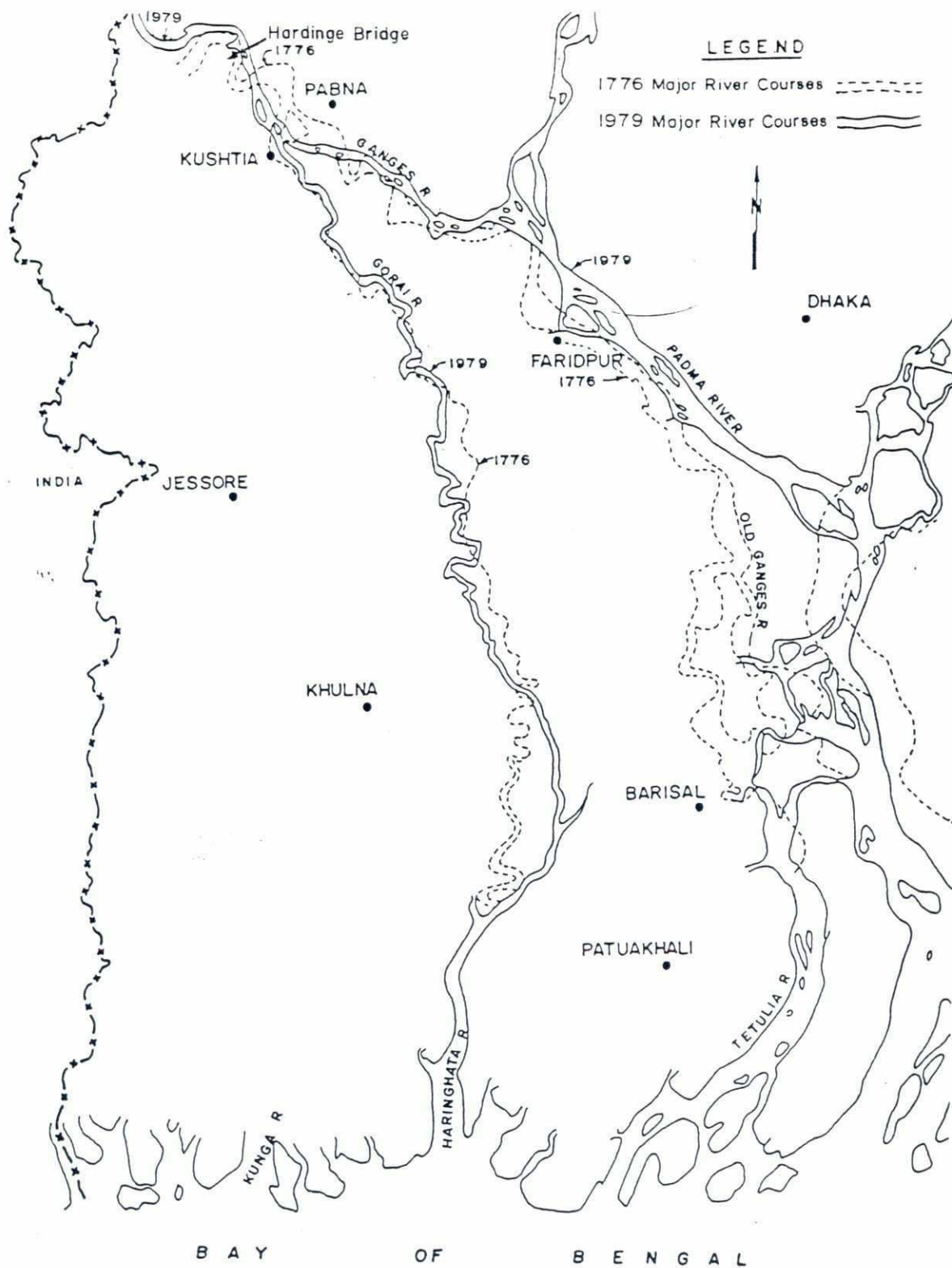


Figure 3.18 Shifting of the course of the Ganges River

Bends, bank erosion, cutoffs and widening

The meandering Ganges River has four distinct and wide bends from the Indo-Bangladesh border to the confluence location at Aricha. The average sinuosity of the river in this reach appears to indicate a cyclic changes over the years. For example, planform analysis by Hossain (1989) indicates that the sinuosity of the river was 1.5 in 1956, decreased to 1.2 in 1976, and again increased to some 1.3 in 1986. Spatially, the sinuosity is higher in upper bends and lower in lower bends. Similar to the temporal trend of the sinuosity, the meander length (L , km) and the meander belt width (W , km) has a decreasing tendency over the years. Some empirical observations by Hossain (1989) indicate the following relations.

$$L = 9.8 B \quad \dots\dots\dots 1956,$$

$$L = 7.6 B \quad \dots\dots\dots 1976,$$

$$W = 3.6 B \quad \dots\dots\dots 1956,$$

$$W = 2.9 B \quad \dots\dots\dots 1976.$$

Where, B is the channel width in km.

An interesting empirical observation was made by Hossain (1989) which relates a geometrical shape factor (width/depth) to flow dynamics. The flow dynamical parameter chosen in this case is the Froude number. A regression relation between the two dimensionless parameters shows an increase in the shape factor with high Froude numbers.

The river width is fixed at the Hardinge Bridge and is about 1.6 km. The width increases both toward upstream and downstream locations measuring up to 8 km at some locations during bankfull stage.

Chars

The Ganges River bed is characterized by large sand banks which are locally known as chars. The majority of these chars are point-bar deposits attached to the inner bend of the meander belt. However, the Ganges River has a relatively wide bed with migrating chars, consequently, channel sections are divided into main and secondary channels. According to NEDECO (1967) findings, the main and secondary channels divided by chars meet at a regular interval of some 20 km. Figure 3.17 shows developments of channel patterns and bars from 1974 to 1980 (Baset Sarker et al, 1984). It appears that these chars migrate with a periodicity of some 20 years. Figure 3.19 shows the bar movement in the Hardinge Bridge-Gorai River offtake area. It indicates that the Gorai River offtake was practically blocked in 1992 by a moving sandbar.

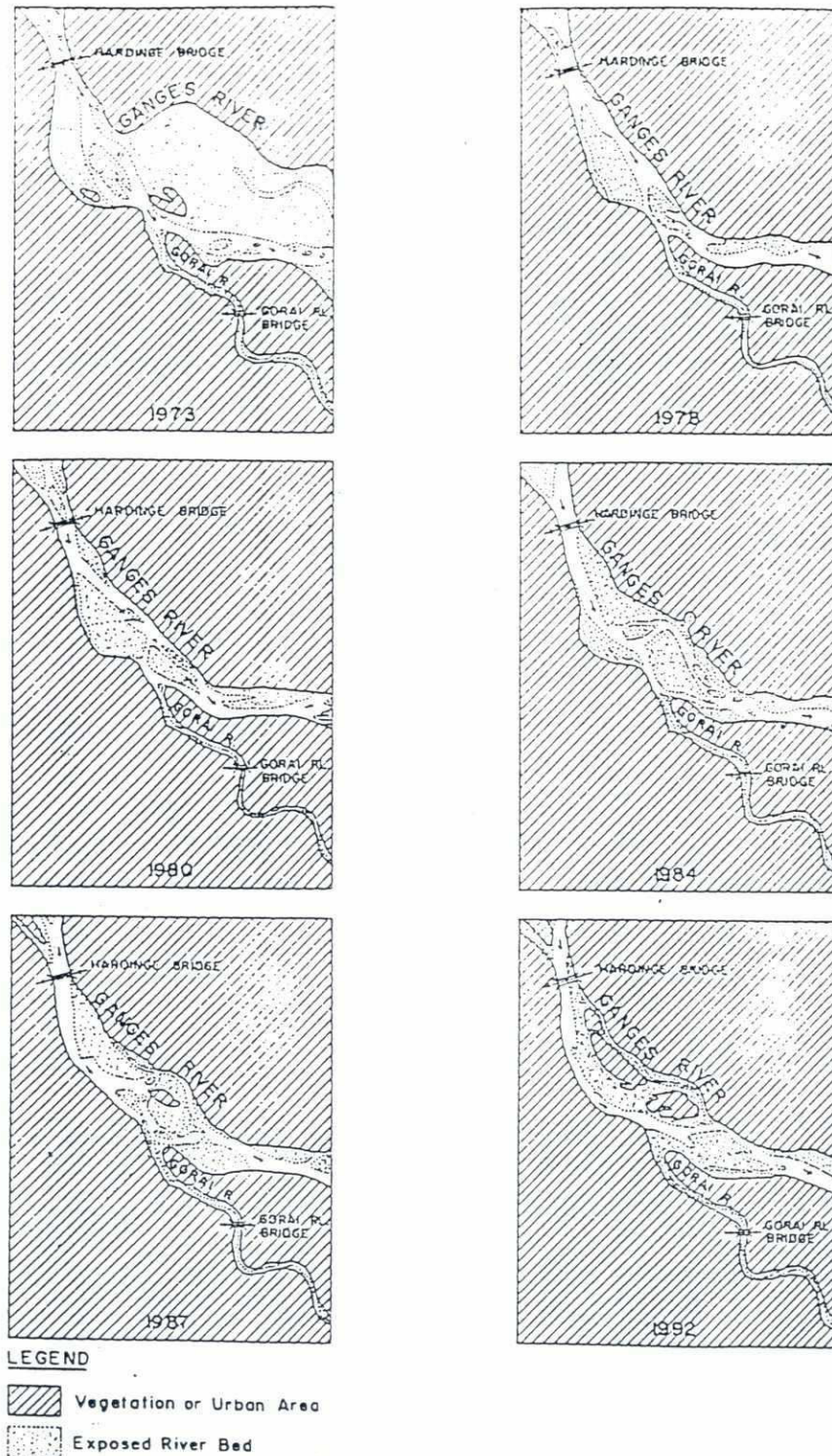


Figure 3.19 Channel migration in Ganges near Harding Bridge - Gorai off-take

Scour

As the nature of a meandering river suggests, the Ganges River is characterized by outer bend scour and point bar deposits. According to NEDECO (1967) studies, scour pools with depths over 10 m occur at the outer bends.

3.4.4 Upper Meghna River

General aspects

The Upper Meghna river flows in the northeastern part of Bangladesh as can be seen in Figure 3.20. It carries the combined flow of the Surma and the Kusiara rivers, which both originate in the Indian hills northeast of Bangladesh. The Surma river flows through what is probably, structurally, the most active part of the Bengal basin, notably the Sylhet depression, that has subsided about 10 meters within the last several hundred years, (Rashid, 1991). This subsidence may be a combination of compaction together with tectonic activity (related to the major fault system bounding the northern side of the area). Together with the compaction, the tectonic activity is another factor affecting the drainage of the Sylhet area. A number of tributaries of the Surma originate from the Silong hills in India and from predominant areas. They bring quite some sediment (boulders, gravel, sand), that mostly is deposited in the Sylhet area. Hence, the prevailing morphological action in this upper catchment area is sedimentation rather than erosion (Hoar Development Reconnaissance Study, 1986).

Going in downstream direction, the Meghna river is joined by the Old Brahmaputra at Bhairab Bazar. The Dhaleswari is another tributary and it joins the Meghna river at Munshiganj on the right bank. Some tributaries that originate from the Tripura hills join the Upper Meghna at the left bank. Although having some reaches with a system of various channels, the Upper Meghna river can be characterized as a river mainly meandering within a well defined high water bed and having flood discharges up to some 20,000 m³/s while the annual discharge is 1.13×10^{11} m³.

The deeply flooded area in Sylhet is in fact an area which is inundated by the backwaters of the Ganges and the Jamuna. Because of the high water-levels in these rivers, the floods from the Sylhet area do not have sufficient slope to be rapidly evacuated to the Bay of Bengal. This "impeded drainage" causes the floodwater to accumulate in the deeply flooded area, causing silting up, and so creating an enormous basin which only gradually drains into the Meghna. The river is about 110 km long and three quarter to one kilometre wide.



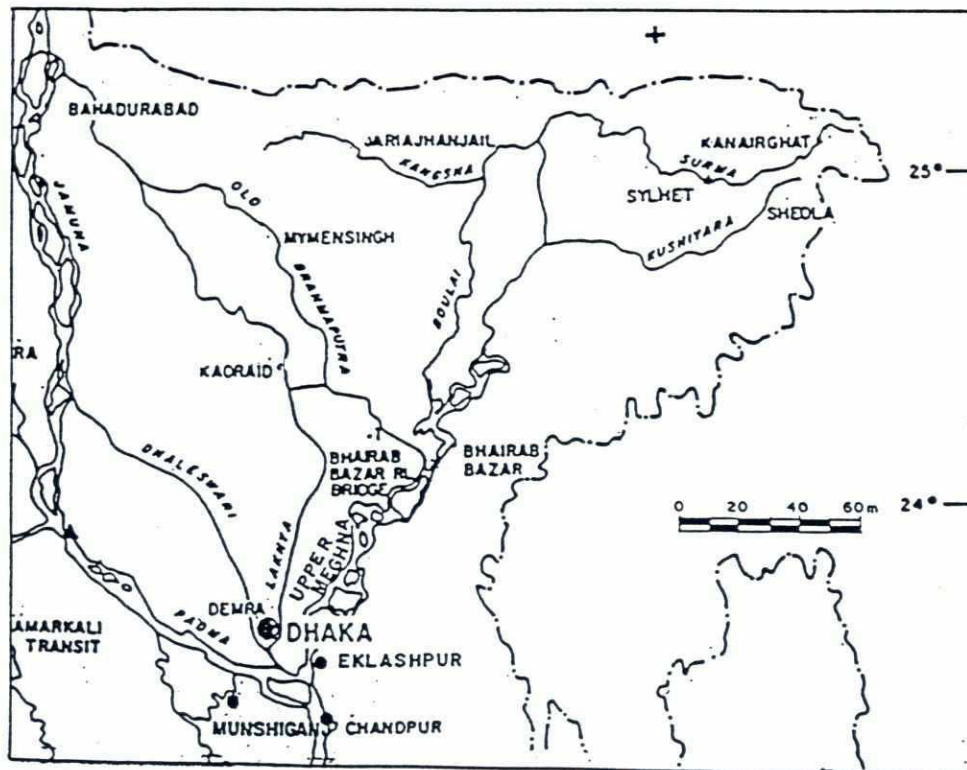


Figure 3.20 The Upper Meghna river (Source: Haskoning/Delft Hydraulics/BETS, 1992)

Hydrology

The discharges of the Upper Meghna River at Bhairab Bazar vary between almost zero to some 20,000 m³/s. The duration curve of the daily discharges is given in the Figure 3.21.

The average daily water-levels at Bhairab Bazar vary between 0.81 m and 7.65 m above mean sea level. During low flow conditions the tidal influence at its confluence with the Padma is about 1 m. During floods the tidal effect becomes almost negligible. The water-level slope of the Upper Meghna river varies between almost zero during low flow to about 0.2×10^{-4} during floods.

River Characteristics

Probably the bed of the Upper Meghna River has been shaped by the Brahmaputra River when it still flowed along its Old Brahmaputra course. As a consequence the river is probably "oversized". The present river is still in the process of adapting its bed to the new ultimate condition. From an analysis presented in Annex B of the Final Report of FAP 9B (Haskoning/DELFT HYDRAULICS/BETS, 1992) it appears that the

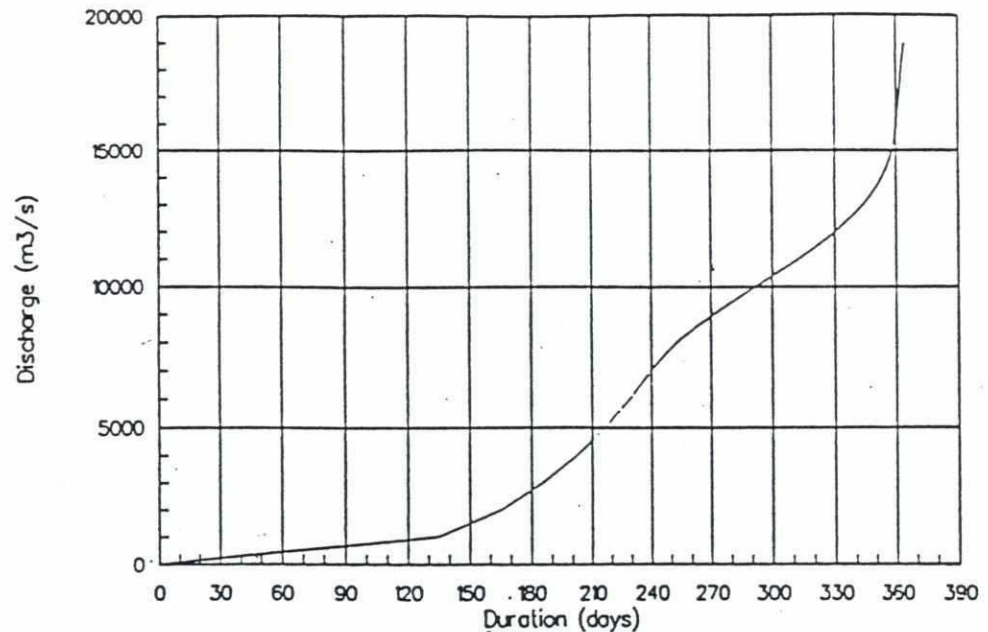


Figure 3.21 Duration curves of the daily discharges at Bhairab Bazar (Source: Haskoning, Delft Hydraulics, BETS, 1992)

width of the channels are smaller than according to the regime equations for the Jamuna River would have been expected. The depth of the channels is larger than expected, which can also be related to the influence of the subsidence and the retarded adaptation of the river to the new conditions. The bankfull discharge is about 8,000 m³/sec. The dominant discharge is about 11,000 m³/sec. The cross-section of the Upper Meghna River increases in downstream direction probably due to the tidal effect.

The characteristic particle diameters of the Upper Meghna River hardly vary in longitudinal direction. The bed material is fine and fairly uniform sand, D_{50} of the river being 0.14 mm and D_{84} about 0.25 mm. The bed material is always in motion, and suspension is the dominant mode of transport. Sediment loads are very low however. The estimated yearly sediment transport load is slightly more than 1 million tons, corresponding to about 0.2% of the yearly load of the Jamuna River.

The northern zone of the Upper Meghna subsides as a result of neotectonic movement. The rate of land subsidence is considerable and cannot even be replenished by the enormous sediment load which is coming with the flow in the rivers of that zone. At the start of the monsoon, when the water-level in Meghna is low, a steep water-level gradient forms from north to south in the rivers just upstream of the Upper Meghna. Due to

this the Kalni river upstream of Upper Meghna is migrating westwards. This steepness causes substantial sediment transport for a short period and slowly diminishes as the water-level in Meghna rises with the monsoon and thereby causes sedimentation and flooding in the upper reaches.

FAP 6 has analyzed sediment data of Bhairab Bazar on the Upper Meghna and found them very unreliable and scattered. In one instance the sediment concentration was 1mg/litre. No correlation between the discharge and the sediment load could be established.

Planform Characteristics

The planform of the river consists mainly of one single channel and over two reaches two parallel ones of similar importance (Figure 3.22a). There are many abandoned channels or channels which carry no water during the low flow season. The reason for this may be that the river is flowing in a bed which has been shaped by the flow of the Brahmaputra river before it changed its main flow to the Jamuna. This can be seen from Figure 3.22b. It can be assumed from an observation of the figure that in and around 1776 the behaviour of the Upper Meghna had a braided pattern like the present Jamuna.

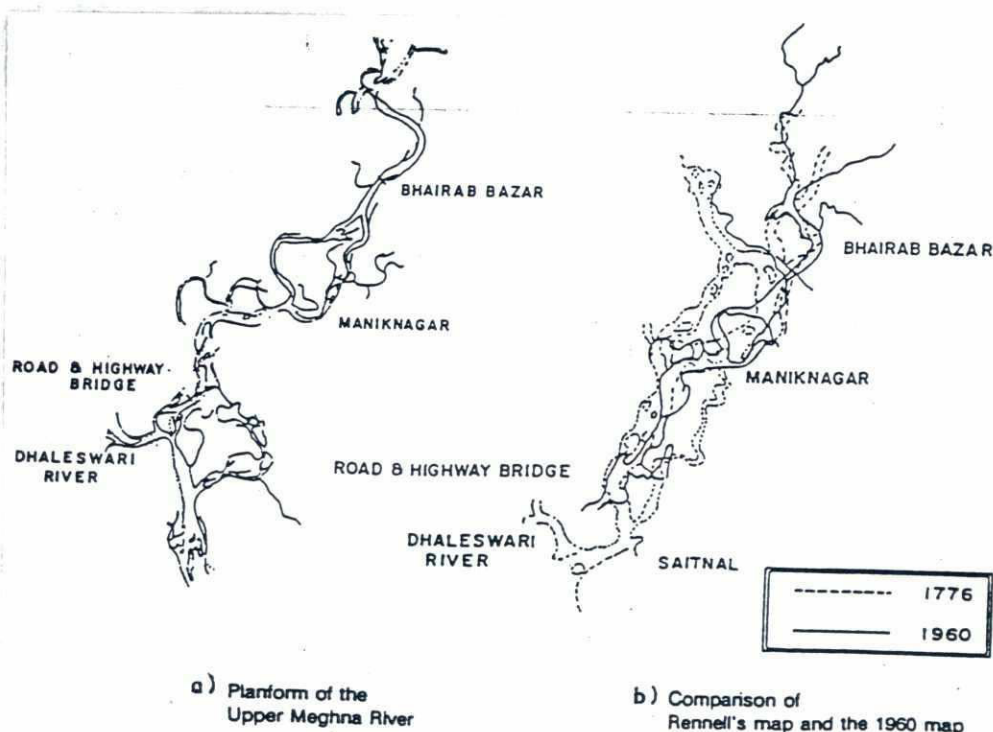


Figure 3.22 Adaptation of the bed of the Upper Meghna river (Source: Haskoning, Delft Hydraulics, BETS, 1992)

Shifting characteristics

The Upper Meghna River appears to be fairly stable. The historical changes were studied by FAP 9B using old maps, satellite images and cross-sections. It was observed that the changes over the period 1973-1990 were too small to be detected with satellite images. Overall it appears that, apart from the transition to a meandering river, the river has remained in its previous location.

Bends, bank erosion, and cutoffs

Bends in the Upper Meghna River vary in radius of curvature between 1,250 and 25,000 m, while the arc length varies between 40 and 140 degrees.

Bank erosion rates were studied by FAP 9B for specific locations where the bank erosion was maximum. Typical values found were 0 at Bhairab Bazar to some tens of meters a year at a very pronounced bend at Maniknagar. Hence bank erosion is minor compared to e.g. the Jamuna River.

Cutoffs are not regularly occurring in the Upper Meghna River. Rather there is some anastomosing behaviour in some reaches.

Scour

Also in the FAP 9B studies estimates are made on the scour depths in the Upper Meghna River, in particular at Chandpur. It was found that the scour is a combination of constriction scour (Klaassen and Vermeer, 1988b), bend scour and local scour. Maximum scour depths of about 40 m were predicted for extreme flood conditions and a severe constriction as is present in Bhairab Bazar. At other locations the maximum natural depths are more in the order of 20m.

3.4.5 Padma/Lower Meghna River**General aspects**

Here the Padma and Lower Meghna River are discussed as one river because it is felt that nowadays the Lower Meghna River is rather the continuation of the Padma River than of the Upper Meghna River. The Padma river is the name of combined flow of the Ganges and the Jamuna River. It is 120 km long and joins with the Upper Meghna River near Chandpur.

The Lower Meghna carries the combined flow of the Padma and the Upper Meghna rivers. The Padma river in turn carries the discharge of the Brahmaputra and the Ganges river. Hence the Lower Meghna river is

one of the largest rivers in the world. The river flows from the confluence of the Upper Meghna river and the Padma river via Chandpur into the Bay of Bengal (see Figure 3.23).

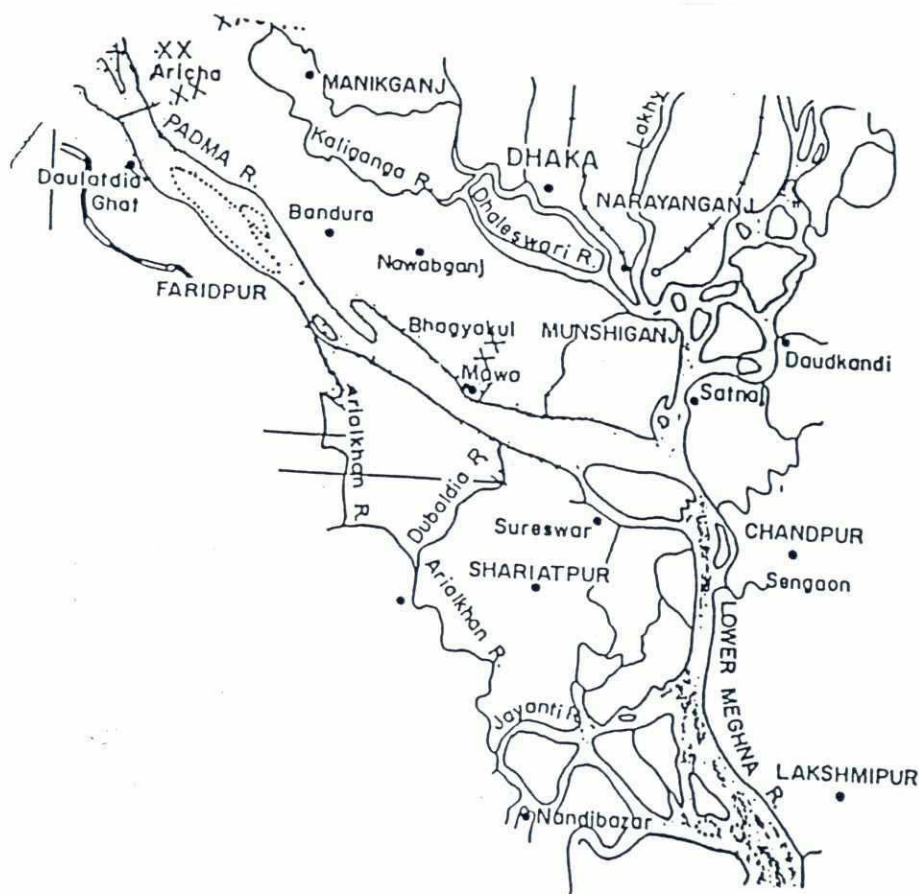


Figure 3.23 : Padma and Lower Meghna River

Hydrology

The average daily water-level of the Lower Meghna River at Chandpur varies between 0.56 m to 4.99 m above MSL. The river is subjected to tidal influence. During low flow a vertical tide of some 1.6 m is noticeable in Chandpur.

The discharge of the Lower Meghna at Chandpur varies between 10,000 m^3/sec to 160,000 m^3/sec . A tentative duration curve for the daily discharges at Chandpur is given in Figure 3.24.

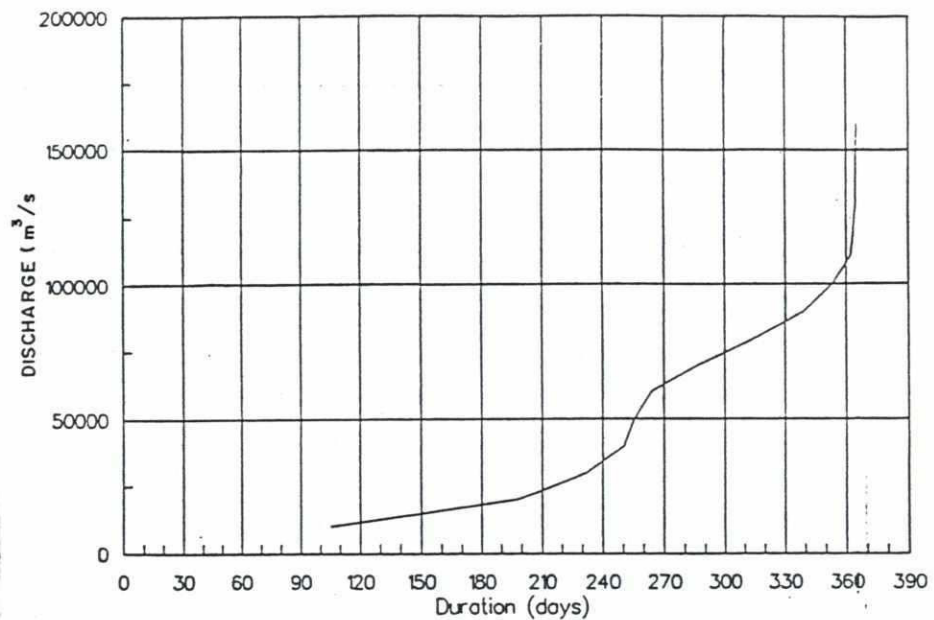


Figure 3.24 Tentative duration curves of the daily discharges at Chandpur (Haskoning et al, 1992)

River Characteristics

The average slope of the Padma river is around 0.5×10^{-4} . The width of the Padma River varies from 4 to 10 km. In the upstream reaches the Padma river appears to be a straight river with chars moving in it. The lower half appears to be a fairly stable braided river with islands travelling through it. The flood plain is composed of clay of median size 0.03 - 0.045 mm. The difference of elevation between the flood plain and the channel bed is ± 10 m. The dominant discharge is about 80,000 m³/sec which is slightly lower than the bankfull discharge of 82,500 m³/sec.

The average slope of the Lower Meghna varies between 0.1×10^{-4} (during low flows) and almost 0.4×10^{-4} (during flood conditions).

The bed material of the Padma River is fine fairly uniform sand, D_{50} of bed material being 0.09 mm, while D_{84} is about 0.20 mm. For the Lower Meghna River these values are about 0.09 mm and 0.19 mm. Apparently there is hardly any influence from the Upper Meghna River, which underlines the very small amounts of sediment being carried downstream. From an analysis by FAP 9B it was concluded that bed material of the Padma and the Lower Meghna River is always in movement. It was also observed that dominant mode of transport is apparently the suspended load. The yearly bed material transport was estimated to be around 70×10^6 ton.

The Padma River at the confluence had two channels in the past until 1982, one at Goalonda and another at Baruria. The Goalonda is closed off firstly due to natural aggradation and later on by human intervention. Coarse suspended sediment transport data are available at Goalundo for the periods 1966-1969 and 1976-1982 and at Baruria for the periods 1968-1970 and 1976-1989. Fine suspended sediment transport data are available at Goalonda for 1967-1970 and for Baruria 1966-1988. The FAP 24 analysis reveals that the transport in Goalonda in the past was very low which was about 2 percent of the transport in Baruria. A detailed analysis indicates that the data from the period 1968-70 at Baruria suggest a significant (3.5 times) higher sediment transport than suggested by the 1976-1989 data. Analysis of these data will be presented in the Morphological Report of FAP 24. It can be mentioned here that data for the period 1968-1970 gives reliable sediment balances for the Ganges-Padma-Brahmaputra system.

FAP 24 has derived equations for the coarse and fine suspended bed material transport in the Padma River at Baruria Station which read as:

Coarse sediment

$$S = 4.578 * 10^{-08} * Q^{2.865} \text{ for the period 1968-1970}$$

$$S = 1.147 * 10^{-09} * Q^{3.08} \text{ for the period 1976-1989}$$

Fine sediment:

$$S = 0.0107 * Q^{1.78} \text{ for the period 1968-1970}$$

Where S is in tons/day and Q is in m³/s.

The average yearly (25 years), coarse suspended sediment transport at Baruria is approximately 370 million ton and fine suspended sediment transport is approximately 520 million ton. Suspended sediment data at Goalonda are also analysed which will be produced in the Morphological Report of FAP 24.

Planform Characteristics

The Padma River over the reach upstream of Mawa is fairly straight. It is a river reach in which chars are moving. These chars seem not to exist near Mawa, but this is due to the extreme depths over there. Downstream of Mawa the river widens again and there very quickly chars emerge again. These chars are travelling in downstream direction in what appears to be a periodic movement.

The Lower Meghna river system is characterized by a fairly narrow river bed of several kilometres width in which various channels develop in combination with large propagating sand bars (locally called chars). A very peculiar aspect is the sudden turn to the south of the Lower Meghna

river just downstream of the confluence with the Upper Meghna river. This sharp turn has been present for a very long time and may be the cause of the gradual shift of the Ganges river, and later the combined Ganges and Jamuna system, in easterly direction. The overall tendency of the Lower Meghna river is erosion on the eastern bank and accretion on the western bank.

Smaller tributaries join the river on the left side downstream of the confluence with the Upper Meghna river, notably the Gumti river and the Dhakatia river.

The large bend downstream of the confluence has a radius of curvature of some 15 km. At the inner side of this bend a large point bar appears to be present. Here the river narrows again to a few kilometres only. The geometry of the confluence has changed substantially over the last three decades, mostly due to the continuing bank erosion along the outer bend. As can be observed from maps and satellite images the islands that are generated downstream of Mawa vanish when entering the bend. During some years a "southern" channel is present in the bend, that acts as a short cut. There are some indications that this is some kind of periodic behaviour with a periodicity of some 15 years. This is illustrated in Figure 3.25, where the observed changes in planform near the confluence of the Padma and the Upper Meghna River are presented. In particular the formation of a cutoff channel e.g. in 1990 is important as this relieves the "pressure" along the left bank downstream of the confluence.

Chandpur is located at the lower end of this bend. About 15 km downstream of Chandpur Haimchar is located. Near Haimchar a large bend used to be present but over the last two decades a natural cutoff has occurred, and now the river reach near Haimchar is essentially straight.

Shifting characteristics

According to the available information the Padma River is fairly stable. Bank erosion is probably very much retarded by the presence of clayey deposits, the most pronounced being at Mawa.

Along the left bank of the Lower Meghna at some sites erosion causes severe problems. Going in downstream direction, problem sites are or have been in the recent past: Eklashpur, Chandpur and Haimchar. There appears to be an overall tendency of the river to move in eastern direction. This could be caused by tectonic effects or by the pronounced bend that is present downstream of the confluence. It is interesting to note that this easterly movement seems to be a continuation of the movement of the Ganges mouth in the past towards the East.

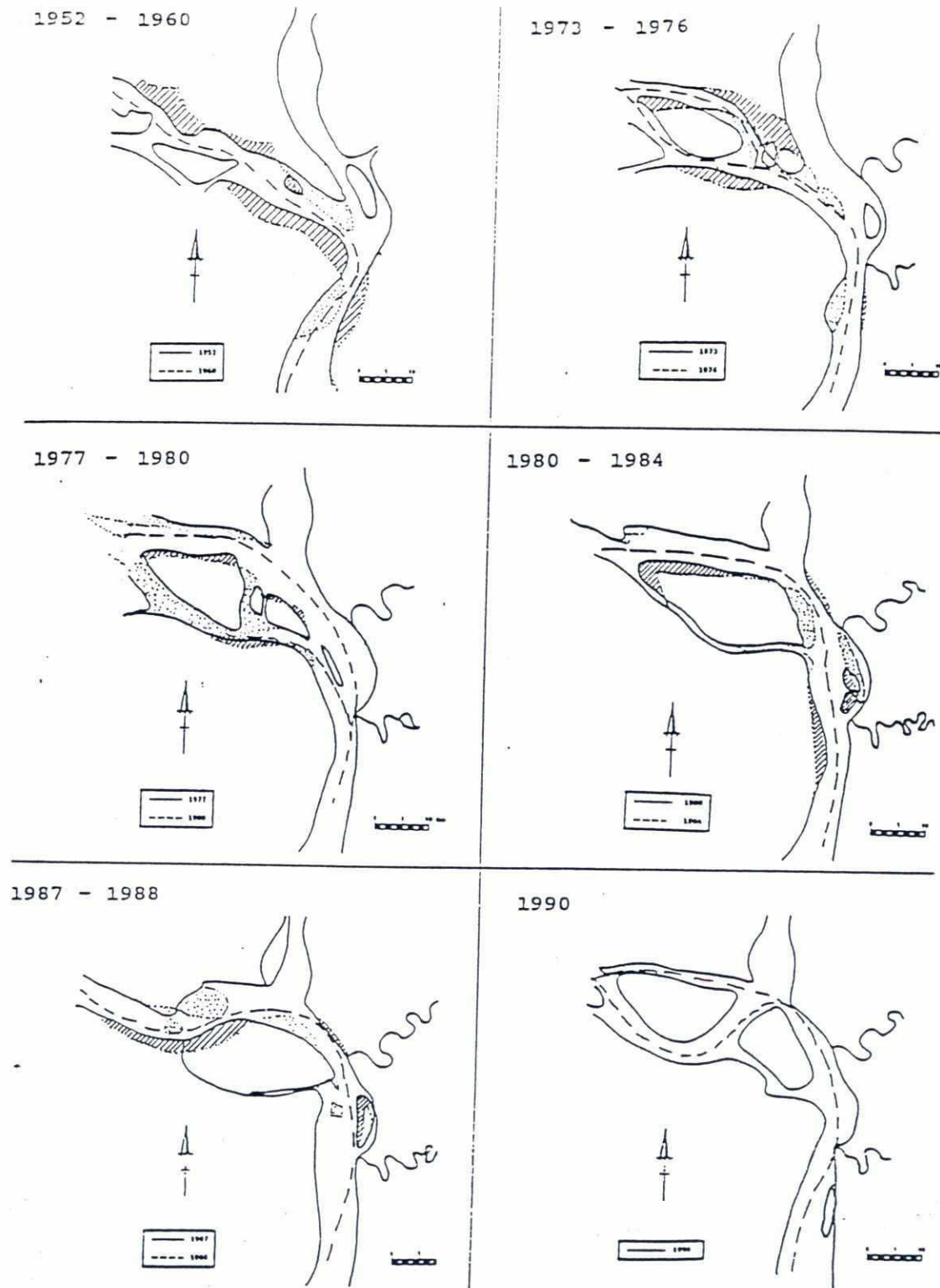


Figure 3.25 Changes in planform near the confluence of the Padma and the Upper Meghna River

Bends, bank erosion, cutoffs and widening

The only pronounced bend which is located near the confluence with the Upper Meghna River has already been discussed. Bank erosion along the Padma River is negligible. Along the Lower Meghna River it varies between about 100 m to about 200 m/year on the average. As was demonstrated by FAP 9B there appears to be some periodicity upstream of Chandpur.

Downstream of Haimchar there has occurred a major cutoff during the last decades. As could be demonstrated it took about 20 years for the cutoff to be fully materialized.

Mega-chars and attached chars

In the Padma River chars occur both upstream and downstream of Mawa. Downstream of Mawa the Padma River is widening again and that gives rise to the emergence of attached bars and islands. It seems as if locally the Padma River regains the character of the Jamuna River, the number of parallel channels increasing to about 3. This could indicate that in narrower reaches the width is the limiting factor for the formation of islands and chars.

Scour

Excessive scour depths have been observed in the Padma River at Mawa and in the Lower Meghna River at Chandpur. At Mawa this is due to the total width of the river being only less than 4 km wide, which is lower than the width of the Jamuna River if all the channels would be combined to one. Hence also substantial constriction scour occurs. Figure 3.26 present a cross-section of the Padma River near Mawa. It can be observed that the maximum scour depths reach values of more than 60 m. Also it can be observed that even through this deep section attached bars (alternate bars) are travelling.

Within the FAP 9B study scour depths at Chandpur were studied. It was found that the maximum scour depths at Chandpur vary between 25 and 50 m. The observed scour depths are a combination of constriction scour, outer bend scour, local scour, sometimes confluence scour and what was called in the FAP 9B study protrusion scour. It was furthermore shown that the actual scour depth is closely related to the actual channel pattern. Prediction of future scour depth developments appear to be in line with recent observations.

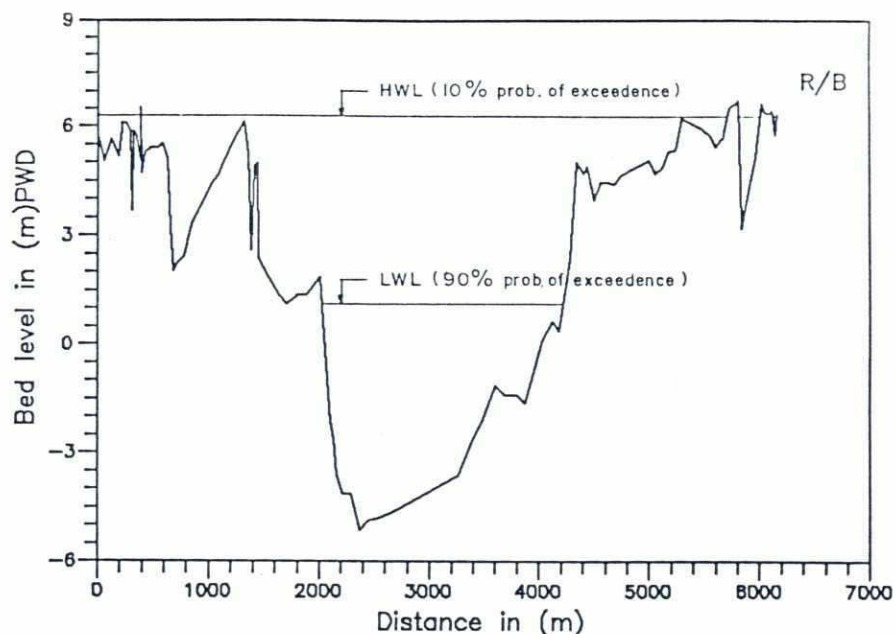


Figure 3.26 Cross-section of the Padma River near Mawa

3.5 Distributaries

General

The major part of Bangladesh consists of a flood plain of the three major river systems; the Brahmaputra/Jamuna, the Ganges/Padma and the Lower/Upper Meghna. These river systems along with their large number of tributaries and distributaries have formed a river network that inundates the country's flood plain every year.

The distributaries, apart from draining a part of the main river flow, drain the excess local rainfall. They serve as a surface water resource during dry seasons.

The important distributaries are :

- o the Old Brahmaputra,
- o the Dhaleswari originating on the left bank of the Brahmaputra-Jamuna,
- o the Gorai, and
- o the Arial Khan originating on the right bank of the Ganges' Padma

In the following sub-sections, the river characteristics of these distributaries are described. The following aspects are considered:

- o General aspects
- o Hydrology
- o River characteristics

3.5.1 Old Brahmaputra

General aspects

The Old Brahmaputra is the first left bank distributary of the Brahmaputra / Jamuna River and the off-take is located at the north of the North Central Region. The river generates some of its own distributaries such as Sirkali, Sutia, and Lakhya. It finally drains into the Meghna just south of Bhairab Bazar Figure 3.27

The BWDB maintains 10 water-level gauging stations. The discharge gauging is made at Mymensingh and Bhairab Bazar Railway Bridge. The river, at present, acts as an interconnecting channel between the Brahmaputra/Jamuna and the upper Meghna. According to the BIWTA river route map, the river is 220 km long from its offtake from the Brahmaputra to its outfall into the Meghna.

River cross-section survey data of 36 locations are available.

Hydrology

The river being a distributary of the Brahmaputra-Jamuna, drains to its bankfull flow during high river stage. It is also an interconnecting river, as such hydrology of the upper river reach is governed by the hydrology of the Brahmaputra-Jamuna while the hydrology of the lower reach is influenced by the Meghna River stages as well. Figure 3.28 shows the monthly flows (maximum, mean, and minimum) of the river at Mymensingh for the period 1964-91. The hydrographs shows the typical nature of a river governed by a cyclic monsoon climate.

Figure 3.29 shows the trend of the annual mean flow from 1964 to 1991. The annual mean flow over the years show a decreasing trend. A flow of about 800 m³/s during mid seventies reduces to about 550 m³/s during the early nineties. This is equivalent to a reduction of about 30%. This reduction becomes even more pronounced when the annual flow of the Old Brahmaputra is expressed as a percentage of the Jamuna flow (Figure 3.30). It is observed that a diversion rate of about 4% during the mid-seventies has reduced to about 2.5% during the nineties.

Moreover, it is interesting to observe a certain periodicity of about 5 years. The main question is, whether and how the trend may be extrapolated (linear extrapolation means dying in 25 years).

The annual peak discharge of the river at Mymensingh ranges between 4,910 m³/s to 1,930 m³/s with a mean value of about 3,058 m³/s.

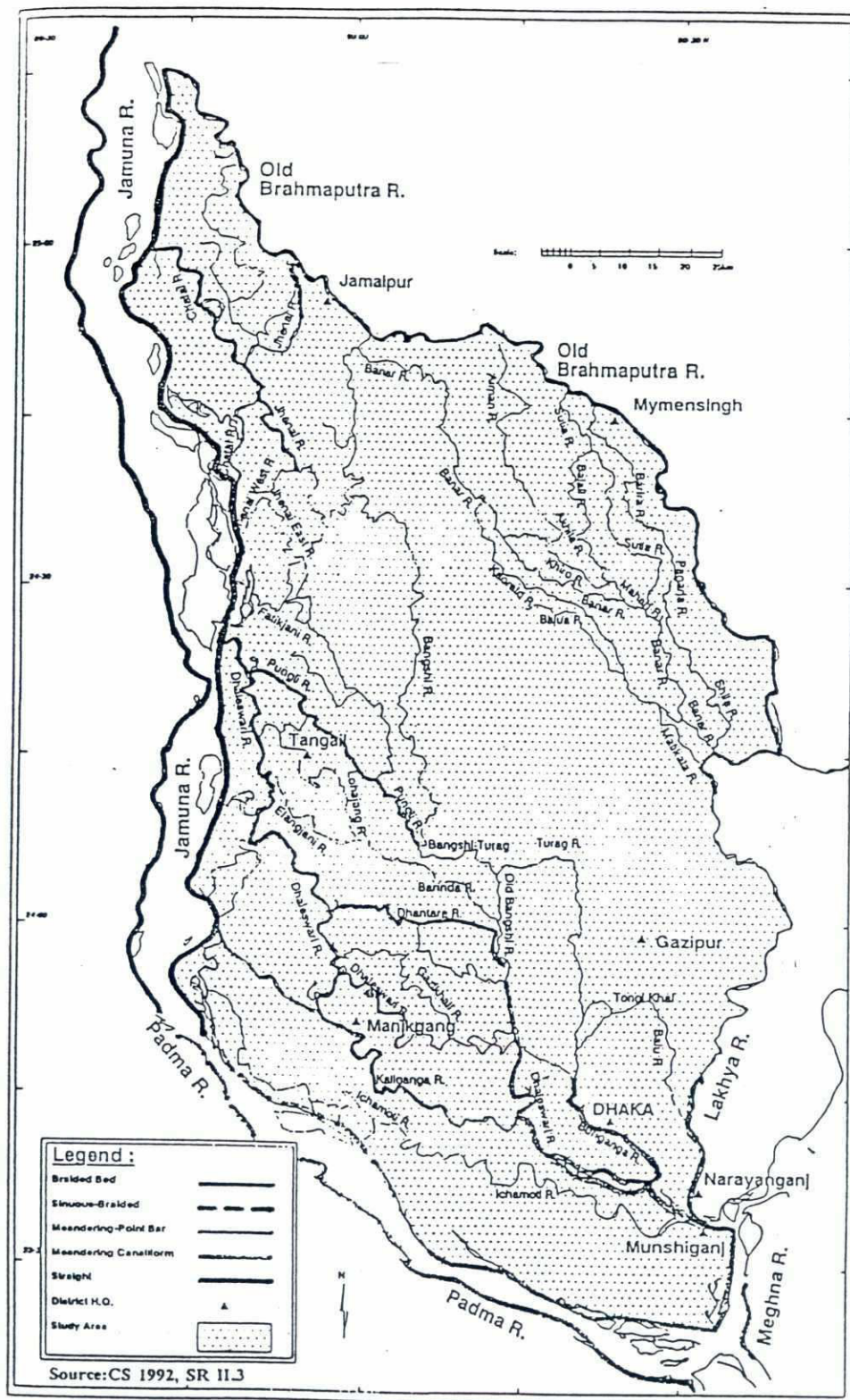


Figure 3.27 Left bank distributaries of the Jamuna River

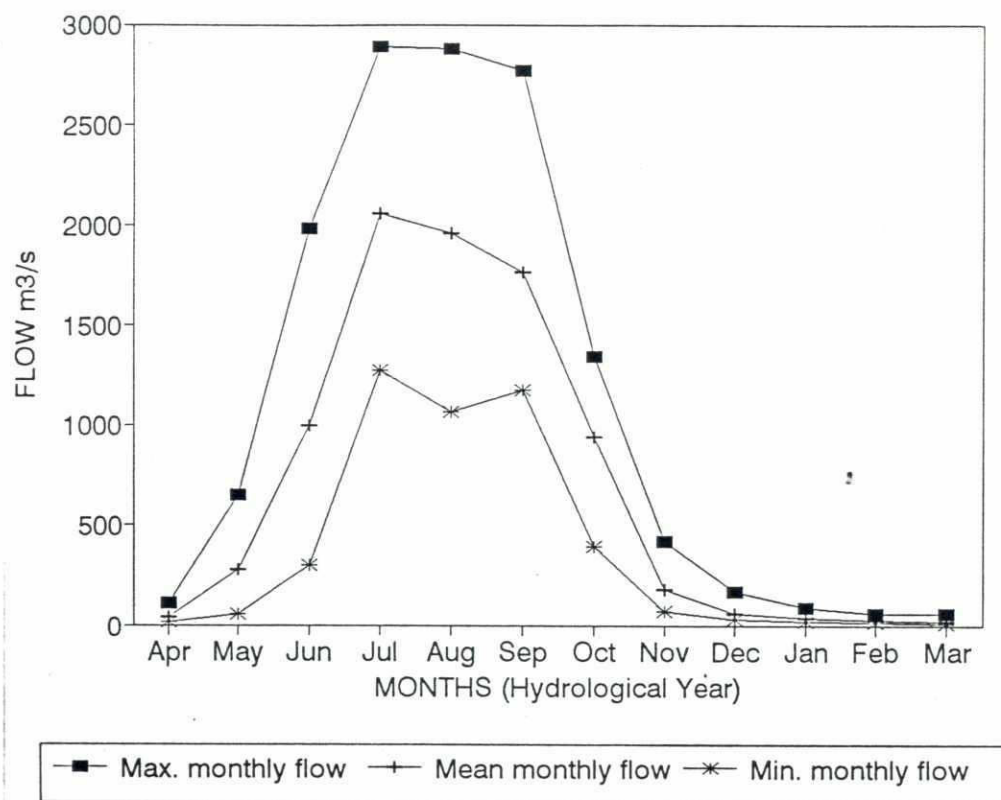


Figure 3.28 Monthly flow regime of the Old Brahmaputra at Mymensingh

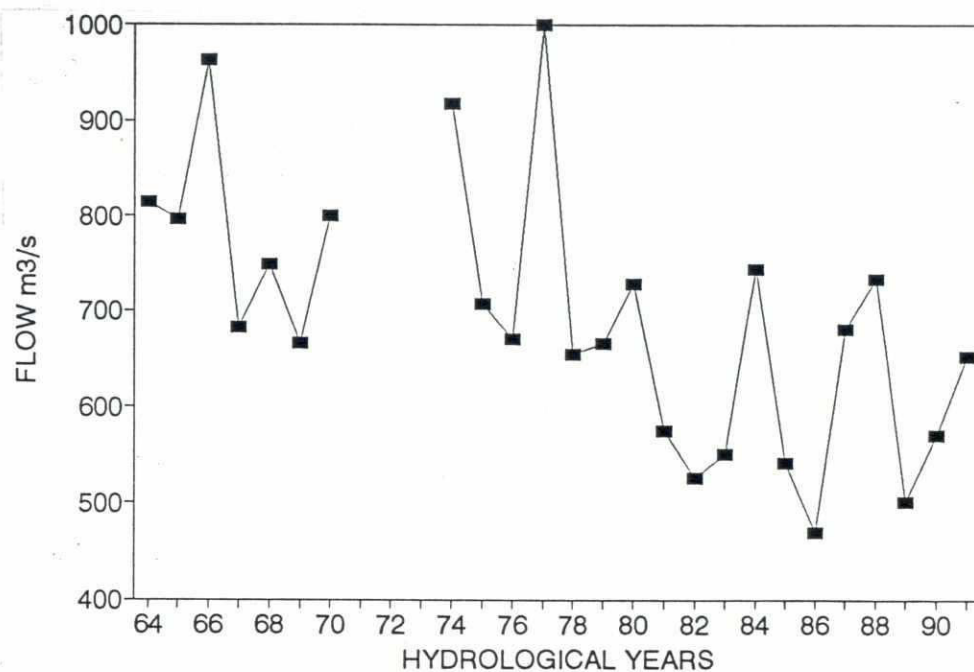


Figure 3.29 Trend of annual flow of the Old Brahmaputra at Mymensingh

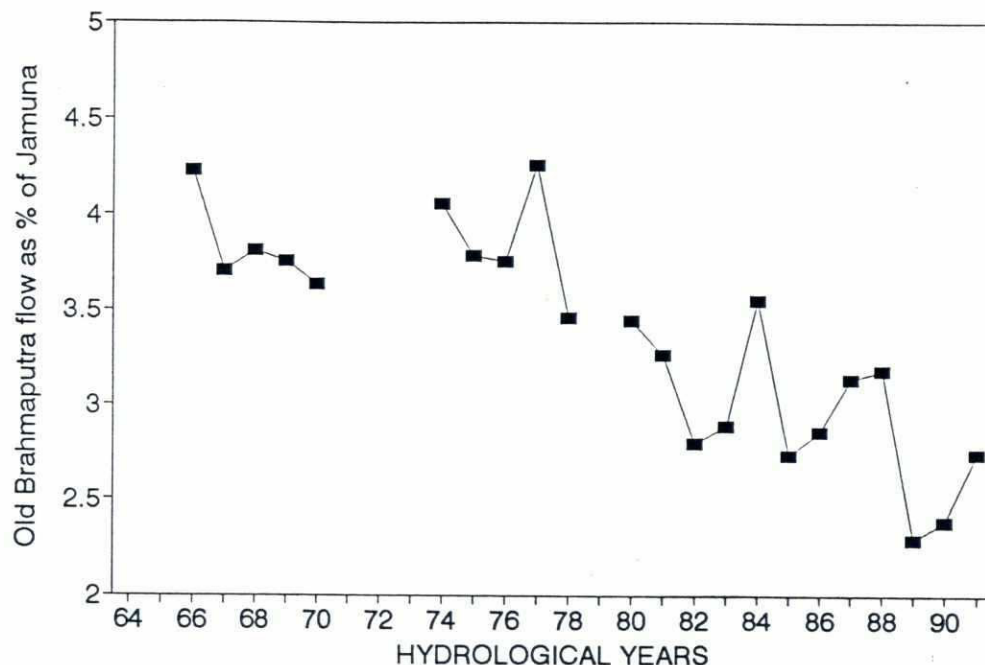


Figure 3.30 Trend of Old Brahmaputra flow as % of Jamuna

River characteristics

The Old Brahmaputra is the original course of the Brahmaputra and during the last 200 years, the river was gradually abandoning the course in favour of the new course, the Jamuna. The Old Brahmaputra has retained the braided course upstream of Mymensingh and the areas close to the offtake, Dewanganj and Jamalpur suffer from bank erosion. The river down stream of Mymensingh however shows a more stable meandering course.

Suspended sediment transport rates for coarse sediment at Mymensingh is available with the River Survey Project for the period 1966-1969. The derived relations for coarse suspended bed material load reads as:

$$S = 0.0188 * Q^{1.793}$$

Where S is in tons/day and Q is in m³/s.

3.5.2 Dhaleswari

General aspects

After the Old Brahmaputra, the Dhaleswari-Kaliganga system is the next major distributary on the left bank of Jamuna. At Tilli, some 48 km downstream from its offtake in the Jamuna, the Dhaleswari bifurcates into

the Dhaleswari and the Kaliganga and reunite at Kalatia before finally draining into the Meghna near Munshiganj (Figure 3.27).

According to the BIWTA route map, the river is 153 km long. There are 8 water-level gauges maintained by BWDB, and the discharge is measured at Jagir on the Dhaleswari branch, and at Taraghat on the Kaliganga branch. Each of these two locations are some 64 km downstream from the offtake.

Hydrology

Like the Old Brahmaputra, the Dhaleswari is also a loop channel between the Brahmaputra-Jamuna and the Meghna. As a result, the hydrology of the river in its upper reach is influenced by the hydrology of the Brahmaputra-Jamuna and in its lower reach is influenced by the hydrology of the Meghna as well. In addition, the river has a large local drainage area, through the Bangshi-Turag river.

The monthly flow (maximum, mean, and minimum) is shown in Figure 3.31 which represents the total flow of the Dhaleswari and the Kaliganga for the period 1964-91.

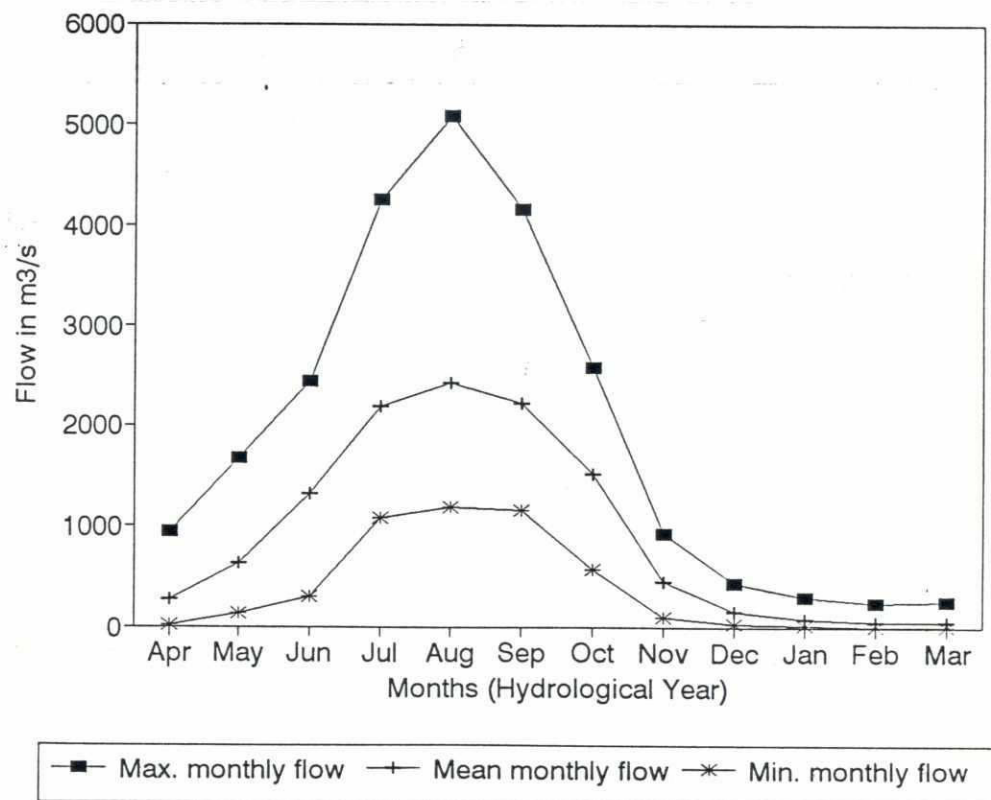


Figure 3.31 Monthly flow regime of the Dhaleswari.

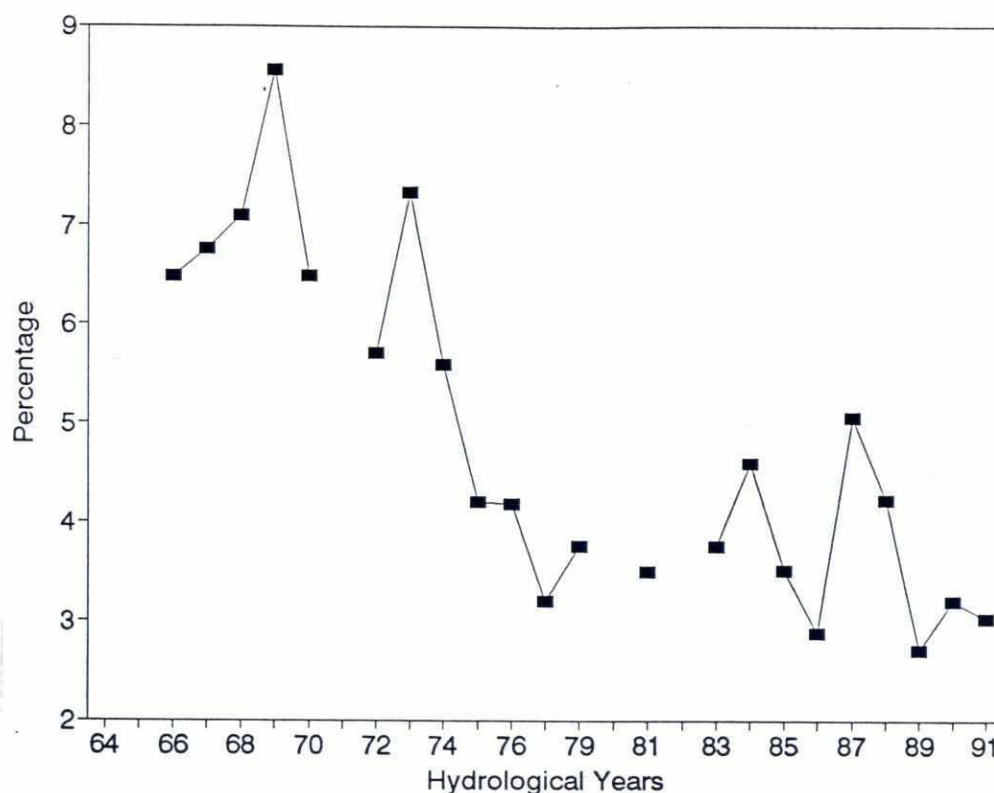


Figure 3.32 Trend of annual flow of Dhaleswari as % of Jamuna flow

Figure 3.32 shows the trend of the Dhaleswari River flow as % of the Jamuna flow. It is noticed that from the mid sixties to the mid seventies the Dhaleswari flow has rapidly reduced from about 7% to 3.5%.

Comparison of the trends of the Old Brahmaputra with the Dhaleswari shows that in both the rivers the flows are substantially decreasing but the years in which this happened are different.

River Characteristics

Because of the shifting characteristics of the Jamuna River, the reach close to the offtake is unstable. Lateral migration of some 2 km with simultaneous down valley translation are observed in aerial photographs. The downstream channels of the Dhaleswari system are relatively old and appear to have reached a mature regime whilst the upstream ones are unstable (NCRS, 1993).

Main morphological characteristics of the Dhaleswari river system are tabulated in Table 3.2

RIVER	Qbank m ³ /s	slope cm/km	depth m	width m	length channel	length valley	sinuosity	river pattern
Upp. Dhaleswari	2100	6.0	7.0	300	40 km	25 km	1.60	sinuous point-bar
Mid. Dhaleswari	1700	4.5	7.0	250	20 km	12 km	1.66	sinuous point-bar
Kaliganga	1700	3.7	9.5	200	49 km	34 km	1.44	sinuous point-bar
Low. Dhaleswari	3000	2.7	10/11	250/300	26 km	21 km	1.25	straight
Old Dhaleswari	200	3.3	3.0	60	62 km	30 km	1.90	meandering
Barinda	400	5.8	2.0	100	52 km	33 km	1.57	meandering
Bangshi South	1300	3.1	10/15	150	25 km	21 km	1.20	sinuous canaliform
Upp. Jhenai	300	3.7	5.0	120	37 km	30 km	1.23	sinuous point-bar
Low. Jhenai	?	5.6	3/4	40/50	85 km	61 km	1.40	meandering
Upp. Bangshi	?	4.2	4.0	50	32 km	18 km	1.80	meandering
Pungli	350	6.7	4/5	80	53 km	38 km	1.40	sinuous point-bar
Bangshi-Pungli-Turag	1300	3.9	7.0	100	78 km	60 km	1.30	meandering
Buriganga	1300	1.5	10/14	150/200	39 km	38 km	1.0	straight
Lakhya	1700	3.0	10.0	200/250	65 km	53 km	1.20	sinuous canaliform
Old Brahmaputra								
--> Jamalpur	2800	8.4	6.0	500	48 km	40 km	1.20	sinuous point-bar
--> Hymensingh	2800	7.4	6.0	200/300	62 km	49 km	1.24	sinuous point-bar
--> Toke	2800	5.8	8.0	200/300	80 km	61 km	1.30	sinuous point-bar

Table 3.2 Regional rivers - main morphological characters

Suspended sediment data are available with the River Survey Project for Jagir and Taraghat. The Dhaleswari at Jagir started silting up in late sixties, the Kaliganga in the late seventies. The flow in the Kaliganga is stronger than in the Dhaleswari during flood condition. Coarse suspended sediment transport data are available at Taraghat for the periods 1967-1969 and 1970-1988 and at Jagir for the period 1967-1969. Fine suspended sediment transport data are available at Taraghat for the period 1967-1970 and at Jagir for the period 1967-1970. The analysis of the River Survey Project reveals that the sediment measurement at Taraghat for the periods 1967-1969 and 1970-1988 is consistent. The coarse sediment transport at Jagir is approximately 15 percent of the transport at Taraghat. Analysis of these data will be presented in the forthcoming Morphological Report of the River Survey Project.

The empirical relations derived by the River Survey Project for the coarse and fine suspended material transport read as:

For coarse sediment:

$$S = 1.767 * Q^{1.247} \text{ at Taraghat, for the period 1967-1969}$$

$$S = 2.03 * Q^{1.238} \text{ at Taraghat, for the period 1970-1988}$$

$$S = 1.15 * Q^{1.394} \text{ at Jagir, for the period 1967-1969}$$

For fine sediment:

$$S = 0.0107 * Q^{1.78} \text{ at Taraghat, for the period 1967-1969}$$

$$S = 597.7 * Q^{0.612} \text{ at Jagir, for the period 1967-1969}$$

Where S is in tons/day and Q is in m³/s

The average yearly coarse suspended sediment transport at Taraghat is approximately 3 million tons and fine suspended sediment transport is approximately 13.7 million tons. The average yearly coarse suspended sediment transport at Jagir is approximately 0.4 million tons and fine suspended sediment transport is approximately 2.7 million tons.

3.5.3 Gorai

General aspect

The Gorai is a major right bank distributary of the Ganges River (Figure 3.33). The Gorai River passes through the center of the northwest region and debouches into the Bay of Bengal through the Kunga and Haringhata estuary. The river is very important for the southwest region as it conveys fresh water in the saline zone around Khulna.

Hydrology

The mean monthly flow of the Gorai River is shown in Figure 3.34. The annual peak discharge of the river ranges from 8490 m³/s to 4250 m³/s with an average of 6320 m³/s.

The Gorai along with its parent river the Ganges has been affected by the reduced flow due to the withdrawal at Farakka. The trend of the annual flow of the Gorai expressed as percent of the Ganges flow, shows that the flow through the Gorai is declining. From the mid sixties the Gorai flow has reduced from say 16% to about 11% by the early nineties (see Figure 3.35).

River characteristics

The Gorai is a meandering river in planform. It is likely that the Gorai is adjusting its channel geometry to its reduced share of the Ganges flow.

Suspended sediment transport rates at Gorai Railway Bridge are available with the River Survey Project for the period 1966-1970 for coarse suspended sediment transport, and for the period 1967-1970 for fine suspended sediment.

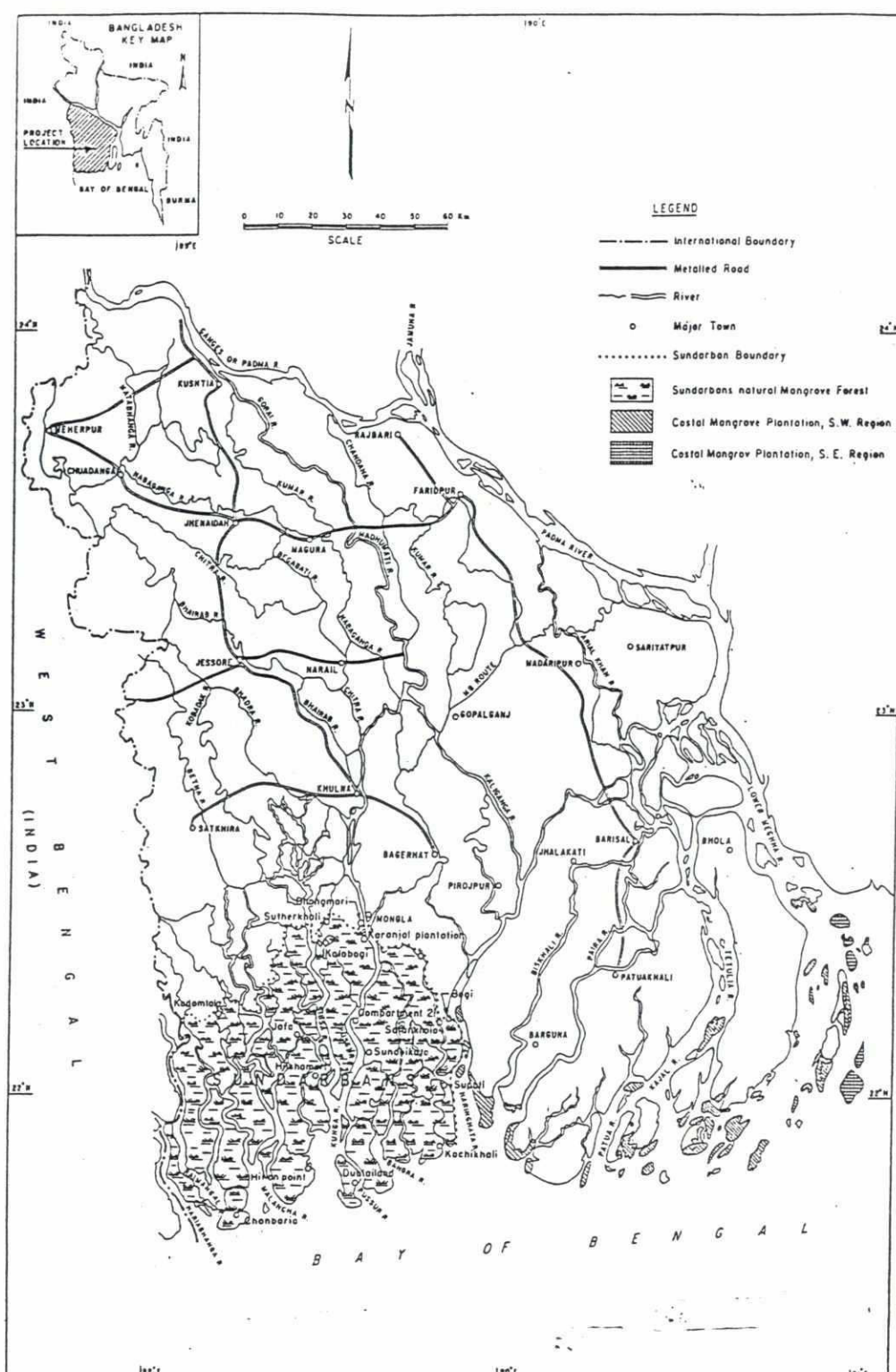


Figure 3.33 Southwest region

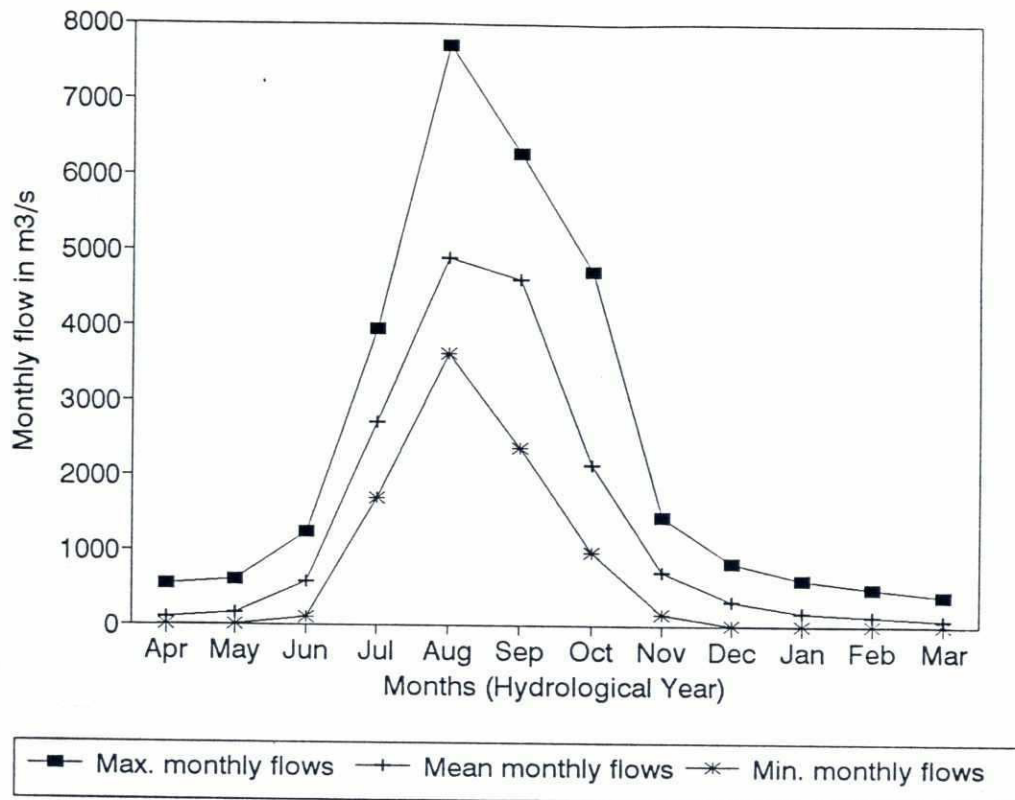


Figure 3.34 Monthly flow regime of the Gorai at Gorai Railway bridge

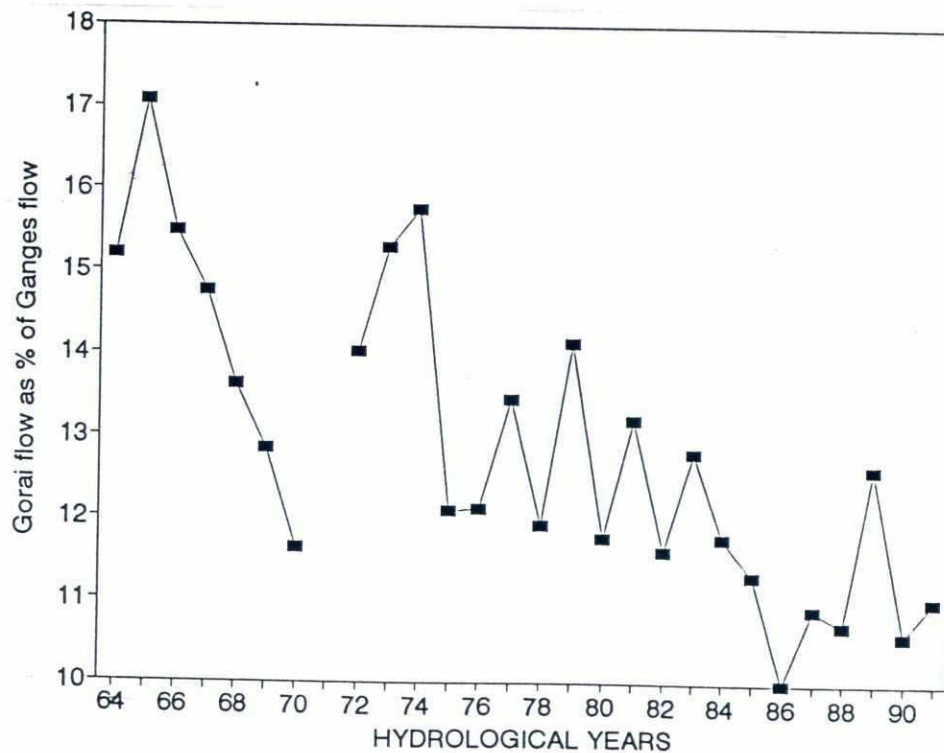


Figure 3.35 : Trend of annual flow of the Gorai as % of Ganges flow

The empirical observation for the Gorai River by the River Survey Project indicates the following relations:

For coarse sediment:

$$S = 4.59 * Q^{1.249} \text{ for the period 1966-1970}$$

For fine sediment:

$$S = 0.524 * Q^{1.57} \text{ for the period 1967-1970}$$

Where S is in tons/day and Q is in m³/s

The average yearly coarse suspended sediment transport is approximately 17 million tons and the fine suspended sediment transport is approximately 29 million ton.

3.5.4 Arial Khan River

General aspect

The Arial Khan is a right bank distributary of the Padma River some 20 km upstream of Mawa. The offtake of the Arial Khan is seasonally tidal and the lower reach of the river discharges into the Bay of Bengal through various branches.

Hydrology

Mean monthly flow of the Arial Khan is shown in Figure 3.36. The annual peak discharge of the river ranges from 4,890 m³/s to 1,130 m³/s with an average of 2,568 m³/s.

The Arial Khan River has more than one offtake and the river is gauged at its main offtake at Chowdhury's char. The trend of the annual flow at the main offtake is shown in Figure 3.37. The trend shows a gradual increase of annual flow in the Arial Khan from about 500 m³/s in the mid sixties to over 1,000 m³/s in the late eighties. Since the river has more than one offtake, it is difficult to infer from the figure whether the total flow of the Arial Khan is really increasing.

River characteristics

The Arial Khan is a meandering river with the meander bends migrating downstream, and some of its meander bends develop cutoffs causing extensive damages to agricultural lands.

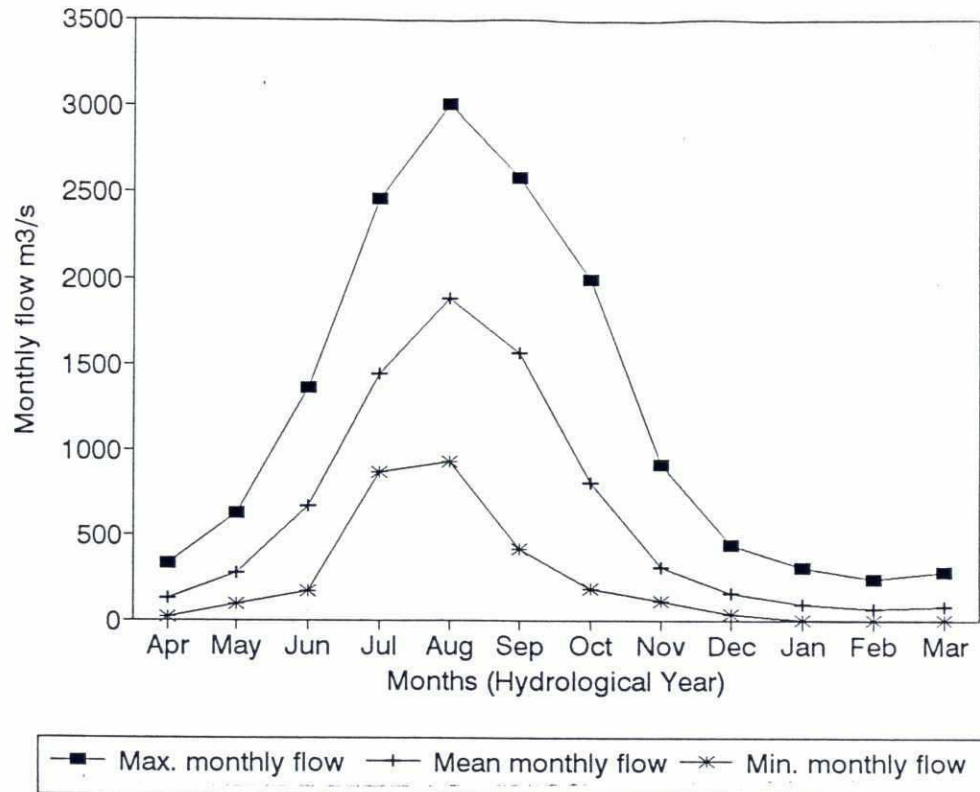


Figure 3.36 Monthly flow regime of the Arial Khan

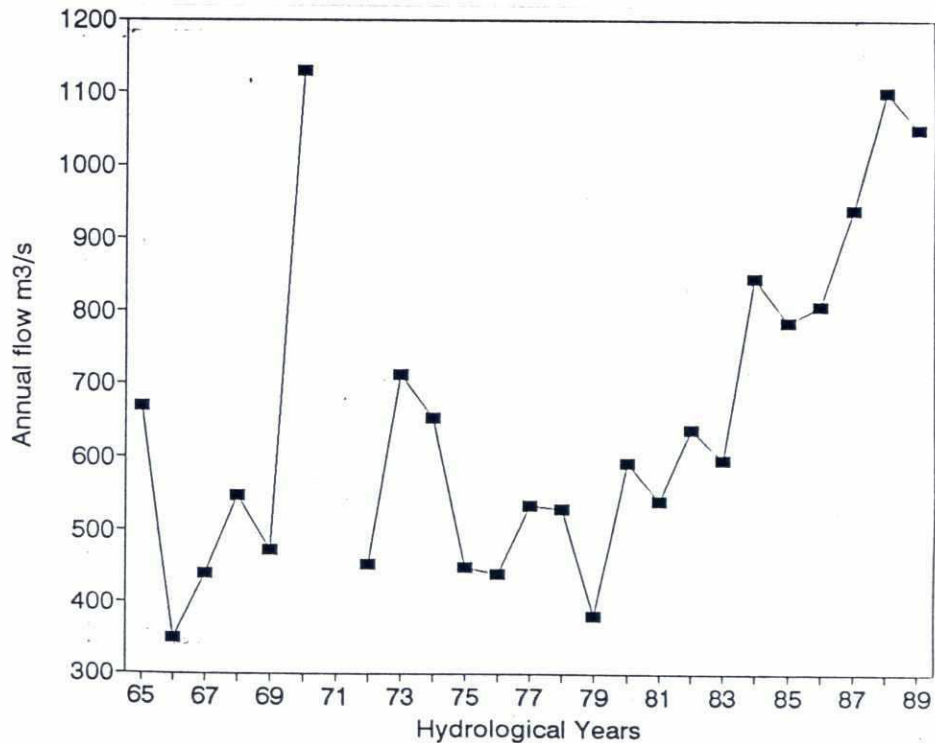


Figure 3.37 : Trend of Annual flow at the offtake of Arial Khan

3.6 Interaction between the different reaches

3.6.1 General

The conditions in the main rivers and in the distributaries are influenced by the interaction between the different river reaches. This interaction takes place where these reaches are linked. Typically these links are at offtakes and at confluences. In this section these interactions are discussed, where a distinction is made between:

- o interaction at offtakes, and
- o interaction at confluences.

For reasons of simplicity the discussion in the subsequent section is limited to confluences of two rivers and to offtakes where one distributary takes off from a main river. Initially steady and 1-dimensional conditions are discussed, but in a second step also variable discharges are taken into account. Finally also 2-dimensional aspects will be discussed. Hereafter first confluences are considered as they are relatively simple. After that the conditions near offtakes are reviewed. The emphasis of the discussion is on the effect of the conditions at the confluence and the offtakes on the adjacent river reaches.

3.6.2 Interaction at confluences

First consider a simple confluence of two rivers, numbered 1 and 2. See Figure 3.38. Downstream of the confluence only one channel remains, channel 3. Consider first also steady flow and hence steady sediment transport conditions. Furthermore 1-dimensional conditions are assumed. This means that the differences in lateral direction are assumed to be minor, and width-averaged parameters can be used.

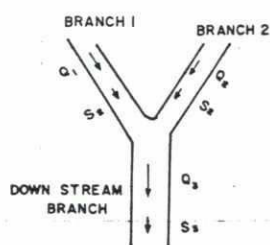


Figure 3.38 Schematized confluence with used nomenclature

For the internal boundary conditions at the confluence it holds that the continuity of flow and sediment transport has to be fulfilled. This means that:

$$Q_1 + Q_2 = Q_3$$

where Q_i = discharge in river i , and furthermore:

$$S_1 + S_2 = S_3$$

where S_i = sediment transport in river i . Hence the discharge in the downstream river 3 are given. This means that given the width of river 3 (the width probably given by a regime equation), and based on the imposed discharge and sediment transport, the slope and depth of the downstream river are determined. For these steady conditions in all three rivers uniform conditions will be present. The water depth in the downstream river will usually be larger than in anyone of the upstream rivers, hence there will be in addition to a difference in slope, also be a "step" in bed level.

Turning now to the unsteady conditions (e.g. with a yearly hydrograph in each of the upstream rivers), it holds also here that at any time:

$$Q_1 + Q_2 = Q_3$$

For the sediment transport it holds that on the average all the sediment that is supplied at the upstream side has to be transported in the downstream reach. Hence for the sediment transport it holds that:

$$\int S_1 dt + \int S_2 dt = \int S_3 dt$$

where the integration is carried out over e.g. the whole year. Also in this case the slope of the downstream river will be adjusted in such a way that on the average the flow but in particular the sediment that is supplied at the confluence can be transported.

The water-level in the downstream river will hardly ever be such that in the upstream reaches uniform flow exists. More common the typical flow profile will either be a drawdown curve or a backwater curve, depending on whether it is low flow or flood, but more importantly on the discharge is the other confluencing channel. In alluvial rivers such deviations from uniform flow will give rise to either degradation (drawdown curve) or aggradation (backwater curve). Hence the reaches upstream of a confluence are in real rivers all the time adjusting but at the same time fluctuating around an average bed level. Hence it is a truly dynamic equilibrium.

Similarly it can be shown that downstream of the confluence alternating aggradation and degradation does occur. This gives rise to the generation of sand waves which travel through the downstream river. Hence the picture that emerges of a confluence of rivers with realistic hydrographs is a system in which all the time adjustments are taking place, and where sand waves are generated and are travelling through the downstream reach. This dynamic system is schematically indicated in Figure 3.39

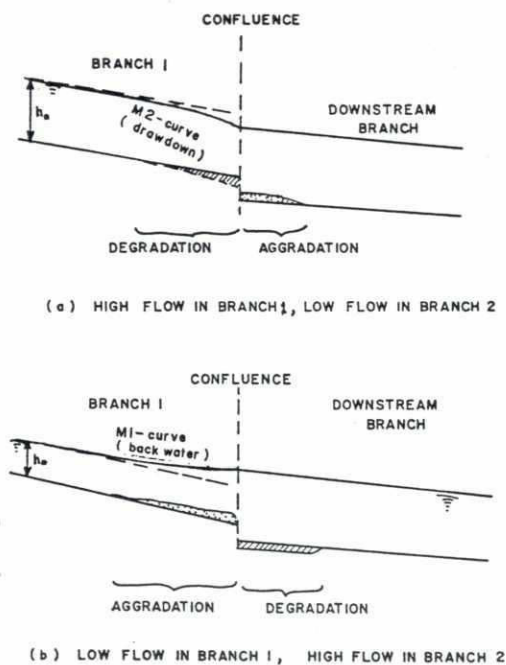


Figure 3.39 Dynamic equilibrium around a confluence

The 2-d bed topography and the 3-d flow pattern make the conditions even more complicated. Due to the chars travelling through the system, the actual location of the confluence varies over the years. The degradation of the upstream reaches during the occurrence of drawdown curves takes place in existing channels rather than on chars (see also Germanonski and Schumm (1993) for a recent experimental study into this phenomenon). This means that during the whole year a re-distribution of the sediment has to take place in lateral direction too, otherwise there is no dynamic equilibrium. Finally it should be mentioned that downstream of the confluence a deep scour is usually present, often referred to as the confluence scour. Design graphs for estimating of the depth of these scour holes are available (Klaassen and Vermeer, 1988a).

Summarizing it can be stated that:

- o Confluences give rise to the so-called dynamic equilibrium behaviour
- o This dynamic effect is most pronounced immediately upstream of the confluence, but reduced in upstream direction (after some tens of kms the effect is hardly noticeable
- o In the downstream channel sand "waves" are generated which travel in downstream direction and are dampening while doing this
- o The specific conditions, and hence the river characteristics, of the confluencing rivers and also of the downstream river are not really affected by the presence of the confluence
- o Some more 2-dimensional complicated phenomena occur near the confluence

but on a larger scale the interaction at confluences is not of major importance for the development of the upstream and downstream rivers.

3.6.3 Interaction at offtakes

At offtakes the conditions are much more complicated than at confluences, and it will be shown that they are very important for the characteristics and even pure existence of distributaries. This is due to the fact that here 2-and even 3-dimensional effects are much more influential, as will be discussed hereafter. In this section the emphasis is mainly on distributaries branching off from main rivers, because in the context of the main river system this is quite relevant. The behaviour at bifurcations in braided rivers is quite similar and this will be discussed at the end of this section.

First consider again a simple bifurcation and steady conditions, and assume furthermore that the main river and the offtake channel can be schematized as 1-d channels where the width and variations in the width can be neglected. See Figure 3.40 for the schematization. The upstream channel is referred to as channel 1, while the two downstream channels are referred to as the channels 2 and 3.

For the flow it holds (because of reasons of continuity) that :

$$Q_1 = Q_2 + Q_3$$

but this is not sufficient to find magnitudes of Q_2 or Q_3 . The other requirement that should be fulfilled at the offtake is that the stages in both downstream river reaches are equal. Should there be a difference then a redistribution of discharge will take place until this condition is fulfilled.

The discharge distribution is hence determined by the conveyance of the two downstream reaches.

For the sediment it holds that

$$S_1 = S_2 + S_3$$

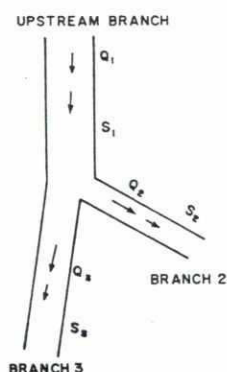


Figure 3.40 Schematized offtake with used nomenclature

but also here the magnitude of S_1 and S_2 cannot be established in a straightforward way. The problem here is that this sediment distribution depends on three parameters, notably:

- o The discharge distribution Q_1/Q_2
- o The importance of bed load relative to suspended bed material load, often characterized by the value of u_* / w , where u_* is defined via:

$$u_* = \sqrt{ghi}$$

and w = fall velocity of the sediment

- o The geometry of the bifurcation

The geometry is usually discussed in terms of the angle of the offtake channel relative to the angle the main channel downstream is making with the upstream channel and the location of the offtake relative to location in the curved channel (Vanoni, 1976). It should be realized that in the case of the rivers in Bangladesh chars that travel through the system may have a pronounced influence. Hence the amount of sediment entering the downstream channels is quite variable in time. This also has repercussions for the conditions in the upstream reaches of these downstream channels: they are subjected to either aggradation or degradation, but again as a

dynamic equilibrium. This is schematically indicated in Figure 3.41

This is even more pronounced when a variable discharge is taken into account. This has influence on the value of Q_1/Q_2 , and also on the quantities of sediment transport entering into the distributary because of the influence of the geometry.

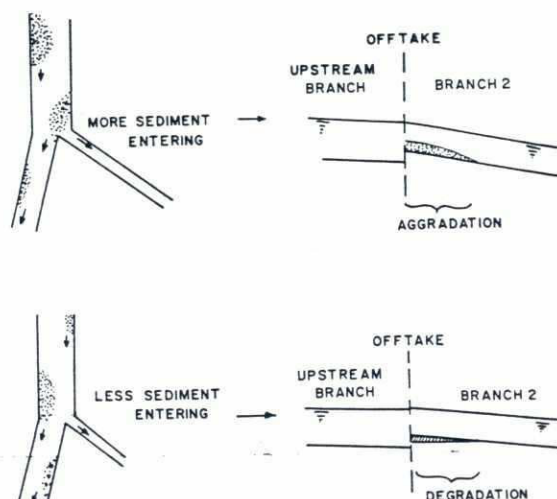


Figure 3.41 Dynamic equilibrium around a offtake.

In addition it may be that in front of the offtake a char is present. During falling stage the water depths over this char will reduce. At the same time the char level will probably lower due to (retarded) erosion, as the char level for lower discharges corresponds to a low char level. Usually however the falling of the stages goes faster than the lowering of the char level and hence the chars emerge from the river. At that moment the scouring stops. The connection between the main river and the offtake in this case is a channel in the char. During the falling stages also this channel has to scour to keep the connection between the main river and the offtake. This scour however is also retarded and it may be that it is not able to keep ahead of the falling of the stages. Hence there is the risk that during low flows there is no connection any more and no water is entering in the offtake. This is exactly what is happening at the offtake of the Gorai River, probably also because the retarded scour in the Ganges River is less pronounced than before due to the Farakka Barrage. Similar phenomena will also occur at the oftakes of the Old Brahmaputra and the Dhaleswari Rivers.

A possible solution is to open up the connection by dredging, but whether

this really is effective depends also on the conditions in the distributary downstream of the offtake. Here the conditions of the river are fully governed by the quantities of water and sediment that at the offtake enter into the distributary. If relatively too much sediment is entering the river has to react with increasing its slope. As a consequence the water-levels will rise resulting in even less water entering into the distributary. Hence, here a process starts that may accelerate itself. The process may result in the "dying" of the distributary.

Also theoretically it has been shown that, although there may be some form of equilibrium at a bifurcation for quite some time, this may suddenly and relatively quickly result in closing of one of the branches (Wang et al, 1992). It seems that some of the old branches of the Ganges River have experienced this and there is some evidence that also the major distributaries of the Jamuna River are experiencing the same fate (see the previous Section 3.5). At present it may hold also for the Gorai River, which in the past had a flow regime which was clearly affected by the chars in the Ganges River, but at present also appears to deteriorate.

Finally the attention is drawn to the similarity of offtakes and bifurcations in braided rivers. Under FAP 21/22 it was shown that downstream channels of a bifurcation may quickly lose their importance depending on the geometry of the bifurcation (see Figure 3.9). Also this shows the importance of the geometry of the bifurcation. It was shown (FAP 21/22 Final Report, Annex 11, see also Mosselman et al, 1993) that for braided rivers like the Jamuna River the geometry is dominant over the cutoff ratio (Klaassen and van Zanten, 1989).

Summarizing it can be stated that:

- o The distribution of flow and discharge over a main river and a distributary are influenced by different factors, of which downstream conveyance and geometry of the bifurcation are the most important
- o In Bangladesh also chars may play a very important role
- o The natural tendency of distributaries is probably gradual "dying"
- o The "fate" of the distributaries is almost completely determined by the phenomena at the offtake
- o There is a clear similarity between an offtake and a bifurcation in a braided river, and also for bifurcations it holds that the geometry is very important

Hence, on a larger scale the offtakes play a major role in the development of the main river system in Bangladesh, in particular as far as the

distributaries is concerned.

3.7 Flooding, overland flow and sedimentation

Until now the considerations presented here are limited to the main channels. In addition it is important to consider what is happening during the above bankfull discharges. For the Jamuna River the bankfull stage corresponds to about 44,000 m³/s and on the average this discharge is 2.5 months a year exceeded. Hence the phenomena occurring at that time are quite important for the river system.

The main questions are to what extent overland spilling is an important contribution, and whether this brings substantial amounts of fine sediments to the fields. This could happen not only from the main rivers but also via the distributaries towards the interior of Bangladesh.

At this moment information on this issue is almost completely lacking. Existing information appears to suggest that the contribution of overland flow to the total flood discharge is fairly low and hence the quantities of sediment depositing on the lands that origin from the main rivers may also be fairly small. More insight is needed before the importance of this issue can be assessed. For the time being it can therefore not be neglected.

3.8 Autonomous development

Autonomous development is the development that the river system is undergoing under the influence of outside controls (read independent variables). As discussed in Section 2.2.2 these outside controls are variables related to the catchment and in particular like climate and the geology (including its tectonics) of the catchment and the base level of the system. Hence, a discussion of the autonomous development should concentrate on these issues. Even when they are constant the river is experiencing changes due to the gradual changes e.g. due to an imbalance between uplift of the (upper part of the) catchment and the erosive forces and any delta formation at the downstream end of the river. It may be argued whether climate changes and related sea level (=base level) rise should be included in the autonomous development. Here this is supposed to be the case, and hence the considerations in the next section ("Human impact") are limited to physical interferences with the river system.

The geological setting of the catchments of the Ganges and the Brahmaputra Rivers was discussed in Section 3.3. There is a fair balance between uplift of the Himalayas and the erosive action due to weathering. Hence it may be assumed that the sediment supply to the river will remain fairly constant, at least as far as undisturbed conditions are concerned. The influence of an eventual climate change as induced by pollution of the atmosphere, may have an effect on the

erosive forces in the Himalayas, but no study results and/or data are available to estimate the effect of such a change. See also Section 2.2.4 on the response time of the system.

At the downstream end of the river is the active delta. Growth of this delta is far less than may be expected from the huge sediment supply by the river system (Fergusson, 1863; 1963; and Coleman, 1969), certainly not comparable with the Mississippi River or the Yellow River. This is true despite the fact that some coastal islands grew seaward by about 50 km during the last two centuries (Barua and Koch), 1985). Several likely explanations are provided by different investigations. The most attractive explanation attributes the presence of a submarine canyon, the 'Swatch of No Ground' at the river mouth. Most recent evidence in support of this hypothesis comes from Kuehl et al (1989), Segall and Kuehl (1992) and Barua (1992). Dating of sediment cores obtained from the canyon suggests a high accumulation rate in the region (Kuehl et al, 1989. Segall and Kuehl (1992) observed different clay size mineralogical distribution on both sides of the canyon suggesting trapping of sediments by the canyon. Some dynamical evidence is shown by Barua (1992) which indicates a residual flow pattern toward the canyon during the fall of the monsoon. However, what happens during the monsoon is not known. The strong argument against this explanation comes from Emmel and Curry (1985) who could not document any evidence of recent deposits on the deep sea Bengal Fan. They, therefore, suggested that sediments are being trapped in the lower deltaic plain by the Holocene Transgression. In the light of the above discussion, it seems that some uncertainties remain on the backwater effect induced by an advancing delta.

Hence, there is no backwater effect of an advancing delta for the natural case. Over the coming decades, however, backwater may be induced by a possible sea level rise and this will result in rising stages in the upstream reaches. This will definitely affect the drainage of the interior regions of Bangladesh.

Under the Jamuna Bridge Study, Phase II a special study was carried out into "general scour" (RPT/NEDECO/BCL, 1990b), using essentially a 1-dimensional modelling approach including the whole alluvial reach of the Brahmaputra River from the Chinese border to the confluence with the Ganges River. In this model also the influence of sea level rise was studied and it was found that this becomes quickly noticeable upstream due to the quick response time of the river system.

Finally also the local tectonic activity in Bangladesh should be mentioned here as a factor that may induce autonomous development. There is some evidence (see Hartmann et al, 1993 or Mosselman et al, 1993) that the planform of the Jamuna River is affected by these local tectonic effects. Also the gradual movement of the upstream Jamuna River in wester direction may be explained by tectonic effects. In the past there have also been suggestions that tectonic activity has been

responsible for the avulsion of the Brahmaputra to its present Jamuna course (Morgan and McIntyre, 1959). Furthermore the rapid lowering of the Haor area in Sylhet and its possible consequences at the long term may be indications of the importance of the local tectonics for river processes in Bangladesh.

Summarizing it can be stated that the possible autonomous development, including sea level rise and local tectonics, may have a profound influence on the main river system in Bangladesh.

3.9 Human impact

The human impact on the main river system appears to be fairly minor until now. Hereafter the main human interventions with the river system are summarized, together with their potential effect:

- o Embankments in India along the Brahmaputra, which may have led to the reduced storage of flood water in India and hence an increase of the (moderate) floods (but not of the highest ones!)
- o Abstraction of water from in particular the Ganges River mainly during the low flow season, resulting in lowering stages downstream, but not causing major changes in characteristics of the main rivers
- o Farakka Barrage which diverts substantial amounts away from the Ganges River, in particular during the low and moderate flow conditions, which causes reduced retarded scour and reduced flows into the Gorai River
- o Embankments along most of the main rivers in Bangladesh, their level however often less than the stage of the highest floods and sometimes not in a good shape a.o. due to damage owing to continuing bank erosion
- o At some locations in Bangladesh impressive bank protection works, like in Sirajganj and in Chandpur, which locally have had a pronounced effect on the river course
- o Locally some dredging like at ferry sites and at critical points for navigation by BIWTA and for the Ganges-Kobadak Irrigation Project

Overall, however, human intervention with the main rivers has had minor impact up to now.

4. FAP project components

4.1 Introduction

This Chapter describes the different component of the Flood Action Plan (FAP). The discussions presented here mainly serve to highlight those projects and aspects of the FAP that may affect the conditions in the main river system. The ultimate purpose is to identify any deficiencies in knowledge and understanding of the main river system which affects adversely the preparation of the project plans and which may make it more difficult to assess the impact of the proposed projects. This identification is presented in Chapter 5.

For the purpose of the present discussion FAP can roughly be divided in three different types of projects, notably:

- o Regional studies
- o Bank protection studies, and
- o Supporting studies

Hereafter the various relevant FAP projects are discussed under these headings. Regarding the supporting studies not only those that may affect the river via physical measures are summarized but also attention is drawn to some FAP projects that may be of assistance to the purpose of the FAP 24 project or with which cooperation may be possible.

4.2 Regional Studies

4.2.1 Introduction

Five regional projects were undertaken under the Flood Action Plan (Fig. 4.1). Regional water resources management issues are addressed in these projects. The planned activities of these projects (when completed) would affect the hydro-morphological system of the river network, either by construction of hydraulic structures (such as a drainage sluice, a barrage, etc.) or by placing of embankments on the river bank. However, in most regions embankments or structures were already existing, implemented primarily by Bangladesh Water Development. The FAP regional projects propose either to improve or to change the existing infrastructure with a view to ensure a comprehensive water management. The regional projects provide only a tentative indication of possible initiatives to be investigated in more detail, they do not provide detailed design of structures.

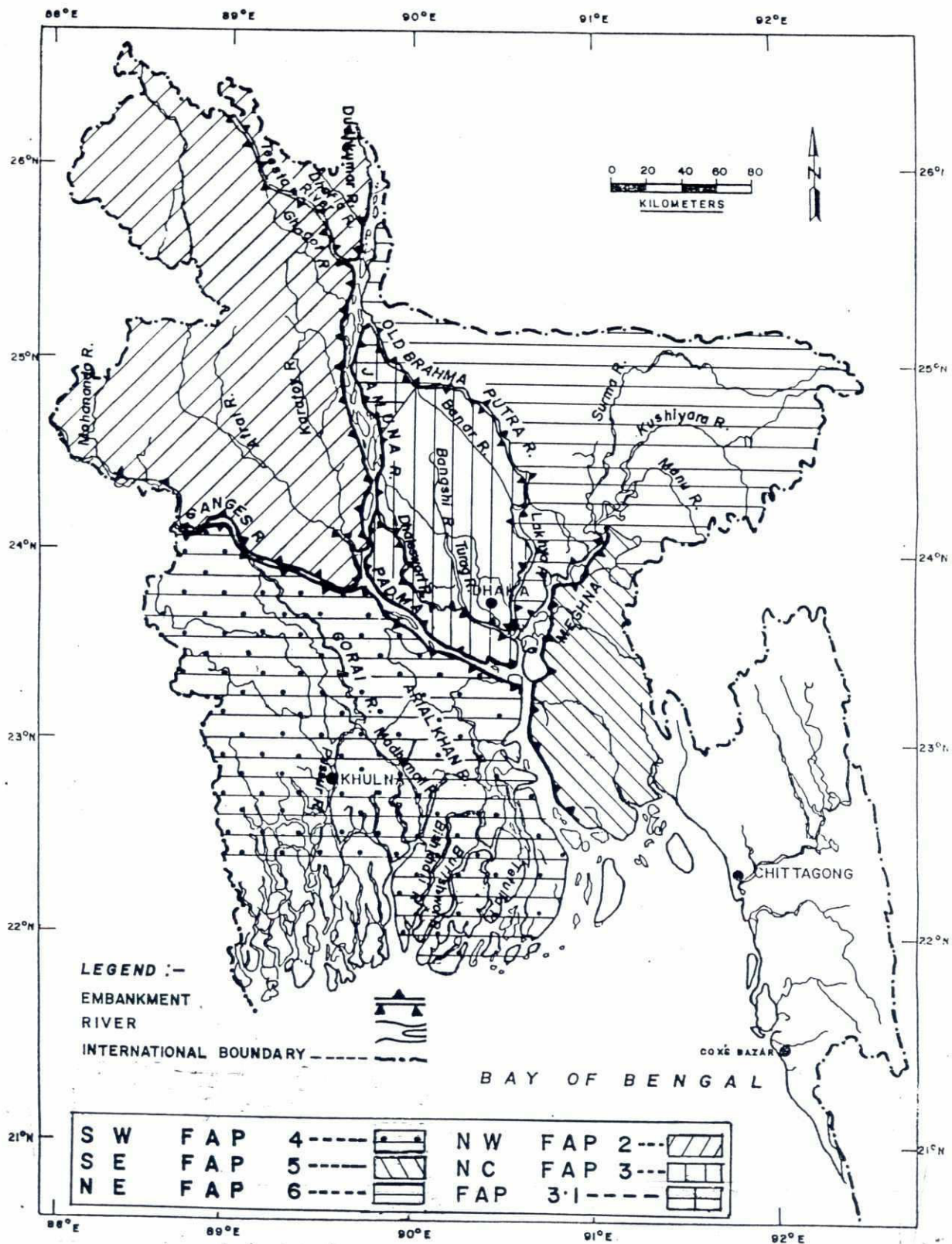


Figure 4.1 FAP regional projects and possible major interventions.

Interventions on the major river system and their possible impacts are discussed in this section by reviewing the physiographic characteristics of each region. The regional and major drainage networks are highlighted with discussion of nature and extent of floods.

4.2.2 FAP 2: Northwest Regional Study

The region is located in the northwest corner of Bangladesh bounded by the Brahmaputra River on the east and the Ganges River on the south. The information provided in this section is obtained from some regional study reports (NWRS, 1992a, 1992b, and 1993). The total area of this region is about 34,200 km². The region can be divided into 5 physiographic units (Alam et al, 1990) each having its own characteristic parameters, they are: (1) the Teesta Fan, (2) the Barind Tract, (3) the Brahmaputra Flood Plain, (4) the Atrai Flood Plain, and (5) the Ganges Flood Plain. The local rivers in this region are tributaries of the major rivers. For example, Darla, Dudhkumar, Teesta and Karatoya-Atrai system are tributaries to the Brahmaputra River and Mahananda is a tributary of the Ganges River. Major causes of flood in the region are the spills from the major rivers, spills from the regional rivers during high local rainfall and last but not least is the impeded drainage of regional rivers due to higher stage in the main rivers. Among the five physiographic units, the Barind Tract is flood free, the Teesta Fan is flooded from the spill-over flows of Darla, Dudhkumar and Teesta rivers. Among the different drainage networks in the region, the Karatoya basin drains some 20% and the Atrai basin drains some 35% of the area.

Several Flood Control and Drainage (FCD) and Flood Control, Drainage and Irrigation (FCD/I) projects were existing in the region which are shown in Fig. 4.2. Under the Northwest Regional Study, the region is divided into 15 planning units. Among the several suggested activities, the relevant ones for morphological impacts on the river system include strengthening of Teesta River right and left embankments and river training works, complete sealing of the existing Brahmaputra Right Embankment (BRE) and river training works, and complete sealing of Ganges Left Embankment (GLE). The construction of BRE extending from Teesta River outfall to Hurasagar is completed in 1960, with occasional breaching of the embankment during high flood stage and by river bank erosion. The other part of the right embankment includes the embankment upstream of Teesta outfall (from the

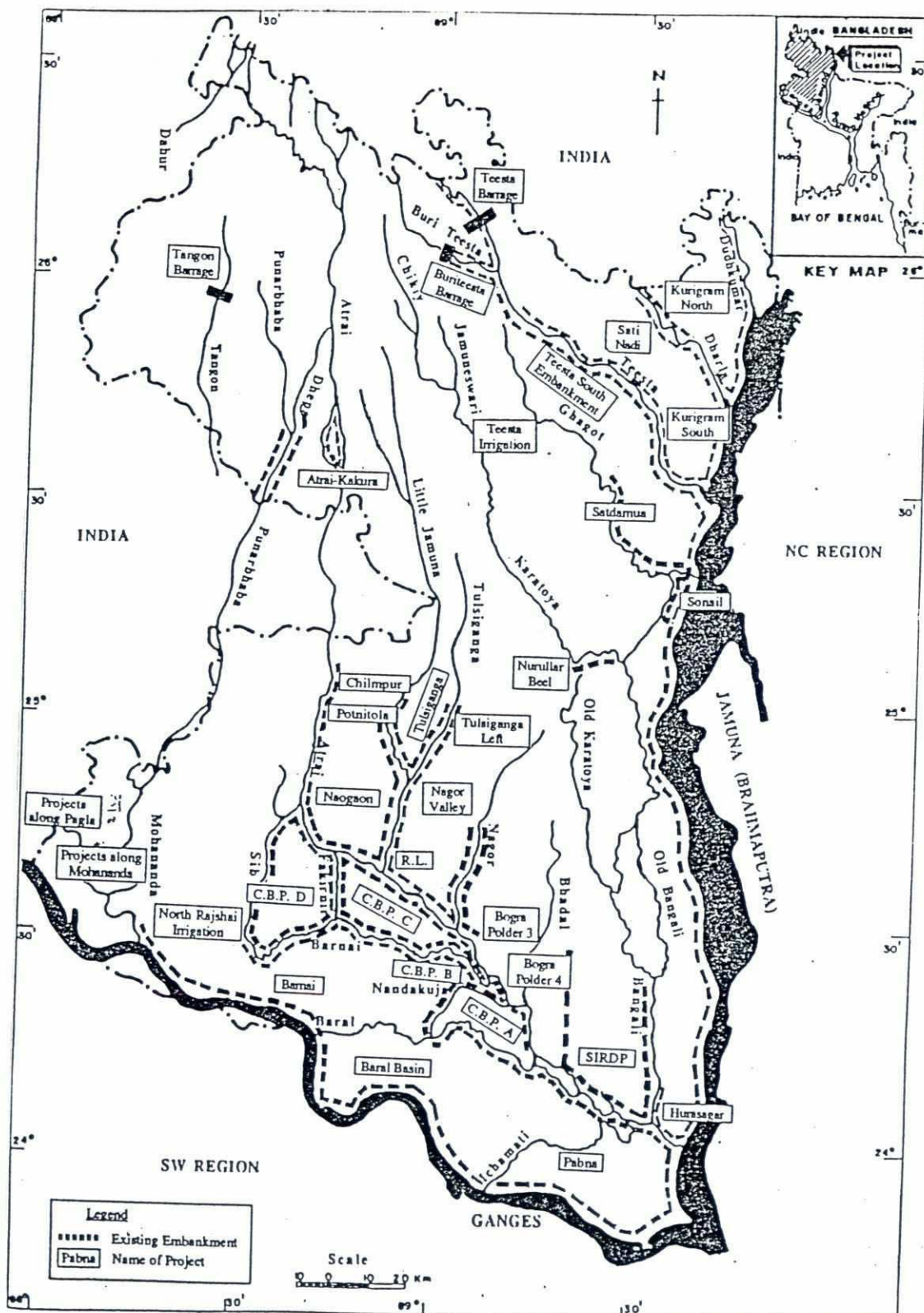


Figure 4.2 Existing water development projects and embankments in the north-west region (after NWRS, 1992a).

Kurigram project) and the embankment downstream of the Hurasagar River (from the Pabna IRD project). The Teesta Barrage (Fig. 4.2), a large hydraulic structure (40 openings), is built on the Teesta River to improve irrigation during low flow of the river.

Apart from FAP 2 some other FAP projects are involved in the study of some kind of interventions in the region. They are (1) strengthening of BRE under FAP 1, (2) evaluation of the impact of previous FCD measures under FAP 12, (3) the compartmental pilot project in the north of Sirajganj under FAP 20, (4) the active flood plain management and the river training pilot project in Gaibandha area under FAP 21/22.

4.2.3 FAP 3: North Central Regional Study

This region is located in the middle of the country bounded by the major rivers, the Jamuna-Padma, the Old Brahmaputra rivers and the Lakhya River in the east (Fig. 4.3). The information provided in this section is obtained from FAP 3 study reports (NCRS, 1993). The total area of this region is 12,000 km². A total of four physiographic units can be identified in this region. They are: (1) the Jamuna flood plain (35%), (2) the Old Brahmaputra flood plain (20%), (3) the Madhupur Tract (30%), and (4) the Padma flood plain (15%). The local rivers in this region are distributaries of the major rivers. The Old Brahmaputra-Banar-Lakhya system is a distributary of the Brahmaputra River flowing through the eastern part of the region. The Dhaleswari-Kaliganga system is also a distributary of the Brahmaputra River flowing through the southwestern part of the region. The Bangshi-Turag river system is a local drainage system which is a tributary of the Meghna River. The Old Brahmaputra and the Dhaleswari systems are although distributaries of the Brahmaputra, they are also tributaries of the Meghna River, forming the so-called loop channels. Flooding of the region is caused by local rainfall during June/July. Spill-over flows from the major rivers are the other major cause of flood. Impeded drainage occur through the Old Brahmaputra and the Dhaleswari system when the Meghna River remains at a higher stage.

The region is subdivided into seven projects (Fig. 4.4) where regional water management issues are studied at a pre-feasibility level. These are: RS1 - Jamalpur Priority Project, RS2 - Jamalpur to Bhuapur Development, RS3 - Dhaleswari-Kaliganga Development, RS4 - Bangshi River Improvement, RS5 - Muktagacha - Bahluka Development, RS6 - Bhuapur-Aricha Development, RS7 - Tongi-Gazipur Development. The Jamalpur Priority Project (RS1 or FAP 3.1) considers four different alternatives which are flood reponse measures, controlled flooding and

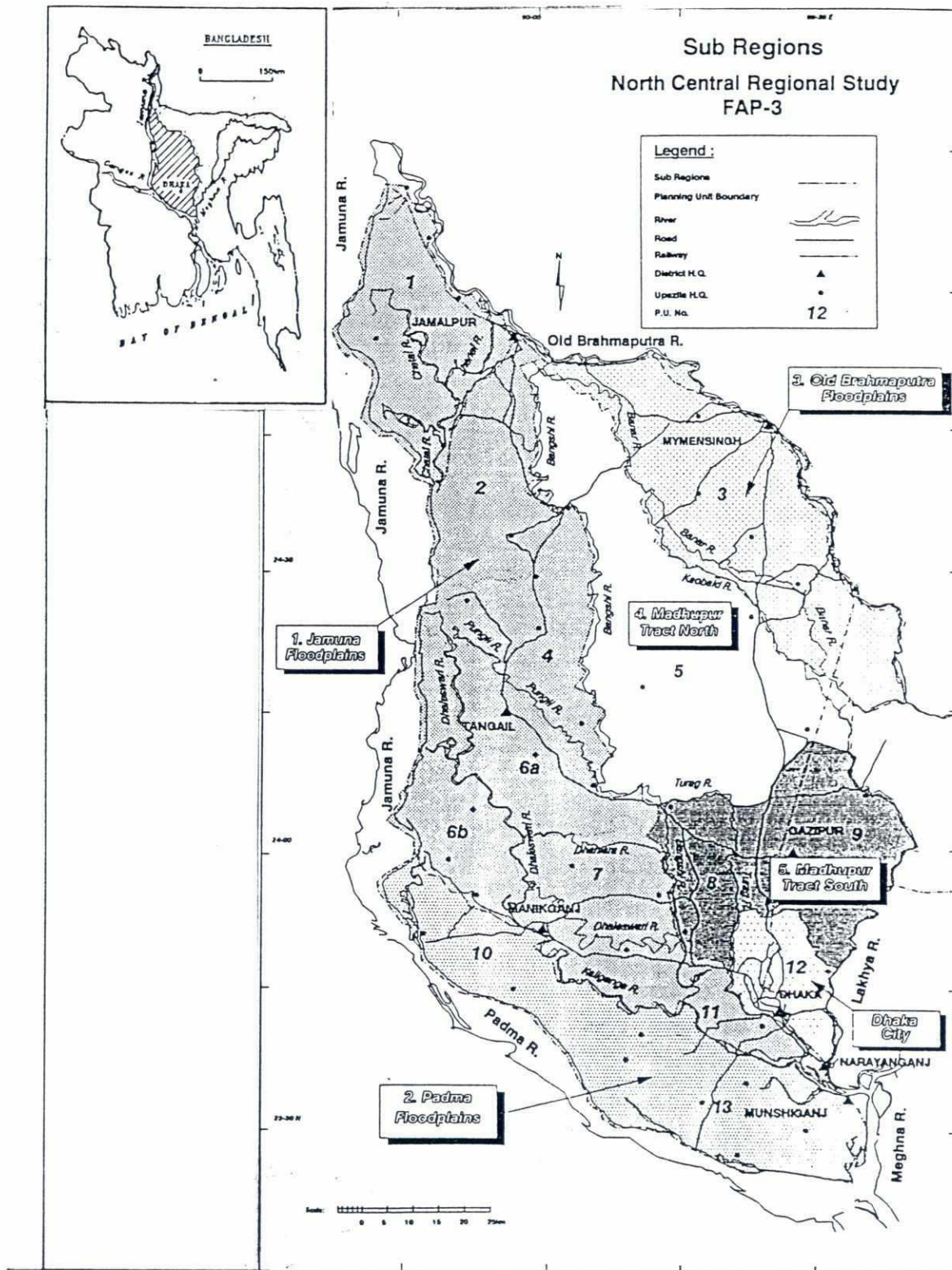


Figure 4.3 Sub-regions or physiographic units of the north-central region (after NCRS, 1993).

flood proofing, combination of controlled flooding and flood response measures, and full flood protection. Full flood control option envisages flood embankments around the whole area with bank protection works on the Jamuna River left bank. Also, several flushing sluices and some major hydraulic structures are suggested in this option. The RS2 area is already protected from flood through Jagannathgonj-Jamalpur railway embankment and a BWDB embankment from Bhuapur to Jagannathgonj. The suggested flood plan envisages improvement of these embankments. RS3 area includes the FAP 20 Compartmentalization Pilot Project at Tangail. The proposed developments under this sub-project include construction of embankments for controlled flooding along the Dhaleswari-Kaliganga. In addition, some semi- and fully controlled hydraulic structures are planned. Under Bangshi River drainage improvement project (RS4), a channelization scheme (river straightening, widening and deepening) for a length of 80 km is envisaged. Under RS5, improvement of drainage and water management issues are addressed. The Bhuapur-Aricha Development project (RS6) is an alternative to RS3. In this project an embankment is envisaged along the left bank of the Jamuna River from the Dhaleswari offtake to Aricha and connecting it with Padma left embankment of the BWDB. In Tongi-Gazipur Development project (RS7) some limited and small drainage improvement works are envisaged.

4.2.4 FAP 4: Southwest Area Water Resources Management

This region is located in the southwest corner of Bangladesh bounded by the Ganges-Padma-Meghna rivers and the Bay of Bengal (Fig. 4.5). Information presented in this section are primarily obtained from Southwest Area Water Resources Management Project (SWRMP, 1993a, 1993b, 1993c). The total area covered by this region is about 40,450 km². Three major physiographic units can be identified in this region, they are: (1) the inactive Ganges Deltaic Plain in the west, (2) the active Ganges Deltaic Plain in the east, and (3) the tidal Deltaic Plain along the coast (Alam et al, 1990). A particular characteristic of this region is the existence of a mangrove forest, the Sundarbans, at the southwest corner covering about 10% of the total area. The major drains in this region are distributaries of the Ganges-Padma-Meghna rivers. The Gorai-Modhumati is a distributary of the Ganges River, the Arial Khan River is a distributary of the Padma River, the Buriswar, Bishkhali, and Tetulia rivers are distributaries of the lower Meghna River. Flooding in the region is caused by spill-over flows from the boundary rivers, from the regional rivers and from coastal saline water floods during storm surges. 33% of the total region is flooded by the Ganges River and its distributary the Gorai-Modhumati system, 52% is flooded by the Padma River and its distributary the Arial Khan River,

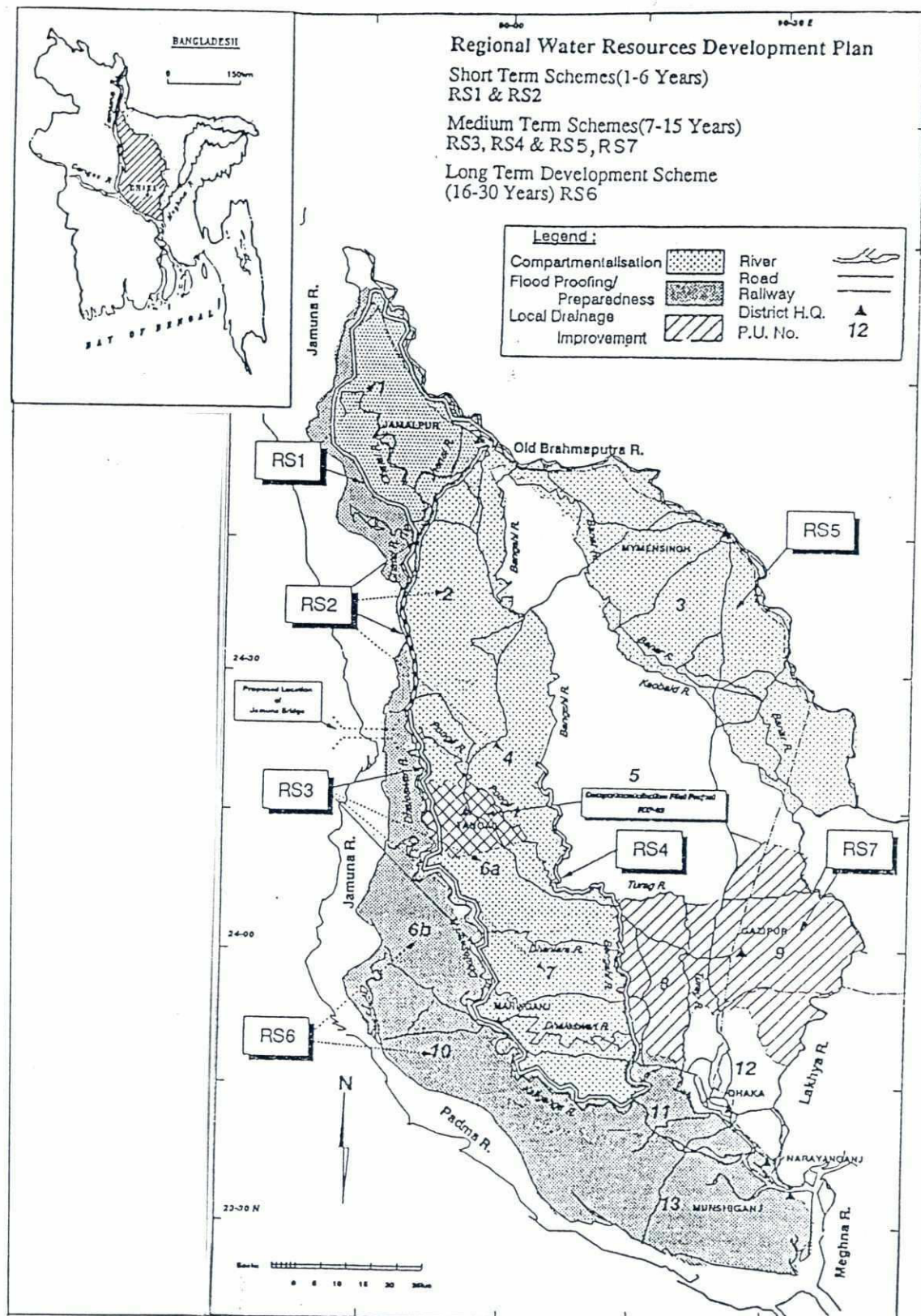


Figure 4.4 Sub-regional projects in the north-central region (after NCRS, 1993).

and 15% is caused by the lower Meghna River.

In the southwest region existing and ongoing projects are numerous. Among these projects, the significant ones are, the Ganges-Kobadak Irrigation Project (GK project), the Barisal Irrigation Project, the Bhola Irrigation Project, the Modhumati-Nabaganga Project (under third Flood Control Drainage Project III), and about 76 polders of the Coastal Embankment Project (CEP). Figure 4.5 shows some proposed development initiatives in the southwest region. These include groundwater development, surface water augmentation through the Gorai River, construction of a Ganges Barrage, Arial Khan - Madaripur beel route transfer, Ganges-Padma right embankment, coastal polder rehabilitation, etc.

There is a growing evidence that the Gorai River is receiving less flow from the Ganges River (SWRMP, 1993c). The surface water augmentation through Gorai River includes a proposal to place an intake structure at the Gorai offtake to control wet season flows. The purpose of it is to ensure a required wet season flow through the Gorai River.

In order to improve water resources management in the region a Ganges Barrage is proposed together with the Gorai augmentation project. Among others, the project will benefit the GK project by reducing its pumping head. Another option considered to increase surface water flow in the southwest region is the Arial Khan - Madaripur Beel Route Transfer.

The Ganges-Padma right embankment, together with works on the Arial Khan River would provide flood protection in the southwest region. Embanking the Padma River right bank was originally conceived in a plan drawn up in 1960. But its construction is limited to implementing some discontinuous reaches, thus spills from Padma River continues. About 144 km of flood protection embankments exist along the right bank of the Ganges River together with another 120 km along the right bank of the Padma River. Several agencies such as the Bangladesh Water Development Board, the Department of Roads and Highways, and the Local Government are responsible for building these embankments. The regional plan envisages coordination of these activities and to improve the condition of the embankments either by raising the crest level or by repairing of breaches.

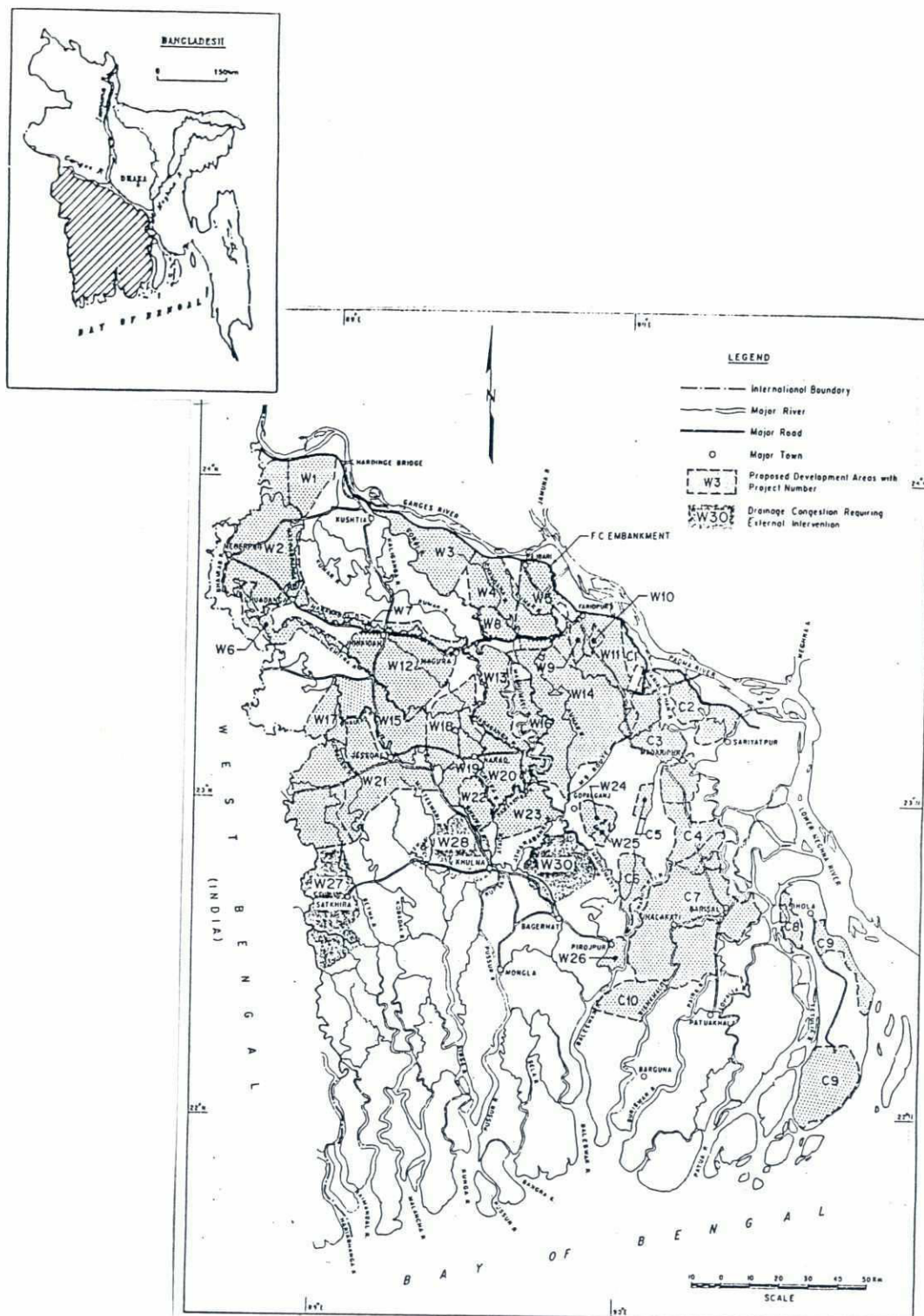


Figure 4.5 Development initiatives proposed by FAP 4 (after SWSMP, 1993b).

4.2.5 FAP 5: Southeast Region Water Resources Development Program

This region (Fig. 4.6) is located in the southeast corner of Bangladesh with the lower and upper Meghna River and the Bay of Bengal as the boundary drains (SERWRDP, 1993). Four major physiographic units of this region are (1) the Tripura Hills, (2) the Meghna Flood Plain, (3) the Tippera Surface, and (4) the Meghna Deltaic Plain. The valley slope of the region runs from northeast to southwest. The regional rivers such as Titas, Salda and Gumti are tributaries to the upper Meghna River. The Dakatia River is a tributary of the lower Meghna. The little Feni and the Feni River (closed since 1987 at the outfall with a regulator draining the excess flow) system drains southward to the Bay of Bengal. Flooding in the region is caused by local rainfall in the catchment (in Bangladesh and in the Tripura hills of India). The drainage of the regional rivers are impeded when the Meghna River stage remains high.

From some irrigation projects such as Meghna-Dhonagoda and Chandpur Irrigation Project embankments exist along the left bank of the lower Meghna River. In the upper Meghna River, scattered Food For Works (FFW) embankments exist along the left bank. With the completion of Gumti Phase II project, a continuous embankment is expected along the left bank (Flood modelling and management project, 1993). Figure 4.6 shows the projects in the region with monsoon problems in different sub-regions.

4.2.6 FAP 6: Northeast Regional Water Management Project

This region (Fig. 4.7) is located in the northeast corner of Bangladesh comprising a total area of 24,200 km² (NERWMP, 1993). The region has six physiographic units, they are (1) the Sylhet Hills and the Meghalaya Foothills (8%), (2) the Madhupur Tract (2%), (3) the Piedmont Floodplain (4%), (4) the Meghalaya Alluvial Fan (6%), (5) the Meghna Floodplain (55%), and (6) the Sylhet Depression (25%). The flooding in this region is caused by local rainfall in the catchment basin (both in Bangladesh as well as in India). The catchment area is located in one of the highest rainfall areas in the world. The major drain of this region is the Meghna River with its numerous tributaries such as Surma-Kushiyara system, the Manu River, the Khowai River, the Kangsa River, etc.

This regional project is in a initial planning stage, therefore, only potential initiatives are indicated in its report (NERWMP, 1993). Number of full-flood control initiatives with embankments and drainage

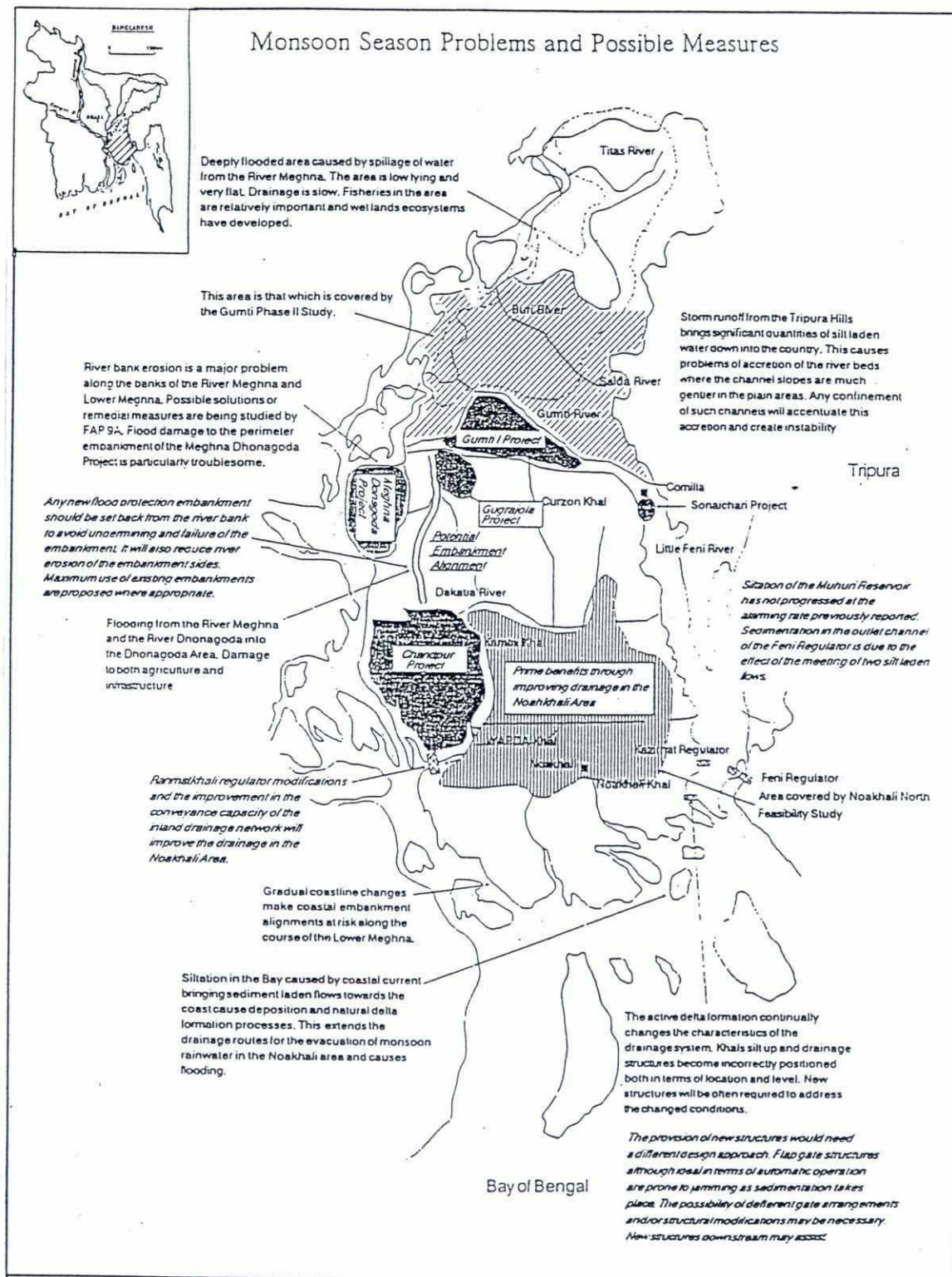


Figure 4.6 Monsoon river problems and possible measures in the south-east region (after SERWRDP, 1993).

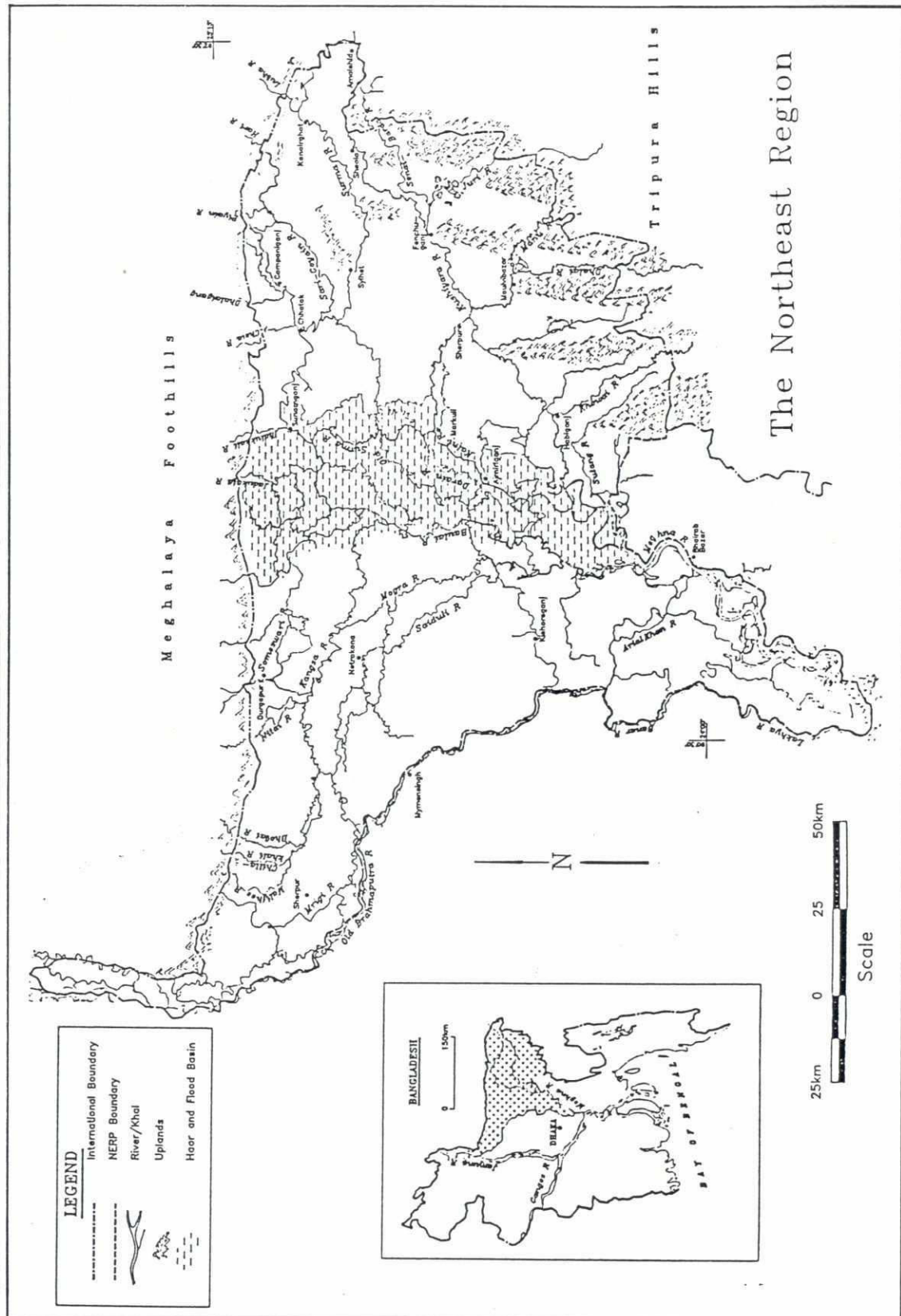


Figure 4.7 Physiography of the northeast region (after NERWMP, 1993).

structures are proposed. The proposed drainage improvement projects include dredging and river improvement and proposed water resources development initiatives include several river basin development projects.

Major interventions in the main river system of these sub-regional plans involve construction of the Meghna right embankment from Bhairab Bazar to downstream.

4.3 Bank protection studies

4.3.1 Introduction

Bank protection may affect a river in several ways. If bank protection is provided for on both banks of the river, then the width of the river may be affected, usually resulting in a reduction of the slope of the river. If bank protection is provided for only at one side then the impact may be less serious, unless the river tends to move towards this bank and again the width of the river will be affected.

Under FAP 2 bank protection projects have been undertaken, notably:

- o FAP 1: Brahmaputra River Studies
- o FAP 9B: Meghna River Bank Protection Short Term Study

In the next sections these two projects are summarized in scope and recommendations. In addition, problems which were experienced when preparing plans are outlined.

4.3.2 FAP 1: Brahmaputra River Studies

The Brahmaputra-Jamuna river system is accounting for more than 50 percent of the total inflow into Bangladesh from all cross-border rivers. It is a braided river which shifted to its present course about 200 years ago. Short term channel migration can be quite drastic with annual rates of movement as high as 800 m. Within the study area overall width varies between 6 km and 14 km. The river cross section has a highly irregular bed elevation and the main channel may be upto 35 m deep although the mean depth is only 7 to 8 m. Brahmaputra Right Embankment (BRE) made of earth is 220 km long, has been constructed to protect the western land against floods. However, every year this embankment has to be retired landward at several places due to bank erosion. About 140 km of retired embankment has been constructed over the past 20 years.

The terms of reference of the study read:

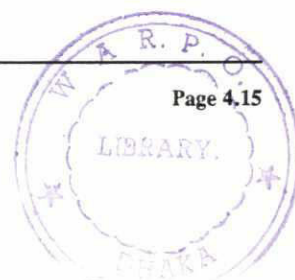
- o Possible measures and their technical and economic feasibility for an improved performance of the BRE for flood protection in terms of appropriate design.
- o Proper river training for permanent protection of BRE and its effect on environment; operation and maintenance aspects shall also be taken into account.
- o An implementation schedule for measures proposed
- o Master Plan shall be consistent with the overall strategy of the Flood Action Plan.

The principal objectives of the study are:

- to formulate a master plan for the long-term protection of the BRE, and
- design of short-term measures at critical sections along the right bank for early implementation.

The conclusions of FAP 1 studies have contributed to the formulation of the Master Plan for stabilization of the right bank of the river and hence protection of the Brahmaputra Right Embankment in the long term. These studies have led to the selection of locations for the implementation of river training measures in the short term, and to the design of appropriate structures. The major conclusions are:

- o The present west ward movement of the right bank will continue for several decades, probably at a similar rate to that experienced over the last 35 years; at the same time the river is becoming steadily wider
- o Guidelines have been established for the prediction of the evolution of aggressive bends and a direct link has been demonstrated between bank erosion and char building
- o The planning of stabilization works based on the understanding of the bank erosion process, the role of bends and the dominant waveforms with which they are associated. This led to the setting of priorities for early implementation of individual elements.
- o 1-D and 2-D morphological models together with the physical scale model have assisted in drawing above conclusions.



The Draft Final Report (January 1993) of FAP 1 (HALCROW, 1993) provides the findings of the detailed studies of the three year Brahmaputra River Training Studies programme and the Master Plan Report (May 1993) gives the additional considerations and set out proposals for improved performance of the BRE, river training schemes and schedule for implementation.

The programme for implementation of the Master Plan is based on a combination of economic considerations and technical priorities, planned in following phases:

- Phase 1A: Early implementation of river training measures in critical locations, commencing with the Brahmaputra Right Bank Priority Works at Sariakandi, Mathurapara and Sirajganj.
- Phase 1B: Stabilization of hard points at two locations north of Sirajganj - at Simla and Sailabari Groyne, and two locations north of Sariakandi - one east of Naodabaga and one approximately 3 km north of Kalitola Groyne.
- Phase 1C: Bank stabilization comprise the remainder of the six priority locations selected originally but not included in Phase 1A, namely Betil, Fulchari and Kazipur.
- Phase 2: The remaining river bank stabilization along the right bank over the entire study reach from the Teesta to the Hurasagar river.

The environmental aspects of the river training measures envisaged, and the sociological aspects of land loss and resettlement are considered elaborately.

Tender Documents for the Phase 1A Priority Works have been prepared and pre-qualification took place around mid 1993. Contract award is expected during the second quarter of 1994. The construction period for the works at Sariakandi and Mathurapara is 24 months and at Sirajganj it is 36 months. Phase 1B works would commence some 5 years after the commencement of Phase 1A. The commencement of Phase 1C after 10-20 years.

The Phase 1A activities are taken up by IDA for implementation.

It is interesting to know the problems encountered in the BRE studies which might be of interest to FAP 24 to develop further understanding.

o **Improved understanding on the changes in channel geometry**

Analysis of river cross-sections surveyed regularly since 1964 shows a considerable short term temporal and spatial scatter in the values of the principal channel parameter, mean and maximum depth, width and conveyance, but a notable overall long term consistency with no discernible trends and little longitudinal variation. Stabilization of the bankline could however be expected to result in some greater regularization of the thalweg pattern and therefore rather less variability in the channel geometry about the mean values **which needs further confirmation.**

o **Estimate of bed Aggradation/Degradation in the unconfined reach of the river**

The effect of confinement of out-of-bank flows between continuous flood embankment may result in increased transport capacity in the confined reach of the river, resulting in a lowering of the bed level and consequent deposition in lower Padma (unconfined reach) and possibly to some extent in Dhaleswari until a new equilibrium is established. **Hence there is a need for prediction of bed aggradation/degradation.**

o **Estimate of the changes in Macro Planform**

Confining the river could encourage it to change from a predominantly braided planform to a more meandering form which means that larger, more aggressive and less stable bends could become more active. The FAP-1 study reflects that stabilization of the right bank alone will have no impact on the shape of the dominant discharge curve and therefore should have no impact on channel morphology overall. There is no standard method to predict the future development of Macro planform given that some points have been fixed. **Hence there is a need for planform prediction of rivers where the river is confined.**

o **Estimate of bank erosion**

The bank erosion contributes a high proportion of sediment transport in the Brahmaputra River. It is known that there is a close relationship between net bank erosion and net char growth and that the time interval linking the two process is relatively short. As it is said that the Brahmaputra river is in a dynamic equilibrium that means that any new

material introduced from the bank is not taken by river as wash load must be deposited in a char or temporarily stored in a sandbar. It is still difficult to understand these two exchanges, **hence there is a need for improved understanding of char and bar development related to bank contribution when the bank is stabilized.**

o **Estimate of design scour depth for the bank protection at Sirajganj**

The Phase 1 Priority Works are aimed at the stabilization of the bank-line in the immediate vicinity of Sirajganj and along the 15 km reach centred on Sariakandi where there is a high probability of an early breakthrough of the Brahmaputra into the Bangali river with consequent disruption and loss of BRE. For the determination of the design scour depth for the bank protection works, there is some uncertainty regarding the scour that will develop after the protection and the contribution of the active scour in the river.

The FAP 1 study reveals that the dynamics in bend scour development are very sensitive and a state of equilibrium is probably never reached because the parameters mentioned above change continuously in the Brahmaputra. The deep scour in the Brahmaputra could not be simulated by the bend model alone, the inference being that such scour must be related to other flow conditions, such as those associated with flow convergence at confluences downstream of islands and flow along protruding objects. There remain some uncertainties in understanding the mechanism of bend scour.

The consequence of reduced bank sediment contribution, the scour adjacent to a stabilized length of bank will tend to increase and this will provide a preferential path of flow. However it is known from examples such as Sailabari Groyne that this in itself is not sufficient to hold the thalweg in a position that is inconsistent with the current dominant main wave form of the river. Besides examples there is no such theoretical understanding of scour along the bank which is protected.

Hence there is a need for improving understanding of the scour resulted from the stabilized bank and the scour already existing in the river.

o **Morphological study for long term node stabilization**

The principle behind node stabilization is that if this naturally occurring confluence-bifurcation can be constrained longitudinally and laterally

then it will help to stabilize the overall river planform and counter any tendency for the river to migrate sideways as a whole. It will not directly prevent bank erosion upstream nor prevent switching of predominant anabranches, although it may provide an upper limit on the extent of the former. In the Brahmaputra there are two nodes along the stretch of the river lying in Bangladesh. One is at the south of Sirajganj, which is the proposed site for the Jamuna Bridge. The second lies to the north of Sarikandi and is currently less clearly defined. Construction of the Jamuna Bridge would provide a very effective node stabilization which with complementary bank hardening upstream, to prevent outflanking, would counter any tendency to migrate laterally. **Further study of the river morphology as a whole is required before it can be decided whether such a nodal stabilization would be cost effective.**

o **Effect on major offtake channels**

Stabilization of banks along the Brahmaputra river may cause changed conditions at an offtake and consequently changes in the downstream distributary. The effect on the morphology of the distributaries is not clear, **hence there is a need for improved understanding of the morphological effect on the bifurcation / offtake due to channel stabilization.**

o **Effect of thalwegs on populated Chars**

The populated chars whose tops are at the same level as the river flood plain may be effected by the shifting of thalweg due to stabilization of banks, **which is hard to predict.**

4.3.3 Study FAP 9B: Meghna River Bank Protection Short Term

FAP 9B has studied the need for and the technical and economic feasibility of bank protection works along the Upper and Lower Meghna River. According to the Terms of Reference the following locations that are threatened by bank erosion had to be studied:

o Upper Meghna River:

- Bhairab Bazar Railway Bridge
 - Bhairab Bazar Town
 - Maniknagar
 - Meghna Roads and Highway Bridge

o Lower Meghna River (left bank):

- Eklashpur
- Chandpur
- Haimchar

and in addition Munsjiganj that actually is located along the Dhaleswari but only slightly upstream of the confluence with the Upper Meghna River.

The objectives of the study were:

- o To provide short term measures for protection against erosion of seven locations on the Meghna River and one location on the Dhaleswari
- o To gradually implement a coherent and phased programme of works, aiming at the control of erosion on the defined stretches of the rivers Meghna and Dhaleswari; the protection of the locations indicated above should logically fit into this programme.

The final recommendations of the project are to implement bank protection works for the following locations:

- o Bhairab Bazar town and railway bridge
- o Munsjiganj
- o Chandpur.

The present status is that on short term none of these proposed bank protection works will be implemented, as funds are lacking.

Nevertheless it is interesting to summarize here the most important problems related to the main river system and its behaviour that have affected the project performance. These are listed below:

- o Future planform development upstream of Bhairab Bazar;
- o Estimate of design scour depth for the bank protection works at Bhairab Bazar
- o Estimate of future bank erosion rates along the Lower Meghna at Eklashpur and at Chandpur for evaluating the economic feasibility
- o Cyclicity of char formation process and its link to bank erosion and scour depth
- o Prediction of design scour depth at Chandpur
- o Effect of bank protection works along the Lower Meghna River on future planform development.

These are discussed hereafter in some more detail:

o **Future planform development upstream of Bhairab Bazar**

The future development of the planform upstream of Bhairab Bazar is very important for the estimate of the design scour depth for the future Bhairab Bazar bank protection works. For the time being it was assumed by the Consultants that a bend could develop upstream which would result in bend scour becoming more important than at present. Other developments could also have been predicted which would have resulted in other estimates for the design scour depth. **Hence there is a need for improvement of the techniques available for planform prediction.**

o **Estimate of design scour depth for the bank protection works at Bhairab Bazar**

Apart from the possible importance of bend scour (see above) for the determination of the design scour depth for the bank protection works, there is also some doubt regarding (i) the magnitude of the individual contributions to the total scour and (ii) the combination of the different types of scour that may be active in Bhairab Bazar. For the bend scour only limited data were available to make fair estimates. The local scour near revetments was based on model experiments, but there is some doubt also in relation to values used for FAP 1 for similar structures. Regarding the combination of the different contributions it holds that there was some uncertainty regarding the method applied. (Although two different approaches, one based on combining different contributions and one based on the more empirical regime approach, resulted in approximately the same designs scour depths.) **Hence there is a need for improving the magnitude of the various contributions to the combined scour, and improved methods for combining the various contributions (here bend scour, constriction scour and local scour).**

o **Estimate of future bank erosion rates along the Lower Meghna at Eklaipur and at Chandpur for evaluating the economic feasibility**

For the assessment of the economic benefits of bank protection works there is a need for predictions of the future bank erosion without the bank protection works being implemented. Luckily

often the value of the land is fairly evenly distributed, and hence average values suffice. In the case of the Lower Meghna River the value of land at Chandpur is an order of magnitude higher than of the adjacent areas under agricultural use. Hence estimates had to be made of the bank erosion rates at Chandpur for the case of no further or limited maintenance. Also for Eklashpur similar estimates had to be provided, both without and with a relatively light bank protection. This task was complicated by the difficult and complicated relation between bank erosion and channel processes. **Hence there is a need for improved techniques for estimating bank erosion and related channel development.**

o **Cyclicity of char formation process and its link to bank erosion and scour depth**

One of the most challenging tasks in the FAP 9B project was to improve the understanding of the development of chars downstream of Mawa and their movement through the Padma and Lower Meghna rivers. By study of satellite images and historical maps, it was deduced that a cyclic process could be present, and this was used for making prediction of both bank erosion rates and scour depth development at Chandpur. For both a cyclic behaviour was assumed. This was based purely on empirical relationships. **There is a need for improvement of the understanding of formation of chars in general, their movement and deformation, and their relation to bank erosion and scour depth development.**

o **Prediction of design scour depth at Chandpur.**

Also for Chandpur estimates of the scour depths for different combinations of "attack" had to be made. In doing this the observed cyclic behaviour (see previous point) was applied but again the different contributions to the scour were estimated and they were subsequently combined. **Here the same recommendation as under estimate of design scour depth applies.**

o **Effect of bank protection works along the Lower Meghna River on future planform development.**

By constructing bank protection works along the Lower Meghna the planform development will be influenced. There is no

fullfledge method to predict the future development of the Lower Meghna planform given that some points have been fixed. Hence there is a need for planform prediction of rivers where some parts of the banks have been fixed.

In addition there are of course some question marks as to the type of materials to be used, their size, and other aspects related to the design, but for the present identification of the study topics for FAP 24 these are not relevant.

4.4 Supporting studies

4.4.1 Introduction

In addition to the Regional Plans and the Bank Protection Studies there are a number of Supporting Studies under FAP. Most of them do not lead to any physical interference in the river system apart from FAP 21/22, which will be described hereafter. Some supporting studies are also studying the behaviour of the main river system and these are listed here as well. In some studies under FAP 24 it may be advantageous to plan combined actions.

4.4.2 FAP 21/22: Bank Protection and River Training (AFPM) Pilot Project

The Bank Protection and River Training (AFPM) Pilot Project consists of two parts, notably FAP 21 and FAP 22. They will be discussed hereafter separately.

FAP 21

The objectives of FAP 21 are "to find improved solutions for bank protection works against erosion, by designing, specifying and constructing different types of groynes and revetments using different materials and protective layers and investigating at the same time the suitability of local materials and construction methods. After construction of the test structures at two selected locations on the Jamuna River, their behaviour shall be monitored for a period of several years. The final objective is to develop and optimize design criteria, cost-effective construction and maintenance methods which shall serve as future standards, most appropriate for the prevailing conditions at the Jamuna and other rivers in Bangladesh" (RRI/L&P/CNR/DELFT HYDRAULICS, 1992, Vol. IA).

FAP 21 has finalised the Planning Phase early 1993 and the project has at present entered in the Implementation Phase. During the Planning

Phase an important issue was where the test structures should be built. For this the future morphological development of the Jamuna River had to be predicted, especially at locations which were proposed as possible sites for the test structures. Out of a long list of potential sites, four sites were selected, notably:

- o Kamarjani along the right bank
- o Bahadurabad along the left bank
- o Chandanbaisa along the right bank
- o Nakalia along the right bank

In a later stage two additional sites were added, notably:

- o Sariakandi
- o Kazipur

For the prediction of the possible developments for the first time use was made of a conceptual model described by Klaassen et al (1993). Based on this analyses but also on a number of other considerations tentatively Kamarjani and Bahadurabad were selected as test sites.

A second step in the planning stage were tentative designs and these had to be based on a.o. design boundary conditions. These design boundary conditions concern maximum scour depths for a design flood, stages, velocities both in magnitude and direction. For the generation of these boundary conditions essentially the same approach as used for the Jamuna Bridge Study (see Figure 2.8) was applied. Hence a three stepped approach:

Step 1 Morphological boundary conditons

In the Jamuna Bridge Study in fact a statistical approach was used to generate possible attacks. In the FAP 21 the outcome of the predictions of future planforms near the proposed test sites (as used for the selection of the sites) were used here too. As these provide only channel planform, depth contours were added based on the characteristics of channels in the Jamuna River (Klaassen & Vermeer, 1988a).

Step 2 Hydraulic boundary conditions

Use was made of a mathematical model to generate the flow pattern given the bed topography determined in Step 1. Simulations were made for different discharges (as the maximum discharge in the coming period of say 5 years cannot be predicted).

Step 3 Physical model tests

Physical model tests were done for proposed lay-outs of the test structures using the bed topography and hydraulic boundary conditions determined in the Steps 1 and 2. During these model tests the velocity field near the structures and the local scour depths were observed. These finally were used for the design of the test structures.

It should be noted that under FAP 21 some additional studies were carried out which have increased the understanding of some aspects of braided sand-bed rivers like the Jamuna River and maximum scour considerably. One additional study was an extensive study of morphological processes on the basis of an extensive series of satellite images (for almost every year between 1973 and 1992). The study aimed in particular at increasing the understanding of changes in planform over the year with the aim to in due time arrive at a modelling approach. Results are presented in Annex 11 of the Final Report of FAP 21 and in Klaassen et al (1993) and Mosselman et al (1993). Using internal research funds of DELFT HYDRAULICS also arranged for an exploring study into possible tectonic effects on planform development which was carried out by the University of Amsterdam. First results are presented by Hartmann et al (1993). Another additional study was a limited experimental study into combined scour. The results of this study are presented in Annex 15 of the Final Report of FAP 21 as tentative guidelines how to combine bend scour and local scour in the case of grayness in outer bends.

During the Planning Phase of FAP 21 a number of difficulties were met as far as the understanding of the river processes and of the future attack by the river on the test structures is concerned. The most important ones are listed below:

- o Prediction of sites eroding after 2 to 5 years
- o Celerity of bank erosion over the coming years
- o Prediction of channel pattern after the same 2 to 5 years
- o Influence of bank erosion products on bend scour
- o Design scour depth for grayness and revetments
- o Development of scour in time

These difficulties are discussed hereafter in some more detail:

o Prediction of sites eroding after 2 to 5 years

An important aspect of the site selection for the test structures is that they should be attacked over the period that the FAP 21 will last (estimated to continue until 1997). In that period the test structures should be built and they should be "tested" (by the river!). Based on

the satellite study and previous results obtained during the Jamuna Bridge Study a conceptual modelling approach was used but this approach gives only approximate answers. **There is a need for improved prediction techniques for locations where bank erosion will occur in 2 to 5 years ahead.** This is also important for the planning of new bank protection works or for decisions regarding maintenance.

o **Celerity of bank erosion over the coming years**

Not only the site of the test structures had to be determined but also the distance from the present bank where the test structures has to be built the idea is that over the coming 1 or 2 years the river will erode the land between the present bank line and the location of the test structure. **Hence there is a need for reliable prediction techniques for rates of bank erosion 1 to 2 years ahead.**

o **Prediction of channel pattern after 2 to 5 years**

The same as stated under (1) holds for the channel pattern, as this is determining the attack on the test structures. It is intended that the test structures will experience some damage, but this damage should not be such that the structure collapses. **There is a need for improved prediction techniques for channel patterns that will occur at selected sites some 2 to 5 years ahead.**

o **Influence of bank erosion products on bend scour**

For the estimate of the bed topography in front of test structures it is not enough to use empirical data from presently eroding channels in the Jamuna River. Estimates have indicated that the bank erosion products have in the case of the fast eroding channels of the Jamuna River a significant (reducing) effect on the bend scour. If the bank erosion is blocked, the bend scour could increase significantly (see also Annex 15 of the Final Report of FAP 15 where some exploring tests were done). **There is a need for increased understanding of the effect of bank erosion products on bend scour.**

o **Design scour depth for grayness and revetments**

Also for the test structures under FAP 21 it holds that the total scour that may be expected is a combination of different types of scour. **There is a need for improvement of the determination of the total combined scour near bank protection structures.**

o **Development of scour in time**

Until now all the estimates of the total scour near bank protection works are based on the assumption that the design discharge continues very long, hence equilibrium scour holes occur. It may be however that the time scale of the development of certain types of scour is longer than the time scale of the extreme flood events. In that case a reduction of the scour estimates may be appropriate. **Hence there is a need for improved insight into the development of scour in time.**

FAP 22

The scope and objectives of FAP 22 "are focussed on an "active" approach trying to divert the flow of the Jamuna River away from reaches threatened by bank erosion and outflanking channels" (RRI/L&P/CNR/DELFT HYDRAULICS, 1992, Vol. IB).

The River Training and Active Flood Plan Management (AFPM) Pilot Project (FAP 22) concentrates on the development of the Jamuna River (RRI/LEP/CNR/DELFT HYDRAULICS, 1993), although its results are applicable for other rivers. The project will Investigate ways of refining the design criteria and improving the construction and maintenance of bank protection works. It will also investigate methods of possibly employing the river's own fluvial processes to stabilize its course and to reduce the risk of sudden channel displacements.

FAP 22 has finalized the Planning Phase early 1993. Under the project measures to "manage the Jamuna floodplains" were studied, This was interpreted as the use of recurrent measures in a flexible way in contrast to building bank protection works at fixed places. The rationale behind this study is that there is quite some logic in tackling a braided river like the Jamuna River (which is extremely movable and unstable due to the fine nature of its sediments) also with flexible means which can easily be shifted to another location.

In the FAP 22 different recurrent methods were studied and tentatively floating panels, mounted on ships were selected as promising. The main function of these floating screens would be to adjust the sediment and water distribution at channel junctions such, that one of the channels (the one that is most aggressive) will silt up relatively quickly. As an alternative not fully detailed also the use of dredging was proposed to initiate cutoffs. Probably not be such that it is possible to work "against" the river.

As an important issue of FAP 22 it was required to study different options for training the Jamuna River, as the application of recurrent

measures should fit into an overall strategy for training the Jamuna River in due time. Also it was necessary to indicate the ecological and socio-economic impact of the different strategies on a pre-feasibility level. Finally some institutional aspects were dealt with, mainly to explore whether recurrent measures which imply timely application, "learning by doing" and a good understanding of behaviour of the river, can be implemented in Bangladesh in this stage.

On the request of the funding agencies an expert meeting will be held in Dhaka in the beginning of November 1993, to discuss the findings and recommendations of the FAP 22 team.

During the Planning Phase of FAP 22 a number of difficulties were met as far as the understanding of the river behaviour, the efficiency of the proposed recurrent measures and the impact assesment is concerned. The most important ones are listed below.

- o Working with the river
- o Efficiency of proposed floating panels
- o Dredging as viable option
- o Best strategy for river training
- o Impact assesment

These difficulties are discussed here in some detail.

Re (1) Working with the river

The main idea behind Active Flood Plain management is to use the force of the river to create favourable conditions. This can only be done succesfully with limited means if the intervention in the river is in line with the tendency of the river. If for instance a channel would close in one or two years, then probably it is possible to accelerate this process with fairly modest "power". If however the river is in the process of opening up a channel, major intervention would be needed with related major costs. Hence a conditio sine qua non for the application of recurrent AFPM methods is a sufficient understanding of processes in braided sand bed rivers. This condition is definitely not fulfilled at present. More insight into these processes is needed.

Re (2) Efficiency of proposed floating panels

Assumptions were made on the efficiency of floating panels in changing the sediemnt and discharge distribution at bifurcations. This was done using simple mathematical models. This model, however, did not include spiral flow and its effect on sediment transport distribution at

bifurcations. There is a need for better tools, probably quasi-3 dimensional mathematical models, to make better estimates of the efficiency of these surface screens, but such models need better insight into sediment transport phenomena.

Re (3) Dredging as viable option

In the FAP 22 report also dredging is proposed as option for recurrent river training measures. Important questions when considering dredging as an option are:

- o Where should be dredged (in line with the "working with the river" discussed under (1))?
- o How much should be dredged in which time span?
- o Is agitation dredging sufficient?
- o Where should the spoil be released in order to have maximum benefit?

Answers to this type of questions again require more detailed insight into the riverine processes.

Re (4) Best strategy for river training

In the FAP 22 report also strategies for training of the Jamuna River are discussed, in particular in relation to the possible role that recurrent measures could play in the different strategies. One of the critical issues in this is whether the permanent chars, as according to FAP 1 have developed over the past decades are a permanent feature and whether river training with two parallel channels would be preferable. These are typically the type of questions that cannot be solved at this moment and for which again much more insight is needed.

Re (5) Impact assessment

The last major issue that could only be assessed roughly is the impact of the possible river training on the river characteristics and on the conditions in the adjacent areas. For the time being this assessment was based on the computational frame-work for river characteristics as presented in Annex 1. This frame-work however is partly based on emperical relations, which have not been tested thoroughly and hence which can give only rough ideas about the impact. There is an urgent need for an improved frame-work but this can only come via improved

insight into the mathematical-physical description of the processes involved.

4.4.3 Other relevant FAP studies (FAP19 and FAP 25)

Two supporting FAP projects are of interest to the study component of FAP 24. That is the reason why they are mentioned here. These two projects are:

FAP 19 Geographic Information System (GIS)
FAP 25 Flood Modelling Management Project

FAP 19 is dealing with the introduction of a GIS system in the FAP, but in the project also remote sensing techniques are being used on a fairly wide scale. In the last year two very relevant studies were finalized, notably:

- o A study together with FAP 1 into channel changes of the Jamuna River (HALCROW. 1993), and
- o A study of the permanent chars in the Jamuna River together with FAP 3.1 (SOGREAH/HALCROW/LAHMEYER (1992), Jamalpur Priority Project Study, Char study report Vol.10).
- o This year a study into possible applications of Radar Technology for FAP is undertaken which is of great interest for FAP 24.

It is of interest to explore possibilities of common interest between FAP 19 and FAP 24 in which cooperation can be established.

FAP 25 is dealing with flood modelling and it is carried out at the Surface Water Modelling Center of the River Research Institute.

In the last year both FAP 25 and SWMC appeared to be of interest to FAP 24. Subjects of common interest were for instance:

- o Scope of morphological studies for FAP
- o Role to mathematical models in these studies
- o Validation methods for hydrological data
- o Use of the General Model by FAP 24

So, further and more intensified cooperation between FAP 25, SWMC and FAP 24 is envisaged in the years to come.

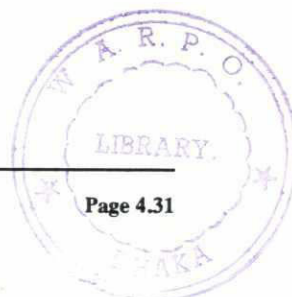
4.5 Possible future river training

In due time, which by the way could take many decades, the Jamuna River and the other main rivers will be trained. Under FAP 22 attention was given to possible future river training strategies too. To some extent this can be seen as a continuation of the ideas generated by the China-Bangladesh Joint Expert Study Team Report on Flood Control and River Training. Although a complete training of the main rivers is far beyond the scope of the FAP, still it may be useful to keep this distant goal in mind when defining study topics. It is felt, however, that at this moment the ideas generated are still so vague that it is difficult to derive from them specific study topics. In general terms however there is a need for increased understanding of the main rivers, and in addition there should be sufficient knowledge to be able to assess the impact of such large scale river training works on the river itself and on its environment.

In the FAP 22 report an attempt is made to make a first assessment. Use is made of the conceptual frame-work for analysis that is provided in this report as Annexure 1. As is stated in this Annexure (Section 4), there is a need for improvement and extension of this method. For this, however, additional studies are needed. Some of these studies are listed below:

- o prediction of the number of channels of a braided river, and also how this number is affected by a reduction of the total width available for the river
- o sinuosity as dependent variable, determined by the consistency of the floodplains, which in turn is affected by the characteristics of the bed material load and the wash load (see further point (1) of Section 4 of Annexure 1)
- o bankfull discharge as dependent variable, the floodplain level being determined by the balance between the vertical sedimentation in the floodplain and the horizontal erosive action by the eroding channels.

It should be stated that also the concept of how to train the rivers is not fully elaborated under FAP 22 and it may well be that a further elaboration of any plans in this direction would lead to the identification of more key problems in Chapter 5. It is felt however that this is outside the scope of the present identification of key problems and study topics for FAP 24.



5 Key problems

5.1 Introduction

If one would ask any Bengali about what he considers to be the key problems related to the main rivers, the answer would be different depending on the person and where he and/or his family and relatives are living, or where they have lived previously. Typical answers one would probably get are:

- o Regular flooding and erosion of land
- o Hardly any flow in the low flow season
- o Siltation in particular rivers in relation to navigation, drainage and water supply
- o Problems with the ferries due to the ghats either being eroded or silted up
- o Shifting of channels causing navigational problems, and
- o Bank erosion in general and more particular in certain thana's and towns (like Chandpur, Sirajganj) which are particularly threatened.

Some professionals in Bangladesh (like BWDB officials) will add to these points more technical issues from their understanding of the river system in Bangladesh, like:

- o The reduced flow into the Gorai
- o The failures of the embankments along the Jamuna River due to continued bank erosion and the destruction of important infra-structure like the Manos regulator
- o The possible "dying" of the distributaries, and
- o The detrimental influence of Farakka on the south-west region.

Although these are in the end the problems for which solutions have to be found, also these are probably not the key problems the FAP 24 Terms of Reference is referring to. In the Terms of Reference ("key problems in the understanding of the behaviour of the main alluvial rivers in Bangladesh") rather the underlying problems are meant which in the end cause that people in Bangladesh are experiencing so many problems with their rivers. These are typically related to the development of the main river system over time, and how it is influenced by natural developments and how human interference can change these conditions.

In this Chapter an attempt is made to identify these key problems in understanding the behaviour of the river system and in assessing the impact of the various FAP components. In a further step in the next Chapter these key problems are dissected in separate study topics which are even more abstract and at a larger distance from what people experience as "their" problems, but the solution of which is essential for any further improvement of the conditions

of the population being subjected to the vagaries of the rivers in Bangladesh.

5.2 Identification of key problems

For the identification of the key problems use is made of the frame-work for analysis that was sketched in Chapter 2. In particular Figure 2.7b is used here to identify the key problems and to arrive at a classification of the key problems. This figure is repeated here in a slightly different form as Figure 5.1.

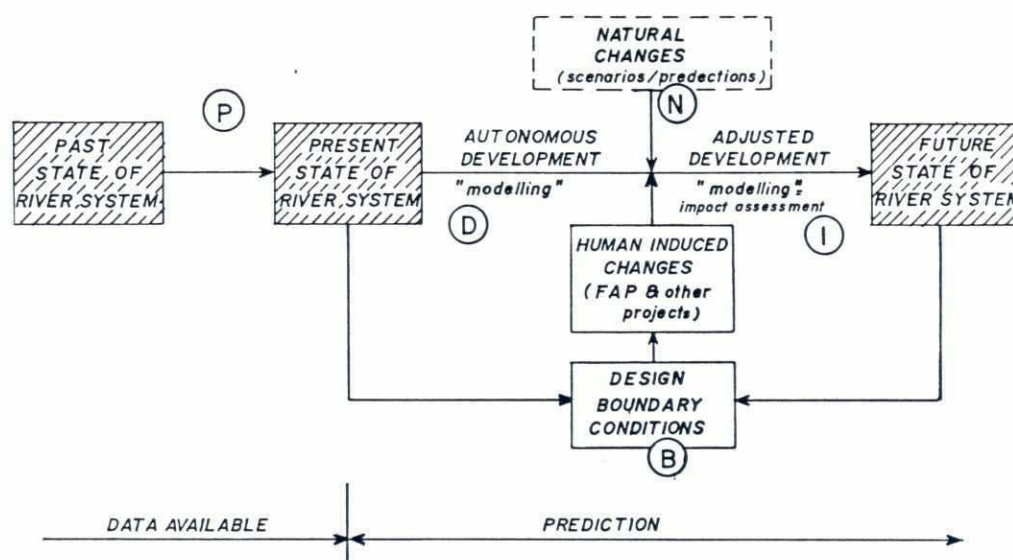


Figure 5.1 Identification and classification of key problems

The following comments are made on this Figure 5.1:

- o In addition to the "Present state" of the (river) system also the "Past state" has been added as the existing data base relates to both the past and present conditions and allows to study the river behaviour over time. Furthermore, the present state of the system is not fully known (also not because the river state is fluctuating) and to a certain extent the knowledge of the past has to be added to get a fairly complete picture.
- o Natural changes cannot be predicted fully, especially not if they relate to tectonics either upstream or locally. This should be tackled by making assumptions as to future behaviour ("scenario's") or intelligent "predictions" have to be made by experts.
- o Human induced changes can be either FAP-projects or other projects. For these projects boundary conditions are needed. These boundary conditions should take into account not only the present state of the river system, but also the future development of the river system.

- o Future states of the river system have to be predicted if the impact of e.g. FAP has to be assessed. It is clear that the future state is not only determined by (1) the (past and) present state of the river system and (2) the impact of FAP, but also by (3) the autonomous development of the river (which is the aftermath of previous changes in independent variables), (4) changes in the natural conditions and finally (5) other projects.

Based on the river characteristics (Chapter 3) on the one hand and the possible FAP projects (Chapter 4) on the other hand, it is now possible to identify key problems in the understanding of the behaviour of the main alluvial rivers in Bangladesh. These key problems are typically problems for which answers have to be found or at least fair assumptions have to be made for the time being, before further steps can be taken as to the planning and implementation of FAP components. The identified key problems are listed hereafter, and a more detailed description is provided in the subsequent Sections.

The key problems are classified according to Figure 5.1 into five categories:

- o Understanding of the present (and recent past) behaviour of the river system;
- o Autonomous development of the river system, without influence of changes in the independent variables or human-induced changes;
- o Natural changes mostly in the independent variables;
- o Boundary conditions for the design of embankments and of groynes and revetments as part of FAP or other structures along the main rivers, relating both to the present and the future conditions;
- o Assessment of the impact of the combined effect of the FAP components, which cannot be differentiated from the effect of autonomous development and from natural changes.

These are divided hereafter in some more detail, whereby a certain coding is used:

- P: relates to the understanding of the present (and past) behaviour;
- A: relates to the autonomous developments of the main river system;
- N: relates to the natural changes in independent variables;
- B: relates to design boundary conditions for the various structures;
- I: refers to impact assessment.

Understanding of the present behaviour of the river system:

- (P1) Limited data on present state
- (P2) Dynamic fluctuations around equilibrium
- (P3) Difficulties in measuring in large rivers

Autonomous development of the river system:

- (A1) Widening of the Jamuna River
- (A2) Adaptation of the Upper Meghna River
- (A3) Fate of distributaries
- (A4) Bank erosion over 2 to 3 years

Natural changes in independent variables

- (N1) Shifting of river courses
- (N2) Major changes possible?

Boundary conditions for design

- (B1) Design boundary conditions embankments (discharges, stages and safe distance)
- (B2) Design conditions for groynes and revetments (stages, magnitude and direction of velocities and bed levels)

Impact assessment

- (I1) Impact of regional plans on river characteristics
- (I2) Effect of narrowing/bank protection works/AFPM measures
- (I3) Effect of embankments on sediment flux towards fields and on siltation in floodplains outside embankments
- (I4) Impact of developments upstream
- (I5) Influence of climatic changes

These key problems will be described in the subsequent sections in some more detail.

It is stressed here that when in the above (and hereafter) the term "impact assessment" is applied it should be read as the impact on the physical characteristics of the rivers only. Hence the impact assessment indicates how the river characteristics and the river behaviour might change. The resulting changes in chemical and biological factors, often referred to as the environmental impact (but in this definition only part of it), are not included in this impact assessment. Not because these problems are less important, but because it is beyond the scope of FAP 24 and should be covered by other FAP components.

5.3 Understanding of the present (and past) behaviour of the river system

5.3.1 Limited data on present state (P1)

In trying to understand the present river system historical data are being used. The amount and the quality of these data is however doubtful. There is an urgent need for validating these historical data. This is already being taken up by FAP24. This activity should be expanded, e.g. via the use of satellite images. In addition water and sediment balances should be made. They are important as checks on the understanding of the river system. Furthermore they are, in combination with bed level soundings, a key towards evaluating the reliability of the historical data.

5.3.2 Dynamic fluctuations around equilibrium (P2)

As was outlined in Chapter 2 even for a river which is in equilibrium (no changes in the independent variables and no human impact) the dependent variables are not constant but they are fluctuating around an average. This fluctuation makes any interpretation of field measurements more difficult. Trends that can be observed can either be real ones or they can be the reflection of this dynamic equilibrium. A better understanding of dynamic equilibrium and how it can affect dependent variables is very much needed for a further understanding of the present state of the river system.

5.3.3 Difficulties in measuring in large rivers (P3)

Limitations in understanding the present behaviour of the main rivers in Bangladesh is at least partly linked to problems to measure river characteristics of very large rivers. Necessarily the collection of data has to be limited as really collecting all the required is simply far beyond the possibilities of any agency within Bangladesh. Still there is a profound need for more, more frequent and more detailed data. At present FAP24 is filling in this urgent need for improved measuring methods which can be applied to the large rivers in Bangladesh. In particular the use of remote sensing techniques should be assessed for various purposes like measuring the water depths as a substitute for time-consuming hydrographic soundings, and measuring wash load concentrations from reflection intensities.

5.4 Autonomous development of the river system

5.4.1 Introduction

As discussed extensively in Chapter 3, the main river system in Bangladesh is still undergoing changes, probably mainly as a consequence of tectonic effects. The most remarkable developments are:

- o The continuous widening of the Jamuna River over the last 25 years, in combination with the gradual movement in Western direction,
- o The slow adaptation of the Upper Meghna River towards its new conditions with substantially reduced discharges and sediment loads,
- o The movement of the upper reach of the Lower Meghna River into Eastern direction, and
- o The gradual "dying" of the distributaries, in particular the Old Brahmaputra and the Dhaleswari River.

The real causes of these changes are not yet fully understood, and hence it is very difficult to make any predictions of the future behaviour of these river reaches. In addition there is the anticipated effect of the sea level rise over the next 50 years. Also this may affect significantly the characteristics of the main rivers in Bangladesh and in addition the opportunities for drainage.

The relevance of the developments described above is obvious: any regional plan either borders a main river, is -at least partly- dependent on water supply from it or considers drainage by one of the distributaries. Any significant changes will affect the regional plans in some respect. Hence a key problem is the prediction of the future development of the main river system in Bangladesh.

5.4.2 Widening of the Jamuna River (A1)

What is stated above for the main river system of Bangladesh in general, holds even more pronounced for the Jamuna River. According to the evidence available this river is (in addition to possible movement in Western direction upstream of Sirajganj) gradual widening. It may be connected to the formation of stable chars in the middle of the river. Further identification and improved understanding of this phenomena seems to be a key to predicting the future behaviour of the Jamuna River, and as such is relevant for any planned development along the Jamuna River.

5.4.3 Adaptation Upper Meghna River (A2)

Also the Upper Meghna River is in a state of adaptation to new equilibrium conditions. This adaptation however appears to go at a very slow rate. Still it appears that gradually the Upper Meghna River is transforming into a meandering river with fairly low bank erosion rates. Understanding of this process would allow to possibly accelerate this adaptation process and hence to use more land what is presently still reserved for the river, for other purposes.

5.4.4 Fate of distributaries (A3)

The main river system of Bangladesh is characterised by a number of main rivers (Brahmaputra/Jamuna, Ganges, Padma and Meghna Rivers) and a number of distributaries. These distributaries still carry substantial discharges during the flood season, but it seems that in most of them (Old Brahmaputra, Dhaleswari and Gorai Rivers) the flow is declining. The questions is whether these rivers are "dying". If so, then this would have a major effect on the availability of water in the different regions during the low flow season and it would have a major impact on the regional FAP plans.

The "fate" of the distributaries is determined by the distribution of sediment and discharge at the offtakes, and hence this distribution can be considered as an important boundary condition for the development of the bifurcating branches. Provided this boundary condition is known, the long-term development of such a distributor can be modelled mathematically with some confidence. Hence, in order to make long-term predictions of the development of the branches it is necessary to gain insight into the long-term development of the sediment transport and discharge distribution at the off-take, and hence, an understanding of the development of the bathymetry and planform at the offtakes. A thorough analysis of the past behaviour of the distributaries is needed to make extrapolations into the future.

Why this is a key problem for the FAP is obvious: a number of regional plans (FAP 3, FAP 3.1, FAP 4 and FAP 5 and FAP 6 to some extent) and also FAP 20 depend on the water in various distributaries during the low flow season.

5.4.5 Bank erosion over 2 to 3 years (A4)

For the planning of both bank protection works and remedial measures it is very important to be able to predict the location of bank erosion 2 or 3 years ahead. For meandering rivers this is not very difficult, as the future bank erosion can be extrapolated fairly well from historical data. For braided rivers, however, the predictability is considerably less (Klaassen et al., 1993). Nevertheless it seems possible to develop a prediction technique which allows to indicate where major bank erosion will occur over the coming years, be it within the frame-work of a probabilistic approach.

The relevance of this is obvious: once it is clear where with a high probability bank erosion will occur, it is possible to take appropriate actions with (on the average) the highest "rate of return". This can be either fixed bank protection works or remedial measures as proposed by FAP 22.

5.5 **Natural changes in independent variables**

5.5.1 Shifting of river courses (N1)

Bank migration rates along Bangladeshi rivers are only approximately known and predictable. Nevertheless, it is important to be able to estimate the bank erosion rates over the next years to decide on the necessity of bank protection or to decide on the alignment of retired embankments in relation to the present river alignment. It may be assumed that these bank erosion rates are related to local conditions (river characteristics and bank material characteristics). Hence for every main river the bank migration rates should be known.

The relevance of this topic is obvious: any bank protection work has to be assessed as far as the economic feasibility is concerned on the basis of benefits. Typical benefits for bank protection projects are the losses which would occur if no bank protection works would be implemented. The estimate of future bank erosion is not trivial: for the Lower Meghna River upstream of Chandpur it was shown (Haskoning et al, 1991; see also Section 3.3) that the bank erosion is a cyclic process. Similar detailed studies may be needed for other river reaches.

What is written above in general holds even more pronounced for the Jamuna River upstream of Sirajganj. It is extremely important to assess whether or not this trend of bank erosion along the right bank is going to continue or not. If so, there is scope for fixed bank protection works

along the right bank to protect the embankments to be built or improved under FAP1/FAP2. If this trend is not going to continue, than it is more reasonable to (temporarily) protect the banks of the river via remedial measures (with FAP22 techniques), as in that case it may be assumed that the present phase of bank erosion will change into a period of bank accretion. Hence a key problem is to predict what will be the future bank erosion along the Jamuna River.

5.5.2 Major changes possible? (N2)

The location of the main rivers in Bangladesh appears to be affected substantially by local tectonic effects. For long-term planning of measures to train the main rivers, insight is needed into the future changes into the locations of the river courses. Any future changes are largely influenced by the tectonic activity in the region. Hence a thorough understanding of these tectonic processes is crucial for any predictions on the long term developments. This holds even more for catastrophic events, like disastrous floods or major earth quakes with substantial changes in terrain level, which may cause that the river courses are fully altered. The predictability of these events are very low, which causes an inherent risk associated to any fixed river training works.

5.6 **Boundary conditions for design**

5.6.1 Design boundary conditions for embankments (discharges, stages and safe distance) (B1)

Within the framework of the FAP a number of structures may be implemented in due time. Also a number of other projects (like Jamuna Bridge) require accurate boundary conditions. If these boundary conditions are not known accurately enough, the consequence is either a more expensive design or less safety.

Within the FAP typically these "structures" are embankments and groynes and revetments. For these structures design boundary conditions are required. For embankments in particular the discharges and the corresponding stages, as these determine the levels of the embankments, and the determination of the safe distance, i.e. how far away from the river should the embankments, possibly with expensive drainage structures, be constructed. For groynes and revetments not only the stages are important, but also the magnitude of the velocities to which they are subjected and their direction. And finally for groynes and revetments also the bed levels near the groynes are important as

these determine the design of the protection layers. Groynes and revetment works are discussed in more detail under B2 in Subsection 5.6.2. Here the emphasis is on embankments.

For embankments the discharges and stages are of quite some relevance. There is some uncertainty as to the larger discharges in the Jamuna River. This is due to the specific conditions in braided rivers, where probably under certain conditions it is very important to measure the direction of flow in addition to the flow magnitude, see Hydrology study Phase 1 (RSP, 1993). In the other river reaches these issues are less controversial. In a further step these discharges have to be translated into stages, and here some balancing is taking place: if the discharges are estimated too high, automatically the roughness coefficients have to be adjusted. This may result in extremely low roughness values as have been used by some recent studies (SWMC, 1992 and Haskoning et al, 1991). A thorough analysis of the available data and their interpretation appears to be very appropriate.

Regarding the safe distance the following can be said. Over the last decades regularly embankments that had been constructed some time before were eroded by the rivers during flood and as a consequence of continued bank erosion. This has happened in particular along the left bank of the braided Brahmaputra/Jamuna River, but also along e.g. the meandering Gorai River. In this process also important structures may be lost, as is the case with many drainage structures like the Manos regulator near Gaibanda this year. Often retired embankments are constructed at these places, but the drainage structures are not rebuilt. This has necessitated the farmers to create artificial breaches in levees during the recession of the flood waters in the main rivers.

This raises the question of what is the "safe distance" of embankments to be constructed along the rivers in Bangladesh. Above a distinction was made between braided and meandering river systems. This was done because it is felt that conditions along meandering rivers are much better understood than along braided rivers. Along meandering rivers the location of bank erosion can be fairly good predicted, and using models like MIANDRAS or DELFT HYDRAULICS, calibrated for the specific conditions in Bangladesh, it appears to be possible to make predictions of future bank erosion. Especially when the occurrence of natural cutoffs can be included in these analyses. The safe distance of the embankments for these rivers can be decided upon using economic considerations. For braided rivers the conditions are much more difficult: the locations of severe bank erosion can be predicted only with limited accuracy and only with a certain probability of occurrence

(Klaassen et al, 1993). For the Jamuna River a complicating factor exists due to the continued movement of the river reach upstream of Sirajganj towards the West (see Subsection 3.4.2) probably due to tectonic influences.

For both type of rivers prediction methods for the future planform behaviour are very much needed. This should lead to guidelines for the safe distance of embankments.

A special case is the Upper Meghna River. In the present plans of FAP6 the safe distance is taken from the most Eastern channels of the river. As was shown by FAP9B, however, some of these channels are fairly shallow and in the process of silting up. This is the delayed effect of the shift of the Jamuna River to its present Jamuna course. A thorough study of this, including its implications for the locations of the embankments along the FAP6 planning borders, appears to be appropriate (see also Section 5.3.2).

5.6.2 Design conditions for groynes and revetments (discharges, stages, magnitude and direction of velocities and bed levels) (B2)

For groynes and revetments not only the stages are important, but also the magnitude of the velocities to which they are subjected and their direction. In addition also the bed levels are important for the design of groynes and revetments as these determine the design of the protection works.

Stages and discharges are discussed in Subsection 5.6.1 and these discussions are not repeated here. The magnitude and direction of the future velocities are determined by (1) design discharges, (2) magnitude, direction and curvature of the channel attacking the bank protection works, and (3) the local influence of the bank protection works. This implies that for establishing design conditions for the velocities predictions of future conditions have to be made. Partly this should be based on understanding of the behaviour of meandering and braided rivers, partly this should be based on physical model investigations.

Design bed levels are a combination of (1) the natural bed levels, (2) the guidance effect of river defence works in the surrounding, and (3) the effect of the structure via local scour. This requires insight into the cause of deep parts in the river. By now it is clear that in the Jamuna

River these deep parts occur naturally especially downstream of confluences. Outer bend scour appears to be less important, but this probably is due to the input of bank erosion products. When this would be blocked by protection works, it could lead to very deep scour holes. Deep scour holes in outer bends have been observed in meandering rivers with less fast bank erosion. Observations during floods are needed because during floods the scour holes become deepest.

One of the most difficult issues in the prediction of the bed level near future structures is how to combine the different types of scour. For considerations on this issue reference is made to the Final Report of FAP 21. Field data are very much needed on this aspect.

5.7 Impact assessment

5.7.1 Impact of regional plans on river characteristics (I1)

Different interventions in the main river system are proposed in the different regional plans. A summary of these regional plans is given per regional plan in Section 4.2 of this report. In Section 4.5 an overview of the possible interventions is provided. Although no definite decisions have been taken regarding implementation of any of these measures, still it can already be stated that generally speaking the interference is small. Nevertheless, some impact on the characteristics of the main rivers and the distributaries may occur. This holds in particular for any plans (see also Section 4.5):

- o To raise or built embankments that would result in reduced spilling into the adjacent areas and hence increased discharges more downstream;
- o To built any barrages across the main rivers (conceptually studied under FAP4);
- o To divert water from the Brahmaputra River to the Ganges River (do);
- o To improve the conditions at the offtakes of some of the distributaries (studied under FAP 3 and FAP4);
- o To built embankments (with possibly bank protection works) (too) near to the distributaries and the main rivers, hence reducing the width of the meander/braid belt (FAP1, FAP3, FAP4, FAP5, FAP6);
- o To create artificial cutoffs in distributaries to increase their conveyance capacity and to increase the flow into them (FAP4).

To study the effects of these possible measures is, according to the Terms of Reference, one of the main study topics of FAP24. How this impact should be assessed is not a trivial question, as no verified

methods are available to predict the changes in river characteristics for rivers with the size and complexity of the main rivers and the distributaries of Bangladesh.

5.7.2 Effect of narrowing/bank protection works/AFPM measures (I2)

Some of the FAP components are dealing with river training. Within FAP1 and FAP9B proposals have been prepared for the erection of bank protection works as fixed points. These will affect the planform changes of the rivers, but their impact is difficult to predict with the present state of understanding of river dynamics.

Within FAP 22 strategies for river training of the Jamuna River have been assessed. These strategies vary in the extent to which fixed river training works are combined with more flexible remedial measures like floating surface screens or dredging, but all result in some form of narrowing of the braiding belt. In the FAP22 report an attempt is made to assess the impact of narrowing and it was found that these strategies result in a reduction of the slope of the river and hence in a lowering of the water levels upstream. This in turn might affect e.g. the inflow into the Old Brahmaputra River. Hence it is important to verify and if required to improve the applied impact assessment method, and to assess the effect on the distributaries.

5.7.3 Effect of embankments on sediment flux towards fields and on siltation in floodplains outside embankments(I3)

This topic addresses two related topics, notably the sediment fluxes towards the fields and the effect if embankments would be constructed that would block this flux and possibly result in siltation of the floodplains on the river side of the embankments.

Floodplain sedimentation may be of considerable influence along the main river systems in Bangladesh. Also subsidence may be important. The possibility exists that the subsidence is in some places balanced by sedimentation of fine sediments, partly originating from the main river system. Embankments could disturb this balance by disrupting the supply of fine sediments. This could in due time lead to lowering of the embanked areas and increasing drainage problems.

In some river systems in the world substantial sedimentation has been experienced in the floodplains outside the embankments once embankments had been built. A notorious example is the Yellow River in China. It should be remarked, however, that the Yellow River is

discharging into a shallow sea into which rapidly a delta is being built out. This causes substantial backwater effects, which are probably the major cause of the floodplain sedimentation. Also quite some sedimentation has occurred along the Rhine River in The Netherlands, but this is at least partly due to fixation of the planform of the river in combination with the building of so-called summer dikes which created almost stagnant pools during the floods in which the wash load could settle. An understanding of the siltation rate to be expected after construction of embankments along the main rivers in Bangladesh is quite important for the possible impact on the flood levels. Floodplain sedimentation may also be advantageously though, as the deposits could be used for the production of bricks.

5.7.4 Impact of developments upstream (I4)

Only a fairly small part of the catchment of the three large rivers flowing through Bangladesh is actually in the country. Hence developments in India and Nepal could adversely affect the conditions in and along the main rivers and their distributaries. Some insight into the sensitivity of the river system for future developments are urgently needed for long-term planning.

5.7.5 Influence of climatic changes (I5)

It is expected that over the coming decades the climate may change, which will have consequences for the independent variables of the river basins of three major rivers that discharge via Bangladesh into the Bay of Bengal. This climatic change may induce changes in the hydrographs, changes in the sediment delivery to the rivers and changes in sea level. Although some insight into the sensitivity of the Jamuna River to these changes was obtained during the Jamuna Bridge Study, more studies are needed to evaluate the sensitivity of the system to these changes.

6 Possible study topics

6.1 General

In the previous Chapter key problems in understanding the behaviour of the river system and in assessing the impact of the various FAP components were identified. Different topics will have to be investigated in order to be able to solve these problems. Study topics have to be derived from these key problems.

What are study topics in this context? Study topics are fairly well described investigations for which the rationale for carrying out the investigation, the approach, the required input in manmonths, the required field data and the expected output can be defined properly. As will be shown in the subsequent Sections the various key problems can be dissected into such study topics. Once these study topics have been brought to satisfactory conclusions, it is also possible to formulate answers to the key problems. As will be shown hereafter for some examples, different key problems can be dissected into study topics that are partly the same for these key problems and partly are different.

In this chapter the various study topics that emerge after dissecting the key problems identified in Chapter 5, will be presented. The study topics are referred to as "possible study topics" as a selection will have to be made for implementation by FAP 24 because of the limited resources available. This selection will be based on the priority felt by the FPCO and the different FAP components. This is done in Chapter 8.

6.2 Dissection of key problems

A satisfactory answer to the various key problems can only be given when answers have been provided for by the different study topics into which these key problems can be dissected. In the following some key problems will be considered and it will be indicated which study topics can be derived from them. This is done to indicate the procedure used for all key problems for identifying possible study topics.

The following key problems have been selected for this "exercise":

- (P1) Limited data on present state
- (A3) Fate of distributaries,
- (A4) Prediction of bank erosion 2 to 3 years ahead,
- (B2) Design conditions for groynes and revetments (stages, magnitude and direction of velocities, bed levels), and
- (I2) Effect of narrowing/bank protection works/AFPM measures.

Re (P1) Limited data on present state

To increase the understanding of the present state based on the limited data, it is required that the available data are used as much as possible. This concerns both the hydraulic data and the morphological data. In fact this key problem was already tackled during Phase 1 of the present project, but based on the outcome of the studies in this Phase a number of additional study topics can be identified as:

- o Improved Bahadurabad discharges and rating curves: because of major differences observed during the last year
- o Improvement of the historical Bhairab Bazar discharge data using a simple mathematical model that can simulate the interaction between two confluencing channels
- o Water balances and overland flow: tackling one of the most difficult issues in Bangladesh, the consistency between the discharge data at different sections understanding of the overbank flow is also crucial for assessing the role that sedimentation in the floodplain may play
- o Water level profiles and water level slopes: indispensable information to assess the sediment transport capacities
- o Sediment rating curves and sediment balances: allow, in combination with cross-sectional soundings of BWDB to get an insight into the stability of the river system
- o Integration of the existing knowledge via available data into a 1-dimensional mathematical model of the morphology of the different rivers to check on inconsistencies and to assess the sensitivity of the system to changes in the upstream sediment transport, and
- o Floodplain sedimentation and subsidence: the relative importance of each being extremely important for impact assessment.

The totality of these studies will substantially increase the understanding of the present state of the river system.

Re (A3) Fate of distributaries

For studying the "fate" of the different distributaries, the following study topics have to be tackled:

- o Water balances: estimates of the quantities of flow entering into the distributaries from the main river
- o Sediment rating curves and sediment balances: for each of the distributaries sediment rating curves have to be prepared in addition data on bed levels (via BWDB cross-sections) have to be elaborated and these should be compared with the differences in rating curves
- o Integration of existing knowledge via 1-d morphological model: fairly simple modelling can be applied of a part of the main river and of the distributary: the sediment distribution at the offtake has to be

- introduced as a fair estimate, later to be refined on the basis of the further studies of the conditions at the offtake, and
- o Long-term development of the distributaries: based on the analyses discussed before prediction can be made of the long-term development of the different distributaries.

Re (A4) Prediction of bank erosion 2 to 3 years ahead

This prediction is a fairly complicated matter and can only be approached with stochastic prediction methods. Details on this prediction are presented by Klaassen et al (1993). An analysis of this paper indicates that the following study topics should be tackled:

- o Bank erosion rates
- o Channel cutoffs
- o Effect of tectonics on bank erosion
- o Influence of cohesive (bank) material on the planform characteristics
- o Local water level slope differences and their relevance for planform changes
- o Occurrence and dimensions of bars, important because it is felt that bars have a very pronounced influence on the development of the planform, and
- o Time-dependence of the bars, as an extra complication.

Re (B2) Design conditions for groynes and revetments (stages, magnitude and direction of velocities, bed levels)

For the determination of the design conditions for groynes and revetment works study topics have been identified related to the hydraulic aspects (stages, magnitude and direction of velocities) and morphological aspects (maximum scour depths):

- o Hydraulic aspects:
 - improved insight in design discharges (for Jamuna River, Upper Meghna River and other rivers)
 - water balances (determining how much flow actually passes through the rivers under consideration)
 - water-level profiles (important for the average velocities)
 - braiding (division of water over the different channels), and
 - bend scour (determining near bank velocities)
- o Morphological aspects:
 - channel dimensions (determines average depths in a channel)
 - bend scour (determines maximum water depths)
 - confluence scour and how it is affected by the passage of bed-forms

- time dependent behaviour of the bed level upstream of confluences
- local scour around groynes and in front of revetments
- time dependent behaviour of local scour (may yield a reduction as the maximum local scour may not be reached)
- influence of bedforms on the local scour (to what extent determines the passage of a bed-form deeper scour depths?), and
- how to combine different types of scour.

Re (I2) Effect of narrowing/bank protection works/AFPM measures.

The effect of narrowing/bank protection works/AFPM measures was studied under FAP 22. The most important study topics relate to:

- o Integration of the existing knowledge in a 1-d morphological model that can be used to study the time-dependent behaviour
- o Simulation of the response of the different FAP strategies on the number of channels, channel dimensions, etc.

For the latter it is needed to have better insight into:

- o Planform classification and braiding and meandering characteristics, and
- o Channel dimensions.

As is shown in the above examples every key problem can be dissected in a number of potential study topics. Also it can be concluded that for each key problem a number of study topics can be defined that are sometimes different from study topics needed for other key problems, but sometimes they are the same. That means that some study topics are required for different key problems. E.g. understanding of hydrological aspects is required for a number of key problems and also planform characteristics, braiding and meandering are important study topics for many key problems.

6.3 Preparing list of possible study topics

Based on the analysis of the different key problems it is possible to identify the different possible study topics. A tentative list of possible study topics was already prepared by Consultants in the proposal phase. This list was included in their proposal in Annexure 6. In this Chapter an updated list is presented. The list in Annexure 6 of the proposal was prepared from the outcome of meetings between the staff of DELFT HYDRAULICS and Danish Hydraulic Institute, which had substantial experience in a number of projects in Bangladesh. At the time the proposal was prepared, an insight was obtained from working-experience with the following projects:

- o Ganges Kobadak Rehabilitation Project

- o Jamuna Bridge Project
- o Bangladesh Inland Water Transportation Master Plan Studies
- o Assistance to Surface Water Modelling Center in modelling the main rivers of Bangladesh, as part of the General Model
- o FAP 1: Brahmaputra River Training Studies
- o FAP 9B: Meghna River Bank Protection Studies

This experience, together with the suggestions in the Terms of Reference, allowed to prepare an extensive tentative list of possible study topics.

Since quite some time has elapsed between the preparation of the proposal and the writing of this Interim Report, it seems appropriate to update the list of possible study topics. This is done on the basis of continued experience of Consultants in other projects in Bangladesh and, more recently, on the basis of discussion within the framework of FAP 24 and screening recent reports prepared by others. Recent projects of relevance in which Consultants were or still are involved are:

- o FAP 4: South West Regional Study
- o FAP 21/22: Bank Protection and River Training (Active Flood Plain Management) Pilot Project

The updating was done applying the systematic approach described in the previous section, so first identifying key problems and in a second step deriving study topics from them.

This list was sent to the different FAP projects who could be interested in additional studies, notably FAP 1 through FAP 6, FAP 9B FAP 17 through FAP 20, FAP 21/22 and FAP 25, with the request to reflect on these topics. Next, most of the Team Leaders of the FAP projects and also SWMC were interviewed regarding their ideas about the key problems, possible study topics and related surveys needed. Also FPCO and its Project Adviser were interviewed formally and the same holds for the local and expatriate Panels of Experts of FPCO.

Based on these discussions it was found necessary to extend and regroup the list of study topics. This has resulted in a total of 48 potential study topics.

6.4 List of possible study topics

Hereafter the list of possible study topics prepared as indicated in the previous section is given in Table 6.1. The topics are grouped into the following categories:

- o Hydrology (5 topics)
- o Sediment transport and river aggradation and degradation (6 topics)
- o Planform characteristics and channel dimensions (10 topics)
- o Offtakes and bifurcations (4 topics)
- o Confluences (3 topics)
- o Bars (2 topics)
- o Bedforms (4 topics)
- o Local scour (4 topics)
- o Measuring techniques (6 topics)
- o FAP impact on the river system (4 topics)

In Table 6.1 an overview of the possible study topics is given. In Annexure 2 these topics are described in some detail. There furthermore per topic the possible approach and the required study tools, a tentative ranking, the expected results and the required input are listed in addition.

The first tentative ranking was done during the proposal phase on the basis of the experience from the other projects. This ranking was updated in Chapter 8, where a tentative selection from the possible study topics is made.

The first two categories Hydrology and Sediment Transport, are fundamental. They have a high priority and have partly been taken up during the phase 1 study. The last category, FAP impact on river system, is considered a major task with a high priority for the overall Flood Action Plan. During phase 1 of the project this category has already been taken up as to arrive at a preliminary, quantitative assessment of the response of the river system to the implementation of the various flood control schemes. During phase 2 the impact simulation will be further developed to arrive at a quantitative assessment.

The other categories are not less important. They will improve the understanding of the specific behaviour of rivers in Bangladesh, which certainly will contribute to the quality of the impact assessment. The priority of these categories also depends on the river study requirements of the other FAP components. For that reason it is already assumed that the fourth category, Planform Characteristics and Channel Dimensions, has a high priority.

Some of the categories will be looked into by other projects as well, in particular FAP 1, FAP 9B and FAP 21/22. The extent to which these categories will be studied by the other projects, will be carefully followed in order to avoid duplications. Topics covered during phase 1 are not included in this report. This concerns topics like data collection and analysis, review of other studies and the establishment of the database.

6.5 Relation between key problems and study topics

As was explained before, the study topics were derived from the key problems, presented in Chapter 5, initially intuitively but later more systematically. Based on the analysis of the key problems as indicated in Section 6.3, it is possible to indicate the relation between the key problems and the study topics. This relation is provided in Table 6.2.

This table can also be used for the selection of study topics as the consequences of not selecting a study topic that concerns a particular key problem is that that particular key problem can only be solved in an approximate way. Also it can be read from this table that certain study topics are more vital than others, as they are required for providing answers to a number of key problems instead of only one. For example, study topics related to bed-forms (Topics 7.1 through 7.4) are apparently less urgently needed than a study topic related to planform classification and braiding and meandering characteristics (Topic 3.1).

	Category	Sub-number	Topic	Tentative ranking
1	Hydrology	1.1	Improved Bahadurabad discharges and rating curves	1
		1.2	Improvement historical Bhairab Bazar discharges	1
		1.3	Water balances and overland flow	1
		1.4	Water level profiles and water level slopes	1
		1.5	Phase 2 updating	1
2	Sediment transport and river aggradation and degradation	2.1	Rating curves and balances	1
		2.2	Sediment transport predictors	1
		2.3	Integration of existing knowledge via 1-d morphological model	1
		2.4	Long-term development of distribution	1
		2.5	Floodplain sedimentation and subsidence	2
		2.6	Phase 2 updating	1
3	Planform characteristics and channel dimensions	3.1	Planform classification and meandering and braiding characteristics	1
		3.2	Channel dimensions	1
		3.3	Bank erosion rates	1
		3.4	Outer bend scour	1
		3.5	Channel cutoffs	1
		3.6	Effect of tectonics on planform characteristics	2
		3.7	Influence of cohesive material on planform characteristics	2
		3.8	Local slope changes and their importance for planform changes	1
		3.9	Prediction of medium-term planform changes	1
		3.10	Long-term changes of the location of the rivers	1
4	Offtakes and bifurcations	4.1	Discharge and sediment transport distribution	1
		4.2	Seasonal variation of erosion and deposition	2
		4.3	Influence of bars	1
		4.4	Influence of bed-forms	3
5	Confluences	5.1	Erosion and deposition of out-of-phase floods	2
		5.2	Influence of bars and bed-forms	3
		5.3	Confluence scour	3
6	Sand bars	6.1	Occurrence, dimensions and dynamics of bars	1
		6.2	Time-dependence of bars	2
7	Bed-forms	7.1	Occurrence, dimensions and dynamics	1
		7.2	Time-dependence of bed-forms	1
		7.3	Three-dimensionality of bed-forms	1
		7.4	Roughness and bed-forms	1
8	Local scour	8.1	Dimensions of local scour around structures	1
		8.2	Time-dependence of local scour	2
		8.3	Influence of bed-forms	2
		8.4	Combination with other types of scour	2
9	Measuring techniques	9.1	Selection of measurement sites	1
		9.2	Optimization of hydraulic measurements	1
		9.3	Optimization of sediment measurements	1
		9.4	Bed load transport via dune-tracking	2
		9.5	Bathymetry and remote sensing	1
		9.6	Sustainable survey techniques	1
10	FAP impact on river system	10.1	Formulation of scenario's	1
		10.2	Simulation of ultimate river response via analytical modelling	1
		10.3	Quantitative assessment of FAP impact with 1-d morphological model	1
		10.4	Morphological model river system including changes in braiding and meandering characteristics	1

Table 6.1 Possible study topics

Num ber	Category	Sub num ber	Topic	Key problems													Impact assessment											
				Present state			Autonomous de- velopment				Natural changes				Design Conditions													
				P1	P2	P3	A1	A2	A3	A4	N1	N2	B1	B2	I1	I2						I3	I4	I5				
1	Hydrology	1.1	Improved Bahadurabad discharges and rating curves	*	*									*	*				*									
		1.2	Improvement historical Bhairab Bazar discharges	*	*										*	*												
		1.3	Water balances and overland flow	*	*										*	*					*							
		1.4	Water level profiles and water level slopes	*	*										*	*												
		1.5	Phase 2 updating	*	*										*	*												
2	Sediment transport and river aggrada- tion and degrada- tion	2.1	Rating curves and balances	*	*		*													*								
		2.2	Sediment transport predictors	*	*		*													*								
		2.3	Integration of existing knowledge via 1-d morphological model	*	*															*								
		2.4	Long-term development of distribution	*	*		*							*														
		2.5	Floodplain sedimentation and subsidence	*	*																		*					
3	Platform charac- teristics and channel dimensio- na	2.6	Phase 2 updating	*	*																							
		3.1	Platform classification and meandering and braiding characteristics	*	*		*					*			*	*				*								
		3.2	Channel dimensions	*	*										*	*				*								
		3.3	Bank erosion rates	*	*							*				*	*				*							
		3.4	Outer bend scour	*	*											*	*											
4	Offakes and bifur- cations	3.5	Channel cutoffs	*	*										*	*												
		3.6	Effect of tectonics on platform characteristics	*	*											*	*				*							
		3.7	Influence of cohesive material on platform characteristics	*	*							*			*	*					*							
		3.8	Local slope changes and their importance for platform changes	*	*							*			*	*					*							
		3.9	Prediction of medium-term platform changes	*	*							*			*	*					*							
5	Conflu- ences	3.10	Long-term changes of the location of the rivers	*	*								*	*						*								
		4.1	Discharge and sediment transport distribution	*	*		*								*	*					*							
		4.2	Seasonal variation of erosion and deposition	*	*		*								*	*					*							
		4.3	Influence of bars	*	*		*								*	*					*							
		4.4	Influence of bed-forms	*	*		*								*	*					*							
6	Sand bars	5.1	Erosion and deposition of out-of-phase floods	*	*										*	*				*								
		5.2	Influence of bars and bed-forms	*	*		*								*	*				*								
		5.3	Confluence scour	*	*		*								*	*				*								
		6.1	Occurrence, dimensions and dynamics of bars	*	*		*								*	*				*								
		6.2	Time-dependence of bars	*	*		*								*	*				*								
7	Bed-forms	7.1	Occurrence, dimensions and dynamics	*	*		*							*	*				*									
		7.2	Time-dependence of bed-forms	*	*		*								*	*				*								
		7.3	Three-dimensionality of bed-forms	*	*		*								*	*				*								
		7.4	Roughness and bed-forms	*	*		*								*	*				*								
		8.1	Dimensions of local scour around structures	*	*		*								*	*				*								
8	Local scour	8.2	Time-dependence of local scour	*	*		*							*	*				*									
		8.3	Influence of bed-forms	*	*		*								*	*				*								
		8.4	Combination with other types of scour	*	*		*								*	*				*								
		9.1	Selection of measurement sites	*	*		*								*	*				*								
		9.2	Optimization of hydraulic measurements	*	*		*								*	*				*								
9	Measuring techniques	9.3	Optimization of sediment measurements	*	*		*							*	*				*									
		9.4	Bed load transport via dune-tracking	*	*		*								*	*				*								
		9.5	Bathymetry and remote sensing	*	*		*								*	*				*								
		9.6	Sustainable survey techniques	*	*		*								*	*				*								
		10.1	Formulation of scenario's	*	*		*								*	*				*								
10	FAP impact on river system	10.2	Simulation of ultimate river response via analytical modelling	*	*		*							*	*				*									
		10.3	Quantitative assessment of FAP impact with 1-d morphological model	*	*		*								*	*				*								
		10.4	Morphological model river system including changes in braiding and meandering characteristics	*	*		*								*	*				*								
															*	*				*								

Table 6.2 Relation matrix key problems - study topics

7. Possible assistance by universities and other institutions

7.1 Introduction

In Chapter 6 possible study topics to tackle the key problems are identified and listed, see also Annexure 2. Straight from this list (Table 6.1) it is clear that all topics cannot be covered by the River Survey Project. As a first step the possible assistance by universities and other institutions are discussed in this chapter. As a next step in Chapter 8 a tentative selection from the possible topics is made indicating which topics can be handled by the Consultant.

The rationale behind this is that within the frame-work of FAP 24 it is possible to do field investigations at a level that until now has not been possible in such large braided sand-bed rivers. From a scientific point of view there is a lot of interest in using this survey capability and to use the eventual data for increasing the understanding in physical processes active in this environment. This was clearly demonstrated by the keen interest of e.g. the University of Leeds, which was initially short listed by the CEC and which decided to link to the proposal of this Consultant.

Hereafter, first the criteria to be applied for selection of a topic and a university to take part under certain conditions are discussed. Next some possibilities for assistance by universities are discussed in more detail, based on existing contacts that Consultants have established over the past year. Finally the practical implications of including some Universities are discussed briefly.

7.2 Criteria

For collaboration with universities some criteria should be fulfilled. These criteria are elaborated hereafter in some detail:

o **Interesting topic**

It may be expected that for the topics to be tackled some activities from FAP 24 will be required, in particular as far as field measurements are concerned. Hence the topic to be tackled should be relevant for the mission of FAP 24 and hence be linked to one of the key problems identified in Chapter 5.

o **Specific expertise**

By including some universities in the study part of the project it is possible to introduce in the project specific expertise from some top level researchers from all over the world. This will definitely add value to the output of the project.



- o **Interesting exchange rate**
It is of interest to the project that a maximum input from a university is ascertained versus a minimum input from the side of the project. The input from a university is typically either a Ph.D. or a M.Sc. student with support from a professor. This means as a minimum 8 months to 3 years of M.Sc./Ph.D.-student input and about 1 to 4 months input at the level of a professor. In discussions with relevant universities this ratio should be maximised. Furthermore there could be opportunities for co-funding by a scientific organization, but this should typically be explored by the interested universities.
- o **Compatible within time schedule of FAP 24**
The River Survey Project will finalize its last surveys probably in 1996 and the project itself should produce its results latest early 1997. The time schedule of field investigations for the study topic to be taken up by the respective university should be in line with this. Practically it probably means that new Ph.D studies can not be covered in the time schedule.
- o **Part of training**
One of the objectives of the River Survey Project is training of local staff. Bangladeshi students could be involved in some of the studies, e.g. by doing their M.Sc. on the basis of one of the study topics. This could be students studying at BUET or students studying abroad (e.g at IHE Delft).

It seems fair that if a number of the above criteria is fulfilled and an agreement is reached, that the project covers some additional expenses like travelling costs, living allowances, etc. both for the student and for the professor who is giving guidance.

7.3 Possible topics

7.3.1 General

Herafter a short description is given of topics that have already been identified as topics that could be taken up by a university and for which first contacts have been established. For more information on these topics reference is made to Annexure 3, where the relevant correspondence is presented. Mainly this correspondence gives a more detailed outline of the proposed activities.

It is expected that more contacts will be established over the coming months and that more proposals may be forthcoming. All will depend

on the results of the International Workshop and the recommendation of the Project Adviser and the possibility to allocate the required resources.

7.3.2 Tectonics and its influence on river characteristics

In the recent past and financed by internal research funds of DELFT HYDRAULICS, the University of Amsterdam, The Netherlands, in particular the Alpine Research Group has carried out an investigation into faults and their influence on planform behaviour of the Jamuna River. This was done on the basis of some satellite images provided by DELFT HYDRAULICS, which purchased these under the FAP 21/22 project. Some preliminary results are presented in Hartmann et al (1993) and Mosselman et al (1993). One of the most interesting conclusions from this study is that possibly the faults and possible related upheavals and subsidence, that can be identified in the landscape adjoining the river, may have a substantial effect on the river pattern. This is in line with previous observations by Watson et al (1983) for the Mississippi River, where they state that "available evidence suggests that subtle uplift rates in the order of 3 mm/year can affect the planform of the Mississippi". Figure 7.1 provides an overview of the many faults that were identified during the study.

Based on these preliminary results it was discussed with Dr. Rupke of the University of Amsterdam to what extent more detailed studies can be carried out under the FAP 24 project. In the correspondence included in Annexure 3, the first ideas are given. Tentatively it is concluded that the kind of studies proposed do not fit into the present River Survey Project, as the type of investigation needed deviate considerably from the field investigations done under FAP 24. It seems more logic to include this aspect into a future fluvio-geomorphological study.

This is not to say here that faults, upheaval and subsidence are not important for the river system but they should be studied outside FAP 24. FAP 24 could possibly be instrumental in searching for alternative funding.

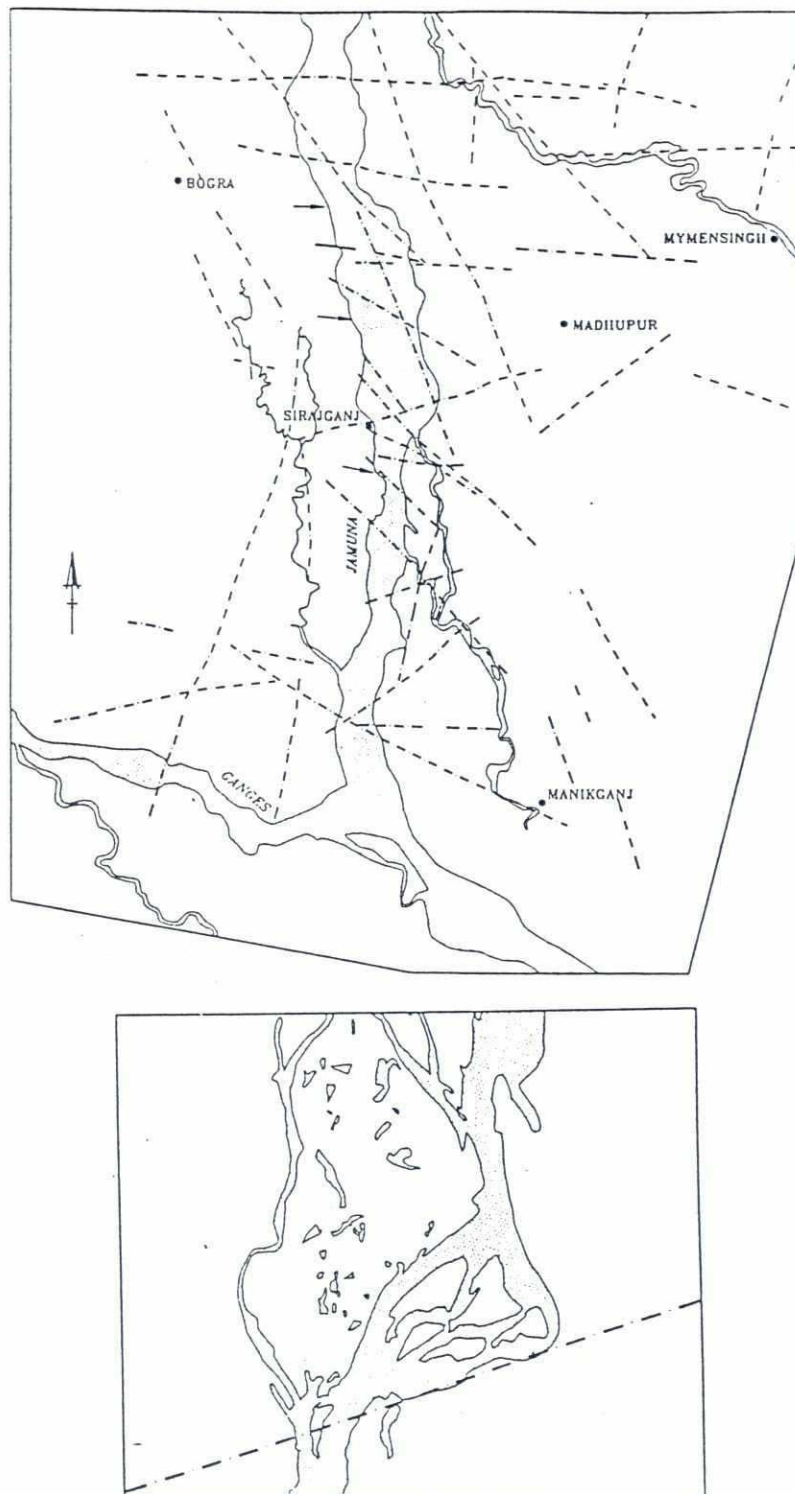


Figure 7.1 Faults along the Jamuna River (Hartmann et al, 1993)

7.3.3 Subsidence and sedimentation

Various investigations indicate that subsidence is an important phenomenon in Bangladesh due to its location in a tectonically active zone (Morgan and McInire, 1959; MPO, 1985; Rashid, 1991). Estimates of subsidence vary depending on investigators (Rashid, 1991). Studies using gravity anomaly with Bouguer correction (MPO, 1985), indicate that tectonic subsidence at the rate of some 2 mm/yr occurs at Sylhet depression (Figure 7.2). In addition, decrease in the thickness of sediment layers due to consolidation, may result in subsidence, especially when no fresh sediments are deposited. Continued subsidence is detrimental to an effective drainage of flood flows. It is believed that a delicate balance exists between sedimentation and subsidence in the annually flooded areas. This means that engineering interventions in the floodplain have to be carefully planned such that the balance is not destroyed. But careful planning is only possible if the sedimentation and subsidence rates are known quantitatively.

Dating of radio isotopes such as ^{14}C , ^{210}Pb and ^{137}Cs occurring naturally in sediments, is a recognized method of determining sedimentation and subsidence rates. Through a cooperation between the University of South Carolina (USA) and the Land Reclamation Project of Bangladesh Water Development Board, such techniques were applied in the past to determine sedimentation rates on the Bengal shelf (Kuehl et al, 1989). Based on the usefulness of such a cooperation, it was discussed (see Annexure 3) between FAP 24 and Dr. S. A. Kuehl of the University of South Carolina (now at the Virginia Institute of Marine Science, USA) to apply the same technique to study floodplain sedimentation and subsidence of the Bengal Basin. The outcome of this study would result in an identification of areas having different rates of sedimentation and subsidence. And comparison of this information with the frequency, duration, and extent of annual flooding, will help to understand the balance of river-borne sediments.

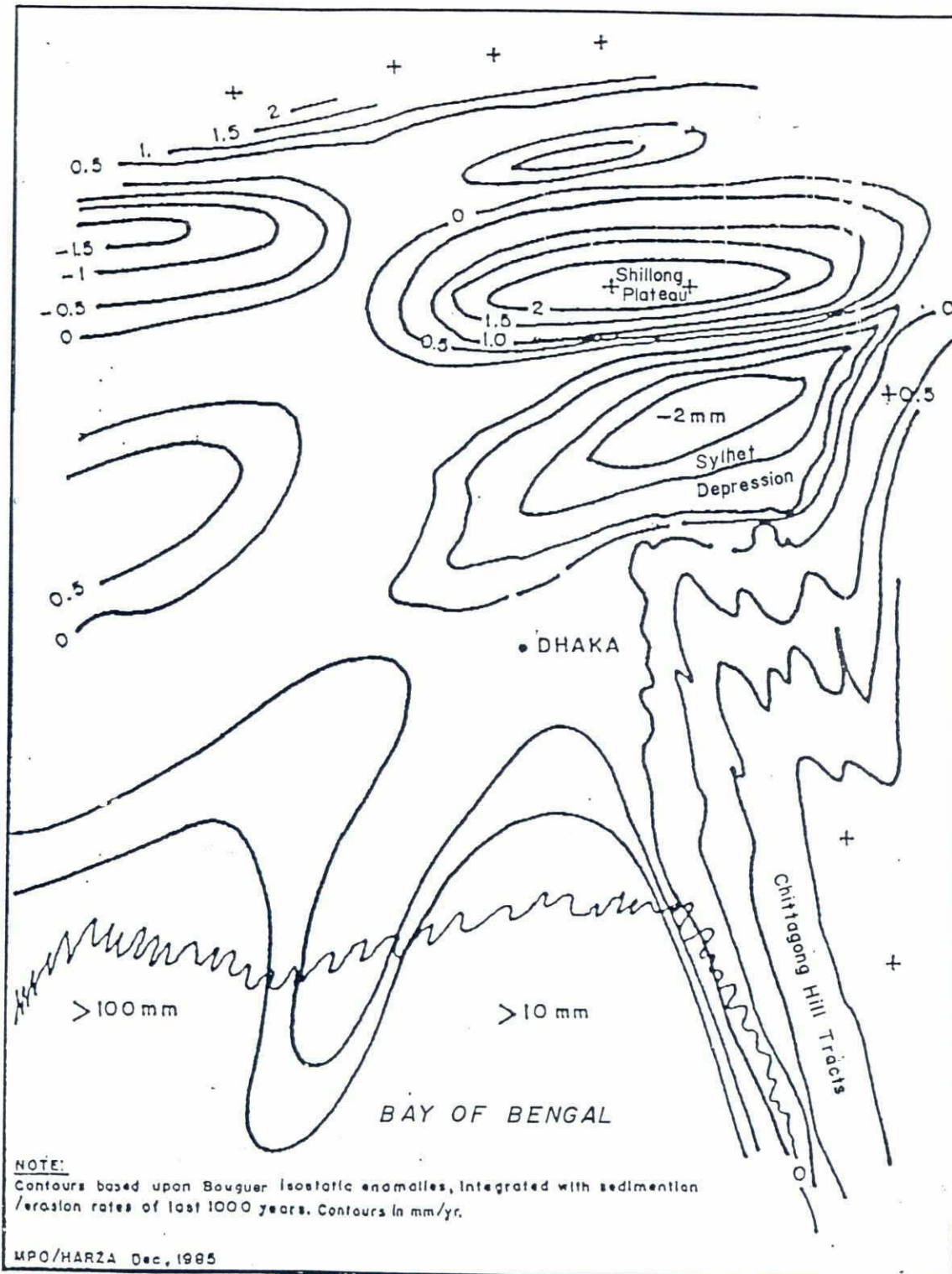


Figure 7.2 Neotectonic sketch map of Bangladesh.

7.3.4 Fate of distributaries

The limited data available (see Chapter 3, Section 3.5) suggest that the importance of some of the distributaries (notably the Old Brahmaputra and the Gorai) is rapidly declining. The evidence comes mainly from an analysis of low flow data. There is an urgent need to study this aspect in more detail. It is important to compare the available cross-sections and BIWTA soundings, if and when available, over the years with the trend shown by the hydraulic data. Also the possible reasons for these trends should be studied. These reasons could be unfavourable developments at the offtake, while in the case of the Gorai the influence of Farakka on the hydraulic regime in the Ganges could aggravate the conditions at the offtake.

The conditions at the offtake can be studied from maps, aerial photographs and in particular satellite images, in combination with available soundings of BIWTA. In addition 1-dimensional models could be used to simulate the effect of the changed supply of flow and sediment on the development of the distributaries. In a later stage of course the results of field surveys at the different offtakes should be included in this analysis also. In total this would be a concerted effort to understand this specific behaviour of the main river system.

The first part, the study of the existing data and combining them to get the beginning of an understanding should be done at short notice. IHE Delft has expressed its interest to take this up as a M.Sc.-topic for a Bangladeshi staff member from River Research Institute, who just obtained the IHE Delft diploma and who was academically accepted for M.Sc. who would get a unique opportunity to work in FAP 24 with the combination of BWDB cross-sectional soundings, BIWTA soundings, satellite images and simple 1-d mathematical models.

Regarding the criteria listed above it appears that almost all criteria are met, as also the academic guidance will be provided by the senior morphologist of Consultants.

7.3.5 Mid-channel bar growth and the rate and incidence of bank erosion

Dr. P.Ashworth and Dr. J. Best of Leeds University have proposed to do a study into mid-channel bar growth and the rate and incidence of bank erosion. Mid-channel bar formation has shown to be an important issue, e.g. downstream of Mawa and as such one of the determining factors for the severe bank erosion along the Lower Meghna River. The

same holds for the Jamuna River, as rightly indicated by Thorne & Russell (1993). The proposal is in particular related to the study topics 6.1 and 6.2 (Bars) and also to 3.4 (Outer bend scour). The interest of the FAP 24 project is very much in the key role that bars play in bifurcations and more in general in bar formation, in particular as far as their influence on planform changes is concerned. In the proposal it is mentioned that also experiments in a flume will be needed. "There will also need to be a contribution to flume costs ...". It is felt that this is beyond the scope of FAP 24, hence this part has to be discussed in further detail with Leeds University staff members. It is felt that by bringing in unique field data plus some travel and living allowances, the contribution of FAP 24 is already sufficient.

7.3.6 Bedform dynamics and migration in unsteady flows

Dr. P. Ashworth and Dr. J. Best of Leeds University have proposed to do a study into bedform dynamics and migration in unsteady flows and zones of appreciable scour. This project would be related to the topics 7.1 through 7.4 (and according to Leeds also to other topics: 5.1 through 5.4, 8.3 and 8.4). It is proposed to study "the dynamics of large-scale bedforms and their morphological response to both (i) changing flow stage and (ii) migration into and around areas of substantial bed scour (especially channel junctions). The first topic is definitely in line with the interest of the FAP 24 project, especially if the echo-soundings that are proposed would be combined with discharge and slope measurements. The relevance of the second part for FAP 24 is less obvious, also considering the priorities felt (see Chapter 6, in particular the tentative ranking in Table 6.1). Further discussions with Leeds University will be needed to refine the study proposal. In itself it is felt that a study into bedforms, their dynamics and their hydraulic roughness is very much needed and that the proposal from Leeds University is appropriate. Also the expertise brought in by Leeds is appreciated and will definitely add to the value of the project.

7.3.7 Bed load measurement via dune tracking

Professor J. Fredsoe from ISVA (Technical University of Denmark, Copenhagen), has expressed his interest to work on the topic "Bed load measurement via dune tracking" (Topic 9.4). One of his Ph.D. students is developing a mathematical model that describes the flow over bedforms. Also the suspended sediment transport verticals and their variation in longitudinal direction can be computed with this model.

Such a model can be used advantageously for the study of the influence

of suspended load on bed load determination by dune tracking. As is shown in one of the FAP1 reports deposition in the wake of the bed-forms may substantially contribute to the movement of the dunes. Hence, the bedload determined from the traditional dune tracking method has to be corrected for the presence of suspended load. This can be studied with the mathematical model in combination with special field measurements. For the field measurements possibly in particular the ADCP can be used in combination with the very accurate positioning system. The output to be expected are probably graphs from which the value of a correction coefficient can be read as a function of a.o. the Rouse parameter u_*'/w , being an indicator of the importance of the suspended load.

In Consultants' opinion this proposal meets all criteria set above and should be accepted, provided satisfactory arrangements can be made.

7.3.8 Analysis of longitudinal soundings

Longitudinal soundings reflect a combination of phenomena. First of all the shape of second-order river channels (see Figure 2.5) results in a particular bed topography, e.g. characterized by outer bend pools, point bars, etc. This is reflected in longitudinal soundings in deeper and more shallow depths. This phenomena is linked to changes in the second-order channel and hence changes over the years with continuing bank erosion and other phenomena that affect the planform of the second-order channels. In addition to this islands and bars are travelling through the second order channel and also this is causing bed level fluctuations. In the Jamuna River these bars travel over several hundreds of meters in a year. Superimposed on these two phenomena bed-forms of different sizes are present. These travel with a celerity of tens of meters a day.

If one of these phenomena has to be studied then it has to be isolated from the effect of the other phenomenon. E.g. if hydraulic roughness is the topic of interest then especially the bed-forms are of interest and hence the other phenomenon have to be filtered out. Something similar holds for outer bend scour. There the contribution of bed-forms has to be eliminated. This implies that the longitudinal soundings have to be further elaborated depending on the topic of interest.

The Governmental Water Board of The Netherlands is carrying out extensive studies in bed-forms, their influence on hydraulic roughness and dune tracking. Within this frame-work they have developed a programme that can be used to further elaborate longitudinal soundings.

This so-called DULOC (dune location) programme computes among others from longitudinal soundings dimensions of bed-forms of the different arrays of bed-forms, and it identifies their location. Filters can be applied to remove phenomena that are not of interest. In addition software is incorporated to estimate the bed load transport via dune tracking.

It is felt that this DULOC programme after adaptation to the conditions and data generated under the River Survey Project, can be extremely convenient and it is proposed to use one manmonth for adapting the programme. This will be done in a combined action by the Project and the Governmental Water Board of The Netherlands.

7.4 Practical aspects

As becomes clear from the above discussion, some of the proposals fit nicely into the FAP 24 set-up, but some should be discussed further. During these discussions not only the topics that will be tackled have to be adjusted in some cases, but also a number of practical aspects has to be arranged.

If it is accepted that some or all of the above study topics are taken up by universities a number of practical aspects still has to be settled. Firstly arrangements have to be made as to the reimbursing of travelling costs, living allowances, costs of producing and reproduction of reports, etc. Secondly the required field measurements have to be detailed and it has to be verified that these can be fitted into the overall field surveys programme. Finally it has to be ascertained that the results of the studies by the university still are in time for the project to benefit from them. It may be needed to verify certain aspects during further surveys, and also this should still be possible within the time frame of the project. Finally some kind of contract has to be made between the respective university and the Consultants.

8 Tentative selection of study topics

8.1 Objective

From the description of input requirements (Annexure 2) the total input for the possible study programme has been computed to amount 176 and 444 manmonths for expatriate and local staff respectively. As elaborated in Section 8.4, this amount by far exceeds the available resources within the River Survey Project. The ratio between required input and available resources is in the order of three. So it is needed to define which part of the total study programme can be tackled by the River Survey Project.

In the previous chapter it is already discussed which topics can be covered by various universities. In this chapter the selection of the topics is described. First the applied selection method is given (Section 8.2). Thereafter this method is elaborated in the various subsequent sections.

It is stressed here that this tentative selection of study topics is the Consultants proposed selection of September 1993. This selection will be reviewed during the workshop on "Morphological behaviour of the major rivers in Bangladesh", scheduled to be held early November 1993. After the workshop a final decision on the study programme will be taken by the GoB. And thereafter further updating is possible. Some flexibility in the selection and content of the study topics is required, also during phase 2, to be able to re-direct some of the studies if necessity arises (see also Section 1.6).

8.2 Approach

The tentative selection of the study topics is obviously based upon the assessment of the importance of the topics and the available resources within the River Survey Project.

However, as discussed in Chapter 6, the study topics are no purpose on their own, but aim at a better understanding of the past, present and future behaviour of the main rivers. And also a better understanding of the rivers is no purpose on its own, but aims at solving key problems experienced now (for instance the problems related with the impact assessment of possible FAP interventions). Therefore the key problems should be prioritized and selected first. Thereafter the selection of the study topics follows more or less automatically.

For the selection of key problems and topics the following approach has been applied:

First step (Section 8.3)

- o Discussions with other FAP teams
- o Discussion with the PoE and the PA
- o Sounding the meaning of the GoB

This resulted in a tentative ranking.

Second step (Section 8.4)

- o Assessment of required input for highest ranked topics
- o Comparison with available resources (manmonths of expatriate and local staff)

This resulted in the need for further reductions in the study programme

Third step (Section 8.5)

- o Development of criteria
- o Consistent selection of key problems and topics

This has resulted in the tentative selection of the study topics

Fourth step

- o Assessment of the additional survey work needed for the selected study topics
- o Check in how far this work can be done within the available survey resources
- o Integration of the survey and study programme

The first three steps are discussed in the following paragraphs. In the next chapter (Chapter 9) the fourth step is discussed.

8.3 Interventions

As a first step the importance of key problems and study topics was discussed with other FAP teams, with the PoE and the PA. Last but not least the opinion of the GoB was sounded. And this resulted in a tentative ranking of the study topics.

In discussions with the Team Leaders of the different FAP's their interest in the different key problems and study topics was assessed and in addition their reports as far as available were reviewed. Based on that we have prepared a tentative table (Table 8.1) in which the interest of different FAP's is indicated.

Sub number	Topic	FAP components											
		1	2	3	3.1	4	5	6	9B	16	19	21/22	25
1.1	Improved Bahadurabad discharges and rating curves	+	+	+	+	+	+	+	+			+	+
1.2	Improvement historical Bhairab Bazar discharges	+					+	+	+			+	+
1.3	Water balances and overland flow	+	+		+				+	+	+	+	+
1.4	Water level profiles and water level slopes	+							+			+	+
1.5	Phase 2 updating	+	+	+	+	+	+	+	+			+	+
2.1	Rating curves and balances	+							+			+	+
2.2	Sediment transport predictors	+							+			+	+
2.3	Integration of existing knowledge via 1-d morphological model	+	+	+	+	+	+	+	+			+	+
2.4	Long-term development of distribution	+	+	+	+	+	+	+	+			+	+
2.5	Floodplain sedimentation and subsidence	+	+	+	+	+	+	+	+			+	+
2.6	Phase 2 updating	+	+	+	+	+	+	+	+			+	+
3.1	Planform classification and meandering and braiding characteristics	+	+	+	+	+	+	+	+		+	+	
3.2	Channel dimensions	+				+							
3.3	Bank erosion rates	+		+	+	+			+		+	+	
3.4	Outer bend scour	+				+			+			+	
3.5	Channel cutoffs	+				+			+			+	
3.6	Effect of tectonics on planform characteristics	+							+		+	+	
3.7	Influence of cohesive material on planform characteristics	+							+			+	
3.8	Local slope changes and their importance for planform changes	+							+			+	
3.9	Prediction of medium-term planform changes	+							+			+	
3.10	Long-term changes of the location of the rivers	+							+			+	
4.1	Discharge and sediment transport distribution	+		+	+	+		+	+			+	
4.2	Seasonal variation of erosion and deposition	+		+	+	+			+			+	
4.3	Influence of bars	+		+	+	+			+			+	
4.4	Influence of bed-forms	+		+	+	+			+			+	
5.1	Erosion and deposition of out-of-phase floods	+	+						+				
5.2	Influence of bars and bed-forms		+										
5.3	Confluence scour	+							+			+	
6.1	Occurrence, dimensions and dynamics of bars	+				+			+			+	
6.2	Time-dependence of bars	+				+			+			+	
7.1	Occurrence, dimensions and dynamics	+							+			+	
7.2	Time-dependence of bed-forms	+							+			+	
7.3	Three-dimensionality of bed-forms	+							+			+	
7.4	Roughness and bed-forms	+							+			+	
8.1	Dimensions of local scour around structures	+							+			+	
8.2	Time-dependence of local scour	+							+			+	
8.3	Influence of bed-forms	+							+			+	
8.4	Combination with other types of scour	+							+			+	
9.1	Selection of measurement sites	+							+			+	
9.2	Optimization of hydraulic measurements	+							+			+	
9.3	Optimization of sediment measurements	+							+			+	
9.4	Bed load transport via dune-tracking	+							+			+	
9.5	Bathymetry and remote sensing	+							+			+	
9.6	Sustainable survey techniques	+							+			+	
10.1	Formulation of scenario's	+	+	+	+	+	+	+	+	+	+	+	+
10.2	Simulation of ultimate river response via analytical modelling	+	+	+	+	+	+	+	+	+	+	+	+
10.3	Quantitative assessment of FAP impact with 1-d morphological model	+	+	+	+	+	+	+	+	+	+	+	+
10.4	Morphological model river system including changes in braiding and meandering characteristics	+	+	+	+	+	+	+	+	+	+	+	+

Table 8.1 Possible study topics and interest of different FAP's

Some tentative conclusions are:

- o Most of the interest appears to be in the simulation of the river response on local, on more regionalized or on country-wide scale
- o Also overland flow appears to be an important and until now unsettled issue, that needs further attention
- o More understanding seems to be required into the role of off-takes in determining the long term "fate" of different distributaries
- o There are a number of topics that are not of interest for the regional studies, but that are considered very important by the three FAP components dealing with the major rivers: FAP 1, FAP 9B and FAP 21/22.

Discussions with the PoE and the PA reveals that in broad terms there is a consensus with the topics selected by the Consultants. The main remarks from their side were related to

- doubt in how far various mathematical modelling activities should be executed within the present FAP 24 contract, and
- doubt about the importance of the confluences

It was decided to discuss these subjects in the forthcoming International Workshop.

For the opinion of GoB special reference is made to the third FAP conference of May 1993 during which on several occasions priorities were indicated by various GoB officials. It was concluded that one of the most crucial problems consists of the uncertainties in the impact assessment of FAP interventions. This is felt to be a major obstruction in the government's development of a comprehensive Flood Action Plan.

Summarizing these discussions and opinions led to a tentative ranking of study topics (as already indicated in Table 6.1).

8.4 Input requirements and available resources

As a second step the total input requirement in terms of expatriate and local manmonths was computed to be 176 and 444 respectively. For the input requirements per study topic see Annexure 2.

If the tentative ranking is used (see Section 8.3 and Table 6.1) and only those topics are taken up with a first priority ranking, then the total input requirement comes down to 142 and 366 for expatriate and local manmonths respectively.

Also the assistance from universities and other institutions (see Chapter 7) leads to a possible reduction of manmonths, which is indicated in the following table.

Topic	Ranking	100 % input from FAP 24	Reduced input from FAP 24	assist. from universities, etc.
2.4	1	3/6	.6/6 (1)	IHE
2.5	2	3.5/6	.7/3 (-)	USC
3.6	2	6/1	1/1 (1)	UvA
6.1	1	6/18	.6/18 (.5)	Leeds
6.2	2	2/4	.2/4 (.5)	Leeds
7.4	1	3/12	.6/12 (.5)	Leeds
9.4	2	6/12	1/12 (1)	ISVA

x/y expatriate / local manmonths

(z) miscellaneous expatriate manmonths to cover cost of universities, etc.

Table 8.2 Manmonth reductions

Note:

It should be noted here that it is questionable whether the proposed assistance can be realized by the universities and other institutions within the available fees for miscellaneous manmonths. Other resources should be found to cover the various type of costs and this holds particularly for contribution of the University of Carolina containing an additional field survey.

However, considering that the available manmonths for study within the River Survey Project amounted per 1 June 1993 to 64/170 (expatriate / local respectively) it will be clear that a further reduction of topics is required.

8.5 Consistency in selection

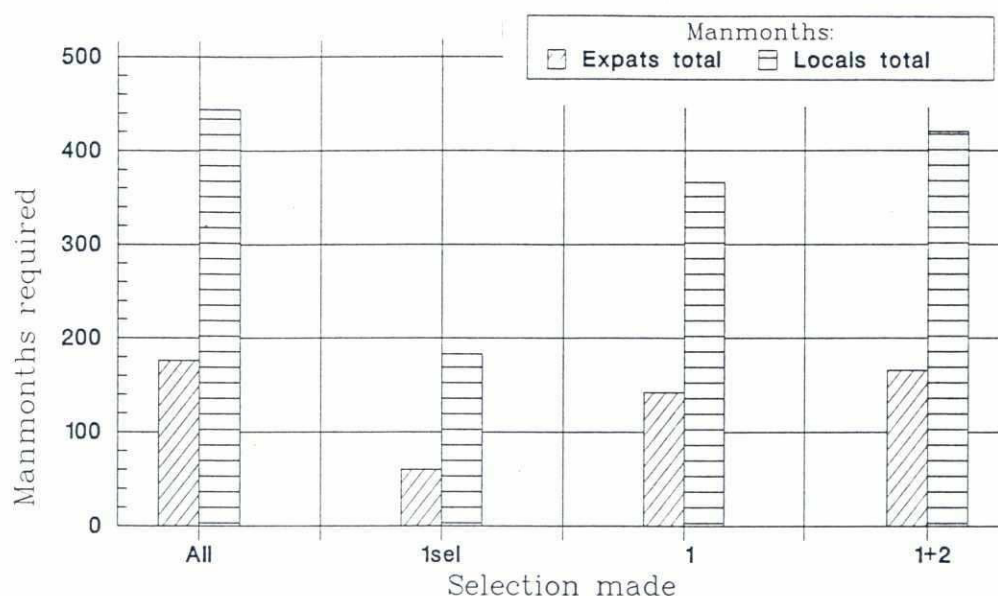
As a third step a series of selection criteria were developed to come to a reduced but balanced and comprehensive study programme. These criteria are listed as follows:

- o Required for the impact assessment of the combined FAP's ("impact criterion")
- o Of interest for the feasibility but more often the detailed design phase of the regional FAP's ("regional criterion")
- o Required for the FAP components that are dealing with bank protection and river training works ("river training criterion")
- o Can be studied in much more detail with the up-to-date surveying possibilities of the FAP 24 vessels ("availability criterion")

- o Study can be done with fairly low investment in manmonth ("investment criterion")
- o Is of academic interest ("research criterion")
- o Is emphasizing the overall behaviour over local phenomena ("aggradation criterion")
- o Is tackling the most important key problems ("key problems criterion")

After various attempts to apply these criteria mostly in combination, the most meaningful one appeared to be the last one which is elucidated hereafter.

The key problems - study topics relation (see Table 6.2) is used to select the topics in such a way that most of the key problems can be tackled appropriately. Also some topics viz. 3.4 and 3.8 were omitted because they are only supporting one key problem already badly addressed. Topic 10.4 had to be omitted because of the considerable input requirement. Further reductions were obtained by cancelling the optimization of bed load measurements being part of Topic 9.3 and by assuming that a substantial part of Topic 9.5 can be done by FAP 19. Moreover, Topic 9.5 does not include the pilot study into the possibilities to derive a bathymetric map from radar imagery. Both reductions in Topic 9.3 and 9.5 are expected to become point of discussion during the workshop. The final selection is given in Table 8.3.



Legend	All	=	total input for all possible study topics
	1 set	=	proposed tentative selection
	1	=	only topics ranking first
	1+2	=	topics ranking first and second

Figure 8.1 Number of manmonths according to different selections.

From this table the consequences of the selection can be seen. A number of key problems are not addressed properly, viz.

- P2 : Dynamic fluctuation around equilibrium
- A4 : Bank erosion over 2 to 3 years
- B1 : Design boundary conditions, embankments
- B2 : Design conditions for groynes and revetments

8.6 Final result

The result of the selection described in the previous section is given in Table 8.4 and in the Figures 8.1 and 8.2. The required input amounts 60 / 185 manmonths for expatriate and local staff respectively excluding the miscellaneous manmonths for the universities and other institutions.

The input comes rather close to the available resources per 1 June 1993 amounting 64 and 170 manmonths for expatriate and local staff respectively.

It is questionable whether all manmonths should be allocated beforehand. Flexibility asks for spare capacity.

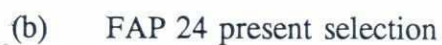


Figure 8.2 Study topics versus manmonths

Num ber	Category	Sub num ber	Topic	Key problems																						
				Present state			Autonomous de- velopment				Natural changes			Design Conditions			Impact assessment									
				P1	P2	P3	A1	A2	A3	A4	N1	N2	B1	B2	I1	I2	I3	I4	I5							
1	Hydrology	1.1	Improved Bahadurabad discharges and rating curves	•	•									•	•	•										
		1.2	Improvement historical Bhairab Bazar discharges	•	•									•	•	•										
		1.3	Water balances and overlaid flow	•					•					•	•	•			•							
		1.4	Water level profiles and water level slopes	•										•	•	•	/									
		1.5	Phase 2 updating	•	•									•	•	•										
2	Sediment transport and river aggra- dation and degra- dation	2.1	Rating curves and balances	•		•	•											•								
		2.2	Sediment transport predictors	•		•												•								
		2.3	Integration of existing knowledge via 1-d morphological model	•	•											•	•									
		2.4	Long-term development of distribution	•			•					•														
		2.5	Floodplain sedimentation and subsidence	•															•							
		2.6	Phase 2 updating	•	•																					
3	Planform charac- teristics and channel dimensions	3.1	Planform classification and meandering and braiding characteristics		•		•	•					•		•	•	•	•								
		3.2	Channel dimensions		•											•	•	•	•							
		3.3	Bank erosion rates									•														
		3.4	Outer bend scour															•								
		3.5	Channel cutoffs		•																					
		3.6	Effect of tectonics on planform characteristics														•									
		3.7	Influence of cohesive material on planform characteristics		•												•									
		3.8	Local slope changes and their importance for planform changes														•									
		3.9	Prediction of medium-term planform changes		•													•								
		3.10	Long-term changes of the location of the rivers															•								
4	Offakes and bifur- cations	4.1	Discharge and sediment transport distribution				•																			
		4.2	Seasonal variation of erosion and deposition																							
		4.3	Influence of bars				•																			
		4.4	Influence of bed-forms																							
		5.1	Erosion and deposition of out-of-phase floods		•													•								
5	Conflu- ences	5.2	Influence of bars and bed-forms		•													•								
		5.3	Confluence scour																•							
6	Sand bars	6.1	Occurrence, dimensions and dynamics of bars																							
		6.2	Time-dependence of bars																							
7	Bed-forms	7.1	Occurrence, dimensions and dynamics																•							
		7.2	Time-dependence of bed-forms		•															•						
		7.3	Three-dimensionality of bed-forms																	•						
		7.4	Roughness and bed-forms																		•					
8	Local scour	8.1	Dimensions of local scour around structures																	•						
		8.2	Time-dependence of local scour		•																•					
		8.3	Influence of bed-forms																			•				
		8.4	Combination with other types of scour																				•			
9	Measuring techniques	9.1	Selection of measurement sites			•																				
		9.2	Optimization of hydraulic measurements			•																				
		9.3	Optimization of sediment measurements			•																				
		9.4	Bed load transport via dune-tracking			•																				
		9.5	Bathymetry and remote sensing			•																				
		9.6	Sustainable survey techniques			•																				
10	FAP impact on river system	10.1	Formulation of scenario's																							
		10.2	Simulation of ultimate river response via analytical modelling																							
		10.3	Quantitative assessment of FAP impact with 1-d morphological model																							
		10.4	Morphological model river system including changes in braiding and meandering characteristics																							

Table 8.3 Selection of key problems and study topics.

Num ber	Category	Sub num- ber	Topic	Tentative ranking	Manmonths allocated		Assis- tance from outside FAP 24
					Expatriate staff	Local staff	
1	Hydrology	1.1	Improved Bahadurabad discharges and rating curves	1*	1	1	
		1.2	Improvement historical Bhairab Bazar discharges	1*	2	2	
		1.3	Water balances and overland flow	1*	.5	1	
		1.4	Water level profiles and water level slopes	1*	.5	1	
		1.5	Phase 2 updating	1	1	2	
2	Sediment transport and river aggrad- ation and degradation	2.1	Rating curves and balances	1*	1	4	
		2.2	Sediment transport predictors		1	4	
		2.3	Integration of existing knowledge via 1-d morphological model	1	3	6	
		2.4	Long-term development of distribution	1	.6	6	IHE
		2.5	Floodplain sedimentation and subsidence	2	.7	3	USC
		2.6	Phase 2 updating	1	1	3	
3	Planform characteristics and channel dimensions	3.1	Planform classification and meandering and braiding charac- teristics	1	4	12	
		3.2	Channel dimensions	1	2	6	
		3.3	Bank erosion rates	1			
		3.4	Outer bend scour	1			
		3.5	Channel cutoffs	1			
		3.6	Effect of tectonics on planform characteristics	2	1	1	UvA
		3.7	Influence of cohesive material on planform characteristics	2			
		3.8	Local slope changes and their importance for planform changes	.1			
		3.9	Prediction of medium-term planform changes	1			
		3.10	Long-term changes of the location of the rivers	1	1	2	
4	Offtakes and bifurcations	4.1	Discharge and sediment transport distribution	1	8	24	
		4.2	Seasonal variation of erosion and deposition	2			
		4.3	Influence of bars	1	4	10	
		4.4	Influence of bed-forms	3			
5	Conflu- ences	5.1	Erosion and deposition of out-of-phase floods	2			
		5.2	Influence of bars and bed-forms	3			
		5.3	Confluence scour	3			
6	Sand bars	6.1	Occurrence, dimensions and dynamics of bars	1	.6	18	Leeds
		6.2	Time-dependence of bars	2	.2	4	Leeds
7	Bed-forms	7.1	Occurrence, dimensions and dynamics	1			
		7.2	Time-dependence of bed-forms	1			
		7.3	Three-dimensionality of bed-forms	1			
		7.4	Roughness and bed-forms	1	.6	12	Leeds
8	Local scour	8.1	Dimensions of local scour around structures	1			
		8.2	Time-dependence of local scour	2			
		8.3	Influence of bed-forms	2			
		8.4	Combination with other types of scour	2			
9	Measuring techniques	9.1	Selection of measurement sites	1	2	4	
		9.2	Optimization of hydraulic measurements	1	5	10	
		9.3	Optimization of sediment measurements	1	6	10	
		9.4	Bed load transport via dune-tracking	2	1	12	ISVA
		9.5	Bathymetry and remote sensing	1	2	4.5	FAP 19
		9.6	Sustainable survey techniques	1*	4	8	
10	FAP impact on river system	10.1	Formulation of scenario's	1	.5	1	
		10.2	Simulation of ultimate river response via analytical modelling	1	2	4	
		10.3	Quantitative assessment of FAP impact with 1-d morphological model	1	4	9	
		10.4	Morphological model river system including changes in braiding and meandering characteristics	1			

Table 8.4 Tentative selection of study topics

9. Workplan and staffing schedule

9.1 Introduction

This chapter presents the workplan and the staffing schedule for the implementation of the selected study topics for phase 2. The study topics selected in Chapter 8 for implementation were based on the number of manmonths available for studies. The workplan and staffing schedule have been arranged in such a way that the work load is properly distributed over the experts taking into consideration their different disciplines and availability.

First in Section 9.2 the activities are indicated that have been selected to be executed in the transition period between phase 1 (June 1993) and the approval (December 1993?) of the study programme presented in this report. The work programme for phase 2 from November 1993 onwards is presented in Section 9.3 and the related staffing schedule in Section 9.4.

9.2 Period between phase 1 and approval phase 2

In the Draft Notes on Planning presented in June 1993 some priority study topics were selected to be executed awaiting the approval of the phase 2 study programme. The following criteria had been applied for the selection of the study topics:

- o logical continuation of phase 1 study activities,
- o possibly affecting the FAP 24 measuring technique or programme,
- o probably not affected by the International Workshop, and
- o relation to other ongoing topics.

Based on these criteria the study team worked on the following study topics:

1. **Hydrology**
 - 1.1 Improved rating curves and discharges at Bahadurabad.
 - 1.2 Improved historical discharge time series at Bhairab Bazar and Mawa.
 - 1.3 Water balances and overland flow.
 - 1.4 Water-level profiles and water surface slopes.
2. **Sediment transport**
 - 2.1 Rating curves and balances.
9. **Measuring techniques**
 - 9.1 Selection of measurement sites.
 - 9.2 Optimization of hydraulic measurements.
 - 9.3 Optimization of sediment measurements.
 - 9.4 Bed load transport via dune tracking.

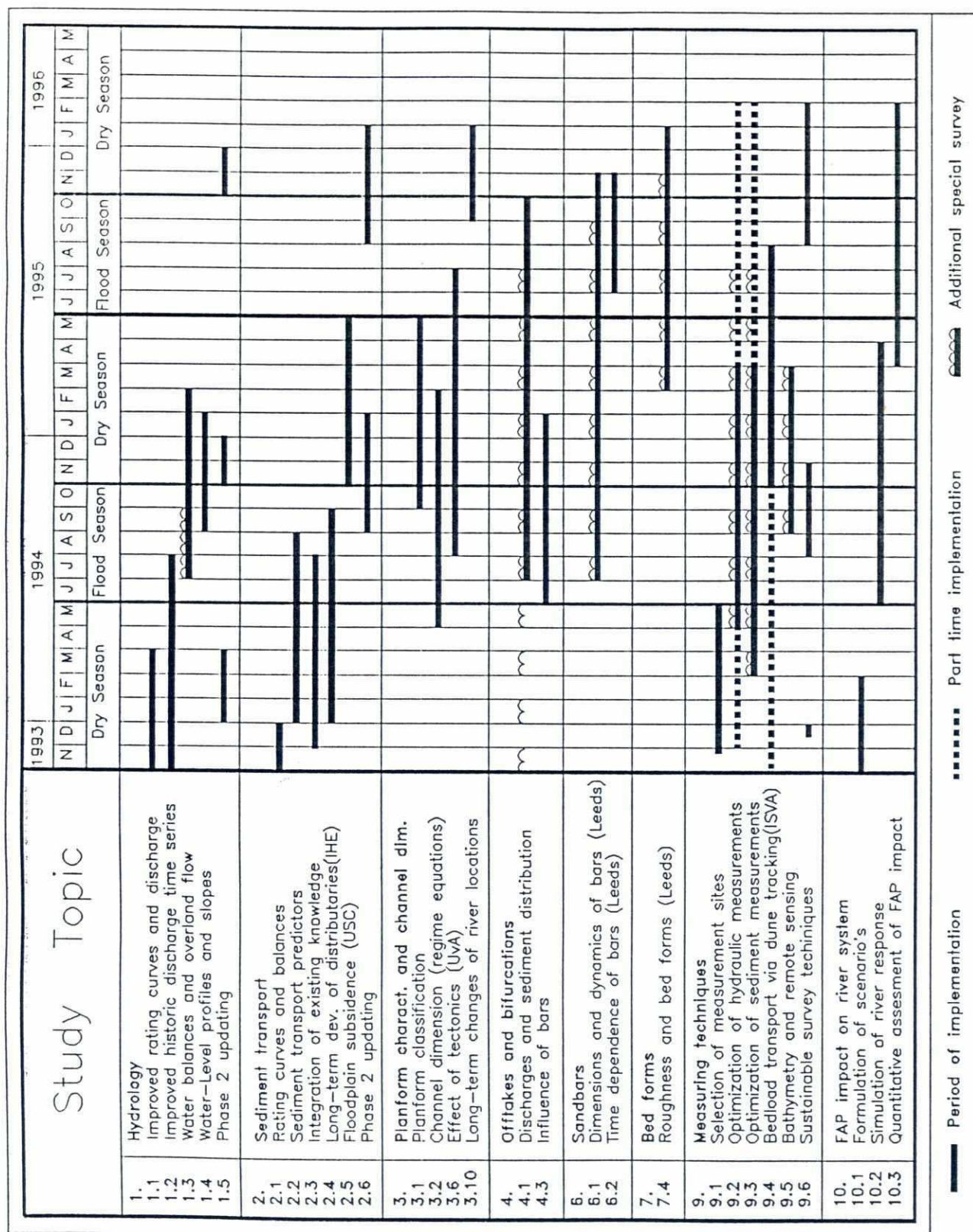


Figure 9.1 : Barchart of selected study topics phase 2

In addition the study team spend a considerable amount of time on the preparation of the present report on the selection of study topics for phase 2.

The work programme in Section 9.3 indicates what further activities will be taken up from November 1993 till the approval of this programme, depending on the review during the International Workshop.

9.3 Work programme

The workplan for the study topics selected in Chapter 8 and presented in Figure 9.1 of this section is a summary of the activities described in the previous chapters. It covers the period from November 1993 till the end of the project (June 7, 1996). The time schedule is subject to change as a consequence of possible other study topics being put higher on the "priority list" after the Workshop. Also it is tentative as during the project the priorities may shift based on outcomes of studies and surveys or other developments.

The selection of the study topics was required because of the number of expert manmonths available to do the study (64 manmonths expatriate and 170 manmonths local for phase 2). With the formulation of the workplan the proper expertise was selected for each topic and next the distribution of the work load among the experts for the whole project duration was considered. Some study topics are related to the dry season or the flood season or both. This has been taken into consideration as well when preparing the workplan.

Indicated in the workplan are the topics for which special measurements in addition to the standard routine measurements will have to be executed. However, it is not yet considered whether these measurements can be incorporated within the proposed survey spread with respect to capacity and timing. The programme proposed for the standard routine survey has been formulated on the basis of the results of the test gaugings executed in August 1993 and will be presented simultaneous with the present report on the selection of phase 2 study topics. A next step is the integration of the survey and study programme which will be done at the moment the two reports are available. This might result in some modifications of the programme presented in Figure 9.1.

With the topics 2.4, 2.5, 3.6, 6.1, 6.2, 7.4 and 9.4 the institutes are mentioned in Figure 9.1 that showed interest in participation in these study topics, and of which Consultants are of the opinion that their specialised expertise could make a substantial contribution with a relatively limited demand on project resources. Details on this participation are given in Chapter 7 and Annexure 3. Although the study topics are already integrated in the workplan, their actual implementation will depend on the approval of the



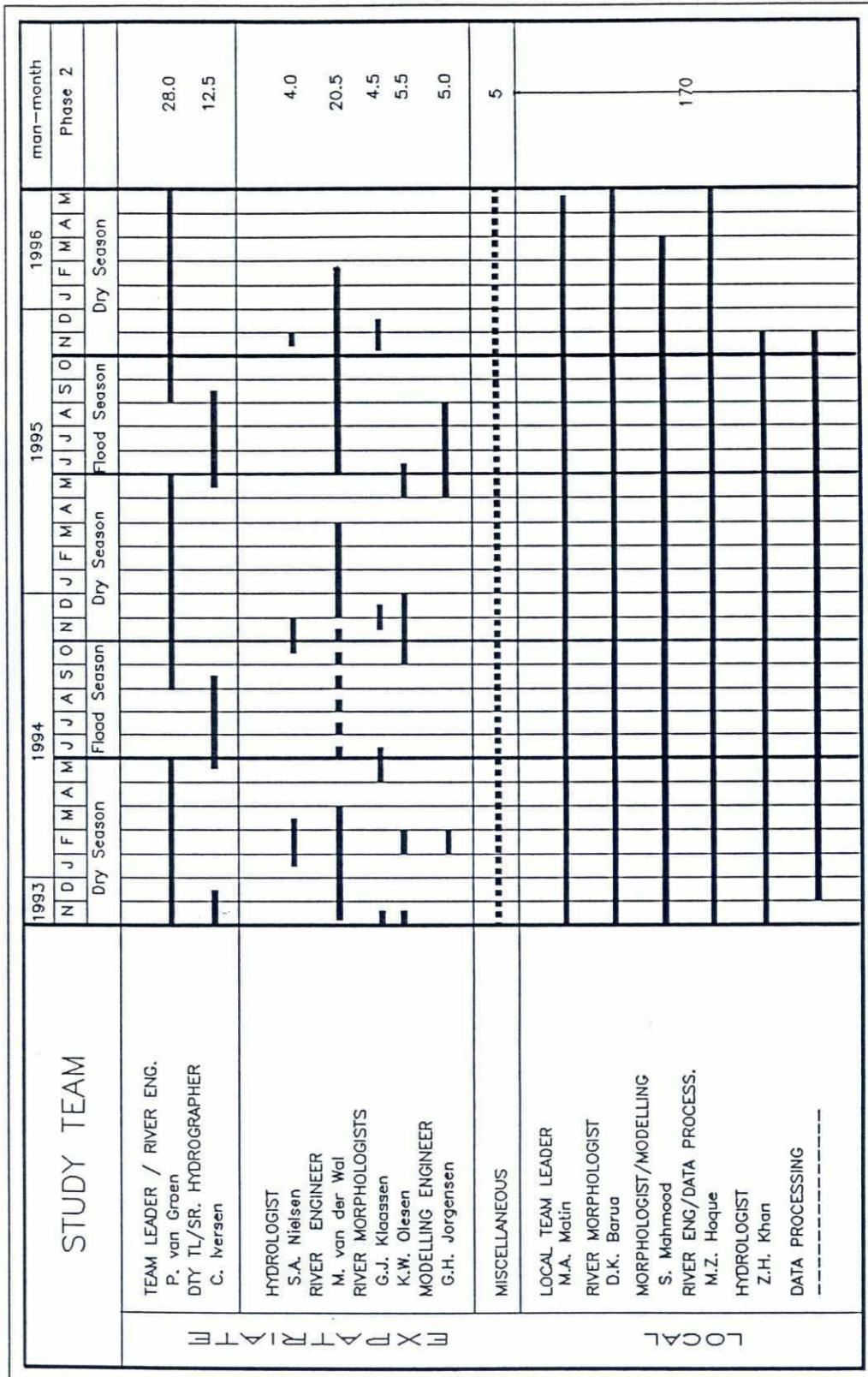


Figure 9.2 : Staffing schedule phase 2

participation of the institutes by FPCO and on the approval of the CEC to allocate the required project resources for these topics. After that has been agreed too, Consultants will try to come to an agreement with the institutes on how to get their contribution integrated in the FAP 24 programme.

Reporting on the study activities is not specifically indicated in the workplan. On completion of each study topic it is foreseen to present a Working Paper reporting on the execution of the study topic and the results of the analysis. If considered usefull Working Papers could also be issued during the study before the study on the topic is completed. Groups of Working Papers will be compiled to Study Reports. The Study Reports will be integrated in the Final Report to be issued at the end of the project. For the preparation of the Final Report and to accommodate delays in the execution of the studies a period of three months has been kept available in the workplan.

9.4 Staffing schedule

The staffing schedule presented in this chapter in Figure 9.2 concerns the staff for the study component which includes the staff required for the general project management. During phase 1 of the project the Team Leader and the Deputy Team Leader had to spend around 75% of their time on general project management, which was more than originally planned. Based on the experience of phase 1 it is foreseen that 50% of their time will be required for general project management during phase 2 and that additional management support will be required. The additional management support will be worked out seperately in more detail in order to find a solution for the financing of that input. Awaiting such a solution already 7 manmonths additional input for management support have been included in the barchart of the staffing schedule.

The number of manmonths mentioned in the last column indicate the number of manmonths for phase 2 including the transition period in between June 1993 and November 1993.

Later adaptation of the staffing schedule might be required when the workshop in November 1993 will result in a modification of the study programme or when results of the studies will lead to a modification of the study programme.

The work programme and the staffing schedule do not allow for time to be allocated especially for training only. Training wil have to be really on-the-job as an integrated part of the implementation of the study activities.

10. Towards an integrated survey and study programme

10.1 Introduction

The present report concerns the studies to be executed by the River Survey Project for the period ending May 1996. Parallel to the studies the project executes an extensive survey programme. To a large extent this survey programme consists of standard surveys prescribed by the FAP 24 ToR. There is some room for additional surveys that are special supplementary surveys to support certain study topics.

The combination of surveys and studies in one project offers the possibility of an optimal integration of surveys and studies. The formulation of the studies has been based on the key problems on river training and flood control that Bangladesh is facing and that have a high priority to be solved. Integration in this case means that the surveys required for the studies are incorporated in the survey programme as additional surveys and that the standard survey programme is as much as possible tuned to the requirements of the studies in order to make an optimum use of these surveys, which will contribute to the quality of the studies.

A brief description of the standard survey programme is presented in the next Section 10.2. A summary of special surveys that are required for the possible study topics indicated in Chapter 6 is presented in Section 10.3. A discussion on the integration of surveys and studies is presented in Section 10.4. As this report concentrates on the selection of the study topics this chapter will not present a workplan integrating studies and surveys. Such a programme should take into consideration the survey methods to be recommended after the test gauging. That goes beyond the scope of this report and such an integrated work programme will be presented separately.

10.2 Standard survey programme

The standard survey programme consists of bathymetric surveys, discharge measurements and sediment transport measurements (both suspended and bed load) at several locations. The programme is presented in Table 10.1 where the "existing" programme refers to the standard programme according to the contract. These measurements will be supported by automatic gauging of the river stages at eleven locations.

Station	Q.S			B		
	existing	proposed	modified	existing	proposed	modified
Offtake Old Brahmaputra	-	4/3	+ 4/3	2	2	-
Mymensingh	4/3	4/3	-	-	-	-
Bahadurabad	8/5	8/5	-	-	5	+ 5 a)
Sirajganj	8/5	4/3	- 4/2	- 4/3	-	-
Offtake Dhaleshwari	-	4/3	+ 4/3	24/3 + Q.S	2	-
Tilly	4/3	4/3	-	-	-	-
Outlet Hurasagar	-	-	-	2	-	- 2
Confluence Jamuna + Ganges	-	-	-	2	1	- 1 b)
Aricha	2/0	2/0	-	-	-	-
Hardinge Bridge	8/5	8/5	-	-	-	-
Offtake Gorai	4/3	4/3	-	2	5	+ 3 a)
Baruria	8/5	4/3	- 4/2	-	-	-
Mawa	2/0	2/0	-	-	-	-
Offtake Arial Khan (one section)	4/3	4/3	-	2	2	-
Offtake Dubaldia	-	4/3	+ 4/3	24/3 + Q.S	2	-
Bhairab - Bazar	3/3	4/3	+ 1/0	-	-	-
Total			+ 5/5 a)			+ 5 c)
Legends: - B = Bathymetry - Q = Discharge - S = Sediment transport - 8/5 = Seasonal number of measurements HW/LW - 2 = Annual number of measurements remarks a) these are the stations where bathymetric surveys will be done over at least one monsoon b) reduced soundings c) it is assumed (for the time being) that this extra work can be paid from left over measurements						

Table 10.1: Existing and proposed standard survey programme

Table 10.1 was presented in the "Draft Notes on Planning" prepared by FAP 24 in June 1993, and concerns a proposed modified standard survey programme based on a first indication of supplementary survey requirements for certain study topics. This proposed modification was intended as a preliminary and tentative integration of studies and surveys and was based on the following considerations:

- o Bifurcations is one of the main study topics selected, special attention will be given to the long term development of the main branches (topic 2.4). A prime issue is whether these branches are dying. Therefore it is proposed to pay more attention to the main offtakes and measure not only the bathymetry but also discharge and sediments.
- o A second adaptation is related to the bathymetry. On the one hand the confluences are not included in the selected study topics but on the other hand more frequent measurements are desired over the monsoon period. Therefore, it is proposed to reduce the bathymetric surveys at the confluences and use the gained work to measure at some locations with a higher frequency.
- o A third adaptation is required for the monitoring of river morphology for which tentatively a left channel section of the Jamuna downstream of Bahadurabad is selected. It is proposed to set-up a detailed monitoring programme to be continued for the remaining project duration. Such a programme in a stretch of tens of kilometers and a width of hundreds of meters will yield a wealth of data that will contribute to a number of study topics such as 2.2, 3.2, 3.10, 6.1, 6.2, 7.4 and several topics related to the measurement techniques.

Based on the study topics selected in Chapter 8 and the survey methods to be recommended after the test gauging the survey programme will have to be modified again, which will not be part of this report.

10.3 Identification of additional surveys

For all possible study topics formulated in Chapter 6 the required survey is identified. Due consideration is given to the possibilities offered by the availability of the sophisticated and extensive survey spread and data processing facilities. A summary is presented in Table 10.2.

Topic		Tentative indication of additional surveys	Comment
1.1	Improved rating curves at Bahadurabad.	Simultaneous BWDB and FAP24 measurements at Bahadurabad.	Plus standard surveys.
1.2	Improved historical discharge time series at Bhairab Bazar and Mawa.	None	SWMC hydrodynamic modelling and 1993 FAP 24 surveys.
1.3	Water balances and overland flows.	Additional discharge measurements at Sirajganj, Aricha and Tilly (on Dhaleswari).	Tilly is not at the off take of the Dhaleswari but immediately u/s of bifurcation of the river. BWDB discharge stations on these two arms are at Jagir and Taraghat.
1.4	Water-level profiles and water surface slopes.	Topographic survey to check zero of the gauges if required.	Check survey has been done. Reconciliation with BWDB is necessary and further survey need is to be identified.
1.5	Phase 2 updating.	None.	Regular updating of hydrological studies based on updated measurements.
2.1	Rating curves and balances.	Not assessed now.	Standard on the station surveys will be used.
2.2	Sediment transport predictors	None	
2.3	Integration of existing knowledge via 1-D morphological model.	None.	General Model of SWMC will be used as 1-D model and additional need of survey may come up at a later stage.
2.4	Long term development of distributaries.	Measurement of discharge and sediment distribution at the major off takes of Old Brahmaputra, Dhaleswari and Gorai.	Part of modified standard programme
2.5	Flood plain sedimentation and subsidence.	Special boring to determine age of deposits.	Expected to be executed with assistance from a university.
2.6	Phase 2 updating.	None.	Regular updating of morphological studies based on updated data.
3.1	Planform classification and meandering and braiding characteristics.	None.	To be based primarily on remote sensing information standard surveys and BWDB and other historical data.
3.2	Channel dimensions (regime equations).	None.	Same as above.
3.3	Bank erosion rates.	Special measurements during a number of months per year (could be combined with topic 3.3), in which on a frequent basis an area near an eroding bank is sounded together with the occurrence of bank failures. In addition flow field measurements at such sites will be made.	Plus standard surveys.

Table 10.2 Summary of study topics and additional survey requirements

Topic		Need for survey	Comment
3.4	Outer bend scour	See surveys for topic 3.3 plus flow field measurements	
3.5	Channel cutoffs	Discharge and sediment distribution measurements at potential cutoff points. Local slope measurements and its variation in time. Sampling of flood plain soil samples.	
3.6	Effect of tectonics on planform characteristics.	Boring in the flood plain at selected locations: can only be done if a University from outside the project is interested in this investigation. Possibly to be combined with topic 3.7	
3.7	Influence of cohesive material on planform changes.	Boring at selected places in combination with activities under the topics 2.4 and 3.6.	Plus bore-log data to be collected from other sources.
3.8	Local slope changes and their importance for planform changes.	Water level measurements at a number of selected river reaches during a number of selected periods. Precise levelling between the gauges, also when they are at opposite river banks.	Out of 20 locations estimated for the study, such gauges has been installed at Bahadurabad only. This situation need evaluation for further action.
3.9	Prediction of medium term planform changes.	None.	Action is necessary to predict mathematical model MIANDRAS to predict meader developments.
3.10	Long-term changes in the location of the rivers.	None.	Historical geo-morphological information to be used.
4.1	Discharge and sediment transport distribution.	Discharge and sediment distribution at the major off takes during different stages over a number of years, in combination with downstream water stages and possibly cross sections in the downstream branches. Sounding of a number of off takes. Same for some selected bifurcations in the braided Jamuna river.	It is not clear if the discharge and sediment measurements at Gorai Railway Bridge will serve this purpose for the Gorai. Old Brahmaputra at Mymensingh and Dhaleswari at Tilly are too far down stream to serve the purpose.
4.2	Seasonal variation of erosion and deposition.	Repeated cross-sections or areal sounding in distributors over some years, covering the whole hydrological year, with a frequency of say four times a year.	Plus a sensitivity analysis via the mathematical model.
4.3	Influence of bars.	None.	Standard surveys to be used.
4.4	Influence of bed-forms.	In addition to regular measurement programmes at the offtakes, the sounding of bedforms and measurement of discharge distribution in cross-sections at different stages.	Plus standard surveys.
5.1	Erosion and deposition for out-of-phase floods.	Sounding of bed configuration at confluences, in particular at the confluence of the Jamuna and the Ganges River through the whole season at regular intervals.	_____
5.2	Influence of bars and bed-forms.	Special measurements of bed topography and the occurrence of bars and bed forms throughout the flood season but also receding stages.	_____

Table 10.2 - continued

Topic		Need for survey	Comment
5.3	Confluence scour.	Special measurements during the flood and the recession during some years of the confluence scour in addition to the dimensions of the confluencing channels. Also the discharge from these channels should be measured. Typical confluences are the confluences of Ganges and Jamuna River, the Padma and the Meghna River and confluences in the Jamuna River.	There seems no programme surveying the confluence of the Padma and the Meghna River.
6.1	Occurrence, dimensions and dynamics of bars.	Special measurements of the bed topography in a selected river reach throughout the year to identify bar dimensions and their celerity. Also measurements of the hydraulic characteristics (discharges, velocities, depths) and the over all channel dimensions.	_____
6.2	Time-dependence of bars.	Special detailed measurements of bar dimensions in a selected river reach throughout the year. Special attention to be given to the bar in the Ganges River in front of the offtake of the Gorai in view of the pronounced influence of the Farakka dam on the Ganges hydrograph.	Covered by the 6.1 measurements _____
7.1	Occurrence, dimensions and dynamics.	Initially no need for additional measurements. During further analysis the need for hydraulic data in addition to the measured bed-forms may arise.	_____
7.2	Time-dependence of bed-forms.	Initially no need for additional measurements. During further analysis the need for hydraulic data in addition to the measured bed-forms may arise.	_____
7.3	Three-dimensionality of bed-forms.	Initially sounding with the side looking sonar. In a latter stage also sounding and velocity measurements where the direction of the flow is also measured. Also the discharge distribution over the cross-section may be required in some stage of the analysis.	_____ _____
7.4	Roughness and bed-forms.	Roughness measurements (discharge, slope, width, depth etc) along with sand dune survey at selected reach.	Covered by 6.1 measurements _____
8.1	Dimensions of local scour around structures.	Special surveys near bank protection works.	_____
8.2	Time-dependence of local scour.	Measurements distributed over a time to see evolution of scour holes.	_____
8.3	Influence of bed-forms.	Special measurements with side scan sonar.	_____
8.4	Combination with other types of scour.	Special measurements	

Table 10.2 - continued

River Survey Project FAP 24

Topic		Need for survey	Comment
9.1	Selection of measurement sites.	None.	To be reviewed and updated regularly based on changed circumstances.
9.2	Optimization of hydraulic (discharge) measurements.	In addition to the routine FAP 24 discharge measurements, some supplementary measurements are envisaged for instance in view of water slope analysis and near river-bed flow profiles.	
9.3	Optimization of sediment measurements.	Special detailed Q and S measurements at selected reaches along the main rivers with special equipment. Detailed near bed sediment transport survey	Plus standard survey results.
9.4	Bed load transport via dune tracking.	Detailed measurements of concentration verticals along dunes and measurements of the velocities at the top of dunes. Possibly also measurements with the ADCP to assess changes in the sediment concentration.	Already covered by the 9.2 and 9.3 measurements
9.5	Bathymetry and remote sensing.	Extensive bathymetric surveys in alternative way to verify bed topography.	
9.6	Sustainable survey technique.	Routine measurements of FAP 24 will provide the necessary data.	Evaluation of adapted technique will be made over time.
10.1	Formulation of scenarios.	None.	Use of standard surveys
10.2	Simulation of river response via analytical techniques.	None.	Use of standard surveys
10.3	Quantitative assessment of FAP impact with 1-d morphological model.	None.	Use of standard surveys
10.4	Morphological model river system including changes in braiding and meandering characteristics.	None.	Use of standard surveys

Table 10.2 - continued.

The next step will be the integration of the surveys indicated for the selected study topics with the standard survey programme.

10.4 Towards integration

In a separate report on the test gauging a programme will be formulated for the standard surveys for the coming years. In combination with the additional survey requirement as presented in this chapter and the description of the selected study topics it should be possible to formulate an integrated survey and study programme fulfilling the following requirements:

- o Optimal use is made of the availability of high-tech survey equipment.
- o The standard survey programme will be tuned as much as possible to the needs of the studies in addition to its original purpose.
- o Improvement of the quality of the studies and the surveys.

This integrated work programme will be presented shortly as a separate document. The possibility to implement such an integrated study and survey programme will depend on the available resources such as survey spread, man power, time and budget. Possible implications of these constraints will be indicated in the integrated work programme.

The principles of integrating survey and study activities in the River Survey Project are indicated in Figure 10.1

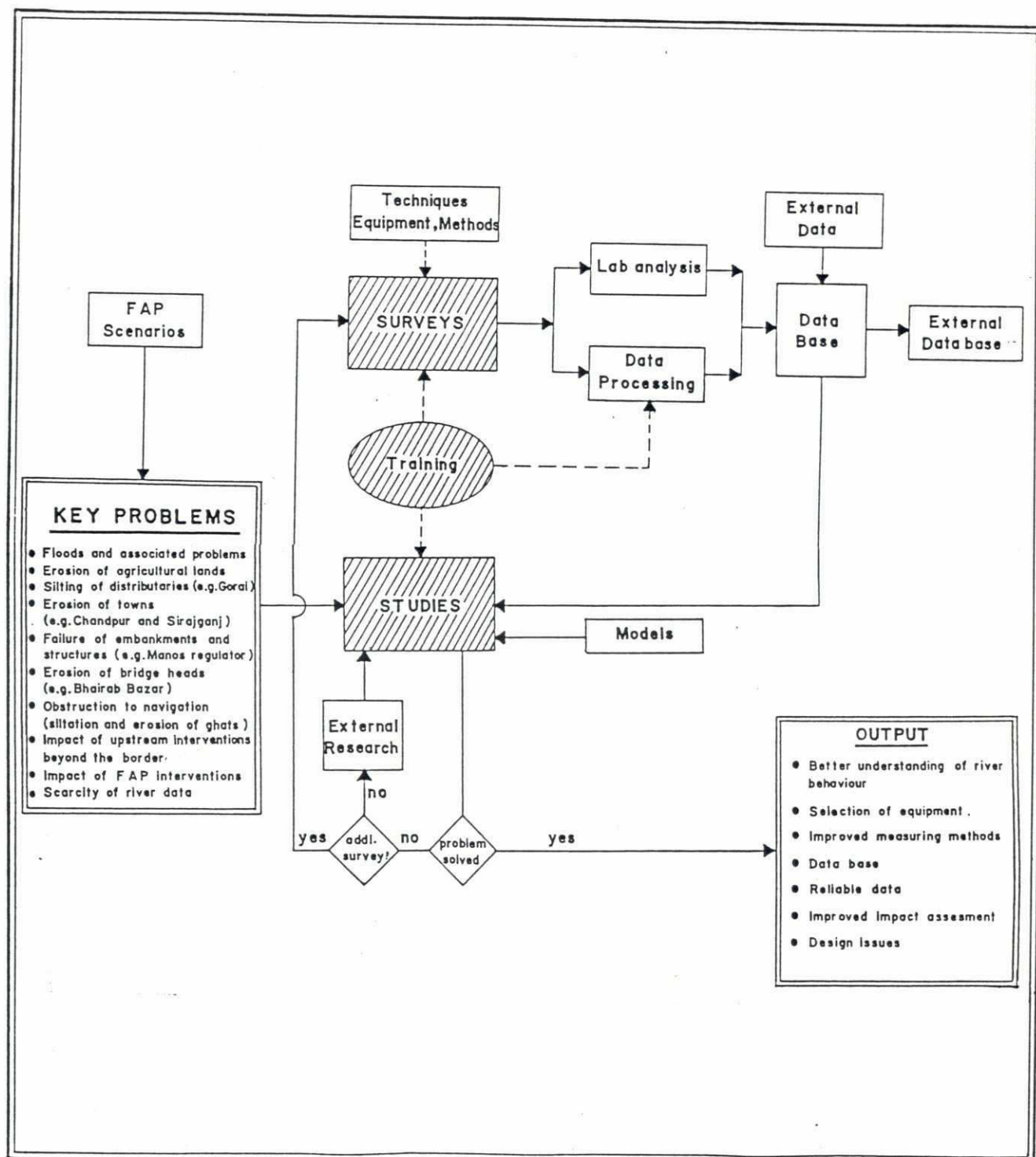


Figure 10.1 Integration of survey and study activities.

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Annexures

Annexure 1

**Computational framework for
river characteristics****Contents**

Symbols

1. Introduction	A1-1
2. Approach	A1-2
3. Prediction methods used	A1-4
4. Discussion	A1-7

1. Introduction

This appendix provides a description of the computational frame-work applied for predicting the characteristics of rivers under equilibrium conditions and without human impact. Equilibrium conditions indicates that the independent variables of the river system have been constant over a very long period. At the highest level aggregate level these independent variables are the climate and the geology, and at a lower level and at each point in the river system the independent variables in a river system are:

- (1) the (yearly?) **hydrograph** $Q(t)$, which can be characterised by a duration curve;
- (2) the average **volume of sediment** (bed material and wash load), that has to be transported through the river reach;
- (3) the characteristics of the sediment that has to be transported through the river reach, in particular the **particle distribution** and density of the bed material load;
- (4) the **valley slope**.

The computational frame-work presented here allows for the determination of the dependent variables given the above independent ones. Not all relations presented here are undisputed. See for a discussion of this aspect Chapter 4 of this Appendix and Section 2.2 of the main text.

In the present report this computational frame-work is not used as such, but it is important for the identification of the gaps in our understanding of the behaviour of river systems. Hence it is used here to identify possible study topics, as far as relevant for the prediction of e.g. the FAP impact on the main river system in Bangladesh.

It is stressed here that the computational frame-work used here holds for natural river systems, not influenced by human interventions. Generally speaking human intervention tends to fix dependent variables, hence making them independent variables imposed by river engineering works. Hence in general making the determination of the dependent variables more easy, as less freedom is left for the river.

2. Approach

Here the computational frame-work developed under FAP 21/22 is used. This approach has the advantage that in addition to changes in water depth and slope also the effect on the width of the channels, the planform, the braiding and meandering characteristics can be estimated.

The approach is based on the combination of theoretical and emperical relations. Emperical relations were used only when no theoretical relations were available. In this respect it should be realized that emperical relations are commonly being used in river mechanics because the application of theoretical approaches is limited due to the need to integrate over large spacer and time scales and the related closure problems.

Some details about the method proposed to apply are given hereafter. The method described hereafter, and in particular some of the emperical equations used, was developed especially for the Jamuna River, but it can be used with proper modifications to the other main rivers in Bangladesh as well. The philosophy behind the development of such a prediction method was that if and when possible a theoretically based predictor should be used, but if not available an emperical predictor would be applied. Here also a Table is copied from the FAP 22 report, to (1) to clarify the steps taken in the development, and (2) to indicate which parameters were considered as independent and which as dependent, and which equations are used in the method. See Table A1-1.

Step number	Parameters			Equations			
	Independent	Dependent	Additional independent	Theoretical	Emperical	Additional theoretical	Additional emperical
1: fixed bed, width fixed, straight channel	Q, B, D, i_b	C, u, h		Continuity equation Equation of motion	Nikuradse roughness Chezy coefficient as function of roughness height		
2: movable bed, width fixed, straight channel	Q, B, D, i_b	C, u, h, S		Do	Nikuradse roughness not applicable; instead to be used alluvial roughness predictor		
2a: movable bed, width fixed, straight channel, but now slope as dependent variable	Q, B, D, S	C, u, h, i_b		Do	Do		
3: as 2a, but with width as dependent variable	Q_b, D, V	B_b, C, u, h_b, i_b		Do	Do		Regime equation for width
4: as 3 but with curved channel	Q_b, D, V	B_b, C, u, h_b, i_b, p	i_v	Do	Do	Geometrical equation for sinuosity	
5: as 4, but with more than 1 channel	Q_b, D, V, i_v	$B_b, C, u, h_b, i_b, p, k$		Do	Do	Do	Number of channels k maximum
6: as 5	Q_b, D, V, i_v	$B_b, C, u, h_b, i_b, p, k, B_t$				Geometrical relation for total width	Meander length as function of e.g. discharge

Table A1-1 Development of prediction method for response of Jamuna River

3. Prediction methods used

The method applied here can be summarized as follows:

- (1) Prediction of slope of river for given Q , V (the sediment transport integrated over the year) and D , via

- (a) the continuity equation of the water, which in elementary form reads as:

$$Q = B h u$$

but which for bankfull conditions and for k channels reads as:

$$Q_b = k U_b h_b B_b$$

- (b) the sediment transport equation via:

$$S_b = \frac{V}{\alpha_Q * 365 * 86,400}$$

$$S_b = \frac{S_b}{B_b k}$$

and

$$S_b = \alpha_s \sqrt{g \Delta D^3} \frac{0.05}{1 - \epsilon} \left(\frac{h_b i_b}{\Delta D} \right)^{\frac{5}{2}} \frac{C^2}{g}$$

- (c) the equation of motion for the water which for uniform steady flow reads as:

$$u_b = C \sqrt{h_b i_b}$$

- (d) a hydraulic roughness predictor:

$$C = C(h, i_b, \Delta, D, \dots)$$

- (e) a regime equation for the width, for which the Jamuna predictor is taken:

$$B_b = 16.1 \left(\frac{Q_b}{k} \right)^{0.53}$$

- (2) Prediction of the sinuosity via:

$$p = \frac{i_v}{i_b}$$

- (3) Prediction of the total width of the braided system via:

$$B_t = 2 k A + B_b$$

where

$$\lambda = 10 B_b$$

and λ and α are determined via geometric relationships:

$$\alpha \text{ via } P = \frac{\alpha}{\sqrt{2 (1 - \cos \alpha)}}$$

and

$$A = \frac{\lambda/2}{\sqrt{2 (1 - \cos \alpha)}} (1 - \cos \alpha)$$

- (4) Repeated computations for different values of k until the maximum value of k is found for which still the sinuosity p is (slightly) above 1.

The following remarks (also partly copied from the FAP 22 report) are made regarding the development of the method used here:

- (a) Steps 1 through 2a in Table 7.6 correspond to the "normal", non-disputed approach, although it involves two empirical relations, notably an alluvial roughness predictor and a sediment transport predictor. The difference between step 2 and 2a is the selection of dependent and independent parameters.
- (b) The steps 1 through 2 are valid for any value of the discharge. Accepting the slope of a river as a dependent variable can only be done if an equation for the slope is used. Here "dominant" conditions are considered and for the time being the bankfull discharge is accepted here as dominant discharge for the channel dimensions. Hence

$$B_b = f(Q_b)$$

- (c) In the equations a factor α_Q is applied. This factor represents the influence of the hydrograph. Usually less sediment is transported over a whole year if the full hydrograph is considered compared with the case that the dominant discharge would be present during the whole year. Hence the sediment transport during bankfull discharge is determined by dividing the average sediment transport over the year by the factor α_Q , which is always less than 1.
- (d) The calibration factor α_s takes care for the deviation of the actual transport compared with sediment transport predictors. For the Jamuna River it was found that α_s corresponds to about 2.75, but for other rivers this factor can be different.
- (e) The equation for the total width is derived from geometrical considerations (see Annex 1 of Final Report of FAP 22, Figure 7-14). It is felt that this corresponds to the minimum total width. The presence of permanent chars would increase the total width of the braided system. It would also mean a transition to a more anastomosing system.
- (f) From the sinuosity the amplitude A of the curved channels can be determined. Also this is related to geometry (see Annex 1 of Final Report of FAP 22, Figure 7-15). The used equation holds only for real circles, but is probably a good approximation for low sinuosities.
- (g) An important parameter is the wave length as this wave length determines the total width. It would be logic to relate the wave length λ to the bankfull

discharge Q_b , but such a relation is not available. From the literature some relationships between the wave length λ and the channel width B_b are available (see e.g. Leopold et al, 1976 or Jansen (1979)). Here a relationship proposed by Leopold & Wolman (1960) is used. This relation reads:

$$\lambda = 10.1 B_b^{1.01}$$

In FAP 22 a simplified expression was proposed, reading

$$\lambda = 10 B_b$$

In combination with the regime equation for the width this formula can be read as:

$$\lambda = f \left[\frac{Q_b}{k} \right]^{0.53}$$

Hence, for a given value of Q_b the wave length λ is a function of k only.

The above method still needs to be calibrated before it can be applied to estimate the response of the river system to the river training and AFPM scenarios. Overlooking the method above the following independent input data are needed:

- bankfull discharge Q_b ;
- frequency distribution of the discharges $f(Q)$ to determine αQ (for the time being it is assumed that all discharge is conveyed in the channels, neglecting the flow in the floodplain and over the chars; this is a good first approximation and would if assumed otherwise only result in a slightly different value of α_Q);
- yearly volume V of bed material load to be transported;
- characteristic particle size of the bed material D ;
- valley slope i_v .

The dependent variables for freely flowing river systems are the hydraulic roughness C (in principle a function of Q), bankfull depth h_b , the bankfull width B_b , the number of channels k , the average slope of the channels i , the sinuosity p of the channels, and the (minimum) total width B_t of the river. Checking the equations proposed above for the prediction of the river behaviour, it can be concluded that there is only one calibration parameter left, notably α_s . Hence a value of α_s has to be found that results in all dependent values to obtain fair values. This is less risky than it seems because for some of the dependent variables (roughness, sediment transport, width) relationships are proposed that will be derived on the basis of empirical data.

4. Discussion

The following observations are made, based on a further reflection of the method described above:

- (1) In the method presented the valley slope is considered as an independent variable, while the sinuosity and the number of channels being variables depending on this valley slope. It may be argued however that the sinuosity of a river system is determined by how quickly cutoffs take place (at which cutoff ration, see Klaasen & van Zanten, 1989). Hence it would be determined by a combination of the valley slope and the consistency of the floodplain which in itself again is a function of the washload and bedmaterial characteristics. The reasoning would then be that the river is increasing its valley slope, until the preferred sinuosity corresponds to the ratio between the ultimate valley slope and the slope of the river. Consultants would like to explore this avenue of reasoning under one of the study topics.
- (2) As independent variable still the bankfull discharge has to be imposed on the method. Consultants are presently considering whether it is possible to determine the bankfull discharge also as an dependent variable. For this it may be required to go into more detail as to the role of the wash load and the balance between the vertical aggrading effects during overbank flow and the horizontal eroding effect due to bank erosion.
- (3) In applying the method to other rivers than the Brahmaputra/Jamuna river a more simplified approach is possible, as these rivers are meandering ones. Hence the number of channels is removed from the list of dependent variables.
- (4) Considering the relative youth of some of the rivers in Bangladesh it may well be that not all rivers have already reached a state of equilibrium. See also Chapter 2 of the main text.

Annexure 2

Possible study topics

Contents

0.	Introduction	A2-1
1.	Hydrology	A2-3
2.	Sediment transport and river aggradation and degradation	A2-10
3.	Planform characteristics and channel dimensions	A2-18
4.	Offtakes and bifurcations	A2-27
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10.	FAP impact on river system	A2-52

0 Introduction

This annexure provides a description of possible study topics which could be selected to be taken up during Phase 2 of the River Survey Project. This list is based on a preliminary list that was prepared during the proposal phase. This list was included in the proposal of September 1991 as Annex 6. Here an updated list is presented, amended on the basis of (1) recent projects in Bangladesh Consultants have worked on, (2) discussions with different FAP projects, FPCO, the expatriate and the local Panel of Experts, etc., and (3) the results of surveys and studies in phase 1 of the River Survey Project.

The list in Annex 6 of the proposal, which was used here as a basis, has been prepared during meetings of staff of both DELFT HYDRAULICS and DANISH HYDRAULIC INSTITUTE, which have substantial experience in a number of projects in Bangladesh. At the time the proposal was prepared, the insight obtained from working in the following projects was "pooled":

- o Ganges Kobadak Rehabilitation Project,
- o Jamuna Bridge Project
- o Bangladesh Inland Water Transportation Master Plan Studies,
- o Assistance to Surface Water Modelling Center in modelling the main rivers of Bangladesh, as part of the General Model,
- o FAP 1: Brahmaputra River Training Studies, and
- o FAP 9B: Meghna River Bank Protection Study

This experience together with the suggestions in the Terms of Reference, allowed to prepare an extensive list of tentative study topics.

As mentioned above, quite some time has elapsed since the preparation of the proposal, and therefore, it seemed appropriate to update the list of possible study topics. This was done on the basis of continued experience of Consultants in other projects in Bangladesh and, more recently, on the basis of discussions within the framework of FAP 24. Recent projects of relevance in which Consultants were or still are involved are besides River Survey Project:

- o FAP 4: South-West Regional Study, and
- o FAP 21/22: Bank Protection and River Training (Active Flood Plain Management) Pilot Project.

The first updating of early 1993 resulted in a total of 39 potential study topics, which are listed in the 1st Interim Report. In a further step discussions were held as indicated above. This has resulted in a re-arrangement and extension of the list of possible study topics. Now in total 48 possible topics are included in this "long list".

In the following pages these 48 topics are described. Furthermore per topic the possible approach and the required study tools, a tentative ranking, the expected results and the required input in manmonths for study are listed in addition. If appropriate, also the requirements for additional field surveys is indicated.

The tentative ranking was done on the basis of the experience from the other projects, and indicates the preference of Consultants for study topics mxder FAP 24. The procedure how study topics for Phase 2 under FAP 24 were selected is described in Chapter 7 of this report.

The topics are divided in a number of groups. The groups 1 and 2, Hydrology and Sediment transport and aggradation and degradation, are fundamental as they are dealing with data previously collected, their validation and processing and interpretation. They have a high priority and partly they were taken up already during the phase 1 study. Group 10, FAP impact on river system, mxs considered a major task with a high priority for the overall Flood Action Plan. During phase 1 of the project this topic is already taken up too, so as to arrive at a preliminary, qualitative assessment of the response of the river system to the implementation of the various flood control schemes. During Phase 2 the impact simulation will be further developed to arrive at a more quantitative assessment.

The other study topics are not less important. They will improve the understanding of the specific behaviour of rivers in Bangladesh, which certainly will contribute to the quality of the impact assessment. The priority of these topics also depends on the river study requirements of the other FAP components. For that reason it is already assumed that Group 3, Planform Characteristics and Channel Dimensions, has a high priority, as is argued in Chapter 7 of the main text.

Some of the topics will be looked into by other projects as well, in particular FAP 1, FAP 9B and FAP 21/22, or their "successors". During phase 1 of the River Survey Project the extent to which these topics will probably be studied by the other projects, is assessed in order to avoid duplications.

Topics covered fully during phase 1 are not included in this Annexure. This concerns topics like data collection and analysis, review of other studies and the establishment of the data bases for the main rivers.

1. Hydrology

Topic 1.1 Improved rating curves and discharges in particular for Bahadurabad

Description

Under this topic a number of separate but interrelated study topics are collected, which are related to rating curves and the determination of discharges:

- o Further documentation/explanation of the indicated systematic discharge overestimates at Bahadurabad during the recent years.
The simultaneous discharge measurements by BWDB and FAP 24 at BWDB's traditional cross-section at Bahadurabad during the 1993 monsoon will be analysed in details to reach a final conclusion and explanation of the observed too high BWDB discharge measurements and time series during the recent years.
- o Separate rating curves for left and right channel at Bahadurabad for improvement of the accuracy of the discharge time series.
Comparison of historical water-level data from Bahadurabad on the left bank and from Fulcharighat on the right bank shows that the stage in the left and right channel are very similar during the major part of the year but different during the rising flood in the beginning of the monsoon period. Therefore it would probably be more accurate to apply separate rating curves for the left and right channel instead of the present procedure where the total measured discharge is related to the stage in the left channel only. The effect of applying two rating curves instead of one may not be that big due to the facts that 1) the larger part of the total discharge is flowing in the left channel and 2) the difference in water-levels is only observed in a small part of the year as mentioned above. It will however be worth to quantify the effect by simple comparison of the results of applying both procedures.
- o Loops in rating curves
At river gauging stations located in a reach where the slope is very flat, the stage-discharge relation is frequently affected by the superimposed slope of the rising and falling limb of a passing flood wave, i.e. rapidly changing discharge. During the rising stage, the velocity and discharge are greater than they would be for the same stage at steady flow conditions. Similarly, during the falling stage, the discharge is less for any given stage than it is when the discharge is constant. In addition, time lag effects in the adaptation of bed-form dimensions (see Topic 8.2) will introduce hysteresis in the rating curves. Corrections for such loop effects are important for the assessment of the discharges during large floods.

Approach

The following approaches for the three different topics are considered:

- o Systematic discharge overestimates at Bahadurabad
The simultaneous FAP 24 and BWDB discharge measurements will be compared. For the purpose of detailed comparisons the original field sheets from BWDB's survey should be made available for FAP 24. The effect on the FAP 24 discharge estimate by applying BWDB's procedure for correction for flow directions will be calculated in order to see directly if the flow directions can explain the observed differences. Possible differences in other measured parameters, e.g. the flow areas, will also be analysed as required.
- o Separate rating curves for left and right channel at Bahadurabad
Based on the new FAP 24 discharge measurements at Bahadurabad in 1993 separate rating curves for the left and right channel will be established, and the observed 1993- time series of mean daily water-levels at Fulcharighat and Bahadurabad will be converted into corresponding discharge time series.

The traditional single rating curve for the total discharge will also be established, and the 1993-time series of mean daily water-levels at Bahadurabad will be converted into corresponding discharge time series. The two generated 1993-time series of total discharge will be compared to assess the effects of applying two separate rating curves instead of one.

If the results show that the effect is important for the accuracy of the discharge time series at Bahadurabad it should be considered to carry out a special study for improvement of the historical time series 1966-92 as well. That will involve comprehensive data collection of additional separate data for each channel from BWDB and establishment of two rating curves for each year. Such a study is not included in the estimate of required input below.

- o Changes in rating curves
The study of changing curves in alluvial rivers must be based on the available corresponding stage-discharge measurements from the gauging stations. A plot of stage against discharge will very often scatter widely and thus be intermediate. Sometimes it is possible to obtain an improved hydraulic relationship by changing variables, e.g. replacing stage by hydraulic radius and discharge by mean velocity.

Various correction methods for variable rating curves are available, e.g. the Stout method for making adjustments for shifting control. If variable back-water occurs at a gauging station, an additional variable, slope or change of stage, will have to be included in order to define the discharge rating. In the second phase the effect of bed-forms, cutoffs and moving bars (see Topics 5, 7 and 8) will be incorporated by establishing relationships between these phenomena and the rating curves.

Expected result

- o Full documentation and explanation of the systematic discharge overestimates during the recent years at Bahadurabad. Based on this an attempt to establish improved approximate rating curves and discharge time series for the same years.
- o Assessment of the effect on estimated discharge time series at Bahadurabad 1993 of applying separate rating curves for the left and right channels instead of one rating curve for the whole river cross-section.
- o The study will result in improved rating curves for all gauging stations and thus more reliable discharge time series.

Ranking 1**Required input**

Expatriate hydrologist	1 manmonth
Local hydrologist	1 manmonth

Need for additional surveys

See above under Approach.

Topic 1.2 Improved historical discharge time series at Bhairab Bazar and Mawa.
Description

The hydrological studies during Phase 1 of FAP 24 revealed that the traditional curve fitting technique for establishment of rating curves in general did not provide satisfactory results for Bhairab Bazar in Meghna River, and this was also to some extent the case for some years at Mawa in Padma River. The reason is that the Q-h measurements are very scattered due to the combined effect of backwater from the downstream confluence of Padma and Meghna and tidal effects. This means that there exists no unique relationship between water-level and discharge at the two stations, but rather a whole family of rating curves each corresponding to a certain combination of downstream flow/tide conditions. This complicated phenomenon makes an assessment of rating curves by traditional curve fitting methods extremely uncertain resulting in very uncertain discharge time series.

It is therefore proposed to describe these complicated phenomena by means of a hydrodynamic model of the actual river system which can then be used to generate more reliable discharge time series at the two stations.

Approach

A reduced version of SWMC's General Model will be set up, covering the area between Baruria, Bhairab Bazar as the main upstream boundaries and the Bay of Bengal with the existing water-level stations as downstream boundaries (or alternatively Chandpur as downstream water-level boundary). For Baruria FAP 24's updated discharge time series will be used as Q-boundary whereas Bhairab Bazar has to be a H-boundary.

The model will be calibrated and tested applying all available H-and Q time series from stations along the rmxers in the model area. New detailed 1993 measurements by FAP 24 may be used for refinement of the model calibration.

The calibrated model will be run for all years with data available for the boundary stations and will as a result directly provide complete discharge time series at Bhairab Bazar and Mawa (as well as H-and Q time series at any other point of interest within the model area). The calibrated model may also be used to establish family rating curves at the two stations as various model runs can generate water-levels as a function of discharge at the actual stations and downstream water-level/discharge.

Expected result

Hydrodynamic model able to describe the complicated flow characteristics in Padma and Meghna rivers and their interactions. Generation of more reliable discharge time series at Bhairab Bazar and Mawa.

Required input

Hydrodynamic modelling expert (from SWMC) 1 manmonth

Hydrologist 1 manmonth

Local hydrologist 2 manmonth

Need for additional surveys

None.

Topic 1.3 Water balances and overland flow**Description**

Water balances for the main rivers on the basis of comparison of streamflow volumes from the available discharge stations can provide 1) check of the consistency of the discharge time series from the individual discharge stations and 2) assessment of inflows to or outflows(offtakes or overland flow) from the rivers between the discharge stations under various flow conditions.

Approach

Historical time series of annual and seasonal flow volumes for the discharge stations in the main rivers will be calculated from the updated time series of mean daily discharges. Several water balances for areas between stations will be set up, e.g.

- o Comparison of Baruria and Mawa, which should be similar apart from the offtake to Arial Khan and local minor inflows/outflows
- o Flow volumes at Hardinge Bridge minus Gorai Railway Bridge plus Bahadurabad should be similar to those of Baruria apart from local inflows or outflows in the area between these stations

Outflows from rivers in form of overland flow during high flow conditions are known to be a particular important issue in the Jamuna River where the overland flow is diverted into the catchments in the North-Central Region. An assessment of the magnitude and importance of this overland flow on the basis of the present few available discharge stations is not possible. The field programme of FAP 24 however includes continuous water-level measurements and regular discharge measurements at two additional stations along the Jamuna (at Sirajganj and Aricha) and in the offtake of Dhaleswari at Tilly. Based on these new data it should be possible to establish water balances during high floods in Jamuna River for the areas between the stations to quantify the overland flow more or less as the difference between the discharge volumes upstream and downstream. However, as the magnitude of overland flow most probably is small compared to the high flows in Jamuna during floods the assessment based on differences of large and somewhat uncertain flood discharges will of course be a rough estimate only.

Expected results

Additional consistency checks of discharge time series by water balances between stations. Information on the importance and magnitude of overland flow in various areas along the Jamuna River during high floods.

Required input

Expatriate hydrologist 0.5 manmonths
Local hydrologist 1 manmonth

Need for additional field surveys

Regular discharge measurements at two additional stations along the Jamuna (at Sirajganj and Aricha) and in the offtake of Dhaleswari at Tilly.

Topic 1.4 Water-level profiles and water surface slopes.**Description**

Already during Phase 1 of the hydrological study the overall water-level profiles and slopes for the major rivers were studied on the basis on observed water-levels from the stations along the rivers. As mentioned in Section 7.5 of Study Report 2 several improvements, e.g. assessment of local slopes between stations, will be possible when the final results of FAP 24's field checks of gauge datums and more recent BWDB-water-level data become available.

Furthermore, SWMC's hydrodynamic model for the main river system, the General Model, directly provides detailed simulations of the water-level profiles for each time step. These simulated water-level profiles include the dynamic routing effects when a flood wave moves from upstream to downstream and they include simulated local slope variations in great detail.

Approach

Refinements of the plotted water-level profiles on the basis of new and datum-corrected observed water-levels from the gauging stations along the major rivers. Comparisons with simulated water-level profiles from SWMC's General Model for the same selected flow situations and assessment of local slope variations.

Expected results

Refined water-level profiles/ water surface slopes including local variations.

Required input

Expatriate hydrologist 0.5 manmonths

Local hydrologist 1 manmonth

Need for additional field surveys

Topographic field work to check zero-levels of gauges.

Topic 1.5 Phase 2 updating**Description**

This topic regards the regular updating of Phase 1 hydrological studies of historical data by including new data 1993 and onwards. The new FAP 24 discharge measurements at 11 sites in the main river system during the coming years will provide the basis for regularly updating of the various analyses carried out for the historical time series during Phase 1 by including these new data.

Approach

The following activities can be foreseen at this very moment:

- o Establishment of rating curves for 1993 and onwards based on FAP 24's new discharge measurements for 11 sites.
- o Check of measured FAP 24 water-level time series for the 11 sites for 1993 and onwards by the procedures described in Chapter 5.
- o Generation of discharge time series for 1993 and onwards on the basis of the above water-level time series and rating curves.
- o When available, collection of BWDB-data from 6 of the above 11 sites (BWDB's permanent discharge stations) for 1993 and onwards and comparisons with the FAP-data including rating curves and estimated discharge time series.
- o Consistency check of rating curves and discharge time series for preceeding years by comparison with new rating curves and time series for 1993 and onwards. Updating of the various presented trend analyses (Chapter 5) by including the additional time series for 1993 and onwards.
- o Updating of presented frequency curves and flood frequency estimates(Chapter 6) by including the additional time series for 1993 and onwards.

Other activities may be required depending on the outcome of future surveys.

Required input

Expatriate hydrologist 1 manmonth

Local hydrologist 2 manmonths

Need for additional field surveys

None.

2. Sediment transport and river aggradation and degradation**Topic 2.1 Rating curves and balances****Description**

During Phase 1 of the project the available sediment transport data for the main rivers in Bangladesh were collected and entered into a data base. Inconsistencies were identified and when and where appropriate data were verified. Per station comparisons were made to identify changes over the years. A critical evaluation was made of the measuring methods employed in the past and the same was done as far as the storage of the data was concerned. It was observed that part of the inconsistencies that were observed previously could be explained. The above analysis was limited to an assessment per station.

In addition sediment balances can form a useful check on data on sediment transport rates and, provided the data are sufficiently accurate, they can also give an indication of the long-term development of the river system.

Approach and study tools

It is proposed to use the data from the sediment gauging stations at the main rivers for a sediment balance analysis. A distinction will be made between bed material load and wash load. An estimate for the daily sediment transport rate will be worked out by interpolation of the observed (and checked) sediment transport rates using available discharge and water-level data (rating curves). These data will then be used for the sediment balances. In the balances it will also be necessary to estimate sediment load from tributaries and from bank erosion (this may be important in the Brahmaputra River).

Ranking: 1**Expected result**

The accuracy of the observed sediment data and estimate of sediment load from tributaries and bank erosion may be too small to make any firm conclusions regarding the long term development (erosion or deposition) in the main river. The main outcome of this study topic is a re-check and verification of the sediment transport data.

Required input

Expatriate morphologist 1 manmonth
Local morphologist 4 manmonths.

Need for additional field surveys

Cannot be assessed at this moment

Topic 2.2 Sediment transport predictors

Description

Sediment transport formulae are describing the relation between the flow characteristics and the quantities of bed material being moved. Quite a number of sediment transport formulae exists, the newer ones often relating the dimensionless sediment transport rates as a function of the Shields parameter, hence

$$\frac{S}{\sqrt{g\Delta D^3}} = f\left[\frac{h\Delta}{\Delta D}\right]$$

One such formula is the Engelund-Hansen predictor, which has been used in Bangladesh in some mathematical models as part of a number of projects (Jamuna Bridge, FAP 1, FAP 9B and FAP 21/22), with and without adaptations. Also other types of sediment transport formulae have been proposed in which the sediment transport is related to the flow velocity, the stream power and the specific stream power.

Predictors to describe sediment transport are important for at least two reasons. Firstly they determine the sediment transport rates, and this again is linearly proportional to the celerity of the morphological processes. Secondly spatial variations in sediment transport determine deposition and erosion, and this is fully governed by the non-linearity of the sediment transport formula. Sometimes the sediment transport formulae are simplified to

$$s = mu^n$$

where the power n varies between 3 and 6. It can be shown that for the Engelund-Hansen formula n equals 5. The importance of the power n for other phenomena has been demonstrated by Struiksmas et al (1985), Struiksmas and Klaassen, (1990), where it was found that bar formation, bar dimensions, the transition between meandering and braiding and the braiding index are all closely linked to the power n . Hence sufficient reason to determine a sediment transport formula especially suited for Bangladeshi conditions. A complicating factor is that the most appropriate form of a predictor may be different for different locations (river reaches) in Bangladesh, although the variations in bed material size (often the most important factor) are minor.

For the derivation of an appropriate sediment transport formula data on sediment transport should be used. As such a formula can only be derived for bed material transport if it can be tested against observed data on the sum of the bed load and the suspended bed material load (see Section 2.2 of the main report). This can partly be historical data and partly fresh data collected during special measuring campaigns.

Approach and study tools

The proposed approach consists of comparing measured values of bed material transport in the main rivers in Bangladesh to predictors like Engelund-Hansen and, if appropriate, to adjust one of these formulae to get appropriate sediment transport predictors. Special attention to be paid to the power of the non-linearity. Partly historical data will be used but most probably mainly fresh data from the River Survey Project is required. It is proposed to execute a detailed analysis for one location and a less detailed review for the transport at the other main survey locations.

Ranking: 1**Expected results**

Appropriate sediment transport predictors for the main rivers in Bangladesh, though not necessarily the same for all rivers.

Results will give inputs for Topics 9.3 and 9.4

Required input

Expatriate river morphologist 1 manmonth. Local morphologist 4 manmonths.

Need for additional field surveys

Detailed measurements of sediment transport (both suspended bed material and bed load) at various locations and for different stages. It is assumed that this will be covered by the standard survey programme and the special measurements for Topic 9.3 and no additional field measurements are required. However, this assumption may change during the execution of this study topic.

Topic 2.3 Integration of existing knowledge via 1-d morphological model**Description**

Since the sixties data have been collected that are relevant for the morphological behaviour of the main river system in Bangladesh. Until now no attempt has been made to integrate these data, in an attempt to check whether the data obtained until now are in line with each other. A consistency check in addition to the sediment balances as proposed under Topic 2.1 will allow for the identification of inconsistencies and will give guidance to the surveys to be carried out under FAP24. It will e.g. allow to establish what accuracy is needed for determining the distribution of the sediment at the major offtakes.

Furthermore very little is known about the sensitivity of the Bangladesh river system in terms of morphology. At the same time, several very ambitious schemes have been

proposed for the river system, including huge embankment schemes, diversion of river water, barrages etc. without any consistent morphological impact assessment having been carried out. In addition the effect of changes in the boundary conditions of the river on the morphology of the entire river system (e.g. a possible sea level rise, further deforestation in the catchment, major diversions, etc.) has not been investigated in some detail.

It is proposed to establish a mathematical modelling tool for the investigation of the sensitivity of the river system and for the morphological assessment of various large scale schemes. In this way it will be possible to define limits for what is feasible in terms of the prediction of the impact of the human interference with the river system.

Approach and study tools

The General Model (GM) developed at the 'surface water modelling centre' will form the basis for this morphological study. In a simplified version of this model the present knowledge on the river system will be entered. This will be done on the basis of the morphological version, in which already the Brahmaputra/Jamuna, Ganges and Padma Rivers are included. The model will be run on the basis of the historical data available, and the predictions will be compared with the actual developments. Critical are the assumptions as to the discharge and sediment distribution at the offtakes, and this will be varied during the simulations.

Ranking: 1

Expected result

The output of this study topic will be an important insight into the reliability of the historical data and the need for improving the data and understanding of the discharge and sediment distribution at the offtakes.

Required input

Expatriate mathematical modelling expert 2 manmonths
 Expatriate river morphologist 1 manmonths
 Local morphologists 2.5 manmonths
 Local mathematical modelling expert 3.5 manmonths

Need for additional field surveys

None.

Topic 2.4 Long-term development of distributaries

Description

The main river system of Bangladesh is characterised by a number of main rivers (Brahmaputra/Jamuna, Ganges, Padma and Meghna Rivers) and a number of distribu-

aries. These distributaries carry substantial discharges during the flood season, but it seems that of most of them (Old Brahmaputra, Dhaleswari and Gorai Rivers) the flow is declining. The question is whether these rivers are "dying". If so, then this would have a major effect on the availability of water in the different regions during the low flow season and it would have a major impact on the regional FAP plans.

The "fate" of the distributaries is determined by the distribution of sediment and discharge at the offtakes, and hence this distribution can be considered as a boundary condition for the development of the bifurcating branches. Provided this boundary condition is known, the long-term development of such a distributor can be modelled mathematically with some confidence. In order to make long-term predictions of the development of the branches it is therefore necessary to gain insight into the long-term development of the sediment transport and discharge distribution at the offtake, and hence an understanding of the development of the bathymetry and planform at the offtakes (see Topic 4.1).

A thorough analysis of the past behaviour of the distributaries is needed to extrapolate this into the future.

Approach and study tools

It is proposed to study this topic using satellite imagery and available cross-sectional data in combination with discharge and water-level data for the distributaries. It is proposed to select two offtakes which are representative of the conditions in a meandering and in a braiding river.

The conditions around bifurcations are subject to seasonal variation (see Topic 5.2) and variation due to migrating bars (see Topic 4.4). Thus, in order to determine long-term developments from field data, it is necessary to have access to a large dataset.

Historic satellite imagery can be used to determine long-term development of the planform around bifurcations. In addition, satellite imageries taken at different stages in conjunction with water-level data can be used to produce contour maps of the areas above minimum water-level at the bifurcations.

Cross-sections at the bifurcations or in the upstream parts of the distributors, and discharge and water-level (in conjunction with reliable rating curves) data will reflect any changes at the bifurcation. Analysis of such data will therefore give an indirect indication of the changes taking place at the bifurcation.

Simulation of the long-term development of the bifurcating branches will be based on one-dimensional mathematical models.

Ranking: 1

Expected result

It will not be possible to develop a detailed prediction tool for the development of distributaries, but some realistic ranges for the variability of the sediment transport and discharge distribution at the bifurcations can be achieved. This will have a significant impact on the reliability of long-term morphological predictions of the river system, in particular for the role of the distributaries.

Required input

Expatriate mathematical modelling expert 1.5 manmonths

Expatriate river morphologist 1.5 manmonths

Local morphologist 6 manmonths

Need for additional field measurements

Measurements of the discharge and sediment distribution at the major offtakes (Old Brahmaputra, Dhaleswari, Gorai) for different stages. Other needs cannot be assessed at this moment, but it may turn out that on the basis of the analysis of the existing data a need for additional surveys will arise.

Topic 2.5 Floodplain sedimentation and subsidence**Description**

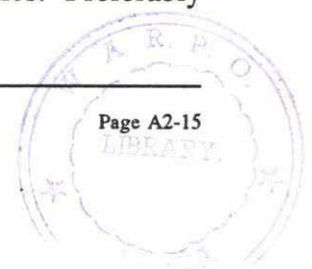
Floodplain sedimentation and subsidence may be of considerable influence on the main river systems in Bangladesh. Some indications of recent subsidence are:

- o The thick layers of sediment underlying the present river system,
- o The major avulsion of the Brahmaputra River to its present Jamuna course which may very well be explained in terms of the subsidence;
- o The present trend of erosion along the right bank of the Jamuna River between Bahadurabad and Sirajganj;
- o The continued lowering of the beel area in the upper reaches of the Meghna River in Bangladesh.

Also when studying satellite images of Bangladesh quite often faults can be observed, which could be signs of subsiding areas. The possibility exists that the subsidence is in some places balanced by sedimentation of fine sediments, partly originating from the main river system. Embankments could disturb this balance by disrupting the supply of fine sediments. This could in due time lead to lowering of the embanked areas and increasing drainage problems.

Approach and study tools

A study into subsidence and the balancing effect of sedimentation should address both components of the balance. Subsidence can be studied on the basis of satellite images in combination with topographic maps and by studying boring profiles. Preferably



special borings should be done and the age of deposits should be determined with special techniques. In addition available literature on the recent geology of Bangladesh and the surrounding countries will be studied. This will allow to get a rough estimate of the subsidence rate in the past being a first estimate of the present rates as well.

Sedimentation of fine sediments can be studied by making sediment balances for the fine sediments. In particular for the overland flow. This approach is not an easy one, and before applying it on a larger scale, order of magnitude estimates will be made to check on the accuracy that can be obtained.

Ranking: 2

Expected results

Rough estimates of subsidence rates for the different regions of the country will be obtained. The same holds for the sedimentation rates.

Required input

Expatriate geomorphologist 2 manmonths
 Expatriate geologist 1 manmonth
 Expatriate morphologist 0.5 manmonths
 Local morphologist 6 manmonths

Need for additional field surveys

See under "Approach". It is stressed that the type of surveys is slightly out of the main scope of FAP24. Only when outside expert assistance, e.g. by a University with specialized equipment can be assured, this study topic can be tackled.

Topic 2.6 Phase 2 updating

Description

This topic regards the regular updating of Phase 1 morphological studies of historical data by including new data 1993 and onwards. The new FAP 24 discharge and sediment transport measurements at 11 sites in the main river system during the coming years will provide the basis for regularly updating of the various analyses carried out for the historical time series during Phase 1 by including the new data.

Approach

The following activities can be foreseen at this very moment:

- o Improved sediment rating curves
- o Improved sediment balances
- o Improved insight into the contribution of bed load in the total bed material

- load
- o Improved insight into the suspended transport concentration verticals

Other activities may be required depending on the outcome of future surveys.

Ranking: 1

Required input

Expatriate morphologist 1 manmonth

Local morphologist 3 manmonths

Need for additional field surveys

No need for specific measurements, but in addition to the regular measurements as mentioned under "Approach" the results of field surveys of various other study topics will be used.

3. Planform characteristics and channel dimensions

Topic 3.1 Planform classification and meandering and braiding characteristics

Description

Some of the FAP components are resulting in changed conditions in the Bangladeshi rivers. This may result in changes in planform characteristics (changes braiding towards meandering, increased meandering, etc). To predict these changes classification methods are available, but these methods are derived from field data of rivers outside Bangladesh. Because the determining factors are not fully known, the applicability of these methods is doubtful. Classification methods for Bangladeshi conditions is urgently needed. The same holds for prediction methods for braiding characteristics and meandering dimensions.

Approach and study tools

Braiding and meandering characteristics can conveniently be determined from satellite images taken during low flow conditions. In addition, old maps and aerial photographs can be used. Furthermore, data on discharges, slopes, bed material size etc are needed. These data should be processed in combination. It may also be required to study satellite images taken during higher stages to investigate the time-dependency.

Ranking: 1

Expected result

Improved classification methods and predictors for braiding and meandering characteristics, verified for Bangladeshi conditions.

Required input

Expatriate river engineer/morphologist 4 manmonths

Local morphologists 12 manmonths

Need for additional field surveys

None

Topic 3.2 Channel dimensions (regime equations)

Description

Embankments may change the total width of Bangladeshi rivers and the contribution of the flood plains in the conveyance of the floods. Hence, the embankments will affect the dimensions of the channels. This can be estimated if regime equations are available, as these equations relate these dimensions to bankfull discharge. Regime equations for rivers are, however, probably affected by the sediment loads in the rivers. Hence, regime equations for the Meghna River may be different from the

regime equations for the Jamuna River. Regime equations are also useful as a basis for the estimation of e.g. outer bend scour, confluence scour and local scour.

Approach and study tools

Regime equations can be derived by analyzing the BWDB cross-sections and BIWTA soundings. For an analysis of the cross-sections, especially for the braided Jamuna River but also for the meandering rivers, satellite images should be used to correct for the deviations from the perpendicularity of the cross-sections from the river axes. Also the results of sediment transport measurements can be used in the analysis.

Ranking: 1

Expected result

Regime and at-a-station equations for Bangladeshi rivers, possibly including the effect of the sediment transport rate (during flood).

Required input

Expatriate river engineer/morphologist 2 manmonths
Local river morphologists 6 manmonths

Need for additional field surveys

None

Topic 3.3 Bank erosion rates

Description

Bank erosion rates along Bangladeshi rivers are only approximately known. Nevertheless, it is important to be able to estimate the bank erosion rates over the next years to decide on the necessity of bank protection or to decide on the alignment of embankments retired in relation to the present river alignment. It may be assumed that these bank erosion rates are related to local conditions (river characteristics and bank material characteristics).

Approach and study tools

Bank erosion rates can be studied using multi-temporal analysis (different years) of satellite images. Sufficient geometrical control allows for estimates with a fair accuracy. Local river characteristics can also be determined from satellite images, but additional measurements of cross-sections etc. should be done. Also velocity measurements should be done to relate "excess velocity" to bank erosion rates.

Special observations can be made to study the bank erosion phenomena during and after floods and to determine the importance of groundwater-levels after floods. Analyses of bank material characteristics should also be done, and the results should

be analysed together with the other observations.

Ranking: 1

Expected result

Improved methods to predict the erosion rates along meandering and braided rivers in Bangladesh.

Required input

Expatriate river morphologist 1.5 manmonths

Expatriate soil mechanics expert 0.5 manmonth

Local morphologist 6 manmonths

Need for additional field surveys

Detailed measurements of bank erosion rates in combination with (1) measurements of the outer bend depth and its changes in time, (2) near bank velocities, possibly including secondary flows.

Topic 3.4 Outer bend scour

Description

During the Jamuna Bridge project and FAP 1 it was found that bank erosion products do have a significant effect on the scour in outer bends. The larger the bank erosion rates, the smaller the outer bend scour. Bank protection works do, however, block this supply of bank erosion products and this will lead to increased scour. Insight in this phenomenon is very important in view of the maximum depth in front of the bank protection works. An important input parameter will be the celerity of bank erosion, hence there is a close link with topic 3.3.

Approach and study tools

In this study field measurements (including historical data), the analysis of satellite images, theoretical analyses and two-dimensional mathematical model studies can be combined. The field measurements will provide cross-sections near eroding banks. Field measurements of bank erosion can be extended with measurements from satellite images, whereas two-dimensional morphological (mathematical) models can be used to calibrate some coefficients in the predictive equations. Some theoretical studies are required to interpret the results and to "simplify" the results obtained to predictors for the effect of bank erosion on the scour depth in outer bends.

Ranking: 1

Expected result

Improved predictors for outer bend scour, in which the effect of bank erosion is included. This will allow the estimation of the increase in bank erosion due to the

blocking of this source of sediment supply by bank protection works.

Required input

Morphologist 2 manmonths

Mathematical modelling expert 2 manmonths.

Local morphologist 6 manmonths

Need for additional field surveys

Special measurements during a number of months per year (could be combined with topic 3.3), in which on a frequent basis an area near an eroding bank is sounded together with the occurrence of bank failures. In addition flow field measurements (see under 3.3).

Topic 3.5 Channel cutoffs

Description

Cutoffs are the balancing mechanism for channels outflanking too much and thus threatening embankments along braided and meandering rivers. Artificial cutoffs can help to mitigate the attack of these outflanking channels. Limited understanding is available on the onset of cutoffs and their development in time. This information is required (1) to predict when cutoffs will occur and (2) for the design of artificial cutoffs. For the latter distinction should be made between a cutoff in a braided river like the Jamuna River where the bed material is essentially loose sand, and in a meandering river where the cohesion of the floodplain deposits may be important.

Approach and study tools

It is proposed to study the time-dependent development of a number of cutoffs, both historical ones and ones that are occurring over the study period. For the historical ones satellite images should be combined with existing soundings, hence is the availability of sounding data an overriding factor in the selection of the cutoffs to be studied. For the cutoffs in the study period special measurements are needed, not only in the cutoff but also in parallel channels especially during and after the flood. An important aspect to measure is the discharge and sediment distribution in the developing cutoff. In the various channels also detailed water-levels should be measured to assess the importance of local slope variations for the prediction of occurrence of cutoffs.

Flood plain characteristics like the composition and the erosion behaviour of the flood plain soils also have to be determined. In addition a one-dimensional branched morphological model and analytical models can be useful in interpreting the results and in deriving predictive equations for the occurrence of cutoffs.

Ranking: 1

Expected result

Predictors for the occurrence of cutoffs, including the celerity of the cutoff process and of the silting up of the channel that is being cut off, which is an indication for the duration and extent of eroding channels. Appropriate rules for the design of artificial cutoffs, for both braided and meandering rivers.

Required input

Morphologist 1 manmonths

Soil mechanical expert 1 manmonth

Local morphologist 6 manmonths

Need for additional field surveys

Discharge and sediment distribution at potential cutoffs. Local slope measurements and its variation in time. Sampling of flood plain soil samples

Topic 3.6 Effect of tectonics on planform characteristics**Description**

As discussed under topic 2.4, there is some evidence that tectonics may be important for the main river systems in Bangladesh. Not only because of the subsidence but possibly also because it may affect the planform changes of the rivers. This would mean that (1) the location of more permanent chars, (2) the frequent occurrence of some chars at the same location and (3) preferred bank erosion in some areas, and (4) old channels being occupied could be all determined by tectonic effects. Within the framework of FAP 21/22 a limited study has been done into the effect of tectonics and the first results demonstrate that there may indeed be some effect. This should be explored further.

Approach and study tools

The limited study under FAP 21/22 was based on the interpretation of satellite studies. Due to time and budget constraints only a few satellite images could be studied. The study proposed here would have to be based on the analysis of more images, in combination with field visits.

Ranking: 2**Expected results**

A report discussing the importance of tectonics for planform changes, together with recommendations how to incorporate this aspect into modelling concepts for planform changes of main braided and meandering rivers in Bangladesh.

Required input

Geomorphologist 6 manmonths, including 1 month field visits

Local river morphologist 1 manmonth

Need for additional field surveys

Corings in the floodplain at selected locations (see also Topic 2.4): can only be done if a University from outside the project is interested in this investigation. Possibly to be combined with topic 3.7?

Topic 3.7 Influence of cohesive material on planform changes

Description

According to Coleman (1969) there is quite some influence of cohesive material on the erosion of the banks of the Jamuna River. This seems in contradiction with findings under the Jamuna Bridge Study (no difference in erosion rate between chars and "old" land) and with the bank material sampling of FAP1. Still this issue has to be resolved, in particular as far as the possible consequences for planform changes and their prediction is concerned.

Approach and study tools

The best way to study this aspect would be by collecting primary evidence via borings. At present, however, this is not foreseen within FAP 24. In a number of FAP's though borings have been carried out in relation to foundations (Jamuna Bridge, FAP1, FAP 9B, FAP 21/22 and possibly more). The results of these borings should be collected and be studied in the present light. In addition discussions to be held with Geological Survey of Bangladesh and satellite images to be studied to identify differences in reflection, moisture and vegetation, which could indicate differences in soil composition. In addition borings can be considered in selected places in combination with activities under the topics 2.4 and 3.6.

Ranking: 2

Expected results

Report with indications of the presence of cohesive sediment along the main rivers and their relevance for bank erosion processes.

Required input

Soil scientist 2 manmonths
River engineer 1 manmonth
Geomorphologist 1 manmonth
Local morphologist 6 manmonths

Need for additional field surveys

See above under approach

Topic 3.8 Local slope changes and their importance for planform changes

Description

There are indications that the prediction of planform changes in braided rivers can be improved by including the local water-level slope and its variation into the different modules of the modelling methodology outlined under 4.7. A field study into the order of magnitude of these changes could provide indications to what extent it may be advisable to include this variation in prediction methods. From the field observations in combination with the development of the planform where the measurements are being done, it may be possible to develop more refined modules for prediction of planform changes.

Approach and study tools

A number of gauges will be installed in one or several of the locations where the bathymetric surveys are carried out. The gauges will not only be installed along the river, but also at a number of keypoints in the river itself, though at locations which are assumed not to be eroded. These gauges will be connected by precise levelling. During one or several monsoons the gauges will be read. Fluctuations in water-level slope will be analysed. If substantial, the planform developments as observed from satellite images over these years will be interpreted in the light of local water-level slopes.

Ranking: 1

Expected results

Better insight water-level changes over short distances and their role as indicators for planform development

Required input

Expatriate river morphologist 1 manmonths

Expatriate river engineer 1 manmonth

Local morphologist 6 manmonths

Land survey team for $2 * 2 = 4$ months

Gauge reader estimated for $20 \text{ (locations)} * 6 \text{ months} * 2 \text{ years} = 240 \text{ manmonths}$

Need for additional field surveys

Water-level measurements at a number of selected river reaches during a number of selected periods. Precise levelling between the gauges, also when they are at opposite river banks.

Topic 3.9 Prediction of medium-term planform changes

Description

There is a need for tools to estimate planform changes of braided and meandering rivers over medium-term time periods. Here medium-term is used in relation to the celerity of the morphological processes. Hence medium term means 1 to 3 years for the Jamuna. For these rivers such a medium-term prediction is needed for the planning of river defence works like groynes and revetments, and for decisions regarding maintenance e.g. for the future Jamuna Bridge. For meandering rivers, where the morphological processes are proceeding at a lower speed, the medium term would be in the order of 10 years. Under FAP 21/22 a beginning has been made with the development of a prediction methodology for braided rivers, but this methodology should be extended to a computer model because of the stochastic approach that necessarily has to be taken. For meandering rivers a mathematical model exists, but this should be tested for its applicability for the conditions in Bangladesh.

Approach and study tools

The approach taken for braided rivers is described in Klaassen et al (1993). It involves the development of a mathematical model with a core a number of modules related to bank erosion, mid-channel bar formation, cutoffs, etc. and as a shell pre- and post-processing on the basis of satellite images. For meandering rivers the mathematical model MIANDRAS could be used. Its applicability to e.g. the Dhaleswari River could be tested. Probably it will be required to adapt the program to take into account the input of bank erosion products. Close cooperation with FAP 19 is appropriate.

Ranking: 1

Expected results

Dedicated version of mathematical models that can be used for planning and management of braided and meandering rivers at medium-term intervals.

Required input

Expatriate river morphologist 12 manmonths
Expatriate remote sensing specialist 3 manmonths
Local morphologist 24 manmonths

Need for additional field surveys

None

References

Klaassen, G.J. & G. & Masselink (1992), Planform changes of a braided river with fine sand as bed and bank material, Proc. 5th Intern. Symposium on River Sedimentation, Karlsruhe, F. R. of Germany,

Klaassen, G.J., E. Mosselman and H. Bruhl (1993), On the prediction of planform changes in braided sand-bed rivers, Proc. Intern. Conf. on Hydrosience and Engineering, Washington, U.S.A.

Topic 3.10 Long-term changes of the location of the rivers

Description

The location of the main rivers in Bangladesh appears to be affected substantially by local tectonic effects. For long-term planning of measures to train the main rivers, insight is needed into the future changes into the locations of the river courses.

Approach and study tools

An estimate of future changes in river course location should be based on an understanding of the past. Hence there is a close link between this topic and topic 3.6. The present study topic can only be tackled once topic 3.6 is successfully finalized. The approach to be taken is the extrapolation of observed past tectonic tendencies.

Ranking: 1

Expected results

Predictions of future river course changes, to be used in long-term planning of bank protection and river training works. For all major rivers in Bangladesh, but in particular for the Brahmaputra/Jamuna river system and the Lower Meghna River, notoriously being the most unstable rivers in Bangladesh.

Required input

Geologist 0.5 manmonth

Expatriate river morphologist 0.5 manmonths

Local morphologist 2 manmonths

Need for additional field surveys

None

4. Offtakes and bifurcations

Topic 4.1 Discharge and sediment transport distribution.

Description

Distributions of discharge and sediment transport at river offtakes and at bifurcations in the braided system is one of the key factors for the long-term morphological development of the distributaries (including their flood levels and the low flows) and for the changes in planform in braided rivers.

The discharge distribution at bifurcations is to a large extent determined by the hydraulic capacity along the entire bifurcating branches. The relative discharge distribution can therefore be strongly stage dependent, as for instance at the Gorai offtake from the Ganges River. The sediment transport distribution, on the other hand, is strongly influenced by the local planform and bathymetry at the bifurcation.

Approach and study tools

An increased insight into the mechanics and dynamics of bifurcations can be achieved by studying series of bathymetric charts in conjunction with flow and sediment transport data. Differential charts will be produced from digitized bathymetrical charts in order to investigate the development of the bathymetry at the bifurcations (see also topics 5.2 and 5.4.). It is proposed also to use two-dimensional mathematical models of the flow and sediment transport at the bifurcations in order to gain insight into the sensitivity of the processes governing the sediment transport distribution.

The Gorai offtake from the Ganges River is of particular importance for the conditions in the South West Region of Bangladesh, as the salinity intrusion in that region is strongly dependent on the discharge in the Gorai. The planform at the Gorai offtake is relatively stable which will facilitate data interpretation and mathematical modelling. It is therefore proposed to study this offtake intensively and use the findings obtained here, at other similar bifurcations at a later stage in the study.

Also the Dhaleswari offtake from the Brahmaputra River is of particular importance, since the flood levels around Dhaka to a large extent can be influenced by the conditions at the offtake. The Dhaleswari offtake consists of a number of minor channels, which can change rapidly from year to year. This makes the use of mathematical models doubtful, since the geometry is poorly defined. It is therefore proposed, as a first step, to investigate this offtake using satellite imageries and the survey data (bathymetrical charts, flow and sediment data).

Finally some bifurcations in the braided reaches of Bangladeshi rivers can be studied. Also here discharge and sediment transport will be measured, but it should be part of a more extensive survey in which also other river and branch characteristics are determined.

Ranking: 1**Expected result**

Prediction methods for the sediment distribution at offtakes and at bifurcations. The integrated approach proposed for the study of offtakes will give valuable insight into the bifurcation mechanism and will improve the possibilities to predict mathematically the sediment and discharge distribution at offtakes. This is a prerequisite for a reliable prediction of the long-term development of the distributaries.

Required input

Expatriate mathematical modeller 4 manmonths,
Expatriate river morphologist 4 manmonths
Local mathematical modeller 12 manmonths
Local river morphologist 12 manmonths
Computer facilities

Need for additional field surveys

Discharge and sediment distribution at the major offtakes during different stages over a number of years, in combination with downstream water stages and possibly cross-sections in the downstream branches. Soundings of a number of offtakes. Same for some selected bifurcations in the braided Jamuna River.

Topic 4.2 Seasonal variation of erosion and deposition**Description**

The discharge and sediment transport distribution at bifurcations and offtakes can be strongly stage dependent during some parts of the year (see Topic 5.1). One implication of this is that in parts of the year a distributor may be overloaded with sediment (depositing) whilst during another part it may have a sediment deficit (eroding). This variation can induce "pulses" or "plugs" in the sediment transport in a distributor. The extreme case is when a distributor is inactive during the dry season and is eroding a new channel during the rising stage.

Approach and study tools

It is proposed that the seasonal variation of erosion and deposition be derived from series of bathymetric charts, and that the effect on the sediment transport conditions in the distributary be derived from time series of cross-sections in the distributary, if sufficient cross-sectional data are available.

In addition, the seasonal variation of the bifurcation can be modelled using a two-dimensional mathematical model. Transport of sediment "plugs" through a river can be modelled with detailed one-dimensional model setups of the distributaries. An increased understanding of this problem can be achieved via a sensitivity analysis with

the mathematical model.

Ranking: 2

Expected result

The expected output from this study topic is an increased understanding of the bifurcation mechanism in general and, in particular, the seasonal variation. This will improve the ability to model the short-term (seasonal) development of the bifurcations and the distributors. In addition, an improved understanding of "pulsation" of sediment transport will be obtained.

Required input

Expatriate mathematical modeller 1 manmonth

Expatriate river morphologist 1 manmonth.

Local mathematical modeller 2 manmonths

Local river morphologist 2 manmonths

Need for additional surveys

Repeated cross-sections or areal soundings in distributaries over some years, covering the whole hydrological year, with a frequency of say four times a year.

Topic 4.3 Influence of bars

Description

At the Gorai offtake from the Ganges River there are indications that a bar is located in front of the offtake partly blocking the inflow to the Gorai. There is evidence that this bar is part of a system of bars slowly migrating with a certain periodicity. The variation of the inflow to the Gorai has a large impact on saline intrusion into the South West Region and on the morphology of that region. These bar systems seem to be an essential element governing the bifurcation mechanism, probably not only in the Ganges River but also in the other main rivers with distributaries.

Approach and study tools

The cyclic behaviour of bars at offtakes can be analysed by studying discharge and water-level data in the offtake channel and in the main river. In addition, the position of such bars can be determined from low stage satellite imagery of the bifurcation. Hence it will be possible to determine the migration speed directly from a series of satellite imagery. It is, moreover, proposed to use two-dimensional mathematical modelling to investigate the dynamics (migration speed, growth and decay) of the bars in detail. This will contribute to the understanding of bar dynamics. The model setup of the Gorai offtake proposed under Topic 4.1 can form the basis for this model investigation.

Ranking: 1**Expected result**

The output of this study topic will be an improved understanding of the influence of bars around bifurcations which is a prerequisite for long-term predictions of the functioning of river branches such as the Gorai and the Dhaleswari. For the Gorai this is related to the saline intrusion and morphological conditions in the southwest region. At the same time, an improved understanding of migrating bars in large rivers will also be gained. The improved understanding will also allow a better assessment of the efficiency of dredging operations at river oftakes and irrigation water intakes (for example, Ganges-Kobadak scheme).

Required input

Expatriate mathematical modeller 2 manmonths

Expatriate river morphologist 2 manmonths.

Local mathematical modeller 4 manmonths

Local river morphologist 6 manmonths

Need for additional field surveys

No additional measurements in addition to the soundings as part of the regular sounding programme.

Topic 4.4 Influence of bed-forms**Description**

Bed-forms have a substantial influence on hydraulic resistance. The dimensions of the bed-forms depend on the flow conditions and sediment properties and may change significantly in time. At high flow rates bed-forms can vanish altogether and the hydraulic resistance will decrease significantly.

At a bifurcation, various bed-forms may develop in the bifurcating branches. For instance, transition to flat bed may take place in one branch while the bed in the other branch is covered with dunes. This will induce a change in the discharge distribution, which may not be insignificant. As a consequence, also the sediment transport distribution is likely to change.

Approach and study tools

The dimensions of the bed-forms and their variation can be obtained from the soundings from the bathymetric survey around the bifurcations. The applicability of the use of the side scan sonar for the collection of data on bed-forms will be studied. An analysis of these data will give a first indication of whether the problem described is significant for the prevailing conditions in the main rivers of Bangladesh.

If it proves to be important, modelling of the bed-form dimensions and the associated hydraulic resistance can be included in both the one-dimensional and two-dimensional mathematical models proposed in study topics 5.1 to 5.4.

Ranking: 3

Expected result

The expected output of this study topic will be an improved description of the distribution of flow and sediment transport at bifurcations.

Required input

Provided Study Topic 4.1 and 4.2 are running parallel:

Expatriate sediment transport expert 1 manmonth.

Local morphologist 2 manmonths

Need for additional field measurements

In addition to the regular measurements programmes at the offtakes, the sounding of bed-forms and measurements of the discharge distribution in cross-sections at different stages.

5. Confluences

Topic 5.1 Erosion and deposition for out-of-phase floods

Description

The stages in a river reach upstream of a confluence are determined not only by the discharge of this river reach itself, but also by the discharge in the other confluencing river. Especially when the rivers are not in phase (as is the case with the Jamuna and the Ganges Rivers), this may induce complicated scour and deposition processes. In addition, also the actual planform of the two rivers will interfere causing the actual confluence to change constantly its location. This also induces a very unstable behaviour. A study of bank erosion near confluences should take these aspects duly into account.

Approach and study tools

This study will use satellite images, soundings of the bed topography, and possibly mathematical modelling. From the satellite images the locations of scour and of deposition and of bank erosion can be determined and this should be combined with soundings. In addition, it can be considered to apply a two-dimensional (mathematical) flow model to predict the flow pattern and a two-dimensional (mathematical) morphological model to test these models for their predictive power for these conditions.

Ranking: 2

Expected result

Improved insight and possibly predictors for the erosion and deposition and of the bank erosion at confluences. Apart from the relevance for some FAP components, the results may be useful for BIWTA with respect to some ferries that are traversing the river at the confluence of the Ganges and the Jamuna Rivers.

Required input

Expatriate hydrologist 0.5 manmonth, morphologist 1 manmonth, mathematical modeller 3 manmonths. Local hydrologist 1 manmonth, morphologist 2 manmonths and mathematical modeller 4 manmonths

Need for additional field surveys

Soundings of bed configuration at confluences, in particular at the confluence of the Jamuna and the Ganges River. Through the whole season at regular intervals.

Topic 5.2 Influence of bars and bed-forms

Description

It may be that bars and bed-forms have a significant effect on the development of confluences, especially due to the time-dependent behaviour of the river bed. The actual bed topography and channel alignments during low flow conditions may be significantly affected by the actual location of bars at the end of a flood. The bed topography of the major river at the confluences with a smaller river will have a strong effect on the discharge capacity of the smaller river like the Atrai/Hurasagar confluence with the Jamuna.

Approach and study tools

The effect of bars and bed-forms can be studied by doing special soundings during the flood season and afterwards. Also satellite images can yield additional (historical) information. Also the use of a riverbed profile (such as a sideways-looking sonar) can be appropriate to study the 3-dimensional characteristics of bars and bed-forms and to derive transport patterns from multi-temporal soundings. Special attention will be paid to the complicated situation of the Hurasagar/Atrai confluence with the Jamuna river.

Ranking: 3

Expected result

Improved insight into the possible effect of bars and bed-forms on the conditions of confluences.

Required input

Expatriate morphologist 2 manmonths.

Local morphologist 6 manmonths

Need for additional field surveys

Special measurements of bed topography and the occurrence of bars and bed-forms throughout the flood season but also in receding stages.

Topic 5.3 Confluence scour

Description

Downstream of confluences deep scour holes occur. These scour holes can occur near bank protection works in rivers that are not fully trained. They are also important for the scour depth near bridge piers. It seems that the depth of these scour holes is determined by the conditions in the confluent channels, while also the angle between the two channels is important. The causes of this confluence scour are not fully known. Neither is the effect of the controlling factors (dimensions of both upstream channels, sediment transport rate, time dependency).

Approach and study tools

The proposed approach is an analysis of existing soundings at confluences. In addition, special measurements should be done of not only the bed topography at confluences, but also of the discharges and the sediment transport in the confluencing channels. These measurements should be done during the flood period, but also in the receding stage. It may be of interest to include also results from other studies in different types of braided rivers, to test the results for a wider range of conditions.

Ranking: 3

Expected result

Improved predictors for confluence scour.

Required input

Expatriate morphologist 2 manmonths.

Local morphologist 6 manmonths

Need for additional field surveys

Special measurements during the flood and the recession during some years of the confluence scour in addition to the dimensions of the confluencing channels. Also the discharge from these channels should be measured. Typical confluences are the confluences of Ganges and Jamuna River, the Padma and the Meghna River and confluences in the Jamuna River.

6. Sand bars

Topic 6.1 Occurrence, dimensions and dynamics of bars

Description

In the major channels of braided rivers like the Jamuna, but also in rivers like the Padma and the Lower Meghna substantial bars are present. These bars have probably a major influence on various morphological phenomena such as the distribution of water and sediment at bifurcations (see Topic 5.4), the occurrence of cutoffs and bank erosion phenomena. There is hardly any information on these bars that travel through the river system. Nowadays some prediction methods for occurrence, dimensions and dynamics are becoming available, but application of these methods to Bangladeshi rivers results in unrealistic predictions. Hence, there is a need for the development of predictors especially suited for Bangladeshi conditions. This will enable doing a better prediction of the development of the river systems a number of years ahead.

Approach and study tools

This study should be based on the confrontation of modern predictors and field measurements. The analysis of a series of satellite imagery taken during low river stages will allow a description of the bar characteristics. Further to historical data, special measurements will be needed (as the historical data were not especially done to identify and study bars). These special measurements will be required at different intervals during the flood and during the recession of flood waves. For testing analytical methods including non-linear effects will be used. Finally, the application of two-dimensional (morphological) models may be appropriate to test the understanding that will emerge from the preceding confrontation and the subsequent refinement.

Ranking: 1

Expected result

Improved predictors for bar occurrence, dimensions and dynamics, that in turn will yield improved understanding of the morphological system over the years.

Required input

Expatriate morphologist 4 manmonths
Expatriate mathematical modeller 2 manmonths.
Local morphologist 12 manmonths
Local mathematical modeller 6 manmonths

Need for additional field surveys

Special measurements of the bed topography in a number of selected river reaches to identify bar dimensions and their celerity. Also measurements of the hydraulic characteristics (discharges, velocities, depths) and the overall channel dimensions.

Topic 6.2 Time-dependence of bars**Description**

It may be that time-dependence is an important characteristic of the bars in systems like the Jamuna and the Padma/Meghna rivers. This time-dependence is introduced by the discharge hydrograph. To study this, a detailed investigation of typical length, width and heights of bars in some selected reaches in the main rivers is required. This topic can be combined with topic 6.1.

Approach and study tools

Special field measurements, possibly in combination with some theoretical analyses and mathematical modelling with a two-dimensional morphological model.

Ranking: 2

Expected result

Understanding of the importance of the time-dependence on bar formation. This may lead to an adaptation of the approach followed in topic 7.1.

Required input

Expatriate morphologist 1 manmonth and mathematical modeller 1 manmonth.

Local morphologist 2 manmonths and mathematical modeller 2 manmonths.

Need for additional field surveys

Special detailed measurements of bar dimensions in some reaches throughout the year. Special attention to be given to the bar in the Ganges River in front of the Gorai River in view of the pronounced influence of the Farakka dam on the Ganges hydrograph.

7. Bed-forms

Topic 7.1 Occurrence, dimensions and dynamics

Description

The main rivers in Bangladesh have large bed-forms. In the Brahmaputra river the bed-forms can be several meters high and more than 100 metres long. The bed-forms have a large influence on the hydraulic resistance, sediment transport and scour at structures in the river.

The size of these bed-forms varies both temporally (see Topic 7.2) and spatially. In connection with the design of structures in rivers it is of great importance to know whether the large bed-forms also occur where the largest scour (e.g. at bends and confluences) is found. The spatial and temporal variation of the bed-forms is also of great importance for the modelling of the hydraulic resistance and hence flood levels.

Approach and study tools

It is proposed to extract the bed-form dimensions from the echo soundings used for the bathymetric surveys. These data will form the basis for a classification of the various bed-form types. Analysis of these data, in conjunction with flow and sediment transport data, will be used to develop a prediction tool for the occurrence and dimensions of the various types of bed-forms. This prediction tool can be implemented in both the one-dimensional and two-dimensional mathematical models and form the basis for a sensitivity analysis of the interaction between flow and bed-forms leading to an increased understanding of the river response to changing flow conditions.

Ranking: 1

Expected result

The output of this study component will be a classification of the bed-forms found in the main rivers and a prediction tool for the dimensions of the bed-forms. This will improve the design basis for structures in the rivers (bed-form scour), and improve the ability to predict the hydraulic resistance and the associated flood levels in the rivers (see also topic 7.5).

Required input

Expatriate sediment transport expert 2 manmonths and mathematical modeller 2 manmonths. Local morphologist 6 manmonths and mathematical modeller 6 manmonths.

Need for additional field surveys

Initially no need for additional measurements. During the further analysis the need for hydraulic data in addition to the measured bed-forms may arise.

Topic 7.2 Time-dependence of bed-forms

Description

During low flows very large sand dunes, compared to the water depth, are found in the main rivers. This is reflected in very high hydraulic resistance. The equilibrium dunes for these flow conditions are small. This is a 'time lag' phenomenon. The dunes are formed during high flow or falling stage, but the time required for modification of the dune dimensions is much larger than the time available.

During very high flow, transition to flat bed may take place in some parts of the river, resulting in a smaller hydraulic resistance. In some rivers this transition results in a water-level drop while the discharge is increasing (i.e. a local maximum on the rating curve). This phenomenon has, however, not been documented for any of the Bangladeshi main rivers.

An important implication of the time lag is that for the same discharge during rising and falling stage the dune configuration at the riverbed can be significantly different, hence the hydraulic resistance and the water-level will be different. This is reflected in the rating curves as loops (hysteresis effects), see also Topic 1.4.

Approach and study tools

The dimensions of the bed-forms and their variation can be extracted from the echo soundings used for the bathymetric surveys. These data should be analysed in conjunction with the flow and sediment data in order to assess the importance of the time lag phenomenon.

Both the proposed one- and two-dimensional models have the provision for calculating the dynamic development of the bed-form dimensions and the associated hydraulic resistance. The field data mentioned above can be used to calibrate these model formulations if the initial analysis shows that the effect is significant for the morphological development of the river system.

Ranking: 1

Expected result

It is expected that this topic will result in a tool for the prediction of the hydraulic resistance and its variation during the hydrological year. This will contribute to an improved understanding of the flow pattern as well as of the sediment transport conditions in the rivers.

Required input

Expatriate sediment transport expert 2 manmonths and mathematical modeller 3 manmonths. Local morphologist 6 manmonths and mathematical modeller 6 manmonths.

Need for additional field surveys

Initially no need for additional measurements. During the further analysis the need for hydraulic data in addition to the measured bed-forms may arise.

Topic 7.3 Three-dimensionality of bed-forms**Description**

There are several indications that the bed-forms of the Brahmaputra are highly three-dimensional, i.e. short-crested. Directional flow-velocity data collected in the Brahmaputra River under FAP 1 show large variations in direction close to the riverbed. In addition, a theoretical model for the calculation of the hydraulic resistance from observed dune height and length tend to significantly overestimate the observed resistance. This theoretical model is based on long-crested dunes (two-dimensional) and has performed well in rivers with those type of dunes. The three-dimensionality of the dunes also has an impact on the interpretation of dune tracking data and on the sediment transport conditions. It is, therefore, important to get insight into the extent of this three-dimensionality, to assess the influence on the sediment transport and to modify existing models for long crested dunes to account for the three-dimensionality dunes.

Approach

It is proposed to base this study on interpretation of field data in conjunction with a theoretical desk study of the processes involved. The application of the side scan sonar could add valuable information required for this study.

Ranking: 1**Expected result**

This study will lead to an improved understanding of the bed-form pattern and an improved description of the hydraulic resistance and sediment transport in the mathematical models.

Required input

Expatriate sediment transport expert 2 manmonths. Local morphologist 6 manmonths.

Need for additional field surveys

Initially soundings with the side looking sonar. In a later stage also soundings and velocity measurements where the direction of the flow is also measured. Also the discharge distribution over the cross-section may be required in some stage of the analysis.

Topic 7.4 Roughness and bed-forms

Description

During the flow modelling carried out by SWMC (Surface Water Modelling Center) regularly it is required to assume that the river bed becomes very smooth during floods. Similar experience was obtained during FAP 9B, where values of the Chezy coefficient of $125 \text{ m}^{0.5}/\text{s}$ were used. These high values can be explained by assumptions: the discharge in the river is assumed to be too large (see Topic 1.1), the overbank flow is underestimated (see Topic 1.3) or the water-sediment interface becomes very smooth. The latter can be studied under this topic, whereby attention should be given to a transition to flat bed and the slope of the lee-side which can become so gentle that hardly any energy losses occur any more.

Approach and study tools

It is proposed to measure the roughness characteristics of some selected reaches in combination with measurements of the bed-form characteristics. To determine the roughness it is required to measure the slope in selected reaches, in combination with other characteristics like the discharge in the channel and its average width and depth. Also the slope of the bed-form should be measured and comparisons should be made with methods in which the influence of the lee-side slope is indicated (Klaassen et al, 1987).

Ranking: 1

Expected results

An answer to the question whether the bed-form dimensions and hence the form roughness and its variation with the discharge explain the assumption that the river bed becomes very flat during floods. If so, also good estimates of the roughness of the river bed during extreme floods. A result could also be that one of the other explanations (see under "Description") provides a better explanation.

Required input

Expatriate sediment transport expert 3 manmonths

Local morphologist 12 manmonths

Need for additional field surveys

See "Approach". Possibly to be combined with other topics, like 7.1 through 7.3 and 3.8.

8. Local scour

Topic 8.1 Dimensions of local scour around structures

Description

Around bank protection works such as groynes and revetments local scour occurs. The depth of this local scour depends on the local depth, on the flow field near the structure (and thus on the bed topography), on the bed-material size and on the dimensions (planform slope) of the bank protection works. Prediction methods for local scour are available but they have not been tested systematically against field observations in the major rivers of Bangladesh.

Approach and study tools

Special field measurements should be done near existing bank protection works (Rashahi, Sirajganj, Bhairab Bazar, Chandpur) and near works to be erected shortly (e.g within the frame- work of FAP 21). The results of these measurements should be compared with existing predictors and, if necessary, these predictors should be modified to arrive at predictors suited for Bangladeshi conditions.

Ranking: 1

Expected result

Improved predictors for local scour around bank protection works.

Required input

Expatriate morphologist 2 manmonths

Local morphologist 4 manmonths.

Need for additional field surveys

See under "Approach", implying special measurements near existing bank protection works (Rashahi, Sirajganj, Bhairab Bazar, Chandpur) and near works to be erected shortly (e.g within the frame- work of FAP 21). Especially during the flood season, but also during lower stages.

Topic 8.2 Time-dependence of local scour

Description

Local scour may show a time-dependent behaviour because of the variation in discharge. It may thus be that the maximum local scour as found in scale-model investigations, is not reached in reality because the floods have only a limited duration.

Approach and study tools

To measure the local scour around some selected bank protection works during a full flood, so including the rise and the fall. Comparison of the local scour at the same stage will provide insight in the time-dependence. A comparison can be made with analytical expressions for the time-dependent behaviour (as developed in e.g. the Jamuna Bridge project).

Ranking: 2

Expected result

An answer to the question whether time-dependence can be taken into account when predicting the local scour around bank protection works. If yes, then lower-cost designs may be possible.

Required input

Expatriate local scour expert/morphologist 1 manmonth. Local morphologist 3 manmonths.

Need for additional field surveys

Special measurements during a whole flood cycle. Can be combined with measurements under Topic 8.1.

Topic 8.3 Influence of bed-forms**Description**

Bed-forms in the major rivers may have very large dimensions (in the Jamuna River dunes up to 10 m high have been observed). There is some doubt as to whether these bed-forms are also noticeable near structures or that bed-forms are not present in local scour holes. This is important for the determination of the minimum level of the protection works.

Approach and study tools

Special measurements may be done near bank protection works, but concentrating on the possible occurrence and the dimensions of the bed-forms. This can be done by longitudinal soundings, although a better (but more expensive) alternative is a side scan sonar device.

Ranking: 2

Expected result

An answer to the question whether bed-forms should be taken into account in estimating deepest scour holes near bank protection works.

Required input

Expatriate local scour expert/morphologist 1 manmonth. Local morphologist 3 manmonths

Need for additional field surveys

Special measurements at selected places, in which also the side-looking sonar can be applied. Can be combined with the measurements for the Topics 8.1 and 8.2.

Topic 8.4 Combination with other types of scour

Description

There is some doubt as to how different types of scour have to be combined with local scour around bank protection works. Within FAP 21 a special scale-model study was carried out recently to investigate the combination of bend scour and local scour. There is, however, the need for field testing of the different proposals for how to combine these different types of scour, notably the following combinations:

- o bend scour and local scour,
- o confluence scour and local scour,
- o bend scour, confluence scour and local scour.

This can only be done in combination with topics 3.4, 7.3 and 8.1 (and 8.2), as these topics will provide field predictors for the individual types of scour.

Approach and study tools

Special measurements near bank protection structures. The locations should be selected on the basis of the criterion that they are located along an outer bend or near a confluence. The results have to be compared with local scour predictions of confluence scour and outer bank scour alone. In addition it can be considered to study some combinations in 2-d mathematical models for the prediction of bed topography, but this has not been included here in the estimate of the manmonths requirement.

Ranking: 2

Expected result

Improved understanding of how to combine different types of scour. This may lead to safer and lower-cost designs for bank protection works.

Required input

Expatriate local scour expert 1 manmonth and morphologist 1 manmonth. Local morphologist 4 manmonths.

Need for additional field measurements

Special measurements of combinations of scour at selected locations.

9. Measuring techniques

Topic 9.1 Selection of measurement sites

Description

The selection of sites for discharge and sediment transport measurements in dynamic alluvial rivers has to be reviewed regularly. Migrating channels, moving bars and bed-forms are forcing to shift the measuring sites. Morphological changes are affecting the flow patterns, changing the flow distribution including flow directions in a measuring section. Also the sediment transport characteristics are changing. The key issue is to monitor the time scale of the changes and based upon that develop a practical method for selection and control of the measuring sites.

Approach and study tools

The morphological characteristics of the rivers in Bangladesh will be studied partly in the group of Topics 3.1 through 3.10. Also the detailed measurements under FAP 24 will provide additional insight regarding the morphological changes in the various rivers and their effect on the representivity of measuring sites. This information will be assessed properly and the results will be used to judge the existing standards for site selections and recommendations will be done to modify the standards.

Ranking: 1

Expected result

The study will provide recommendations for site selection in the dynamic alluvial rivers in Bangladesh, whereby probably a distinction will be made between the meandering and the braiding river reaches. Due consideration will be given also to possible stable sites (cohesive banks? influence of tectonics?).

Required input

Expatriate River morphologist 1 manmonth
Expatriate River engineer 1 manmonth.
Local morphologist 4 manmonths.

Need for additional field surveys

None

Topic 9.2 Optimization of hydraulic measurements (discharge measurements)

Description

The following type of measurements are considered here:

- o Water-level and water-level slope
- o Flow velocity and direction patterns
- o Discharge

Obviously the studies supporting the selection and further optimization of hydraulic measurement techniques, will basically compare the prevailing hydraulic conditions in detail and the way these conditions will be measured applying the various techniques considered. In fact the whole assessment of accuracies is based on the knowledge of the variability (spatial and temporal) of the flow and the schematizations (integration area and/or time) due to the applied techniques.

Points of study should be:

- o Review of objectives and acceptable accuracies
- o Review of temporal variability:
 - turbulence versus sampling time
 - possibilities of pulsating flow
 - duration of a measurement (contemporaneity)
- o Review of spatial variability:
 - density of verticals
 - points per vertical
- o Water-level slopes, desired applications and accuracies
- o Vertical data coverage in high sediment concentrations and desired ADCP frequencies
- o Variation of flow direction as function of the water-level
- o Additional flow information required for morphological analysis
- o Near river-bed flow profiles
- o Further optimization of flow measurements, especially to develop a blend of traditional and modern techniques

This list contains typically a mix of hydraulic river characteristics and related measurement issues. This means that the studies can be done for a certain river (location) and a certain technique plus all kinds of combinations.

Approach and study tools

Hydraulic survey work has to be attended and analysed. Analysis of standard FAP 24 measuring data will give part of the answer. But supplementary measurements are envisaged for instance in view of water slope analysis and near river-bed flow profiles. Use will be made of existing methods to optimize the spatial density.

Ranking 1

Expected result

Recommendations to improve the current techniques of hydraulic measurements and to optimize the hydraulic measurements especially those in the tidal areas.

Required input

Expatriate hydraulic engineer 3 manmonths, database engineer 1 manmonth and field engineer 1 manmonth. Local hydraulic engineer 6 manmonths, database engineer 2 manmonths and field engineer 2 manmonths.

Need for additional field surveys

See under "Approach".

9.3 Optimization of sediment measurements

Description

Sediment sampling is often a rather time consuming affair, which makes optimization highly interesting. This holds both for bed load and for suspended load measurements. A problem with the measurements, the analysis and the use of transport data is that sediment transport in the main river is not uniformly distributed but varies as well in the longitudinal as in the transverse direction. These variations are partly caused by large scale changes in water depth, flow velocity and mean grain size, but also because the bottom is covered by sand waves over which the sediment transport is highly non-uniform. The sediment transport is higher at the top of the sand wave than over the deeper located part of the sand wave. The wave length of the sand waves is typically of the order 50-200 m, and because the sediment transport measurements are point measurements there will be a very large scatter in the measured results. This scatter occurs because the measurements are performed at different locations along the sand waves. Based on the knowledge of the variability of sediment transport, faster and/or cheaper methods are sought while maintaining the required accuracy. The various techniques applied in Bangladesh will be studied:

- o Trap samplers
- o Depth integrating method
- o Pump-bottle method
- o Optical turbidity measurements
- o The acoustic methods

Approach and study tools

Specific points of study are:

- o Review of objectives and acceptable accuracies

- o Review of the variability of the suspended load and bed load for instance as a function of the bed-forms. Study on suspended load/bed load relations.
- o Study on the characteristics of the various techniques applied in Bangladesh (see above).
- o Study into the possibility of combining optical and acoustic techniques with the moving boat method
- o Experiments to distinguish bed material load and wash load
- o Monitoring new developments

Survey work will be attended and analyzed. Special measurements have been done and will be done to obtain insight in the variability of both bed load and suspended load. Literature on the various techniques applied in Bangladesh will be collected and studied including monitoring of new developments. Experiments in the field are required to compare techniques and assess the operational problems. For the detailed near bed measurements special equipment need to be tested first.

Ranking 1 and 2

a) Suspended load ranking 1 and b) bed load ranking 2

Expected results

Recommendations to improve the current techniques including optimization of sediment measurements for the specific conditions in Bangladesh.

Required input

a) for the suspended load study

Expatriate morphologist 4 manmonths, field engineer 1 manmonth and database engineer 1 manmonth. Local morphologist 6 manmonths, field engineer 2 manmonths and database engineer 2 manmonths.

b) for the bed load study including special equipment

Expatriate morphologist 1½ manmonths, electronic engineer 1 manmonth, software engineer ½ manmonth. Local morphologist 2 manmonths and software engineer 1 manmonth.

Need for additional field surveys

Special detailed measurements of discharge and sediment transport at selected reaches along the main rivers. At various flow ranges.

For near river bed measurements special equipment (for instance a carrier with vertically adjustable ultrasonic sensor) need to be tested

9.4 Bed load transport via dune tracking

Description

Bed load transport can be determined via dune tracking data by assuming that all sediment depositing on the lee side of the sand dunes is bed load. However, theoretical analysis of dune tracking and suspended load data from the Brahmaputra River carried out under FAP 1 (BRTS) has indicated that up to 80 per cent of the lee side deposits originate from suspended load. This finding was also supported by the fact that the lee side of the sand dunes are less steep than found in rivers with smaller suspended sediment transport rates.

This implies that bed load transport can only be determined from dune tracking data if the part of the lee side deposits originating from suspended load can be determined accurately. This is extremely difficult to do from field data, since it depends very much on the processes in the thin high concentration layer close to the bed. The possibility for determining bed load transport in any other way in large rivers like the Brahmaputra, where the bed-forms can be several meters high, are very limited. Hence there is a need for methods to correct the results obtained from dune-tracking by "subtracting" the contribution of the suspended load.

Approach and study tools

It is proposed to make an analysis of the concentration and velocity profile close to the bed in order to obtain an insight into how much suspended sediment will be trapped at the lee side of the dunes, see also Topic 9.3. With this information the bed load transport can be derived from dune tracking data. In addition field measurements should be carried out to check the analysis.

Ranking: 2

Expected result

The results to be expected are correction factors to be applied on the results obtained via dune-tracking. These correction factors will be functions of the Rouse parameter, the dune dimensions, the velocity of the water and hence the roughness and possibly other factors.

Required input

Expatriate sediment transport expert 6 manmonths. Local morphologist 12 manmonths.

Need for additional field surveys

Detailed measurements of concentration vertical along dunes and measurements of the velocities at the top of dunes. Possibly also measurements with the ADCP to assess changes in the sediment concentration. As this is done for Topic 9.3 for this topic no additional measurements are needed.

9.5 Bathymetry and remote sensing

Description

Optimization of charting is an important item especially for the main river system in Bangladesh with its fast braiding channels. In general bathymetric measurements are executed to produce charts for various reasons, for instance navigation. The dry parts of the area to be mapped are to be covered by topographical measurements. Important points of study are:

- o How to combine bathymetric and topographic information
- o How to optimize topographical measurements
- o How to collect and combine water line information
- o How to combine and optimize this way of charting with remote sensing techniques
- o How to present these data (GIS?)

The first part of the study is to optimize a combination of rather traditional measuring techniques. In the second part specially the possibilities of the various remote sensing techniques should be reviewed. Observations of inundation limits at various flood stages provides height contours. Inundations limits can be observed by both optical and radar sensors, but the latter are more feasible because radar penetrates the clouds that are ubiquitous during the flood season. Bathymetry may be derived from radar images because very short waves on the water surface carry bathymetric information and produce variations in radar backscatter. Optical images may provide information on soil moisture from which the topography of the dry part may be inferred.

Approach and study tools

The first part of the study is an experimental one, trying to combine and optimize the more traditional techniques of bathymetric, topographic, and water line measurements and get it operational.

For the second part a detailed programme has to be worked out with others (e.g. FAP 19) based on the data (made) available. In this context the digitized optical data available with the consultant and the radar images to be collected via CEC need to be mentioned.

The bathymetry is determined through an iterative procedure which starts with an assumed bathymetry. Numerical models for water flow, wave generation and radar backscatter are used to compute the corresponding radar image. Comparison of this simulated image with the real image provides the required adjustment of the assumed bathymetry. The bed levels are corrected and the whole procedure is repeated until the differences between the simulated image and the real image are smaller than a prescribed accuracy level.



Expected results

A description of an optimum combination of traditional measuring techniques including data processing to produce river charts. Recommendation on the applicability of the various available remote sensing techniques and formulation of further steps to be taken. Recommendations on presentation techniques (GIS).

Ranking 1**Required input**

Expatriate field engineer 3 manmonths, database expert 2 manmonths, remote sensing specialist 2 manmonths and GIS specialist 1 manmonth. Corresponding local specialists 18 manmonths. This input is excluding modeller manmonths.

Need for additional field surveys

Although these cannot be specified at this moment, it may be expected that extensive bathymetric surveys will be needed to verify bed topography collected in an alternative way. Also other field measurements may be needed, for instance to calibrate the numerical models for water flow and waves.

9.6 Sustainable survey techniques**Description**

At present the survey techniques applied in Bangladesh by for instance BWDB and BIWTA are rather traditional. The techniques used by the River Survey Project FAP 24, on the contrary, are fairly advanced. The question comes up which techniques (or combination of techniques) are appropriate and sustainable in Bangladesh subsequent to the completion of FAP 24. Points of study are:

- o Analyses of present traditional techniques (so-called reference technique see Interim Report Annexure 1.5)
- o Possibilities of improvements (slight, low cost, short term changes)
- o Summarizing the results of the study topics 9.1 through 9.5 in draft guidelines
- o Sustainable techniques from technical point of view

A complete study on sustainable techniques should include

- o The economy of the techniques
- o The maintenance and repair situation including the availability of and access to spare parts
- o The timing of implementation
- o The training requirements

This, however, is not included in this study topic. Only the technical/operational

aspects will be considered.

Approach and study tools

This is a distinguished phased approach:

- o First field visits are made to observe ongoing surveys and analyse the measurements including the data processing
- o Based on own experience, short term improvements will be recommended
- o Later, after completion of topics 9.1 thru 9.5, the results of these studies will be summarized in the form of draft guidelines
- o By the end of the River Survey Project all field experiences gained by that time will be used to advise on sustainable techniques, in close cooperation with BWDB and BIWTA.

Expected results

The following results can be expected:

- o Recommendations for short term improvements of current survey techniques.
- o Draft guidelines on how to measure in dynamic alluvial rivers.
- o Recommendations on technical and operational aspects of sustainable survey techniques in Bangladesh.

Required input

Expatriate field engineer 2 manmonths, river morphologist 1 manmonth and hydraulic engineer 1 manmonth. Local field engineer 4 manmonths, morphologist 2 manmonths and hydraulic engineer 2 manmonths.

Need for additional field surveys

Probably no need for specific measurements: use will be made of experience obtained during the "routine" measurements of FAP 24.

10. FAP impact on river system

Topic 10.1 Formulation of scenarios

Description

The flood control schemes being prepared as part of the Flood Action Plan will interfere with the present river system and could change the characteristics of the system. Interventions will be embankments that reduce the flood plain, closing of offtakes (for example, the Daleshwari), increased water withdrawal from tributaries (for example the Teesta) which will affect the discharge and sediment transport capacity of the main river, withdrawal of more water from the main river (for example, Gorai, Arial Khan and Ganges-Kobadak intake) and river training works reducing the width of the flow channel.

In order to assess the reponse of the river system to the impact of these interventions, they have to be considered in combination with the autonomous changes taking place and other external events. Autonomous changes are a result of, for example, sea-level rise, general subsidence, tectonic uplift and subsidence and changes in precipitation in the catchment area. External events are deforestation and large-scale water withdrawal in the catchment area outside Bangladesh.

Approach and study tools

In order to assess the response of the river system to the FAP interventions an understanding of the autonomous developments is required. Various scenarios for the autonomous developments will be worked out to be combined with various development options resulting from the Flood Action Plan. For that purpose an inventory of possible interventions will be made during phase 1. Planning of some schemes will be in the initial stage, and for those projects the possible interventions will be indicative only while requiring updating during phase 2.

The inventory will be based on structured interviews with the different FAP components. The different autonomous development scenarios and the development options will be presented in a report. After having been approved by the FPCO this report will serve as the basis for the assessment of the response of the river system to the planned FAP schemes. During phase 2 some updating of the report might be required.

Ranking: 1

Expected result

An inventory of the possible scenarios of different autonomous developments and possible development options that will be the basis for the assessment of the response of the river system.

Required input

Expatriate river morphologist/river engineer 0.5 manmonths
Local Water resources engineer/River engineer 1 manmonth

Need for additional field surveys

None

Topic 10.2 Simulation of river response via analytical techniques**Description**

During Phase 1 a preliminary assessment is being carried on the impact of the possible implementation of the different FAP projects on the water-levels and bed levels in the main rivers in Bangladesh. This is essentially done using analytical techniques, using the readily available data on the main rivers and applying some relationships derived from the data in a fairly rough way. The results of the assessment relate only to the ultimate response of the river system. Once the available data on hydrology, sediment transport and channel dimensions have been validated and via Topic 3.1 also improved relationships become available, it is possible to arrive at better estimates for the ultimate impact.

Approach and study tools

The approach used is the approach as described in the 1st Interim Report, where the river characteristics are determined as dependent variables on the basis of a number of independent parameters. These independent parameters reflect the influence of the climate and the geology of the catchment, but are being reduced to the discharge hydrograph, the sediment load and the particle characteristics. As an additional independent variable the FAP projects will be introduced and the way in which they affect the independent variables and they fix the dependent variables.

Ranking: 1**Expected results**

Improved prediction of the ultimate impact caused by the implementation of the FAP projects on the bed levels and stages in the main rivers.

Required input

Expatriate morphologist/river engineer 2 manmonths

Local morphologist 4 manmonths

Need for additional survey activities

None.

Topic 10.3 Quantitative assessment of FAP impact with 1-d morphological model

Description

Topic 10.2 is dealing with the ultimate impact of the possible implementation of the various FAP projects on the main rivers in Bangladesh. This ultimate effect, however, may only be reached after a number of centuries. It may therefore be of relevance to study also the time-dependent adaptation towards the ultimate conditions. Whether or not this is important depends on the magnitude of the ultimate changes and on the rate of the changes (do they happen very quickly, then only the ultimate effects are relevant as long as the intermediate effects are not more serious).

Approach and study tools

Water-level variations cannot be predicted without taking into account the morphological changes, especially those related to the morphology of the riverbed. This could clearly be concluded from the first simulations made with the General Model (GM) of the Surface Water Modelling Centre (SWMC). Using a different model (RIVMOR) the Consultant predicted already long-term bed and water-level changes for different scenarios for the Jamuna river over a reach of 1000 km

During first part of the study it is proposed to make a preliminary assesment of the river response impact based on hydrodynamic simulations with the existing GM (without major model refinements) in combination with desk studies of the effect on sediment transport conditions and river regime. In view of the detailed experience of the local staff at the SWMC, the desire for coordination and the time constraints the hydrodynamic simulations can most conveniently be commissioned to the SWMC, whereas the desk study assessment will be conducted by the project's river morphologist.

In the second part of the study more detailed predictions of the morphological changes will be carried out with full dynamic morphological model simulations. Some of the model simulations may require model setup refinements, for which it is proposed to transfer the GM to the project, and do both model refinements and model simulations within the project.

It should be stressed here that the present 1-d morphological models cannot simulate the changes in overall characteristics of the main rivers. Changes in the braiding characteristics are not predicted: essentially the widht of the rivers cannot change in

these models. Such changes, however are included in Topic 10.2. Hence a careful analysis of the combined results of both 10.2 and 10.3 is required in the final interpretation.

Ranking: 1

Expected result

A simplified tool to assess the time-dependent response of the behaviour of the river system to the impact of different interventions as a possible result of the planned FAP flood control schemes, taking into account present autonomous developments. The predicted response will be an essential decision criterion for the implementation of the schemes.

Required input

Expatriate river morphologist 2 manmonths

Expatriate mathematical modelling expert 2 manmonths

Local morphologist.mathematical modeller 9 manmonths

Need for additional survey activities

None

Topic 10.4 Morphological model river system including changes in braiding and meandering characteristics

Description

The present project aims at improved understanding of the main river system in Bangladesh. In due time this improved understanding should also be implemented into models which predict the future behaviour of the river system as it is subjected to autonomous development and impact from water resources projects and river engineering works. This topic relates to the development and building of a 1-dimensional morphological model, in which also the changes in meandering and braiding characteristics are included via changes in the number and the width of the channels.

Approach and study tools

The approach taken would be to built upon the mathematical model developed under Topic 10.3 and to use the increased understanding also to be used under topic 10.2. The exact approach can not be defined at this moment, but it may be assumed that this is a major activity.

Ranking: 1

Expected results

One-dimensional morphological model in which also changes in number of channels

and width of the channels can be simulated.

Required input

Expatriate river morphologist 4 manmonths.

Expatriate mathematical modelling expert 20 manmonths.

Local morphologists/mathematical modelling experts 120 manmonths

Need for additional survey activities

Cannot be assessed at the moment

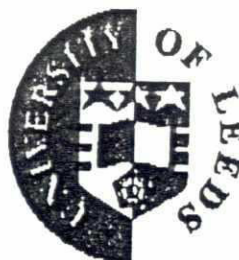
ANNEXURE 3**Possible contributions
by universities****Contents**

1. Correspondence with the University of South Carolina, U.S.A.
2. Correspondence with the University of Amsterdam, The Netherlands.
3. Correspondence with the University of Leeds.
4. Correspondence with the Technical University of Denmark.

4. Correspondence with the University of Leeds

on

Topic	6.1	Occurrence, dimensions and dynamics of bars
	6.2	Time-dependence of bars
	7.4	Roughness and bed-forms



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15th October 1993

Dear Pieter,

Please find attached our proposals for two study topics which are based around the discussions and correspondence we have had with you and Gerrit over the past 18/24 months. We have integrated these into the study topic plan of the proposal and have ensured that they are i) of interest and relevance within the highest ranked topics, ii) may be undertaken in conjunction with other topics as regards maximising field work time etc., and iii) add expertise and dimensions to the project that will, we feel, strengthen the proposal. We will apply (with, we think, a very good chance of success) for studentship grants for these two topics. Please note that your statement in 8.2 (4) is not correct with regards to the British system which requires our Ph.D students to complete within 3 years. If the projects get underway in 1994 then the timing of a three-year Ph.D studentship, ending in 1997, would be perfect for the planned dates you outline. Another critical item is that in order to submit proposals to get these studentships funded, we need to know if these topics will be undertaken in FAP24 as soon as possible. We must know by October 22nd in order to proceed with our studentship applications and therefore would appreciate a FAX before this date. We very much look forward to being able to work on these topics and have students collaborating between ourselves and Delft.

We hope you will realise the enthusiasm that we have for these projects and the considerable effort we have put into these in our past work, ongoing research and discussions with you over the past two years. Our talks in Delft at the initial stages of the consortium proposal seem a long time ago now, but it is good to know that the topics we outlined then, upon junctions, bedform tracking/sediment transport measurement and braid bar growth remain central topics of study. Additionally, we are pleased that our suggestion of using side-scan sonar has been adopted and looks likely to yield unique results. With the good links we have forged between us, we look forward to working with you in the near future,

Yours sincerely,

Drs. Jim Best and Phil Ashworth

Bedform Dynamics and Migration in Unsteady Flows & Zones of Appreciable Bed Scour

(Under study topics 7.1 - 7.4, 5.1 - 5.4, 8.3, 8.4)

Outline of Study Topic

Quantification of bedform dimensions and morphology lie at the centre of predictions of hydraulic resistance calculations, the transport of sediment and the influence of bedforms upon channel planform (e.g. local bank erosion). Lag effects and bedform morphological response to changing flow conditions during the monsoon season are therefore critical and will provide key data into sediment transport calculations and changing resistance criteria. Additionally, the formation, maintenance and infill of scours, especially at key sites such as channel junctions, are radically influenced by bedform migration. This may significantly influence the diversion of flow and sediment within the channel, therefore stimulating both bank erosion and channel change. This study topic will seek to investigate the dynamics of large-scale bedforms and their morphological response to both 1) changing flow stage and 2) migration into and around areas of substantial bed scour (especially channel junctions). Funding will be sought for a Ph.D student from UK sources, the data collection will be nested within survey work already being undertaken in FAP24 with travel, subsistence and associated costs being provided by FAP24.

Methodology

Repeated echo sounder and side scan sonar surveying at selected sites together with ADCP profiling will allow quantification of the morphology and movement of different large scale bedforms. Sites will be selected from those chosen within FAP24 to provide: i) a range of bedforms (including those with transition to upper stage plane beds at high discharges), ii) sites with superimposed bedforms iii) sites with different flow depths at different scours, iv) sites with different morphological (channel cross-section) characteristics.

Benefits to the Project

The topic will provide several key databases and analyses that form a core of several of the priority listed projects: 1) Analysis of changing flow resistance and bedform response under changing flow conditions. This will both link with topic 7 and with the complementary proposal of Professor Fredsøe concerning dune tracking, 2) Bedform migration and tracking will permit quantification of the principal sediment

transport pathways around and within scour sites. This will provide important information not only on the sediment dispersal at these scours but also on the likely infill of these sites, and therefore the effect upon larger scale channel change, and, 3) Quantification of bedform hierarchies within channel and scour sites and an assessment of their generation, migration and attenuation (and concomitant influence on resistance, sediment transport and aggradation/erosion).

Leeds University Expertise

Extensive ongoing research by the Leeds team is detailing the turbulence field over sand grade bedforms, the initiation of sediment movement, the nature of large bedforms in modern and ancient sediments and the fluid dynamic processes of bedform stability (Bridge and Best 1988, Best and Bridge 1992, Best 1992, Bennett and Best in review). Experimental work on fluid and grain dynamics over bedforms is unique. Additionally, past work on the dynamics of channel confluences (e.g. Best 1986, 1987, 1988, Best and Reid 1984, 1987, Best and Roy 1991, Reid et al. 1989) and the nature of large bedforms within modern and ancient braided rivers (Bristow *et al.* 1993) provides unique expertise to the project. Reconstructions of bedform dynamics from large ancient braided rivers and appreciation of the aggradational and sedimentological characteristics of these bedforms adds a dimension not present within a purely 'engineering' approach.

Mid-channel bar growth and the rate and incidence of bank erosion

(Under study topics 3.3, 3.9, 4.3, 5.2, 6.1, 6.2)

Outline of study topic

Initiation and growth of mid-channel bars (chars) leads to a marked change in the local sediment transport path and rate and incidence of adjacent bank, bar and bed erosion (Ashworth *et al.* 1992, Ashworth (in press), Powell and Ashworth (in review)). Thorne *et al.* (1993) have shown that the formation of large island complexes on the Jamuna downstream of major nodes of flow convergence may be responsible for rapid rates of local bank erosion (up to 90 m/yr). The degree to which flow is deflected around aggrading mid-channel bars depends on the ratio of bar height to local water depth and the gross bar morphology. Independent laboratory work by the consultants has shown that when this ratio exceeds 0.55, bedload is routed around the bars and the flow over the bars abruptly switches from convergent accelerating flow to decelerating diverging flow. Growth of bars beyond 55% of the water depth may therefore lead to high rates of bank erosion and channel bed scouring. If the falling stages of the previous monsoon season lead to new char development or repeated echo soundings during high stages reveals rapid local bar aggradation it may be appropriate to initiate an immediate programme of channel dredging to prevent severe bank erosion.

Methodology

More information is needed to quantify the link between channel scour at nodes of flow convergence, bar growth and subsequent bank erosion. This may be achieved through two approaches: field survey and laboratory flume work. Echo soundings and side scan sonar surveys in channels adjacent to known areas of rapid bank retreat will quantify the relationship between bar height, shape and the rate and incidence of bank erosion. Ideally these need to be linked to simultaneous measurement of 2-D velocities with ADCP to enable quantification of the Reynolds Stress field. Paired measurements of bed topography and flow strength and direction need to be repeated at selected periods on the rising and falling limbs of the flood hydrograph. Comparison between successive LANDSAT images of the Jamuna taken at low flow (showing bars) and immediately after the monsoon floods (to measure the location and rate of bank erosion) will highlight the role of bar size and shape on channel change and bank erosion.

These field surveys will be supported by a series of laboratory flume runs in a large tiltable stream table recently built at the University of Leeds through a separate consultancy project. Background to the flume equipment, scale modelling procedures and the present experiments for the hydrocarbon industry are detailed in Ashworth *et al.* (in press), Leddy *et al.* (in press) and several internal reports (for example, Ashworth and Best (1991, 1992)). Presently there are three Ph. D students working in the flume on topics such as the influence of tectonic tilt on fluvial architecture, the 3-D flow structure at confluence and diffluences and the self-similarity/scaling relationships in braided rivers. The flume is almost fully automated with computer controlled water and sediment discharge (programmable to simulate flood hydrographs) and excellent camera and video facilities. A research programme will be initiated that will provide quantitative relationships between bar growth and bank erosion. Because of the scale of the Jamuna/Brahmaputra fluvial system, experiments will need to be generic. Image analysis of time-lapse videos of channel change in the flume will examine to what extent local bar growth is responsible for bank retreat. Particle tracking and flow visualisation will permit quantification of the flow structure and bedload transport paths. Experiments may allow investigation of the influence of bar removal (through channel dredging) on bank erosion rates.

Logistics and General Information

These two study topics will be the responsibility of two three year Ph. D students working in parallel with Ashworth and Best. The supervisors are submitting proposals for Ph. D funding to the NERC (the U.K. Government Research Studentship Scheme) in November 1993. The outcome of these proposals will be known in March 1994 and the studentships will begin on 1 July 1994. If the projects are not funded by NERC (Ashworth and Best have successfully received funding for the past four years) there is a strong possibility of funding through departmental studentships. Each studentship will cover all fees and U.K. maintenance costs. However, FAP24 will need to provide funding for airfares to, and subsistence and local travel in, Bangladesh. There will also need to be a contribution to flume costs and the consultant's time. We envisage the projects beginning on 1 July 1994 and involving at least two monsoon (and possibly one dry) field seasons. This timing will suit the FAP24 schedule. All Ph. D students are closely monitored in Leeds with a high proportion of students completing their thesis in three years and 100% by four years. The Ph. D students will receive a thorough training in quantitative methods and will be expected to attend in-house staff development courses on presentation skills and report writing.

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1. Correspondence with the University of South Carolina, U.S.A.

on

Topic 2.5 Floodplain sedimentation and subsidence.



THE UNIVERSITY OF SOUTH CAROLINA

Department of Geological Sciences

Columbia, SC 29208

April 14, 1993

FAX: 88-02-883568

To: Dr. Dilip Barua, River Survey Project, Dhaka, Bangladesh
From: Dr. Steven A. Kuehl, University of South Carolina
Subj: FAP 24

Dear Dilip:

It was good to hear from you and to hear that you and your family are doing well. Concerning your paper, I would still like to publish it in the special volume of Marine Geology I am editing. If I get the revised version from you in June this should be no problem. By that time I should have the final results of the remotely sensed data and will incorporate this into the paper as we discussed.

Concerning the FAP 24 project, I very much appreciate the invitation to perform studies of sedimentation and subsidence rates for the Bengal Delta plain. As you well know, knowledge of these rates holds the promise of vastly improving our understanding of the overall sediment budget of the GMB-river system, and has critical implications concerning the planning of any flood plain management projects. We can learn much from the mistakes and poor planning made in the development of the Mississippi/Atchafalaya flood plain; there should be no reason to repeat the same in Bangladesh.

I would envision such a study to be divided into two logical components based to time scale. The first would be an investigation of 100-y scale sedimentation and subsidence rates. This would involve collection of vibrocores from various locations on the flood plain and employing a variety of dating techniques to estimate sedimentation rates. These would likely include analysis of Pb-210 (a natural radioisotope with a 22.3 y half-life) and Cs-137 (a bomb isotope input since 1954). The second time-scale of interest would cover the period of 100-18,000 years (Holocene). Deeper samples from borings would be needed to penetrate the Holocene flood plain to the Pleistocene surface. Dating of organic material would be accomplished using C-14. In addition, the entire thickness of the Holocene flood plain deposits could be measured through the

combined use of borings and high-resolution seismic reflection studies. Regional variations in this thickness would be directly related to long term regional variations in subsidence rates.

Other related studies could be proposed. One would be a direct measurement of subsidence using high-precision GPS data from a network of receivers strategically deployed on the delta plain. A complete understanding of the nature of subsidence will require detailed stratigraphic studies of key sections of the delta plain. The scope of these efforts would obviously depend on funding availability.

The above represents a few ideas but will need to be woven into a coherent package consistent with the goals and resources of your project. Dilip, as you well know, funding from NSF is often very difficult and time consuming. I feel certain that a large project from this source would be nearly impossible in the time frame of FAP 24. If the project leaders feel that such studies as outlined above are desirable and can commit resources to obtain the necessary equipment needed in Bangladesh, it would be easier to find the funding from this end to participate in the project and perform the necessary laboratory and data analysis, etc.

Please let me know what resources if any, could be obtained from the project to perform such studies as this will determine my ability to participate.

Sincerely,



Steven A. Kuehl
Associate Professor
Geological Sciences/
Marine Science Program



THE UNIVERSITY OF SOUTH CAROLINA

Department of Geological Sciences

Columbia, SC 29208

July 6, 1993

FAX: 88-02-883568
To: Dr. Dilip K. Barua
From: Dr. Steven A. Kuehl

Dear Dilip,

I have talked with Dr. Mead Allison (now at WHOI) concerning the FAP 24 project and he too is very interested in the possibility of participating in the flood plain project under discussion. Mead would like to submit a joint NSF proposal with me to perform a detailed evaluation of subsidence and sedimentation rates for the Bengal delta plain. The main components of such a study would include collecting cores and borings, dating of samples, seismic reflection profiling, and stratigraphic analysis. Mead and I have discussed at length the approach we would like to take, but, of course, much of our planning will depend on your project. As such would you please respond to the questions below.

- 1) In order to understand the Holocene (recent) history of the flood plain, borings of at least 25 m in length are necessary. Since the Holocene deposits are as much as 100 m, 25-m borings will provide us with a significant fraction of the Holocene; obviously deeper cores would be better. Do you have access to any portable drilling rigs that could be used to collect such samples?
- 2) Most of the FAP 24 project emphasis is on the upper delta plain above Dhaka. Questions concerning subsidence of the lower delta plain (Dhaka to the coast) are a critical part of the sediment budget. In addition the coastal areas have a much better balance assured between subsidence and sedimentation making the tie from accumulation rate calculations to subsidence much easier. Also, the lower delta plain contains more peat deposits which are suitable for C-14 dating and establishing a reliable chronology. Thus we feel that the lower delta plain should be considered to answer the important science questions. My question for you concerns the support from FAP 24 we could expect to carry out work in the lower delta plain. Will boats, trucks, labor and other logistical support be made available to us for study between Dhaka and the coast?

3) We have identified some candidate areas to perform detailed coring etc. in the upper delta plain. These are the "BEELS", or floodbasins described by Coleman. Are these accessible by truck or other means for the collection of cores and seismic data?

4) In a previous FAX I sent you details of a seismic system that would be suitable for our work. Is any such system available to us through the FAP 24 project?

Please respond as soon as possible as the lead time for our proposal is short if we are to overlap significantly with the FAP 24 project. You know well the time frame for funding NSF projects and we are anxious to begin. However, it is important to first detail the scope of our project and to get a firm idea of what is possible within the constraints of your resources. Mead and I both believe this is an exciting opportunity to perform some interesting basic research as well as to assist with providing an understanding of the Bengal delta plain as it relates to any river development project being considered. Please FAX your reply to 803-777-6610.

Sincerely,



Steven A. Kuehl
Associate Professor



Telefax No. 001 803-777-6610

July 7, 1993

Page(s) 1

To : Department of Geological Sciences, University of South Carolina, USA

Attn : Dr. Steven A. Kuehl

From : Dr. Dilip K. Barua, River Survey Project FAP 24, Dhaka, Bangladesh

Subject : Contribution to FAP 24 study topics

Reference : RSP/3.6/468

Dear Steve,

Thank you for your faxes. I am sorry that I could not manage to respond to you early. Fred is here at the moment as an acting team leader. I discussed with him about your involvement.

In order to get core samples, drilling rigs can be hired in Bangladesh. I discussed with one Firm here, the drilling and sampling cost for a single 50 m boring is about Tk. 15,000. (~ USD 400.). Wash boring techniques will be applied for the purpose.

Although I do not have a definite idea about the floodbasins, I guess that most are dry during the dry-season when the expedition has to be carried out. Therefore, transport to those places may not be a problem.

I think we have to give up the idea of directly measuring the subsidence by GPS. Longterm involvement required for the purpose will be difficult to handle by the project.

I am afraid that the costs of procuring the seismic profiler could not be arranged from the project fund. However, as I wrote you in earlier faxes, local logistical support such as guest house accomodation, transport, labour etc. can be arranged from the project. This is also valid for places south of Dhaka.

The study topics and the nature of support will be finalised in a workshop in Dhaka in October 1993. However, we are confident that this topic will be taken up. So, in the meantime, you can start writing the proposal for NSF with Dr. Allison if both of you think that the local support is sufficient.

I am sorry that the paper is not finalised yet. I am glad that Dr. Miller finished MSS data processing. Please give me two more weeks, I will send the paper by express mail to you.

Steve please see if I have some mail in the department. Specially, I am expecting the reviewed manuscript from the CERF journal. I would appreciate if you please mail it to me.

Sincerely,

Dilip K. Barua

cc:

Fred G. Koch, acting team leader, FAP 24, Dhaka.



2. Correspondence with the University of Amsterdam, The Netherlands

on

Topic 3.6 Effects of tectonics on planform characteristics.

14th May, 1993

Attention : Dr. G.J.Klaassen
From : Jan Rupke, Harry Seijmonsbergen, Amsterdam
Fax : (00)31-21-5257431
Ref : Your fax 10th May

Dear Gerrit,

Upon receiving your questions we discussed options between ourselves and with Erik. Considering your idea's and texts; keeping in mind the data and recommendations in our earlier report of february '93 we advise as follows:

- o The causal factors lie in active subsurface movements of the basin, knowing tectonic compartments and study of subsidence/sedimentation are directly related. It would be unwise to describe these as separate studies; hence combine topics 4.6 and 2.4.
- o As regards topic 4.8: clays in general allow cohesive reactions of bank material. This however is a matter of knowing old river patterns (high/low energy deposits) and belongs in a detailed pattern analysis, we regard in as belonging in a later phase of study. First a governing pattern and reconstruction must be known, then borehole data fitted into this instead of haphazard local analysis.
- o As may be seen from recommendations (earlier report, p. 25, 26) our approach is also a question of scale and possible detail, further the material data, geophysics and the fitting in of existing and new levelling data are necessary. Advice "Zooming" into the problems as approach means".

Preliminary study, extending the satellite study : define key areas where best chances of further research are located; filter available data in river history vis-a-vis map and satellite records; important is to avail (permitted) airphoto's (stereo black & white) of located key areas. Build up good contact with local engineer/geological departments, discuss in the office but also visit field spots.

Main Study, give follow up on first located field data. Direct interactive photo/field studies in more active zones after integration of local and our knowledge, carry out borings (shallow) at specific sites selected on the basis of 'compartment' theory applied and interpreted in the R.S images and followed up in the field. Avail of geophysical recordings in neighbourhood of proposed construction sites. Spread this integrated (pattern analysis, material analysis and lab analysis) over all the necessary sectors of the river course.

Basic is : to plan in steps:

- a) general scale study, only satellite/map data (done already in part)
- b) give follow up in airphoto scale/literature survey

- c) describe priority area's, first material analysis
- d) enlarge scale in two area's, test present theory of compartments controlling/linking river behaviour to tectonic movements
- e) identify data collection, enlarge scale studies of airphoto's integrated with field views
- f) selected geophysical profiling; test hole drilling up to 100 meters
- g) carry out phases b) onward in good cooperation with counterpart specialists having entry in the various local departments. Get access to classified airphoto material.

Resume'

See two phase: 1) in the available funds (Dfl 25,000 + costs) of FAP 24 : activities of check on data brought out by satellite study and define future key area's, problems, availability of airphoto's, first perusal of A.P's making contacts, further delimiting "compartment patterns". This can be done in winter '93/'94 and should be possible within a few weeks visit if well prepared locally in the necessary departments.

2) Phase two is essentially described in the pp 25/26 of the earlier report, the finances for that can be derived as such and are to be met from other funds. We give a short description of such a first phase activity in the accompanying annexure.

As regards activity by us in other river systems, tectonic active zones in Bangladesh:

- we are definitely interested
- is it not better to first develop a going corporation in Jamuna area with all concerned? When such develops, little doubt, other pieces of research will come up and soak us possibly up.

Hope that this and the annexure are of use to you.

Jan Rupke.

Harry Seijmonsbergen.

5. Recommendations

5.1. Future follow-up studies.

In the light of the indicated neotectonic activity of fault lineaments influencing the sedimentation/erosion and migration of the river it is recommended:

A. on a medium level:

- carry out detailed literature and map investigation for ascertaining pattern evolution, earthquake activity, assembling drilling data to avail of Tertiary-Holocene development of sediment records, and correlation with geological - geophysical interpretation.
- carry out detailed airphoto interpretation of particular areas delimited in the present report and work with a legend designed by geomorphologists trained in these areas. This should be done in close co-operation with local earth-scientists/engineers.
- carry out an extensive series of field checks during low discharge periods to follow up on interpreted lineaments with field checks regarding signs of recent activity like sediment layer tilting, lines of infiltration/ponding, sudden changes in recent sediment record as given in the borehole; this should be done in preselected sample areas.
- to bring in the above results into an integrated representation of the worked critical sample areas.
- to relate the evolving understanding continuously in the existing small scale data (Landsat, Spot) and use them to give further direction to follow up investigations.

All the above work is of a medium scale of investigation and rather cheap. It should serve to delineate further critical areas and be followed by geophysical/geo-electrical profiling, and restricted drilling of shallow nature to prove locally displaced sections.

In all the above operations a continuous exchange between engineers/geomorphologists is emphasized.

Our final aim:

1. Define and delineate active zones preferably at design level,
2. Indicate earlier trends in river/subsurface relation,
3. Extrapolate these trends in order to equip the design/river control workers with a well based understanding of the above complex of processes.

5.2. Estimation of costs of follow up studies.

A. Follow up at medium level:

- | | | | |
|--|----------------------------------|-------|----------------|
| - literature study at Dacca Geological Survey | at Dacca Surveyor General Office | | |
| | at Amsterdam | total | 25 man-days |
| - Airphoto interpretation of selected areas at Dacca | | | 30/60 man-days |
| | at Amsterdam/Enschede | | |
| | depending on size and scale: | | 30/60 man days |
| - Field checks on selected test areas, depending on size, | | | 80 man days |
| - Integration of all data: | at Dacca: | | 40 man-days |
| | at Amsterdam/Enschede | | 20 man-days |
| - reporting-presentation | | | 60 man-days |
| - travel, field allowance etc.: 8 return tickets | | | |
| 100-200 days local allowance | | | |
| - various costs, laboratory, drawing office, insurance in field. | | | 10% |
| - overhead | | | 5% |

The investigation would be carried out by a team of two persons: a senior and a junior geomorphologist. Support by I.T.C. Enschede to the University of Amsterdam is assured for technical facilities.

B. Large scale follow-up at a more direct project design level can only accurately be described on the basis of the results produced by the former stage of work. Roughly speaking it would include:

- intensify data collection, both in APL and

- intensify data collection, both in API and geomorphological checks of preferred areas.
- drill test holes
- run geophysical profiles
- bring engineering design expertise in contact with the geomorphological data and results in the field and or in the direct vicinity of projected constructions

The total project phase A should be stretched over 2, max. 3 winter seasons.
The availability of all elements is as follows:

The availability of all clearances to archives, topographic maps, support in local travel/lodging and the availability of aerial photographs is a necessity.

3. Correspondence with the Technical University of Denmark

on

Topic 9.4 Bed load transport via dune-tracking.



Translation of a contribution by Prof. Dr. J. Fredsoe

9.4 Bed load transport via dune tracking

Dune migration is caused by sedimentation of sand on the steep front of the dunes. Usually this is related to deposition of bed load q_b^1 .



However some of the suspended sediment might also be able to settle in the separation roller and hereby contributing to a higher migration velocity of the sand waves.

The present contribution will be to estimate how much of the suspended sediment which will contribute to the dune migration velocity using a theoretical flow description (presumably a $k - \epsilon$ model). The sediment description will be based on the diffusion concept.

The output will be design diagrams, which gives how large a fraction α^2 of the suspended sediment which will be trapped on the dune front.

The parameter α^3 depends on several parameters like fall velocity of suspended sediment w_s , the total shear velocity U^4 , the skin shear velocity U^5 , the geometry of the dune (height, length) and the flow depth. The variation in α with dimensionless quantities of the above mentioned parameters will be studied.

From the design diagrams it will be possible to evaluate the trapped amount of suspended sediment. The total amount of suspended sediment is obtained either from measurements or from theory.

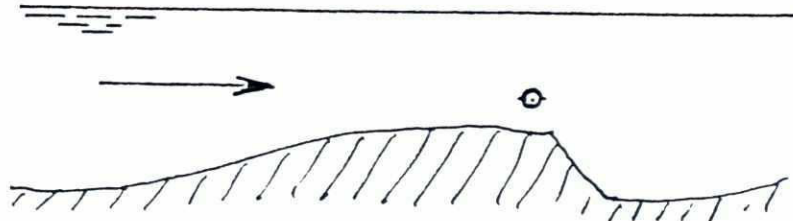
Hereby the bed load transport can be obtained from dune tracking.

Time schedule:

The present study is quite comprehensive and can only be done with a very limited budget because it is coordinated with a Ph.D.- study under supervision of Professor Fredsoe. This means that the model is not fully developed yet so the final results are not to be expected before 1994.

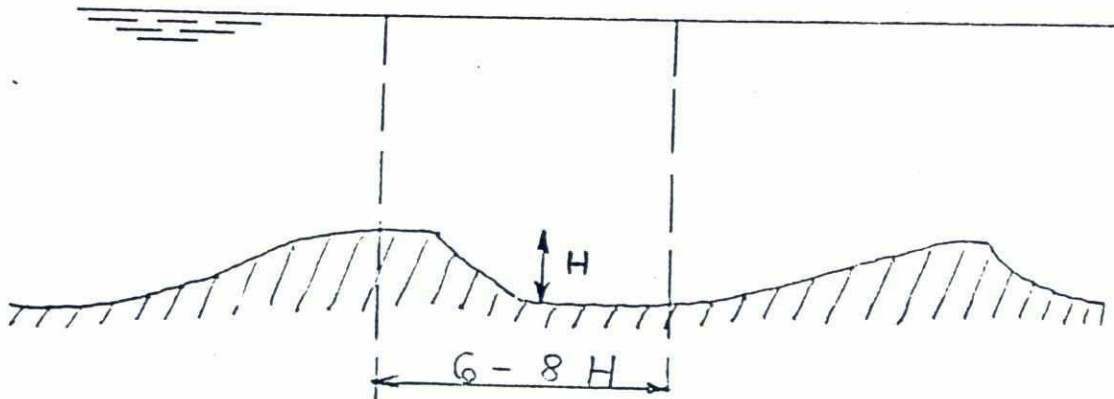
Suggestions for measurements in relation to bed load estimate from dune tracking

1. The most important input parameter will be a current velocity measurement over the crest of the dune.



This measurement will provide information on the near-crest bottom shear stress, assuming a logarithmic velocity profile. In order not to introduce too much uncertainty in this measurement, it is suggested that it is taken a certain distance 1-1½ m above the crest. The exact location of the current meter above the local bed must be known, but the location can be chosen freely.

2. Of second priority, measurements of concentration of suspended sediment along the dune would be of help for the calibration of the model.



Especially knowledge on the rate of suspended load in two verticals would be useful: I located just before the steep backward facing front and II located further downstream about 6-8 times the dune height (so it is not located in the separation bubble downstream the crest - but further downstream).

