Government of the People's Republic of Bangladesh
Bangladesh Water Development Board

River Training Studies of the Brahmaputra River

Master Plan Report

1994

Main Report

Sir William Halcrow & Partners Ltd.
in association with

Danish Hydraulic Institute
Engineering & Planning Consultants Ltd.
Design Innovations Group

HALCROW

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SUMMARY

Based on the findings of the detailed studies of the three year Brahmaputra River Training Studies programme, as recorded in the Final Report (1994) and the further considerations presented herein, the Master Plan Report sets out proposals for:

a) measures for improved performance of the BRE

b) river training schemes suitable for the permanent protection of the BRE

c) a schedule for implementation of the river training schemes.

The Final Report has explained how the various elements of the Study have been carried out, including the river surveys, the hydrological studies, river hydraulics studies, mathematical and physical modelling, geotechnical investigations and the study of river morphology, and how they have contributed to the solutions proposed.

The Master Plan Report gives consideration to the sociological and environmental aspects of implementation, and to the economic viability of the scheme proposed. Proposals are given for the implementation of river training measures on a priority basis in the short term, and in the longer term leading to the permanent protection of the BRE. Containment of the Brahmaputra between the Teesta and Hurasagar rivers - the Study Reach - is addressed.

The report includes the detailed design of the Phase 1 river training works, together with descriptions of how they can be constructed, operated, and maintained. Tender Documents and Drawings for the Phase 1 works are presented.

Implementation will commence with the construction of the Priority Works at Sariakandi, Mathurapara and Sirajganj under the River Bank Protection Project, financed by the International Development Association (World Bank). These works comprise a continuous revetment at Sirajganj incorporating Ranigram Groyne, the construction of revetment type "hard-point" structures at Sariakandi and Mathurapara, and the reconstruction of Kalitola Groyne. They are referred to as the Phase 1A works in this report. Phase 1B comprises the construction of further hard-points upstream of Sirajganj and Sariakandi to secure those reaches of the river. Phase 1C consists of the construction of hard-points at the remaining priority locations of Fulcharighat, Kazipur and Betil. The remaining hard-points necessary to stabilize the right bank of the Brahmaputra from the Teesta to the Hurasagar River would be constructed under the second phase of implementation.

In all, 27 hard-points are proposed for the stabilization of the right bank, to be implemented over a 30 year programme. The financial costs of such an undertaking is estimated, at 1992 prices, to be in the range of Tk 17,300 million (US $ 435 million) to Tk 19,300 million (US $ 487 million). The corresponding economic costs would be in the range of Tk 13,900 million to Tk 15,600 million. Operation and Maintenance costs would rise as more structures were completed, from around Tk 33 million per annum at the start of the period to an average of Tk 315 million per annum at the end.

During implementation of the river training works proposed in the Master Plan, it will still be necessary to retire the BRE in places where the river training works have not, at that time, been constructed. There will, however, be an increasing benefit as the length of the BRE requiring retirement each year gradually reduces.

From the incremental new benefit stream for the Master Plan, derived from consideration of costs and benefits over a fifty year period, an EIRR of 6.8% was calculated, or 2.5% for the higher values in the range of costs given above. While these values are below conventional economic viability thresholds, such thresholds are not wholly appropriate for this major long term capital investment programme in public infrastructure, which will generate considerable benefits not only for the present inhabitants but also for future generations. The eventual cessation of erosion of the right bank of the river, and the relief from the continuing disruption, dispossession and human suffering, cannot be measured entirely in economic terms.

The Main Report is accompanied by separate Annexes dealing in detail with sociological considerations, economic assessment, environmental issues, design and construction, operation and maintenance, and tender documents for the Phase 1B and 1C works.

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05 April 1995   Our ref API/BRT/CONF   Your ref

Dear Mr Hoque

BRAHMAPUTRA RIVER TRAINING STUDY (BRTS)
RIVER BANK PROTECTION PROJECT
Master Plan Report

We have pleasure in submitting our Master Plan Report as required by Clause 5.7 of the Revised Terms of Reference. The FAP Technical Committee approved the report on 9 August 1994.

The report incorporates the modifications to the Master Plan Report (MPR), which was submitted on 28 June 1993, requested by the Technical Committee.

The report is in the form of a Main Report supported by six separately bound volumes of technical annexes.

We acknowledge the assistance of BWDB during the course of the study and the important co-ordination role provided by FPCO.

Yours sincerely

V R Baghirathan
Regional Director

cc: Mr Md Shahidullah Mia, Additional Chief Engineer, Design 2, BWDB
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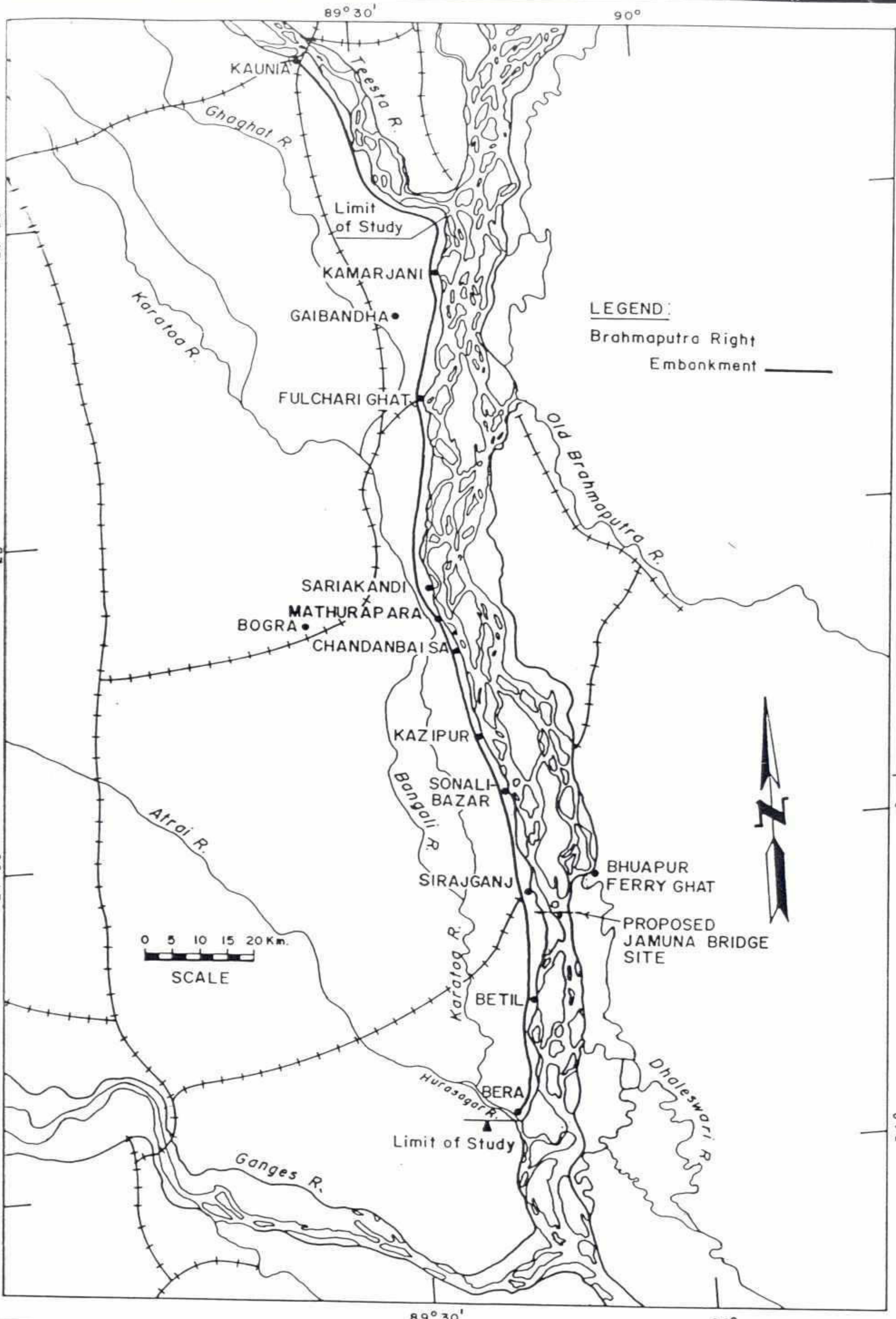

Brahmaputra River Study Area

Halcrow/DHI/EPC/DIG *May 1993*

FOREWORD

The BRTS Master Plan Report was issued on 28 June 1993. Comments from BWDB and FPCO were received from July 1993 onwards, and responses to those comments were issued in a single volume on 7 March 1994. The report was approved at the 20th FAP Technical Committee Meeting on 9 August 1994 subject to certain amendments. The amendments have duly been incorporated and the report was reissued in its present form in December 1994.

ACKNOWLEDGEMENT

Particular thanks are due to the large number of BWDB staff who have contributed to the success of this study. Without their active cooperation the task could not have been accomplished. Thanks are similarly due to staff of FPCO and the World Bank, and to the Team Leaders and staff of the other FAP studies.

RIVER TRAINING STUDIES OF THE BRAHMAPUTRA RIVER

MASTER PLAN REPORT

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GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH
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ABBREVIATIONS

ADB	-	Asian Development Bank
BIWTA	-	Bangladesh Inland Water Transport Authority
BRE	-	Brahmaputra Right Embankment
BRTS	-	Brahmaputra River Training Study
BWDB	-	Bangladesh Water Development Board
DHI	-	Danish Hydraulic Institute
EDF	-	European Development Fund
EIA	-	Environmental Impact Assessment
EIRR	-	Economic Internal Rate of Return
EMP	-	Environmental Management Plan
FAP	-	Flood Action Plan
FCD	-	Flood Control and Drainage
FCDI	-	Flood Control, Drainage and Irrigation
FIDIC	-	Federation International des Ingenieurs-Conseils
FPCO	-	Flood Plan Coordination Organisation
FW	-	Future With (Project)
FWO	-	Future Without (Project)
GOB	-	Government of Bangladesh
HYV	-	High Yielding Variety
ICB	-	International Competitive Bidding
IDA	-	International Development Association (World Bank)
IEE	-	Initial Environmental Evaluation
JMB	-	Jamuna Multipurpose Bridge
JMBA	-	Jamuna Multipurpose Bridge Authority
KfW	-	Kreditanstalt fur Wiederaufbau (Germany)
LCB	-	Local Competitive Bidding
LGEB	-	Local Government Engineering Bureau
LWL	-	Low Water Level
NGO	-	Non-Government Organisation
NPV	-	Net Present Value
O & M	-	Operation and Maintenance
ODA	-	Overseas Development Administration (United Kingdom)
PIANC	-	Permanent International Association of Navigation Congresses
RE	-	Resident Engineer
RRI	-	River Research Institute
SB	-	Set-back Distance
TOR	-	Terms of Reference
TR	-	Trigger Distance

1. INTRODUCTION

1.1 Background

The security of the Brahmaputra Right Embankment (BRE) and consequently the area protected by the BRE has been seriously threatened by continued bank erosion. Since the economic and social consequences of the present approach in dealing with the problem may not be acceptable in the long-term, the Government of Bangladesh (GOB) has commissioned the River Training Studies of the Brahmaputra River (BRTS) to seek a long-term strategy for the protection of the BRE. The project, funded under the IDA sponsored Bangladesh Second Small Scale Flood Control, Drainage and Irrigation Project (Credit No. 1870 BD), is being executed by the Bangladesh Water Development Board (BWDB).

BWDB appointed Sir William Halcrow & Partners Ltd. (Halcrow) in association with Danish Hydraulic Institute (DHI), Engineering and Planning Consultants Ltd. (EPC) and Design Innovations Group (DIG) to undertake this three-year study.

An advisory group from the Bangladesh University of Engineering and Technology (BUET) has been working with the Consultant's Team. The River Research Institute (RRI) were nominated to carry out the physical modelling studies required by the BRTS.

A Letter of Intent was issued by the BWDB on 24th January 1990 to commence the project. The contract for consultancy services was signed between BWDB and Halcrow on 12th March 1990. The Consultant commenced the project on 6th February 1990 by making arrangements to mobilize staff and establish an office and support facilities. Staff inputs commenced on 1st March 1990.

In November 1989, a five year Flood Action Plan (FAP), coordinated by the World Bank, was initiated with the Government of Bangladesh. The FAP is connected with an initial phase of studies directed towards the development of a comprehensive system of long-term flood control and drainage works. Priority has been given to the alleviation of flooding from major rivers, of which the Brahmaputra is a significant source. The BRTS forms component No 1 of a total of 26 components comprising the FAP during the plan period 1990-1995.

Prior to commencement of the consultancy services, the Consultant was instructed by the BWDB to review and revise its work programme and staffing schedule during the inception phase to integrate the project within the FAP.

In accordance with the Terms of Reference, the Inception Report was submitted three months after the commencement of staff inputs, at the beginning of June 1991.

The report included a comprehensive review of the original programme of work in the light of the Flood Action Plan, the delay in project commencement and a greater appreciation gained during the inception phase. This was accepted by the World Bank, BWDB and other related organizations of GOB at a meeting held on 28th July 1990.

A revised staffing schedule was agreed with BWDB at a meeting with Chief Engineer Planning and others on 13th August 1990. The Revised Terms of Reference (TOR) were approved by

FPCO on 6th October; the First Amendment to the consultancy contract was finalised on 29th October.

1.2 The Project

The Brahmaputra-Jamuna river system is the largest and most important in Bangladesh, accounting for more than 50 percent of the total inflow into the country from all cross border rivers. Its dry season planform (March 1992) is shown in Plate 1.

The Brahmaputra moved to its present course about 200 years ago. It is a braided river without fixed banks and with frequently shifting channels. Short-term channel migration can be quite drastic with annual rates of movement as high as 800 m. The bank erosion process is a complex mechanism and is influenced by a number of factors. Within the study reach the overall river width varies between 6 km and 14 km. The river cross-section has a highly irregular bed elevation and, within the study reach, the main channel may be up to 35 m deep although the mean value is only 7 to 8 m.

A 220 km long earth embankment, known as the Brahmaputra Right Embankment (BRE), has been constructed on the western bank of the Jamuna River to protect the lands against the ravages of yearly flood. However, every year this embankment has to be retired landward at several places due to bank erosion; a total length of about 140 km of retired embankment has been constructed over the past 20 years.

River erosion is also causing serious problems at specific locations such as ferry crossings, where the terminal stations (ghats) have to be shifted as a result of eroding river banks.

The principal objective of the Study is to formulate a master plan for the long-term protection of the Brahmaputra Right Embankment (BRE) but also included in the assignment is the design of short-term measures at critical sections along the right bank for early implementation.

The Master Plan is required to address possible alternative measures to river training works - such as embankment retirement or combinations of both types of measures - for ensuring the BRE's satisfactory performance. The selection of the recommended alternatives are to be based on technical and economic analyses, and social and environmental considerations.

1.3 Other BRTS Reports and Technical Notes

Following publication of the Inception Report in June 1990, a Technical Note entitled "Working Paper on 2-D Modelling" was prepared and issued in December 1990. This set out in greater detail the way in which 2-D modelling was to be utilised and gave full details of the modelling system and how it was being set up and calibrated using the river survey data collected for this purpose. The paper also included full details of the associated 1-D modelling system.

A Discussion Paper entitled "Selection of Locations for Priority Works" was issued in December 1990. This provided the background to the problems of bank erosion as perceived at that time and set down the initial screening criteria that were being used to select locations along the river bank for priority attention.

The BRTS First Interim Report (April 1991) presented the findings from the first river survey campaign, carried out during the 1990 monsoon season and the following low flow period, and described the first insights into the behaviour of the river derived from this. The proposed scope and form of the master plan was set out and subsequently ratified by the BWDB, FPCO and World Bank.

Draft detailed designs for priority bank stabilisation works at six locations were prepared together with draft tender documents suitable for international competitive bidding and submitted for discussion and comment in October 1991.

The Second Interim report, issued at the end of the 22nd month of the 36 month study duration (December 1991), marked the substantial completion of all field work although some further near-bank river surveys were carried out during the early months of 1992. By this time the mathematical modelling components were approaching completion and the physical modelling was well advanced; the interim results from both these components were presented in Annexes to the report. Together with the outcome of the morphological studies, these results led to a very much better understanding of the river's characteristics and probable future behaviour. With the combination of this and an improved appreciation of the sociological problems and the agro-economic impacts of breaches in the BRE, it was possible to carry out a more detailed economic assessment of the six priority locations identified earlier. The results of this analysis were presented in Annex 6 to the report and formed the basis for the subsequent preparation of the World Bank financed River Bank Protection Project.

In accordance with the TOR requirement, the formal completion report on the river surveys formed Annex 1 to the Second Interim Report. User Guides for the 1-D modelling, 2-D modelling and the River Survey Databases were compiled and formed the basis for training of BWDB and SWMC staff and a formal handover took place in April 1992, marking the actual completion of these components.

A revised Design and Construction Management Report was prepared and issued in August 1992. This comprised a complete update of the design procedures and criteria in the light of the improved understanding of the river conditions and the results of the physical modelling and also described in detail the construction methodology and scheduling on which the design of the Phase 1A (the Sirajganj and Sariakandi/Mathurapara Components) were based.

Following revision and redrafting of the detailed designs and contract documents for the Phase 1A works, the Environmental Impact Assessment for the priority bank stabilisation works was completed and the report submitted in July 1992. Environmental management measures recommended in the EIA were incorporated in the ICB tender documents.

A further report on Provisions for Operation and Maintenance of the Priority Works was submitted in July 1992.

The test bed work at RRI under the BRTS physical modelling programme was completed in May 1992. The physical model testing based on four bathymetries and the model studies of revetment structures is described in detail in the Final Report on Model Studies, prepared jointly by BRTS and RRI and issued in January 1993. Summary reports on the entire physical modelling programme and on the 1-D and 2-D mathematical modelling undertaken by BRTS are presented in the Report on Model Studies, a requirement of the TOR, issued in March 1993. A full list of reports and technical notes is attached in Appendix A.

1.4 Relationship with other FAP Projects

The other FAP studies that have specific links with the BRTS are:

FAP-2:	North West Regional Study
FAP-3:	North Central Regional Study
FAP-3.1:	Jamalpur Priority Project
FAP-9B:	Meghna Left Bank Protection Project
FAP-12:	Flood Control, Drainage and Irrigation Projects Agricultural Review
FAP-13:	Operation and Maintenance Study
FAP-14:	Flood Response Study
FAP-15:	Land Acquisition and Resettlement Project
FAP-16:	Environmental Study
FAP-17:	Fisheries Study and Pilot Project
FAP-18:	Topographic Mapping
FAP-19:	Geographic Information System
FAP-20:	Compartmentalisation Pilot Project
FAP-21/22	Bank Protection and River Training/Active Flood Plain Management Pilot Project
FAP-24:	River Survey Project
FAP-25:	Flood Modelling/Management Project

Close coordination has been maintained with all these studies but particular mention should be made of the close working relations that have been sustained with the two neighbouring regional studies (FAP-2 and FAP-3), the very valuable complementary work being undertaken by FAP-19 and the significant contribution made by FAP-25.

While the delayed start of some supporting studies did inevitably have some impact during the course of the Study, this has not been allowed to materially affect progress and results, conclusions and recommendations have been absorbed as they became available.

1.5 Structure of this Report

The contents of this Master Plan Report have been structured to conform with the requirements of Article 5.7 of the Terms of Reference, which stipulates that the report shall include:

- details of the Master Plan
- detailed design of the river training works for Phase 1 of the Master Plan and tender documents

The details of the Master Plan are presented in Part 1 of this report and the detailed designs for the Phase 1 river training works are described in Part 2, while Part 3 sets out the implementation arrangements, including details of the tender documents for ICB contracts.

The main report is supported by the following technical annexes:

Annex 1 - Sociological Considerations
Annex 2 - Economic Assessment
Annex 3 - Initial Environmental Evaluation
Annex 4 - Design and Construction
Annex 5 - Operation and Maintenance
Annex 6 - Tender Documents (in 2 volumes)

A separate Draft Final Report, required by the Terms of Reference, was issued at the end of January 1993, which provided further details of the studies and their conclusions. A Final Report has been issued in 1994.

1.6 Nomenclature

A list of abbreviations and acronyms used is given at the beginning of this report.

The name frequently used for the Brahmaputra River in Bangladesh is the Jamuna. Although the name Brahmaputra is more generally used in this report, the name Jamuna, when it appears, is not intended to imply any differentiation.

2. OBJECTIVES AND SCOPE

The proposed format of the Master Plan was set out in the BRTS First Interim Report (April 1991) and subsequently formally ratified by the BWDB and the FPCO.

It was agreed that the Master Plan should be fundamentally a detailed strategy for the containment of the Brahmaputra River and the improved performance of flood control measures on the right bank flood plain, with a timeframe that is flexible enough to accommodate financing constraints. It is to cover both structural and non-structural aspects and be geared to meeting both short and long term objectives as set out in the Terms of Reference. It is supported by an indicative draft plan showing the scope of structural works involved as perceived at this stage, and guidelines that will allow planners to respond to the situation as it develops. In this form the plan can be continuously upgraded in response to the changes in the river pattern and as more data becomes available.

The programme for implementation of the Master Plan is based on a combination of economic considerations and technical priorities. Provision is made for early implementation of river training measures in critical locations, commencing with the Brahmaputra Right Bank Priority Works at Sariakandi, Mathurapara and Sirajganj under the River Bank Protection Project. In the context of the Master Plan, these have been described as the Phase 1A works.

During the first phase of the Master Plan, it is expected that hard points to stabilize the reaches immediately north of Sirajganj and immediately north of Sariakandi will be required. Accordingly, 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, have been included as Phase 1B. Phase 1C will comprise the remainder of the six priority locations selected originally but not included in Phase 1A, namely Betil, Fulchari and Kazipur.

The remaining river bank stabilization measures required to stabilize the right bank over the entire study reach from the Teesta to the Hurasagar river, and thereby complete the protection of the BRE, are described as the Phase 2 works.

The scope of the Master Plan Report extends to detailed consideration of the environmental aspects of the river training measures envisaged, and the sociological aspects of land loss and resettlement.

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3. THE TERMS OF REFERENCE

The Study Terms of Reference require that the Consultant shall propose and/or work out:

(a) Possible measures and their technical and economic feasibility for an improved performance of the BRE for flood alleviation in terms of its overall design standard including its crest level.

(b) River training schemes suitable for the permanent protection of the BRE, including the effects to be expected on the environment; operation and maintenance aspects shall also be taken into consideration.

(c) An implementation schedule for physical/other measures proposed under (b) above; the schedule shall be flexible and shall allow for the phased implementation of permanent river works.

They go on to specify the scope of the master plan in that its purpose is the containment of the Brahmaputra river from Chilmari down to the confluence with the Hurasagar. The BWDB have clarified that the scope of the study is limited to that part of the BRE extending from the Teesta confluence to the Hurasagar confluence

There are certain specific issues to be addressed, including:

- possible effect of the proposed multi-purpose bridge;
- the permanent locations for ferry terminals and crossings;
- whether any proposed fixation of particular points or stretches along the river will have any detrimental effect elsewhere.

An important requirement is that the Master Plan shall be consistent with the overall strategy of the Flood Action Plan.

There is also the rider that the Master Plan shall address possible alternative measures to river training works - such as embankment retirement, or combinations of both types of measure - for ensuring the BRE's performance under possible FAP developments. The selection of the recommended alternative shall be based on technical and economic analyses, social and environmental considerations

4. SUMMARY OF THE STUDY COMPONENTS

The description of how the various elements of the Brahmaputra River Training Studies have been carried out, and how the conclusions reached have contributed to the formulation of the Master Plan for stabilisation of the right bank of the river and hence protection of the Brahmaputra Right Embankment in the long term, is the primary function of the Final Report.

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 hydrological studies have helped to define the general hydrological characteristics of the Brahmaputra River System in Bangladesh, and to provide pertinent data for the mathematical and physical modelling, and for the morphological and engineering studies.

The main forms in which mathematical modelling has contributed to the study include:

- the 1-D hydrodynamic modelling programme to determine design water levels, the effects of constriction and confinement of the river, velocity probability distribution, boundary conditions for 2-D modelling, water level and discharge data for the morphological studies and quantification of the effect of breaches in the BRE
- 1-D morphological modelling to assess the magnitude of long term channel geometry changes associated with different levels of river containment
- 2-D modelling to investigate morphological processes such as bend scour, confluence scour, bifurcation, scour around structures and the influence of the Jamuna Bridge embankments. This part of the study has been carried out in close coordination with the physical modelling programme, the two approaches complementing each other.

The extensive physical modelling programme, undertaken at the River Research Institute, Faridpur, has assisted with the identification of the most appropriate layout for river training works to suit the particular conditions encountered within the study reach of the Brahmaputra River, with the derivation of design values for key hydraulic parameters such as near-bank velocity and scour depth, and with the evaluation of the performance of alternative arrangements for protective layers and falling apron.

Velocity measurements taken under the BRTS river survey programme have provided data for calibration and verification of the 2-D modelling system, and have been used in the calculation of discharge. Velocity distribution is highly variable in the Brahmaputra and a probabilistic approach has been adopted to determine the near bank velocity used in design.

The silt fraction, or wash load, carried in suspension, is not considered important in terms of channel morphology; the sand fraction is transported by a combination of true bed load, dune movement and - evidence suggests primarily - by the movement of massive sandbars.

The morphological studies have covered a wide range of activities providing an essential insight into the long term trends of the river in terms of channel geometry and planform, and into the processes involved in its behaviour, including the development of aggressive bends and the longer term bankline movement. These studies have been planned as one element of a fully integrated study programme including mathematical and physical modelling, and values have been derived for the key parameters required for the design of river bank stabilisation and training works.

It appears that the present westward 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 sametime the river is becoming steadily wider. 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, although there is often a time lag between the two processes.

This understanding of the bank erosion process, the role of bends and the dominant waveforms with which they are associated, provides the essential background for the planning of stabilisation works at the study reach level and the setting of priorities for early implementation of individual elements.

The Final Report contains a summary of the Master Plan, including the long term and short term measures for river training, implementation measures, the basis for cost analysis, operation and maintenance and finance arrangements. The Master Plan summary also includes a description of the situation as it exists in terms of river behaviour, with predictions for river's future behaviour and an assessment of the consequences of different levels of intervention; further consideration is given to the status of the BRE, to sociological, economic and environmental aspects of implementation, river transport, and construction management. Brief recommendations for follow-up action are included. The principal design considerations are summarised, with details of how the various parts of the Study have been drawn upon to provide design parameters and guidance as to structural performance. A description of the proposed river training structures is included, together with a description of the methods which may be employed in their construction. These aspects of the study are expanded upon in the Master Plan Report.

5. **THE CHARACTER OF THE RIVER**

5.1 **Introduction**

5.1.1 Brief History of the River

The earliest reliable information on the planform of the river is probably the map published by Rennell in 1765. This shows a braided river hugging the Shillong hills and then taking a south-easterly alignment to follow the eastern edge of the Madhupur Forest tract, which is a slightly elevated area of more resistant Pliocene deposits. Somewhere in the vicinity of Mymensingh the river changed to a much more meandering pattern of low sinuosity (Figure 5.1).

The geomorphological map published by Coleman (1969) shows that the Brahmaputra had previously followed courses further to the north-east and had trended south-west to its 1765 course. Given this trend and the constraint to further movement provided by its contact with the harder Madhupur material, the river was clearly poised for a major channel shift, or avulsion. The two most favoured direct causes of the avulsion are tectonic movement and liquefaction following a major seismic event; it seems likely that the former is responsible for the underlying trend while a liquefaction flow that partially blocked the old channel could feasibly have been the trigger that initiated the avulsion. Details of the process, and the precise timescale, may never be fully known and are probably of only secondary importance with respect to prediction of future trends. Unless the tectonic pattern changes substantially it would seem unlikely that the river would be inclined to return to its old, and considerably longer, course in the foreseeable future. A slow continuation of the westward migration, until the river encounters the harder material of the Barind tract forming the western edge of its valley, appears to be a more probable scenario.

Other, less reliable, maps from the period show the main Teesta river taking a more westerly alignment than today and confluencing with the Ganges, but a left bank distributary channel marks the course of the present river. Suggestions that the addition of the Teesta flow to that of the Brahmaputra was a cause of the avulsion cannot be substantiated. Also shown on these maps are north-south aligned distributaries leaving the right bank of the Brahmaputra in the vicinity of the present day Bahadurabad; these would have provided pilot channels for the new Brahmaputra course and there seems little need to look further for an explanation of the avulsion process.

The map published by Wilcox in 1830, which was drawn up from a systematic triangulated land survey, is considered to provide a reliable picture of the planform of the river a few years after it had effectively completed its avulsion. Bend scars that closely match the form of his mapped bankline can be easily discerned on the SPOT imagery and there is no reason to doubt the accuracy of the map in this respect.

The most distinctive feature of the Wilcox map is the fact that the river south of the avulsion point has an almost exclusively meandering single- thread planform, whereas further north the braided pattern remains strongly pronounced. The underlying straight alignment, corresponding not only to the shortest course but also perhaps linked to the pilot channels mentioned earlier, is also noteworthy in terms of the river's subsequent macro-planform evolution.

By 1914 the major meander loops had broken down through a process of multiple chute channel development to create a largely braided appearance, but with a distinctive long, straight reach north of Sirajganj. Because of the fundamental changes taking place it is hard to compare these two planforms in terms of migration or bankline movement but it would appear that some progressive shifting westwards had already been initiated.

More modern maps based on aerial photography are available for the period 1951-57 and by this time the river had taken on a planform that is generally recognisable today, with island clusters beginning to develop in approximately the same locations as the current vegetated islands (chars).

The present day planform would appear to be approaching the full development of a braided pattern with major islands and their satellites, as illustrated schematically in Figure 5.2. This may be compared with the actual island pattern shown in Figure 5.3. If this model is indeed applicable, one may expect that the evolution over a timescale of the order of 30 years will consist of further widening of the braid belt as secondary islands grow, superimposed on a general tendency for the river to migrate slowly westwards. The highly braided reach of the river located in India a short distance upstream of the border is a model of how such multiple island building can develop; perhaps more likely however is a migration based on the assimilation of chars into the floodplain on one bank of the river. An example of the latter was the attachment of a large island group, located to the south of Sirajganj, to the left bank between 1950 and 1960. A similar process involving the two large islands opposite and to the north of Sirajganj may be in progress today through abandonment of the left bank anabranch flowing past Bhuapur.

The evolution of the river in its new course is consistent with the theory proposed by Bettes and White (1969) which, much simplified, is based on the thesis that a river has a preferred slope which it achieves by meandering if the valley slope is sufficiently flat, but if the valley slope is steeper it can only achieve stability by splitting into one or more anabranches and taking up a braided pattern. The fact that the river passed through the meandering stage and entered the braiding mode, where it has remained since, is a strong indication, though not conclusive, that it is now in its preferred state.

The old bend scars on the left bank flood plain corresponding to the planform shown on the maps of the early 1900's, suggest that the pattern of large bends has been a persistent feature of the lower section of the river. It is possible that the backwater effect of the Ganges, which results in some reduction in average water surface gradient, may have some influence on the planform in this reach.

This apparent tendency for the river south of Sirajganj to display a more meandering form is supported by the analysis of braiding indices for the period 1973 to 1990, but there is no evidence that it is becoming more pronounced. On the contrary, the satellite interpretation completed by ISPAN under the FAP-19 programme shows the steady growth of persistent major midstream islands in this reach, linked to very high sustained bank erosion rates, which points strongly to a long-term increase in braiding. The relatively higher widening tendency of this stretch of river since 1973 can be seen on Plate 16.

5.1.2 Definition of Terms

Anabranch

A second order channel formed by division (bifurcation) of the flow around a medial bar or island and contained within the primary, braided channel.

Thalweg

The deepest point in a river cross-section and the channel line linking the deepest points along the river's course.

Island Char

A relatively stable (meta-stable), primary-scale sediment accumulation with dimensions scaled on the overall width of the braid belt and a top elevation close to, but a shade less than, bankfull elevation of the surrounding flood plain. The upper surface is heavily vegetated and may support permanent dwellings. Island chars may be more or less intact bodies or may be heavily dissected by sub-channels crossing through them. They are believed to be formed by the amalgamation of clusters of sand bars that grow vertically through the deposition of silt and sand.

Sandbar

A second level bed feature which is mobile at all high, in-bank, flows. The upper surface is clear of all but annual vegetation. The bar is scaled on the dimensions of flow in the anabranch containing it and the upper surface elevation is a little less than that of the water surface at dominant discharge.

Bankline

As a part of the BRE assessment survey the BRTS has prepared an accurate map of the existing BRE alignment and the bankline as in December 1990 at a scale of 1:50,000. A plan of the bankline in March 1989 at the same scale has also been prepared from the SPOT image. The definition of bankline in each case has been taken as the interpreted interface between the main river flow surface and the main body of the flood plain at a water level corresponding to dominant discharge. Where a minor channel forms an island whose surface is the same as the flood plain then the island is taken as part of the flood plain unless the channel width at dominant discharge exceeds 100m.

5.1.3 Principal Characteristics of the River

It is the general consensus that the river has strong chaotic tendencies. That is to say that it is inherently unstable and that small changes in the boundary conditions can result in major changes in geometry over a matter of one or two seasons. Two of the key boundary conditions that are effectively outside human control are sediment inflow and rainfall and snowmelt runoff. However, as with any chaotic system, there are discernible persistent patterns of behaviour that permit some degree of forecasting and thereby form a rational basis for medium term planning. Where a link can be established between these patterns and established evolutionary theory or recognised empirical relationships developed for systems having similar characteristics, then confidence in the interpretation of the pattern is significantly increased.

It is on this basis that the morphological parameters of the river have been analysed and trends and patterns sought through both statistical analysis and qualitative interpretation. The evidence gathered and the conclusions arising from this assessment have been described more fully in Annex 2 of the Draft Final Report. The principal conclusions that have a direct bearing on the formulation of a master plan are:

(a) the river north of Sirajganj has a distinctly different character to that south of that point and down to the Ganges confluence; this may in part be related to the backwater effect of the Ganges. The northern portion is more braided and the intensity of braiding may be increasing; the southern shows meandering tendencies but there are also distinct braiding characteristics present.

(b) Within these two major categories the river can be seen morphologically distinct reaches that are associated with five, large meta-stable islands, two less well-defined island clusters and two elongated cross-over zones that have in the past contained islands. (Figure 5.3).

(c) There is positive evidence that the bank to bank width of the river has been increasing monotonically since the avulsion that took place prior to 1820 but at a rate that varies between different reaches.

(d) The evidence for continuing westward movement of the centreline of the river, as distinct from the widening process, is less clear but the geomorphological indications point strongly to this conclusion.

(e) The average rate of bank movement has been quantified for the period from 1953 to 1992 and in the absence of better predictors this may be taken as a conservative estimate of the rate that may be anticipated during the coming two or three decades if no stabilisation measures are implemented (see Table 5.1 and Plate 3).
Table 5.1

Table 5.1 Mean Erosion Rate for Each 10km Reach

Reach (Y coordinates)	1953 - 1992 (m/yr)	1953 - 1973 (m/yr)	1973 - 1984 (m/yr)	1984 - 1992 (m/yr)
845000 - 835000	-14.48	42.29	-43.37	-116.69
835000 - 825000	-80.01	-113.34	-29.69	-65.85
825000 - 815000	-70.86	-48.90	-39.21	-169.25
815000 - 805000	-19.28	-18.42	72.67	-147.87
805000 - 795000	-25.86	85.07	-84.56	-222.45
795000 - 785000	-27.16	90.37	-154.90	-145.35
785000 - 775000	-54.72	-46.95	-94.73	-19.12
775000 - 765000	-14.43	81.24	-168.23	-42.14
765000 - 755000	-60.93	-50.45	-115.12	-12.63
755000 - 745000	-122.89	-147.55	-87.84	-109.41
745000 - 735000	-96.20	-46.69	-166.25	-123.66
735000 - 725000	-110.86	-130.06	-56.19	-138.04
725000 - 715000	-64.81	-8.93	-77.33	-187.28
715000 - 705000	-19.79	-47.24	-24.08	54.72
705000 - 695000	0.22	34.15	81.31	-196.08
695000 - 685000	-16.23	19.10	5.40	-134.29
685000 - 675000	-83.25	-108.28	-112.62	19.73
675000 - 665000	-73.75	-62.32	-90.56	-79.21
665000 - 655000	-18.58	-31.76	11.30	-26.71
655000 - 645000	-34.29	-19.30	-67.29	-26.41
645000 - 640000	-80.99	-136.81	-11.43	-37.09

Note: Accretion positive, erosion negative

(f) Short-term bank erosion rates can be almost an order of magnitude higher than the medium term average. Such rapid erosion is associated with bends that have a life span of the order of five to seven years, during which they are typically very aggressive for no more than two or three years. However there are cases in which a second bend forms out of the first bend and the cycle can then repeat. (eg Fulcharighat).

(g) Because of the highly variable bank erosion rates, which are most probably stochastic in nature, and the very limited historical data, any rational approach to determining "safe" set-back distances for embankments will inevitably have wide confidence limits.

(h) Certain planform characteristics can be discerned within the very "noisy" braid pattern and these together with the spacings set by the islands provide a basis for selecting a channel planform for the planning of long-term stabilisation.

(i) There is thought to be a strong linkage between bank erosion and char development. If this can be confirmed, it would suggest that bank stabilisation will contribute to char stabilisation. If there is no link then stabilisation of one bank could lead to erosion of the opposite bank as the widening associated with char growth continues.

(j) The river is thought to be at present in dynamic equilibrium as far as sediment transport is concerned, although the evidence for this is sparse. Containing and stabilising the river will have a marked effect on high flood flows but much less effect on the morphologically dominant flows that are in any case mainly within bank. The longer term consequences with regard to sediment transport may not therefore be as great as might at first be expected. This important subject is still under active study.

5.2 Hydrological Characteristics

5.2.1 Some Catchment Characteristics

The Brahmaputra river rises in Tibet on the north slope of Himalayas, flows eastward for about 1,100 km, turns south into the Indian province of Assam, and then turns sharply west for about 640 km to the border of Bangladesh (see Figure 5.4). At the border, the river curves to the south and continues on this course to its confluence with the Ganges about 240 km downstream. The catchment area is approximately 520,000 km^2.

Snowmelt accounts for most of the flow of the Brahmaputra, but rainfall in Assam and in the northern part of Bangladesh contribute significantly. Consequently, the river flow has high seasonal variability.

Three major tributaries, the Teesta, Dudhkumar and Dharla, rise in the Himalayas and flow south-east across the North Bengal plains before entering Bangladesh in its north-west corner. These rivers bring down from the Himalayas large quantities of sediment. They drain a high rainfall area and are subject to flash floods. Some of their principal characteristics are summarised in Table 5.2.

Table 5.2 **Characteristics of Major Tributaries**

River	Gauging Station	Catchment Area (km2)	Average Daily flow (m3/s)	Annual Maximum Daily Flow (m3/s)
Teesta	Dalia	10,100	850	9,200
Dudhkumar	Pateswari	7,030	500	8,800
Dharla	Taluksimulabari	5,220	500	7,800

The most important distributary of the Brahmaputra is the Old Brahmaputra, the former course of the Brahmaputra which was abandoned over 200 years ago. Farther downstream, just below Sirajganj, another major distributary, the Dhaleswari, leaves the left bank of the Brahmaputra.

5.2.2 Analysis of Recorded Water Levels

Water Level Data

An extensive network of water level gauging stations on the Brahmaputra and its tributaries and distributaries has been established by the BWDB. Whilst many of these stations have relatively long periods of more or less continuous data, a number have short periods and/or discontinuous data.

A total of 35 stations were selected for defining the water level characteristics of the Brahmaputra and its major tributaries and distributaries. Of these, 19 are on the Brahmaputra from Noonkhawa (No. 45) to Teota (No. 50.6). Porabari (No. 50) and Sirajganj (No. 49) have the longest records of 36 years each. The data at Bahadurabad Transit spans 32 years.

The remaining 16 stations provide satisfactory definition of the major tributaries and distributaries. In addition, water level data for three stations on the Gorai, Arial Khan and Lower Meghna, representing external boundaries of the BRTS 1-D model, were also collected. A summary of the station network for which data were collected is given in Table 5.3. Further details may be found in the BRTS First Interim Report.

General Water Level Characteristics

Twenty nine years (1957-61, 1964-70, 1972-88) of screened mean daily water level data for the Bahadurabad Transit were used to define the general water level characteristics of the Brahmaputra. The water levels in Figure 5.5 show the same general pattern as for the discharge in Figure 5.6 but with substantially less difference between the maximum and 25 percent probability of exceedance values. The small variation in water level from year to year is illustrated by the fact that it was found that in general the difference between the 2 and 25 year return period water levels is of the order of only one metre.

Table 5.3 **Summary of Water Level Data Collection Stations**

River System	Data Collected From (Nos. of stations)
Brahmaputra	19
Bangshi	1
Baral	1
Deonai-Charalkata Jamuneswari-Karatoa	3
Dhaleswari	2
Dharla	1
Dudhkumar	1
Fakirni Barnai	1
Ghagot	1
Jamuna	2
Karatoa-Atrai-Gur-Gumti-Hurasagar	2
Old Brahmaputra	1
Teesta	1
Gorai	1
Arial Khan	1
Lower Meghna	1
Total	38

Peak Water Level Analysis

In general, the Gumbel Extreme Value Type I distribution fitted the 1-day annual maximum water level series of the Brahmaputra at gauging stations where more than thirty years of data are available.

Water levels for different return periods for the eleven selected gauging stations of the Brahmaputra are given in Table 5.4 and the corresponding water level frequency curves for Noonkhawa, Chilmari, Bahadurabad Transit, Sirajganj and Teota are shown in Figure 5.7. These may be compared with those obtained from the 1-D modelling 25 year simulation runs shown in Figure 5.8.

Water surface profiles of the Brahmaputra for selected events are shown in Figure 5.9. The chainages for the gauging stations in Table 5.4 are based on the assumptions made for the schematisation of the Brahmaputra for the BRTS 1-D model (see Chapter 3 of the Final Report). Location of the gauges for Chilmari, Bahadurabad Transit, Kazipur, Sirajganj, Mathura and Teota have been identified by BRTS on the ground and therefore the chainages for these gauges are considered to be reliable. Chainages corresponding to other gauges are only approximate.

Data Quality Control

The quality control of hydrological data is recognised as an essential step in data analysis. A variety of data error sources exist in the normal process of collecting and archiving hydrological data. The following conventional procedures were applied for checking of data:

(a) Plotting the original data serially by date. This plot can detect the misplaced decimal and help screen out any unrealistic peaks and troughs in hydrographs.

(b) Plotting the data of one station versus the data of a nearby station. This plot may indicate the strength of the relationship between the two stations and may indicate data error which has resulted in changes in that relationship.

(c) Double mass curve plotting. This technique is perhaps the most useful in detecting systematic errors in the data. A change in the relationship may be reflected in a change in the slope of the resulting curve.

Data infilling and extension procedures were used where necessary.

5.2.3 Analysis of Discharge Records

Bahadurabad Transit is the only station where the Brahmaputra discharge is currently being measured and flow data are available since 1956. In the past, the Brahmaputra discharges were measured at Chilmari, Sirajganj and Nagarbari and were continued for varying periods ranging from 1 to 3 years. These data however would not provide a reliable definition of the river flow characteristics due to their relatively short period. Therefore the available discharge data at Bahadurabad Transit is considered the most suitable for discharge analysis.

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Table 5.4 Peak Flood Levels in the Brahmaputra

Station	Chainage (km)	No. of Sample	Return Period (Year) 2	4	5	19	50	100	1:100 FAP-25	1988 Flood Level
			Flood Level (m. PWD)							
Noonkhawa	0.0	27	27.49	27.85	27.98	28.06	28.13	28.16	29.20	28.10
Chilmari	34.0	23	23.96	24.30	24.53	24.74	25.02	25.23	25.30	25.06
Kamarjani	46.4	24	22.45	22.93	23.16	23.34	23.51	23.60	24.20	23.43
Kholabarichar	68.7	24	20.69	21.06	21.30	21.53	21.83	22.05		21.68
Bahadurabad (T)	76.6	32	19.76	20.07	20.27	20.47	20.72	20.91	20.70	20.62
Kazipur	135.0	21	15.57	15.92	16.16	16.38	16.67	16.89	16.40	16.77
Jagannathganj	139.0	21	15.38	15.73	15.94	16.13	16.37	16.53	16.40	16.14
Sirajganj	155.8	36	13.88	14.22	14.44	14.66	14.94	15.15	15.10	15.12
Porabari	188.2	36	12.13	12.55	12.83	13.10	13.44	13.70	13.10	13.15
Mathura	225.4	25	10.01	10.47	10.78	11.08	11.46	11.75	11.60	11.35
Teota	237.4	24	9.40	9.82	10.09	10.35	10.69	10.94	10.70	10.58

Notes:

1. The chainages of the gauging stations are based on the schematisation of the Brahmaputra for the BRTS 1-D model.

2. The chainages of the gauges are approximate excepting the location of the gauges at Chilmari, Bahadurabad Transit, Kazipur, Sirajganj, Mathura and Teota which have been identified by the Consultants on the ground.

3. Estimate of the 1 in 100 year water level made by FAP-25 is preliminary.

The river stage at Bahadurabad Transit is observed five times a day on a regular basis. Discharge measurements are also carried out routinely, usually with a frequency of 2 to 3 weeks in order to determine and update the rating curve at this location. These measurements are carried out by the traditional current meter approach (2-point method) using a boat. The alignments of the transit lines are determined using sextants. Available rating curves at Bahadurabad Transit were collected to analyse the measured flow characteristics and to determine the year to year variation in rating curves due to changes in the river hydraulics.

Discharge data are also available for major tributaries and distributaries of the Brahmaputra. Data are usually available from the early 1960's, but with discontinuities at some stations. Available daily discharge data were collected for the following rivers: Bangshi, Baral, Karatoa, Dhaleswari, Charlkata, Dudhkumar, Ghagot, Old Brahmaputra and Teesta.

Daily discharge data of the Ganges and Meghna were also collected to represent the external discharge boundaries of the 1-D model.

5.2.4 Hydrodynamic Simulation

1-D hydrodynamic modelling of the Brahmaputra (Jamuna) River, using a refined version of the SWMC General Model, has been used to provide design water levels for the short-term works, boundary conditions for the 2-D and physical models, water level and discharge data for the morphological studies and as a tool for assessing the hydrodynamic impact of alternative containment strategies. It has also been used to quantify the probability distribution of flow velocities below certain values as a means of determining reliable construction windows for river works. Further details are given in chapter 3 of the Final Report and in Part 7 of the Report on Model Studies.

5.3 Sediment Transport Characteristics

5.3.1 Test Areas 1 and 2

Two sections of the Brahmaputra River were selected as providing in combination suitably representative conditions for calibrating and verifying the 2-D modelling system. These are referred to as "Test Area 1" and "Test Area 2". The former covers the full width of the river over a 12 km long reach south of Sirajganj and contains both major confluence and bifurcation features. The second covers the western anabranch in the vicinity of Kazipur and was chosen for its very pronounced bend scour associated with strong helical flow currents which were not so evident in Test Area 1. The locations of Test Areas 1 and 2 are shown in Figure 5.10.

5.3.2 Sediment Size

The Brahmaputra's catchment supplies vast quantities of sediment from the actively uplifting fold mountains in the Himalayas, the erosive foothills of the Himalayan Foredeep and the great alluvial deposits stored in the Assam Valley. Consequently, the Brahmaputra in Bangladesh carries a heavy sediment load, estimated to be over 500 million tonnes annually. Most of this is in the silt size class but around 15 to 25 percent is sand. Owing to the geology of the catchment, the clay fraction is very small.

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The sand size sediment is relatively uniformly graded as illustrated by a typical particle size distribution shown in Figure 5.11. In all 62 samples were taken from both the river bed and from sandbars by BRTS staff and tested by the RRI at their Faridpur laboratory. Typical grading curves for material sampled from the floodplain and higher levels chars (islands) are also shown for comparison (Figure 5.12). There is reason to believe that the bed material does become slightly finer in a downstream direction although the limited results currently available do not provide conclusive evidence of this. For the purposes of this study the range of D_{50} values has been taken as lying between 0.21 mm at Chilmari to 0.16 mm at the Ganges confluence.

5.3.3 Sediment Transport

The silt fraction, often referred to as wash load, is carried in suspension by the river and it is believed that most passes through the study reach, with only a small proportion becoming deposited in the lower velocity zones on char tops and floodplain during the limited period when the river level is higher than bank level. The silt load is not therefore considered to be important in terms of channel morphology, although probably significant in relation to char morphology, particularly during the final stages of char top building; a conclusion that is consistent with experience in other countries.

The sand fraction is transported through a combination of true bed load, which probably represents about 10 percent of the total sand fraction movement, and a complex pattern of partial suspension that occurs mainly in the zone close to the bed but is seen at higher flows in the form of dramatic "boils" in which the heavier fractions are carried temporarily to the upper levels. This second process is closely linked to the movement of both the smaller dunes and the massive sandbars that are a dominant feature of the braid pattern. Results of dune tracking undertaken in June 1990 indicate that the former were about 3 m high and perhaps 200 m long and their migration rate was found to be of the order of 35 m/hour. The larger sandbars vary in size but most lie in the range of from 3 to 6 km in length and 1 to 2 km in width; they are typically drowned at flows of between 30,000 and 40,000 m^3/s and are capable of travelling downstream during the monsoon season at around 30 m/day, although when associated with an actively eroding bend they may scarcely move for several seasons. There is evidence that these massive sandbars are the primary manifestation of the sand fraction transport.

5.3.4 Sediment Transport Relationships

Data on coarse (i.e. suspended bed load material and excluding wash load) suspended sediment transport in the Brahmaputra River at Bahadurabad are available for the period 1968-70 and 1982-88. The observed suspended sediment transport plotted against discharge is depicted in Figure 5.13 together with a regression line reading.

$$Q_{susp} = 9.1\ 10^{-6} \times Q^{1.26} \text{ (t/s)}$$

A closer analysis reveals that the data from the period 1968-70 suggest a significant (about 3 times) higher sediment transport than suggested by the 1982-88 data. The data are depicted in Figure 5.14. The regression lines are

1968-70:

$$Q_{susp} = 4.97\ 10^{-6}\ Q^{1.38}\ (t/s)$$

1982-88:

$$Q_{susp} = 15.2 \times 10^{-6}\ Q^{1.184}\ (t/s)$$

It is most likely that the apparent increase in sediment transport is caused by either a change in measuring procedure or a change in data processing. An increase of sediment transport with a factor 3 normally would imply an increase of velocity of 30% to 40%. This could only be achieved if very significant morphological changes had taken place, and there is no indication of such morphological changes.

The following is noted:

(a) The high flow (July) data from Test Area 1 suggest a slightly higher transport rate than the 1968-70, although the November data agrees better with the 1982-88 data. It should be mentioned that the Test Area 1 data only represents two sets of observations of the total sediment transport, which is subjected to natural fluctuation due to migrating bars etc.

(b) Most sediment transport models will predict transport rates which agree better with the 1968-70 data than with the 1982-88 data, see Figure 5.15.

The 1968-70 data probably therefore provide a better description of the conditions in the Brahmaputra River, particularly during the monsoon season when the large majority of sediment transport takes place. This is consistent with the relations applied in the JMB feasibility study.

Fall velocity estimated from ASCE Sedimentation Engineering (1975) and a water temperature equal to 20°C. This suggests a fall velocity equal to 2.0 cm/s.

A number of sediment transport formulae have been applied to attempt to describe the sediment transport in the Brahmaputra.

Based on dune trackings, it is apparent that dunes in the Brahmaputra migrate much faster than would be expected from any known bed-load formulae. For this reason, it is necessary to estimate how large a proportion of the suspended sediment transport is deposited in the lee of the sand dunes and activity contributes to their movement. It is concluded that a substantial proportion (more than 50%) contributes to the dunes' movement.

Two models, the Engelund-Fredsoe and the van Rijn models, have been used to calculate the sediment transport in the Brahmaputra. The advantage of these two models is that they are able to distinguish between bed load and suspended load, which is essential for mathematical modelling of bend scour. The two models predict slightly larger transport rates than the Engelund-Hansen model, which is a total load model.

However, the Engelund-Fredsoe model and the van Rijn models correspond very well with the measured field data.

During this and other simulations it was found that using the van Rijn sediment transport model did result in some differences between the computed and observed sediment concentration values but the average level of the simulated and measured concentrations are remarkably equal (0.23 g/l). It is further known that due to the turbulence in nature, the concentration varies much more than in the model. The concentration is high at the upstream end of the shallow areas whereas in the deep channel, the concentration is less.

5.3.5 Dominant Discharge

Determination of the Dominant Discharge

The dominant discharge principle first proposed by Wolman and Miller (1960) is based on the concept that in rivers which experience a highly variable range of flows, the long-term average dimensions and geometry of the channel are determined by the flow which performs the most work, where work is defined as sediment transport. Although Wolman and Miller's concept has frequently been questioned on theoretical grounds, few people question its usefulness and validity as an analytical device in the geomorphological assessment of rivers.

In applying the principle to the Brahmaputra River, daily discharge data for the period 1956/57 to 1988/89 for Bahadurabad gauging station were used to construct a flow frequency distribution relationship. Sediment transport measurements taken between 1968-1970 for sand load and 1982-1988 for both sand and total suspended load were used to construct sediment rating curves, giving the following relationships:

1) Total sediment transport (1982-88 data)

$$Q_{st} = 0.91\ Q^{1.38}\ \text{t/day}$$

2) Suspended sand transport (1982-88 data)

$$Q_{ss} = 0.93\ Q^{1.25}\ \text{t/day}$$

3) Suspended sand transport (1968-70 data)

$$S_j = 4.1 \times 10^{-6}\ Q^{1.38}\ \text{m}^3\text{/s}$$

The last equation was tested specifically to address the fact that this is the curve favoured in the JMBA study and the one preferentially used in the present BRTS study for morphological modelling, even though it is based on a relatively short period of record, on the grounds that the data quality is considered to be better.

The flow frequency curve was divided into discharge classes with increments of 5,000 m^3/s and the frequency of each class was multiplied by the appropriate sediment transport rate, to produce a total sediment load transported by that discharge class during the period of record (Figure 5.16). This was repeated for the different sediment relationships.

Examination of the total sediment transport distributions in Figure 5.16 shows that the choice of sediment rating has little impact. The dominant discharge is defined by the analysis to be 38,000 m^3/s. A much smaller, secondary peak is associated with a discharge of 7,500 m^3/s, which corresponds to base flow for the river.

This figure also agrees with the dominant discharge quoted in the Study Report by the China-Bangladesh Joint Expert Team (CBJET), (1991) of 37,500 m^3/s , which was derived in a similar fashion. Examination of the flow duration curve for Bahadurabad (Figure 5.17) indicates that the dominant discharge is equalled or exceeded 18 percent of the time and that it is always exceeded during the high flow season. These findings are consistent with results for other large rivers.

5.4 Channel Morphology

5.4.1 Upper and Lower Island Chars

Two distinct char top levels may be discerned along much of the course of the river. A typical cross-section. (Figure 5.18) shows a higher char at close to bankfull elevation and lower chars at a little less than dominant flow level. Practically in all cases, the dominant flow inundates the lower chars but does not overtop the upper chars. On this basis, dominant flow may be seen to correspond to bar topping discharge of the lower chars. For the upper chars to be inundated requires "bankfull" flow of perhaps 60,000 m^3/s, compared to the JMB study estimate of 45,000 m^3/s.

In this respect, the lower chars are "adjusted" to the present dominant flow and are contemporary morphological features. The upper chars, or islands, divide the flow even at dominant discharge and their tops are inactive except during high magnitude, out-of-bank flow events. The upper char, or island, surfaces are in this sense more similar to the flood outside within the braid belt then they are comparable to the contemporary chars or bars.

Comparing the cross-sections with the March 1989 SPOT imagery showed a very good correlation between the upper chars and the mature vegetated island areas, providing confidence in the general reliability of the cross-sectional data.

Closer examination of the lower, bar elevations reveals a stepped profile with longer, steeper reaches where the elevation difference between the sand bars and island chars is a metre or more and sand bars are well inundated (Figure 5.19), and shorter, flatter reaches where the difference is much less and the bars are barely inundated at dominant flow. Preliminary investigation shows that the locations of the steps may be related to planform width and stability variations. At this stage it should be noted that "island reaches" show a clearer separation of upper and lower char surfaces than the intervening cross-over reaches.

As a further test of these relationships between discharge, sand bar and island char level, the results of the 1-D hydrodynamic 25 year run were analysed to determine the frequency at which different water levels were exceeded and these were then compared with the sand bar and island char levels shown in Table 5.5. It was found that the water level having 100 percent probability of exceedance for a notional duration (i.e the elevation of land that will be inundated for at least one day every year) corresponded extremely closely with char top level

(Figures 5.20 and 5.21). By back analysis it can therefore be inferred that the water level corresponding to dominant discharge has close to 100 percent exceedance probability.

5.4.2 Ganges Backwater

While discharge peaks annually in late July or early August in the Brahmaputra, peak flow in the Ganges does not usually occur until late August or early September. Hence for the latter part of the summer and early autumn stages in the Ganges are higher than those in the Brahmaputra. This results in a back water curve in the water surface slope of the Brahmaputra that extends from its confluence with the Ganges up to approximately Sirajganj. The whole significance of this effect during waning flow in the Brahmaputra is not known, but it may be at least part of the reason for the observed decrease in braiding intensity downstream of Sirajganj.

5.4.3 Bank Material Characteristics

A systematic geomorphological survey of the right bank has been carried out and is described in Annex 2 of the Final Report. The conclusion is that while distinct zones with different predominant material characteristics can be identified, ranging from almost pure sand to thin strata of relatively cohesive material, overall the material has to be categorised as highly erodible. It has not been possible to establish any link between the bank material composition and short or long term bank erosion and the inference is that in relation to the magnitude of the erosive power of the river the bank material may be considered to be effectively uniform in its resistance to erosion.

It is noteworthy that this conclusion may be extended to include the area south of the Hurasagar, which falls outside the study area, where some reports have suggested that the rather more silty-clayey material may be more resistant to bank erosion.

5.5 Planform Characteristics

5.5.1 Data Sources for Morphological Studies

The sources of data available for the BRTS analysis of river planform characteristics are listed below:

(a) Survey of Bangladesh 1:50,000 scale topographic maps published in 1951-57, 1967-69 and 1978-79. These are considered to be the most reliable record of bankline for the period prior to the commencement of satellite image coverage and are in ready to use form.

(b) SPOT imagery at 1:50,000 scale for November 1989, March 1990 and November 1990 which has been registered to the same grid and sheet specification as used by the survey of Bangladesh. Although this has a higher resolution than the landsat imagery, the limited time period coverage means that it is of less value for morphological studies.

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Table 5.5 Relationship between Bank, Bartop and Chartop Elevations

Cross-Section Number	Reference Chainage (km)	Water Surface Elevation	Mean Bank Elevation	Bartop (Active Char) Elevation	Chartop (Inactive) Elevation
J-17	25.00	23.7	24.6	22.0	23.5
J-16	31.35	22.6	24.0	21.0	23.4
J-15	44.25	21.2	23.0	20.8	22.5
J-15	55.65	20.5	22.0	19.0	21.5
J-14-1	63.00	19.9	21.4	18.2	21.0
J-14	71.00	19.1	20.6	18.3	20.0
J-13-1	81.70	18.6	19.8	18.0	19.5
J-13	84.70	18.4	19.8	17.5	19.0
J-12-1	93.80	17.7	19.1	17.6	18.8
JN-2	95.50	17.6	18.9	17.3	18.8
J-12	100.50	17.3	18.6	17.0	18.1
J-11-1	108.90	16.8	18.0	16.8	17.5
J-11	117.75	16.0	17.2	14.8	16.8
J-10-1	126.50	15.5	16.6	14.6	15.8
J-10	134.30	14.9	15.7	14.6	15.5
J-9-1	139.00	14.5	15.2	14.4	14.9
J-9	142.45	13.9	14.9	13.8	14.8
J-8-1	145.40	13.6	14.6	13.5	14.3
J-8	149.50	13.3	14.2	13.8	14.0
J-7	162.35	12.4	13.4	13.0	13.0
J-6-1	170.75	11.8	13.0	None	12.5
J-6	177.70	11.0	12.5	11.3	12.0
J-5-1	180.60	10.9	12.2	11.0	11.0
J-5	188.20	10.3	12.0	9.8	11.7
J-4-1	195.75	9.7	11.4	9.1	10.7
J-4	201.30	9.3	11.0	9.0	10.2
J-3-1	205.15	9.2	10.6	8.6	10.55
J-3	213.20	9.1	10.1	8.5	8.5
J-2-1	220.00	8.9	9.9	8.0	8.0
J-1-1	229.40	8.5	8.8	5.0	None

Note: All Elevations are in metres above PWD datum.

(c) Partial coverage of the area by photographic prints of 1:50,000 and 1:20,000 scale aerial photography flown in December 1989 by Finnmap. This provides a potentially valuable complement to the SPOT imagery for interpretation of features which are not well defined from space. Its use is limited by the security restrictions imposed by the Ministry of Defence and coverage for certain key areas, such as Sirajganj, is not available.

(d) Good quality copies obtained from the India Office Map Room, London, of the Rennell map of 1765, the Wilcox map of 1830 and the Survey of India map issued in 1914, the latter two at a scale of 1 inch to 4 miles. The 1914 map is a detailed topographic map showing a large number of villages and features in a similar style to modern maps and it may be assumed that its reliability with regard to bankline planform and major char outline is of a high order. The Wilcox map covers only the river and a narrow strip on either side; it is drawn to a high standard with good detail and referenced to longitude and latitude. Cross-reference to villages on modern maps is satisfactory and there is evenly reason to conclude that the map is reliable with regard to planform. The Rennell map is also well drawn and detailed; it is not referenced to longitude and latitude but after adjustment to a common scale, it is possible to relate it satisfactorily through village and town locations and, thereby, establish a common reference with the other maps. The outline of the river fits well with major bend scars and other features identified on the 1:50,000 SPOT imagery and it is reasonable, therefore, to accept it as a reliable record of the location of the main banklines at the time.

(e) River cross-sections surveyed by the BWDB Morphology Division between 1964 and 1989 with a break from 1970 to 1976. These were mainly received in the form of rather indifferent quality ammonia prints and were digitised in the BRTS office. Systematic quality checks revealed significant datum anomalies that set severe limits on the quantitative interpretation of the analyses carried out using this data set.

(f) LANDSAT MSS imagery for February 1973, January 1976, February 1978, February 1980, February 1984 and February 1987, and TM imagery for January 1990 and March 1992 which has been rectified, enhanced and processed by ISPAN under the FAP-19 project. This is high quality data on which much of the quantitative analysis has been based.

(g) Photographic prints at approximately 1:250,000 scale of unrectified LANDSAT imagery for February 1973, January 1976, January 1977, February 1978, February 1980, December 1981, March 1984, March 1985, March 1986, February 1987 and February 1988.

5.5.2 Braiding Characteristics

Preliminary inspection of 1:250,000 scale satellite images of the Brahmaputra river suggested that it could be divided into reaches with distinctive and persistent geomorphological features. On the basis of this visual inspection, seven sub-reaches were identified, as shown in Figure 5.22. Braiding intensities, numbers of anabranches and overall braid belt width were used in analyses which were carried out by the BUET team for the years 1973, 1978, 198[illegible] 1987 and 1989. The analysis for 1992 was added later, using a methodology based on a paper by Howard et al (1970), which was also used in the JMBA study. The full results are given in Annex 2 of the Final Report.

The results confirm that reaches of relatively high and low braiding intensity (E) alternate, but with an overall tendency for braiding intensity, number of channels and overall width to decrease downstream of Sirajganj. However, this is by no means a stable pattern, and the braiding index has been as high as 4.9 for Reach 6 as recently as 1987.

Each of the upper four reaches had in 1989 a significantly higher braiding intensity than in 1973, although the trend is never steady, and higher intensities have occurred earlier in the period of record. Similar trends are also evident in the numbers of anabranch segments (N) and overall widths (C). There is in general a tendency for N and C to increase up to 1987 but then to decline somewhat in the period 1987/89. This could be part of the natural variability, or it would be related to the high magnitude flood of 1988 (return period of the order of 100 years) which might have had the effect of silting in small, island char top and flood plain channels and building attached bars at the flood plain margins to reduce both N and C. No strong relationship between the number of anabranches and their relative sizes was found (see Annex 2 of the Final Report).

5.5.3 Nodes and Island Clusters

From the plot of BRE retirements (Figure 5.23) it can be seen that there is a pattern to the number of retirements. Over certain reaches there have been no retirements to date while in others there have been multiple retirements. This pattern corresponds closely to that seen on the maps showing the bankline movements during the periods 1953 to 1973 and 1973 to 1992 (see Plates 4 and 5).

Combining this evidence leads to the division of the river in the study area into five main reaches associated with major islands and the respective inter-island or cross-over reaches. The word "node" to describe the cross-over reaches has been deliberately avoided because of the implication of fixity and uniqueness that may be misleading. In fact according to some opinion the shorter the cross-over reach, and therefore the more node-like it may appear at any point in time, the less stable it is.

The five reaches are described in Table 5.6 and shown on Figure 5.24. It will be noted that Reach 4 is associated with both Islands D and E, which are now almost combined into one.

Reach 1 has the least well defined of the major island chars. In many years the islands appear as two distinct clusters with a secondary cross-over at latitude 25^0 25', just north of Kamarjani, while at other times these appear more as a single island. Following the 1988 flood flow the islands were heavily dissected and even after the 1990 monsoon season they had not regained any recognisable form. Despite this apparent instability of form, the reach has experienced well below average bank erosion since 1956. Indeed it is probably the absence of consolidated island growth that is the reason behind the relative stability of the bankline.

The only significant bank retreat has taken place between Gidari and the Manas Regulator which was the cross-over reach in 1956 but is now occupied by the downstream portion of Island A. It seems possible that this Island is still at a relatively early stage of evolution and that if this is the case then bank erosion north of the current cross-over at latitude 25^0 15' may become worse during the next decade. For the present however mean erosion rates should remain below average, although localised rapid bank retreat can be expected for short periods at a time in the vicinity of the Manas Regulator and immediately south of the Teesta confluence.

Table 5.6 Island Reach Parameters (km)

Reach	Island	Length	Width	Comment
1	A	31.0	-	Ill defined
2	B	25.0	7	
	b-c	16.0	-	
3	C	16.0	6	
	c-d	3.0	-	
4	D	18.0	6	D and E overlap
	E	18.0	6	
	e-f	14.0	-	
5	F	18.0	5	
	f-g	12.0	-	
	G	18.0	4	Ill defined

The cross-over reach between Islands A and B is fairly well defined with its centre point at about 25^{0} 15', although in many years there is actually little cross-over of flow in this zone. Bank erosion here since 1956 has been minimal and while the cross-over remains laterally stable there is no reason to expect any significant change.

Reach 2 has undergone major change in the last 30 years as Island B has consolidated from a modest cluster of islands and grown to its present length of more than 23 km. The two main anabranches are now spawning secondary islands, some of which have distinct meta-stable elements. The recent serious bank erosion at Fulchari and the current erosion at Bahadurabad are related to substantial secondary islands and further localised erosion may therefore be anticipated at both these locations, and also at points 7 to 8 km upstream and downstream, as further secondary islands develop.

The future evolution of the river over this reach will depend on whether the braid belt as a whole shifts westward. Since the cross-over at the downstream end of the island has scarcely moved since around 1914 and has been remarkably stable since 1973, and the upstream cross-over has been laterally stable since 1956 (see Plate 10) there seems a strong likelihood that any westward drift of the river's centreline will be, at most, relatively slow. If this is the case then a possible model of evolution may be the massive complex of islands that has developed north of the Dharla confluence. This heavily braided reach of the river has an outer bank to bank width of about 18 km compared to the 15km maximum width for Reach 2 at present.

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The downstream limit of Island B is currently at about Latitude 25^0 04'. Downstream of this the pattern is confused with a mass of fragmented islands, some of which have meta-stable elements, occupying the centre of the channel and a substantial char consolidating towards the right bank. The downstream limit of this reach is the poorly defined upper end of Island C at about latitude 24^0 53'. It is interesting to note that in 1956 a cluster of small islands also occupied this reach but never developed into a single consolidated island.

Of probable significance is the fact that the cross-over immediately upstream of Island C, which is an important anabranch bifurcation point, has shifted westward by as much as 3km over the past 30 years. This cross-over coincides with the apex of the macro-form braid-belt bend and it is the behaviour of this hinge point that has a considerable influence on the river reach downstream.

5.5.4 Anabranch Bends

Bend Types

Two main categories of bend scale have been identified as described more fully in Annex 2 of the Final Report. The larger scale, in turns of magnitude, have a wavelength of the order of 17 to 22 km . Their low flow widths are of the order of 1,000 to 1,500 m and bankfull widths are around 3,000 m. These large features carry a large proportion of the bankfull discharge and their bend amplitude may reach 8 km. A double bend comprising one full meander wavelength is not uncommon. They seem to most often occur in the Island B to C reaches and south of Sirajganj and meandering is a persistent feature south of Island F. Scars and vestigial banklines on old maps confirm that this size of bend has been an important influence on the major planform of the braid-belt for at least the last 200 years. The largest recorded example is the single channel bend shown on the Wilcox map (1830) that was situated east of Sariakandi. It was a half cycle bend with wavelength of about 22 km and an amplitude of 8 km. The scar which it has left in the flood plain is clearly visible on the SPOT imagery.

The smaller scale consists of bends with a wavelength of the order of 7 to 11 km. Their low flow widths are of the order of 500 to 700 m and bankfull widths normally fall in the range 1,000 to 2,000 m. They are strongly associated with anabranches skirting the major meta-stable island chars.

It is members of this category of bends that are associated with the recent severe bank erosion at Kamarjani, Fulchari, Kazipur, Simla, Sailabari and Jalalpur.

It appears that the wavelength varies from one year to the next within this range, presumably influenced by the split of flows between anabranches and the dominant channel forming flow for the anabranch during the high flow season (July to November). Where the new dominant wavelength reinforces the old pattern then a bend will tend to grow and where it conflicts the bend will tend to die.

A situation can thus be envisaged that would give rise to adverse conditions from the point of view of bend erosion. During a relatively high flow season the erosive power of the river will tend to produce a well defined wave pattern with bend radius to channel width ratios that are fairly low but not yet critical. During a following year with lower average wet season flow the river will have less erosive power and will at the same time be trying to reduce the wavelength; the combination of these two factors will tend in some cases to produce a bend with a lower radius to width ratio that will now fall into the aggressive range of bend evolution. Such a scenario could explain the development of the very pronounced, aggressive bends with short bend radic at Jalalpur and Fulchari that both occupy longer wavelength embayments.

Bend Characteristics

Rapid bank erosion, that is to say rates of greater than 300 m/y, is in almost all cases related to distinctive anabranch bends. Consequently, a considerable amount of study effort has been expended on analysing the life histories of all the persistent bends that could be identified on the satellite imagery, the objective being to define some measurable characteristics that could provide the basis for the prediction of future bend development.

The first difficulty was to identify bends that were truly persistent for several years and not those that died to be replaced by a new bend that was only slightly offset from the first. The initial screening of the imagery covering the period 1973 to 1990 produced a list of 29 bends of which 10 were concave to the right bank and 12 to the left bank; the remaining seven bends were associated with mid-stream chars. Certain interesting features that emerged from this initial screening were:

(a) The low flow channel widths ranged from 375 m to 1625 m and the radii from 1,000 m to 16,000 m. There was no discernible difference between the left bank and right bank in this respect.

(b) There was no obvious variation in the number of bends active in any one year, although the sample is rather small for such trends to become apparent unless they are very pronounced.

(c) The major active bends tend to be concentrated between Fulchari and Kazipur on the right bank and opposite Sariakandi and Bhuapur on the left bank and a scattering on both banks south of Sirajganj.

(d) Of all bends analysed, only about one quarter displayed a complete life cycle, developing a steadily tightening radius until they died; it is these bends that do the most damage. Other bends were destroyed by other larger scale channel form developments before they could become fully aggressive.

(e) Only two persistent bends have been identified, that is bends that have died and then recurred at almost the same location a few years later. These are both on the right bank, one at Sariakandi and one in the second the embayment immediately to the north, near Naodabaga. It will be noted that both are situated on the concave side and close to the apex of the macro-scale change of alignment of the braid belt.

Based on this information it is reasonable to expect 12 to 15 bends to be active in any one year of which 6 would be on the right bank and 6 on the left. Since the average life span is about 4.5 years, normally only 50 percent bends would be in their peak aggressive range at any one time. The situation in 1988 through to 1990 was on these ground very unusual, with at least six major bends active on the right bank at one time. The 1991 monsoon season, with only three locations reporting severe erosion, is more normal.

A second, more rigorous, screening was then carried out as described in Section 3.3.1 of Annex 2 of the Final Report. This resulted in only eight bends remaining for further analysis. The histories of these bends and the analyses that were carried out are also described in Annex 2. As might be expected from the dynamic character of the river, relationships between radius, width and bend migration were generally weak. The plot reproduced in Figure 5.25 does nonetheless provide an outer envelope and an overall pattern from which two important facts can be inferred. The first is that bends that develop a low flow outer bank radius of less than 4,000 m are very likely to develop aggressive bank erosion but that when the radius tightens to 2,000 m they enter a rapid decline; this is consistent with conventional theory linking meander bend development and decline with the ratio of radius to width, if allowance is made for the changing values of these parameters as the discharge increases towards dominant discharge. The second is that if the bend radius is less that 4,000 m erosion rates are very unlikely to exceed 300 m/y.

It was also noted that bends in an aggressive phase typically did not migrate downstream, as would be expected from meander bend theory and experience, but punched their way laterally into the bank by bend extension. A good example of a bend of this type was the one that caused so much damage at Jalalpur prior to 1990. Although these bends are locally devastating in their behaviour they are fortunately not very common. The analysis of bank erosion shows that rates at this level have a probability of occurrence of less than 5 percent. The conclusion is that forward planning to guard against the impact of aggressive bends is probably impracticable and that when they do occur the most appropriate response will be in the form of emergency measures.

Attempts to derive relationships by making bend geometry parameters non-dimensional were unsuccessful and therefore the inferences drawn are only applicable to the study reach of the Brahmaputra because they are highly scale dependent.

The conclusion is that the practical prediction of bend development will always be limited by a low level of confidence. Certain characteristics have been identified that warn of impending development of an aggressive bend but there is a greater than 50 to 75 percent chance that any such bend will be overtaken by other developments before it can evolve further. With further analysis as more data becomes available over time it may be possible to identify secondary influences that affect the life expectancy of a bend and thereby to improve the prediction confidence. At present the data set is too small for this to be possible.

One characteristic that is of potential use for planning embankment alignments for relatively short life horizons is that in most cases the aggressive bends have a relatively low ratio of lateral to longitudinal movement. This means that they typically punch into the bankline rather than shave slices off it. However there are exceptions to this rule where the bend has followed the initially lateral movement by a downstream migration and actually regenerated again in a new location.

5.6 Planform Trends

5.6.1 The Coleman Report

The first systematic morphological study of the Jamuna River was undertaken by J M Coleman between June 1967 and March 1968 culminating in his paper "Brahmaputra River: Channel Processes and Sedimentation" published in 1969 [1]. He was the first to identify, from interpretation of aerial photography, that the course of the river had progressively moved westward during the Recent geological period until the major avulsion that took place around the end of the 19th century. He tentatively concluded that westward migration was continuing. In addition to this important piece of deductive work he observed and documented many of the sediment transport processes that are distinctive features of the river's braided form. Although Coleman's interpretation of his observations provides much valuable material on the behaviour of the river, he was not concerned with structural intervention in any form and therefore did not focus on many those aspects that are of primary relevance when considering bank stabilisation.

5.6.2 Principal Features

The processes of bankline retreat and accretion on the Brahmaputra river are seen to be dominated by the dynamics of sand bar, island char and anabranch evolution, which in turn are strongly influenced by the pattern of sediment and fluid transport. Since the latter are stochastic by nature it is necessary to look for significant trends that may be used to predict behaviour within specified confidence limits.

When analysing historic data it is important to keep in mind that bank movement is a combination of two distinct processes: widening of the braid belt related to char evolution and migration of centroid of the river related to long term migratory trends.

It has been found that in almost all cases short-term bank erosion is associated with the concave margin of anabranch bends which typically migrate only a relatively short distance downstream before dying out from one of several causes. This results in clearly defined embayments that are a distinct feature of the bankline and produces a scalloped appearance. However, over a period of time it appears that the consecutive embayments are displaced by several kilometres resulting in a relatively uniform average rate of bank retreat in any one reach over a timescale of about 30 years. This can be seen in Plate 3 where the bank lines in 1953 and 1992 have been superimposed. The total bank movement for this period is tabulated for each 10 km reach in Table 5.1.

On a longer timescale, whatever the underlying cause, and tectonic movement is an obvious candidate, there is convincing evidence that the river as whole has moved consistently westward during the last 200 years, and is continuing to do so up to the present (see Plate 10).

The combination of the dramatic change in planform that occurred around 1780 to 1820 and the inherent difficulty of defining the position of a braided river prior to the availability of high resolution imagery, makes it impracticable to think in terms of quantifying average movements

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[1] Sedimentary Geology, Vol 3, August 1969; Elsevier

at this scale. It is, however, possible and useful to infer some broad indicators from comparison of the older maps with the present day planform, particularly when such inferences can be corroborated by visual interpretation of the morphological features that show up clearly on the 1:50,000 scale SPOT imagery. The reach by reach trends identified in this way are described in Annex 2 of the Final Report, in brief:

(a) On the Rennell map of 1765 the Brahmaputra is shown hugging the Shillong hills for a distance of about 20 km north of the present confluence of the Kongkhal and Jinjiram rivers (see Figure 5.1). The Brahmaputra between the Teesta confluence and Bahadurabad has moved westward by a fairly uniform 14 km during the 225 years. Further north, in the vicinity of the present Dharla river confluence, the shift is less at about 8 km. This suggests that the river is capable of sustaining a bodily movement westward at a rate of the order of 60 m/y. It may be expected that the over shorter time-spans, such as 30 years, the rate could be considerably higher or lower than this longterm average.

(b) South of the Old Brahmaputra bifurcation the situation is very different. At the present cross-over zone between Islands B and C the centre of the braid belt appears to have moved westward by only about 2.5 km between 1820 and 1914 (27m/y) while the left bank position remained almost static. As the indications are that this cross-over has been relatively stable laterally for 150 years it is likely therefore to remain so for at least the next decade.

(c) Further south, the centreline of the 1914 braided reach was very close to that of the present braided channel but the outer bank to bank width was only at most 5 km compared to the present day equivalent of about 11 km. This width increase is the equivalent of a bank retreat rate of about 40 m/y. The averaged movement of the right bank of about 70 m/y in this reach is, therefore, probably composed of a combination of widening and overall westward movement of the centreline of the braid belt during this period, which is consistent with the lesser accretion rate experienced on the left bank.

(d) In the reach associated with Island C, the centre of the braid belt on the 1914 map is close to the current braid belt centreline - opposite Sariakandi it actually appears to have been marginally further west than the current centreline, but given the difficulty in defining the centreline, this is not significant. The outer bank to bank width has however increased from 6 km in 1914 to 11.5 km today (an average of 73 m/y). The change since 1956, however, presents a contrasting picture. In 1956 the width was still of the order of 6 km and the centre of the channel was about 2 km further east than that of 1914. Most significantly, the reach contained no metastable islands. The implication is that the islands shown on the 1914 map fused to the right bank creating a zone of temporary accretion. As the islands reformed post 1956 the earlier centreline was retained but the overall width almost doubled to that of today. The net bank erosion since 1914 is thus of the order of 2.5 km (average 33 m/y).

    It must be anticipated that erosion of both banks will continue. Since the right anabranch is still evolving a stable planform, it should be expected that more of the erosion will take place on the right bank. An averaged rate in excess of 100 m/y during the next decade would seem likely.

(e) With the changes that have taken place in the Island C reach, the cross-over at its downstream end has effectively moved westward by about 2.5 km since 1956 and this has had a commensurate affect on the Island D reach.

(f) The cross-over between Islands D and E is poorly defined to the extent that in recent years the flow has only been from east to west and the two islands tend to overlap. If this trend continues, the two islands may coalesce to form one very large island unit of about 36 km length.

(g) South of Island E lies the 10 km long widely recognised throat or 'nodal' reach which has remained effectively a single thread channel with little change in width over a period of about 20 years. However, this reach has not always been so stable. In 1830 a large double meander with a wavelength of 17 km and an amplitude of 12 km was the main feature, and the scars from this period are clearly visible on the SPOT imagery. By 1914 cut-offs had formed across the meanders and the pattern had become coarsely braided with an overall width of about 11 km. The major island length was about 20 km. By 1956 the eastern channels were clearly dying and by 1979 the island complex had become attached to the east bank leaving a single channel in more less the present position. Recently, erosion of both banks has begun.

(h) The Island F reach has seen some substantial changes in planform since 1830. The present major anabranch is the eastern one and this occupies a channel that parallels that of 1830 but is about 2 km to the west. A movement of the right bank by about 5 km appears to have taken place since 1914. At Belkuchi the bankline in 1956 was scarcely different to that of the present day, which implies that bank retreat in this reach took place at the high average rate of well in excess of 120 m/y.

5.6.3 Planform Dynamics

The major underlying questions regarding the planform of the river are:

- is the braid belt consistently migrating as a whole and if so in what direction and at what rate?

- is the overall river width increasing and if so is that an increase in water width or of island size or both?

- is the pattern of islands and inter-island nodal reaches changing over time?

The more immediate questions to be addressed by this study are what is the current rate and pattern of movement of the right bank of the river and what is the predicted future rate and pattern.

The elapsed time since the great avulsion that took place at the end of the 18th century is too short in relation to the timescale of river development for it to be possible to predict whether the river has a sustained tendency to migrate in any particular direction and at what rate. What can be stated with confidence is that over the past 35 years the right bank of the river has consistently eroded more than the left bank and, although this distinction has been less marked during the past 20 years, the rate of erosion on the right bank remains substantially higher than on the left (see Plate 5); moreover accretion on the right bank has been almost negligible while on the left bank it roughly balances erosion. This is reflected by the planform of the river: the alignment of the right bank is seen to be clear cut and relatively straight, in marked contrast to the rather ill-defined and irregular left bankline with its numerous semi-attached chars.

It is difficult to define the centreline of a braided river since the centroid of the channels is constantly shifting laterally, but by applying the simplistic definition that the centreline is the midpoint between the two outer banks it is found that this locus has over the last 35 years shifted systematically over some reaches of the river while remaining notably static in others (see Plate 10). The former are, as would be expected, associated with high rates of bank retreat; the latter include the reaches to the south of Brahmaputra and Sariakandi respectively and in the vicinity of the Jamuna Bridge site. The static lengths coincide with those parts that have earlier been identified as principal nodes of the system. It is notable that movement of the centreline between these nodes has been in all cases been towards the west.

Attempts to quantify the movement of the centroid of the multiple channels from the historic cross-section data produced results that were difficult to interpret and appeared to be inconsistent with the evidence of maps and satellite imagery. It was concluded that this arose from a combination of the unrecorded shifting of the reference monuments as bank erosion took place (it was found through survey undertaken by the BRTS that the actual positions of many of the sections were several kilometres away from those shown in the official record map) together with inconsistency in the direction in which the section was surveyed (see Annex 2 of the Final Report for further details).

Interpretation of the satellite imagery undertaken by FAP-19 does however show clearly that there has been not only a substantial net accretion of charlands since 1973 but that this has taken place mainly on the left side of the river with a consequent shift of the centroid of the channels towards the west. This tendency is most marked in the reach between Sariakandi and Sirajganj (Islands D and E) and south of Belkuchi (Island F). It has been noted earlier that the eastern anabranch in the Island D and E reach has been steadily declining in size over this period and now carries less than 10 percent of the flow. From the both the braiding analysis and the cross-section analysis it is known that anabranches taking such a low proportion of the total flow are very unusual and the inference is that, unless it makes a sudden unexpected recovery, Island D and E will become attached to the left bank within a matter of a few years. This will result in a major westward shift of the nominal centreline and will considerably accentuate the macroform sinuosity of the river.

Closer examination of the bankline movement statistics obtained from the satellite imagery and comparison with the 1956 mapping shows that the average rates of right bank erosion over the past 19 years have been remarkably consistent with the equivalent long-term erosion rates over a 35 year period. This would strongly suggest that these rates may be expected to be continue for at least several decades. Based on this assumption the predicted bankline in the year 2011 has been computed for both 50 percent and 5 percent exceedance probability, as shown in Plate 13. The irregularity of the lines on the left bank reflect the high variability of erosion and accretion that has been noted earlier. This analysis also suggests that the river will continue to move westwards, even without the effect of the possible attachment of Islands D and E to the east bank.

The bankline forecast shown in Plate 13 provides the best estimate currently available of how the river will develop based on historic trends. The only serious proviso concerns the fate of Islands D and E. If they do become part of the left bank floodplain then it should be anticipated, in the absence of bank stabilisation, that the process of bank erosion and related island char growth will transfer to the new single anabranch. The consequence of this change on the rate of bank erosion is at present unpredictable, but could produce rapid widening of the present right bank anabranch.

5.6.4 Bankline Movements

The General Pattern of Bank Erosion

From the discussion in the previous sections it can be seen that there are at least four major processes with different spatial and time scales occurring concurrently and that this in part explains the apparent randomness of bank erosion in terms of both location and severity.

The process with the shortest timescale is the evolution of aggressive anabranch bends. These can result in local erosion rates of more than 500 m/y but such rates are seldom sustained for more than 2 years and rarely more than 6 years (see Figure 5.26, especially Fulcharighat, sheet 1, and the Jalalpur bend downstream of Betil on sheet 4). Rates of 200-250 m/y are more common, but from the preliminary analysis of anabranch bends identified on the LANDSAT imagery over the period 1973 to 1990 it has been estimated that only 10 percent of bends produced erosion rates in excess of 500 m/y and on average only 3 bends a year can be labelled as aggressive. Thus, although major bends may be seen to be very destructive because of the speed of attack they do not comprise the main mechanism of bank retreat over a long period of time.

The second process, which is allied with the first, is the systematic retreat of the bankline due to the widening of the braid belt associated with the formation and growth of both island chars and sandbars. The formation of aggressive bends may play a part in this process, but attack by less aggressive bends seems to be the main mechanism. Average rates of retreat due to this process have historically been of the order of 75 to 150 m/y and these may be sustained over 30 or more years.

The third process is the shifting of the channel centreline at an inter-island cross-over (node). There is some evidence that this may be a cyclical process in some situations and in others it may be a drift in one direction, in which case it is probably more appropriately classified in the fourth category. An example of the apparent cyclical movement is the history of Inter-island zone c-d (Figure 5.27). This shifting may be associated with the attachment of islands to one or the other bank, in which case the transfer may be more abrupt than shown on the Figure. The effect of this process is superimposed on the widening trend, but the erosive power of the river places a limit on the maximum sustainable erosion rate. The timescale for this process seems to be of the order of 30 years.

The fourth process is the larger scale migration of the centreline of the braid belt. Because of its scale and the masking effect of the other three processes, this is the hardest to quantify. It is apparent that north of Bahadurabad/Fulchari the river has moved westward by between 8 km and 14 km since 1765 but it is not known whether the major avulsion was the initiator of this movement or, conversely, that the movement prompted the avulsion. The fact that the centreline of the river at Bahadurabad has scarcely moved since 1830 and that the Island A reach has been similarly stable since at least 1956 suggests that the former is the more likely. This clearly has major implications with regard to the future pattern of erosion in this upper portion of the river.

Between Island A and Island F the cross-overs have all, with the possible exception of cross-over b-c, shifted westward in relation to the centreline of the 1830 and 1914 alignments, but the magnitude of the movement is relatively small and of the same order as potential registration error in the case of the 1830 map.

From Island F southward the situation becomes even less clear, with the river behaving more like a meandering river but with strong, and probably increasing, braiding tendencies. The scars of big bends very similar to those of the present day indicate that the river centreline is now at least 7 km west of its position in the early 1900's; this is consistent with the westward movement of the right bank by this same order over that period. This is the equivalent of a movement rate of the order of 100 m/y, which suggests that the erodibility of the Atrai/Gur deposits south of the Hurasagar is little different to the less clayey material further north.

5.6.5 Bank and Char Sediment Exchange

Conceptually, the sediment that is produced through the process of bank erosion may be disposed of by the river in one of three ways:

(a) transported out to the Bay of Bengal as suspended load;

(b) carried some distance before being deposited in a mobile bed form or sand bar;

(c) transported some distance before being deposited as long-term storage in an upper level meta-stable island char.

If the river is in dynamic equilibrium, as indicated by the specific gauge analysis and the interpretation of the long section data, then it would be expected that the bed and suspended sand load leaving the end of the river reach should be equal to that entering at the top of the reach, plus any sediment derived from local inputs, measured over a reasonable period of time. Conversely, this need not be true for the silt load which has little impact on the river morphology and whose concentration in the water is, in practical terms, not dependent on the discharge.

As a test of this hypothesis, and in order to obtain a measure of the scale of the process in relation to the total sediment transported by the river, a pilot exercise was carried out using data from the 1986 and 1987 imagery derived maps contained in the JMBA Report for the reach between sections J-11-7 and J-5-6 (a distance of 76 km) and the measurements of sediment load at Bahadurabad made during the interval.

These preliminary results indicated that bank erosion in the study reach adds a negligible percentage to the already vast load of silt transported by the river, but that the sand fraction was probably 10 to 30 percent of the incoming sand load. Additionally, a significant amount of sand supplied by bank erosion is deposited in the form of char building/bank accretion. The y?

inference is that a large proportion of bank silt yield is transported directly to the Bay of Bengal but that the sand yield follows relatively short travel distances from bank source to either the mobile bed forms or the meta-stable island chars.

The implications with regard to the consequences of bank stabilisation are substantial and so further analysis was carried out using data generated by ISPAN, under the FAP-19 study, from interpretation of the LANDSAT imagery listed above. The ISPAN output was in the form of land areas, defined as floodplain, char and sandbar for a series of 2 km wide transverse strips across the braid belt, for each of the images. This data was then further processed by BRTS to derive volumes of material, based on the average depth of the river and relative heights of chars and sandbars obtained from analysis of the BWDB cross-sections. The results strongly confirm the earlier hypothesis. Even allowing for some degree of uncertainty as to the silt content of the chars, the plot reproduced as Figure 5.28 shows clearly the close relationship between bank erosion and island char building over a period of time. Also apparent from Figure 5.29 is the far lower correlation between bank erosion and sand-bar growth and decline which is consistent with the hypothesis that the sand-bars reflect the relatively more uniform annual transport of sand fraction sediment through the system, whereas the island chars represent long-term sand, and to a lesser extent silt, storage

Figure 5.30 illustrates how the amount of bank erosion and the change in char and sandbar volume, accumulated over the total time period, has varied over the length of the river. The major island zones and inter-island nodal reaches show up very distinctly, confirming the close relationship between bank erosion and char expansion and suggesting that the sand fraction products of bank erosion do not travel far before becoming deposited in a char.

Figure 5.31 shows how the overall balance for the sand fraction only has varied over the different time periods. It is apparent that the production of sand by bank erosion was unusually high in the period 1986-88 but that this was not reflected in an equivalent increase in the total sand volume of chars and sandbars. The inference is that the balance was washed out of the system during the exceptionally high flow years of 1987 and 1988. The equivalent plot for the 1990 to 1992 period shows a compensating net increase in char and sandbar volumes, suggesting that the river is now gradually recovering its morphological process form balance.

5.6.6 Macro Planform Trends

For the rational selection of set-back distances for the right bank flood embankment (BRE) the main source of data is the historic bankline movement, as described in the earlier section on bank erosion prediction, but it was also seen that an appreciation of the large scale processes is necessary for the interpretation of this historic data. The larger scale processes are also of importance in relation to the planning of a large scale river training programme, which must take into account the possible changes in the macro planform of the river during the period of implementation, which could be phased over as long as 100 years or more.

The geomorphic map prepared by Coleman (1969) indicates that the Brahmaputra's course can be mapped as it moved steadily south-westwards from an alignment close to the Shillong hills in early recent times to its course as shown on the Rennell map of 1765 at which time it was hard up against the Pleistocene Madhupur Tract sediments. Given this history it should not be a surprise that this westward movement continued and gave rise to the avulsion some

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time after 1765. Perhaps the only question is why the point of avulsion was apparently just north of Jamalpur. A possible cause may be the restriction of the old Brahmaputra channel in the vicinity of Jamalpur due to earthquake related upwards and sideways movement of sedimentary deposits on its north bank. This would have caused a local raising of the water level and resulted in a large proportion of the flow moving down what is now the Jhora khal. The 1.5 km wide scar of a Brahmaputra scale channel can be traced on the SPOT imagery and is visible as a 3 km wide flood path on the 1977 LANDSAT image. It may be surmised that this channel subsequently died as the river found a preferential overspill route north of Bahadurabad.

Coleman described the sedimentary material between the Barind tract and the present Brahmaputra as a combination of older Teesta deposits and more recent Bangali-Hurasagar deposits. He identifies the Teesta sediments on the left bank to pre-date those on the right bank, which could partly explain why the Brahmaputra selected the course that it did after the avulsion.

A question not answered in Coleman's paper relates to the earlier course of the Brahmaputra. It seems unlikely that it was stationary along the foot of the Shillong Hills for any great length of time. The shape of the present river macro planform strongly suggests that it may have occupied the same valley between the Barind and Madhupur tracts at some earlier period. This would have had to have been sufficiently long ago to allow the complete reworking of the sediments by the Teesta and Bangali river systems. This hypothesis is strongly supported by the form of the boundary between the Barind Tract and the Recent deposits north of Latitude 25° 00'. This feature has a planform that is identical with that of other established large Brahmaputra bend scars and is consistent with the dimensions of present day large bends.

All the available evidence therefore leads to the inference that on a geological timescale the Brahmaputra river is migrating westwards and, since this is most probably associated with tectonic trends, it may be anticipated that the drift will continue at a comparable rate until it encounters the less erodible material of the Barind Tract. At the maximum probable average migration rate of 50 m/y this would take approximately 450 years. If it is envisaged that river training works might take of the order 100 years to implement, then this type of timescale becomes significant. Even at a rate of only 10 m/y the consequences of sustained migration for a river training programme cannot be ignored.

The manner in which the river would move westward at this longer timescale is also largely a mater of conjecture: the two main processes being incremental, systematic bank erosion and anabranch avulsion. The nineteenth century, major avulsion shows that under the right circumstances the river is capable of forcing a completely new channel through the Teesta/Bangali sediments in a matter of at most a few decades. In this context it is instructive to note that on the 1914 map two major distributaries are shown leaving the Brahmaputra a short distance south of Sirajganj and flowing into the Hurasagar. In fact one channel is labelled the Hurasagar and the other the Old Jamuna. The width of the combined channel is about 800 m, which is comparable with a small anabranch. The channel length of the water route by this alternative route is about 64 km compared with the 58 km following the main river; a difference of only 10 percent. Given the additional roughness of the smaller channel it would be expected that flow will under normal circumstances continue to favour the larger channel. However, if the gradient in the main channel were to be only moderately increased.

by natural causes or human intervention, then the situation could rapidly reverse. The implication regarding works that might restrict the flow at high stages has to be taken into consideration.

5.7 Channel Geometry and Hydraulic Characteristics

5.7.1 Cross-section Conveyance

To complement similar work recently undertaken at the SWMC for the 1986/87 cross-sections, the variation of hydraulic properties of the sections has been compared for all years by co-registering the plots of the conveyance factor ($AR^{2/3}$) versus depth; a relative stage of 30m has been set to correspond to a conveyance factor ($AR^{2/3}$) in each year equal to 140,000, which corresponds to near-bankfull flow (Figures 5.32 and 5.33).

5.7.2 Mean Depth

Hydraulic Geometry Analysis of Anabranch Channels

The JMBA study gives the following equations for downstream hydraulic geometry.

$$\bar{h} = 0.23\ Q_b^{0.32}$$

$$B = 16.1\ Q_b^{0.53}$$

where:
$\bar{h}$ = Mean depth at bankfull flow (m)
B = Water surface width (m)
Q_b = Bankfull discharge of the anabranch (m^3/sec)

The same study also suggests another set of equations for at-a-station hydraulic geometry.

$$\bar{h} = 0.56\ Q^{0.23}$$

$$B = 18.9\ Q^{0.51}$$

where $\bar{h}$ and B are as defined above and

Q = observed discharge corresponding to the observed values of width and depth.

The validity of the equations has been checked against the data from the surveyed cross-sections and found to be consistent. The degree of variance is however very clear from Figures 5.35 and 5.36. Part of the scatter can be explained by data error; both width and mean depth are very sensitive to stage in the vicinity of dominant discharge as can be clearly from Figure 5.37.

Mean Width and Depth

It was also found that the relationships between discharge and channel width and mean depth proposed by the JMB Study provided a good description of the median values for these parameters but that there was a considerable distribution of observed values about these medians. It can be seen from Figure 5.35 that the width of a single thalweg channel can range from 80 percent greater than the value predicted by the relationship to 40 percent less. Similarly Figure 5.36 shows that the mean depth distribution is more skewed with possible values ranging from 75 percent greater to 30 percent lower.

If it is accepted that the channel conveyance characteristics have remained the same, and the evidence provided by the good correlation between the water levels predicted by the 25 year runs using the 1-D hydrodynamic model and historic water levels points strongly to this inference, then the more than 35 percent increase in wetted width of channel indicated by Figure 5.38 would be expected to result in a decrease in the mean depth of the order of 17 percent. This may partly explain the scatter of values shown in Figures 5.35 and 5.46.

These relationships provide useful guides for planning purposes and, for example, provide the basis for predicting, within the confidence limits described, the channel shape that would arise if the number of thalweg channels were to be artificially reduced or if the dominant discharge were to be changed due to intervention upstream.

5.7.3 Bend Scour

The objectives of the bend analyses were:

- to determine the most sensitive parameters for river bend development as a means of quantifying the uncertainty attached to various predictors of maximum depth and velocity, whether these be formulae, physical or mathematical models;

- specifically, to verify the simple deterministic BENDFLOW (Bridge, 1982) programme which calculates bed topography and depth averaged velocity distribution in river bends;

- to derive relationships between h_{max}/h_{mean}, v_{max}/v_{mean} and Radius/Width that may be used for predicting maximum scour depth and velocity based on bend characteristics that are specifically applicable to the Brahmaputra conditions.

The models were based on the bathymetry observed in Test Area 2, which represents a fairly severe set of conditions with a slope of 11×10^{-5} being greater than the average for the river as a whole, and an initial bend radius of 3,000 m. The flow was taken to be the equivalent of dominant discharge for the anabranch giving a mean depth of 7.0 m and a mean velocity of 2.0 m/s.

The output from a numerical model is sensitive to the values assigned to a number of parameters, some of which are difficult to quantify through field observation. The degree of sensitivity was assessed by running the model with values representing the range of conditions that might be encountered in the Brahmaputra. The simulation time in all cases was 167 days real time, by which time nearly all cases had reached full equilibrium. The results in terms of both h_{max}/h_{mean} and time for development of the scour is depicted in Figure 5.39.

Comparison with the BENDFLOW model was carried out for two water depths: 4.0 m and 7.0 m. The run time in this case being 417 days. The results in Table 5.7 show that the

BENDFLOW model, which is based on bed load transport only, tends to underestimate the scour while slightly overestimating velocity.

Table 5.7 Comparison between the 2-D model and the BENDFLOW model

Model	h_{min}	h_{max}	h_{max}/h_{mean}	v_{mean}	v_{max}	v_{max}/v_{mean}
2-D BENDFLOW	1.46 1.79	8.09 7.15	2.02 1.79	1.53 1.51	1.94 2.01	1.26 1.33
2-D BENDFLOW	1.47 3.12	15.07 12.51	2.17 1.79	2.03 2.00	2.53 2.61	1.25 1.31

The influence of the ratio of Radius/Width was simulated for six different cases with values ranging from 2 to 10. It was found that no scour took place for the lowest value but that in all other cases there was the expected link between scour depth and R/W (see Figure 5.40). This is consistent with both theory and observation that when a bend becomes over-tight it can no longer sustain itself. Of relevance to the understanding of bend development in the Brahmaputra is the timescale for scour: equilibrium was only reached after about 170 days of steady flow conditions, which is considerably longer than the duration of the normal high flow season.

It was found that the very deep scour observed 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 around protruding objects, for example the situation at Fulcharighat in 1990/91. To investigate this relationship further the depth of scour was deliberately exaggerated by an adjustment to the model and the relationship shown in Figure 5.41 was derived. The very strong and significant influence of V_{max}/V_{mean} on h_{max}/h_{mean} is clearly demonstrated; an increase of the former from 1.3 to 2.1 results in an increase from 2.0 to 5.5 in the latter.

The conclusions in summary are as follows.

The study has shown that the most sensitive parameters in the development of bend scour are the slope of the water surface, grain size, bank erosion rate, eddy viscosity representing the degree of turbulence, and the variation in bed resistance over the cross section.

The last two of these are compound parameters that are used in the process description and their values are normally best determined by calibration.

The study revealed 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. One of the most important degrees of freedom, the horizontal movement of a bend, was fixed in the 2-D model. Instead the bank erosion was included as a lateral inflow of sediment. The dynamic interaction between bank erosion and planform movement cannot be explored with a 2-D model at the present state of development.

However, the sensitivity analysis showed the significance of bank erosion on bend scour for instance if a revetment was constructed. The difference in maximum depth would be in the order of 2 m.

The 2-D model and the simpler analytical BENDFLOW model were compared and the results were found to be compatible when the sensitivity of the various parameters was taken into consideration.

The BENDFLOW model underestimates scour and marginally overestimates velocity amplification.

The modelling of the bed levels reached a state of equilibrium after approximately 170 days, when the maximum depth would be about 15 m. The results give an indication of the time scale of bend scour development (but not planform movements) although the flow would not be steady for the whole period as assumed in the model. Another approximation was that the planform geometry was fixed.

In this connection, it is important to compare the results of the JMB studies. Collected data on bend scour from surveys carried out by BIWTA gave depth below Low Water Level (LWL) ranging from 6 to 23 m. The mean value from 27 measurements was 13.4 m with a standard deviation of 3.6 m. The dominant discharge water level is almost 4 m higher than LWL indicating that the 2-D model simulated scour depths, of the order of 10 m below LWL, are less than those actually observed in the Brahmaputra.

The 2-D bend model could not simulate the development of the large scour holes at, for instance, Kazipur. However, from the verification of the model on Test Area 2, it was shown that the model was able to simulate the migration of the scour hole once it was formed. The reason why the creation of the scour hole cannot be adequately simulated is believed to be because other modes of scour, and particularly confluence and "protrusion" scour, interact with bend scour produce the excessive depths. This has been studied in more detail in the model dealing with confluence scour, where this explanation was confirmed.

With fixed bed levels, the maximum near bank velocity as a function of scour depth was simulated. The BRTS physical modelling showed that a ratio of upto about 2 between maximum and mean velocity is possible. The 2-D model predicted a similar ratio when the maximum scour depth was about 5.5 times the mean depth.

5.7.4 Confluence Scour

Prediction of Confluence Scour from Approach Channel Geometry

The JMBA report proposes a relationship between confluence scour depth (h_s) approach channel depth (h), and approach channel convergence angle (Θ):

$$h_s/h = 1.292 + 0.037\ \Theta$$

where $h = (h_1+h_2)/2$ and h_1 and h_2 are the depths in the two approach channels. This relationship was tested using data from Test Area 1 and from the 1986/87 survey. The data and results are given in Table 5.8.

Table 5.8 Confluence Scour Prediction

Location	Angle Θ (deg)	Mean Depth (m)	Scour Actual (m)	Scour Predicted (m)	Error (%)
B.78/C-50	55	5.39	20.2	17.9	11
J-6/J-7	40	7.34	17.8	20.3	- 14
J-12/J-13	55	4.21	11.5	14.0	- 23

Comparison of the monsoon peak and post monsoon surveys for Test Area 1 indicate that contrary to popular opinion bed level in confluence scour holes does not change appreciably with discharge. This was confirmed by the behaviour of the deep scour trench at Kazipur during the monsoons of 1990 and 1991; although the conditions that had created this feature were no longer extant, the depth of the trench was retained almost unchanged during the 1991 monsoon season, although it moved about 800 m downstream. The BRTS 2-D modelling system was able to simulate this movement and also able to create the deep scour downstream of a typical confluence that matched the JMB relationship very closely (see Section 3.5 of the Final Report). However the 2-D modelling also showed that considerably deeper scour could develop depending on the distribution of flow between anabranches. The relationship must therefore be seen as representing the median value with the 95 percent confidence limit being perhaps of the order of 20 percent higher.

5.7.5 Hydraulic Roughness

Roughness coefficients N (=1/n) used for the Brahmaputra varied within the range 31-50 at bankfull conditions and 20-40 at low flows. The 1-D hydrodynamic model performance was compared against the 1988 observed water levels at Chilmari, Bahadurabad (T), Mathurapara, Kazipur, Sirajganj, Mathura and Teota and produced a good fit for the gauge sites on the right bank. The match at Bahadurabad , the only station on the left bank, was less good, however, with the model predicting a higher level than that recorded at the station. The mis-match can be explained in terms of a combination of three factors:-

- overestimation of the input boundary flow, (i.e. errors in flow gauging)
- datum inconsistency between bench marks on the left and right banks,
- local datum transfer error at Bahadurabad

To investigate the sensitivity of the river network to a variation in flow the model was run with up to 20% less flow; this indicated that a reduction in flow of approximately 15% would be sufficient to result in a good match between the modelled and observed levels at Bahadurabad. This flow adjustment was within the estimated confidence limits for the gauging at Bahadurabad (see First Interim Report).

5.7.6 Velocity Distribution

In any river there is a variation in velocity vertically due to boundary shear effects, horizontally in a lateral direction due to helical flow resulting from centripetal forces, and longitudinally due to changes in channel geometry. In a reasonably stable meandering river the velocity at any point in the river will, for a certain discharge, tend to be relatively consistent in magnitude and direction over time (setting aside the hysterisis effect common to sand bed rivers). In a braided river such as the Brahmaputra the velocity is far more variable. Not only is the thalweg constantly shifting in planform in response to varying flow conditions but also the migration of the macro sandbars is superimposing additional variable constraints on the direction of flow and the cross-sectional area of the thalweg. Furthermore, the confluence of flow streams downstream of a char can result in zones of unusually high velocity and turbulent conditions. The combination of these effects produces a much larger spatial and temporal scatter of velocity than would be expected in a meandering river. Moreover, it is not possible to predict by any deterministic means what the velocity will be at a particular point in the river for any given discharge.

5.8 Vertical Stability

5.8.1 Specific Gauge Analyses

When analysing the medium to long term behaviour of river, a specific gauge analysis can be used to determine if there are any trends with time in the elevation of the water surface corresponding to a given discharge. The analysis must be based on sound, historical stage-discharge records for a gauging station with an open-river section. In this study, the records from Bahadurabad between 1963/64 and 1988/89 were used. This is the only flow gauging station on the river in the relevant reach and it is the only place that a specific gauge analysis can correctly be performed. The work was carried out by the BUET team and checked by the BRTS staff. Out of this period, rating curves for the years 1969/70, 1971/72 and 1978/79 were unavailable.

The method of analysis was based on discharges of 7,000, 14,000, 28,000, 42,000, 60,000 and 80,000 m^3/s and the corresponding water stages from the rating curves for the available years. For the 80,000 m^3/s flow, mostly extrapolated values of stage had to be used. Water stages were then plotted versus year of observation on an arithmetic plot (Figure 5.42).

The limitations of the gauging records must be taken into account when interpreting these results (see Annex 2 of the Second Interim Report for a discussion of the magnitude of errors) but with this proviso the following inferences can be drawn.

The results suggest a very slight overall rising trend in water stages for the period of observation. Lates (1988) showed that during the period 1956-68 low water levels (14,000 and 28,000 m^3/s) at Bahadurabad had a rising trend, while intermediate flows (42,000 m^3/s) were constant and the stage associated with high flows (70,000 m^3/s) fell slightly. In the period 1968/69 to 1985/86 the rising trend of the lowest flows (7,000 and 14,000 m^3/s) continues, while the intermediate flows fall slightly and the high flows rise markedly. Since 1985/6 all but the lowest flow (7,000 m^3/s) show a marked reduction in stage (Figure 5.43).

A similar analysis was carried out for Sirajganj but in this case some assumptions had to be made because at site flow measurements were not available. The main assumption was that while the flow remained within bank there was a simple unique relationship between the flow at Bahadurabad and that at Sirajganj on the same day. Best fit relationships were then generated between the water level at Sirajganj and the flow at Bahadurabad for each of the hydrologic years, two power curves were found to give a satisfactory representation in each case. The remainder of the analysis was as for the Bahadurabad data.

The results shown in Figure 5.44 indicate that there has been no significant change in water level for a given discharge and therefore probably no sustained aggradation or degradation of the section. The small trend gradients shown are comparable to the measurement errors involved and inclusion of data from 1955 to 1960 would actually reverse the trend in some cases. The apparent cyclical trend in water levels is of possible relevance; the amplitude of around 1 m and wavelength of around 7 years is comparable to that observed at Bahadurabad. Although not conclusive this is additional evidence that the river appears to be in dynamic equilibrium.

Stage changes like this are characteristic of a large, braided river with a highly mobile bed. The passage of macro-scale bedforms such as sand waves, and the shifting of braid bars and chars can radically alter the resistance characteristics and water surface topography, so altering the stage-discharge relationship. Also, unsteady flow effects, varying sediment transport rates and bedform hysteresis can produce marked changes during a single annual hydrograph (Vanoni, 1975). The degree of variability observed in the stage-discharge relations is, therefore, to be expected.

Those trends in the data that are maintained for periods of five to seven years are probably not associated with hydraulic roughness or sediment transport effects: they may be representative of systematic trends in the bed level associated with the passage of pulses of sediment moving through the fluvial system. Pulsed movement of bed load is widely observed in rivers. It may be attributed to unsteady supply from outside the channel associated with non-fluvial events such as tectonic events. In the case of the Brahmaputra, sediment inputs associated with major landslides in Assam during earthquakes are known to have occurred (Goswami, 1985). However, bed load pulses are known to develop even in cases of steady sediment supply in flume experiments (Thorne et al., 1987) and so they would probably be a feature of the Brahmaputra with or without the effects of landslides upstream.

Any persistent trend in the stage-discharge relations over the twenty five years period of record could be indicative of net degradation or aggradation of the channel. When analysing the records to identify any trend it would be inappropriate to use least squares regression because of the high degree of `noise' in the data. Instead application of a robust assessment of trend and non-homogeneity based on 3-point moving medians was undertaken. The results indicate that the stage-discharge relations for all six discharges do not show any significant trend at a 5 percent confidence level. It may, therefore, be concluded that the records do not indicate net aggradation or degradation over the whole period of record.

5.8.2 Analysis of the Long-Profile

The long profile of the Brahmaputra River in the study reach has been investigated using the records for the surveyed, monumented cross-sections established by the BWDB (Figure 5.45). As described in Chapter 2 of Annex 2 of the Final Report, the sections were digitised and entered into a computerised data-base by BRTS. The period covered by available data spans from 1964 to 1989, but with a gap from 1970 to 1976.

The data were used to produce two measures of channel stability. These are the vertical and lateral movement of the centroid of cross-sectional area below the water level at dominant discharge at each surveyed section. In a river with a complex cross-section it is difficult to characterise any overall trends towards aggradation, degradation or lateral instability. The centroid is a good measure of the overall location of the channel and movement of its coordinates can be used to identify both vertical and lateral shifting.

Plots of the vertical (z) elevation of the centroid versus chainage for various periods are shown in Figure 5.46.

Examination of the plots indicates that within reaches there may be net erosion or deposition occurring over the period 1965 to 1989 while in terms of overall charge for the full length of the river there is no discernible trend. Inability to resolve datum errors that appear to be present in data sets for certain years limit any further conclusions based on this data.

5.8.3 1-D Morphological Modelling

The 1-D morphological model has been used to predict the effect of various schemes proposed for implementation in the Jamuna River and the effect of changed boundary conditions for the river in the form of an increased sediment input to the river, for instance caused by changed land use in the catchment, and a general sea level rise due to the greenhouse effect. In addition, the 1-D morphological model has been used to investigate the sensitivity of the river response to various degrees of artificial narrowing of the river. The following scenarios have been investigated.

(a) constriction to 6000 m width

(b) constriction to 5000 m width

(c) constriction to 4000 m width

(d) construction of Jamuna Left Embankment

(e) construction of the Jamuna Multi-purpose Bridge

(f) a 50 percent increase of sediment input to the river

(g) a 0.5 m sea level rise

Each of these seven scenarios has been investigated in the following way:

- a 100 year morphological simulation using 25 years (1966 - 1991) records of observed water level and discharge repeated 4 times as boundary condition.

- morphological simulation of the 1988 flood (close to the 1 in 100 year flood) immediately after implementation (before significant morphological changes have taken place).

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- morphological simulation of the 1988 flood using the bed levels obtained from the 100 year morphological simulation (i.e. after significant morphological changes have taken place).

In addition to the 7 scenarios described above, a 100 year baseline simulation (i.e. no changes to the system) and a 1 year baseline simulation of the 1988 flood have been carried out. Thus, in total 8 no. 100 year simulations and 15 no. 1 year simulations have been carried out. All simulations have been carried out with time steps of four hours in the hydrodynamic model and two days in the sediment transport/bed level routine.

The conclusions of the applications of the 1-D morphological model can be summarised as follows:

- The time scale for river response is relatively large

- The bed and water levels in the Jamuna are relatively insensitive to moderate constrictions of width

- Very severe constrictions of width (say to less than 5000 m width) will give a significant increase of flood levels immediately after implementation. In the long term, when the river has adjusted to the constriction, the river bed will be significantly lower than in the existing conditions giving rise to a significant lowering of the low flow water levels.

- Construction of the Brahmaputra Left Embankment will give rise to erosion of the bed in the lower reach of the river, but the effect on the water levels is modest.

- The Jamuna Multi-purpose Bridge will only have local effects in the vicinity of the bridge on bed and water levels. Constriction scour will develop rapidly reducing the backwater effect of the Bridge. The depth of constriction scour will generally increase during rising stage and decrease during falling stage.

- An increased sediment input to the river will give rise to an increased slope, which, especially in the upper reaches, will cause a significant increase of bed and water levels.

- A rise of sea level in the Bay of Bengal will cause sedimentation in the river, which will migrate very slowly upstream. A general rise of water level in the Padma-Meghna confluence of 0.5 m results in the model in 0.22 m accretion in the lower Jamuna after 100 years.

6. COMMENTARY ON PREVIOUS WORKS

6.1 Previous River Training Works

On the Brahmaputra, a considerable investment has been made in bank stabilization measures over the past 20 years but the only example of relative success is the Sirajganj town protection, consisting primarily of multiple layers of randomly dumped concrete cubes, although that is now at risk. The protection of Sariakandi by means of the Kalitola groyne may be considered a partial success in that the erosion was controlled for long enough to see the main point of attack move further downstream. Both these structures suffer from the absence of a durable filter layer.

Works constructed on the Ganges at Rajshahi, comprising brick-mattressed revetment and groynes, appear to have been relatively successful in protecting the river frontage. Groynes constructed at the Gorai River off- take have been effective in controlling the flow although there is considerable embayment between them. The guide banks at the Hardinge Bridge have been effective, on the whole, in preventing the bridge from being outflanked by the river, though the right bank has come under severe attack and suffered local failure. Emergency river bank protection works have been undertaken at Chandpur on the Lower Meghna, although these are now showing signs of distress and further works are planned.

6.2 Performance of River Training Works

Within the study reach, the focus historically has been on the stabilization of the river bank in areas where erosion is resulting in the loss of agricultural land or threatening property and infrastructure. Where the stabilization results in some accretion then this is an added benefit. As noted in the previous section, however, the present works have been only partially successful and the inference is that the approach to design and construction currently followed will suffice for moderately aggressive conditions but will not provide the level of performance required under the more severe conditions. In this respect it is significant that the size of protective block required to resist flow drag is proportional to the square of the velocity. Thus for example an increase in velocity from 3.0 to 3.6 m/s requires an increase in block size from 35 cm to 50 cm (brick aggregate), and a further increment to 4.2 m/s calls for a block size of about 70 cm weighing almost 700 kg. The high velocities that can be induced round the noses of groynes and the upstream terminations of hard-points therefore demand larger blocks than can be easily man-handled.

The size of blocks is not the only potential cause of failure. The uniformly graded sand of which the bank and bed is composed has very low strength and transport resistance. The turbulent flow induced by the protective blocks will tend to draw the sand easily through the coarse matrix of dumped blocks; pore pressures in the bank during falling stages will exacerbate this tendency resulting in rapid slumping of the underlying material and its consequent exposure to the full force of the current as the protective layer subsides. Traditional khoa filters would be ineffective under these conditions, even if they could be placed to a specification.

Finally there is the major problem of controlling the distribution of blocks when placed in depths of more than 10 m and with flow velocities even at low flow of more than 1.0 m/s and high turbidity. Because of the high material cost, there is a natural tendency to place on the absolute minimum number of blocks. Under such conditions uneven coverage is almost inevitable, and it requires only one exposed area to initiate a progressive failure of the whole system.

Given these constraints and difficulties, the low success rate for structures built in accordance with the normal practice is only to be expected.

6.3 Requirements for Improved Performance

The essential features required for improved performance of river training works include:

- a formed slope that is designed to be stable under normal combined earthquake loading and drawdown conditions.

- A geotextile fabric laid on the slope that is designed to permit drainage of the underlying soil while preventing migration of soil particles under differential pressures induced by wave action, turbulent river currents and soil-water flow.

- An armour layer designed to hold the geotextile firmly in position and therefore capable of resisting the forces induced by high velocity flow and wave action; It must be sufficiently robust and durable to withstanding abrasion due to sediment laden water and inter-block movement.

- An apron, commonly called a falling apron or launching apron, consisting of armour material placed at the toe of the slope; this acts as a stockpile that is drawn upon through a natural bed armouring process when unusually deep scour develops off the toe of the revetment.

6.4 BRE Inventory

6.4.1 Background

The construction of the BRE started in 1957 between Belka (on the Teesta) and Fulchari. The remainder, from Kaunia to Belka and Fulchari to Bera, was constructed between 1963 and 1968, providing an overall length of 220 km.

During the last 24 years, some 140 km of the retired embankment have been built. In addition measures have been taken at various points in the attempt to maintain the security of the flood defence. These measures have included cross-bars and groynes, and bank revetment.

6.4.2 Objectives and Scope

The objectives of the BRE Inventory survey were:

(a) to establish the bank height over the full length, from which the risk of overtopping could be determined at any section on the embankment;

(b) to determine how well the existing embankment had performed in terms of:

- location, length, frequency of breaches;

- causes of breaches

- relationship, if any, between original embankment geometry, soils, construction techniques, vegetative cover, use, maintenance regime, and the probability/frequency of failure.

(c) to provide the basis for drawing up guidelines for construction of embankments that will have the desired life. In particular to identify possible measures and their technical feasibility for improved performance of the BRE in terms of flood protection, including the practicability of retirement of the embankment in different reaches.

The task was divided into two phases:

Phase 1 covering the initial objective data gathering, the purpose of which was to provide a reliable frame of reference with as much relevant detail as possible. This comprised three main activities:

- establishment of a network of bench marks along the BRE (extended also to providing bench marks at the locations of active bank erosion);

- surveying cross-sections of the embankment

- preliminary condition assessment

Phase 2 comprised the engineering assessment of the embankment and associated structures. This was timed to follow on from Phase 1 in order that the basic inventory and position referencing would be available. The entire length of the embankment was again walked over by BRTS engineers and an assessment made of the following characteristics:

- evidence of geotechnical weaknesses

- significant changes in soil types and form of modification of the embankment geometry by encroachment

- evidence of variation in construction standards

- wave induced damage

- integrity of cross-drainage structures, particularly the structure/embankment abutment and channel scour that could threaten the stability of the structure

- the condition of associated channel stabilization works

The locations of the BRE kilometre posts are shown in Figure 6.1

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6.4.3 Methodology

Vertical Control

All elevations were referenced to the nearest SoB permanent bench mark. Local bench marks were established along the whole length of the BRE at 1 and 2 km intervals and elevations transferred by second order levelling. All values quoted are relative to the PWD datum which is 1.5 ft (approximately 450 mm) higher than the national GTS datum.

Horizontal Control

The BRE planform has been plotted by reference to the rectified 1:50,000 scale SPOT imagery supplemented by the 1:50,000 aerial photography to provide infill where the resolution of the imagery was inadequate. The alignment was further verified and updated by a full walkover, with key points being picked up using the newly available GPS system. Original Mileage references had become very distorted as a consequence of multiple retirement and temporary kilometre reference posts were established; these were all referenced to latitude and longitude in addition to longitudinal chainage (km) and the original BRE Mile Posts.

Engineering Assessment

The whole length of the BRE was walked over by BRTS engineers during the period May to August 1991 and a proforma completed at approximately 500 m intervals, or more frequently if there were features of interest, describing the condition of the embankment. Particular attention was given to the condition of the slopes with a visual assessment of any signs of local slumping, slip failure, wave erosion, tension cracking or any other indications of geotechnical instability. Local opinion on the performance of the embankment was sought covering all aspects, including its efficacy, quality of construction and whether there was any problem over drainage on the landward side that was attributed to the BRE. A hand auger was used to take samples from the embankment wherever there was a notable change in the material. A similar assessment was made of all structures. The results of the engineering assessment of the embankment are shown graphically in Figures 6.2 to 6.5, and details of the regulating structures are given in Tables 6.1 and 6.2.

Vegetation

During the walk-over survey, a note was made of the principal forms of vegetation on the BRE, including banana crop. The results are shown in Figures 6.6 and 6.7.

6.5 Performance of the BRE

6.5.1 Historical Perspective

In 1959 the Government of the day commissioned the firm of IECO to carry out a feasibility study for the protection of the right bank area from flooding from the Brahmaputra river.

Table 6.1 **BRE Regulating Structures - Locations**

Sl. No	Name of Structure	BFE Mileage
01	Chandpur Regulator	27.03
02	Lanchamar Regulator	28.50
03	Sreepur Regulator	31.40
04	South Sreepur Multi Vent Regulator (6 vent)	33.89
05	Manosh Regulator	39.76
06	Ratanpur Regulator	45.40
07	Chitulia Regulator	49.76
08	Bharatkhali Regulator	51.45
09	Kachua Regulator	53.30
10	Hasekandi Regulator	55.33
11	Badinarpara Regulator	58.22
12	Mohammedpur Regulator	60.11
13	Partitparal Regulator	70.12
14	Aowlakandi Regulator	81.84
15	Monshakandi Regulator	89.19
16	Betgari Regulator	92.28
17	Charsubogacha Regulator	93.75
18	Subogacha Regulator	94.20
19	Chormara Regulator	94.75
20	Vatpiari Flushing Inlet-2 (Small one)	98.75
21	Vatpiari Regulator-1 (Large one)	99.04
22	Shailabari Flushing Inlet	100.89
23	Banitara Regulator	109.10
24	Banitara Regulator (3 vent)	109.50
25	Digrirchar Inlet	109.90
26	Flushing Inlet	113.15
27	Ambaria Regulator	113.96
28	Mohammedpur Flushing Inlet	118.76
29	Hatpacril Flushing Inlet	125.88
30	Monakosha Flushing Inlet	126.52
31	Deethpur Regulator	129.37

The original set-back distance was about 1.50 km, giving the embankment a nominal life of about 25 to 30 years. From the late 1970s the embankment started to come under isolated attack due to bank erosion. There are no substantiated reports of other forms of failure (eg overtopping, piping, slumping) during this period and the embankment therefore appears to have functioned satisfactorily in this respect. The impact on fishermen and those engaged in water transport can only be surmised.

During the mid-1980s the frequency at which the BRE came under attack from the river increased rapidly as greater lengths came within the range of rapidly eroding bends, which can cause bank retreat rates of more than 800 m per year with little warning.

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Table 6.2 BRE Regulating Structures - Inventory

Sheet 1 of 3

SL. NO.	Date of Inspection	Chainage BFE Miles	Structure State/No of Gates	State of Abutment /Wingwall	Gate Type /Condition	Gear Condition	Local Comment	Remarks
01	3.7.91	27.03	Good/Two	Sound	Steel/Fair	Fair	Operation Satisfactory	Over all condition Good
02	3.7.91	28.50	U/S /One	Some Failure	Wooden/Poor	Poor	Operation Unsatisfactory	Very poor
03	3.7.91	31.40	U/S /One	U/S /Fair	Steel/Poor	Poor	Operation Unsatisfactory	Very poor
04	2.7.91	33.89	Fair /Twelve	Some Failure	Wooden/Good	Good	Operation Satisfactory	Good
05	2.7.91	39.76	Fair /Twelve	Fair	Wooden /Good = 11 Poor = 1	Good = 9 Poor = 3	Operation Satisfactory	Poor
06	2.7.91	45.40	Fair/One	Fair	Steel/Fair	Fair	Operation Satisfactory	Not Good/Fair
07	1.7.91	49.76	Good/Two	Sound/Some Spalling	Steel/Good	Good	Operation Satisfactory	Good
08	1.7.91	51.45	U/S /Two	Sound	Steel/Fair	U/S	Does not Operated	Very Poor
09	1.7.91	53.30	Good/One	Sound	Steel/Fair	Fair	Operation Satisfactory	Good
10	1.7.91	55.33	Same Spalling /One	Fair	Wooden/U/S	U/S	Operated Inefficiently	Poor
11	30.6.91	58.22	Good/One	Fair	Steel/Fair	Fair	Operation Satisfactory	Not Good/Fair
12	30.6.91	60.11	Some Spalling /One	Some Failure	Wooden/Fair	Poor	Operation Satisfactory	Poor

Table 6.2 BRE Regulating Structures - Inventory

Sheet 2 of 3

SL. NO.	Date of Inspection	Chainage BFE Miles	Structure State/No of Gates	State of Abutment /Wingwall	Gate Type /Condition	Gear Condition	Local Comment	Remarks
13	8.6.91	70.12	Good/One	Sound/Some Failure	Steel/Fair	U/S	Operated Unsatisfactory	Not Good/Fair
14	10.6.91	81.84	Fair/One	Fair	Wooden/Fair	Poor	Operation Satisfactory	Overall Condition Good
15	25.6.91	89.19	Some Spalling /One	Some Failure	Steel/Poor	Poor	Operation Unsatisfactory	Poor
16	27.5.91	92.28	Fair/One	Sound	Not seen /Opening totaly closed	Poor	Does not operated or closed	Poor
17	27.5.91	93.75	Fair/One	Some Failure	Steel/Fair	Good	Operation Satisfactory	Fair
18	27.5.91	94.20	Fair/One	Sound	Not Seen	Fair	Operation Satisfactory	Fair
19	27.5.91	94.75	Fair/One	Some Failure	Steel/Fair	Fair	Operation Satisfactory	Fair
20	23.5.91	98.43	Good/One	Sound	Steel/Fair	Fair	Not Known	good
21	23.5.91	99.04	Good/One	Sound	Wooden/Fair	Fair	Operation Satisfactory	Good
22	23.5.91	100.89	Good/One	Sound	Steel/Fair	Poor	Operation Satisfactory	Fair
23	20.5.91	109.10	Fair/One	Some Failure	Steel/Fair	Fair	Operation Satisfactory	Overall Condition Fair
24	20.5.91	109.50	Good/Three	Fair	Steel/Fair	Fair	Operation Satisfactory	Overall Condition Fair

Table 6.2 BRE Regulating Structures - Inventory

SL. NO.	Date of Inspection	Chainage BFE Miles	Structure State/No of Gates	State of Abutment /Wingwall	Gate Type /Condition	Gear Condition	Local Comment	Remarks
25	20.5.91	109.90	Good/One	Sound	Steel/Good	Good	Operation Satisfactory	Very Good
26	20.5.91	113.15	Fair/One	Sound	Steel/Fair	Poor	Operation Satisfactory	Overall Condition Fair
27	20.5.91	113.96	Good/One	Fair	Wooden/Fair	Fair	Operation Satisfactory	Fair
28	24.5.91	118.76	Some Spalling /One	Some Failure	Steel/Fair	Fair	Operation Satisfactory	Needs Maintenance
29	23.9.91	125.88	Good/One	Sound	Steel/Fair	U/S	Operated Inefficiently	Poor Gear needs to be replaced
30	23.9.91	126.52	Some Spalling /One	Some Failure	Wooden/U/S	Fair	Operation Unsatisfactory	Poor Gate needs to be replaced
31	22.9.91	129.37	Fair/One	Fair	Steel/Good	Good	Operation Satisfactory	Overall Condition Good

Notes:

1. All lifting gear is of the worm and screw type
2. All chainages are in BFE miles measured along the alignment of the BRE at the time of inspection

During the 1988 flood the embankment was breached in 3 known locations, all apparently attributable to river bank erosion. In 1991 only 70 km of the original embankment survived in reaches where erosion has been relatively minor during the last 30 years.

The majority of the embankment is now less than 800 m from the river bank and is therefore within the one season erosion range of an aggressive bend.

Since bank erosion appears to be so unpredictable, there is a naturally strong resistance from those most immediately affected to the retirement of the embankment until it is clearly under threat. This means in practice that there is usually not time to complete the process of planning designing and constructing a retirement before the original embankment is breached, and typically the process is only initiated after a breach has occurred. This policy is in the interests of those living in the zone between the two alignments but not in the interests of the people of the flood plain as a whole.

Greater confidence in the prediction of active bends may therefore help those responsible for maintaining the embankment to initiate retirements ahead of a breach.

6.5.2 Pattern of Retirements

The pattern of retirements of the BRE is shown in Figure 6.8. The number of retirements to date generally ranges from one to three. In only two locations has it been necessary to make four retirements and the case of Jalalpur with its seven retirements is unique.

6.5.3 Present Planform

The position of the BRE in relation to the March 1992 bankline is shown in Plate 6. Based on 1990 mapping, some 20 km of the BRE lay within 200 m of the bankline, 38 km within 300 m, 78 km within 500 m and 119 km within 700 m.

6.5.4 Breach History

It has proved difficult to build up a reliable history of breaches. Most people's recollection becomes hazy prior to the 1988 breaches and official records other than the bankline sketch maps maintained by the BWDB since about 1980, are not readily available.

From the latter it is possible to estimate that the first retirements took place, possibly in the vicinity of Kazipur, around 1975, only a little over 10 years after the original construction but that the problem started to become significant in the early 1980's. It is clear however that the problem has become more serious during the past 5 years as progressively more of the BRE becomes within range of aggressive bend erosion.

Five principal failure mechanisms are, theoretically at least, potentially causes of breaching the BRE. These are:

overtopping

slope failure

wave action

piping

undermining

Of these, by far the most significant is undermining as a result of river bank erosion. The other factors play a relatively minor role.

Significant damage to the river side slope due to wave action is surprisingly rare, even where the embankment is very close to the river bank. The probable explanation lies in the shallow depth of water over the bank even at high flood levels and the relatively dense low vegetation that rapidly attenuates the waves. The indications are that a distance of no more than 100 m with the right type of vegetation cover can be sufficient to effectively suppress wave action to a level that good grass cover on the embankment can withstand.

The two lengths were significant damage attributed to waves was observed are in the southern section. One is the 5 km long most recent retired embankment at Jalalpur and the other a short distance north of the Baral (Hurasagar) River confluence where a 1 km long retirement has been made at Benutia Bazar. In both cases the damage was observed equally on both faces but not on the adjoining lengths of older embankment, some of which are equally exposed to the river and landward impounded water. In the second case part of the old embankment actually shields the retired embankment from river waves. In both cases localised slumping of the embankment face is also reported in the same lengths and of both faces. The inference is that the problem in both cases is associated with the poor consolidation and over steep slopes of the hastily retired embankments. It is possible that the observed damage was also in part due to seepage through the under consolidated embankment. Both these cases require early remedial work.

Localised slumping of a less serious nature has also been observed at Haripur, Belka and Saghata in the northern section. This is thought to be also related to poor construction.

6.5.5 Present Geotechnical Condition

<u>Cross Section</u>

Cross-sections of the embankment have been surveyed every 300 m and the crest elevation has been recorded by level traverse every 50 m. Local depressions associated with paths and roads crossing the embankment were particularly recorded. More than 40 percent of the length of the embankment has been occupied by temporary housing, but only part of this on both sides, and most of this is situated on benches cut about half way down the slope. Over almost 20 percent of the length this benching is present on both faces of the embankment and in addition, more surprisingly, over more than 10 percent of the length it is on the river side only.

It has been judged that over more than 50 percent of the length of the BRE slopes on each face are in fair to good condition and require no urgent slope face maintenance, a further 30 percent are affected by temporary housing and rather less than 20 percent requires early attention. The pattern is very similar on both faces of the embankment.

Typical cross sections are shown in Figures 6.9 to 6.12.

From the data collected for preparation of the Inventory, slope correction diagrams have been plotted, Figures 6.13 to 6.16, showing the extent of the BRE over which work is required to restore a satisfactory standard of side slope. The term "slope correction" has been incorporated in the Inventory survey to define the length of embankment requiring maintenance to provide a side slope not steeper than 1 vertical: 2 horizontal.

The requirements for slope correction shown in the diagrams include:

(a) Slope correction with enchroachment

   i) Non-uniformity of side slope due either to existing or previous public occupancy of any kind, i.e. enchroachment.

   ii) Sudden fall in the side slope due to benching.

(b) Slope correction without enchroachment.

   i) Non-uniformity of side slope due to rilling as a result of rainfall, or any settlement of embankment fill on the slope.

The extent of encroachment is shown in Figures 6.17 and 6.18.

Materials Investigation

More than 90 auger samples were taken during the Inventory Survey. The grading envelope (sand fraction) is shown in Figure 6.19.

Stability

No signs of instability associated with benching have been noted, nor have any reports been received to this effect. Since this feature has been present for several years, including the 1988 high flood year, the inference is that it is not intrinsically detrimental from a practical performance viewpoint. The forming of berms can in principle be beneficial, both by providing increased toe weighting and by lengthening the seepage path. The main danger would be that the oversteep slope above the bench might collapse if it became saturated. Provided that the crest width is wide enough, such a failure would at worst temporarily restrict use of the embankment for access purposes.

Further consideration of the design cross-section is given in Chapter 15.

6.6 Requirements for Improved Performance

6.6.1 Crest Level

The present longitudinal profile of the BRE is shown in Figures 6.20 to 6.22. Plotted in addition to the BRE crest level are the simulated maximum water levels for a 100 year return period as derived by the 25 year 1-D hydrodynamic model runs for three different scenarios, namely:

(i) existing condition
(ii) existing condition + Jamuna Multi-Purpose Bridge (JMB)
(iii) existing condition + JMB + FAP-3 left bank proposals.

The recommended crest height for the upgraded BRE is for scenario (iii) + 1.5 m freeboard. If initial upgrading to a lower level were undertaken, then a very substantial amount of further work and dislocation would be necessary upon construction of JMB and/or a Brahmaputra Left Embankment. The extent of upgrading which will be necessary can be seen from the longitudinal sections.

The existing crest levels indicate considerable variation. In the region of Fulchari there is a length of some 10 km of BRE where the crest appears to be conspicuously lower than elsewhere. Level traverses have been run in both directions along this lower section, tying in with bench marks at either end from which the adjacent higher sections were surveyed. It thus appears that depression in the Fulchari area is real rather than the result of a datum error.

Breaches not repaired at the time of the survey also feature on the longitudinal sections.

6.6.2 Side Slopes

Slope stability analysis undertaken by BRTS has indicated, under a combination of water levels, with and without earthquake loading, the following side slope requirements:

i) Section without berm

river side	1V:3H
country side	1V:2.5H

ii) Section with berm

river side	1V:3H
country side above berm	1V:2H
country side below berm	1V:2.5H

This is discussed further in Chapter 15.

6.6.3 Crest Width

A minimum width of crest is required for two purposes, firstly to provide good access for maintenance, and secondly to ensure an adequate seepage path. The proposed design cross section has a crest width of 6 m, which will be sufficient for access purposes even allowing for some deterioration at the edges.

6.6.4 Other Geotechnical Aspects

Consolidation is important to reduce the risk of piping and to improve slope stability, clod breaking is absolutely the minimum requirement. Silt free fine uniform sands, which are difficult to consolidate and have high permeability, should be avoided as construction materials.

6.6.5 Use of Vegetation

The use of suitable vegetation for the purposes of wave attenuation on the river side of the embankment and soil stabilization on both slopes, is recommended. Vetiver grass, which is found in Bangladesh and has a deep and intense root system to bind the soil, would be suitable. Vetiver can also be used, where desired, in a mix with cash crops on the embankment slopes. This aspect of crop production is discussed later in this report. The use of vetiver for soil erosion control on embankments is the subject of a special report prepared in 1992 for the World Bank by Dr. P K Yoon of the Rubber Research Institute of Malaysia.

6.6.6 Planned Retirement

The extent of flooding and disruption resulting from breaches can be minimised by planned retirement of the BRE. If a length of BRE coming under threat of erosion attack can be identified sufficiently far in advance, the necessary procedures can be accomplished and a retired length of BRE constructed prior to any breach in the original section. Further, the area of land between the old and new embankments can continue under flood protected cultivation almost up to the time of the anticipated breach of the old embankment. The old embankment should be breached deliberately and in a controlled manner shortly before its collapse into the river, so that the effects of a sudden inrush of flood water are avoided. It will be necessary to allow for drainage of the empoldered area prior to breaching of the old embankment.

6.6.7 Optimal Set-back Distance

An optimal strategy for selective realignment of the BRE is one which maximises the economic benefit of realignment relative to costs and the disbenefits of so doing in order to provide an acceptable level of security against breaching by river bank erosion.

Determining an optimal strategy needs to take into account:

- direct costs such as land acquisition, embankment construction and maintenance

- disbenefits such as loss of flood protection for areas exposed by embankment realignment

- direct benefits such as flood protection and enhanced security against breaching of the embankment

- indirect costs associated with the disruption and relocation of affected people

- indirect benefits accruing from an enhanced level of confidence amongst those who receive an improved standard of flood protection or for whom the risk of damage from an embankment breach is reduced.

The key variables in the decision making process (see Figure 21.1 for definition sketches) are:

- the set-back distance (SB) between the old and new embankment alignment

- the trigger distance (TR), being the minimum distance between the embankment and the bankline that triggers the decision to realign.

The optimal strategy should minimise both SB and TR, thereby minimizing the cost of each retirement as well as the disbenefit from loss of flood protection, whilst achieving a given level of security against breaching. It would also seek to reduce to a feasible and acceptable level the frequency with which the embankment would need to be realigned. This is discussed further in Chapter 7 of Annex 2 to this report.

6.6.8 Planned Routine Maintenance

Proper maintenance of all sections of the BRE is essential, and regular inspection necessary so that any areas of potentially rapid detioration can be dealt with in a timely manner.

One way which has been suggested, by the World Bank and others, to establish effective and on-going maintenance, is to give the people in the locality, those who already dwell on the BRE and those who may have to move there in the future following erosion of their land, an interest in the condition of the BRE. It is proposed that the future and upgraded sections of the BRE include the provision of a 5 m wide berm upon which such persons may be housed. This will have the twin advantages of removing the need (illegally) to cut benches in the BRE, and secondly to give people an interest in maintaining it.

The following extract from the IDA Appraisal Mission's Aide Memoire of July 1992 describes the proposal in more detail.

"The rural population in the locality affected by embankment retirement would be given first priority of sanctioned homestead construction on the land-side berm in return for participation in routine maintenance of the embankment strip (6 meters wide) covered under their settlement sanction; planting of trees or crops would be proscribed to allow only approved vegetation on the land-side. Thus, in addition to a 6 x 5 meter homestead plot, up to 80-90 sq.m. may be available for subsistence activities under a tenancy arrangement with BWDB. Families in the "unprotected" area or foreland of the retired BRE section would be given the option of a BRE homestead plot - under the above arrangement - as compensation for possible increased flood vulnerability. Similar options would be provided to squatters (erosion displacees and landless people) wishing to relocate to the retired embankment section. These arrangements are proposed on a pilot basis under the project in order to develop suitable solutions to social problems associated with embankment retirement impact problems, while attempting to simultaneously control the damage from terracing of the BRE structure by squatters."

7. EROSION PREDICTORS

7.1 Objectives

There are three principal applications for the Erosion Predictors:

(a) To provide warning to those owning land and property in the vicinity of the river bank as to the likelihood and magnitude of erosion so that appropriate preparations may be made to minise the impact;

(b) To provide the BWDB with the means of assessing the probable pattern of erosion and the risk that any section of the BRE will be breached as a direct result of bank erosion. This will allow them to determine (a) the latest time at which the embankment should be pro-actively realigned further landwards, before a breach occurs and (b) the most appropriate setback distance for the realigned embankment, taking into consideration the trade-off between low risk of breaching, frequency of realignment and area of land unprotected on the riverside of the embankment;

(c) To provide the basis for planning the medium and long-term measures for stabilizing the river's course and setting targets and priorities.

7.2 The Limitations on Prediction

All natural rivers with alluvial channels have an inherent tendency to meander with increasing sinuosity until a bend cut-off occurs and in a braided river consisting of multiple thalwegs, each deepwater channel will display this same characteristic. The meander wavelength is a function of the discharge and a single-thread river in reasonably stable valley will tend to take up the form that corresponds to the dominant discharge; adjustments to suit the varying flow are seen as growth and erosion of point bars. If the valley deposits are relatively erodible and mobile then seasonal variation will have more impact and planform changes will be more rapid but the dominant waveform will remain related to dominant discharge. In a braided river the situation is far more complex because the proportion of the total discharge carried by each deepwater channel, or anabranch, is constantly varying in response to the change in the angle of approach of the flow to the bifurcation. This angle of approach is in turn affected by the upstream confluence geometry, which itself is adjusting in response to the changing flow division around the upstream island or sandbar. A small change in the division of flow at the head of the system thus results in a highly non-linear chain reaction of adjustments all the way down the river. It is therefore not possible to define the dominant discharge of an individual channel in a braided river and consequently there is no definable single dominant meander wavelength. However since the river as a whole has a dominant discharge it is reasonable to expect that there will be some dominant pattern discernible, however complex this may be.

In rivers such as the Yangtze, which have lower sediment transport rates, this process is slower than in the Brahmaputra but is it very similar in form.

The relatively steep gradient and great discharge of the Brahmaputra together produce high stream power which, combined with the size of bed material results in high bedload and suspended sand size sediment transport rates. The large seasonal range of flow conditions means that the braided channel is constantly adjusting to the changing flow and these changes result in rapid movement of large volumes of sand, both as sand dunes and the much larger sandbars. The dunes move at about 100 m/d while the bars have an average migration rate of around 30 m/d. Significant local changes in channel geometry and bifurcation conditions can, therefore, take place over a timescale of weeks and the division of flow between channels is equally variable. The attempt of each channel to adjust its waveform to the changing conditions combined with the inherent tendency to increase sinuosity results in high rates of erosion along the concave bank of channel bends; where the channel impinges on the main floodplain or one of the more stable island chars, loss of cultivated land is inevitable unless the bank can be artificially hardened.

Prediction of precisely when and where such erosion will take place is simply not practicable because of the timescale and complexity of the processes at work and the stochastic nature of the flow variation. Even on the Yangtze, where the processes operate on a slower timescale and the river behaviour has been monitored for many years, it was not possible to predict where erosion would take place until the planform had been at least partially stabilized.

It is, however, possible to identify boundaries to the behaviour of the river and to assign probabilities to the range of values for parameters of practical interest, such as local rates and durations of erosion or accretion, velocity distribution, maximum near bank channel depth, overall bank movement and planform characteristics.

7.3 Local Bank Erosion Prediction

The primary concern in this case is likely to be the probable future duration of active erosion and whether it is likely to become more or less aggressive during the next high flow season.

Bank erosion is associated with acceleration of the near flow velocity and the most common causes of this are (a) the development of short radius bends, (b) the concentration of flow around one or both flanks of a large sandbar as it migrates down a relatively narrow channel and (c) the intensification of flow turbulence where two streams join downstream of an island or large sandbar, resulting in confluence scour.

Prediction of the initiation and progression of bank erosion, therefore, depends on recognizing which of these primary processes is, or is likely to be, dominant and then interpreting the data obtained from examination of the satellite imagery for the period 1973 to 1992 and the analysis of river cross-sectional data, in order to assign probabilities to alternative possible scenarios. The uncertainty attached to the prediction will be greatest at the commencement of the erosion period and will decrease gradually as the erosion cycle nears its end.

It will rarely be possible to predict the onset of severe erosion at a particular location due to the development of the relevant symptoms more than one year in advance, but it is possible, through a broad interpretation of the recognised cyclical patterns, to identify reaches that are likely to experience erosion within the coming one to three years. The probability of exceedance of erosion rates of varying intensity can also be computed for any reach of the river based on actual erosion that has taken place since 1973 or, with less confidence, since 1953.

The following river characteristics are pertinent when assessing the likelihood of erosion commencing, continuing or ceasing within a certain timescale.

(a) When considered as a whole, the river has shown a notably steady widening trend side since 1953 (Figure Plate 3) and it is reasonable to expect that this trend will continue, at least during the next decade.

(b) When viewed at the valley scale, the right bank of the river consists of relatively straight segments tens of kilometres long. Indentations or embayments rarely exceed 2,000 m and in general the variation is less than 1,000 m. The inference is that over a period of time bank erosion takes place fairly uniformly over the whole length of the river and that a reach that is currently experiencing no erosion, or some accretion, may be expected within a few years to experience erosion. This is consistent with the pattern of overall bank movement since 1953 shown in Plate 3, although it is clear that there are some reaches (such as between Fulchari and Sariakandi and between Sirajganj and Belkuchi) where the overall rate of right bank erosion since 1953 has been substantially lower than elsewhere.

(c) The 1988 monsoon season flood was substantially greater than normal both in terms of peak magnitude and total volume of flow, the latter probably being more significant morphologically. This resulted in markedly accelerated overall bank erosion that year followed by reduced erosion in the following years as the river reverted to its normal regime. However, the impact of the 1988 flood was also seen in 1989 and 1990 in the form of continuing, severe, localized erosion where aggressive bends had developed at Kamarjani, Chandanbaisa, Kazipur, Simla, Bera and Betil (probably associated with the movement of large sandbars formed from the excess sediment produced by the heavy bank erosion in 1988). By 1991, of these only Kazipur was still experiencing severe erosion. Thus, this recent flood event and its aftermath have inevitably produced a distorted perception of the severity and pattern of erosion in most people's eyes.

(d) Short radius, aggressive bends produce the most dramatic rates of erosion, with reliably recorded movement at the apex of up 700 m per year and the probability of even higher rates. Initially, it was thought that these bends were the primary mechanism of overall bank erosion, but more detailed examination of the satellite imagery has shown that they are in general shorter lived than previously thought and in fact are a relatively unusual phenomenon. Most bank erosion is associated with longer radius bends that tend to have a life of only one or two years and produce rates of erosion in the range of 100 to 300 m/y. Such bends are usually intermediate between no-bend and aggressive bend status.

This is consistent with the results of the analysis of the movement of the bankline since 1973, which has shown that the median value of bank erosion is of the order of 120-150 m/y (applicable to those stretches that are eroding, which constitutes some 75 percent of the entire bankline at any one time) while there is only 10 percent probability of its exceeding 300 m/y, and for 400 m/y it is a mere 5 percent. Aggressive bends wil continue to cause havoc when they do occur, if only because of their infrequency and rapid development. Early indicators are a bend radius, measured to the centre of the channel, reducing towards 3,000 m, and an angle of approach of the upstream anabranch to the mean bankline of between 25 and 35 degrees.

(e) Initial indications that high rates of bank erosion were directly linked with deep scour have not been substantiated by further investigation and this is an area that deserves further study. The tentative inference from the limited evidence is that bank erosion is associated primarily with high near bank velocities arising from bends and channel constrictions, whereas deep bed scour is associated with combinations of strong helical flow and intense turbulence. The key difference is the proportion of bed material being transported in short-term suspension. Thus, high rates of bank erosion are always associated with deep scour, but they can also occur under conditions of only modest bed scour where near bank velocities are high (e.g. Simla in 1988-89 and Mathurapara in 1988-92).

(f) Examination of the pattern of right bank movement since 1953, at 500 m intervals along the river, has shown that in general there appears to be an underlying mean rate of movement with alternating periods of more rapid erosion and balancing periods of slow erosion or accretion (Figure 7.1). There is insufficient duration of data for the identification of any sustained cyclical pattern, but from a systematic analysis of the available data from the satellite imagery starting in 1973 it has emerged that periods of both sustained erosion and accretion only infrequently exceed 5 years in duration, although periods of slow erosion may sometimes persist to 10 years or more. This is consistent with the life time of bends derived from the bend study and from general observation.

The procedure for predicting the probability of erosion and its magnitude over any short reach of the river, say of the order of 5 km, is therefore as follows:

Step 1

Determine from Figure 7.2 the primary reach number (1 to 4) and look up in Table 7.1 the mean erosion rates for the reach for the period 1973-92 for 5, 10, 50 and 90 per cent probability of exceedance. Note also the proportion of zero erosion and how this has varied with time; the erosion rates given relate only to those parts of the bank that were experiencing erosion during the respective period. Refer also to Table 5.1, which shows how overall mean erosion rates have varied with time.

Step 2

From Plates 3 to 5 note how erosion has varied spatially and temporaly in the vicinity of the reach in question.

Step 3

Pick out the plots of bank movement against time for the period 1953 to 1992 for the 500 m intervals in the study reach and at least 5 km upstream and downstream (10 km upstream and downstream will provide a broader overview). Note how movement rates have varied with time and relate these rates to planform changes visible on the satellite imagery. Features to note are:

(a) is present position above or below the long-term trend?

(b) is gradient over the past 3 to 5 years flatter or steeper than the long-term trend?

(c) if significantly flatter or steeper, how many years have elapsed since the last significant change in gradient?

(d) how does the study reach compare in these respects with the reaches upstream and downstream?

From the answers to these questions it should be possible to obtain a broad picture of the pattern of erosion and from reference to Figures 7.3 and 7.4 a reasonable estimate of the likely duration of current conditions.

Step 4

From examination of the satellite images determine what changes have taken place with regard to:

- char planforms;
- relative size of near-bank anabranch;
- general braid pattern in the vicinity and upstream;
- movement and change in shape of large sandbars in the immediate vicinity;
- angle of approach of the near-bank anabranch;
- bend radius of the near-bank anabranch;

From this information and reference to Figures 7.5, 7.6 and 7.7 it will be possible to infer the overall trend of the braid pattern in this vicinity and the most likely anabranch development that would be consistent with the pattern of bank erosion that is to be predicted from the results of Step 3.

An earlier example of this procedure is the note prepared in November 1992 concerning the layout of bank stabilization works for the Sariakandi/Mathurapara reach. This note is reproduced as Appendix B.

7.4 Reach Level Bank Erosion Prediction

At the reach level there is likely to be less concern with predicting the local pattern of erosion within the coming one or two years and greater emphasis on the probable movement of the bank over a timescale of 5 to 10 years, as this is the period over which the determination of the set-back distance for a realigned embankment will be based.

The considerations and approach will be in general similar to that described in the previous section, but with the main emphasis on the mean erosion rate and the expected duration of the general erosion pattern.

The strong consistency in the cumulative frequency plots shown in Figures 7.8 to 7.11 for seven different periods spanning 1973 to 1992 confirms that use of average values obtained from a reasonably long time series provides the best basis for planning purposes. These values must, however, be used in conjunction with an appreciation of the recent history of bank erosion in the subject reach and the long-term trends that are apparent from Plates 3 to 5.

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7.5 Longer Term Prediction

It can be seen from Plates 2 and 10 that three has been a modest net tendency for the river to move westwards as a whole since the avulsion that took place at the end of the 18th century and that this trend remains discernible during the period 1973 to 1992, although south of Sirajganj there is an indication of some net eastward movement.

Such a long-term westward trend, if it is indeed continuing, is however far less significant to bank erosion prediction than the strong tendency for the river to become wider which is very apparent in Plate 3 and Figure 7.12.

Setting aside morphological interpretation and arguments about the possible westward migration it is possible to forecast the bankline in the year 2011 by the simple method of extrapolating the movement that has taken place during a preceding period. For this purpose the detailed information obtained from analysis of the satellite imagery has been used to produce the result shown in Plate 13.

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Table 7.1 Bank Retreat (Sheet 1)

Reach 1: Northing 845000 to 780000

Proportion of zero erosion:
25.4 percent on average

Period	Percent
73-76	38.9
76-78	19.9
78-80	35.1
80-84	13.7
84-87	13.0
87-90	6.1
90-92	51.2

For the total period:

Exceedance percent	Rate m/y
5	500
10	400
50	150
90	70

Most severe period (highest median rate):	80-84	240 m/y
Most severe erosion (highest 5 percent exceedance):	84-87	650 m/y
Most mild period (lowest median rate):	90-92	100 m/y

All periods except 80-84 and 90-92 follow the mean for the period very closely

Reach 2: Northing 779500 to 757000

Proportion of zero erosion:
20.5 percent on average

Period	Percent
73-76	2.2
76-78	10.9
78-80	21.7
80-84	2.2
84-87	43.5
87-90	8.7
90-92	54.4

For the total period:

Exceedance percent	Rate m/y
5	420
10	330
50	140
90	70

Most severe period (highest median rate):	76-78	210 m/y
Most severe erosion (highest 5 percent exceedance):	76-78	500 m/y
Most mild period (lowest mediam rate):	90-92	110 m/y

All periods except 80-84 (high) and 90-92 (low) follow the mean for the period very closely

Very much less regular pattern than Reach 1. Very distinct tail off above 200 m/y. 76-78 and 80-84 stand out from the rest as periods of higher erosion rates.

2C

Table 7.1 Bank Retreat (Sheet 2)

Reach 3: Northing 756500 to 706000

Proportion of zero erosion:
20.9 percent on average

For the total period:

Exceedance percent	Rate m/y
5	420
10	330
50	150
90	70

Period	Percent
73-76	15.7
76-78	14.7
78-80	37.3
80-84	21.6
84-87	18.6
87-90	8.8
90-92	29.4

Most severe period (highest median rate):	87-90	240 m/y
Most severe erosion (highest 5 percent exceedance):	90-92	550 m/y
Most mild period (lowest mediam rate):	80-84	110 m/y

All periods except 80-84 (low) follow the mean for the period very closely

Overall period pattern almost identical to Reach 2. Individual periods less irregular. 80-84 stand out from the rest as period of lower erosion rates.

Reach 4: Northing 705500 to 640000

Proportion of zero erosion:
26.5 percent on average

For the total period:

Exceedance percent	Rate m/y
5	370
10	300
50	120
90	60

Period	Percent
73-76	20.5
76-78	25.8
78-80	35.6
80-84	47.0
84-87	6.1
87-90	8.3
90-92	42.4

Most severe period (highest median rate):	90-92	190 m/y
Most severe erosion (highest 5 percent exceedance):	90-92	570 m/y
Most mild period (lowest mediam rate):	80-84	100 m/y

All periods except 76-78 (fairly high) and 90-92 (high) follow the mean for the period very closely. Overall period pattern similar to other three reaches. Individual period patterns fairly regualr except for 90-92 which shows much higher rates in the 10 to 50 percent exceedance range.

8. THE SCOPE FOR CONTROLLING THE RIVER

8.1 The Objectives and Timescales

Before considering the scope for controlling the river it is first necessary to detail the objectives and the order of timescale attaching to these.

It is understood that the long term national objective is to stabilize the course of the river within defined limits and to provide controlled inundation to all agricultural land on both banks, and to any stable chars, and flood protection for substantial investment concentrations, in such a manner that any adverse environmental impacts are mitigated. It is accepted that this is an ambitious target and that it may take many decades to realise.

In the medium term the objective is to provide a more reliable level of inundation control within the flood plain areas, in order to encourage agricultural production and the growth of the rural economy, in such a manner that minimises the social stresses associated with the frequent breaching and retirement of the BRE and ensures that any adverse environmental impacts are mitigated.

In the shorter term the objective is similar to the medium term target but with the emphasis on mitigating, at the earliest opportunity, specific problems at a limited number of locations that have been identified by the Government as deserving priority attention. As far as possible these priority works should be consistent with the longer term targets.

As far as the short term objective is concerned, the scope of the BRTS is limited to the right (west) bank of the river. The medium term objective is such that the emphasis remains on the right bank but some consideration has to be given to the implications of any active intervention measures on the left bank and the central islands (chars). For the longer term targets, the river must be treated as whole and any comprehensive solution will involve at least some works based on the left bank.

8.2 Structural Intervention Options

Setting aside financial constraints, the conceptually possible modes of structural intervention, which are not mutually exclusive, may be classified as:

(a) Overbank flood flow control by means of one or more simple earth embankments constructed at a variable setback distance such that an optimal balance is achieved between benefits arising from reliability and controlled operation and disbenefits such as land loss and other social distress.

(b) Local stabilization of the existing bankline at locations where current and likely future bank erosion would result in severe damage to infrastructure and other investment and/or result in a substantial reduction in the flood control level of service that can be provided.

(c) A comprehensive set of large scale structural measures aimed at regulating the river planform at the reach level (say in 20 to 25 km units corresponding to island reaches). This work to be phased over several tens of years and to be responsive to the changing river behaviour.

(d) Active intervention in channel evolution by means of dredging and the construction of obstructions to flow.

The first three of these forms of intervention are technically feasible from an engineering viewpoint. The construction of the low earthen embankments involved presents no significant technical difficulties and if they are constructed to specification and receive an appropriate level of maintenance their life expectancy will be more than adequate. The provision of adequate cross-drainage facilities is similarly a straight forward engineering task. Although some minor slope instability has been observed on short sections of the existing embankment, there have been no substantiated cases of failure of properly constructed and maintained embankments from causes other than direct erosion or undermining by the river. The occasional reports of failure due to "rat-holes" are almost certainly cases of piping that have developed due to insufficient attention to routine maintenance. The engineering aspects of embankment design are discussed further in Chapter 15 of this report.

The basic technology for the design of bank stabilization works, and more active forms of river regulation structures such as groynes, is established and the only significant limitations lie in the vagaries of the river and the relatively difficult construction conditions that call for a higher than normal level of skill and management. By providing adequate contingency provisions and factors of safety, and accepting that designs will have to modified in response to actual performance, these limitations can be accommodated.

The technical feasibility of the fourth category has yet to be confirmed. The results of the 2-D morphological model studies described in Part 13 of the BRTS Report on Model Studies indicated that dredging in one channel and deposition in another, at the bifurcation at the upstream end of an island for instance, could have some limited effect. Such effect, however, was found to be relatively minor when compared to the effect of changes which might occur naturally, for example a change in the direction of flow immediately upstream.

9. THE CONSEQUENCES OF DIFFERENT LEVELS OF RIVER TRAINING (INTERVENTION)

9.1 General

The philosophy underlying the river management programme proposed in the Master Plan is the minimum divergence from the natural characteristics of the river. The concept is one of encouraging the river, by means of selected structural intervention, initially to become stabilized within its present boundaries. Only after this first stage has been achieved and the response of the river quantified would consideration of possible further confinement into a single channel be appropriate.

The principal forms and processes on which intervention could potentially have an impact have been addressed as follows:

9.2 Change 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 parameters, mean and maximum depth, width and conveyance, but a notable overall long term consistency with no discernible trends and little longitudinal variation. It is reasonable to infer from this evidence that the channel characteristics are prone to a stochastic variability, this being a reflection of the dynamic nature of the braided channel, but that provided the dominant discharge is not significantly changed there should be no induced change in the mean channel geometry. 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.

9.3 Bed Aggradation/Degradation

Well known cases of bed aggradation following on from river canalization have drawn attention to this potential hazard. This effect may result from either increased transport in the confined reach of the river, causing deposition in a lower unconfined reach, or from the planform stabilization of a river that is in a naturally aggrading state.

Although the timescale of the available data is short in relation to that of this type of process, the specific gauge analyses and the cross-section data analysis both indicate that the river is in a state of dynamic equilibrium. This was further endorsed by the 1-D morphological modelling carried out jointly with the SWMC. On these grounds, stabilization of the river alone should have no impact on mean bed level.

The effect of confinement of out-of-bank flows between continuous flood embankments has been investigated both through determining the impact on the dominant discharge and by means of the 1-D morphological modelling. The former showed that the impact of confinement only became significant if all left bank distributaries were closed off. The latter predicted that a confinement of the river to a maximum width of 6,000 m over its full length would have only minor impact on the average depth and bed level but that further confinement would result in increased sediment transport, resulting in a lowering of the bed level and consequent deposition in the Padma downstream until a new equilibrium was established.

The degree of stabilization and management presently envisaged should therefore have no impact on the average river bed level.

9.4 Change in Macro Planform

It has been suggested that confining the river could encourage it to change from a predominantly braided planform to a more meandering form and that this in turn might mean that larger more aggressive and inherently less stable bends could become more common.

The concern seems to arise from the perception that the river is in an unstable transition between meandering and braided and that any intervention may push it over the line into a meandering phase. The further presumption is that this would be hazardous because the meandering river would be less stable. The arguments applying to potential change in channel geometry would seem to apply equally in this case. Stabilization of the right bank alone will have no impact on the shape of the dominant discharge curve and therefore should have no direct impact on channel morphology overall. If it were to result in a lower braiding intensity locally due to channel planform stabilization then this could only be advantageous from a human perspective provided that the stabilization works were designed to prevent bends of dangerously short radius from developing.

9.5 Induced Bank Erosion and Scour

The problem of intervention at one point resulting in adverse impact elsewhere in the system is widely recognised. If accretion is encouraged in one location then this will normally be at the expense of net material loss at another location; this may take the form of bed scour or erosion of the opposite bank.

In the case of the Brahmaputra River, in which the products of bank erosion represents a high proportion of the net sediment throughput, there is the particular concern as to the consequences of arresting or reducing this erosion. It has been established that there is a close relationship between net bank erosion and net char growth and that the time interval linking the two processes is relatively short.

If it is accepted that the river is in dynamic equilibrium then by simple conservation of matter, any new material introduced from the bank that is not removed by the river in the form of wash load must be deposited in a char or temporarily stored in a sandbar. Although it is difficult to measure these two exchanges accurately, the computations that have been carried out support this thesis. In which case stabilizing the bank may be expected to have the effect of stopping further char growth but should not on average cause any loss of char land.

It is also expected that as a 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 for the 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 waveform of the river.

Looking for precedents, the only example of long-term stabilisation on the Brahmaputra is that associated with the town of Sirajganj, which dates back at least 20 years; the reach of the river immediately downstream is noted for its remarkable stability over the same timescale.

In short, the impact of right bank stabilisation works is expected to be a general stabilisation of the planform but that this may take several years to become discernible against the normal background of local planform variability.

9.6 Effect on Populated Chars

The more stable chars, whose tops are at much the same level as the river floodplain, are distinguished by their strong vegetative growth and semi-permanent population. Although the cores of many of these islands have a long life the peripheries undergo constant, and sometimes dramatic, change in shape. Stabilization of the main river banks alone will have no effect on the dominant discharge nor the frequency and duration of inundation of the chars; the influence on the stability of the islands arising from other processes, such as the shifting of thalwegs, is hard to predict but there is no known reason to suppose that the situation will become any worse than at present.

The construction of a continuous left bank flood embankment would result in some short-term increase in the frequency and duration of inundation of the chars, as would the construction of the Jamuna Bridge. The strip of floodplain between river bank and flood embankment would be similarly affected. The evidence provided by the development of new chars, with tops at floodplain level, over a period of only a few years suggests that this adjustment process could take place over a similar timescale.

10. SOCIOLOGY

10.1 The Sociological Impacts of River Training and Non-Intervention;

Socioeconomic field investigations have confirmed that for the riparian population perceived priorities are firstly bank stabilisation and secondly protection from major river flooding. The former to provide security at the most basic level and the latter to provide a major improvement to the opportunities for income generation at all levels in society. Opposition to flood protection is negligible.

Since an intensive bank stabilisation programme would involve large scale investment spread over several decades, the problems associated with bank erosion and maintenance of an effective flood protection structure have to be addressed in the short and medium term.

The principal issues then become firstly the setting of priorities for bank stabilisation, secondly ensuring that the interim measure of flood embankment realignment is carried out in the most efficient and least socially disruptive manner and thirdly, and perhaps most critically, how to accommodate the large number of people who will become displaced through bank erosion.

It is estimated that at present over 100,000 people are squatting, illegally, on the BRE and a further 30,000 have found temporary refuge in and around Sirajganj. It is further estimated that during the coming five years alone more than 7,000 ha will be lost to erosion and at least 50,000 more people will become homeless. The accretion of habitable new char land is relatively small in comparison to the loss of mainland to erosion, and since there are many displaced householders on the chars, the net benefit of resettling these newly emerged areas is insignificant. Since the BRE is rapidly becoming fully utilised as a refuge this will mean that a large number of people will find themselves with no immediate solution to their dilemma and the problem will spread to an increasing hinterland. The social and political ramifications are self-evident.

Compared with this major problem, the issues relating to the optimal management of planned flood embankment realignment may appear parochial but they are of importance not only to those immediately affected but also to the large number of farmers in the floodplain who suffer whenever there is a breach in the embankment. At present the process of realignment is carried out with only a low level of consultation and opportunities for local participation are not exploited. Certain key issues need to be addressed. Firstly, at the local level: setting up an effective procedure for reaching agreement on the optimal tradeoff between the two conflicting requirements of providing the maximum number of people with flood protection (minimising set-back) and the social upheaval, disruption and division that is associated with frequent realignments. This can only be effectively addressed at the local level. Secondly, at the national level: upgrading the institutional structure to enable the sensitive subject of land acquisition to be implemented in a manner that is equitable and efficient. Both these issues fall within the scope of FAP-15. Thirdly, also at the national and regional level, institutional arrangements have to be strengthened in order to provide the framework for the setting of priorities for bank stabilisation, providing the necessary financial and logistical support for planned BRE alignment, addressing the plight of the massive displaced population, and mitigating the harsh conditions faced by those left exposed on the river side of the embankment.

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Much can be done to improve conditions for this latter group in the way of relatively low cost measures that fall under the general heading of Flood Proofing: improved raised earthfill platforms for houses and commercial and public premises; road and footpath embankments; livestock and human refuge highpoints; secure dry storage facilities; reliable all season water supply; effective relief and rehabilitation services; flood warning.

The impact of flood embankment realignment can be alleviated by local consultation and greater involvement of those affected. Many of the reported problems relating to holding fragmentation and exacerbated social division are potentially capable of mitigation given the appropriate approach to the issue. Loss of productive land to borrow areas can be mitigated by a greater emphasis on sourcing of material.

For those displaced by erosion the problems are more difficult to resolve but priority should be given to formalising the occupation of the flood embankments and designing the realigned sections in order to provide the maximum refuge potential. Participation in maintenance, and possibly also realignment, by those resident on the embankment is a possibility that deserves serious consideration.

10.2 Master Plan Alternative Strategies

The social impact analysis shows an overall strong preference for maximum flood and bank protection.

- The first option of taking no action would be seriously damaging. Increasing breaches and the probable break through of the Brahmaputra into the Bengali would seriously harm livelihood of some 3 million people. Bank erosion would continue to displace 10,000 a year and they would have an ever-decreasing area on which to resettle. The remaining developmental benefits of 25 years of flood protection would ultimately be lost.

- The second option, retaining the BRE but not undertaking protection works, would require the realignment of the Bengali River if the southern reaches are not to be affected as in option 1. Even so, the southern reaches would be very vulnerable and over a million people living downstream of Sariakandi could be directly affected. Erosion and its harmful social effects would continue unabated.

- The third option comprises three parts which if all followed, would form a sequence.

- Priority bank protection works at two localities

- Further protection works at three further localities

- Full stabilisation of the right bank.

From the social perspective bank protection works with continued presence of the BRE is the ideal. Realignment of the embankment would ultimately cease after an intervening period of planned realignment. Displacement by erosion would be insignificant compared with the present situation. The BRE could be developed as a stable flood proof housing development for some 170,000 people will small scale food production, good communications and reliable protection for the population to the west.

These issues are discussed in greater detail in Annex 1 to this report.

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11. AGRO-ECONOMIC AND OTHER BENEFITS

11.1 Introduction

11.1.1 Background

Over a period of 15 to 20 years since its construction, the BRE provided effective relief from uncontrolled and sustained inundation resulting from high flood flows in the Brahmaputra River. This has facilitated a substantial increase in agricultural production, as well as enhancement in the general development in the protected areas, despite having an adverse impact on the fisheries sector.

In recent years, the continuous erosion of the right bank of the river has resulted in frequent breaches of the BRE, and consequently the level of security against damaging floods has significantly declined. Furthermore, river bank erosion has very considerable direct consequences with the loss of agricultural land and settlements displacing large numbers of people.

Breaches of the BRE are increasing in frequency as progressively greater lengths of the old BRE become within range of aggressive river bends. The present strategy of realigning the BRE at relatively short set back distances from the bankline has also led to a higher degree of breaching and frequent retirements of the BRE within a reach experiencing rapid erosion.

The Economic Assessment, Annex 2, is primarily concerned with the economic implications of the bank protection and BRE realignment at several priority locations, but also addresses other aspects of the Master Plan such as an optimal strategy for BRE realignment and the overall economic costs and benefits of long term bank stabilization. Financing constraints to the implementation of the Master Plan are also considered.

11.1.2 Objectives of the Economic Assessment

The main objectives of the economic assessment are to:

- evaluate the economic consequences of river bank erosion in relation to land, property and infrastructural losses;
- evaluate the economic consequences of flooding from a breach in the BRE with regard to crop and livestock losses, property and infrastructural damage;
- estimate the economic capital and recurrent costs of river bank protection works and BRE realignment;
- determine the economic viability of each priority location, and rank projects on the basis of standard economic criteria.
- determine an optimal strategy for embankment realignment; and
- evaluate the economic costs and benefits of long term bank stabilization

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11.1.3 Information Sources

The information required for the evaluation of the consequences of river bank erosion and flooding from a breach in the BRE has been collected from both primary and secondary sources.

With regard to the primary sources, a field survey was undertaken in November 1990 as part of the preliminary selection and ranking of priority locations. This survey was undertaken by the BRTS Team Leader, Economist and River Engineer in order to obtain a contemporaneous set of data of the consequences of river bank erosion and breaches in the BRE. In early November 1991, a further rapid rural appraisal was conducted with a view the assessing the current situation in relation to bank erosion and BRE retirement, as well as to update and supplement information gathered during the 1990 survey. The 1991 survey was undertaken by the BRTS Economist and Sociologists (N.B. one of the primary tasks of the survey was to undertake an assessment of the social implications of the river bank erosion). All six priority sites were visited, namely Fulchari, Sariakandi, Mathurapara, Kazipur, Sirajganj and Betil.

Given the limited time available for primary data collection, particularly with regard to information required for a thorough assessment of the wider agricultural implications of flooding from breaches in the BRE, the economic appraisal was very dependant on secondary sources. The main sources of secondary data are given in Table 11.1.

Links were also established with other FAP studies, e.g. FAP-5 (S.E. Regional Study), FAP-14 (Flood Response), and FAP-23 (Flood Proofing).

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Table 11.1 Main Sources of Secondary Data

Source	Information Available
NW Regional Study (FAP-2)	Cropping systems; irrigated areas; crop yields and input usage; labour and draft power requirements; livestock and fish production; input and output prices; crop and non-agricultural flood damage.
FCD/I Agricultural Study FAP-12(Rapid Rural Appraisal)	Similar data to FAP-2, but for specific locations within BRE project area, ie. Kazipur and Kamarjani.
Bangladesh Bureau of Statistics (BBS)	Farm structure; land use crop areas; crop yields, crop flood damage; livestock and fish production. Size and distribution of population (1981 census); Public welfare facilities; Rail and Road infrastructure.
BWDB Evaluation Study of BRE, 1986	Agro-economic data similar to FAP-2
BWDB	Crop and Non-Agricultural Flood Damage Capital and O & M Expenditure on major Civil Works
Local Government Engineering Bureau (LGEB)	Unit costs of public buildings and infrastructure
Master Planning Organisation (MPO)	Flood regimes and agricultural production systems, irrigated areas
Jahangirnagar University (Geography Department)	Study of the Socio-Economic Impact of Bank Erosion
Urban Development Directorate, Ministry of Works	Sirajganj Paurashava Master Plan
Ministry of Local Government	Municipal Budgets
Ministry of Finance	Macro-economic trends Government Expenditure Foreign Aid

11.1.4 FAP Guidelines for Project Assessment

The methodology applied in the economic analysis has been based on the principles and procedures outlined in the FAP Guidelines for Project Assessment (FPCO July 1991). The Guidelines are based on internationally accepted techniques for the economic appraisal of investment projects. In addition to establishing a standard methodology for economic assessment of FAP projects, the Guidelines also provided the conversion factors to adjust financial prices to economic prices, and these have been used in the analysis.

11.2. River Bank Erosion Losses

11.2.1 General

On the basis of the information gathered during the field surveys and from secondary sources the economic consequences of river bank erosion were derived.

The economic implications were estimated from a valuation of the land, property and infrastructure likely to be lost as a result of river bank erosion over a thirty year period (i.e. the economic life of a project as given in the FAP Guidelines).

11.2.2 Land

For the purpose of valuation, land was divided into five categories - protected (by the BRE) agricultural land, unprotected agricultural land, market land, land within Upazila HQs and urban land. Estimates of the areas likely to be eroded over the next five years for each of the six priority locations are summarized below in Table 11.2. Area estimates have been based on length of reach experiencing erosion and the expected rates of erosion. Expected erosion rates have been determined from an analysis of the frequency of different erosion rates at a given location over a period of 20 years (1973 to 1992), i.e a probabilistic approach has been applied.

Table 11.2 Area and Economic Value of Land Expected to be Eroded over the Next Five Years at Priority Locations

Priority Location	Length of Reach (km)	Expected Erosion Rate (m/annum)	Total Area of Eroded Land Over the Next 5 Years (hectares)	Total Economic Value (`000 Tk)
Fulchari	12.5	60	375	86,900
Sariakandi	11	100	550	174,000
Mathurapara	11	100	550	74,375
Kazipur	17	75	640	128,500
Sirajganj	19	90	855	1,571,000
Betil	18	95	855	187,500

It is evident from the above table that there are significant differences between the various sites, which mainly reflect the expected rates of erosion but in the cases of Sirajganj and Sariakandi are a reflection of the urban development.

The disparity in land values can be seen from the economic prices applied, as shown in Table 11.3.

Table 11.3 Economic Prices of Land

Land Category	Economic Value: (`000 Tk/ha)
Agricultural Land (Unprotected)	125
Agricultural Land (Protected)	200
Market Land	500
Upazila HQ Land	1,000
Urban Land	3,000
Peri-Urban Land	900

The economic prices of agricultural land were determined on the basis of the present value (PV) of the economic net value of production over 50 years at a 12% discount rate. The prices of market and Upazila HQ land were derived from the current financial prices.

Urban and Peri-Urban land prices were based on the estimates given in the Sirajganj Master Plan (1991) prepared by the Urban Development Directorate of the Ministry of Works. The economic prices of non-agricultural land are assumed to equate with their financial values.

11.2.3 Property and Infrastructure

In order to estimate the economic value of property likely to be lost or displaced over the next thirty years, public and private property were divided into three broad categories - pucca, semi-pucca and katcha. Estimates of the number of properties within each category for each location were made, based on Upazila statistics and information collected from local government officials during the course of the field surveys, as well as interpretation of aerial photographs. For Sirajganj, some information was also provided in the Sirajganj Master Plan (1991), but regrettably no aerial photographs were available for the town.

With respect to the valuation of these different categories of property, it should be noted that for semi-pucca and katcha buildings including weaving sheds, the values are based on the costs of relocation coupled with the damage to the existing structure during dismantling whereas pucca buildings have been priced at their full replacement cost (based on LGEB rates). The economic unit values of the property likely to be lost or displaced were derived from their current financial value adjusted by the standard conversion factor of 0.82. The economic and financial unit values are given in Table 11.4.

Table 11.4 **Economic Prices of Property**

Type of Property	Financial Unit value (`000 Tk)	Economic Unit Value (`000 Tk)
Public Building [1]/		
-pucca	1,500	1,230
-Semi-pucca	250	205
Commercial/Industry		
-pucca	1,500	1,230
-semi pucca	250	205
Private Houses/Shops		
-pucca	300	246
-semi-pucca	15	12.3
-Katcha	5	4.1
Weaving Sheds	30	24.6

1. School, health centres, clinics, government offices, P.O.s, godowns, covered markets, banks, mosques etc.

An attempt was also made to estimate the value of the potential loss of public infrastructure, such as roads, bridges, culverts, railway embankments, at risk from erosion over the next 5 years. Estimate of the likely physical losses were made on the basis of aerial photographs, maps and inspection during the field trips.

The economic unit values applied to the physical parameters were derived from the current financial unit value (based on LGEB rates) and adjusted by appropriate conversion factor (see Table 11.5). The costs of relocating the ferry ghats are based on the economic costs of employing a labour gang to regularly reshape the gangways and ramps to floating pontoons and jettys and to reconstruct a temporary bulkhead, during periods of active erosion. At Fulchari, the cost of land acquisition to resite the railway sidings is also included.

Table 11.5 Economic Prices of Infrastructure

Type of Infrastructure	Financial Unit		Conversion Factor	Economic Unit Value (`000 Tk)
	Unit	Value (`000 Tk)		
Pucca Road	km	2,000	0.80	1,600
Katcha Road	km	400	0.76	304
Railway Embankment	km	3,000	0.76	2,280
Power and Telephone Lines (relocation cost)	No.	25	0.83	20.75
Ferryghat (relocation) costs/annum)	No.	240	0.76	182.4
Bridges/Culverts (road and railway)	No.	300	0.78	234

The total economic value of property and infrastructure likely to be lost to river erosion over a five year period at each priority location is summarized in Table 11.6.

Table 11.6 Economic Value of Property and Infrastructure Expected to be Lost over the Next Five years at Priority Locations.

Priority Location	Property	Economic Value ('000 Tk) Infrastructure	Total
Fulchari	42,312	15,060	57,372
Sariakandi	69,003	16,708	85,711
Mathurapara	12,505	4,018	16,523
Kazipur	39,934	9,044	48,978
Sirajganj	322,055	54,880	376,935
Betil	56,375	15,328	71,703

11.3 Losses Related to a Breach in the BRE

11.3.1 Impact on Agriculture and Fisheries

Estimates of the economic consequences of flooding from a breach in the BRE were also taken into account in the appraisal. The economic implications were derived from a valuation of:

- crop damage;
- livestock losses;

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- impact on future agricultural and fisheries production; and
- property and infrastructural damage

Crop Damage

Crop damage due to flooding through a breach in the BRE can broadly be divided into two categories:

- areas severely affected in the immediate vicinity of the breaches, where crops are devastated by the volume and velocity of the flood water and sand deposition;

- areas partially affected by breaches, as a result of higher levels and longer periods of inundation.

(a) Severely Affected Areas

In the severely affected area within the close proximity of a breach, it has been assumed that a total loss of one years cropping will be experienced. In economic terms, this is reflected in the overall annual net agricultural benefits for the total area severely affected. In the locations where breaches have recently occurred, e.g. Kazipur, Mathurapara and Sonali bazar, farmers report a total loss of the monsoon rice crop following a breach. It is also very difficult to successfully cultivate a monsoon rice crop in subsequent years when the area is exposed to high velocity flood water and deep inundation.

Furthermore, a heavy deposition of fine sand occurs at the time of the breach which initially renders the land unsuitable for crop production in the following Rabi season. In subsequent years, farmers attempt to grow Boro rice or other Rabi crops, but productivity is low. Increasingly, these areas are being planted with sugarcane, which is able to withstand high levels of inundation although yields are reduced.

The scale of the areas severely affected by a breach in the BRE varies between locations and is related to the length of the breach. However, information based on the interpretation of aerial photographs, coupled with field visits to breach locations, indicates that a breach typically devastates an area extending to approximately 3.5 to 4 sq.km (400 ha). This estimate was used in the analysis at each priority location.

With regard to the valuation of the crop losses in the severely affected areas, the overall gross margin per hectare (in economic terms) that would be obtained from one year's crop production has been applied to the area affected. In subsequent years, it has been assumed that only sugar cane will be produced for a five year period, so the annual gross margin for sugar was used. The cropping patterns within the two agricultural zones of the BRE project area, together with the derivation of the economic crop gross margins, are fully discussed in Appendix B of Annex 2.

The total area and net economic value of production lost due to flooding in severely affected areas at each priority location are summarized in Table 11.7.

Table 11.7 Total Area and Net Economic Value of Crop Production Expected to be Lost in Severely Affected Areas

Priority Location	Severely Affected Agricultural Area (ha)	Reduction in Net Economic Value per Hectare		Overall Reduction in Net Economic Value:	
		Initial Year	Future Years	InitialYea r	Future Years
		(Tk/ha)		(`000 Tk)	
Fulchari	400	23,581	13,898	9,432	5,559
Sariakandi	320	24,140	14,457	7,725	4,626
Mathurapara	385	24,140	14,457	9,294	5,566
Kazipur	360	22,413	12,730	8,069	4,583
Sirajganj	100	21,559	11,876	2,156	1,187
Betil	345	21,559	11,876	7,438	4,097

N.B. Non-agricultural land (e.g. market, Upazila HQ and town land) severely affected has been excluded from the calculation of crop damage estimate.

(b) Partially Affected Areas

In the areas affected by higher level of inundation caused by breaches in the BRE, a more objective assessment of crop damage was undertaken. In this assessment, the timing, duration and depth of flooding was related to the stage of growth of the crop, taking into account the range of cropping patterns that are likely to be prevail within each zone.

Time series data on the magnitude of change in the depth and duration of flooding resulting from various breach scenarios, at a given 10 day time interval, were generated by the Breach Simulation Model (see Annex 2 of the BRTS Second Interim Report). In spite of the limited time series data available (1986 to 1989), the results of the simulation model did permit the derivation of crop damage frequency curves, and thereby the calculation of expected annual crop losses at each priority location. The crop loss estimates obtained were regarded as a sufficiently accurate representation of a typical year for the purpose of the economic analysis.

On the basis of this information on the timing, duration and depth of flooding, it was possible to estimate the incremental areas affected (i.e. additional to normal flooding) for each breach location during the peak flood period in 1986, 1987, 1988 and 1989. This was derived from the cultivated areas which remained submerged, i.e. switched from F0 to the F1, F2 and F3 flood regimes (see Appendix B) for a period is excess of 10 days. These areas are presented in Table 11.8. For example, in Fulchari an additional 8,630 hectares of F0 land remained inundated for a period in excess of 10 day during mid to late July 1989. The reduction in unit economic crop gross margins for each year were then applied to these incremental crop areas in order to derive the overall net economic value of production losses.

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Table 11.8 Incremental Areas Affected by Flooding From a Breach

Priority Location	Incremental Area Affected (ha)			
	1986	1987	1988	1989
Fulchari	145	29,563	35,787	8,630
Mathurapara/Sariakandi	373	49,344	59,835	41,891
Kazipur	280	17,692	19,659	12,946
Sirajganj	23	2,547	996	1,295
Betil	26	2,380	257	216

Estimates of the percentage crop loss resulting from different durations and depths of flooding at various stages of growth (from planting to harvesting) were made for each crop during the Kharif season.

Return periods were then assigned to each year based on the 10 day annual maximum flood flows in the Brahmaputra between 1956 and 1989. Frequency (probability of non-exceedence) estimates were than derived from these return periods for each year (1986 to 1989) and plotted against the overall net economic value of production losses. On the basis of these crop damage frequency curves, estimates of the expected annual average crop losses (calculated as the sum of the cost and frequency differentials) were determined for each priority location. The values of expected crop losses are summarized below in Table 11.9.

Table 11.9 Net Value of Production Expected to be Lost as a Result of Inundation from Breach in the BRE

Priority Location	Expected Net value of Production Lost ('000 Tk)
Fulchari	55,499
Sariakandi/Mathurapara	181,435
Kazipur	58,245
Sirajganj	5,909
Betil	2,121

N.B. In the breach simulation model, the impact of breaches at Sariakandi and Mathurapara were regarded as identical, given their close proximity.

Changes in Cropping Patterns as a Result of Regular Annual Flooding

In addition to the specific crop losses resulting from a breach in the BRE, the other main area of concern is the effect on future cropping systems and agricultural development within the BRE protected area. In the analysis, it has been assumed that if a breach remains open farmers would not just accept annual crop losses from repeated flooding, but would adjust their cropping patterns in response to the changes in flood regimes. This situation only arises at the Sariakandi/Mathurapara location. For the other locations, it has been assumed that a breach would be repaired under the present `ad hoc' system of embankment realignment.

Most of the agricultural benefits from flood control have primary resulted from an expansion of HYV T Aman during the Kharif season replacing either B Aman or a mixture of B Aus and B Aman. With continued exposure to flooding from a breach, this development will be reversed. The Rapid Rural Appraisal (RRA) of Kazipur, undertaken by FAP-12, found evidence for this change in cropping systems resulting from a frequent breaching of the BRE.

Livestock

Discussion with farmers during the field surveys revealed that significant livestock losses were experienced in the areas severely affected by a breach in the BRE. No accurate statistics are available on livestock losses, and the approximate numbers of cattle, goats/sheep, and poultry can only be estimated. The valuation of these livestock losses were based on the current market prices converted to economic values by the standard conversion factor. The overall valuation of livestock losses at each priority location is given in Table 11.10.

Table 11.10 Economic Value of Livestock Losses as a Result of a Breach in the BRE

Priority Location	Value of Livestock Losses ('000 Tk)
Fulchari	1,070
Sariakandi	1,021
Mathurapara	1,070
Kazipur	1,046
Sirajganj	484
Betil	996

With regard to the impact on future livestock development within the BRE protected area, it has been assumed that breaches in the BRE would not have a significant effect.

In general, flood control projects have had an adverse impact on livestock feed resources through reducing fallow and grazing land, and by switching to short-strawed HYV of rice. (HYV straw also has much lower levels of digestibility and palatability than local varieties).

This has led to a deterioration in livestock health and productivity, as well as a marked decline in livestock numbers, particularly cattle which are reported to have decreased by 25 % to 40 % over the past ten years in certain parts of the BRE protected areas. Coupled with the increase in cropping intensity, this decline has created a noticeable shortage of draft power, especially for small and marginal farmers.

Flooding from a breach in the BRE is not likely to make a significant contribution to livestock feed resources, and so will have neither a negative nor positive impact on future livestock populations and productivity.

Fisheries

Capture fisheries has been identified as one of the sectors worse affected by flood control projects. The main negative effects of FCD/FCD1 schemes on fish production can be summarized as follows:

- construction of flood control embankments has reduced the area of perennial beels and floodplain available for fish spawning, nursery and feeding grounds, thereby reducing the overall fish production potential. This not only affects capture fisheries, but also pond culture fisheries which depend partly on the collection of fish fry from the wild;

- construction of regulators and cross dams prevents migration of fish to and from breeding grounds, has resulted in reduced stock of migratory species (principally higher value carp and prawns) and different species composition;

- the reduced area of open water within the flood protected area has severely restricted subsistence fishing, with detrimental consequences on the income and nutrition of the poorest section of the community;

- reduced fish stocks and lower catch rates have endangered the livelihood of fisherman, many of whom have been forced to migrate from the protected areas in search of alternative employment;

- increased uses of chemical fertilizers and pesticides, associated with the adoption of HYVs has led to the pollution of natural water bodies and to higher fish mortality rates.

Quantification of any of these impacts is subject to a high degree of uncertainty, but it is now well accepted that flood control projects have very serious detrimental impacts on fish production and fishermen within the protected areas of a floodplain.

Capture fisheries appears to have suffered seriously in the past decade. Recent appraisals undertaken by FAP-12 in the BRE project area suggested that the annual fish production has decreased by about 35 % to 40 % in the Kamarjani area (as reported by fishermen and fish traders). Similarly, in the Kazipur area, fish production is estimated to have declined by up to 50 %.

Some improvements could be made to increase fish stocks in the floodplain; but, without natural replenishment, stocks will continue to decline.

To a limited extent, these negative consequences can be offset by:

- a reduction in the risk of losses of fish pond stocks due to flooding, which could encourage a more rapid development of fish farming;

- an improvement in the prospective returns from fish production in other water bodies, such as borrow pits.

With regard to river fishing (primarily artisanal), the situation is also one of decline with diminishing annual fish catches and reduced stocks.

11.3.2 Property and Infrastructural Damage

Damage to property (public and private) and infrastructure has also been divided into (a) areas severely affected in the immediate vicinity of the breach, devastated by the volume and velocity of the flood water, and (b) areas partially affected by the breach as a result of higher levels and longer periods of inundation.

(a) Severely Affected Areas

In the severely affected areas, the number of properties likely to be damaged or relocated as a consequence of a breach at each priority location have been estimated. These estimates are based on interpretation of aerial photography and information collected during the field surveys. With respect to the valuation of the different categories of property, the values of semi-pucca and Katcha buildings are based on the costs of relocation and the damage to the existing structure during dismantling. Whereas, damage to pucca buildings has been taken at 50 % of their full economic replacement value.

An attempt was also made to estimate the value of the damage to public infrastructure at risk from flooding. Estimates of the likely physical impact were made on the basis of aerial photographs, maps and inspection during the field trips. The valuation of this infrastructural damage was based on full economic replacement cost of the damaged length of road, railway embankment etc.

The total economic value of property and infrastructure likely to be severely damaged or relocated as a result of breach at each location is presented in Table 11.11.

Table 11.11 **Economic Value of Property and Infrastructure Expected to be Damaged by Flooding in Severely Affected Areas**

Priority Location	Economic Value of Property and Infrastructure Damaged by Flooding ('000 Tk)		
	Property	Infrastructure	Total
Fulchari	6,929	7,030	13,959
Sariakandi	20,295	8,800	29,095
Mathurapara	7,175	2,222	9,397
Kazipur	13,243	6,194	19,437
Sirajganj	77,572	20,807	98,379
Betil	22,161	8,028	30,189

(b) Partially Affected Areas

Severe floods of the magnitude of those in 1987 and 1988 can cause extensive damage to property and infrastructure, as well as causing temporary dislocation of economic activity. However, in most years the effects of flooding on property and infrastructure are minimal. To quantify the likely extent of flood damage averted by flood control embankments, it is necessary to calculate the mean expected damage without protection by deriving a flood damage frequency curve.

On the basis of flood damage frequency curves derived for the N.W. Regional Study (FAP-2) annual values of expected damage were determined for each district. A summary of the expected damage is given in Table 11.12 below.

Table 11.12 **Economic Value of Property and Infrastructure Damage Expected in Partially Affected Areas**

Priority Location	Value of Property and Infrastructure Damage ('000 Tk)
Fulchari	1,170
Sariakandi/Mathurapara	4,263
Kazipur	1,359
Sirajganj	139
Betil	44

11.4 Indirect Economic Effects and Transport Considerations

11.4.1 Indirect Economic Effects

The immediate threat of river bank erosion is obviously an extremely strong disincentive to both private and public investment. This is illustrated in Fulchari, where no replacement or repair has been undertaken of the public buildings and roads in recent years. River bank erosion also marks an abrupt end to the benefits derived from previous investment; thereby severely curtailing their effectiveness.

By enhancing the current levels of public and private investment within the BRE protected areas, greater growth would be generated thereby increasing employment opportunities in both agriculture and rural industries. Increased public investment would also lead to an improvement in communications and transport which would further enhance incomes and employment opportunities. Similarly, greater government investment in schools and health centres would improve the quality of life of families living within the BRE project area.

The approach used in the economic analysis, in accordance with the FAP Guidelines, was not to quantify these secondary and multiplier effects. Any assumption made with regard to these effects would be wholly speculative and with little foundation as there is insufficient of data on which to make reliable estimates. Nevertheless, these secondary benefits could make an important contribution to the economic development of the BRE project area.

It should be noted that, in rural areas, these indirect economic effects are not wholly attributable to the capital investment in river bank protection, and so there is a danger of overstating these potential benefits. For example, agricultural production is likely to continue to be increased with an expansion in Rabi season cropping as a consequence of irrigation development (see Appendix B of Annex 2). However, for urban areas such as Sirajganj, river bank erosion and flooding have very considerable implications for the neighbouring population and other towns with trading links. A factor in the order of 1.25 to 1.30 could be applied to the direct benefits of the Sirajganj Town protection works to reflect these indirect economic losses.

11.4.2 Transport Considerations

<u>River Navigation</u>

An explained in more detail in Annex 2, the effects on river transport are likely to be minor, and limited to the periods of construction. Such effects will arise primarily from the dredging operation, either from deposition of sediments or interference from floating discharge lines. Contractors will be obliged to keep these adverse effects to the minimum.

The impact of river bank erosion on ferry ghats has already be taken into account in the assessment of project benefits (Section 11.2.3), in which an allowance was made for the cost of relocating ghats at regular intervals during periods of active erosion. This is not regarded as a difficult operation, and disruption to services is kept to a minimum.

Overall, the impact on river navigation is therefore likely to be small either with or without the project.

Railway Transport

Bangladesh Railway operates two ferry ghats along the right bank of the Brahmaputra, one each at Sirajganj and Fulcharighat. In both cases the ferry vessels have a loaded draft requirement of 1.5 m. During the dry season, January to March, the service is sometimes discontinued for want of adequate depth of water.

River bank erosion does not create any major problems for the railway services, as ghats are relocated and railway track realigned as and when necessary; with little disruption to services. However, at Fulchari, after a period of between five and ten years, a marshalling area will be at risk and consequently will require relocation. At a later date, bank erosion may have progressed to a point where the main railway line is under threat, and realignment will inevitably create some disruption to the train services.

In general, there is not likely to be any major impact on railway services as a consequence of the implementation of bank protection works. In contrast, the construction of the Jamuna Bridge would effectively result in the termination of ferry services at Sirajganj, and considerably reduce the importance of Fulcharighat hastening its present decline. The Jamuna Bridge will clearly have an overriding impact on not only the ferry services across the Brahmaputra, but also the whole transport system of the North West Region. Any effects (either direct or indirect) on transportation as a consequences of river bank erosion or flooding are therefore insignificant in relation to the impact on communication resulting from the construction of the Jamuna Bridge.

Road Transport

The direct consequences of bank erosion on the road infrastructure have been taken into account in the assessment of benefits to the projects (Section 11.2.3). Similarly, the economic consequences of flooding from a breach in the BRE have also included road infrastructure. However, the temporary dislocation and disruption to services caused by damage to roads and bridges has not be formally quantified in the analysis. These intangible benefits to improving flood protection should not be over looked and could be included to enhance the economic benefits of BRE realignment. Given the very strong economic case for a planned strategy to realign the BRE along reaches that will remain unprotected from river erosion, such increases in the benefit stream are unnecessary.

As with rail transport, the construction of the Jamuna Bridge will have a major impact on the present and planned road transport services, as well as the future development of road infrastructure, throughout the North West Region. In comparison, the effects of bank protection work and BRE realignment are of little consequence.

11.5 Social Consequences and Employment Impact

11.5.1 Social Consequences

In the economic analysis of priority locations, the social consequences of river bank erosion and flooding from a breach to the BRE, have merely been reflected in terms of the number of people likely to be displaced over the next five years (see Table 11.13). A more thorough assessment of the social implications is presented in Annex 1. While population data are useful for comparative purposes, there is the danger of understating the dire consequences of river bank erosion and severe flooding for a very substantial number of poor families. The loss of land and livelihood, as well as physical, emotional and financial costs of displacement, which renders the vast majority of the displaced population destitute, cannot be adequately assessed in quantitative manner. It is also inappropriate to evaluate these social costs or to equate them with the economic consequences of river bank erosion and breaching. There are, at present, no government programmes to resettle, rehabilitate or even assist these displaced families in finding alternative sources of income, and this must become a matter of priority.

It should also be noted that there is often loss of life at the time of a breach; and although this has not been quantified in the analysis, it is clearly an important factor to take into account in the appraisal of proposed capital investment. In general, from both the social and economic viewpoints, it is imperative that the serious consequences of a breach in the BRE are avoided through a timely and planned realignment of the BRE (in the absence of bank protection works) during periods of active erosion.

Table 11.13 Population Expected to be Displaced by River Bank Erosion and Flooding over the Next Five Years

Priority Location	Number of People Displaced by	
	Bank Erosion	Flooding in Severely Affected Area
Fulchari	13,500	3,600
Sariakandi	20,200	8,700
Mathurapara	8,450	5,000
Kazipur	15,940	7,600
Sirajganj	46,000	31,000
Betil	18,500	8,800

11.5.2 Employment Impact

With regard to the employment impact, the primary aim of bank protection works is to avoid the loss of land and capital resources and consequently the flow of production and employment benefits which are generated by the use of these resources. In the FWO scenario, food grain production and agricultural employment benefits are expected to be lost either directly from bank erosion or as a consequence of flooding from a breach in the BRE.

In addition, there would also be considerable employment and production disbenefits resulting from the loss and/or damage to agro-industrial complexes in urban centres (such as Sirajganj).

The further loss of employment opportunities and sources of income for the population living in the vicinity of the Brahmaputra right bank will considerably aggravate the already very serious under-employment currently being experienced in the area. The large number of people that have been displaced by bank erosion in recent years now forms a very large pool of surplus labour with little or no prospect of securing permanent employment in the foreseeable future. In some locations, it is reported that certain levels of under-employment prevail even throughout the paddy harvest.

It is also important to note that construction of bank protection works and embankments will require a substantial labour force. This will help to alleviate, at least temporarily, the currently high levels of under-employment. The provision of direct employment for a large number of displacees with very limited sources of income could be regarded as one of the most important economic, as well as social, benefits of the priority works programme. For example, it is estimated that at Sirajganj, a total of 13,000 man-years will be required for the first phase of the town protection works. The estimated number of man-years of employment likely to be generated by the various priority works is given below:

Table 11.14 Employment Generated by Priority Works

Priority Location	Number of Man-years of Employment (`000)
Fulchari	10.2
Sariakandi/Mathurapara	24.9
Kazipur	13.6
Sirajganj	18.5
Betil	10.3

11.6 Breakthrough into the Bangali River

An investigation was undertaken in May 1993 by the Surface Water Modelling Centre for BRTS, wherein flooding resulting from a breakthrough of the Brahmaputra into the Bangali River in the vicinity of Mathurapara was modelled for the years 1986 through 1989. The investigation does not form part of this report, and the economic outcome has yet to be analysed, but an increase in flood extent of 50 per cent and a water level rise in excess of 1m over and above the BRE breach scenario for the year 1988 indicate the serious consequences of such an event.

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12. ENVIRONMENTAL ASSESSMENT

12.1 Introduction

The recurrent breaching of the Brahmaputra Right Embankment (BRE) as a direct consequence of progressive erosion of the right bank of the river, and the Government's desire urgently to address this serious problem, were the principal reasons for the formulation of the project.

In addition to the long term objective, the Master Plan strategy provide for early implementation of river bank stabilization measures in critical areas. From an extensive programme of field visits and considerations of the risk and consequences of river bank erosion, breaching of the BRE including social upheaval and disruption, and economic considerations, ten locations emerged from the initial ranking. Of these, six were selected for detailed design.

Based primarily on economic criteria, it was agreed between the Government and IDA (World Bank) that river bank protection measures should proceed as a priority at Sariakandi and Mathurapara, in view of the danger of breakthrough by the Brahmaputra into the Bangali River, and at Sirajganj, an important regional centre threatened by river bank erosion. These three locations are the subject of the Priority Works Environmental Impact Assessment (EIA) of July 1992. The remaining three locations, Fulchari, Kazipur and Betil, are still part of Phase 1 of the project, but with a lower order of priority.

The long term aim is the implementation of a river training scheme which will afford permanent protection of the BRE. The Initial Environmental Evaluation (IEE), which constitutes Annex 3 of this report and covers the Master Plan, represents the second part of the environmental assessment, the first part being the Priority Works EIA.

12.2 Breaching of the BRE

The ToR emphasise the need to find means by which the frequent breaching of the BRE can be prevented. From the detailed survey of the BRE undertaken by BRTS, it became clear that although records and memories of causes of early breaches are indistinct, river bank erosion is by far the main cause of breaching; the problem has become more pronounced in recent years. Of the 220 km of the BRE, some 140 km has had to be retired over the last 20 years because of river bank erosion. This has resulted in loss of infrastructure, private property and land, and has caused social and economic disruption and displacement of persons.

Bank erosion has a devastating impact on the lives of those whose farmland has been washed away by the river. The BRE survey results give some indication of the scale of this problem: it is estimated that around 100,000 people are squatting on the embankment as the only available place for them to find sanctuary; in addition it is estimated that at least 30,000 more are squatters in the Sirajganj municipal area. All of these people have been displaced by bank erosion.

The resettlement of displaced persons is a major problem in Bangladesh as a whole because of the high utilisation of land. The most direct way of tackling the issue in the case of the Jamuna is to address the root cause; that is to stabilise the river bank. An ameliorating measure is to provide improved conditions for settlement on the BRE but this can never help all those in already in need, let alone those who will join the ranks of the displaced in the coming years.

12.3 The Human Environment

12.3.1 General

The population density in the region approaches 1000 per sq.km in some areas, with a rural population of about 85 percent in the study area. The average farm size has been declining over the last 20 years and the number of landless households is increasing. Many of the people have been displaced by the continuing erosion of the river, and they remain homeless through the lack of available resettlement land under control of the Government and local authorities.

Agriculture remains the main source of new employment in rural areas, both directly and indirectly through linkages to input supply and processing industries. FCD/FCDI schemes have provided increased yields to those rural families that own land, and there is employment as farm workers for some displaced persons. However, the trend is for increasing unemployment, with a consequent drift to the towns and an increase in poverty levels in this section of the community.

12.3.2 Social Impact of River Erosion and Flood

The social consequences of river bank erosion and flooding from a breach in the BRE can be reflected in terms of the number of people likely to be displaced over the next five years (Table 12.1). While population data are useful for comparative purposes, there is the danger of understating the dire consequences of river bank erosion and severe flooding for a very substantial number of poor families. The loss of land and livelihood, as well as the physical, emotional and financial costs of displacement, which render the vast majority of the displaced population destitute, cannot be adequately assessed in a quantitative manner.

Table 12.1 Expected Land Loss and Population Displacement over the Next Five Years

Priority Location	Total Area of Eroded Land over the next 5 years (hectares)	Total Economic Value ('000 Tk.)	Number of People Displaced by	
			Bank Erosion	Flooding in Severely Affected Area
Fulchari	250	38,200	12,250	3,600
Sariakandi	300	63,000	17,700	8,700
Mathurapara	500	63,125	7,950	5,000
Kazipur	250	40,175	11,320	7,600
Sirajganj	375	168,750	126,000	31,000
Betil	250	52,500	10,000	8,800

There are, at present, no government programmes to resettle, rehabilitate or even assist these displaced families in finding alternative sources of income, consequently they remain destitute and depend almost entirely on hiring out their labour (mainly to local farmers). It is evident that both a firm political policy and a programme are urgently required for the rehabilitation of these displaced families in order to address this chronic problem.

12.3.3 Reaction to the BRE

The views of the local communities with respect to the improvements in quality of life offered by FCD/FCDI schemes is very important, if the full value of the scheme is to be realised. Under the BRTS the views of leaders, groups and individuals as to the value of the BRE to their communities and themselves have been sought directly.

The primary purpose of the BRE Inventory Survey, covering the full length of the embankment, was to assess the condition of the structure; however the opportunity was taken to elicit the views of local groups at each of 129 reference sections. The persons interviewed were mainly those living along the embankment crest, and most would fall into the category of landless squatters who had migrated to the BRE for reasons of safety.

The responses were consolidated for each section and provide some insight into the opinions of this group of people. Not only was a positive/negative response to the BRE sought, but also any comment on its possible improvement. Only at three sections was there a general consensus that the BRE was not desirable. These sections were centred around Mathurapara/Chandanbaisa, where the BRE is under active erosion and multiple breaching had recently occurred.

The other sections provided views that the BRE was "a good thing/doing its job/reliable". Some 80 percent of the people offered advice on improvements of the BRE covering aspects including increase in height, better compaction, local retirement, width improvements, maintenance and overall improved construction standards.

The general picture that emerges is that at all levels in the rural society the BRE is perceived by the large majority as providing clear net benefits to the community as a whole. The desire is that ways be found to improve the performance of the BRE so that confidence in its function may be enhanced. This improved performance is commonly linked in people's minds with stabilization of the river bank and the consequent reduction in loss of arable land and homesteads. There is, however, generally very little comprehension of the magnitude of the task and the scale of the costs involved.

12.3.4 People's Participation

In addition to the views of the local communities concerning the BRE discussed above, there are two major aspects of people's participation requiring attention in development projects such as the protection of the right bank of the Brahmaputra. The first consideration is that of keeping the populace at large well informed of future proposals, and giving those who will be directly affected the opportunity to make their views and preferences known as far as practicable. The second aspect is the opportunity for employment.

Under the River Bank Protection Project, public meetings have been held under the auspices of the DCs at Sirajganj and Bogra. The wishes of those who will be affected and displaced by the construction of the Right Bank Priority Works have been sought and recorded in the project resettlement plans, and the consensus view has been taken into account in the resettlement planning strategy. Similar action will be required for future construction.

There will be the prospect of enhanced employment in the areas of major civil engineering works construction, although as recruitment of labour under ICB contracts is the sole responsibility of the contractor, the extent of the benefit cannot be predicted with certainty. Further opportunities will exist in the reconstruction (and maintenance) of the BRE to revised alignments compatible with the river bank protection works.

These aspects are considered further in section 5.6 of Annex 1 to this report, Sociological Considerations, and in the River Bank Protection Project Resettlement Action Plans.

12.4 Agriculture

12.4.1 The Rice Crops

Rice in the region generally falls into three categories: local varieties, local improved varieties (pajam), and high-yielding varieties (HYV). The first crop is planted between mid-February and early September and is transplanted Boro rice. The spring rice, Aus, is usually broadcast (B Aus) in March/April, though occasionally it is transplanted (T Aus). The summer crop is Aman rice. Fixed height Aman (local and HYV) is transplanted in July/August (T Aman). Floating aman can be broadcast (alone or mixed with Aus) in March/April, or transplanted (after Boro) in June. Floating Aman is capable of growing to survive flood waters.

12.4.2 Effect of Breaches in the BRE on Rice Crops

The direct consequence of flooding due to a breach of the BRE is the loss of at least one crop. Much depends on the severity of the breach, the duration of flood and the height of inundation. Crops are particularly vulnerable to flood damage at the times shown in Table 12.2. The cumulative effect of an open breach is most damaging, as it is very difficult successfully to cultivate a monsoon crop in subsequent years when the area is exposed to high velocity flood water and deep inundation.

Table 12.2 Critical Stages of Growth by Crop

Crop	Month	Stage of Growth
B Aman	October	Flowering/Maturing
B Aus	June	Flowering/Maturing
T Aman	July-November	All stages
T Aus	April-July	All stages
Boro	April-May	Flowering/Maturing

Locally, heavy deposition of sand occurs at the time of the breach which initially renders the land unsuitable for crop production in the following Rabi season. In subsequent years farmers attempt to grow Boro rice or other Rabi crops but productivity is low. Increasingly, these areas are being planted with sugar cane, which can withstand high levels of inundation, but with lower yields.

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12.5 The Master Plan Strategies

12.5.1 Introduction

The Master Plan has two primary components which are dependent on the time frame of implementation. The components are:

- the stabilization of the river channel
- the improvement of flood embankment performance.

Both components need to be put in place, but as stabilization measures proceed the requirements for planned retirement of flood embankments will be reduced. Thus, although each component serves to address a different issue, the components are intrinsically linked, and the final form of the strategy will depend on the actual time frame allocated for the implementation of any component.

12.5.2 The Strategy Options

A summary of the Master Plan strategy options, as considered in the IEE, is given below:

Option 1: the 'no change' strategy

The simplest strategy available is to maintain the status quo. Under this arrangement there would be no pro-active form of intervention and the BRE would be retired at short notice as necessitated by conditions, and without long term consideration of confinement of the river channel or bank stabilization.

Option 2: planned retirement of the BRE

The second option would be to plan the retirement of the BRE in advance of any possible breach. This strategy is still effective only in localised areas, but nevertheless provides a pro-active solution to the flood protection problem (though it does not address bank stabilization). This second option uses predictive procedures as a 'triggering mechanism' to define what lengths of the BRE need to be retired. The set back distance would be selected so as to provide an optimal level of security against breaching, equivalent say to four years anticipated erosion. The planning horizon of 4 years is taken as this is the minimum time necessary to observe and confirm an erosion hazard and to complete the necessary retirement of the BRE.

A more permanent variant of the second option would be strategically to retire the BRE to a distance such that a breach would not be expected within 30 years. Such a strategic retirement would need set back distances of between 2 and 5 km from the present alignment.

Option 3: beneficial 'hard points'

The third option considers both components of the Master Plan, and introduces the concept of bank stabilization. In this option, bank stabilization by means of 'hard-points' and revetments would be undertaken where benefits were clear. Additionally planned retirements of the BRE (as under

Option 2) would be undertaken, and the BRE rehabilitated where necessary. This strategy has an advantage in that the works can be phased progressively as both the physical condition of the river and finances dictate. Effectively, this option will be initiated by implementation of the Priority Works.

Option 4: strategic bank stabilization

This option considers that the 'hard point' concept be implemented, regardless of the immediate benefits at any area (but still prioritizing construction) and that the right bank be completely stabilized. In addition there will be a need for retirement of the BRE to ensure flood protection until bank stabilization is completed for the entire length of the study reach.

This option would require a committed programme of development, and would be executed over the longest time frame. However, it offers the most secure long term solution to the flood protection problem. For the strategy to be fully effective as a river training (as opposed to a bank protection) strategy, it needs to be integrated with the strategies defined for the left bank of the Brahmaputra River.

12.5.3 The Strategy Timetable

Whatever strategy is finally chosen, the optimal concept is to ensure that the Brahmaputra River is fully stabilised. This requires consideration of both banks and of the stable island chars. Such a programme of river training will require a considerable number of years to implement. At each stage in the possible development of the continuing strategy it is important that a detailed environmental impact assessment be executed. It is likely that the cumulative changes produced by each stage in the programme will show up strongly as major impacts (both positive and negative) in the later stages of the programme.

12.6 Initial Environmental Evaluation (IEE)

12.6.1 Introduction

Account has been taken during the preparation of the IEE of the FPCO's May 1992 EIA Guidelines (that being the edition current at the time of IEE preparation). The Guidelines are, however, structured essentially for schemes involving active intervention measures aimed at flood control and drainage, such as the construction of new flood embankments and polders, and as such are not directly applicable to the Brahmaputra situation.

The environmental assessment has identified the important environment factors within the project area and, with respect to these, assessed the possible impacts of each Master Plan strategic option. A discussion and outline of the system applied, and the criteria chosen, together with scoring system are given in Appendix A to Annex 3 of this report.

Evaluation of the impacts was set against a baseline situation, taken as the present regime of flood protection as provided by the BRE.

For each of the environmental components a score was determined, which provided a measure of the benefit/disbenefit. To ensure that the evaluation complied with the FPCO multi-criteria analysis scale of $\pm$ 5 (in accordance with the May 1992 FPCO Environmental Guidelines), a conversion was derived by which the project assessment score could be confidently translated to the $\pm$ 5 scale.

It should be noted that this environmental evaluation is not a substitute for a full environmental impact assessment, which will be needed at every stage of strategy development.

12.6.2 Environmental Assessment Components

Primary Environmental Elements

The four primary environmental elements are defined as follows:

PHYSICAL/CHEMICAL

Covering all physical and chemical aspects of the environment, including finite (non-biological) natural resources, and degradation of the physical environment by pollution.

Within this assessment two important, common aspects of this element have been identified, both relating land loss. The strategies are too long term, and passive, to have major impacts on water quality.

BIOLOGICAL/ECOLOGICAL

Covering all biological aspects of the environment, including renewable natural resources, conservation of bio-diversity, species interactions, and pollution of the biosphere.

Two resources, fisheries and timber, are important within the strategies, and these have been identified in four components.

SOCIOLOGICAL/CULTURAL

Covering all human aspects of the environment, including social issues affecting individuals and communities, together with cultural aspects, including conservation of heritage, and human development.

Security of homesteads, changes in livelihood, nutrition, and artisanal transport are components in this element that are assessed. These provide a broad measure of the social impacts of each strategy. Additionally, impacts on important local social centres are considered.

ECONOMIC/OPERATIONAL

To identify qualitatively the economic consequences of environmental change, both temporary and permanent, as well as the complexities of project management, within the context of the project activities.

The strategies all involve passive constructions, but there are components of operation and maintenance, as well as inter-institutional linkages, that will affect the success of any option.

Important Environmental Components

The specific components of each element which have been considered in the IEE are as follows:

Physical/Chemical - River flood protection

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- Land loss to embankments and borrow pits

Biological/Ecological
- Floodplain fish migration
- Spawn-fish capture
- River fishery
- Village forest groves

Sociological/Cultural - Security of households
- Change in agricultural livelihood
- Change in fishery livelihood
- Artisanal transport
- Nutrition
- Sites of social/cultural value

Economic/Operational - Operational simplicity

12.6.3 Assessment Baseline

The present system of flood protection by reliance on the BRE is taken as the baseline condition. For assessment purposes this condition would normally score zero, as a 'no change' condition. However, there have been positive and negative impacts brought about by the BRE, and it is important to understand the true environmental status of the present situation.

The IEE (Annex 3 of this report) shows the matrix evaluation for the present situation compared to the original floodplain. Comparison the present situation with the earlier floodplain that existed before construction of the BRE demonstrates the effect both on fishing and agricultural livelihood. Whilst the floodplain fishery has suffered from restrictions to stock recruitment, the improvement in agricultural production, and hence incomes, has been equally significant.

It is against this understanding of the historic reduction in fish production, and the establishment of thriving agriculture by the provision of flood protection, that any new environmental evaluation must be made.

12.6.4 Impacts of Common Issues

Brick making

There is a need for bricks in the construction and rehabilitation of revetments. It is also common in Bangladesh to break down bricks for aggregate in concrete. This practice makes use of exploitable natural resources, whilst also providing labour both in expanded brick making and the reduction of bricks into aggregate. The brickfields are extensively spread throughout the country and provide local employment for labour, as well as a market for landowners to sell clay and timber. Brickfields are developed on rented land close to a source of clay, and are temporary works, operating only in the dry season.

Traditionally the brick works have used timber or coal, with a preference for timber which is a locally produced resource. To preserve the rapidly dwindling stocks of timber, a prohibition on timber firing in brickfields was introduced in 1983/84. Nevertheless, timber is still extensively used in present brick making operations.

While in operation, brickfields deny land for cultivation, and are often not reinstated properly after abandonment. The main concern in environmental terms, however, is the use of timber in making the bricks. Although the use of brick aggregate in the construction of the river training works would bring considerable local employment for the production period, this benefit must not be offset by increased consumption of timber, which is a rapidly dwindling resource.

For the Priority Works, two steps have been taken by which the use of timber in the manufacture of bricks will be avoided.

- Tenderers are required to price for armouring not only of brick aggregate concrete blocks but also for alternative stone aggregate blocks and for dumped rock.
- The Specification prohibits the use of bricks from brickfields not using coal-fired kilns, so that if the use of brick aggregate concrete block armouring provides the most attractive tenders, consumption of timber will not increase. This policy should also be adopted in future construction contracts.

Navigation

Impact on navigation is likely to be small and confined to some minor disruption of navigation channels and perhaps ferry terminals during dry season periods of construction. Sedimentation of the main shipping channels is unlikely to be a problem if the works are executed to the accepted standards required of International Competitive Bidding (ICB) contracts. In all cases, however, close liaison should be maintained with the appropriate authorities.

Dredging and Hydraulic Fill

Any adverse impacts of the dredging and hydraulic filling operations will be localised and will occur only during the period of construction. Model studies have indicated that the sediment (mainly fine sand) displaced by the dredger will not travel far (Figure 12.1) and will be limited in concentration. The effect will be negligible compared to the sediment transport of the river. Any effect on local fishing is more likely to arise from construction activity in the immediate area than from increased levels of sediment concentration as a direct result of dredging.

Water, Sanitation and Public Health

The direct effects on water, sanitation and public health arising from, and subsequent to, construction itself are likely to be small. However strict standards must be laid down regarding the contractors' labour camps and any relocation of squatter families. Adequate drainage will be of fundamental importance in these instances.

Resettlement of Squatter Families

Arrangements must be made for families residing on river embankments or at certain urban centres (e.g. Sirajganj) affected by the works. These people have generally lost their land because of river bank erosion or for other reasons, and form part of a large community of landless people. The problem is found throughout the country, but no adequate solution or political policy has yet been formulated.

These families will need to be relocated, either temporarily and allowed eventually to return to their original position, or permanently, depending on the circumstances at each location. In each case a detailed resettlement plan will need to be drawn up, based on the findings of socio-economic surveys and discussions with all parties concerned.

In many cases it would be appropriate for provision of the basic infrastructure for the resettlement site to be made through the construction contract. Attention is drawn to the draft Resettlement Plans for the Priority Works contracts, which address these issues.

Transport Consideration and On-Site Activities

Access to construction sites will generally be by road or by boat, only Sirajganj and Fulchari on the Brahmaputra right bank being served by rail. Transport of personnel, provisions and construction materials will require careful planning, especially at sites not served by roads. The BRE is unsuitable for site access and, and its use for such purpose is proscribed in the Priority Works contracts; other roads may be unsuitable for construction traffic or require restrictions in the construction contracts upon their use.

This means that in many instances the river will be the primary mode of transport, and in others creation of new access roads will be necessary. Construction of access roads may impact on local settlements, and construction of wharfage may have some impact locally on artisanal fishery.

Manufacture of armour units (assuming concrete blocks are used), transport movement and construction itself will inevitably cause a certain amount of noise and dust and although many of the sites, but not all (e.g. Sirajganj) will be remove, requirements should be included in the ICB contracts to mitigate adverse impacts, including proper clearance and reinstatement of the Site upon completion of the Works. This is discussed further in Section 12.7.4.

Other Impacts

Excavation of borrow pits, if not managed property, can be destructive locally. The design envisaged for future retired lengths of BRE, and cross-bars to hard-points, envisages a depth of pit of not more than 2 m, which will allow subsequent use of the pits for cross or fishpond.

The project area comprises localised areas of urban development or cultivated land, and the wildlife baseline is correspondingly localised and poor. Adverse impacts will be limited to the construction period and will be comparatively minor.

As noted elsewhere, any disruption of fishing arising from construction of river training works will be local in extent and shortlived in duration. To assist with floodplain fishery, structures incorporated in the retired BRE could be designed to permit entry of surface borne spawn to the flood plain at the beginning of the flood season, and for adult fish to migrate to the river at the end of the season. This, however, will require proper operation of the structures at the requisite times, and the appropriate institutional arrangements will need to be made.

In the longer term, a full programme of river bank stabilization, with flood protection embankments on both banks of the river, would severely affect floodplain fishery. To avoid such adverse effects, it would be essential for suitable structures - to permit passage of spawn and adult fish - to be incorporated in the embankments, and for the institutional arrangements to be set in place to ensure their proper operation.

The consequences of different levels of intervention strategy are discussed in detail in Chapter 9, and the sociological impacts are discussed in summary in Chapter 10 and in detail in Annex 1 to this report.

12.6.5 Evaluation of Strategy Options

Following on from the considerations above, and using the methodology outlined earlier in this chapter, the principal strategy options listed in Section 12.5.2 have been evaluated. The evaluation is given in matrix form in Annex 3, wherein Options 2, 3 and 4 are compared to Option 1, the present situation.

Option 2 shows a largely neutral strategy that provides some benefit in respect of flood protection and land loss, as well as security of households, agricultural livelihoods and nutrition.

Options 3 and 4 improve on the positive benefits of Option 2, although negative impacts would result from the loss of land to construction and, were the use of coal fired bricks not to be enforced, (assuming brick aggregate concrete armouring), from the use of timber in brick making.

12.7 Outline Environmental Monitoring and Action Plan

12.7.1 Introduction

It is important that construction not only proceeds in an environmentally and socially sensitive manner, but that the benefits of the works are maximised as well as any negative impacts reduced. This requires a number of continuous actions that should begin in the pre-construction phase, and be maintained well after completion of the project. Such a programme must operate within the legal, cultural and institutional frameworks that exist in Bangladesh.

For the full project benefits to be realized, a system of liaison between institutions and groups should be set up and maintained. Such liaison will allow all interested parties to become aware of the progress of the project, allow project decisions to respond to local interests and concerns as they may occur, provide greater public confidence in the purpose of the project, and ensure the efficient and economic execution of the works. The BWDB will bear the responsibility for developing the system of liaison, particularly within the localities of the project sites, with the Engineer playing an important role in the construction contracts.

Liaison will be required between the local administration, other public institutions and utilities, and local public interest groups, all of which will require different degrees of interaction with the project.

At the national level the FPCO and BWDB will continue to maintain an on-going exchange of information with the national bodies regulating sectors affected by the project, together with the donor agencies and international agencies.

There are a number of active NGOs in Bangladesh, as well as international agencies that have programmes of assistance to rural areas. These bodies can play an important role in the liaison process, as well as in public awareness and assistance to specific communities.

The need to ensure that local people and officials are made aware of the works that will be undertaken, of the local importance of these works, of the benefits that will accrue to the communities and of how best the people themselves might benefit from these works, can be undertaken by the pourashava or upazilas, although it may be possible to involve local bodies and NGOs in the programme.

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12.7.2 Consultation

The system of liaison will need to take account of the interests of the people who will be affected by the project, as well as the regulatory and planning concerns of the authorities. To this end, the liaison system will need to coordinate a series of consultation activities to obtain public opinion.

Direct consultation with affected individuals, householders and land owners is needed when land acquisition or displacement activities are planned. This consultation should include group and public meetings, as well as consultations with affected individuals. It is important to include in the consultation process all persons that might be affected in the localities, not merely the persons whose land or homes are to be acquired.

As a part of the consultation process, surveys of interest groups should be undertaken, particularly when a project activity has indicated a possible impact (positive or negative). These may be household or sector groups. To provide data for future decision making, follow-up surveys of these same groups should be undertaken to determine public opinion on the success of the operation.

12.7.3 Monitoring

The project will not significantly impact on natural resources or sensitive ecological zones, but may provide local changes that need to be taken account of in river and floodplain management programmes, which fall within the remit other projects under the Flood Action Plan (FAP).

There are no authorities that, at present, have the institutional capabilities or resources, at a local level, to monitor environmental change, or adequately provide a record of environmental and social change at this time. Accordingly a method must be found whereby some records can be presented at regular (say six-monthly) intervals to allow independent scrutiny and evaluation of any on-going negative impacts.

It is proposed that the BWDB take on the responsibility for assessing these impacts during the course of the project and of reporting on these aspects of the work. After completion of the project the BWDB may continue the process of monitoring or may mutually agree to pass this task over to a national or local body which may, by then, be able to take on this role.

Consideration has been given to the setting up of a Monitoring and Resettlement Section within the Bangladesh Rural Development Board (BRDB), but it has now been decided that this role will be filled by BWDB.

12.7.4 Mitigation Control

Certain mitigation measures will be applied as a result of the consultation and liaison processes. Many will be effected by the standard construction impact and nuisance mitigation measures available under ICB conditions of contract and the contract specification. The Engineer will be responsible for monitoring and enforcing these measures.

The process of land acquisition for future works will be conducted in accordance with the foregoing consultation procedure. Resettlement of persons displaced by the works is a particularly sensitive matter and will require full consultation with the people affected and the local authorities, and regular monitoring to ensure the success of the operation. In many instances it will be appropriate to arrange provision of basic infrastructure for the resettled families through the construction contracts.

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Impacts during the course of construction can be mitigated by enforcement by the Engineer of the relevant clauses of the ICB conditions of contract, and by the drafting and enforcement of specification clauses appropriate to the local conditions and particular job requirements. Such impacts would include the contractor's land acquisition and site development, production, transport and stockpiling of materials, dredging and hydraulic fill, construction of new revetments and embankments, the operation of borrow pits and site clearance.

By way of example, the Action Plan for Monitoring and Mitigating Impacts, drawn up for the Priority Works EIA, is included as Appendix B to Annex 3 of this report.

12.7.5 Environmental Impact Assessment

The actual implementation of any strategy will require careful evaluation as to its environmental, sociological and economic impacts. These may change within the timeframe considered for any strategy, and such changes are likely to be pronounced at the local level.

To ensure that the strategy can be implemented optimally, each stage of implementation should be undertaken only after a full environmental impact assessment has been executed. In undertaking such an assessment, the views of local people should be carefully and widely canvassed, so as to ensure that the component of the strategy is in line with the expectations and wishes of the people most likely to be affected.

These assessments should also identify permanent and non-permanent impacts; as well as highlighting both positive and negative impacts arising from strategy implementation, the EIA should show how mitigation may be used to minimise the negative impacts of the works.

As the strategy proceeds, it is likely that impacts, both positive and negative, may become cumulative. It is thus important that the earlier EIAs are undertaken in a transparent manner to ensure that their reasoning can be applied, or modified, as appropriate to the on-going situation.

13. INSTITUTIONAL CONSTRAINTS

13.1 Introduction

The principal focus of the Terms of Reference for the master plan study is on identifying the most appropriate measures for the improved performance of the BRE. It is perceived that the major threat to the BRE is direct attack by the river and that a range of technically feasible options may be considered as an improvement on the current ad hoc realignment of the BRE as it comes under threat. These range from major proactive realignment of the BRE to a "safe" distance from the river in order to minimise the risk of breaches to stabilizing the river bankline. Implicit is the assumption that abandonment of the BRE, with the consequent substantial drop in agricultural productivity in the flood plain, disruption of communications and its negative impact on the local economy in general, is simply not an acceptable option in Bangladesh today. After the passage of more than 20 years, the physical and socioeconomic conditions have adjusted to the modified regime and the BRE is seen as an established, and valued, part of the regional infrastructure.

At the same time it is acknowledged that if, in the 1960's, the evaluation of the costs and benefits of constructing the BRE had been carried out in a manner that has today become accepted as being correct, then the design of the embankment and the institutional arrangements made for its sustained operation and maintenance would almost certainly have been significantly different.

During the course of the BRTS programme it has become apparent that the stabilization of the bankline of the river is as important an issue in its own right as the sustainability of the BRE's flood protection function. The steady erosion of the fertile and densely populated flood plain land not only represents a recurrent loss of a scarce resource but has also creates a major sociological problem that becomes more severe every year as more and more families are made homeless. It is important to keep the scale of this problem in view: in the study area alone, on average more than 1,000 ha of land are lost each year and some 10,000 persons are made homeless and lose their livelihood as a direct consequence.

The philosophy underlying the river management programme being proposed in the Master Plan is based the principal of minimum divergence from the natural characteristics of the river. Hard engineering measures are used only to constrain the river within these natural bounds. In this way the potential for adverse impact is minimized and the timescale of any undesirable consequences that may emerge will be such that there will be time to respond appropriately before irreversible damage results. Monitoring of the behaviour of the river is essential in order to provide sufficient advance warning of any such trend.

It is also important to recognize that implicit in any form of intervention is a long term commitment to routine maintenance and the acceptance that supplementary hard engineering works may be required in the medium term in order to achieve the desired results. If it is to be effective, management of a river cannot be treated as a one-off investment in physical works.

Both the realignment of the BRE, in order to minimise the risk of breaches arising from river bank erosion, and the selected stabilization of the river bank, within a longer term plan for river channel stabilization, must therefore be seen as activities within a continuous

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management programme and not limited duration investment projects. Planning and monitoring tasks should be intimately linked and the responsibility of one organisation, which would also be responsible for maintenance and the initiation of supplementary works. In this situation the operational element of O & M will thus be concerned primarily with this monitoring and planning role, rather than the adjustment of physical controls (e.g sluice gates). However there is, and will continue to be, a need for management of cross flow control structures built into the BRE for drainage, irrigation and fisheries interests; a task that at present does not receive as much attention as it deserves. As containment of the river within flood embankment is extended over a period of time, this form of control will become increasingly important.

13.2 Different Perceptions of the Problem and Appropriate Solutions

13.2.1 Bank Erosion Control

Public Awareness

Awareness of the problem of bank erosion is widespread in Bangladesh. The press regularly reports cases of land and property loss. Less well known, and certainly less appreciated, is the scale of human suffering that results. It has been estimated that more than 100,000 people are squatting on the BRE for want of anywhere else to live and many more are camping on the outskirts of Sirajganj and the other larger population centres. On average an additional 10,000 people are displaced by erosion every year and most of these are unable to find alternative land on which to settle. Since most gained their livelihood from the land that has disappeared, under-employment amongst this category is very high and prospects for redeployment are poor. Since this group is unable to mobilize support on its own behalf, the onus is on the District level authorities and NGOs to ensure that their plight is drawn to the attention of those able to provide support and assistance.

Attitudes

There has been considerable vocal opposition amongst elements of the professional community in Dhaka to the very principle of "training" the Brahmaputra river but there has been a dearth of constructive proposals for alternative action. In marked contrast, there is strong pressure from the affected communities for early positive action to be taken. There can certainly be no question of "living with bank erosion" in the same sense as the principle of living with flooding has been propounded by some. With the national land scarcity and a growing population, a high proportion of those displaced by the erosion of the land from which they gained their livelihood become destitute. Much of the opposition appears to be misplaced in that bank stabilization has become confused with the linked but quite distinct matter of the performance of the BRE and the wider issue of the desirability of providing flood embankments along the major rivers. It would seem that further effort is needed in order to ensure that professionals in all disciplines are properly apprised of the different issues involved and the feasible treatments.

Feasible Action

Prevention of bank erosion by means of hard engineering measures is technically feasible and, if properly carried out in a manner that is compatible with the river's morphological characteristics, is a sustainable solution that will have only temporary, and relatively mild, adverse environmental impact during the construction period. Such hardening of sections of the river bank is a common practice worldwide and has been implemented for many years on the Ganges and Brahmaputra with no known adverse consequences. The constraint is one of cost. The scale of the Brahmaputra River and its above average erosive power mean that any physical intervention has to be carried out on an equivalent scale if it is to be effective. Soft measures such as introduction of vegetation to reinforce the soil structure are ineffective against this level of erosive power.

Involvement at District Level

The skill and resource demands of bank stabilization activities are well beyond the capacity of the local community and have to be planned and executed at the regional or national level. The scale at which such measures have to be planned will often mean that works as designed may appear to the local community to be failing to address their immediate problems. As an example: if a riparian village community is experiencing local bank erosion and learns that plans are being made to construct a length of bank stabilization some distance from this particular spot, their uninformed reaction will be to oppose such a move. Conversely, those liable to lose land as a result of the stabilization works may see this as the unnecessary act of a government with motives that are not aligned with the needs of the community.

Lack of appreciation of the scale of the problem is also to be found amongst BWDB engineers in the riparian Districts, many of whom have previously been only assigned to posts where their experience of river bank erosion was confined to minor rivers, on which the problem could be treated primarily as a local problem. It would be preferable for BWDB engineers to receive short-course training in river engineering for the major rivers of the country prior to their posting to any riparian District. Such courses could be provide through BUET. With this background they would be better able to respond appropriately to demands from local community leaders for the implementation of low-cost "emergency" measures at sites of current high erosion, that in almost all cases are totally ineffective and a wasteful allocation of scarce resources.

Consultation

Although it may appear to the designer that there is little that the local community can contribute to the planning and design process, it is beneficial to inform them as to the strategy behind the proposed action and how it will benefit them in the medium to long term. During numerous discussions with groups of people in the project area it was found that there was a general lack of awareness as to the scale of the problem and the cost of intervention measures. Similarly the popularity of groynes rather than bank revetment as a stabilizing measure, because of their perceived ability to induce land accretion, was in most cases modified when the relative costs were presented and the very high cost of the venture was realised (the greater potential adverse impact of groynes, in the form of knock-on effects further downstream, tends to carry little weight). Given a fixed amount of available investment, most communities will opt for maximizing the length of bank to be stabilized.

Consultation at the detailed design stage is also important. Although there will normally be little scope for altering the basic design of the works, the precise location of a hard-point forming part of a reach level stabilization programme is typically flexible within a range of

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several hundred metres. The location can thus be adjusted so that the land a acquisition required for the cross-bar connection to the BRE does not result in unnecessary displacement of housing or land holding fragmentation; the revetment itself can be positioned, within the permissible limits, so that the community is satisfied that it is appropriate to their needs. Plans need to be drawn up to ensure that those displaced are in a position to re-establish themselves satisfactorily or to identify what supplementary support may be required.

This process has been carried through successfully for the Sariakandi and Mathurapara reach stabilization proposed for implementation under the IDA financed River Bank Protection Project. The Resettlement Plan that has been prepared provides a model for future projects such as this. It has to be recognised however that these actions are in addition to those that have in the past been undertaken by the BWDB and will involve strengthening of their institutional capability in this respect. Consideration should be given to whether it would be preferable to assign such tasks to suitably experienced consultants.

13.2.2 Improved Performance of the BRE

Public Awareness

At the outset of the BRTS study there was uncertainty as to what extent the unacceptably frequent breaching of the BRE was due to inadequate design standards, poor construction and maintenance, public cuts of direct undermining by bank erosion. The study has shown that the original design standards were adequate, although cross flow provisons have proved to be insufficiently planned in many cases. Poor construction was only the cause of breaches in a few cases where a realigned section of the BRE had been constructed as an emergency measure under the FFW programme and control had been of a low order. One case has been recorded of a breach that was initiated by flow through rat holes that should have been treated under the routine maintenance programme, but in general preventative maintenance is carried out to a minimum standard that prevents failures under normal conditions and emergency response is adequate to address the more unusual severe events. Public cuts are almost entirely confined to the northern reach upstream of Fulcharighat where the natural drainage was towards the river. The majority of breaches were the direct result of river bank erosion and the resulting undermining of the embankment.

Whereas the public as a whole is conscious, through the media, of the serious nature of bank erosion on the major rivers, there is less awareness of the repercussions with regard to the security of the BRE and the scale of damage that results from breaches.

Attitudes

As noted earlier, there has been considerable vocal opposition amongst lobby groups in Dhaka to the principles believed to be embodied in the BRTS. This seems to arise largely from a number of misunderstandings that have proved hard to dispell. One misconception is that the study is dedicated to finding the best hard engineering means of reducing the frequency and severity of riverine flooding, with the construction of "mud walls" as the most favoured. This completely ignores the fact that the BRE has been in existence for more than 20 years and that the ecology of the area affected and the structure of the community has adjusted to the new inundation regime. Even the more ardent supporters of conservation have stopped short of publicly proposing that the BRE should be torn down and the area allowed to return to the state of substantially lower productivity that existed prior to its construction. The objective of the BRTS study is to find the most appropriate means of sustaining the existing condition of controlled inundation for the benefit of the community as a whole.

Another widely held perception is that the Master Plan is aimed at the early channelization of the river between flood embankments with scant regard for the morphological consequences. This is also wide of the truth. The Master Plan is designed to provide a framework for managing the river in a sustainable manner that is compatible with its morphological and ecological characteristics and which will provide an improved way of life for those living on the flood plain. Further efforts are required to spread a better appreciation of the objectives and the environmentally sensitive manner in which the studies have been carried out.

Amongst those directly answerable to those who benefit from the flood protection afforded by the BRE, and amongst the beneficiaries themselves, there is a marked difference of attitude. The frequent need to realign the embankment, as the right bank of the river continues to erode, creates severe controversy and conflicting pressures from rival powerful lobbies. This may be seen as opposition to embankment realignment but is in fact a trade-off process in action, whereby the advantages of alternative degrees of setback and length of realignment are weighed against the benefits as perceived by the local community. The outcome to date has always been eventual agreement on an acceptable alignment, although this has on occasions come too late for the construction to be complete before the onset of the monsoon. It is arguable that the weakness of this system, in addition to the slow speed of decision making, is that it favours the more influential in the community who tend to represent the interests of a numerical minority.

Feasible Action

Some improvements to the performance of the BRE can be achieved through better maintenance and the provision of local cross-flow structures or collector drains where land drainage is sometimes impeded. It is clear however that the most important concern is to prevent the embankment being undermined and breaches as a direct consequences of bank erosion. There are only two options open: either the river bank must be stabilized or the embankment realigned further back from the river bank whenever it is seriously threatened and before there is a significant risk of failure. Strengthening the embankment alone is not a technically feasible option. The former is an order of magnitude more costly than the latter and only in situations where the benefits are deemed to be equally high can it be economically justified.

The Government has a commitment to addressing the serious socio-economic problems arising from the need to repeatedly realign the embankment and favours the stabilization of the bank as the most effective long term solution. To realize this goal will however involve a very large investment and it will have to be spread over a reasonable period of time, possibly of the order of 25 to 30 years and possibly longer than this, depending on national priorities. In the meantime it will be necessary to continue the planned realignment of the embankment and measures are required to make this procedure more effective and to minimise the adverse impact on the affected community and the environment as a whole.

Involvement at District Level

In contrast to the river bank stabilization works, improvements to the performance of the BRE are of a nature that is largely compatible with the manpower, skill and equipment resources available within the riparian Districts. Maintenance of the embankment can be carried out by labour intensive methods and there is a good opportunity to mobilise the large potential workforce squatting on the embankment for this purpose. Routine maintenance of the cross-flow control structures is within the capability of local petty contractors and skilled craftsman.

The periodic realignment of the BRE is also within the scope of District level resources, with the possible exception of the relocation of cross-flow structures, which may require the employment of one of the smaller national contractors. The detailed planning of realignment is best carried out in the field in consultation with those affected, but some support will be required in the form of specialist advice as to the most appropriate timing, set-back and length of the realignment.

Consultation

Consultation at every stage of the planning, design and construction process is essential if the work is to proceed smoothly and realignment is to be completed in advance of the threat.

The first step should be the introduction of the affected community to the basic characteristics of the river so that they may appreciate the scale of the problem, what is known about the pattern of erosion and the difficulties of prediction. They should be involved in the decision as to the most appropriate trigger distance (the minimum width of land between the BRE and the bankline that signals the need to realign the embankment), set-back distance and the length of the realigned section. The most appropriate value for all three of these factors will be strongly influenced by their perception of the risks involved and the consequences for them of taking the decision to realign. The decision cannot however be left to those directly affected alone because they will inevitably give a low weighting to the interests of others further back on the flood plain who would suffer in the event of a breach. Some form of representation for the latter group has therefore to be built into the process.

Consultation at the detailed planning and design stage is the most essential. It is at this time that decisions will be made on the precise alignment of the embankment and the location and geometry of borrow areas, decisions that have a major impact on the lives of those affected. This process is likely to be protracted and sufficient time must be set aside for the purpose. The specific issues relating to the vexed issue of land acquisition are discussed in Annex 1 to this report.

13.3 Institutional Requirements

In the introduction to this Chapter it was noted that although the stabilization of sections of the river bank and the planned proactive realignment of the BRE were closely linked, they were distinct activities, each of which had its own institutional requirements. It would thus be feasible to assign responsibility for these two areas of activity to separate organizations, although in the interests of coordination and the optimal utilization of resources and facilities, it would probably be preferable for a single organization to have overall responsibility.

Common to both major activities will be the need for monitoring of the river behaviour and the skilled interpretation of the data collected. For the realignment of the BRE, the prediction of bankline movement will be a key factor in the decision making process. It will affect both the timing of construction and the length of new set-back distance of the realigned section. The development and sustainment of a strong capability in this field must be given a high priority (see Section 13.6).

Implementation of new engineering works will require very different institutional arrangements. Once a decision has been taken to realign a section of the BRE, and the alignment has been agreed, the majority of construction will comprise earthworks and can be carried out using local resources. Geotechnical design decisions are largely limited to the selection of suitable continuous borrow areas for the embankment fill. Construction quality supervision will involve the control of line and level control, earthfill material and compaction. Most of the relatively few reinforced concrete control structures involved are of a simple standard design and the construction of even the occasional multiple gated structure is within the capability of the larger local contractors. The whole process can thus be planned and executed at the District level, with some specialist design support if needs be.

The implementation of new bank stabilization or river training works do however require a higher level of planning, design and construction skills, and this will not normally be available at the District, or even the Divisional level under the current organizational arrangements. The poor performance of most of the works constructed on the river in the past is a clear testament to this.

The design of river training works on this scale calls for a thorough understanding of river morphology and hydraulic theory and familiarity with the particular stretch of the river under review. Such skills are in short supply within Bangladesh and outside assistance will have to be sought from time to time. In parallel to this, efforts are needed to build up the indigenous skills through specific training and attachments overseas (e.g at the Hydraulics Research facilities in the UK). Under normal circumstances, staff who have received such specialist training stand a high chance of being assigned to a post which does not call upon their new skills. Specific arrangements must therefore be made to retain the trained staff in a planning unit of similar organization. It would be rational to set this up for coverage of the major rivers.

Construction of such works also calls for specialist skills, experience of operating under similar difficult conditions, adequate resources to permit rapid reaction and to ensure timely completion. Such resources and skills are not currently available in sufficient quantity and initially it will be necessary to employ international contractors. In order to build up the experience and skills within the country, which will also be required for recurrent maintenance and supplementary works, international contractors should be encouraged to enter into an active working association with a Bangladesh contractor of proven competence.

For supervision of time sensitive contracts of this magnitude with all their inherent risks and potential for cost overrun, previous experience on similar projects is essential. Until this experience has been built up in Bangladesh it will be necessary to assign such roles to international consultants.

During the construction of the works, BWDB personnel should be seconded to the supervising engineer's staff and if possible to the Contractor on some form of rota arrangement. This

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secondment would take the form of a formal training programme with performance monitoring and qualification tests so that on completion of the construction phase the skills are in place for the maintenance of the works. Suitable motivation and incentive will have to be provided to ensure that the trained staff do not become dispersed until they have been able to pass on their skills to others. This retention of capable and motivated staff on what is commonly seen as deadend routine maintenance work, with little opportunity for supplementary income, is a serious problem that must be addressed if the dependence on international technical support is to be phased out.

13.4 Source of Revenue for Operation and Maintenance

Although it would be desirable in principle to recover revenue from the beneficiaries to support the operation and maintenance costs, thereby introducing a greater degree of accountability within the O&M organization and reducing dependence on the fickleness of the central government budget allocations, it would be very hard to implement in this case because of the difficulty of defining the individual beneficiaries.

Some tentative suggestions for the recovery of a cess from urban dwellers benefitting directly from bank stabilization and flood protection have been put forward but to implement this will require further detailed study.

13.5 Land Acquisition Procedures

The social and other problems associated with land acquisition have been studied and reported on by FAP-15.

It has been noted that each kilometre of BRE requires around 3 hectares of land which must be purchased from villagers. It is agreed by local people and BWDB engineers that land acquisition is one of the most important issues in embankment construction. When the BRE was first created local people were said to be content with the acquisition process, receiving due payment for the current value of their land. Since then there has been increasing resistance to acquisition stemming from four main concerns: the loss of land, the differential effect of the BRE on the potential and price of land and the delays and losses associated with compensation.

Land Loss

The FAP-15 study reported that 90 percent of the households in Shahzadpur suffered land loss for the construction of the embankment; Shahzadpur was clearly very profoundly affected by the land acquisition process (and was affected more than the locations on the embankments studied elsewhere in Bangladesh). The principal burden of land loss was generally distributed equitably across land ownership categories but the losses of buildings and trees fell more severely on the land-poor households. The functionally landless lost the highest proportion (57 percent) of their land and the large owners the lowest (9 percent). No significant out-migration as a result of the acquisition was reported, so the overall affect has been a reduction in average holding size and an increase in landlessness.

Land Prices

Acquisition has a treble impact on land prices:

(a) When acquisition is in the offing, there is a tendency for landowners to register a number of spurious sales at inflated prices in order to raise the acquisition price.

(b) Since acquisition takes a significant proportion of the land out of production, land prices rise.

(c) Land on the river-side of the BRE line is immediately perceived to be vulnerable to worse damage than that on the landward side. No compensation is paid to the owners of river-side land which is depressed in this way.

Compensation

Despite the 1989 Land Acquisition legislation which attempted to make the processes quicker, it can take a long time for land owners to receive compensation. As an example: it is reported that in one case ten percent of those affected were paid within a month, 34 percent in six months and 44 percent between seven months and a year. Some had not received final payment four years after the acquisition but the report does not state how many cases were under active arbitration. Not only is the official payment inadequate to replace all that was acquired because of acquisition-induced price rises, but also the delay and reduced net amount received mean that the owner is twice deprived. Many households have been through this process more than once and are understandably unwilling to part with land yet again.

Local Power Structures and Delays

Nobody wishes to have their land acquired, so anyone with influence makes strenuous efforts to deflect the alignment onto a neighbour's land - and their pressure will always be in the direction of the river bank. It is reported that the surveyors have developed counter-techniques, such as initiating the survey further inland than necessary in anticipation of being persuaded to shift the alignment. The final alignment tends therefore to be generally closer to the river than engineering design would dictate and more damaging to the interests of the poorer villagers.

Beneficiary Consultation

FAP-15 found in Shahzadpur that 21 per cent of the households had received an explanation of the project, 3 per cent had discussion of the alignment and 77 per cent had received proper notice of acquisition. Even allowing for illiteracy and incomprehension it is clear that there was insufficient dialogue with the local community.

Beneficiary participation is a notoriously difficult issue in a society where the survival of the individual household is paramount.

It is an area in which NGOs have valuable experience and the success they have achieved usually stems from the active participation of local people from the initiation of planning.

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13.6 Planning and Design

13.6.1 Data Acquisition, Processing and Storage

Surveys and Primary Data Collection

The scale of the problems and the rate of change of conditions is such that the collection of primary data has to be seen as an essential element of not only planning of new works but also for ensuring the existing works perform to specification and that timely maintenance is undertaken.

The present skills and logistic resources of the BWDB are currently insufficient for this purpose, particularly in the important field of river surveys. The need for vessels designed for survey in the Brahmaputra conditions and the funds to maintain and operate them to the requisite standard has been highlighted by the BRTS survey (see Annex 1 to the Second Interim Report).

Data Processing, Storage and Retrieval

Once the data is collected the processing, storage and retrieval become the key considerations. Those responsible for these tasks are in the main seriously under-resourced in relation to the magnitude of the task. Consequently the quality control on data processing is not always maintained and some data, obtained at considerable expense, becomes for one reason or another unavailable to the potential user.

13.6.2 Forward Planning for Engineering Works

Planning, Design and Implementation of Bank Stabilization Works

It has been seen that for effective planning of new works and the planned maintenance of existing work it is essential to establish and maintain a constant high level of monitoring of the river and the BRE strip. The difficulties faced by the BRTS before the relatively contemporary satellite imagery and aerial photography became available are graphic illustrations of the importance of having such information readily available to those responsible for planning, design and maintenance.

The SPOT and LANDSAT imagery is perhaps the most readily available and cost effective form of remote sensing at present but for detailed field work the better resolution of the aerial photography is of great value. While the Government continues to impose stringent restrictions on the use of such materials by field staff and planners, their full value cannot however be realised.

Use of this type of information does require some specialist skills and, perhaps more importantly, familiarity and experience. Means by which a cadre of skilled and motivated professionals can be established and their continuity of service in the post maintained therefore must deserve early attention.

13.7 Operation and Maintenance

Maintenance of Structural Works

The levels of maintenance for the BRE and the river training works are at opposite ends of the spectrum and need to be planned accordingly. While the former offers considerable scope for local participation and the employment of unskilled labour, the latter is a task that must be organized in a very efficient manner and will involve the rapid mobilization of heavy plant and materials and the deployment of skilled manpower to deal with maintenance demands in a timely manner as they arise.

Performance Monitoring and Feedback

Further consideration has also to be given to finding the best and most cost-effective means of monitoring the performance of the works, both as a early warning of essential preventative maintenance requirements and also as a feed-back to the planners and designers of new works. The present arrangements certainly require considerable strengthening in this respect.

13.8. Recommendations

1. BWDB District staff to receive training in public consultation theory and techniques. Standing Orders to be issued requiring all responsible BWDB staff to undertake full consultation as a standard procedure during the planning, design and construction of all works.

2. River Monitoring and Planning Unit to be established within the BWDB as soon as possible with staff selected for their ability to learn new techniques such as morphological interpretation of satellite imagery and hydrographic survey data (this recommendation is discussed further in Annex 5). Support to be provided by international consultants for an initial period of two years, with the need for further support to be determined at the end of this period. This unit would be responsible for all hydrographic and associated land survey work not already covered by the FAP programme, the storage and safekeeping of all data, the procurement of processed imagery and the preparation of annual data year books and interpretive reports.

3. BWDB to finance NGOs and/or Universities and individual consultants to carry out field work and prepare recommendations for specific resettlement requirements associated with bank stabilization and BRE realignment.

4. Specialist Operation and Maintenance Unit to be established within the existing BWDB O & M framework but with special provisions for on- the-job training through attachment to consultants and contractors and for work experience overseas. Minimum assignment to the unit to be 5 years with guarantees of career advancement for those wishing to stay longer. The Unit would be responsible for carrying out all routine maintenance by direct labour and appointing contractors where necessary for constructing supplementary and emergency response works. Strict ratio to be maintained between budgetary allocation for maintenance works and for establishment costs. If the former is cut then the latter must also be cut and staff redeployed. In the absence of such an

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arrangement, priority tends to be given to maintaining establishment levels at the expense of actual maintenance work.

5. BWDB to review the design of the BRE when realigned to ensure that appropriate provision is made for its use for temporary refuge housing. Also that the borrow areas are designed to minimise loss of productive land and to avoid the risk of their development into flow paths.

6. International consultants and contractors to be employed for the detailed design and construction of river bank stabilization works until such time as the necessary level of skills and experience has been established in Bangladesh. BWDB staff to receive formal training during this period to speed up the skill and knowledge transfer.

14. DESIGN OF RIVER TRAINING WORKS

14.1 Functional Requirements

14.1.1 Introduction

The river training works that lie within the scope of this study fall into two categories. Firstly there are the works associated with the local stabilization of the river bank at locations that are currently experiencing serious bank erosion, essentially the Phase 1 works. In these cases the primary purpose of the works is to stabilize the bank at locations where the potential effect of river bank erosion is critical in the short term.

The secondary category covers works whose primary purpose is to encourage the river channel to follow a specific planform. The object behind this function may be either bankline stabilization or channel stabilization for navigation. The first category may therefore be considered as a sub-set of the second category.

In either case the works must be designed in such a manner that they will perform satisfactorily under the worst combination of hydrodynamic and morphological conditions that may be experienced for a hydrological event with a 100 year return period for a design life of at least 20 to 30 years and require relatively low maintenance during this period. Because of the turbidity of the Brahmaputra water, even at times of low flow, and the rapid deposition of sediment during flow recession, much of the works will remain invisible under normal circumstances. It is therefore particularly important that the portion of the works below low water level is robust and that if local failure does occur this does not lead to rapid progressive failure.

The highly mobile river bed and the potentially high flow velocities combine to form a demanding environment in which to construct works and the design must reflect these conditions in order that the completed product in practice may meet the functional requirements.

14.1.2 River Bank Stabilization

River bank stabilization, whether by groynes or revetments, is appropriate at areas where the consequences of continuing erosion are particularly serious. Examples of such cases are Sirajganj, where the existing revetment and groyne, themselves examples of river bank stabilization, are at risk of failure and further measures are required, Sariakandi and Mathurapara, where rapid erosion threatens the BRE and resulting flooding is particularly severe (also there is a very real danger that the Brahmaputra will break through into the Bangali River) and Jamuna Bridge, where revetment works will protect the bridge abutments. In fact revetments are the selected stabilization measure in all three examples. The relative merits of groynes and revetments are discussed in Section 14.3.2.

The principles of river bank stabilization are extended, under the Master Plan, to the whole study reach, where the long term aim is to stabilize the right bank and thereby protect the BRE from continuing bank erosion. The examples above, although priority requirements for implementation in themselves, will also conform to the longer term strategy of protecting the BRE.

14.1.3 Channel Stabilization

Situations where channel stabilization is of primary concern are generally related to navigational requirements. In some circumstances the construction of groynes may be appropriate; by their nature they move the centroid of the channel away from the river bank, although to maintain a stable channel (and to prevent erosion of the opposite bank) a complementary set of groynes would be required on the opposite bank. This would be an expensive solution for a river such as the Brahmaputra, although groynes may have a more limited role to play at the entrance to ferryghats, for instance.

Traditionally navigability of the Brahmaputra has been maintained by dredging, although as a long term solution to channel stabilization, dredging appears to have only a minor effect. As explained below, attempts to undertake active channel training by means of dredging are rapidly overwhelmed by natural forces.

14.1.4 Overall Planform Stabilization

This is a strategic level approach to bank stabilization in which key sections of the river are fixed and the river is allowed some degree of freedom in between. Selection of the key sections is central issue. As far as the Brahmaputra is concerned, this is a higher level of stabilization than that discussed in section 14.1.2, where attention is (in accordance with the Study Terms of Reference) concentrated on the right bank. A combination of revetments and groynes may be appropriate.

The topic of node stabilization, which may well form an important element of longer term river training, is addressed in Chapter 17.

14.2 Design Concept

14.2.1 Short and Long Term Considerations

The Study Terms of Reference use the term short-term works to describe those works that are identified as required to treat immediate problems of severe bank erosion. In this context the short-term refers to the timescale for implementation rather than implying a limited life expectancy.

It is self-apparent that, for the conditions encountered on the Brahmaputra, designing bank stabilization works for anything other than to perform under severe conditions cannot be cost-effective. By definition, the locations that are identified as requiring priority attention are those where the hydrodynamic and morphological conditions are in or close to the severe category. For such works to survive for even one season the design must be such that the costs involved will be measured in hundreds of millions of taka, or millions of dollars. With this level of investment, the works can only be justified if they have a life expectancy measured in tens of years, and this in turn implies that the works must be designed to survive under the most severe conditions that may reasonably be expected to occur during that period.

The TOR also require that the short-term works should wherever possible be consistent with the longer term strategy for river planform stabilization. This reinforces the principle that the short-term works must be designed to satisfy long-term requirements with regard to durability and performance. Long-term in this context is taken to mean a life of 30 years for the concrete blocks, which are the most degradable element.

With regard to hydrodynamic and morphological considerations, the works are all designed to perform satisfactorily under adverse conditions associated with a flow event with a 100 year return period, giving a combined risk of exceedance of not more than 1 percent. Under more severe conditions some displacement of the protective blocks would occur, requiring timely remedial action, but rapid progressive failure should not follow.

The requirement that the short-term works should if possible contribute to the longer term strategy is consistent with the concept that the phasing of major river training works should in general follow the priorities set by the severity of the current problems.

14.2.2 Design Life

The design life of the works has been set at 30 years. This period is used when calculating the probability of exceedance of design conditions and therefore for assigning design values to key parameters such as scour depth and near bank velocity. There is a high probability that given adequate and timely preventative maintenance the actual functional life of the works will be considerably in excess of this.

14.2.3 Use of Local Resources

The TOR require that where possible and practicable the designs for the short-term works shall allow for a maximum use of local labour and materials. Since the routine maintenance will certainly be geared to local labour and material, this requirement has led to the selection of brick aggregate concrete blocks as the preferred principal material for the armour layer for all slope protection exposed to the main river flow.

The large scale manufacture and handling of blocks by labour intensive means is well established and appropriate for the smaller size (55 cm). For the larger sizes (72 and 85 cm) some form of mechanical handling will be required but the casting can remain labour intensive.

Alternative forms of armour material that would be functionally appropriate include boulders, quarried rock, stone aggregate concrete blocks and various forms of flexible matting. Boulders are available from the Sylhet area of Bangladesh but there are only limited quantities of the larger sizes required to satisfy the Brahmaputra conditions and this cannot be considered as a reliable source for this scale of works. Quarried rock is only available from India, Bhutan or further afield and this uncertainty of supply has to be offset against the greater durability potential, and possibly marginally better performance, of rock. Stone aggregate concrete has a higher density than concrete made with brick aggregate, meaning that block dimensions can be reduced and some saving in cement thereby achieved, but this advantage will normally be offset by the higher cost of the stone.

The use of flexible mats has potential cost advantages in a situation such as this where material costs are a major factor, but a higher level of sophistication is required both for initial placing and subsequent maintenance, which in terms of local resources is a disadvantage.

In situations where the forces acting on the revetment are less severe and maintenance is more easily undertaken, for example on the slopes of cross-bars, brick in wire baskets will be used. This form of protection makes maximum use of local material and resources but is not suitable for the more arduous conditions to which the main bank revetment is exposed.

The other major elements of the work are the supply and laying of the geotextile filter and the dredging. Both these require heavy plant and, in the case of the geotextile, imported material, which is unavoidable.

14.2.4 Planned Maintenance

Although the design of the revetment and other works will be in accordance with criteria that are chosen to minimise maintenance, it is anticipated that some local failures will occur that require timely maintenance. It has been assumed that after the first season on exposure to the monsoon flows it will be necessary to place an additional 5 percent of blocks where weaknesses have been exposed. Thereafter the replacement rate should drop to less than 1 or 2 percent per year.

Failure of the slope protection is most likely to be associated with the weakest feature of the structure which is the falling apron. Regular monitoring of the performance of the apron and the slope immediately above it is an essential part of the maintenance programme so that remedial action can be taken before instability develops.

14.3 Bank Stabilization Alternatives

14.3.1 Active Channel Training

The excavation of pilot cuts and the construction of temporary submerged sills to encourage a river to follow a particular course is a well-established practice on meandering rivers. The concept could have some merit on a smaller braided river but the logistics involved for a river the size of the Brahmaputra put the concept in a different perspective.

Simulation of a typical situation involving an anabranch bifurcation around a char was carried out using the 2-D modelling system (see Part 13 of the BRTS Report on Model Studies for details). A dredged trench sized on the capacity of a medium size cutter-suction dredger, typical of those operated by the BIWTA and BWDB in Bangladesh, was simulated in one branch and the equivalent material was dumped in the other channel. After a simulated period of 80 days both the mound and the trench had extended downstream by 4,000 m (50 m/d) and the flow split altered accordingly.

A further simulation was carried out without any movement of material but altering the angle of attack of the flow approaching the bifurcation by 10°. This resulted in double the rate of accretion and erosion to that of the earlier simulation. The inference is that while the pilot channel excavation was very effective with a symmetrical approach channel, the effect would be almost totally masked by a modest change in the angle of approach due to the shifting of the upstream bend. Since this level of shifting can occur very quickly as the flow increases, the concept does not appear very promising.

The findings have important implications with regard to the training of an anabranch bifurcation.

14.3.2 Local Bank Stabilization

Location bank stabilization applies to localities such as those discussed in Section 14.1.2. The approach adopted will depend on the degree to which stabilization is to be imposed. At the most rigorous, the bankline is to be completely defined and for this purpose some form of revetment is the appropriate treatment; this is usually applicable to a relatively short stretch of bankline (e.g up to 2 km) where some specific object or concentrated area is to be protected, such as at Sirajganj. If the exact bankline configuration is not important but there are fixed limits on the extreme positions that the bankline may adopt relative to the mean line, then some form of intermittent erosion resistant structure is appropriate. This may take the form of groynes or hard-points.

In this context groynes are defined as hardened structures that protrude into the main channel, when constructed, with the primary objective of deflecting erosive flows away from the bankline. By their nature, they move the centroid of the channel away from the original bankline and thus unless complementary groynes are provided on the opposite bank (or for some other reason it is erosion resistant), erosion of the other bank will take place to an equal extent. The concept that groynes result in a net land gain may therefore be illusory. Groynes are in general relatively costly to build because of the fact that they have to be constructed in deep flowing water and also because their flanks are exposed to high velocity flows during high river stages. Although scour associated with a groyne can be well in excess of that normally found in a river, the deepest point is typically situated more than six times the depth away from the groyne structure and therefore presents no significant threat to its stability. Scour alone is therefore not a major consideration.

Hard-points differ in concept in that there is no attempt to actively deflect the river. The objective is to hold the bankline at suitable intervals and to allow it to take up its natural shape in between. Until the system settles down there may be some continuing loss of land but this will be substantially less than would have occurred without the intervention. The spacing between the hard-points will be determined by the maximum depth of embayment that may be permitted between the structures. Hard-points are typically constructed with their river face in line with the existing bank this simplifies construction and in particular avoids the high cost of placing materials below the water line while exposed to the full river flow (or alternatively the cost of massive coffer dams). After an upstream embayment has formed, the hydraulic conditions at the upstream nose of the hard-point will become much the same as that of a groyne but the exposure to the highest velocity flows will normally be limited to the nose alone, since there is no exposed flank to protect.

In both cases provision must be made to prevent out-of-bank flow from scouring a channel on the land side of the hardened structure which could result in outflanking. This is most simply and inexpensively achieved with an earth embankment, known in Bangladesh as a "cross-bar", with light protection on the slopes against wave action. An alternative in situations where flood plain conveyance may be considered important would be a low level erosion resistant overspill cill linking the hard structure to the BRE. The disadvantage of such an arrangement would be that there would be no land access to the main groyne or hard-point for maintenance during periods of out-of-bank flow, unless the structure took the form of a bridge or multiple culvert, thereby considerably increasing the cost.

The choice between groynes and hard-points will depend on three considerations: (a) relative cost per linear metre of stabilized bank line, (b) whether thalweg alignment is in itself a primary consideration and (c) the environmental impact.

It has been noted in Section 14.1.3 above that unless complementary groynes are provided on the opposite bank (or for some other reason it is erosion resistant), the construction of one or more groynes on one bank of a river will normally result in erosion of the other bank to an equal extent. The concept that groynes result in a net land gain may therefore be illusory. In this respect, the environmental advantage of a groyne over a hard-point, particularly in terms of social benefit, is therefore limited to situations where the treatment of both banks is appropriate.

14.4 Design Considerations

14.4.1 General

The factors which have been considered in the design of the river training structures proposed in this study, the criteria used, and their influence on the form of the structures, are described in detail in Annex 4 to this report. The main points are summarized in the following sections.

14.4.2 Geotechnical

Soil Characteristics

A considerable amount of geotechnical investigation has been undertaken along the Brahmaputra and in its vicinity for the Jamuna Bridge project and earlier for the East-West Interconnector. This provides a good overall view of the soil characteristics of the area and indicates that the riparian soils are relatively uniform in character. Further site investigations were carried out under the BRTS to confirm the stratification changes and to check the uniformity of the soils. This programme comprised twelve boreholes on the right bank and one on the left bank (see BRTS Report on Priority Works, October 1991, for further details).

The Jamuna Bridge investigation showed the significance of the mica content in the Jamuna sands on deformation characteristics of the sand and interpretation of CPT results. The site investigations and laboratory tests were carried out by international companies to a high standard.

Analyses for the Stage II Jamuna Bridge Studies and for the Brahmaputra Barrage Engineering Appraisal both indicated that soils at Sirajganj and Bahadurabad were prone to liquefaction from design earthquakes to depths of up to 17 m, possibly to 21 m at Sirajganj. This consistency in depth, despite very different design earthquakes arises from denser strata being present on the surface at Bahadurabad than Sirajganj.

The conclusions that emerged are that the soils which influence the Brahmaputra, and any engineering works controlling the Brahmaputra, are primarily micaceous fine to medium silty sands, loose near the surface, generally finest at the surface and becoming coarser with depth.

Liquefaction

Loose fine cohesionless deposits may liquefy under non-dynamic loads, depending on their relative density and initial state of stress. Observations in the field, reports of "fluidised" failure of structures in Bangladesh in the past, and observations by Coleman on his visit to Bangladesh in 1990, all point to the possibility that such phenomena may have occurred here and could well occur again in the future. An analysis has therefore been carried out to see whether the present site investigation and data from the Jamuna Bridge geotechnical report might support this hypothesis.

The results of this analysis show that data from both sets of investigations tend to confirm some strata are sufficiently loose and at an initial state of stress from which liquefaction could ensue. The bulk of the data show the soils to be in a condition that is not conducive to liquefaction occurring. This analysis tends to confirm what little evidence there is that liquefactions or partial liquefactions are possible, but not common.

For the conditions prevailing on the right bank of the Brahmaputra the relatively low risk of failure due to liquefaction would not appear to justify the technical difficulties and high cost of densification, much of which would have to be carried out in the saturated sands.

Piping and Erosion

Seepage forces during the falling stage will cause piping in these fine soils unless filters are provided. The most essential area for the filter is where there are waves and this will also cover the areas where seepage forces are greatest during the falling stage of the river. However, there will be seepage forces occurring down to the river bed and pumping action due to turbulent flow around the block protection will induce particle migration. Protection over the full length of the revetment is therefore required if stability of the slope is to be assured. In these circumstances there would appear to be no alternative to the provision of a suitably designed geotextile filter.

Soil Permeability

The permeability test results at 15 m and 30 m depth in six of the boreholes gave coefficients of permeability consistent with SM/SP and SP soils and confirm that they could be dewatered by pumping from deep wells. Down to 10 m, the soils are quite frequently silt and/or clay and dewatering would best be achieved by dewatering the more permeable sands beneath in a sufficiently large area to cause vertical drainage of the silt.

14.4.3 Availability of Materials

The only potential construction materials that are readily available in the immediate vicinity are the fine uniformly graded river sand and locally fired bricks. Cement is manufactured in Bangladesh but for the quantities involved and the tight time schedules to be met it will be necessary to depend on imported cement.

River-worn shingle and large cobbles are available from the Panchargarh area in Bangladesh in quite large quantities although insufficient to meet the programme for the Phase 1A works. Various grades of stone and crushed rock are imported in large quantities from India across

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the border at Hili.

Geotextiles for the present at least, will have to be imported.

14.4.4 Morphological

The morphological considerations fall into two main categories:

(a) the range of bed bathymetry that may occur in the immediate vicinity of any training or stabilization works, particularly the maximum scour depth that may develop;

(b) the dynamics of channel and bankline planform, which will determine the location of works, their planform dimensions and the geometry of the structures' terminations.

The first of these categories has been investigated through a combination of bathymetric surveys of areas of interest, notably the priority locations, at different times of the year, 2-D mathematical modelling, physical modelling and analysis of morphological statistics. The scope for statistical analysis is limited by the availability and quality of data but sufficient data has been obtained for setting up and verifying the mathematical and physical models, which can then be used to extend the information to cover specific situations of interest. The 2-D modelling has been used to gain clearer understanding of the processes associated with bend and confluence scour and the bifurcation of flow around chars. Physical modelling is used both to complement the 2-D modelling with regard to the prediction of flow fields and amplification factors and to investigate 3-D dominated effects such as the scour associated with groynes and the stability of structural units.

For the second category, the principal source of information is the analysis of historic records, including maps dating back to 1830, and the more recent satellite imagery. The latter provides an almost sequential data set for the period since 1973, which has proved valuable for char and bend evolution analysis. The maps provide the bankline movement data over the longer period required in order to establish trends that are relevant to the timescale of the priority intervention measures. Further details can be found in Annex 2 of the BRTS Final Report.

14.4.5 Mooring Facilities

Existing arrangements for mooring vessels of all sizes from cargo vessels and ferries to country boats are rudimentary. Ferries have pontoons moored to the bank to provide an intermediate platform of fixed height relative to water level but other vessels typically moor up against the natural bank, wherever the deep water channel happens to be located at the time. At Sirajganj this informal mooring extends from the most downstream portion of the existing bank revetment for a distance of about 1 km.

The standard hard-point design includes country boat steps, and at the continuous revetment at Sirajganj, country boat steps are provided at approximately 500 m intervals in addition to the passenger ferry terminal which will replace the existing facility.

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14.4.6 Construction Windows

The design of stabilization and training works must take into consideration their constructability in the Brahmaputra river environment. Since the works will most often be constructed in flowing water in the vicinity of locations where active erosion is taking place, this means that the flow velocities will generally be in the upper quartile. To maintain a high level of construction control in flow velocities which may exceed 3.5 m/s would make the task an order of magnitude more difficult and therefore the construction that much more costly if not impossible.

The cross-sectional data that has been collected for the BRTS was therefore analyzed to determine the period of time during which different flows would not be exceeded for varying probabilities. An example of the output from this analysis is shown in Figure 14.1, from which it can be seen that for a mean velocity of 0.7 m/s, corresponding to a maximum probable velocity of about 1.4 m/s, there is a fairly clear cutoff between 150 and 200 days. In fact it is found that even if a somewhat larger velocity was considered acceptable this would make comparatively little difference to the length of the window.

14.4.7 Method of Construction

The design cross-section has to satisfy the two requirements of working at not too great a depth and providing adequate protection against scour. The structures are protected against scour by a falling (or launching) apron, i.e. armouring placed on the river bed or at a specific dredged level and extending further into the river from the toe of the structure. In the event of scour occurring close to the structure, the "reservoir" of armour material will be displaced and will form a protective layer on the scoured slope, inhibiting further erosion. The scoured slope is expected to be of the order of 1 vertical: 2 horizontal, considerably steeper than the formed slope of the structure (1v: 3.5h). There is thus a balance to be struck between stability of the structure, which would call for a deeper apron, minimising the height of the steeper slope above maximum scour depth, and the practical difficulties in dredging at greater depths (larger dredgers) placing the geotextile at such depths, and retaining the necessary control over distribution of armouring, more difficult at greater depths especially considering the poor visibility which will prevail.

With an estimated scour depth of 29 m below high flood level (HFL) off revetment structures, the apron setting has been put at 19 to 20 below HFL. This means that during the construction season when the river is low, dredging depth and the maximum working depth will be of the order of 13 to 14 m.

14.4.8 Temporary and Permanent Resettlement

In so far as it may be compatible with the technical requirement to provide a comprehensive system of river bank protection measures, the location of individual structures should be selected so as to minimise disruption or displacement of the local community. Almost inevitably in a crowded country like Bangladesh some displacement of persons will result, though the proximity of the structure to an urban centre will have a significant effect on numbers, and possibly, on the latitude available for siting the structure. At Sirajganj, for instance, the numbers displaced (squatters on the BRE particularly at the southern end of the town) will be appreciably greater than at Sariakandi.

Proper arrangements have to be made for these people, whether their displacement is temporary (i.e. they will be able to return after completion of the works) or permanent. In each case detailed plans must be drawn up for their resettlement, as has been done already for the Phase 1A works.

14.4.9 Environmental Impacts

The principal impacts will occur during construction and will therefore be of a temporary nature. This issue is discussed in Chapter 12 of this report, and at greater length in Annex 3, Initial Environmental Evaluation (IEE). Measures to mitigate the environmental impacts are described.

While the IEE gives the overall environmental framework for the Master Plan, it is essential that at each location, prior to construction, a detailed Environmental Impact Assessment (EIA) is undertaken, as for the Phase 1A works. Such EIA must take into account not only the impacts at the location itself, but also, in the context of continuing development of bank protection measures as described in this report, the cumulative effects of the programme at each stage.

14.5 Design Criteria

14.5.1 Hydrological

The standard hydrological design event is one with a 100 year return period. The definition of such an event has been derived by the Flood Modelling and Management Project (FAP-25) based on the data derived from a 25 year simulation using the MIKE 11 General Model. A closely similar approach was followed using the BRTS Jamuna model, which is a refinement of the General Model, to derive the design water levels at the priority locations with specified confidence limits. Such confidence limits do not, however, readily lend themselves to formal statistical methods, and experience and judgement are required to arrive at a reasonable assessment. FAP-25, in the Main Report (June 1992) of their Flood Hydrology Study, list safety margin components as the effects of random morphological processes (shifts of rating curve) errors in model calibration and underestimation of extreme events owing to shortness of records. They arrived at a safety margin on these three counts of 40 cm for a 1 in 100 year event. This margin then has to be considered within the overall safety requirements including freeboard (see also Part 7 of the BRTS Report on Model Studies). The BRTS revetments are designed with top of crest wall 1m above HFL.

For the purposes of designing the Phase 1 works, it has been assumed that the Jamuna Bridge will be built and water levels modified accordingly. No direct provision has been made for the possible construction of a left bank flood embankment because of the uncertainty as to its final layout and therefore its influence on water levels; however this possibility has not been ignored and the works have been designed to facilitate modification to accommodate such an increase in water levels when the need arises.

Low Water Level is defined as the lowest annual river level with a 50 percent probability of occurrence, corresponding to a simulated discharge of 2 year return period. For practical purposes the water level of greater relevance is that which will not be exceeded for a specific degree of probability over a reasonable construction period. For the design of the works this level has been taken as LWL+2m, which corresponds approximately to a 50 percent probability of exceedance within a 160 day window. In practice this means that there is a 50 percent probability that work can be carried out in the dry over a continuous period of 160 days.

14.5.2 Near Bank Velocity

One of the most important design parameters for the bank stabilization works is the maximum near bank velocity. This typically is the ruling criterion for the sizing of the armour layer, the other criterion being resistance to wind induced wave action.

Based on the results of a number of physical model tests and interpretation of the 1-D and 2-D mathematical model results it has been shown that there is a relationship between the mean velocity in the river section as a whole and the maximum velocity that can develop near the bank and around artificial projections such as groynes. The derivation of these values is described in Appendix F of Annex 4 and the results are quoted below in Table 14.1.

Table 14.1 Design Velocities

(Probability for exceedance of 100 year design event is 1% in project lifetime (30 year)).

Type of Structure	Amplification Factor	Design Velocity (m/s)
Revetment straight section	1.1	3.7
Revetment upstream termination	1.3	4.4
Head of groyne*	1.4	4.8

* including upstream termination at Ranigram Groyne, Sirajganj

The formula used previously by the JMBA has been used to determine armour size, and the results compared with those derived from wave considerations (see below). Only in the case of straight revetment did wave action prove the governing criteria. At upstream terminations and groyne heads, the higher flow velocities because the critical factor for armour sizing.

14.5.3 Wind Wave Action

The second most important criterion governing the size of the material in the protective layer for stabilization and training works is that the material must be able to resist the forces induced by wind wave action. The formula developed by Pilarczyk was used to determine the required size of armour units.

A considerable amount of data collection and analysis was carried out as a part of the JMB design studies; this has been reviewed and some further analysis carried out on data from five meteorological stations, including Sirajganj, obtained from the Bangladesh Meteorological Department.

The screening of the data disclosed a number of errors which were corrected by the Meteorological Department. The possibility of further less obvious errors cannot be excluded. A reasonable consistency was found between the five sets of data and from analysis of the data the design significant wave height was found to be 1 m with period 3.0 seconds.

14.5.4 Geotechnical

The stability of the revetment section has been checked by slip circle analysis for both static and seismic conditions. In accordance with recommendations by Seed that for the purposes of pseudo-static analysis, horizontal accelerations of 0.10 g and 0.15 g, used with a safety factor of 1.15, could be taken as representative of earthquakes of magnitude 6.5 and 8.2 respectively, an acceleration of 0.15 g was used for this analysis. As, however, the design earthquake is magnitude 7, a reduced factor of safety of 1.1 is acceptable, or 1.05 for a combination of extreme events. For static loading conditions, including the scoured face at the foot of the revetment, a factor of safety of 1.5 was applied.

Shear strength criteria have been selected on the basis of the site investigations. They are lower than the shear strength assumed for the Jamuna Bridge design on the basis of triaxial tests, but it is considered that this is justified by the universal nature of the revetment design and the need to have a stable revetment where ground condition might not have been specifically investigated.

The apron setting level has been determined from a combination of slope stability considerations, bearing in mind that the scour slope will be steeper than the profiled revetment section, and a reasonable maximum dredging depth. From the results of numerous physical model tests and reported experience in India and elsewhere, it has been concluded that it is reasonable to assume that the slope of the launched apron is unlikely to be steeper than 1V:2H. With this configuration and the base of the apron set at 10 m below LWL it was found that a lower revetment slope of 1V:3.5H gave acceptable factors of safety. The upper slope, above LWL+2m, had to be flattened to the same slope of 1V:3.5V from the earlier design of 1V:3.0H following analysis of the piezometer data collected at Sirajganj over the full annual cycle of water levels. These data showed that during the falling stage the piezometric head in the more clayey/silty strata of the bank could be as much as 1 m higher than the river water level for considerable periods of time.

14.5.5 Morphological

The morphological characteristics of the river that are of most direct concern for the structural design bank stabilization works are:

(a) the depth of scour that may be expected to occur in the immediate proximity of the structure, during its design life, with an approximately 1 percent combined exceedance probability. This will determine the apron geometry and influence its setting depth.

(b) The planforms of embayments that may develop on the upstream and downstream sides of a hard-point or groyne and the velocity field associated with these. These will determine the planform geometry of a hard-point and its associated cross-bar.

Scour Depth

The assessment of maximum scour that can occur has been the subject of several complementary studies:

- physical model studies, using mobile bed conditions to investigate scour associated with groynes and other active forms of training works;
- river surveys of locations were active bank erosion is taking place;
- 2-D mathematical model simulation;
- morphological model simulation for simple bends;
- analysis of BWDB river cross-sectional data surveyed over a period of about 30 years;

Analysis of these studies points to the conclusion that the worst scour that can occur in the study reach arises from exceptional combinations of conditions associated with major anabranch confluences. The next most severe condition is associated with vortex shedding downstream of a groyne nose.

It has been concluded that satisfactory values for design purposes are 29 m for scour at the toe of a bank parallel revetment, 33 m at the nose of a groyne and 33 m at the upstream termination of a bank revetment, measured below the 100 year design flood level. The falling apron is designed to distribute the equivalent of at least two layers of armour material over the deformed slope face with full scour development. Model tests and experience indicate that the redistributed armour material forms a remarkably uniform single layer and it is reasonable to expect that there will in practice be an in-built reserve of material that can be drawn upon in the unusual case of scour exceeding these design values. The apron design adopted will in theory provide sufficient armour material for a single layer over the complete surface for scour depth of 44 m at the nose of a groyne and 33 m at the toe of straight revetment.

The second of the morphological related criteria for design presents the harder problem because of the ever changing conditions on the river and the absence of clear behavioural trends. The location and planform of the works must take into consideration not only the present conditions but what may be expected to occur within the planning horizon for the works concerned, which will normally be 20 to 30 years.

Embayment Planform

In general the location of a hard-point and the length of its revetment will be determined by two considerations:

- providing direct protection to a specific object, such as a substantial town or major infrastructure;

- minimizing the risk of outflanking.

Both these are closely related to the form and depth of embayment that could form. The location and length of the hard-point must be such that protection is provided even with full embayment development, or at least such that relatively low cost secondary works (for example the use of porcupines) would be sufficient to prevent development of the embayment beyond certain limits. Equally important is that the cross-bar should remain functional under similar conditions.

There is very little data on which to base an estimate of the probable maximum embayment development upstream of a hard-point; the approach adopted has been to take the worst anabranch bend/embayments picked from the available satellite imagery and to use these as examples of the aspect ratio (depth to chord length) of a simple, approximately symmetrical, embayment that can be expected to develop anywhere on the right bank. The bends at Jalalpur and Fulcharighat that developed between 1984 and 1990 appear to be unusually severe cases and are appropriate for this purpose. This is discussed further in Annex 4.

14.5.6 Filter Layer Design

The filter layer laid on the formed bank slope is seen as a crucial element of the revetment and its absence in an effective form is thought to have been a major contributory cause to the failure of many river training works constructed on the Brahmaputra in the past. Grading requirements and the extreme difficulties of placing in flowing water effectively rule out mineral filters. A material of proven performance and durability is required, which can be laid without insurmountable practical difficulties.

Geotextiles have been extensively used in other countries for this purpose and under similar environmental conditions and good guidelines for the design and construction of revetments incorporating geotextiles have been published by PIANC (1987). Further advice, particularly regarding material properties was sought from leading manufacturers and the conclusions were set out in a BRTS Technical Note on Geotextile Selection issued in February 1992. This is reproduced as Appendix E of Annex 4.

14.6 Revetment Structures

14.6.1 Layout in Plan

For the reasons described above and in Annex 4, hard-point revetment structures are the principal form of river bank stabilization measure proposed for the short term and long term works.

The layout of a typical hard-point is shown in Figure 14.2. The length of straight revetment is such as to ensure that there will be an acceptably low risk of the embayment, or any re-entry upstream of the hard-point, threatening the integrity of the cross-bar. The cross-bar is angled back in plan to decrease further the risk of erosion from the upstream side. The cross-bar is lightly armoured against wave action from out-of-bank flow by brick mattressing on its

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upstream side, for the whole length back to the BRE, and for the 100 m nearest to the river bank on the downstream side.

The revetment is returned by upstream and downstream terminations. As can be seen from Table 14.1, the upstream termination and the length of straight revetment immediately downstream of it will be subjected to higher flow velocities than the rest of the straight revetment and the downstream termination, and hence heavier armouring is provided as shown in Figure 14.3.

14.6.2 Typical Revetment Section

The essential features of the revetment to be determined by design are:

Crest level

Slope

Geotextile filter membrance

Armouring

Apron

A typical revetment section in shown in Figure 14.4. The crest level is determined from the 100 year return period water level, derived from the 1-D hydrodynamic modelling programme described in Part 7 of the Report on Model Studies, with a 1.0 m allowance for freeboard. A single layer of placed armouring extends from the concrete crest wall to the lowest water level likely to be experienced during construction, LWL + 2 m. From that level to the apron setting depth, armouring will be dumped to form the equivalent of two layers.

The apron setting level has been determined from considerations of slope stability and dredging depth, as explained in Sections 14.4.7 and 14.5.4. The quantity of armour material in the apron is adequate to protect the scoured slope to design scour depth with a thickness of armouring in excess of two layers.

There is strong evidence that a geotextile membrane under the apron would interfere with the launching mechanism leaving the geotextile exposed. It is therefore not continued under the apron beyond the first 2 m.

Based on the flow velocity and wave considerations described above, the following sizes have been determined for concrete cubic block armouring using brick aggregate:

Noses of groynes:	850 mm
Upstream terminations:	720 mm
Linear revetments and downstream terminations:	550 mm

The revetment design provides for a choice to be made between three different armour materials, namely:

- concrete blocks with brick aggregate
- concrete blocks with stone aggregate
- quarried rock.

15. DESIGN OF THE FLOOD EMBANKMENT (BRE)

15.1 Functional Requirements

The purpose of the BRE is to prevent over bank flow from the Brahmaputra (Jamuna) entering in an uncontrolled manner the right bank flood plain, which is most easily defined as the area lying between the west bank of the river and the higher ground of the Barind Tract, and bounded to the north by the Teesta river and to the south by the Atrai/Gur river. The area affected is therefore about 230,00 ha. The area south of the Gur (Hurasagar) river and down to the Ganges river is not included.

Since the strip of flood plain is relatively long and narrow, being on average only 25 km wide, the distance that the flood embankment is set back from the river is clearly significant in terms of the area benefitting. Thus a set-back distance of 5 km, which has been suggested by some as a "safe" set-back, would mean that 20 percent of the area did not receive protection. Another way of looking at the same problem is that if bank erosion continues at the present rate, in 50 years time 20 percent of this fertile and productive area will have been lost.

The embankment is nominally designed to provide protection against a flood event of 100 years return period; that is the top of the embankment is supposed to be set at the water level that could occur at any point with a frequency of one in 100 years plus a freeboard of 5 ft (1.5 m) to cater for wave action and degradation of the crest level with time.

Since any higher ground has intrinsic value for access and housing, the embankment must be able to accommodate these secondary functions while maintaining its primary function.

North of Fulchari the natural ground slope and drainage is towards the Brahmaputra river and so the embankment must be designed both to stand the temporary ponding of water on the landward side at times of suppressed drainage and must be provided with adequate cross-flow regulators so as to efficiently evacuate the ponded water when the Brahmaputra levels fall.

South of Fulchari the river follows the valley slope closely and there are no tributaries entering. On the contrary, before the BRE was constructed there were a number of substantial distributaries that carried flow from the Brahmaputra into the Bangali/Ichamati system at times of high river level in the Brahmaputra. This flow returned to the Brahmaputra through the Hurasagar. These distributaries were significant features both from the point of view of water transport and fisheries but have in almost all cases now become heavily silted and moribund, despite the provision of regulators in the original embankment at the crossing points. The maintenance of flow into these channels is therefore less important than it was at one time.

15.2 Construction Methods

New BRE retirements will be constructed most probably either by local contractor, awarded by the process of Local Competitive Bidding (LCB) or by the BWDB using direct labour. In either case labour intensive methods are likely to predominate, although compaction should be undertaken by mechanical means, and mechanical earthmoving will help to achieve homogeneity where mixing owing to local variability of material is required.

The design should, however, take into account the constraints which may be imposed by limited plant availability and comparatively low standards of working practice. The embankment should be capable of retaining a 2 m depth of water for a period of two months despite lack of compaction and even lack of clod breaking. Freeboard should be adequate to allow for any inadequacies of crest level control, and for the inevitable settlement.

15.3 Geotechnical Considerations

15.3.1 Soil Properties

The soils are generally uniform in character over the length of the study area but there is some variation in stratification with depth. They vary between clays of low plasticity; through silts of low plasticity; non-plastic silts; non-plastic silty fine sands/fine sandy silts; fine sands; and medium-fine (predominantly fine) sands. The sands are extremely uniform, generally with a coefficient of uniformity of between 2 and 3.

In the study area the predominant soils are micaceous fine to medium silty sands, loose and generally finest at the surface and becoming coarser with depth. Occasional thin silty clayey strata or lenses are encountered.

15.3.2 Liquefaction

The results of analyses carried out by the JMB study and the BRTS tend to confirm that some strata are sufficiently loose and at an initial state of stress from which liquefaction could ensue. The bulk of the data show the soils to be in a condition that is not conducive to liquefaction occurring. This analysis tends to confirm what little evidence there is that liquefaction or partial liquefaction is possible, but not common.

For the conditions prevailing on the right bank of the Brahmaputra the relatively low risk of failure due to liquefaction does not justify the high cost of densification.

15.3.3 Piping and Erosion

The soils are inherently weak and erosion of embankments will occur from currents and waves unless measures are taken to prevent it. Under certain circumstances, such as sustained high head differences across the embankment, seepage forces can result in piping in these fine soils unless filters are provided or other precautions taken. Good compaction of the soil is essential as this will simultaneously increase its strength and reduce its permeability.

Surprisingly, there are very few indications of damage by wave action and no substantiated cases of piping on the BRE. Where significant wave damage has been recorded it is invariably associated with retired sections of the embankment where quality control has been lax, side slopes are steep and no attempt has been made to establish grass cover.

The lack of wave damage is attributable to the fact that the vegetative cover on the strip of land between the river bank and the BRE acts as a very efficient wave attenuator. Experimental work carried out by the US Corps of Engineers has shown that a good stand of tall grass or reeds can virtually damp out all waves in shallow water over a distance of 70 m. Positive measures therefore need to be taken to encourage the growth of suitable vegetation in this zone - sugar cane would seem to be one of the more attractive possibilities.

Embankments that are designed to be in direct contact with wave action, such as some cross-bars, must be provided with suitable slope protection laid on a properly designed filter layer to prevent migration of the underlying soil. Because of the wide range in particle size between the fine sand and the protective material, conventional mineral, or khoa filters will require at least three graded layers. The quality control implications make this almost impracticable and a medium weight geotextile filter fabric is clearly indicated.

Good grass cover is an excellent protective surface against wave, rain, animal and human impact. In vulnerable locations it can be effectively reinforced by the addition of a thin geotextile mattress at relatively low cost. The cost-effectiveness of well maintained grass cover should not be underestimated and Vetiver grass has been suggested for this purpose (see Section 6.5.6).

15.3.4 Sources of Construction Materials

Economic considerations rule out the use of other than local materials for embankment construction. This need not, however, be a significant constraint for an embankment which generally need not retain more than 3.5 m depth of water, as borne out by the satisfactory geotechnical performance of the original BRE, constructed from locally available material.

Where there are substantial deposits of consistently more sandy or more clayey soil then these can be used selectively to advantage to improve the embankment stability but in general the variability of the stratification is such that the embankment will have to be treated as homogeneous, in which case the emphasis should be on ensuring good mixing of the material to avoid flow concentrations. This mixing is best achieved through mechanical earthmoving.

Borrow areas must be sited sufficiently far away from the toe of the embankment so as not to affect the slope stability adversely. If excavated on the river-side, which is usually favoured for both social and financial considerations, then they must be made discontinuous and stabilized by the planting of appropriate vegetation to prevent scour and channel evolution. For environmental reasons, i.e. for future use for crops or as fish ponds, it is recommended that the excavated depth of borrow pits does not exceed 2m.

15.4 **Socio-economic Considerations**

The socio-economic implications of BRE construction and retirement have been described in some detail in Annex 1. The principal constraints with regard to the planning and design of the embankment are:

- the significance of local lobbying with regard to the selection of the alignment and the timing of any embankment retirement;
- protection of the interests of the specialist and minority groups, such as fishermen and the handloom community;

- pressures to minimise land acquisition, which have to be set against the needs for an embankment that meets the functional requirements and provides a haven for displaced families;

- the location and subsequent use made of borrow areas.

It has been proposed (see Section 6.6.8) that a berm be constructed on the country side of the BRE in order to provide a refuge for those displaced by loss of their land, either by erosion or by land acquisition for bank or flood protection measures. This approach would obviate the need for making illegal cuts in the crest of the BRE, which happens at the moment and inevitably will continue to happen in the future unless such provision is made. It has been suggested that displaced persons be given some form of security of tenure on the embankment in return for undertaking routine maintenance.

15.5 Agro-economic Considerations

The principal benefits from the BRE arise from agricultural production and the provision of security for major and minor infrastructural facilities. The alignment of the embankment will clearly be influenced to a large degree by these two considerations since other constraints are, with a few exceptions, approximately uniformly distributed throughout the area.

The benefits derived from the BRE increase steadily from south to north, upto somewhere in the vicinity of Fulchari. Thereafter they diminish rapidly in the section upto the Teesta confluence where the natural ground fall is towards the river and the affects of Brahmaputra overbank flow are localized.

In the most southerly part of the area the marginal benefits of the BRE are small because the lowlying land experiences suppressed drainage not only on the Brahmaputra side but also due to the backwater effect up the Hurasagar. These conclusions are consistent with the findings of FAP-2.

It has been noted at the start of this Chapter that the area receiving the benefits from the BRE is relatively long and narrow. There is consequently more than average concern over the proportion of the flood plain that may be occupied by the embankment itself, together with the multiple retired lengths and the zone between the embankment and the river which receives no benefit and possibly some marginal disbenefit. An equal emphasis should therefore be placed on the maximum utilisation of the embankment, the borrow areas and the unprotected strip in order to gain the most production from the area as a whole.

15.6 Environmental Considerations

In contrast to a proposal for a new Flood Control Scheme, the consequences of flood control on the right bank are now, after more than 20 years, effectively established and have been absorbed into the eco-system; the present situation with a relatively high level of flood control represents closely the without project base situation. The impact of frequent breaches since the late 1980s can hardly be considered as the status quo condition, although if this state were to continue for the next 10 or 20 years there would undoubtedly be commensurate environmental changes, some of which could be beneficial but the majority of which would be judged by the local community as a whole as retrogressive.

In short, the environmental considerations in relation to the planning and design of the flood embankments are largely concerned with ways in which full advantage may be obtained from the works through careful attention to design details and methods of construction. As far as the selection of an alignment is concerned, the balance of environmental pro and cons is seen to be clearly in favour of siting the embankment as close to the river as reasonably practicable.

15.7 Land Acquisition

The land required by BWDB for the construction of the BRE is a strip approximately thirty metres wide (excluding the borrow pit which is dug on the river side in order to refill with silt and be returned to productive use). Each kilometre of BRE thus requires 3 hectares of land which must be purchased from villagers. It is agreed by local people and BWDB engineers that land acquisition is one of the most important issues in embankment construction. When the BRE was first created local people were said to be content with the acquisition process, receiving due payment for the current value of their land. Since then there has been increasing resistance to acquisition stemming from four main concerns: the loss of land, the different effect of the BRE on the potential and price of land and the delays and losses associated with compensation. Acquisition is under detailed study by FAP-15 whose summary findings were issued as a workshop paper.

It is also apparent that the greater proportion of loss falls on the poorer sector of the community, not only in terms of acreage but also with regard to buildings and trees. The outcome is a reduction in average holding size and an increase in landlessness, where resettlement once again becomes an issue. This is a matter which now requires urgent attention. Land acquisition and its consequences are discussed in greater detail in Annex 1.

15.8 Optimal Set-back and Trigger Distances

The two variables in optimizing the distance and frequency of retirements of the BRE are the set-back distance (SB) between old and new embankment alignments, and trigger distance (TR) which is the minimum distance of embankment from bankline that triggers the decision to realign. There is a trade-off between the cost of realignment and the reduced value of land no longer protected. This is explored in detail in Chapter 7 of Annex 2.

15.9 Cross-Drainage

Drainage across the BRE is considered to be significant only over a length of about 20 to 25 km, with the Ghagat River forming the approximate southern limit and Teesta the northern limit. In this stretch the general land slope is towards the Brahmaputra and the embankment can therefore restrict drainage. The problem does not, however, seem to be particularly serious except for pockets of low-lying land. The situation is exacerbated by the occasional breaching of the flood embankment on the southern bank of the Teesta in the vicinity of Belka, and public cuts are made in the BRE from time to time to relieve such flooding when homesteads or crops are threatened.

Cross flow control structures were incorporated over the full length of the original BRE, mostly in order to provide the facility for releasing water from the Brahmaputra into what were originally distributary channels, for irrigation and fisheries interests. These channels have in the main become silted up, presumably because of insufficient incentive for the proper operation of the regulators, and their function is consequently in many cases now ill defined.

Of the 31 existing structures, 26 are one gated and 3 are two gated. The major structures are the 12 gated Manas Regulator on the Ghagat River which is currently threatened by bank erosion, and a narrower 12 gated structure north of Kamarjani. Some 20 of the smaller structures have been rebuilt on the retired embankments. Tables 6.1 and 6.2 give the locations and condition of the cross-drainage structures.

15.10 Floodplain Fishery Improvements

The BRE has provided considerable benefit over its history to the agricultural production of the hinterland, but in turn has caused considerable depletion in the recruitment stock of the floodplain fishery. This historic stock depletion has been cumulative over the years, and the present fishery is probably only in existence through recruitment within the left bank floodplain.

The problem is due to the inability of surface borne spawn to enter the floodplain at the beginning of the flood season, and for adult fish to migrate out into the river towards the end of the season. Structures used for drainage could be adequately designed to allow for these two passages to occur, thus improving the floodplain fishery on the right bank.

Design and construction of suitable structures will not, in themselves, be sufficient to ensure a recovery in the fisheries. The structures will need to be operated at appropriate times, and this will require some institutional cooperation between responsible agencies, and incorporation into the operational schedule for these structures. Such institutional changes are relatively slight, and could easily be effected, providing the responsible bodies have the will to ensure the revival of the fishery.

15.11 Design Criteria

The cross-sectional geometry which has resulted from analysis by BRTS is described in Section 6.1, "Requirements for Improved Performance". It is illustrated in Figure 15.1.

The recommended crest height is that which allows 1.5m freeboard above the 100 year return period flood level as determined by the 25 year 1-D hydrodynamic model analysis for the case with Jamuna Bridge and FAP-3 left bank proposals. The recommended crest width is 6m, and the land-side berm, in the section with berm, is 5 m wide.

The side slopes were determined by pseudo-static slip circle analysis using the SLIP 5 programme, to the following stability criteria:

River-side slope: Slope stability

1. With steady state seepage from ponded water on the land-side and bankfull river level - Factor of Safety = 1.1.

2. With seismic loading and full level on river-side - Factor of Safety = 1.25

Normal state - Factor of Safety = 1.5

Earthquake acceleration = 0.15g

Land-side slope: Slope stability

3. With steady state seepage from ponded water on the river-side and saturated soil on the land-side - Factor of Safety = 1.25.

4. With seismic loading and maximum ponded level on land-side - Factor of Safety = 1.1.

Normal state - Factor of Safety = 1.5

Earthquake acceleration = 0.15g

The soil parameters adopted are shown in Table 15.1 below:

Table 15.1 Soil Parameters for BRE Analysis

	Embankment	Foundation
Bulk density (kN/m^3)	19.5	19.5
Effective angle of internal friction, ϕ'	28°	32°
Effective cohesion, $c'(kN/m^2)$	0, 1.5	0, 1.5

Analysis were carried out with c' = 0 (conservative) and c' = 1.5 kN/m^2 (more realistic). The soil undoubtedly has some cohesive properties, although at this order of magnitude, difficult to measure without very sophisticated testing.

The results are given in Table 15.2.

15.12 Construction Standards

It has been noted that economic considerations will normally dictate that the embankment be constructed as a homogeneous section using the locally available silty-sand material.

The performance of the original BRE demonstrates that if the embankment is well constructed then it may be expected to perform satisfactorily. Well constructed in this context means primarily that the material is properly consolidated and that the cross-sectional profile is achieved. It is also desirable that the material should be well mixed, unless larger uniform deposits make local zoning feasible.

Table 15.2 BRE SLIP 5 Analysis

Stability Case		c' = 0	c' = 1.5 kN/m²
1.	Riverside Slope	1.57	-
2.		1.03	1.35
3.	Landside slope (with berm)	1.34	-
4.		0.92	1.36

These considerations point strongly to the use of mechanical plant for the construction of the embankment unless a very high level of management and supervision can be achieved.

With little opportunity to obtain soils from further afield, the best use must be made of the material available locally. Organic material must be excluded, and organic or very silty layers in the foundation must be removed. Compaction should be of as high a standard as reasonably practicable. The absolute minimum requirement is clod-breaking and this should be enforced. Preferably the material should be placed in layers not exceeding 250 mm thick at close to optimum moisture content, and compacted to 95% standard Proctor density.

With reasonable control a crest level of +200 mm -0 should be achievable, with the same order of tolerance horizontally at top of slope (distance from centreline). Toe of slope could be +500 mm -0 from centreline.

Following completion of the embankment, the slopes should be grassed, or, in accordance with proposals for maintenance by displaced persons living on the berm, planted with approved vegetable crop. Equally important is the planting of vegetation resistant to inundation between the BRE and the river for purposes of wave suppression, and to prevent borrow pits from becoming preferential flow channels.

16. SHORT TERM STABILIZATION AND CONTAINMENT WORKS

16.1 Planning Approach

The overall strategy provides for early implementation of river bank stabilization in critical areas. The phrase "short term" refers to works that are to be implemented on a priority basis, as opposed to the longer term programme of full stabilization; it is not intended in any way to imply "temporary". Works for implementation in the short term are referred to in this report as the Phase 1 works; they include the priority locations listed below and the measures to ensure security along adjacent lengths of river bank. As explained, Phase 1 is subdivided into Phases 1A, 1B and 1C.

Early in the BRTS programme, a ranking of priority locations was carried out. An extensive programme of field visits was undertaken by BRTS team members supported by BWDB field officers. The data obtained was examined by adopting an objective multi-criteria approach based on the following principal considerations;

- risk and direct consequence of bank erosion;
- risk and consequences of flooding from a breach in the BRE;
- capital costs of bank protection works and BRE retirement.

From the wide range of potential selection criteria, the following social and economic criteria were consequently selected for ranking purposes:

- number of people displaced by erosion (social upheaval)
- number of people seriously affected by flooding (social disruption);
- value of land, property and agricultural production lost and/or damaged (economic losses);
- infrastructure at risk from erosion and flooding (economic disruption);
- capital costs of priority works per beneficiary (capital investment);
- economic benefit: cost ratio (cost effectiveness).

Further criteria to be considered included the importance of such issues as the possibility of the Brahmaputra breaking through to the Bangali River in the vicinity of Sariakandi, and the security of ferryghats.

Ten locations emerged from the initial ranking, from which six were selected for detailed design, namely (in alphabetical order):

Betil
Fulcharighat
Kazipur

Mathurapra
Sariakandi
Sirajganj

A full economic and sociological assessment of the six locations showed very clearly that, in conventional economic evaluation terms, investment priorities for bank stabilization were: Sirajganj, an important regional centre where the present protection works have deteriorated and which would be seriously at risk in the event of a major flood, and the reach of bankline between Sariakandi and Mathurapara, where serious bank erosion is making a breakthrough into the Bangali an increasingly likely event. While investment at these locations showed respectable internal rates of return, the financial and economic returns to bank protection works at the other three locations was poor.

It was consequently agreed between the Government and IDA (World Bank) that the Phase 1 Priority Works should comprise bank protection works at Sirajganj and Sariakandi/Mathurapara. In the context of the Master Plan, these have been described as the Phase 1A works.

16.2 Phase 1A

16.2.1 River Bank Stabilization

The Phase 1 Priority Works are aimed at the stabilization of the bankline 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 widespread disruption and loss of the BRE. These two situations are distinct in character and consequently involve different conceptual approaches to the design of bank protection measures.

At Sirajganj, more than 2 km of new revetment will be constructed, incorporating the existing Ranigram Groyne and reclamation of land between the groyne and the town (see Figure 16.1). At Sariakandi an Mathurapara (Figure 16.2) the works will consist of reinforcement of the existing Kalitola Groyne and the construction of two hardpoints, consisting of conventional bank revetment with upstream and downstream terminations, and a lightly protected cross-bar on the flood plain linking with the set back flood embankment to prevent out-of-bank flood flows from bypassing and outflanking the hard point.

16.2.2 Flood Embankment (BRE)

Concurrently with the construction of the protection works at Sariakandi and Mathurapara, it will be necessary to retire the BRE over its whole length between the groyne and a point south of Mathurapara. This work will be carried out separately from the works described in Section 16.2.1 above, most likely by a local contractor appointed under Local Competitive Bidding (LCB) procedures. It does, however, form an equally important item of work to be undertaken at this time.

Elsewhere along the river, it will be necessary for tactical retirement of the BRE to continue as before.

16.2.3 Implementation Programme

Tender Documents for International Competitive Bidding (ICB) for the Phase 1A Priority Works have been prepared, and prequalification procedures are expected to commence around mid-1993. Contract award, therefore, would be expected during the second quarter of 1994. The construction period for the works at Sariakandi & Mathurapara is 24 months, i.e. completion mid-1996, and at Sirajganj it is 36 months, leading to a mid-1997 completion date.

16.3 Phases 1B and 1C

16.3.1 River Bank Stabilization

During the first phase of the Master Plan, within a period of 5 to 10 years, it is expected that hard-points to stabilize the reaches immediately north of Sirajganj and immediately north of Sariakandi will be required. Accordingly, 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, have been included as Phase 1B. These works are shown in Figures 16.3 and 16.4

Phase 1C will comprise the remainder of the six locations selected originally, namely Fulchari, Kazipur and Betil (see Figures 16.5, 16.6 and 16.7). The structures for the Phase 1B and Phase 1C works will all be hard-point type revetments, as illustrated in Figure 14.2 although some modifications may be necessary depending on the topography and bathymetry nearer the time of construction, and the precise location will have to be determined in view of the morphological situation in the river and the progress of river bank erosion.

16.3.2 Flood Embankment (BRE)

Tactical retirement of the BRE will continue throughout this period in areas where river bank protection measures are yet to be constructed. Such areas, however, will generally have a lower erosion risk than the priority locations and hence the scale of the problem will be very much reduced.

16.3.3 Implementation Programme

As noted above, a likely timescale for construction of the Phase 1B works would be commencement some 5 years after the commencement of the Phase 1A works, and completion within 10 years of that date. The corresponding period for the Phase 1C works would be 10 to 15 years or possibly 20 years, the latter date being implied by the implementation schedule in Tables 21.5 and 21.6.

17. LONG TERM STABILIZATION AND CONTAINMENT WORKS

17.1 Introduction

The Terms of Reference for the BRTS limit the scope of the Study to the right bank of the river and as such preclude more than an outline consideration of the possibilities for long term stabilization of the river as a whole. The following review is presented as an interpretation of the available data, taking into account parallel studies carried out by the Joint Chinese-Bangladesh Team and by FAP-21/22. Since there are many similarities between the Brahmaputra River and the Yangtze and Huang Ho, a visit was made to China in December 1992 and valuable discussions were held with engineers responsible for planning and implementing river management works on these two rivers. It was notable that in both cases the preferred approach is bend and island stabilization in contrast to the node stabilization concept referred to in much Chinese literature. It was also observed that this approach to bank stabilization is effective in substantially reducing the annual variation in thalweg planform and cross-sectional geometry without creating adverse effects downstream. In contrast, earlier attempts to artificially close off secondary anabranches and other active forms of intervention had resulted in very substantial, and undesirable, morphological consequences. The main river engineering observations of the December 1992 visit are attached as Appendix C.

17.2 Node Stabilization

It is a generally accepted fact that many braided rivers are characterized by relatively more stable reaches that are significantly narrower than the mean braid belt width. Frequently these reaches remain as distinct features on a timescale that may be an order of magnitude or more greater than that of the general braid planform. Because of this relative stability, and the coincidence of these reaches with the confluence-bifurcation of major anabranches between principal island clusters, they are sometimes referred to as nodes. This term may be misleading because of the implication of a fixed point whereas the node is in reality more usually a rather undefined reach of several kilometres in length, within which the narrowest point may migrate up and downstream over time.

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 and downstream nor prevent switching of predominant anabranches, although it may provide an upper limit on the extent of the former.

In the case of the Brahmaputra there are two nodes on the length of the river lying in Bangladesh that are very much better defined and persistent than the other inter-island reaches. One of these is the well known throat section to the south of Sirajganj, which is the site of the proposed Jamuna Bridge. The second lies to the north of Sariakandi and is currently less clearly defined although in the late 1970s it was as distinct as the Sirajganj node.

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 for the river to migrate laterally.

There would remain the possibility of a lateral migration taking place further upstream that if not addressed could result in an avulsion at some time in the future. This at present however

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would appear to be a process with a timescale of decades and not one requiring urgent attention.

Stabilization of this node could however provide other benefits. It can be seen from Plate 17 that the dominant thalweg waveform in plan is undefined in this vicinity. It is as if the river is trying to insert an extra half wavelength, with resulting instability of planform. This may be connected with the approximate coincidence of this nodal reach with the apex of the macro planform leftward bend, which itself has been migrating downstream over the last 20 years.

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.

17.3 Bend Stabilization

This may be seen as the complement to node stabilization and, as noted in the introduction to this chapter, is a strategy that is being successfully followed on the Yangtze River in conjunction with island node stabilisation. On the Huang Ho the same principle is being followed but the extremely braided nature of the river has called for active bend planform management, involving a massive programme of revetments, spurs and multiple raked groynes.

Although stabilization of one bend can be effective in terms of controlling channel planform and geometry in that reach to some degree, it will only satisfy the full objective of a reasonably predictable channel if it is carried out as part of a larger scale programme. On the Huang Ho this long term strategy takes the form of a simple waveform in plan with the concave face of each bend stabilized and the flow induced by means of deflector groyne fields to cross over to the opposite stabilized bend downstream.

On the Yangtze, on which the islands are distinct features and sandbars less volatile, the strategy is to merely stabilize the current bankline by means of rock revetment, and to utilize the hardened noses of islands as controls on the division of flow between anabranches. This requires very much less investment than on the Huang Ho and is proving successful.

The Brahmaputra is in character somewhere between the Yangtze and the Huang Ho, having features that are recognisable in both. The presence of islands is an important factor and one that suggests that the Yangtze model may be the more appropriate starting point. The form of stabilisation will however have to be more robust and in some cases active bend shaping may be necessary. The proposed layout is shown in Plate 17.

The key to effective anabranch stabilization is the control of the angle of approach to the bifurcation. Node stabilization may be one way of achieving this; the alternative and probably less costly method may be bend stabilization, which can be implemented in a phased manner.

17.4 Flood Embankments

Given full planform stabilization, the position of the flood embankment in relation to the river bank will be determined in terms of the trade-off between embankment height, the protected area and the consequences with regard to channel degradation. The closer the embankment is to the river, the less will be the flood plain storage and conveyance and therefore the greater will be the river flow and water level for an event of a given return period. The increased discharge and velocity will also result in increased sediment transport and therefore bed degradation. The sediment tranported through the contained section will tend to become deposited further downstream until the system reaches a new equilibrium. This is discussed in Part 8 of the BRTS Report on Model Studies, although it entails a major simplification in that the model was a fixed bank model. It has been shown that for flow events of up to 100 year return period the water level is not sensitive to the set back distance of the embankment from the present bankline. If the channel width were to be decreased, as would be the case if a single thalweg channel were the objective (see Plate 18) then the width between the left and right flood embankments would become more significant. It is clearly necessary to consider the river as a whole for this purpose and to make allowance for left bank development in order to optimise the flood embankment alignments. This is outside the scope of the BRTS and will be the subject of future studies. There is no great urgency attached to this assessment since for the duration of the present planning period the alignment of the BRE will continue to be determined by the more immediate consideration of security from erosion.

17.5 Ferry Ghats

The principal factors in the selection of locations for ferry ghats are land access routes, local bank stability, local channel stability and continuity of channel between the two terminals during low flow periods. The length of the crossing is a further consideration but one that is subsidiary to the others. Land access on the right bank is not a major problem, although the existing feeder roads and railspurs to Fulcharighat and Sirajganj favour these locations and the road to Sariakandi makes it the third in rank by this criterion. On the left bank the several large distributaries and areas prone to inundation present substantial obstacles and road access in particular is constrained by this.

In terms of local bank and channel stability, the better locations are those lying in the nodal reaches. Plate 5 shows clearly where bank erosion has been least over the last 20 years and Plate 12 shows the pattern of persistence of thalwegs. Nodal reaches also offer the best prospect for reliable continuous navigable channels. If one of the two main anabranches can be relied upon to remain dominant, or if this can be induced by training works, then the typical cross over of this dominant anabranch provides a near ideal route. An example of this would be from Sirajganj to a terminal situated on the left bank close to the site of the Jamuna Bridge.

Sariakandi is sited downstream of the second most distinct nodal reach but at present the cross-over is not well defined. With the stabilization of the Sariakandi-Mathurapara right bank, there would be a need to follow this up with island stabilization and preferably complementary bend stabilization on the left bank. Construction of the node stabilization mooted earlier would of course provide an ideal crossing point.

Fulcharighat, situated as it is halfway down a major island reach, is not well sited morphologically. Given the constraints on left bank land access, which favour Bahadurabad, consideration should be given to stabilizing the upstream nose of Island B, following the Yangtze model, as an aid to controlling the division of flow, and to complement this with upstream bend stabilization to encourage a two-thirds to one-third flow split in favour of the Bahadurabad branch. A new ghat might then be located on the right bank upstream of the cross-over. Maintenance of this cross-over would probably also involve measures to stabilize the presently ill defined `Island A' cluster of small unstable islands.

Construction of the proposed Jamuna Multi-purpose Bridge would evidently have a significant impact on ferry traffic, and would decrease public reliance on ferry services in the lower part of the study reach.

17.6 Description of Long-Term Works

The basic governing principle is to conform as far as possible to natural river planform characteristics. The objective is to maintain as closely as possible the water and sediment conveyance relationships, thereby minimising the risk of adverse consequences, e.g. bed aggradation or knock-on effects. Key considerations in this respect are dominant and bankfull discharges, the former having a major influence on channel form and the latter on char elevation and the frequency-depth-duration of inundation.

A relationship between channel width and bankfull discharge has been proposed by the JMB study team. This has been checked and found to give a reasonable median value when compared with output from the cross-sectional analysis (see Annex 2 of the Final Report). Applying this relationship to derive channel widths for both single and double anabranches resulted in a very close match with the actual channel widths interpreted from the satellite imagery. In general the sinuosity of the anabranches, as distinct from the thalweg channels, has been retained. Wavelengths have been picked out from satellite imagery as being persistent.

Option 1 (See Plate 17)

The basic philosophy behind this approach is the stabilization of the main features of the planform as seen in 1992 with due consideration given to the manner in which these have developed and may be expected to change with time. The method of stabilization is based on the concept of bend stabilization in which the fixing of the outer, concave, faces of the dominant waveform is the priority. Experience shows that if the concave face can be controlled then the natural meandering tendency of the river will look after the remainder. It is expected that the anabranches (as distinct from the individual thalwegs or braid channels) will respond in the same way.

The stabilized planform was selected starting at the Ganges confluence and working upstream mainly because this lower reach has a very much clearer waveform than the part north of Sirajganj. For Option 1, the approach was to encourage the formation of a single meandering anabranch in this reach. This does not imply necessarily a single thalweg channel but with the planform stabilized it is anticipated that this will tend to be the normal pattern, as it is at present. There will be no chars in the sense of islands exposed when the discharge is less than bankfull but there will be large areas of high sandbar. The large islands such as F and G would be induced to become attached to the main flood plain. The upstream limit of this lower reach is the southern end of Island E. From this section up to the upstream end of Island B a different approach is required to take account of the higher braiding level and the strong influence of the major islands. The starting point was the identification of the cross-overs between the islands, which are alternatively referred to as nodal reaches or nodes. As explained above, a node is characterised by the predominance of a naturally occurring confluence-bifurcation and this effectively fixes the inflexion point of the waveform for each anabranch. With two such fixed points there are only a limited number of half wavelengths that will fit in between them. The half wavelength chosen was one that provides the best fit with the secondary island pattern. A cross check against all the available images confirmed that the chosen wavelength was appropriate (see also Plate No. 12). It was noted however that there are years in which a longer wavelength is predominant in the right hand anabranch between Kazipur and Sirajganj. It is this that is associated with the embayment in Island E.

The most difficult section of the river proved to be that between Island C and Island B. It seems that the river itself has difficulty establishing a persistent pattern in this reach, which is distorted by the macroplanform bend with its apex at Sariakandi. The long downstream tail to Island B and the ill-defined and fragmented form of Island C reflect this. It will probably be necessary to go beyond bend stabilization in this reach and establish a firm crossover or node in this vicinity in order to induce the river to adopt a regular pattern. Two possible locations for this nodal stabilization are indicated. The selection will depend on the planform development in this reach.

Island B itself is well defined and its main length corresponds satisfactorily to one of the river's characteristic wavelengths and sinuosity.

From here upto the Teesta confluence the situation becomes again less clear, although not as confused as the inter island b-c reach. For this section no attempt has been made to create mid-stream islands, although this does remain a possible alternative. The reason is that it would probably require more than bend stabilization alone to sustain the pattern. Rather, the channel is encouraged to form a single meandering alignment with rather more pronounced sinuosity than with the section south of Sirajganj to compensate for the reduced braiding intensity.

Hard Point Selection

From the point of view of stabilisation of the right bank of the Brahmaputra and protection of the BRE, the short term measures essentially form the first part of the longer term strategy. The short term protection measures fit into the regional level pattern of hardpoints, while at the same time providing early protection to the more local interests of infrastructure, population and land.

In general hard points have been located at the two extremities of the length of bankline to be stabilised, these sites being just downstream of the inflexion points. Additional points have been added where the planform is less well defined and some further training of the river is indicated, or where the length to be stablised exceeds the typical naturally occurring embayment length in that reach.

Consistent with the terms of reference requiring the formulation of a master plan for the long term protection of the BRE, the locations of the right bank hard points have been identified as far as is possible at this stage, albeit subject to revision in the light of future changes of river planform. The 27 locations thus identified are shown on Plate 17 and are listed in Table 17.1.

Stabilized reaches have also been identified on the left bank, to illustrate how the river might be contained at this level of intervention. The scope of the study, however, does not call for a similar depth of investigation as has been undertaken on the right bank and it would be inappropriate, prior to the execution of a comparable study of the left bank, to quote locations for individual left bank hard-points. Indicative stabilized reaches are, however, shown on Plate 17 and listed in Table 17.2.

Option 2 (See Plate 18)

This represents a higher level of intervention than Option 1, the main focus being on establishing a single meandering channel within which some multiple thalweg formation could be accommodated as is the existing situation south of Sirajganj.

It can be seen that the wavelength is almost uniform over the full length of the river, although the sinuosity varies (it may be necessary to increase the sinuosity in the reach between Kazipur and Sirajganj). The difficulties encountered with Option 1 in the reach between Islands B and D have been eliminated through this more rigorous imposition of a common waveform. It is significant that the overall pattern differs relatively little from Option 1, suggesting that this does represent a fundamentally "natural" configuration of which Option 2 is a modified form designed to match more closely the current planform distortions.

The broken lines indicate the outline of a simplified planform based on the current situation including the islands. This represents an alternative approach to the Option 1 concept. The differences lie basically upstream of Island D.

Although some reaches, or parts of reaches, under Option 2 are common to both Options, the listing of right bank hard-points given above is inappropriate for the higher level of intervention. The Master Plan for the long term protection of the BRE is formulated on the basis of the preferred Option 1, and accordingly for Option 2 stabilized reaches rather than hard-point locations have been shown, indicatively, for Plate 18. They are listed in Tables 17.3 (right bank) and 17.4 (left bank).

Table 17.1 Hard Point Locations, Option 1, Right Bank

Hard Point No.	Location
1	Sirajganj
2	Sariakandi/ Mathurapara (Kalitola Groyne)
3	Sariakandi/ Mathurapara (Sariakandi)
4	Sariakandi/ Mathurapara (Mathurapara)
5	Sariakandi/ Mathurapara (Sariakandi North)
6	Sariakandi/ Mathurapara (Naodabaga)
7	D/S Fulchari
8	Sirajganj (Sailabari)
9	U/S Sirajganj (Simla)
10	U/S Sirajganj
11	Kazipur
12	Kazipur
13	Fulchari
14	Fulchari
15	U/S Kazipur
16	U/S Kazipur
17	Betil
18	Betil
19	U/S Betil
20	U/S Kazipur (node stabilization)
21	Fulchari stabilization
22	Fulchari stabilization
23	Fulchari stabilization
24	D/S Betil
25	D/S Betil
26	U/S Fulchari
27	U/S Fulchari

Note: U/S = upstream D/S = downstream

Table 17.2 **Indicative Locations of Stabilized Reaches, Option 1, Left Bank**

Stabilized Reach	Indicative Location
A	Dhalagachha
B	Harichandi
C	Ghilabari
D	Madarganj
E	Sarishabari
F	Jagannathganj
G	Ghatandi
H	Ramdevpur
I	Chauhali

Note: Place names are intended to identify the locations rather than to define precisely the positions or extent of the stabilized reaches.

Table 17.3 Indicative Locations of Stabilized Reaches, Option 2, Right Bank

Stabilized Reach	Indicative Location
a	Kamarjani
b	Fulchari
c	Sariakandi
d	Kazipur
e	Sirajganj
f	Betil

Table 17.4 Indicative Locations of Stabilized Reaches, Option 2, Left Bank

Stabilized Reach	Indicative Location
g	Rahumari
h	Jigabari
i	Khushalpur
j	Madarganj
k	Pinga
l	Ramdevpur
m	Chauhali

Note: Place names are intended to identify the locations rather than to define precisely the positions or extent of the stabilized reaches.

18. ENGINEERING COST ESTIMATES

18.1 Basis of the Cost Estimates

The Priority works contracts (Phase 1A of the Master Plan) will be awarded to international contractors who will have tendered for the work by International Competitive Bidding (ICB). The tender documents are based upon the World Bank's Sample Bidding Documents, which incorporate the Fourth Edition of the Federation Internationale des Ingenieurs-Conseils Conditions of Contract for Works of Civil Engineering Construction (FIDIC 4).

The rates derived in the estimates are therefore appropriate to international contract.

The methodology used follows closely that described in Annex 5 of the Second Interim Report. Cost data was obtained and updated mainly during the period March to May 1992, and the estimates should therefore be considered as being at April 1992 prices. Bill 1 (General) items have been calculated using experience from other contracts, local estimates of cost/unit area for housing and offices, local prices for supply of equipment, etc. The Bill 1 totals approximated to 33% of the value of the measured work items, which is a fairly usual proportion.

The major unit rates have been derived from first principles, based on likely construction methods and rates of production, materials costs obtained from manufacturers for imported materials such as geotextiles, with additions for storage, transport, duties and taxes. The costs of locally purchased materials have been obtained from local suppliers or derived from earlier BWDB contracts.

A decision is awaited from Government as to whether or not customs duty and taxes will be imposed on materials imported for incorporation in the Permanent Works. In the meantime, however, duty and taxes have been included in the estimated rates, although it is assumed that the contractor's equipment will be brought in duty free and re-exported.

The costs quoted in this report are for the cheapest armouring alternative, namely cubic concrete blocks with brick aggregate. Estimates were also prepared for cubic concrete blocks with stone aggregate (imported) and for brick aggregate blocks above Low Water Level + 2m with rock armour below that level.

25 per cent has been added to the direct cost of measured work to allow for contractor's overheads and profit.

For the Priority Works estimates, the rates were further broken down into estimates of foreign and local currency, and tax. This indicated an approximate split of 51:40:9 foreign currency : local currency : duty and tax.

The economic capital costs were then determined by deducting all duties and taxes on directly imported items, sub-dividing the local currency costs into skilled labour, unskilled labour, materials (e.g. cement, steel, brick aggregate, geotextile) plant/equipment, transport and storage. Foreign currency costs remained unchanged.

In accordance with FPCO Guidelines for Project Assessment, a series of conversion factors were applied to the sub-divided local currency costs. The conversion factors are quoted in Table 18.1 below.

Table 18.1 Construction Conversion Factors

Item	Construction Conversion Factor
Unskilled Labour	0.71
Skilled Labour	0.82
Brick Aggregate	0.82
Machinery/Equipment	0.68
Transport	0.67

A similar basis of costing has been assumed for the Phase 1B, 1C and Phase 2 (long term) works.

The river bank stabilization works will be constructed on unprotected land of generally low value. BRE retirements will be built on protected land of varying values. The economic land prices assumed are quoted in Table 11.3.

18.2 Cost of River Training Works

Using the rates derivation described above, the following costs were obtained for a typical hard-point with a 300 m long straight revetment and 1 km long cross-bar.

Table 18.2 Financial Capital Cost of Typical Hard-point (Tk)

Element	Without Dredging	With Dredging
Upstream termination	100 000 000	125 000 000
Downstream termination	45 000 000	55 000 000
Linear revetment per m	315 000	350 000
Cross-bar per m	30 000	30 000
Country-boat steps	3 000 000	3 000 000
Add dredging (for 300 m hard-point)	45 000 000	-

Notes:
1. Contractor's overhead and profit included
2. Add 33 per cent for Bill 1 (General) items
3. Land Acquisition = 10 ha @ Tk 125,000 = Tk, 1,250,000.

Thus the total financial capital cost of a typical hard point amounts to Tk 420 million. The economic capital cost of a typical hard-point, calculated in the manner described in Section 18.1 above, amounts to 84.7 per cent of the financial cost, or approximately Tk 360 million.

Detailed estimates, from which the above figures were derived, were prepared for the Priority Works contracts (i.e. Phase 1A) in October 1992. These estimates provided the basis for the economic assessment. The estimates, including 5 per cent for physical contingencies, amounted to approximately:

Contract No. B1:	Sariakandi & Mathurapara	Tk	1,290 million
Contract No. B2:	Sirajganj	Tk	1,845 million

	TOTAL	Tk	3,135 million

Following on from this, financial and economic capital costs were derived for the works at each priority location. In addition to the cost of the river bank protection measures given above, these estimates include for BRE retirement and land acquisition costs.

The costs are given below in the Table 18.3.

Table 18.3 Financial and Economic Capital Costs at Priority Locations

Priority Location	Capital Cost (Tk Million)	
	Financial	Economic
Fulchari (Phase 1C)	1,307	1,022
Sariakandi/Mathurapara (Phase 1A)	1,441	1,142
Sariakandi/Mathurapara (Phase 1B,2)	1,306	1,027
Kazipur (Phase 1C)	764	597
Kazipur (Phase 2)	768	600
Sirajganj (Phase 1A)	1,848	1,494
Sirajganj (Phase 1B)	452	353
Betil (Phase 1C)	607	475
Betil (Phase 2)	534	417

The financial capital costs for the full implementation programme of right bank stabilization are given in Table 21.5. The reader is referred to Chapter 21 and to Annex 2 of this report for more details.

18.3 Review of Cost Estimates

At the beginning of February 1993, tenders were received for the Jamuna Bridge River Training Works and Reclamation Contract. Even the lowest unevaluated tender was appreciably more expensive than had been indicated by the estimates, and this gave rise to concern that estimates for the River Bank Protection Project Priority Works might be similarly underestimated. In March 1993, therefore, a complete review of the Priority Works (i.e. Phase 1A) estimates was undertaken, based largely on equipment utilization, but also taking account of a significant increase in the price of brick aggregate. This review indicated that an uplift of approximately 12 per cent would be appropriate, still on the April 1992 base date used previously.

Revised cost estimates were also undertaken for the alternative armouring materials, i.e. concrete blocks with stone aggregate, and rock. Brick remained the cheapest material, though by a smaller margin than previously. The estimates for alternative armouring were more expensive by between 1 and 5 per cent, depending on the assumptions made.

On this basis, a similar increase in the capital costs for the works at all locations might be expected. In view, however, of the uncertainties involved and probable change in costs depending on method of construction, source of materials and economic climate, the costs in Table 18.3 have been retained as the basis of the economic analysis, with the potential increase in cost being provided for in the sensitivity analyses by a 10% increase in total costs and losses. Costs at the higher rates for all the works in the right bank stabilization programme have been calculated also, and these are given in Table 21.6.

18.4 Embankment Costs

Financial and economic costs for BRE sections with and without resettlement berm are presented in Tables 18.4 and 18.5 respectively. Economic costs were estimated to be approximately 75% of the financial costs, using the procedure described previously. Land cost is assumed to be Tk 200,000/ha and includes borrow pits. Construction costs have been calculated on the basis of local competitive bidding.

Table 18.4 Financial and Economic Capital Costs of the BRE per km (Section with Berm).

Priority Location	Land Acquisition		Construction Cost		Total Cost	
	Area	Cost	Finan-cial	Economic	Finan-cial	Economic
	(ha)	('000 Tk)	('000 Tk)	('000 Tk)	('000 Tk)	('000 Tk)
Fulchari	9.47	1,890	4,870	3,650	6,760	5,540
Sariakandi	11.00	2,200	6,680	5,010	8,880	7,210
Mathurapara	11.30	2,260	6,980	5,240	9,240	7,500
Kazipur	9.79	1,960	5,290	3,970	7,250	5,930
Sirajganj	10.57	2,110	6,100	4,580	8,210	6,690
Betil	11.11	2,220	6,810	5,110	9,030	7,330

Table 18.5 **Financial and Economic Capital Costs of the BRE per km (Section without Berm)**

Priority Location	Land Acquisition		Construction Cost		Total Cost	
	Area	Cost	Finan-cial	Economic	Finan-cial	Economic
	(ha)	(`000 Tk)	(`000 Tk)	(`000 Tk)	(`000 Tk)	(`000 Tk)
Fulchari	8.66	1,730	4,260	3,200	5,990	4,930
Sariakandi	10.04	2,010	5,810	4,360	7,820	6,370
Mathurapara	10.32	2,060	6,080	4,560	8,140	6,620
Kazipur	8.95	1,790	4,610	3,460	6,400	5,250
Sirajganj	9.65	1,930	5,320	3,990	7,250	5,920
Betil	10.14	2,030	5,930	4,450	7,960	6,480

An exercise was also carried out to determine the volume of material required and construction costs involved to upgrade the BRE over the study reach to the design section with a crest height of 1.5 m above the 100 year water level determined from the 25 year 1-D hydrodynamic modelling for situations

a. with Jamuna Bridge

b. with Jamuna Bridge and the FAP-3 left bank proposals.

Case (b) is the recommended design crest level (see Section 15.11). The results are set out in Table 18.6.

18.5 Recurrent Costs

Operation and maintenance (O & M) costs of the bank protection measures and the realigned embankment were based on estimates of labour, materials and machinery/equipment required each year to ensure that the engineering works remain viable throughout the project lifetime (i.e. 30 years).

Estimates for embankment maintenance were derived from a review of on-going maintenance programmes, as well as an assessment of the specific requirements of the new designs. Reasonably reliable estimates were thereby obtained. Annual O & M costs were calculated to be in the order of 2.5 per cent of capital requirements.

Table 18.6 Financial and Economic Construction Costs of Upgrading the BRE

Section	Case	Volumes	Construction Cost (Tk million)	
			Financial	Economic
With Berm	a	7,160,000	500	375
	b	8,950,000	620	465
Without Berm	a	3,370,000	235	175
	b	5,150,000	360	270

With regard to the maintenance of bank protection works, it is important to estimate realistically the likely O & M cost required. Given the very substantial capital investment in high quality works, the annual maintenance requirements should be minimal.

To meet these requirements, it is estimated that annual O & M costs amounting to 1 per cent of the capital expenditure would be needed. In addition, a further 5 per cent would be required every five years for more extensive repairs. The derivation of the recurrent cost estimate is described in detail in Annex 5 of the Master Plan Report.

19. CONTRACT MANAGEMENT

19.1 Contract Documents

The Brahmaputra Right Bank Priority Works Contracts (Phase 1A of the Master Plan) will be administered under the Fourth Edition of the Conditions of Contract for Works of Civil Engineering Construction, published by the Federation Internationale des Ingenieurs-Conseils (FIDIC 4). The Contract Documents define the obligations of the parties to the Contract and will include conditions of particular application, specification, tender and appendix to tender, priced bill of quantities and drawings.

19.2 Contractual Arrangements for the Phase 1 Works

Draft tender documents for the Phase 1A works, incorporating the above sections, have been prepared and will be issued to tenderers after approval by BWDB and the World Bank, and completion of prequalification of contractors. Tender Documents for the Phase 1B and Phase 1C works have been prepared along similar lines and are presented in two volumes as Annex 6 to this report.

The Phase 1A contracts will be let as:

Contract No. B1: Sariakandi & Mathurapara
Contract No. B2: Sirajganj

Annex 6 has been prepared on the basis that the following further contracts will be awarded:

Contract No. B3: Sariakandi North and Naodabaga
Contract No. B4: Sailabari and Simla
Contract No. B5: Fulchari
Contract No. B6: Kazipur
Contract No. B7: Betil

Apart from the location and site plan drawings and working area drawings, which are site specific, Annex 6 has been prepared so that it can be used for any of the contracts simply by inserting the contract number and title where left blank - marked < > - and other details as required. Generally, quantities have been inserted in the bills, but earthworks and dredging quantities cannot be entered until detailed topographic and bathymetric surveys have been carried out.

A review of river morphology trends in the vicinity must be undertaken prior to tender, so that any revision to the design or location of the structures can be made. Only then should the quantities be finalized; those given in Annex 6 should be regarded as preliminary until then.

Under the FIDIC General Conditions of Contract, the Employer is obliged to make available to the Contractor, prior to submission of Tender, such data on hydrological and sub-surface conditions as have been obtained by him or on his behalf (the Contractor is responsible for his own interpretation). A volume of such data has been prepared for the Phase 1A works, and is issued as Volume 3 of the Tender Documents. Similar volumes will need to be complied for the Phase 1B and 1C works and issued with the Tender Documents after completion of updated hydrological and river flow studies, geotechnical investigations, and bathymetric and topographic surveys relevant to the specific sites.

19.3 Contractual Framework

The parties to the Contract will be the BWDB - the owner of the Works called "the Employer" in the Contract, and the successful tenderer who will undertake the construction of the Works, called "The Contractor". "The Engineer" is appointed by the Employer to administer the Contract and supervise the construction of the Works. Usually the Engineer is a senior member, director or person of equivalent status, of a firm of consulting engineers, very often the firm that has designed the works and is therefore fully familiar with them. The principal responsibilities of Contractor, Employer and Engineer are detailed in Annex 4 to this report and are summarized below.

19.4 Responsibilities of the Contractor

Construction Methodology

The Contractor is responsible for the way in which construction of the Works is undertaken. Before commencing any major aspect of the work (e.g. dredging, placing the geotextile) however, the Contractor has to submit his method statement to the Engineer for approval. Construction methodology is considered in Annex 4 to this report.

Quality Control

The Contractor is responsible for the quality of his work and for ensuring that the end product is in accordance with the Specification. Quality Assurance procedures are a requirement of the Contract.

Land Acquisition for Temporary Works

Under the Phase 1 contracts the Contractor is responsible for making all arrangements for the procurement of land for Temporary Works, including staff accommodation for himself and the Engineer, offices, workshops, storage areas, wharfage and the like. The arrangements are subject to the approval of the Engineer, and it will be important to ensure that the siting of these facilities is such as to keep any nuisance to local residents to the minimum.

Site Accommodation and Facilities

Details of all domestic and office accommodation must be submitted to the Engineer for approval, including details of furniture and fittings for the facilities for the Engineer and his staff. The Contractor will be responsible for maintaining services - electricity supply, water, drainage and communications - to the residential and working areas. The Contractor will be responsible for the housing and care of his labour force.

Temporary Works

The Contractor will be responsible for the design and construction of temporary works, including wharfage, cofferdams, dewatering arrangements, formwork, etc. Proposals must be submitted to the Engineer for approval prior to implementation.

Borrow Areas

Certain areas of the Sites have been shown on the drawings as borrow areas. The Contractor may work these as a source of fill materials, or may propose alternatives (after satisfactory investigation, for which he is responsible) to the Engineer for approval. The Contractor is responsible for safe working in the borrow areas and for preventing them from becoming a heath hazard.

Programme

The Contractor is responsible for preparing a detailed programme for the Engineer's consent, for following the programme once such consent has been given, and for taking remedial action if he falls behind. Unless events outside his control have occurred to delay him, liquidated damages may be imposed in the event of late completion.

Defects Liability

During the Defects Liability Period, usually and in this case 12 months after the Works are taken over by the Employer, usually and the Contractor is responsible for rectifying defects in workmanship and materials (as opposed to fair wear and tear).

Training BWDB Staff

This will be particularly important in the earlier contracts, before the BWDB has built up the expertise necessary for running its own Monitoring and Maintenance Unit (see Chapter 20 and Annex 5).

19.5 Responsibilities of the Employer

Payment

The Employer is responsible for making payment to the Contractor, within the period stipulated in the Contract, of the amount duly certified by the Engineer in respect of the work measured each month, and in all other instances where payment is due under the terms of the Contract.

Possession of Site

The Employer is responsible for providing the Contractor with free possession of the Site at the time laid down in the Contract. Failure to give such possession will most probably lead to the granting of an extension of time to the Contractor, with payment of any costs that he has incurred as a result. This is particularly serious in the case of the river bank protection works, where even a short delay can result in completion being deferred over a whole monsoon season.

Visas, Work Permits and Duty Free Importation of Equipment

The Contractor is responsible for obtaining visas and work permits for his expatriate staff, but the Employer undertakes to facilitate the process. The Employer will similarly be expected to facilitate the importation of the Contractor's Equipment.

Provision of Personnel for Training

The Employer will provide personnel for training in construction of the works, to enable them to obtain the expertise necessary to staff the BWDB's Monitoring and Maintenance Unit. It is also expected that BWDB employees will be seconded to the Engineer's Staff, to gain experienced in the management of this type and scale of contract.

19.6 Responsibilities of the Engineer

The responsibilities of the Engineer are commonly divided into those that constitute direct support to the Employer with respect to both technical and contractual issues, and those that are more concerned with the day to day supervision of the Contractor's activities on the Site.

For the first category, often referred to as supervision-in-chief, and especially if the site itself is remote, as is the case here, a separate office is usually set up in the capital, in this case Dhaka, or other major regional centre where the Employer's organization is based. Such an office would be headed by a senior member of the consulting engineer's staff, with powers delegated to him by the Engineer, and referred to as the Chief Resedent Engineer - particularly if two or more contracts are running concurrently.

For the day-to-day supervision of the work on site, a Resident Engineer will be appointed for each contract, and given the authority necessary to oversee the proper execution of the Works. He and his staff will live, and have their offices, on the site itself.

The principal activities falling within the two categories will be as follows:

Supervision-in-Chief

- Specifying and supervising surveys and investigations and analysing the results during the period between the award of the Contract and the start of the main construction season; these will be required to provide both the baseline data for subsequent impact monitoring during construction and the current morphological information required for the finalization of the layout of the Works.
- Preparing updated designs to suit the actual reach morphology and bed bathymetry at the end of the monsoon season immediately preceding the start of the main construction period.
- Responding to queries from the Contractor on design and material specification issues.

- Preparing Variation Orders for unforeseen work not covered by the BOQ that may arise during the construction period, and Provisional Sum Orders for work not possible to detail prior to tender.

- Keeping the Employer informed of progress, foreseeing potential difficulties and bottlenecks, and advising the Employer on appropriate action to minimise the probability of situations arising that could lead to the submission of claims by the Contractor.

- Advising the Employer on contractual issues. Evaluating claims and any requests for extension of time submitted by the Contractor.

- Carrying out Quality Assurance audits.

- Certification

<u>On Site Supervision</u>

- Monitoring the Contractor's compliance with the Contract terms and conditions.

- Monitoring the Contractor's compliance with the Specification, including provisions for environmental impact mitigation during construction.

- Monitoring the Contractor's compliance with his Quality Plan

- Monitoring the quality of materials and compliance with construction tolerances, including the supervision of surveys and tests for quality audit purposes.

- Measurement of the Works and checking of the Contractor's submissions for interim payments.

- Progress monitoring, forecasting of bottlenecks and exploring with the Contractor means of addressing them within the provisions of the Contract.

- Checking of the Contractor's setting out, preparation of foundations, fixing of reinforcement steel and the like.

- Checking of the Contractor's method statements and proposals for temporary works, and referral of these to the Engineer for approval; monitoring the Contractor's compliance with these statements.

- Preparation of record drawings.

- Responding to emergency situations as they arise.

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General

Owing to the technical difficulties of construction in a river such as the Brahmaputra, and the programme constraints imposed by the short construction season, it is of the greatest importance that a high level of experience is available within the Engineer's team. As the majority of the works will be below water, it is essential that the Contractor's workmanship is of a high standard with regard to both the preparation and the placing of the construction materials; the Engineer, through the Resident Engineer, will be responsible for bringing any defects to the Contractor's attention so that they can swiftly be rectified. Similarly, prompt action is required to bring to the Contractor's attention any shortfall in progress, and to discuss with him the means to bring about improvement, thereby avoiding what could lead to extremely costly delays. Overall, throughout the construction of the river bank protection works, there is the need for a high level of construction supervision.

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20. PLANNING, OPERATION AND MAINTENANCE

20.1 Provisions for Operation and Maintenance

The provisions necessary for successful operation and maintenance are discussed in detail in Annex 5 to this report. In short, it is recommended that a Monitoring and Maintenance Unit be set up within the BWDB. An outline is given below.

20.2 Principles of Planned Maintenance

The essential features of planned maintenance, such as is proposed, comprise an awareness of the manner in which situations may develop, and the availability in a state of readiness of materials, equipment and manpower to deal in a timely manner with situations as they arise, and before deterioration which requires extensive remedial work is allowed to develop. A key element, therefore, is the monitoring on a regular basis of the structures themselves and of the behaviour of the river, so that early warning is given in areas where preventative measures may be required.

20.3 The Role and Objects of Monitoring

Regular monitoring is the basis upon which maintenance work must be planned and executed. It falls broadly into two categories which are directly relevant to the required maintenance activities, namely:

(a) monitoring the performance of the structural works, including the stability of the armour layer, the deformation of the apron and the stability of the earthworks.

(b) Monitoring river planform changes (particularly in the close vicinity upstream and downstream of structures) that may have an impact on the security and effectiveness of the work. In addition to land and river survey work, access to satellite imagery and aerial photographs will be required.

The monitoring described in (b) will also give an indication of how successful the structures are in achieving the long term aim of training the river, and whether improvements or modification will be required in future works.

A further monitoring activity, which will contribute to the overall store of data and assist in identifying any long term trends, is the regular monitoring (a quarterly basis is recommended) of flow velocities, water levels and channel velocities.

All data so obtained should be presented in monthly reports and an annual summary report, the latter providing the basis for review of investment plans and identification of any constraints affecting the unit.

20.4 Scope of Activities and Priorities

The activities of the proposed Monitoring and Maintenance Unit will include:

(a) monitoring as outlined above

(b) maintenance of adequate stocks of materials, including casting concrete blocks, obtaining geotextiles, etc.

(c) maintenance of river training structures, utilising land based and/or marine equipment as appropriate.

(e) carrying out any additional bank stabilization measures required as a result of unexpected morphological conditions or rapid bank erosion.

Routine monitoring is, in itself, a priority activity, although particular emphasis may have to be given to one or another area; for example if there are doubts about the condition or performance of a structure, an increased frequency of monitoring will be necessary until remedial measures are determined and in hand.

Emergency maintenance measures or remedial work would naturally take precedence over the routine, although planned maintenance and adequate monitoring procedures to give early warning should minimise any potential conflicts. At times of heavy demand on the BWDB Maintenance Unit, or at other times as appropriate, work may be awarded to local contractors.

20.5 Proposed Staff Establishment

A report entitled "Provisions for Operation and Maintenance" was issued in July 1992 containing recommendations for the monitoring and maintenance of the Priority (Phase 1A) Works.

The Priority Works will be situated at Sirajganj, Sariakandi and Mathurapara, over a reach of some 60 km of river. It is considered that a single BWDB unit, based at Sirajganj, will be able to cover all three sites. In order, however, to accommodate further river training works within the same organizational structure, a Head Office/District Office organization has been proposed.

The proposal for the Priority Works is for the Head Office and District Office both to be situated at Sirajganj. It is considered (see Annex 5) that the Phase 1B works can also be covered by the Sirajganj offices, albeit with some augmentation.

By the time that the first Phase 1C works are completed, Fulchari and Kazipur in ten to fifteen years time, an additional District Office will be required in view of the increased number of structures to monitor and maintain, and because of the distance of some 90 km between Sirajganj and the most northern of the "hard-points". It is suggested that the new District Office, which will have the same facilities as the Sirajganj District Office, be set up at Fulchari. It will then have the advantage of good rail and river connections for bringing in heavy materials, and be well placed to command the northern reach of the river.

The Fulchari District Office would be equipped in similar manner to that at Sirajganj, though with the benefit of some years operational experience in the selection of equipment, and with a view to augmentation as construction of the longer term works under the Master Plan commences.

It is proposed that the Head Office should be managed by a BWDB Superintending Engineer. The Head Office organisation would include a central services unit incorporating

- the Marine Survey Group
- the Survey Equipment Maintenance Unit
- the Central Casting and Storage Yard Unit

and the Data Analysis and Monitoring Unit responsible for river planform monitoring.

The District Offices will be responsible within their particular districts for their own

- Land Survey Group
- Marine Maintenance Unit
- Land Based Maintenance and Storage Yard Unit

and Data Analysis and Monitoring Unit responsible for revetments and embankments within that district.

20.6 Plant, Equipment and Logistical Support

Sophisticated survey equipment will be required, including side-scan sonar and electronic positioning system. Maintenance of such equipment is expensive and a special section will be set up, with an adequate spares holding, specifically to maintain this equipment. Computer equipment for survey data processing will be required, as will equipment for the processing of satellite imagery.

Each Marine Maintenance Unit will require a large tug (650 HP is proposed) as well as barges and a pontoon with hydraulic arm. The principal plant item of the Land Based Maintenance Units will be a crane of sufficient size (50 tonne) to place armour units from the crest to any part of the revetment slope above water. Certain smaller items of land based plant have been proposed, although these could equally be provided by a local contractor.

20.7 Training and Technical Assistance

It is proposed that training of BWDB staff in works supervision, quality control, instrumentation and management is undertaken by secondment of these personnel to the consultant's team for the supervision of construction of the Priority Works. Further, the contractor(s) will be required to give practical training to assigned BWDB staff in the use of specialized instrumentation and equipment of the type to be used later in the monitoring and maintenance of the works. Payment to the contractor(s) for this service will be subject to the Engineer's certification that a satisfactory standard of training was provided.

Further, provision is made in the Priority Works contracts for the contractor(s) to assist the BWDB for a period of one year after completion of the Works, i.e. to the end of the Defects Liability Period, by assigning key personnel to provide training and practical experience in the monitoring, operation and maintenance of the works. Depending on progress, arrangements could be made under a separate contract to extend this assistance for a second year. By the time that the Phase 1B and subsequent works are built, it is expected that BWDB will have acquired sufficient expertise not to require further such assistance.

The general procedures for operation and maintenance will be covered in the Operation and Maintenance Manual to be prepared by the consultants during construction, in consultation with the contractor(s) and BWDB.

The performance of the River Training Works will be required to be fully monitored and evaluated, and their impact on the river planform quickly recognised and analysed. In order properly to evaluate the behaviour of the revetments and the river planform, and to modify the monitoring programme in response to that behaviour, a detailed knowledge of the design criteria and assumptions will be required. Moreover, the design criteria may need refinement in response to the observed behaviour.

This is a very different function and requires a totally different mode of training and support to the advice on operation and maintenance provided by the contractor's personnel. These roles would most naturally be executed by staff of the consultants responsible for the original design. It is therefore proposed that a Technical Assistance programme be set up to provide this service for the first two years (at least) after the completion of the works.

Such an arrangement would enable the designs to be refined and optimum maintenance requirements to be formulated with the minimum of effort. It would also facilitate early recognition of any unforeseen behaviour of the works or of the river in response to the works.

It is proposed that over the minimum two years duration of the Technical Assistance programme, a full time River Training Engineer and a part time Hydraulics Engineer/Morphologist from the consulting engineers' organization be provided.

In this way it will be possible to provide continuity of monitoring up to the time that BWDB will have gained sufficient expertise themselves.

20.8 Capital and Recurrent Costs

The capital and recurrent costs of operation and maintenance are considered in detail in Annex 5. Regarding the recurrent costs, it is estimated that annual O & M costs amounting to 1 per cent of the capital expenditure would be needed. In addition, a further 5 per cent should be allowed every five years for more extensive repairs.

21. ECONOMIC ASSESSMENT

21.1 Alternative Realignment Strategies

A long term strategy for reducing bank erosion through river training would have an implementation period of the order of 30 years. Some continuing bank erosion would therefore occur during the implementation period. Until full control of bank erosion is achieved there will still be a need for a planned strategy for realigning the embankment to minimise the risk of breaching.

The objectives are to:

- maximise the degree and extent of flood alleviation provided by the BRE; whilst
- minimizing the risk of breaching of the BRE, and
- minimizing the social upheaval, disruption and loss of livelihood associated with the realignment of the BRE.

The level of flood alleviation provided by the BRE depends on its alignment; to be most effective it needs to be as close to the river as possible. The nearer the embankment is to the river, the higher the risk of breaching unless river training and bank protection works are also implemented, and the more frequent the need to realign the embankment. The risk of breaching can be reduced by realigning the embankment further away from the river. This would however expose the land between the embankment and the river to flooding. Thus in the absence of river training works there exists a tradeoff between embankment security, frequency of realignment and the area protected from flooding.

In order to quantify the tradeoffs involved, a series of representative situations covering the full range of possible realignment strategies has been evaluated. These are summarized below and illustrated in Figure 21.1.

The following three major possible approaches emerged from the initial evaluation:

1. Planned realignment of sections of the BRE whenever the distance between the bankline and the BRE reaches a predetermined minimum value, or trigger distance. This is Example 2 in Figure 21.1, Example 1 being a special case in which the trigger distance and set-back are minimized in response to social pressure.

2. Realignment of the BRE along entire reaches of the river to a set back distance likely to be almost safe from breaching for a period of about 30 years, say 2 to 5 km (Example 3 in Figure 21.1).

3. Realignment of the BRE plus the construction (where the current BRE is breached or lost) of a low secondary embankment offering protection from floods with a return period of 1 in 10 years or less (Example 4 in Figure 21.1). It became apparent, however, that this option was not viable in the case of the Jamuna river, firstly because the difference in water level between the 10 year

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and 100 year flood is small and secondly because the overtopping of the low embankment would result in rapid failure of the embankment and all the local disbenefits of a breach.

An optimal strategy for planned selective realignment of the BRE is one which maximizes the economic net benefit of realignment in order to provide an acceptable level of security against breaching by river bank erosion while minimizing the adverse impacts, including the area of land that is left exposed on the river side of the flood embankment.

Determining an optimal strategy therefore needs to take into account:

- direct costs such as land acquisition, embankment construction and maintenance;
- disbenefits such as loss of flood protection for areas exposed by embankment realignment;
- direct benefits such as flood protection and enhanced security against breaching of the embankment;
- indirect costs associated with the disruption and resettlement of affected people; and
- indirect benefits accruing from an enhanced level of confidence amongst those who receive an improved standard of flood protection or for whom the risk of damage from an embankment breach is reduced.

To assist in the decision making process, a spreadsheet was set up, based on tangible benefits and costs as described below. A qualitative evaluation of intangibles can then be combined with the net present values derived from the computation in order to make a final selection.

The key variables in this decision making process (see Figure 21.1 for definition sketches) are:

- the set-back distance (SB) between the old and new embankment alignment
- the trigger distance (TR), being the minimum distance between the embankment and the bankline that triggers the decision to realign.

The optimal strategy should minimise both SB and TR, thereby minimizing the cost of each retirement as well as the disbenefit from loss of flood protection, whilst achieving a given level of security against breaching. It would also seek to reduce to a feasible and acceptable level the frequency with which the embankment would need to be realigned.

The quantification of costs and benefits is described in detail in Annex 2.

From this analysis it can be seen that the risk of breach damage falls off rapidly as the set-back distance exceeds about three times the mean erosion rate. Thereafter the tradeoff is principally between the cost of realignment, which reduces asymptotically with set-back, and the reduced value of the land that has become unprotected, which increases linearly. The net present value peaks weakly at between eight and ten times the mean erosion rate but there is very little change beyond a ratio of about six. Other considerations, such as the social impacts, will clearly be more important in this range.

Since the value of breach damage is high in relation to all other benefits and costs, the relationship between trigger distance and risk of breaching becomes a significant factor for the lower set-back distances, simply because the embankment is exposed to attack for longer periods. A trigger value of the order of 1.5 times the mean erosion rate would appear to provide a reasonable level of confidence under the idealized conditions simulated in this model. In practice, this will have to be interpreted in relation to the recent history of erosion at the specific site.

Despite these provisos, the analysis demonstrates clearly that a policy of planned phased realignment using an optimized set-back distance is a viable and cost-effective strategy and that it is economically more attractive than a single stage larger scale full realignment of the embankment involving a set-back of the order of 2 to 5 km.

It should be again emphasized that in practice the establishment of the set back distance will be highly influenced by existing villages and other settlements, road and rail infrastructure as well as the irregular alignment of the existing BRE and the bankline. Consequently, while determining a hypothetical optimum set-back distance in economic terms provides a useful guide to decision makers, a more pragmatic approach to determining the alignment of the retired BRE will have to be followed at the local level.

21.2 Capital Costs of Priority Locations

A major factor to consider in the appraisal of the various priority locations is the capital and recurrent costs of the bank protection works required to mitigate bank erosion and to safeguard the BRE, thereby avoiding the economic consequences previously discussed. Capital cost estimates for bank protection works and BRE repair (if necessary) have been prepared on the basis of detailed designs and analysis of current unit rates (April 1992).

Unit rates have been derived from first principles, based on the likely construction methods and current labour, material, machinery and transport costs. Prices of imported materials, such as geotextile, have been obtained from manufactures with additions for storage, transport, duties and taxes. Prices of local materials have been obtained from local suppliers or based on current BWDB contracts. A physical contingency of 5% has also been included in the total cost estimates.

Land acquisition costs for protection works have been based on an average land value of Tk. 125,000 per hectare (i.e for riverside land) and the estimated areas required for each location are given in Table 21.1 below:

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Table 21.1 Land Acquisition for Priority Locations

Priority Location	Protection Works		BRE Realignment	
	Area (ha)	Value (Tk million)	Area (ha)	Value (Tk million)
Fulchari (Phase 1C)	18.5	2.3	75	15.0
Sariakandi/Mathurapara (Phase 1A)	16.8	2.1	115	23.0
Sariakandi/Mathurapara (Phase 1B,2)	12.5	1.6	121	24.2
Kazipur (Phase 1C)	8.5	1.1	88	17.6
Kazipur (Phase 2)	10.0	1.3	88	17.6
Sirajganj (Phase 1A)	6.0	3.6	--	--
Sirajganj (Phase 1B)	2.0	0.3	66	13.2
Betil (Phase 1C)	7.5	0.9	66	13.2
Betil (Phase 2)	10.0	11.3	--	--

To facilitate conversion to economic prices, all estimates were further disaggregrated into local and foreign costs; the local costs being further sub-divided into skilled labour, unskilled labour, materials (e.g cement, steel, brick aggregate, geotextile) plant/equipment transport and storage.

Economic capital costs were then determined by first deducting all duties and taxes on directly imported items and then applying a series of construction conversion factors to the local cost items in accordance with the FPCO Guidelines for Project Assessment. Foreign costs remained unchanged at around 45%.

The detailed financial and economic capital costs at each priority location are summarized below in Table 21.2. Economic costs typically equate to about 82 % of the overall financial valuation.

It should be noted that only a relatively modest capital investment is required for BRE realignment (approximately 5% to 10% of total capital costs) to ensure security from the serious social and economic consequences of a breach. The capital costs of the BRE realignment include the provision of a settlement berm.

Table 21.2 Financial and Economic Capital Costs at Priority Locations

Priority Location	Capital Cost (Tk Million)	
	Financial	Economic
Fulchari (Phase 1C)	1,307	1,022
Sariakandi/Mathurapara (Phase 1A)	1,441	1,142
Sariakandi/Mathurapara (Phase 1B,2)	1,306	1,027
Kazipur (Phase 1C)	764	597
Kazipur (Phase 2)	768	600
Sirajganj (Phase 1A)	1,848	1,494
Sirajganj (Phase 1B)	452	353
Betil (Phase 1C)	607	475
Betil (Phase 2)	534	417

In addition to the above capital expenditure, the costs of engineering design and supervision were also derived and added to the total capital costs at each priority location. Engineering design and supervision costs were estimated at 3% of total capital costs.

The above capital costs were derived on the basis of detailed estimates for the Priority Works contracts (Sirajganj and Sariakandi/Mathurapara) undertaken in October 1992. In March 1993 a review of these cost estimates was carried out which resulted in a 12½ percent increase in construction costs. On this basis, a similar increase in the capital costs for the works at all locations might be expected. In view, however, of the uncertainties involved and probable change in costs depending on method of construction, source of materials and economic climate, the costs in Table 21.2 have been retained as the basis of the economic analysis, with the potential increase in cost being provided for in the sensitivity analyses by a 10% increase in total costs and losses.

21.3 Operation and Maintenance Costs

Operation and maintenance costs of the bank protection and realigned embankment options were based on estimates of labour, materials and machinery/equipment required each year to ensure that the engineering works remain viable throughout the project lifetime (i.e. 30 years).

Estimates for embankment maintenance were derived from a review of on-going maintenance programmes, as well as an assessment of the specific requirements of the new designs. Reasonably reliable estimates were thereby obtained. Annual O & M costs were calculated to be in the order of 2.5 % of capital requirements.

With regard to the maintenance of bank protection works, it is important to realistically estimate the likely O & M cost required. Given the very substantial capital investment in high quality works, the annual maintenance requirements should be minimal.

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To meet these requirements, it is estimated that annual O & M costs amounting to 1 % of the capital expenditure would be needed. In addition, a further 5 % would be required every five years for a more extensive repairs. The derivation of the recurrent cost estimate is described in detail in Annex 5 of the Master Plan Report.

21.4 Economic Appraisal of Priority Locations

21.4.1 Methodology and Economic Criteria

Following completion of the economic valuation of the consequences of river bank erosion and flooding from breaches in the BRE, as well as the capital/recurrent costs of engineering works required to mitigate these consequences, the economic appraisal then adopted an incremental approach by contrasting the Future Without (FWO) and Future With (FW) project situations over a 30 year planning horizon. Discounted cash flow techniques were then applied to the incremental net benefit streams in order to determine the economic viability of the various priority schemes. In accordance with FAP Guidelines, the following indicators of economic viability were derived;

- Net Present Value (NPV)
- Economic Internal Rate of Return (EIRR)
- Net Present Value Ratio (NPV Ratio)

Net present values have been calculated at a discount rate of 12 per cent corresponding to the opportunity cost of capital in Bangladesh. Sensitivity analyses were also undertaken for each priority location to assess the impact on the project's EIRR to changes in the cost and benefit streams.

Switching values (the proportionate change in costs and benefits required to achieve an EIRR of 12 %) were also estimated.

21.4.2 Phasing of the Consequences of Bank Erosion and Breaches in the BRE

In the FWO situation, the economic consequences of river bank erosion have been assessed over a 30 year time period. The phasing of these consequences has been based on the expected rates and extent of erosion at each priority site. The distribution of property and infrastructural losses has taken into consideration their location in relation to the present bankline, and therefore the likelihood of loss in any one year.

The economic consequences of flooding as a result of a breach in the BRE at each priority location were phased according to the timing of the breach. The expected year of each breach (unless a breach is currently open) was determined for each location on the basis the nature and rate of erosion. The specific losses related to crop damage, livestock, property and infrastructure were assumed to be fully incurred at the time of the breach. Subsequent reductions in the net value of agricultural production are related to switches in cropping patterns as a consequence of changes in flooding regimes (Section 11.3).

The avoidance of these economic losses in the FWO situation is therefore regarded as a benefit to the project, and consequently benefit streams were derived for each priority location. It should also be noted that in the derivation of the benefit streams, properly and infrastructure losses have been increased by 3% per annum above the valuations outlined below. This is intended to reflect likely annual growth in the FWO situation, in accordance with FPCO guidelines.

The expected rates of erosion and their consequences, as well as the frequency and timing of breaches, at each priority location are described in Annex 2.

21.4.3 Phasing of Capital Expenditure

The phasing of the works reflects the expected rate and timing of erosion at a given point along the present bankline to ensure the satisfactory stabilization of the reach. Typically, the works at priority locations are divided into two phases with a 4 to 5 year interval between phases.

21.4.4 Economic Viability and Project Ranking

The EIRRS, NPVs and NPV ratios derived from the incremental net benefit stream for each priority location are summarized in Table 21.3 below. For comparison, and with reference to section 21.2, these indicators are also given [in square brackets] for a 10 percent increase in total costs and losses.

Table 21.3 Economic Viability of Priority Locations

Priority Location	EIRR (%)	NPV @ 12 % (Tk million)	NPV Ratio
Fulchari	-0.6 [-1.7]	-643 [-750]	-0.49 [-0.52]
Sariakandi } Mathurapara }	12.0 [9.8]	0 [-175]	0.00 [-0.07]
Kazipur	-1.5 [-1.9]	-562 [-672]	-0.42 [-0.46]
Sirajganj	23.2 [18.6]	532 [353]	0.24 [0.15]
Betil	5.3 [3.8]	-274 [-367]	-0.24 [-0.30]

It is evident from the above Table that there is a good economic justification for bank protection works in Sirajganj, Sariakandi and Mathurapara. These projects meet the economic viability threshold of 12 %. Sirajganj priority works are justified principally on the basis of protecting the large urban area, rather than avoiding agricultural losses as a consequence of erosion or flooding. The benefits of the Sariakandi and Mathurapara works are largely derived from the very adverse consequences of an open breach and the subsequent implications for crop production resulting from the flooding of a large proportion of the BRE protected area. It is also important to note that no allowance has been made for the possibility that the Brahmaputra may partially occupy the Bangali channel as a new anabranch. The consequences of this would be extremely serious, causing a rapid widening of the Bangali River and significant loss of agricultural land.

On purely economic grounds, there does not appear to be adequate justification for the implementation of bank protection works at Fulchari, Kazipur and Betil. The EIRRs fall short of the economic viability threshold, and the capital investment is unlikely to generate sufficient benefits to meet this target. This assessment is based entirely on economic criteria, but there are important social consequences that should also be taken into account when appraisal the various locations; these are outlined in Chapter 11. Although the economic viability of bank protection at these latter sites may be in doubt, there is clearly an immediate need, as well as good social and economic justification, to realign the BRE in the timely and planned manner during periods of active erosion, thereby avoiding the adverse consequences of a breach.

With regard to the ranking of priority works, the NPV ratio was considered the most appropriate criteria. On this basis, the following ranking was derived:

Table 21.4 Ranking of Priority Locations

Ranking	Priority Location	NPV Ratio
1	Sirajganj	0.24
2	Sariakandi/Mathurapara	0.00
3	Betil	-0.24
4	Kazipur	-0.42
5	Fulchari	-0.49

It should, however, be noted that this ranking of priority sites is based on the situation prevailing in 1992 on the assumption that the engineering works for both bank protection and BRE realignment could be implemented immediately. Given the very dynamic and rapidly changing characteristics of river bank erosion along the Brahmaputra, it should not be assumed that the present situation will remain unchanged. The present ranking of priority sites should therefore not be regarded as definitive. Nevertheless, it is extremely likely the Sirajganj and Sariakandi/ Mathurapara will remain top priority for early implementation of bank protection works.

21.4.5 Sensitivity Analysis

Sensitivity tests were also undertaken for each priority location (see Annex 2, Table 6.1). For Sirajganj and Sariakandi/Mathurapara, the results of this analysis highlights how sensitive the EIRRs are to the changes in the cost and benefit estimates used. However, for Kazipur, Fulchari and Betil, the EIRRs appears to be fairly insensitive to major changes in costs and benefits and these locations require a very substantial improvement in benefits to justify the capital investment.

21.5 Economic Appraisal of the Master Plan

21.5.1 Scheduling of Bank Stabilization Works

On the basis of an analysis of river behaviour, and a forecast of the general long term pattern of bank erosion, it is considered that the stabilization of the right bank of the Brahmaputra can be successfully achieved through the construction of a series of "hard-points". These "hard-points" can be regarded as artificially providing solid areas of a bank, similar to more resistant rock formations in nature, which would place a limit on the lateral movement of the river bank. Measures to confine the river to one or more defined channels, i.e river training, are not considered technically appropriate or economically feasible at this time but may become viable as the region develops and data on the river's response to intervention becomes more plentiful.

It is envisaged that these proposed bank stabilization works would be implemented over a 30 year period, divided into three stages. It is anticipated that 27 hard-points would be constructed. The location of these hard-points is illustrated in Plate 17.

In determining the most appropriate implementation schedule the following factors have been taken into consideration:

- anticipated river behaviour and erosion rates over various reaches;
- economic consequences of river bank erosion and flooding from a breach in the BRE;
- social and environmental impact both with and without bank stabilization measures;
- capital and recurrent expenditure and sources of financing; and
- economic justification for individual schemes.

Stage 1

During the first stage of the Master Plan, it is anticipated that two phases of the Sirajganj protection works - Hard-points 1 and 8 and all - the Sariakandi/Mathurapara protection works - Hard-points 2, 3, 4 and 5 - would be completed. In addition, three further hard-points would be constructed; one upstream of Sariakandi (Hard-point 6) and two upstream of Sirajganj (Hard-points 9 and 10). These works would effectively stabilize the reaches immediately upstream of these two key locations. This first stage is expected to be implemented in two construction phases spanning over a period of 9 years, with a 3 year gap between phases (Table 21.5).

Stage 2

After allowing sufficient time (e.g 2 years) to determine the impact of Stage 1 works on river behaviour, as well as to monitor the changes in the nature and rate of bank erosion at various locations, the next stage of the Master Plan would be implemented. The final selection and

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scheduling of the priority sites for Stage 2 would of course, be undertaken following a thorough appraisal of the various technical, economic and social factors influencing the proposed capital investment at various locations. However, for the purpose of the present analysis, it has been assumed the bank stabilization works would include hard-points at:

Kazipur - 2 hard-points (11 and 12)
Betil - 2 hard-points (17 and 18)
Upstream of Kazipur - 2 hard-points (15 and 16)
Fulchari - 2 hard-points (13 and 14)
Upstream of Betil - 1 hard-point (19)
Downstream of Fulchari - 1 hard-point (17)

- node stabilization upstream of Kazipur (Hard-point 20)

- stabilization at Fulchari (Hard-points 21, 22, 23)

- two hard-points downstream of Betil (24 and 25)

- two hard-points upstream of Fulchari (26 and 27)

A uniform level of annual capital expenditure is assumed over a period of 20 years starting in year 11 (Table 21.5).

It should be noted that the selection of priority locations for implementation in the short term implies minor differences in sequence of construction from that indicated in Table 21.5. As required by the ToR, the selection of the priority locations was based on the assessment of the immediate erosion problems at the time (and therefore not necessarily representative of long term trends) and the ranking of these in terms of priority for urgent treatment. As the interrelationship between locations became clearer, the rationale arose for introducing additional hard-points (nos. 7, 10 and 15) in order to stabilize key reaches (as distinct from priority locations). The Master Plan sequence would therefore be preferred if a long term programme were to be embarked upon, whereas the "short term" works are suitable as isolated measures for early implementation in response to immediate needs at specific locations, within a relatively short time-frame, which are nonetheless consistent with the Master Plan.

21.5.2 BRE Realignment Schedule

During the implementation of the bank stabilization programme, long reaches of the right bank will remain unprotected from erosion. Consequently, in conjunction with the construction of bank protection works, it is imperative that a realignment of the BRE is implemented in a timely and planned manner to avoid the serious social and economic consequences of breaches.

As part of the protection works programme, new embankments will be constructed, if required, within the immediate vicinity of the hard-points A total of 120 km of embankment is expected to be built in this manner over the 30 year Master Plan period. These new embankments would, however, not cover the reaches remaining unprotected from erosion. Based on present distance between the bankline and the BRE, expected future erosion rates, and a set-back distance of approximately 500 metres, it has been broadly estimated that an additional 100 km of embankment would need to be constructed over 30 years to ensure that the unprotected areas do not experience breaches. A planned realignment strategy should be followed for these exposed areas as indicated in Chapter 7 of Annex 2.

In the economic analysis of the Master Plan, the length of BRE realignment required each year over a 30 year period has been calculated for both the future with and the future without bank stabilization scenarios. The net length of BRE realignment (ie difference between FW and FWO) was then valued at Tk 9.4 million per km (in economic terms) and added to the benefits of bank stabilization.

21.5.3 Financial and Economic Capital Costs

The estimation of financial and economic capital costs has been based on the levels of expenditure envisaged for the priority works (as outlined in Chapter 5). For hard points not considered as priority locations, typical costs associated with similar works have been assumed.

Over a 30 year period, the total financial cost is estimated at Tk 17,300 million (US$ 435 million) for the bank stabilization works, or Tk 19,400 million (US$ 487 million) based on the March 1993 review of cost estimates.

This capital expenditure would be disbursed according to the implementation schedule outlined in Section 21.5.1 at an average rate of Tk 575 million per annum. Significantly higher rates of expenditure are, however, expected during Stage 1, especially for the Phase 1A works at Sirajganj and Sariakandi/Mathurapara.

Economic capital costs were then derived using the methodology outlined in Chapter 5. Total capital expenditure, in economic terms is estimated to be Tk 13,900 million for the protection works. A detailed capital expenditure schedule is provided in Table 21.5.

The expenditure schedule based on the March 1993 review of cost estimates is given in Table 21.6; the corresponding mean annual expenditure would be Tk 650 million and the capital expenditure in economic terms is estimated to be Tk 15,600 million.

21.5.4 Operation and Maintenance Costs

Operation and maintenance costs for bank protection works were estimated to be in the order of 1% of capital costs per annum. In addition, a further 5% would be required every five years. Overall operation and maintenance expenditure gradually increases as more hard-points are constructed. In year 2, total O & M costs amount to Tk 33 million and rise to around an average of Tk 315 million (in financial terms) at the end of the programme.

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Table 21.5 Implementation Schedule for Bank Stabilization Works

Year Location	Hard Point No	Financial Capital Cost (Tk million)
Stage 1(A)		
0/1 Sirajganj	1	1,848
0/1 Sariakandi/Mathurapara	2, 3 and 4	1,292
2		
3		
4		-------
	Sub-total	3,140
Stage 1(B)		
5 Sirajganj	8	373
5 Sariakandi/Mathurapara	5	575
6 Sariakandi/Mathurapara	6	575
7 U/S Sirajganj	9	600
8 U/S Sirajganj	10	600
9		-------
10	Sub-total	2,723
Stage 2		
11 Kazipur	11	669
12 D/S Fulchari	7	600
13 Fulchari	13	614
14 Fulchari	14	614
15 Kazipur	12	672
16 Betil	17	523
17 U/S Kazipur	15	600
18 Betil	18	534
19 U/S Kazipur	16	600
20 U/S Betil	19	600
21} Fulchari	21	600
22} Stabilization	22	600
23}	23	600
24 D/S Betil	24	600
25} U/S Kazipur	20	1,200
26} (Node Stabilization)		
27 D/S Betil	25	600
28 U/S Fulchari	26	600
29 U/S Fulchari	27	600

	Sub-total	11,426

	Total	17,289
		======

N.B U/S = Upstream

D/S = Downstream

Table 21.6 Implementation Schedule for Bank Stabilization Works based on March 1993 Review of Cost Estmates

Year Location	Hard Point No	Financial Capital Cost (Tk million)
Stage 1(A)		
0/1 Sirajganj	1	2,012
0/1 Sariakandi/Mathurapara	2, 3 and 4	1,513
2		
3		
4		-------
	Sub-total	3,525
Stage 1(B)		
5 Sirajganj	8	420
5 Sariakandi/Mathurapara	5	650
6 Sariakandi/Mathurapara	6	650
7 U/S Sirajganj	9	675
8 U/S Sirajganj	10	675
9		-------
10	Sub-total	3,070
Stage 2		
11 Kazipur	11	750
12 D/S Fulchari	7	675
13 Fulchari	13	690
14 Fulchari	14	690
15 Kazipur	12	755
16 Betil	17	590
17 U/S Kazipur	15	675
18 Betil	18	600
19 U/S Kazipur	16	675
20 U/S Betil	19	675
21} Fulchari	21	675
22} Stabilization	22	675
23}	23	675
24 D/S Betil	24	675
25} U/S Kazipur	20	1,350
26} (Node Stabilization)		
27 D/S Betil	25	675
28 U/S Fulchari	26	675
29 U/S Fulchari	27	675

	Sub-total	12,850

	Total	19,445
		======

N.B U/S = Upstream

D/S = Downstream

21.5.5 Economic Benefits

Economic benefit streams for the Master Plan were largely derived from the estimation of the disbenefits avoided and cost saved from implementing bank protection works, as outlined for the various priority locations (see Chapter 6 of Annex 2). For hard-points not considered as priority locations, benefits were assessed on the basis of the erosion of a typical rural areas with no major settlements or markets, but representative of a particular reach. With the exception of Sirajganj and Sariakandi/ Mathurapara priority locations, the disbenefits avoided have been entirely restricted to the losses due to bank erosion and so have not included agricultural, property or infrastructural losses due to flooding. This has therefore avoided the possibility of double counting the loss due to the consequences of flooding.

The costs saved from the gradual reduction in the length of BRE requiring realignment each year have also been determined and included amongst the benefits to bank stabilization.

Economic benefit streams presented in Table 8.3 of Annex 2 indicate that total benefits increase from Tk 380 million in year 6 to an average of Tk 745 million after year 30. Sirajganj and Sariakandi/Mathurapara priority locations generate the highest benefits and account for almost 50% of total benefits by year 30. During the first five years, the benefit stream is highly influenced by the loss of a substantial proportion of Sirajganj town. These benefits have also been offset by bank erosion losses in the future with project situation.

21.5.6 Economic Justification

An incremental net benefit stream for the Master Plan was derived over a 50 year period from the cost and benefits outlined above and detailed in Table 8.3 of Annex 2.

The following EIRR, NPV and NPV ratio were calculated from the incremental net benefit stream. For comparison, and with reference to Section 21.2, these indicators are also given [in square brackets] for a 10 percent increase in total costs and losses.

EIRR	6.8%	[2.5%]
NPV (@ 12%)	- Tk 285 million	[-Tk 897 million]
NPV Ratio	- 0.06	[-0.13]

The above economic criteria indicate that the bank stabilization Master Plan does not meet the conventional economic viability threshold. It should, however, be noted that the application of high thresholds (eg. 12% EIRR), to determine economic viability, is not wholly appropriate for a major long term capital investment programme in public infrastructure, which generates considerable benefits not only for the present inhabitants on right bank of the Brahmaputra, but also for future generations. Taking into account the long term nature of the investment, the criteria should be based more on social time preference rather than opportunity cost of capital in order to establish economic justification.

In terms of social time preference criterion, which attempts to place greater weight on the direct net benefits to future generations, an EIRR of 6.8% would be regarded as reasonably adequate. On condition that the long term benefits (i.e 30 to 50 years) of the initial capital investment could be clearly demonstrated, without resort to any major additional capital expenditure, there would be a basis on which to provide an economic justification for the programme.

Furthermore, it is probable that capital and recurrent costs would decline, in real terms, as the programme progresses and local expertise is developed, and as the contractors' risks allowed for in the engineering cost estimates become more readily quantified. This has not been taken into account in the analysis, but would further strengthen the economic justification. It is also important to highlight the omission of the proposed Jamuna Bridge in the estimation of the economic benefits of the Master Plan. In the long term, without the bank stabilization

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programme, the future security of the bridge would be under threat. If this investment were included in the present analysis, the EIRR would be significantly enhanced.

Although the economic arguments in favour of the Master Plan may be the subject of debate, the social justification is firmly established. The social consequences of river bank erosion and flooding from a breach in the BRE are briefly outlined in Chapter 10, but discussed in more detail in Annex 1. It is also important to emphasize that there is clearly an immediate need, as well as good economic justification, to realign the BRE in a timely and planned manner at vulnerable locations.

Sensitivity tests were undertaken on the costs and benefits of the Master Plan, which indicated that the programme was fairly sensitive to changes in both the benefit and cost streams. The switching values indicated that an 8% increase in benefits or 7% decline in costs are required to increase the EIRR from 6.8% to 12%.

Finally, in the long term, there are only three realistic options available to the GOB namely:

(a) non-intervention, i.e allowing bank erosion to take its course, and accept the social and economic consequences, including the loss of Sirajganj and the BRE.

(b) progressively realign the BRE, through a combination of strategic and tactical retirements. This would require a major diversion of the Bangali River. Sirajganj town would also be lost.

(c) initiate bank stabilization at the most critical locations as the first stage of a long term strategy to stabilize the right bank of the river.

Option (a) is unacceptable as it would involve considerable loss of land, property and infrastructure and permanently displace large numbers of people as a result of bank erosion. Furthermore, substantial damage would be incurred as a consequence of flooding from numerous breaches in the BRE and the breakthrough to the Bangali River.

Option (b) would be more acceptable than option (a) as it would provide satisfactory level of security from flooding to people living in areas protected by the BRE. This option does not, however, address the problems of bank erosion and consequently accepts the loss of a major urban centre and other settlements. The future security of the proposed Jamuna Bridge would also be at risk.

Option (c) is therefore the only strategy which would provide a solution to the undesirable consequences of bank erosion. In the initial stages, bank protection works would mitigate the impact of bank erosion in locations where there is an urgent need for immediate action. In the long term a bank stabilization programme would provide an effective way of minimizing economic losses and social disruption for a large number of people living in the vicinity of the Brahmaputra right bank.

While there is clearly good social and economic justification for the Master Plan, the principal constraint to implementation would be the availability of finance for both capital and recurrent expenditure. This issue is discussed in Chapter 22.

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21.5.7 Economic Assessment of Hard-Points

The bank stabilization Master Plan comprises the proposed works at the selected 27 hard-point locations. Hence it is not appropriate to make an economic assessment of the individual hard-points as such an assessment may not be valid and difficult to justify. However, the stabilization works are scheduled to be implemented over a relatively long period of time and some form of socio-economic assessment and justification would be needed for each tranche of investment. This will need to be undertaken as individual assessments related to the planning and design of each package of work.

Although the 27 hard-points cannot be realistically considered individually, for the purposes of preliminary assessment the hard-points can be grouped on the basis of river reaches to be protected. The construction of each of these groups of hard-points would have the associated costs and benefits from stabilization of the corresponding river reach. The following groupings of hard-point were considered for this analysis:

River Reach	**Hard-points**
Kamarjani - Fulchari	13 and 14 21, 22 and 23 26 and 27
Sariakandi - Mathurapara	2, 3 and 4 5 and 6 7
Kazipur	11 and 12 15 and 16 20
Sirajganj	1 and 8 9 and 10
Betil - Jalalpur	17 and 18 19 24 and 25

The locations of the 27 hard-points are shown in Plate 17. The different sets of hard-points for a given reach refer to the proposed construction sequence.

An economic assessment for each reach was undertaken based on the financial and economic cost estimates described in Section 21.5.3 and economic benefits described in Section 21.5.5. However, as noted earlier, individual hard-points or river reaches cannot be considered in isolation when describing and evaluating a long-term Master Plan strategy. Therefore, these results should only be considered as indicative of the economic assessment of individual river reaches.

The incremental net benefit stream for each river reach derived over a 30 year period from costs and benefits outlined above are given in Table 8.4 of Annex 2. The following is a summary of the results:

River Reach	Hard-points	EIRR %	NPV @12% (Tk*ml)	NPV Ratio
Kamarjani-Fulchari	13 & 14) 21,22 & 23) 26 & 27)	-0.3	-1,127	-0.48
Sariakandi-Mathurapara	2,3 & 4) 5 & 6) 7)	12.0	203	0.0
Kazipur	11 & 12) 15 & 16) 20)	0.0	-1,148	-0.48
Sirajganj	1 & 8) 9 & 10)	16.3	355	0.07
Betil-Jalalpur	17 & 18) 19) 24 & 25)	2.7	-739	-0.34

The above economic indicators should be viewed in the context of the total bank stabilization Master Plan described in the previous section. Whilst the stabilization works in the Sariakandi-Mathurapara and Sirajganj reaches meet conventional economic viability thresholds, the works for the other reaches do not. However, as described earlier, such criteria are not wholly appropriate to assess the justification of these works which should be more on social time preference considerations. Also, it is not entirely appropriate to assess the economic indicators of separate reaches individually as they form components of a long-term Master Plan strategy.

22. FINANCIAL CONSIDERATIONS

22.1 Financial Constraints to Implementation

The availability of financial resources is regarded as one of the major constraints to the implementation of a comprehensive bank stabilization programme, as envisaged in the Master Plan. Initial projects to protect key locations e.g. Sirajganj and Sariakandi/Mathurapara, are likely to received adequate support from major aid agencies, such as the World Bank. However, the funding required for future capital expenditure on additional bank stabilization measures, for which the economic justification is not so strong, has yet to be established. Given the magnitude of the funding requirements, GOB would clearly not be able to finance the programme from domestic resources.

In addition, concern has been expressed over the ability of GOB to finance recurrent expenditure both for the initial priority works and, in particular, for the whole bank stabilization programme.

22.2 Sources of Finance

The principal sources of finance for a major capital investment programme would include:

- multilateral funding agencies (e.g IDA, EDF and ADB) through loans, credits and grants;
- bilateral aid agencies (e.g KfW, ODA etc) through loans, grants and tied export credits;
- domestic sources, such as GOB, local banks and cost recovery from beneficiaries.

22.3 Cost Recovery

The main difficulty with a project of this nature is the almost complete lack of specific cash revenue that could be generated directly by the programme. Cost recovery from the beneficiaries of bank stabilization and flood protection investments is very problematic, and, in the past, this type of investment has commonly been regarded as the government's responsibility. The scale of the funding required for capital expenditure suggests that it would be unrealistic to expect beneficiaries to make a significant contribution. There is, however, an opportunity to establish the principle of O & M cost recovery for urban centres.

For the bank protection works at Sirajganj, it has been proposed that a municipal cost recovery system be set up to finance a proportion of the expenditure required for maintenance of the protection works. The cost recovery arrangements would be based on a surcharge on municipal holding tax, following the reclassification of land within the municipal boundary which is presently assessed as agricultural. The principle of O & M cost recovery is already legally established for FCDI schemes, so it is not unreasonable to expect urban landowners, who significantly benefit from the protection works in term of land values alone, to make a significant contribution to their maintenance.

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Prior to implementation of the above cost recovery mechanism, a study would be undertaken to: (a) review municipal revenue from various taxes, licenses and fees; (b) assess the ability of different income groups to pay the tax increment; and (c) determine possible measures necessary to increase tax collection efficiency and to implement an advalorem tax structure.

Annual maintenance costs for Phase 1A of the Sirajganj protection works are expected to be in the order of Tk 36 million. Given that the present total municipal income from tax and fees in Sirajganj is approximately Tk 7 million per annum, there would have to be a very considerable widening of the tax base and substantial improvement in collection efficiency to enable the municipality to make more than a token contribution to the annual maintenance of the protection works. Realistically, even if a successful cost recovery mechanism were established, GOB would still be required to make a significant contribution to meeting O & M costs. It is interesting to note that approximately 65% of Sirajganj's current municipal income, required to meet local expenditure on public services, is obtained from GOB grants.

For rural areas and smaller settlements, the establishment of on O & M cost recovery mechanism is not considered feasible. The benefit of bank protection and flood control vary considerably from area to area, depending on proximity to the bankline and the BRE, general topography, and whether land is located on the riverside or landside of the BRE. Consequently, it would be effectively impossible to design an equitable system of direct cost recovery.

22.4 BWDB Current Budget

Without a major source of revenue from a cost recovery programme, GOB would therefore be required to meet a very large proportion of the O & M expenditure on bank protection works. In the initial five years of the bank stabilization programme, O & M costs are estimated to be in the order of Tk 60 million per annum, but rise to around Tk 315 million per annum at the end of Master Plan.

GOB ability to provide adequate funding for the maintenance of the protection works (and the BRE) is a major cause for concern and consequently a risk to the programme. Failure of GOB to provide an adequate and sustainable level of finance for O & M at an early stage of the programme could be regarded by international funding agencies as sufficient justification to discontinue support for future bank protection works, and so place the Master Plan in jeopardy.

Given that BWDB's present annual repair and maintenance budget (excluding Food For Work activities) is approximately Tk 110 million, maintenance of the bank protection works being considered under the Master Plan would immediately require an increase of Tk 60 million (ie. 55% increase) rising to Tk 315 million (i.e approaching a 300% increase) over a period of 30 years.

At present, BWDB repair and maintenance budget is supplemented by Food For Work programme activities, which provides wheat at an estimated value of around Tk 250 million per annum. This supplementary source of "revenue" could also made available for the maintenance of the BRE, which would help to reduce total cash requirements, but as a very high proportion of expenditure on bank protection works is required for materials, machinery and transport, it is unlikely to significantly offset the very substantial increases needed in

BWDB's budget. These funds would have to be made available by GOB in order to ensure that a regular maintenance programme is implemented.

22.5 Government Development Expenditure

GOB's scope for increasing public expenditure is limited by the shortages of domestic currency, as well as procedural and implementation problems, which also slows down effective absorption of foreign aid. Even with an improvement in the mobilisation of domestic resources (via, for example, the widening of the tax base and growth in tax revenue) there is still likely to be a need to reprioritorise the Annual Development Programme (ADP) to ensure that adequate funds are made available for O & M of major public assets; such as bank protection works.

The total ADP budget is approximately Tk 60,000 million, of which Tk 7,500 million (12.5%) is allocated to the development of water resources. External financing accounts for over 90% of the total ADP expenditure, of which project aid represents 60%. Generation of counterpart funds is significantly enhanced by commodity aid, which finances a further 30% of the ADP. It is hoped that, over the longer term, GOB is able to mobilise more domestic resource, so that its own contribution to financing the ADP can expand and so help to reduce its dependence on foreign aid.

With the limited availability of local resources, it is likely that new project aid commitments will adversely affect the implementation of ongoing programmes unless resources are reallocated to high priority projects and/or donors provide a larger proportion of total costs of a new project, including local costs, to minimise the demands on local currency resources. GOB could also place greater emphasis on mobilizing domestic resources to fund the ADP. Government revenue as a % of GDP is presently around 8% to 9% and there is urgent need to increase this proportion primarily through increased tax receipts.

At present, 65% of tax revenue is obtain through customs and excise duties and only 15% and 11% from income tax and sales tax respectively. There is clearly scope to increase the proportions of income tax and sales tax, but this is could only be implemented gradually and is unlikely to make any major impact on the availability of domestic resources in the short or medium term. Foreign aid, both project aid and commodity aid (to generate counterpart funds), will therefore be the main source of finance for both capital and recurrent expenditure in both the short and medium term.

22.6 Financing Capital and O & M Expenditure on Bank Stabilization

The main source of finance for capital expenditure on bank stabilization works will therefore have to be from project aid, in the form of either grants or soft loans from major international donors. To facilitate the flow of project aid, counterpart funds would also need to be made available by GOB in a timely manner.

With regard to capital costs, GOB should provide sufficient funds to BWDB in order the meet land acquisition and resettlement costs, as well as the construction of all sections of retired embankment. Project aid would be required for funding all other capital expenditure associated with the bank protection works including earthworks, dredging, revetment, and general facilities.

O & M costs would be mainly funded by GOB with a contribution from Sirajganj municipality. It is essential that GOB gives priority in the ADP to the bank stabilization measures to ensure that regular repair and maintenance is undertaken. The establishment by BWDB of a river bank protection works maintenance unit, comprising highly trained personnel responsible for the management of all O & M activities (including use of specialist plant and equipment) will greatly assist in enhancing BWDB's capability in the construction and maintenance of bank stabilization works. It successful, this unit will not only ensure continued donor support for the long term programme, but may also provide justification for an increased rate of implementation.

The Master Plan envisages a gradual implementation of river bank protection works over a period of 30 years, with an average rate of disbursement of approximately Tk 600 million per annum. This rate of implementation is designed to ensure that adequate financing of both capital and recurrent expenditure is maintained throughout the programme. However, with the anticipated enhancement in BWDB's capacity to construct and maintain the bank protection works and the willingness of GOB to provide additional counterpart finance, it is possible that aid donors will be able to assist with a more rapid implementation of the programme.

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23. RECOMMENDED FOLLOW-UP ACTION

At this point in time, there are four main streams of follow-up action.

23.1 Implementation of Phase 1A

The first activity is already in hand, and that is the on-going process towards implementation of the Priority Works, Phase 1A of the Master Plan. It is expected that prequalification procedures will commence in the near future (July 1993). Evaluation of applications will follow, from which contractors who satisfy the stated threshold criteria will be invited to bid for the two contracts. The tender process will include a site visit by the tenderers, submission and evaluation of bids, and award of contract. The construction of the works, and the responsibilities of those involved, have been described in Annex 4; responsibilities are summarized in Chapter 19 herein. On the BWDB's part prior to award, there are the particular responsibilities to

i) acquire the necessary land;

ii) ensure that arrangements are in hand to resettle persons who will be displaced by the project;

iii) appoint consulting engineers for the supervision of construction.

23.2 River Monitoring

The second area of follow-up activity is the continuation of the monitoring of the Brahmaputra River. A considerable amount of data has been gathered during the three-year study period, derived both from earlier work and during the course of the Study. This recent acquisition of knowledge about the behaviour of the river now needs to be built upon, and on-going monitoring is an essential part of the process. Such monitoring would fall into two broad divisions, the first being the monitoring of the river planform as a whole, where study of satellite imagery will play an important part. The second is the monitoring of individual critical areas such as Sariakandi and Mathurapara where there is a danger of breakthrough by the Brahmaputra River into the Bangali, and where changes to the location or planform of the proposed structures prior to construction may be required as a result of morphological changes. Again, the responsibility lies with BWDB to make the necessary arrangements.

23.3 Forward Planning and Future Studies

Following on from the construction of the Priority Works, arrangements will need to be put in hand for the implementation of the Phase 1B and Phase 1C works. Consideration initially will need to be given to sources of finance and arrangements for the necessary studies, and for the detailed design work which will be required once locations are finalized. On-going monitoring of the river as a whole will provide invaluable data when decisions have to be taken as to whether the priorities for construction remain as outlined in this report, or whether they have changed. At the same time, the long term considerations discussed in this report should be borne in mind.

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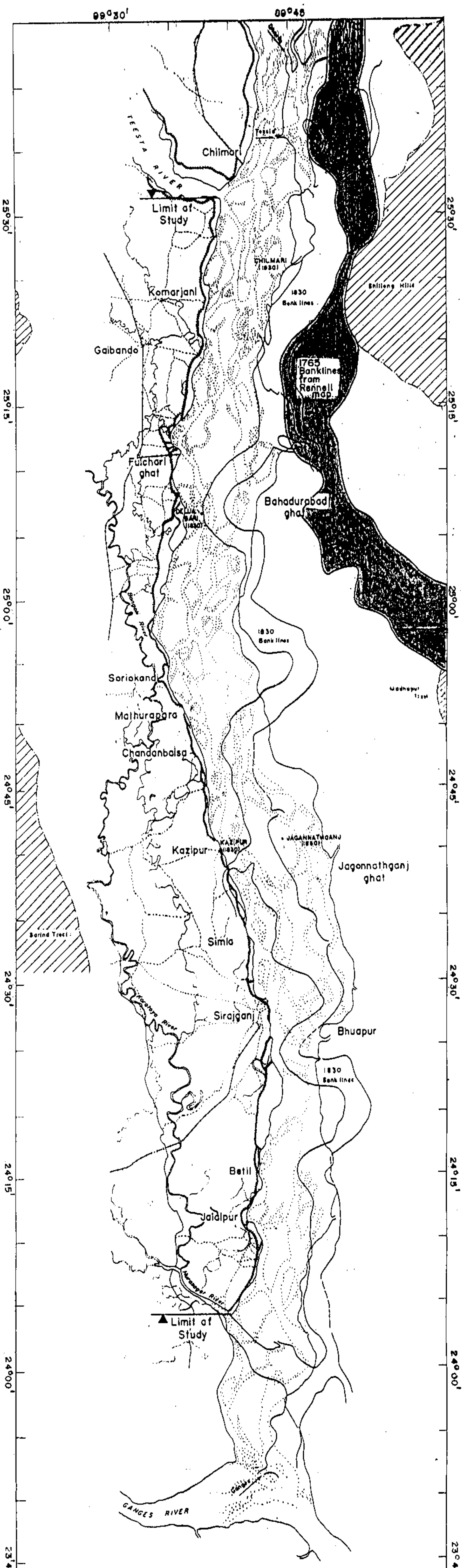
23.4 Operation and Maintenance

Proposals are put forward in Chapter 20 for the establishment of a Monitoring and Maintenance Unit within BWDB. With completion of the first river bank protection works scheduled for mid-1996, arrangements for monitoring and maintaining the completed works need to be finalized fairly soon. It is expected that in time, and as BWDB gain the necessary expertise, the monitoring role of this unit would extend to covering the whole of the river.

FIGURES



NOTE :

The Rennell and Wilcox banklines have not yet been formally registered with the 1990 planform. This overlay is therefore to be treated as preliminary. See Plate 15 for 1830 bankline over 1992 image.

LEGEND :

Bankline of 1989
Bankline of 1830
Bankline of 1765

0 10 20 Km.
SCALE

Superimposition of 1765, 1830 and 1989 Banklines

Halcrow/DHI/EPC/DIG

May 1993

Figure 5.1

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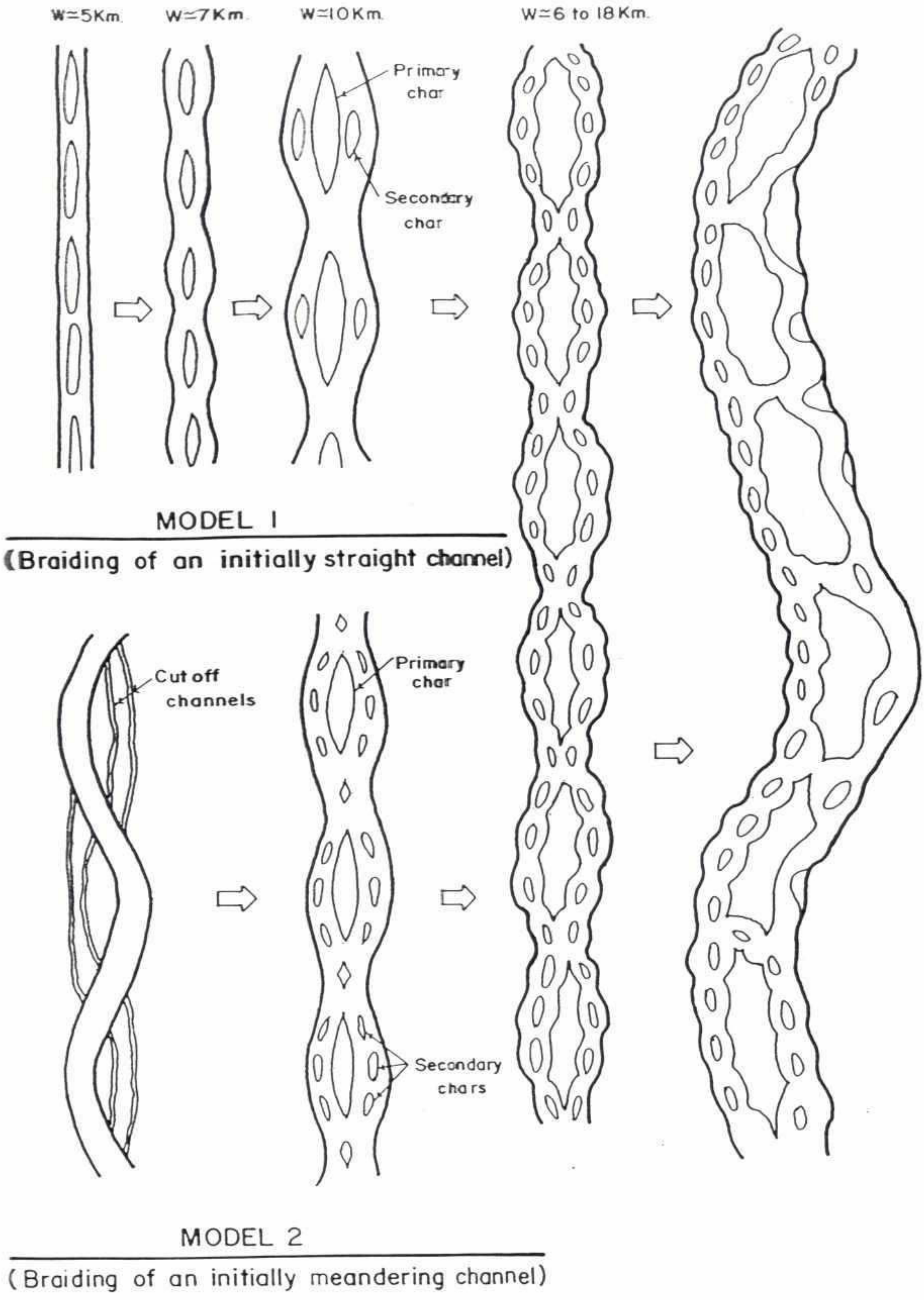
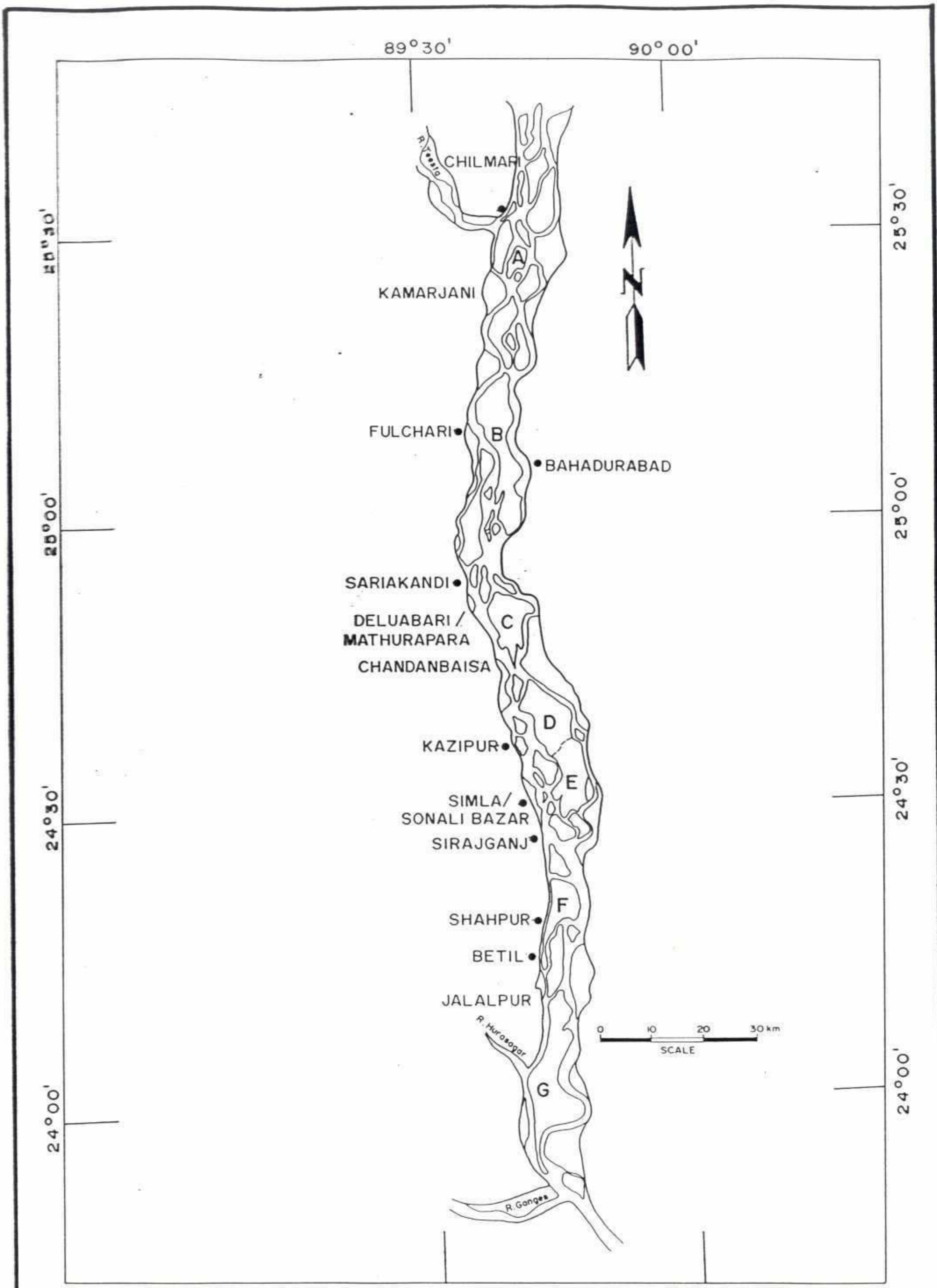


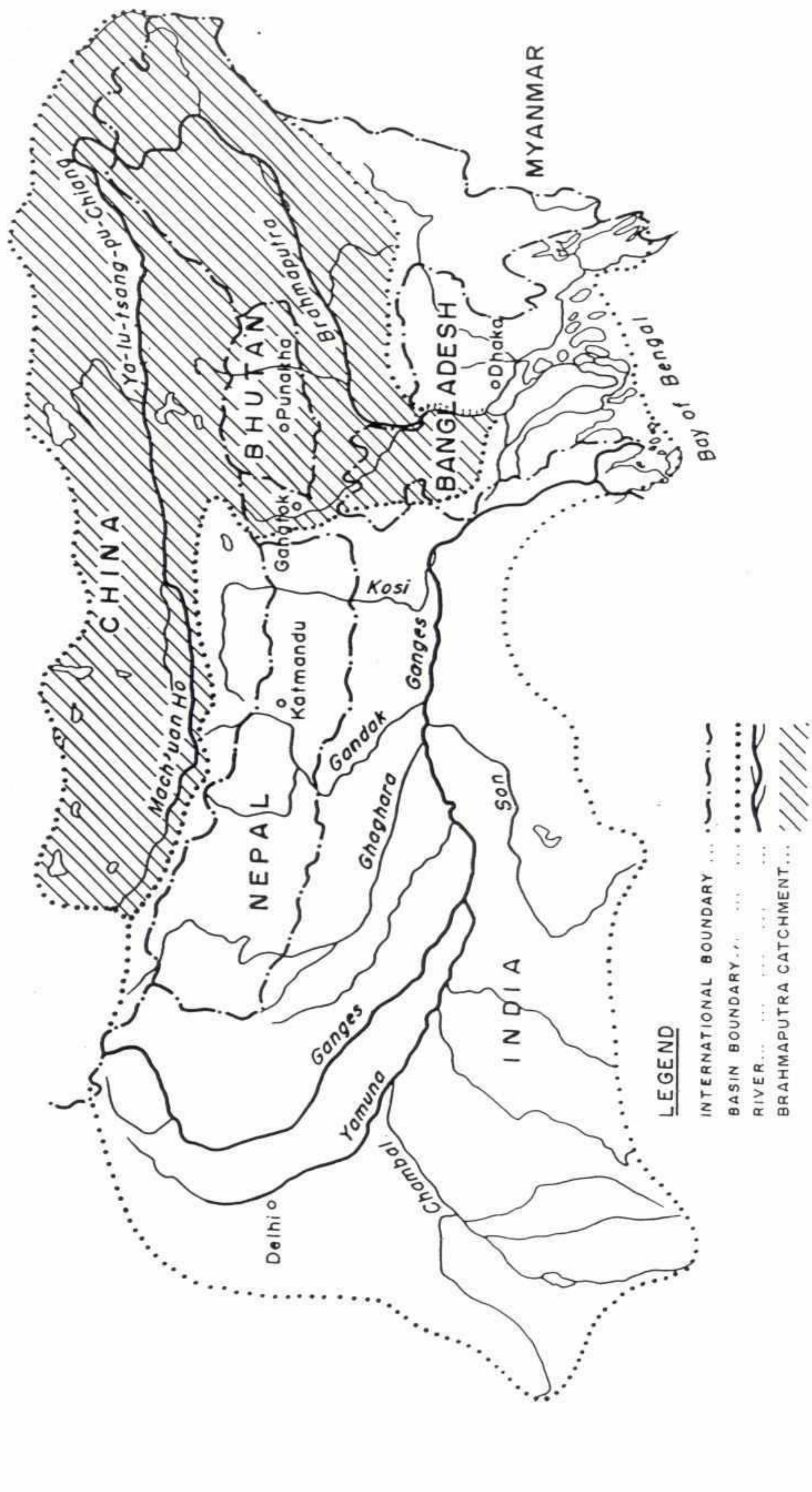
Longterm Channel Evolution Models

Halcrow/DHI/EPC/DIG	*May 1993*	Figure 5.2

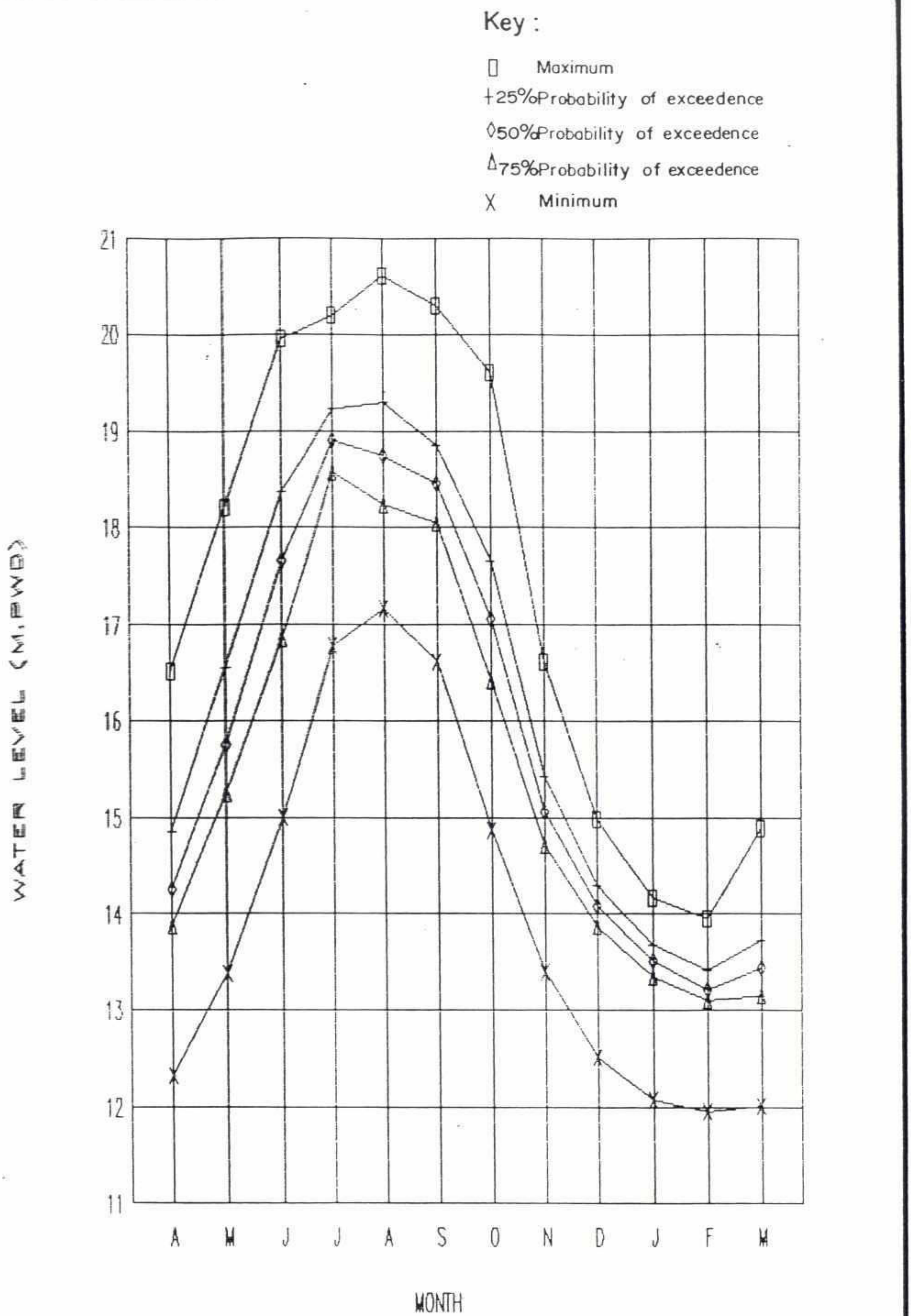


Present Island Pattern

Halcrow/DHI/EPC/DIG *May 1993* Figure 5.3



The Brahmaputra Catchment



General WL Characteristic at Bahadurabad Transit

Halcrow/DHI/EPC/DIG *May 1993* **Figure 5.5**

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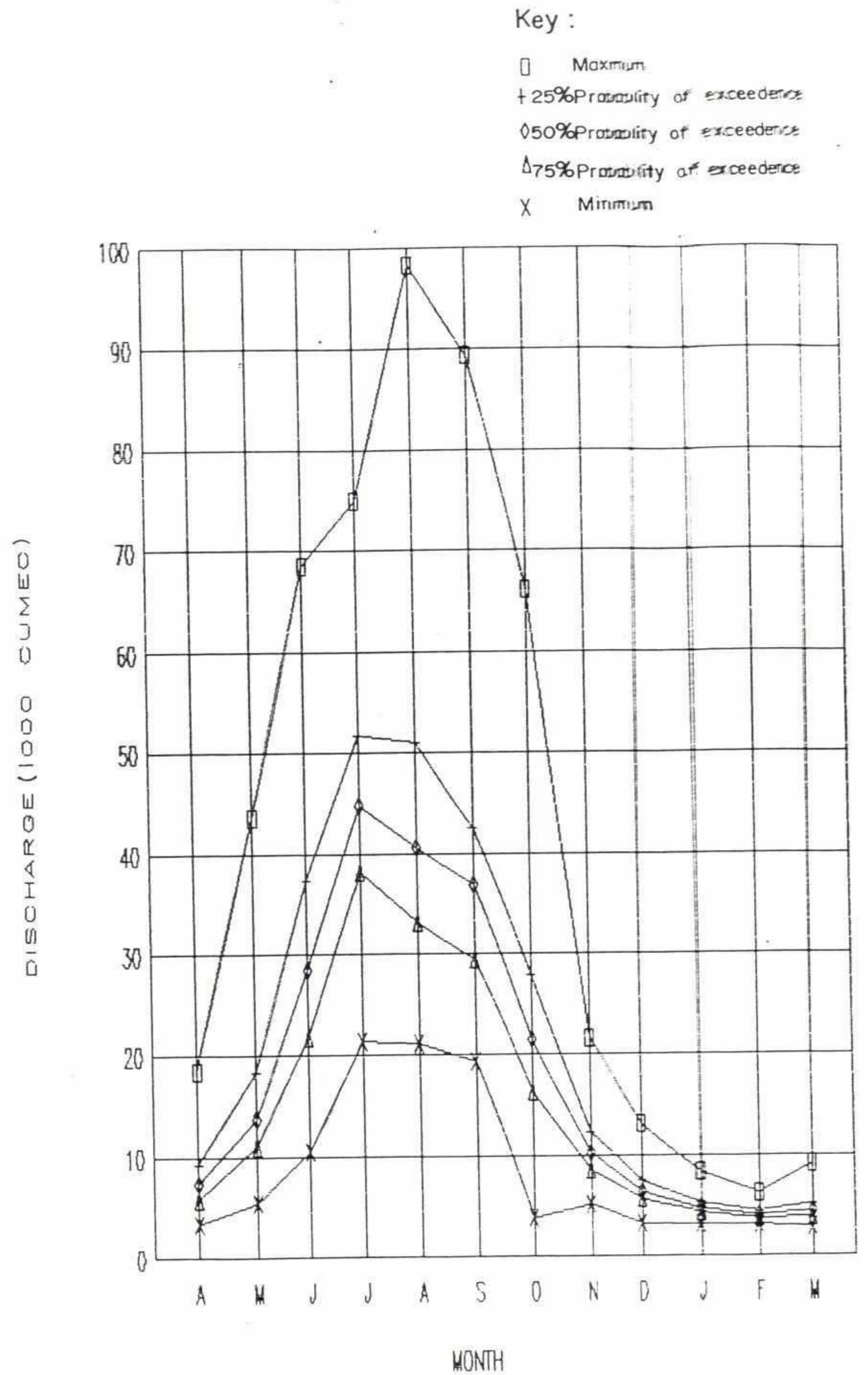

General Discharge Characteristics of the Brahmaputra at Bahadurabad Transit

Halcrow/DHI/EPC/DIG	*May 1993*	Figure 5.6

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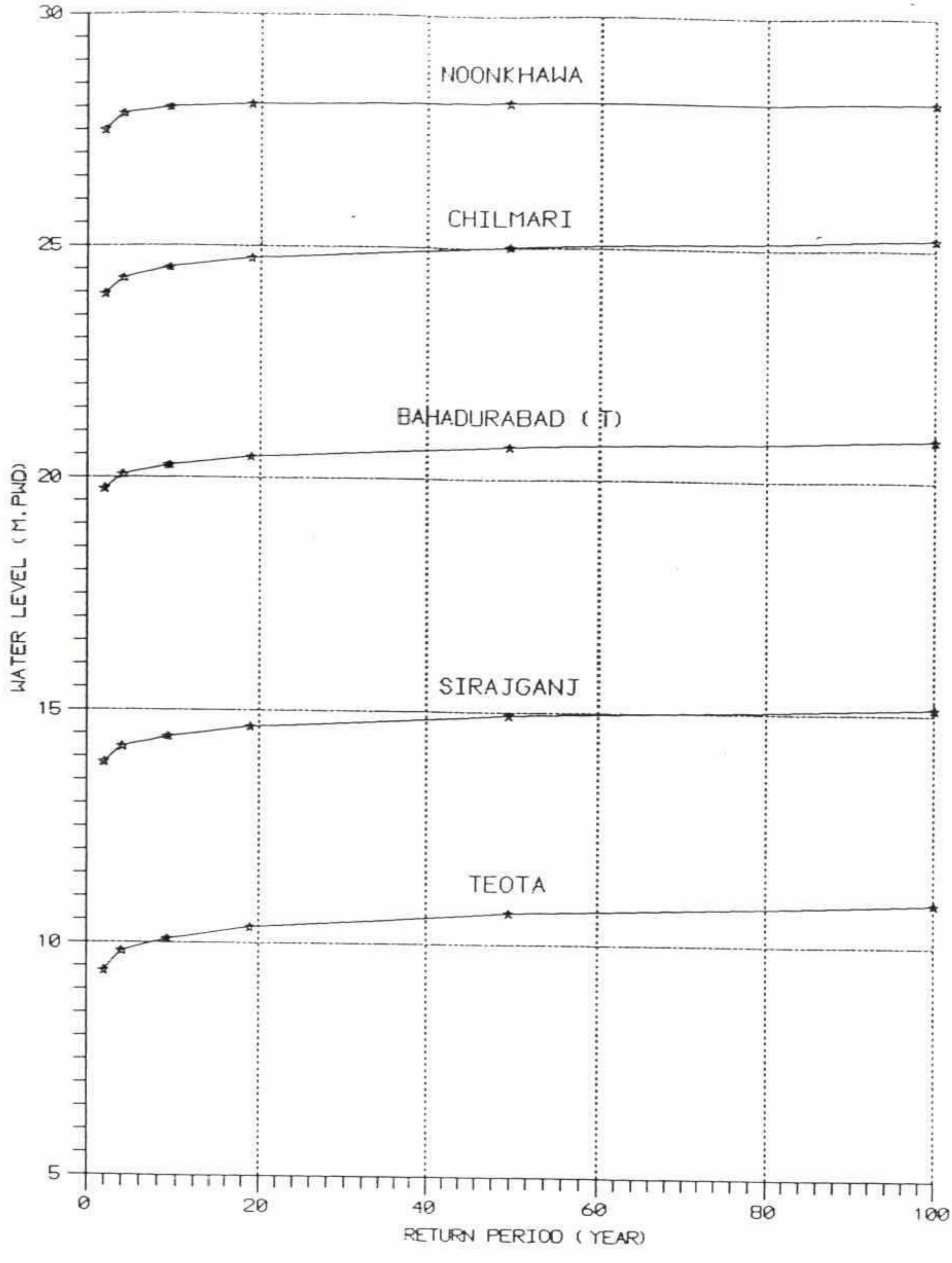
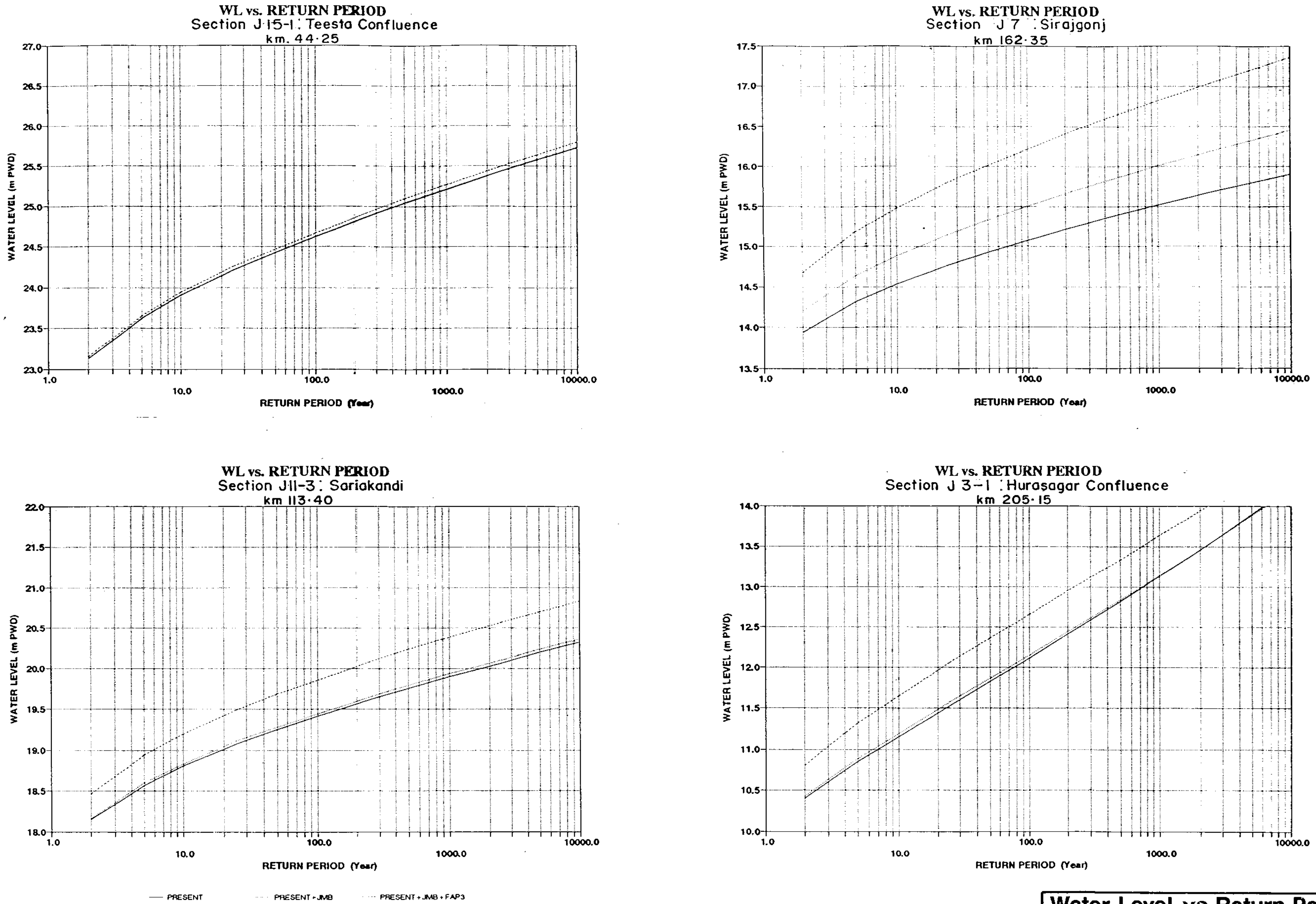


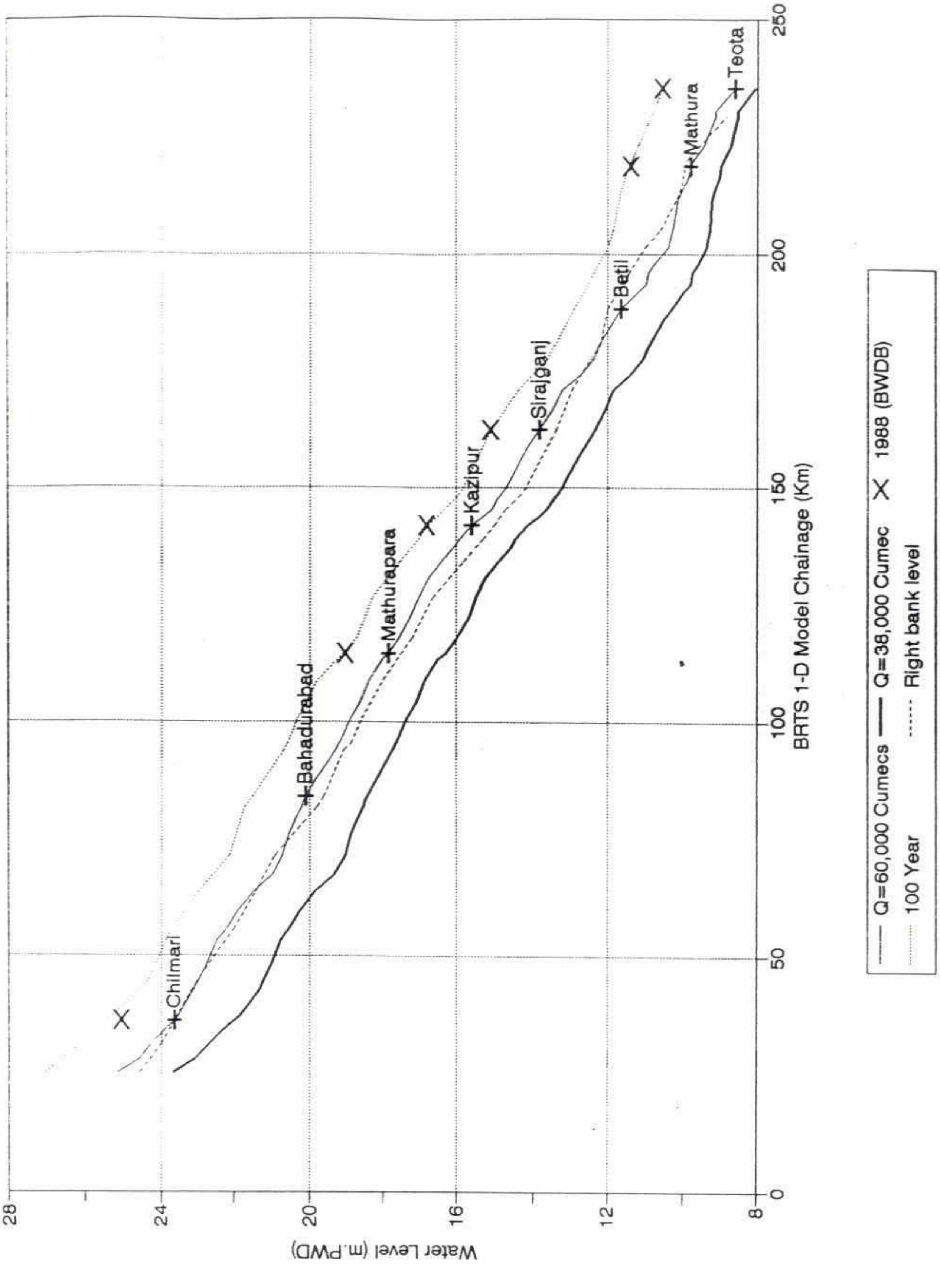
Peak WL Frequency Curves Of the Brahmaputra

Halcrow/DHI/EPC/DIG *May 1993* **Figure 5.7**



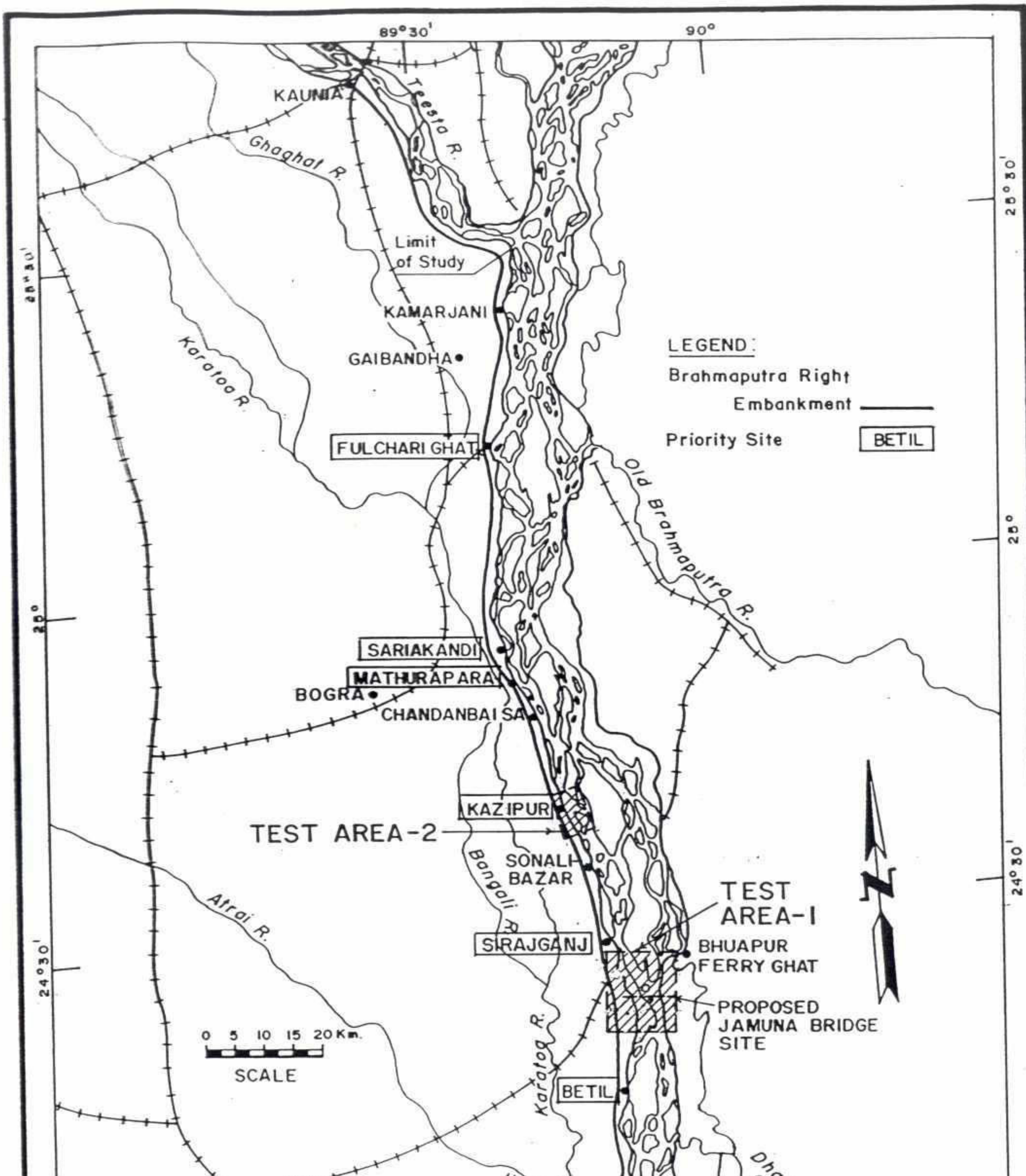
Water Level vs Return Period for Present, Present + JMB and Present + JMB + BLE (FAP-3)

Halcrow/DHI/EPC/DIG	
May 1993	Figure 5.8



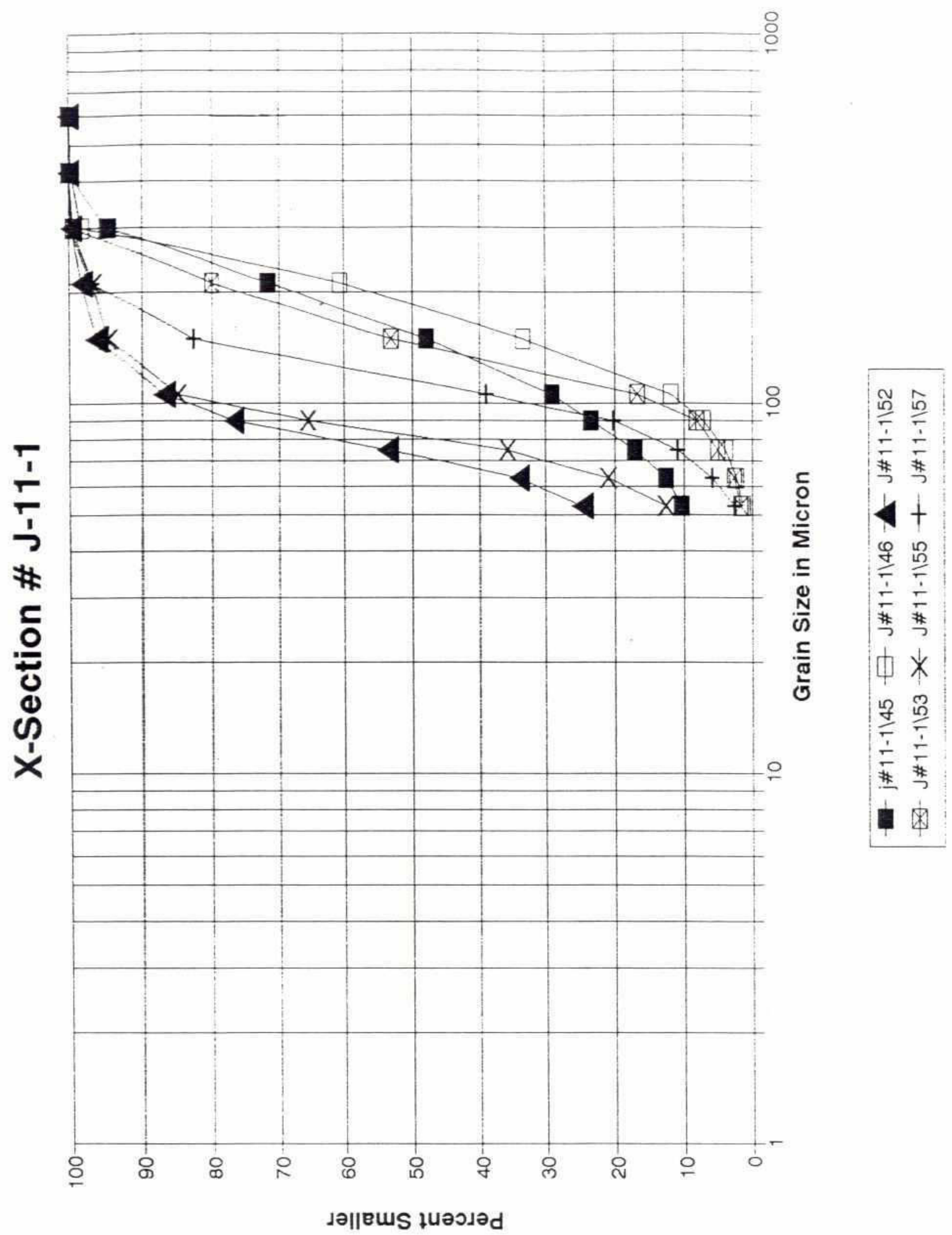
Longitudinal Profiles for Dominant and Bankfull Discharges and 100-Year Return Period (Existing Conditions)

Halcrow/DHI/EPC/DIG	May 1993	Figure 5.9



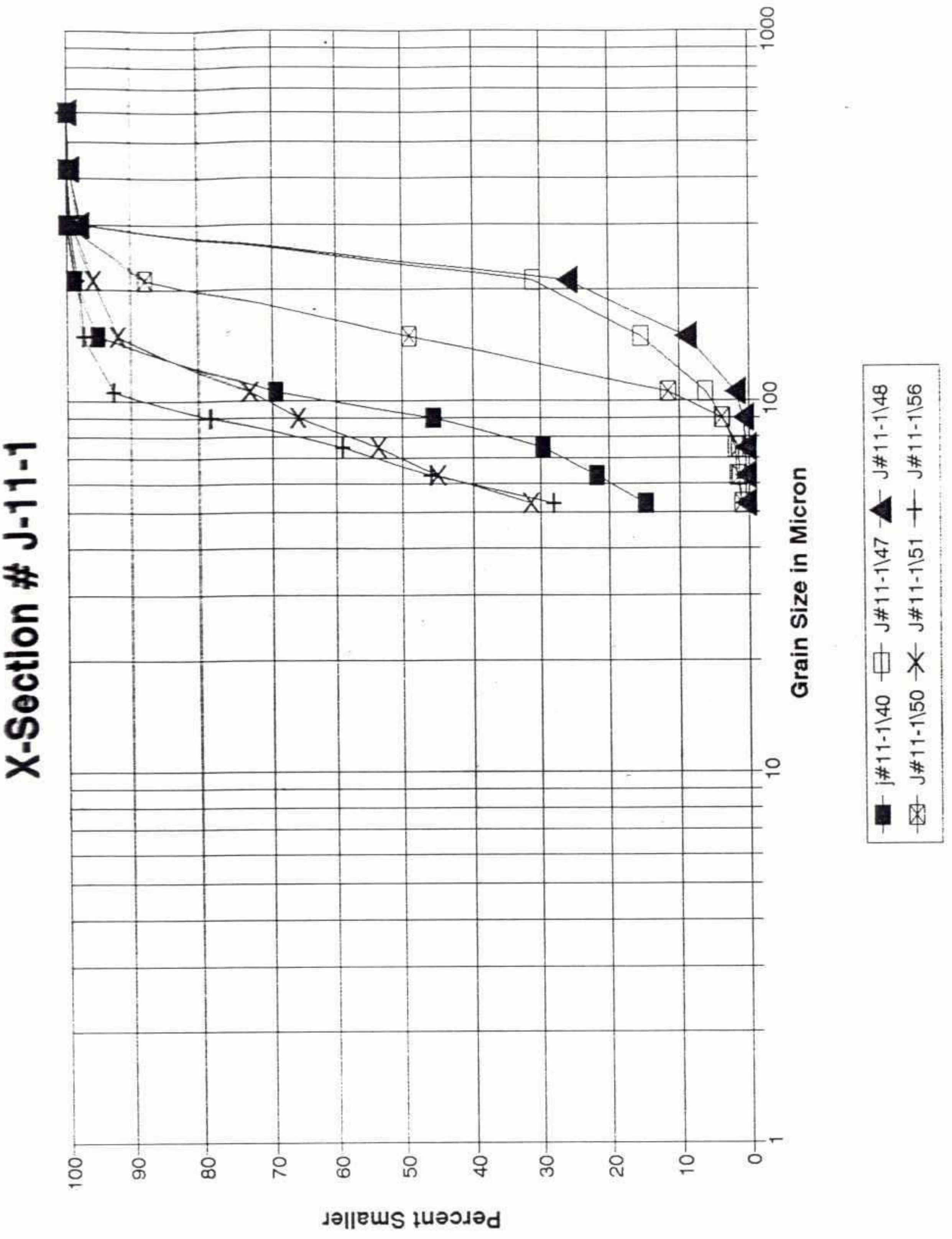
Location Plan of Test Area 1 and Test Area 2

Halcrow/DHI/EPC/DIG | *May 1993* | Figure 5.10



Typical Grading Curves, River Bed and Sandbars

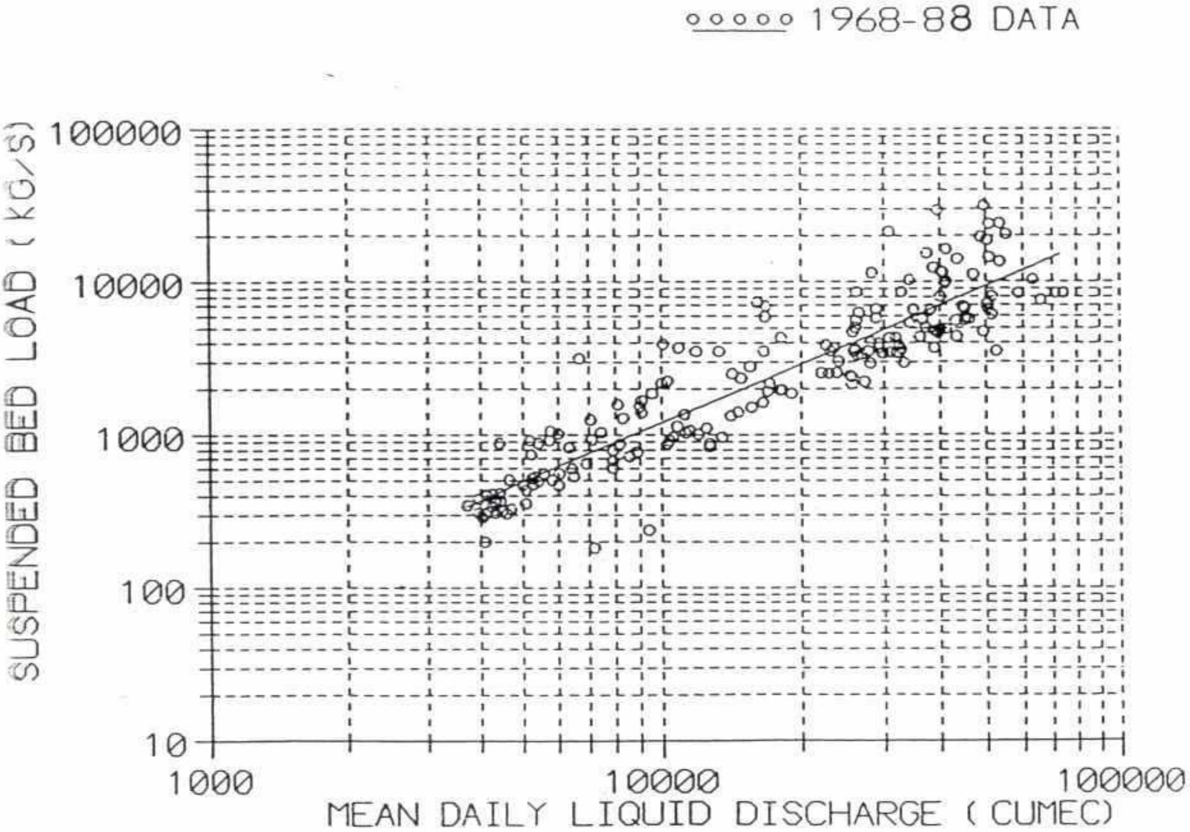
Halcrow/DHI/EPC/DIG	*May 1993*	Figure 5.11



Typical Grading Curves, Floodplain and Island Chars

Halcrow/DHI/EPC/DIG	*May 1993*	Figure 5.12

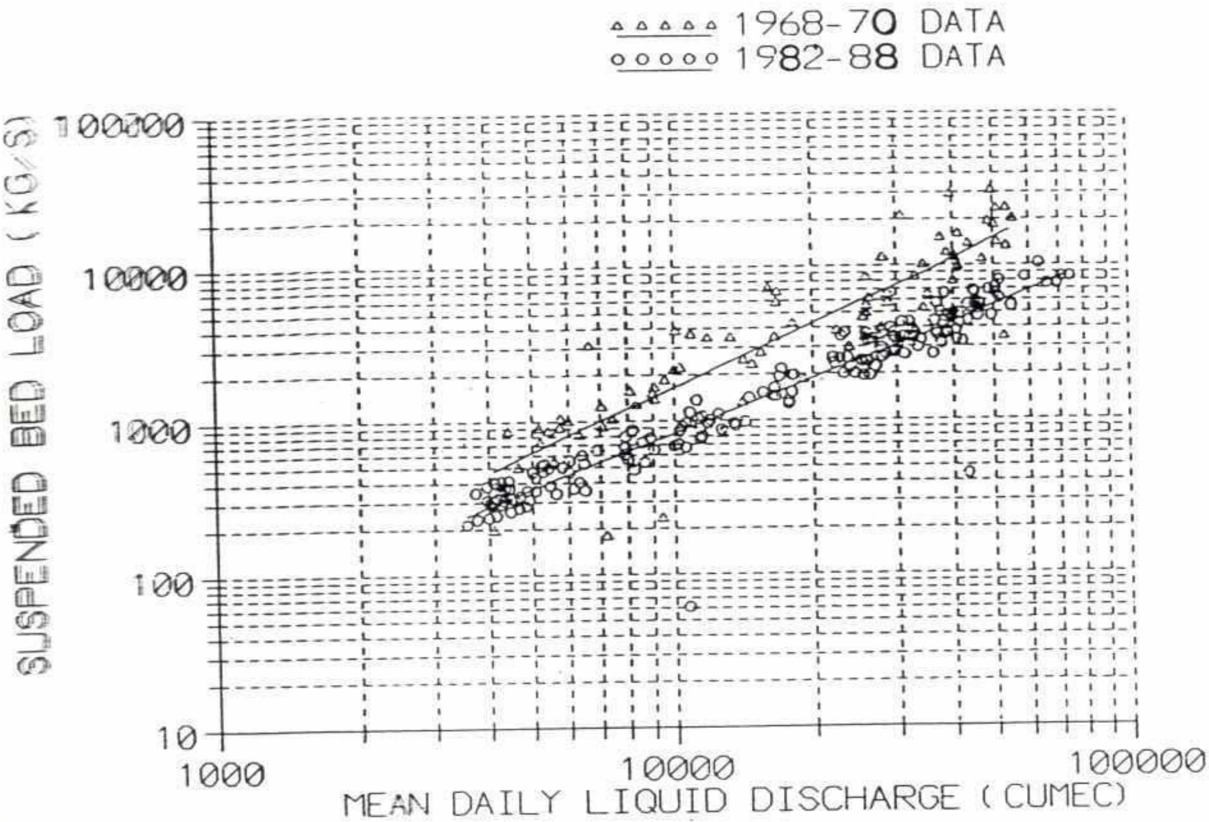
222



Measured Coarse Suspended Sediment Transport at Bahadurabad (1968-88)

Halcrow/DHI/EPC/DIG | *May 1993* | **Figure 5.13**

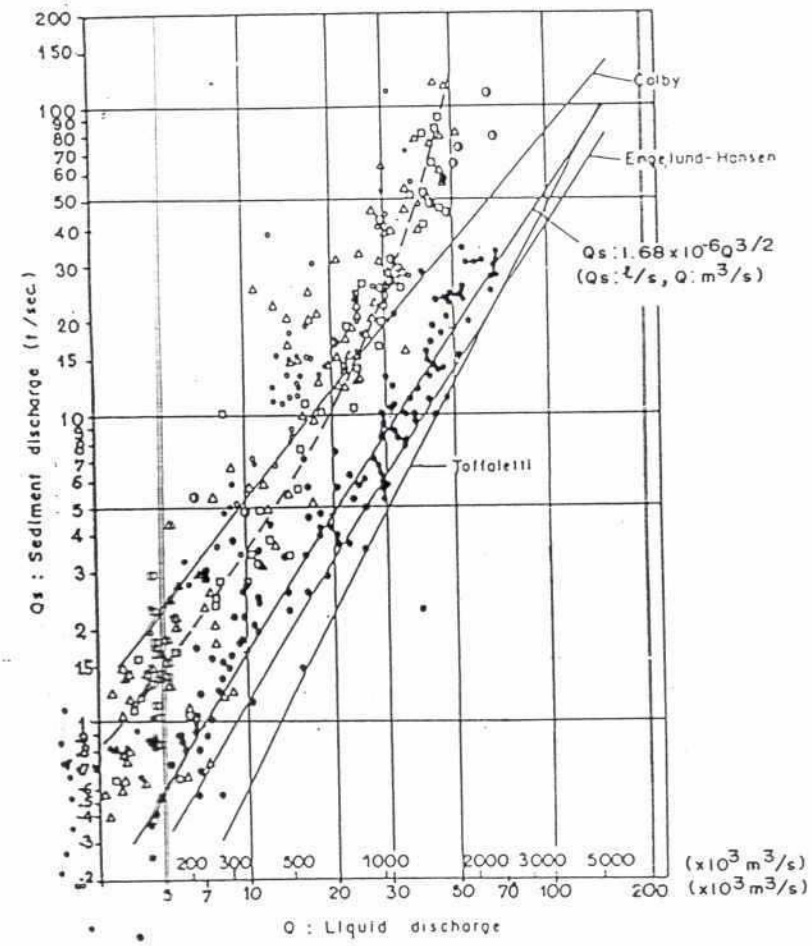
206



Measured Coarse Suspended Sediment Transport at Bahadurabad (1968-70 and 1982-88)

Halcrow/DHI/EPC/DIG	*May 1993*	**Figure 5.14**

268



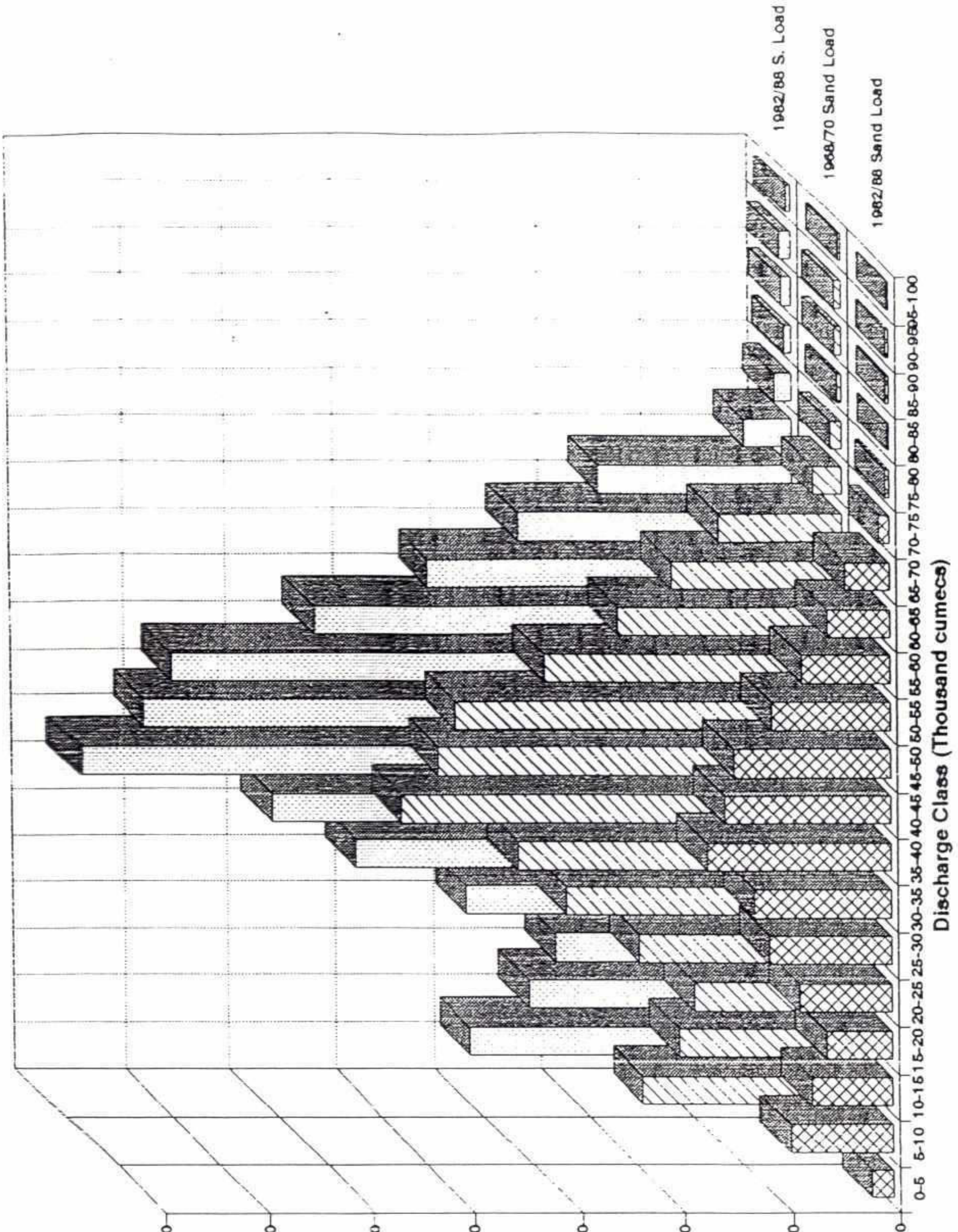
Total Sediment

- ∘ Chilmari from 1966 to 1969
- ○ Bahadurabad in 1966
- △ Nakfater Char from 1965 - 69
- □----Nagarbari from 1967 — 69
- •——Bahadurabad from 1966 — 69

Coarse Sediment (d > 0.05 mm)

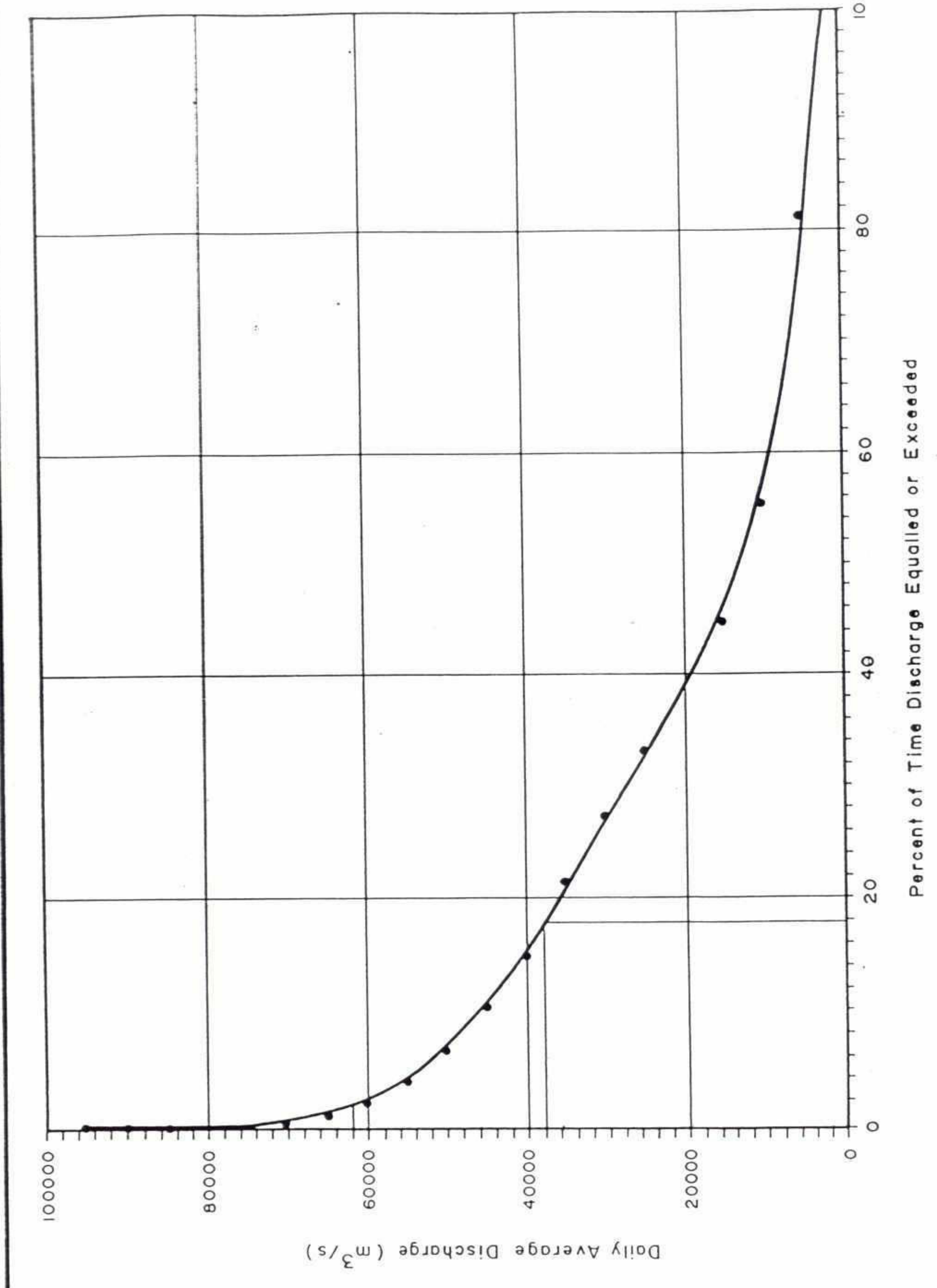
Relationship Between Discharge and Suspended Sediment Transport (after RRI, 1988)

Halcrow/DHI/EPC/DIG | May 1993 | Figure 5.15



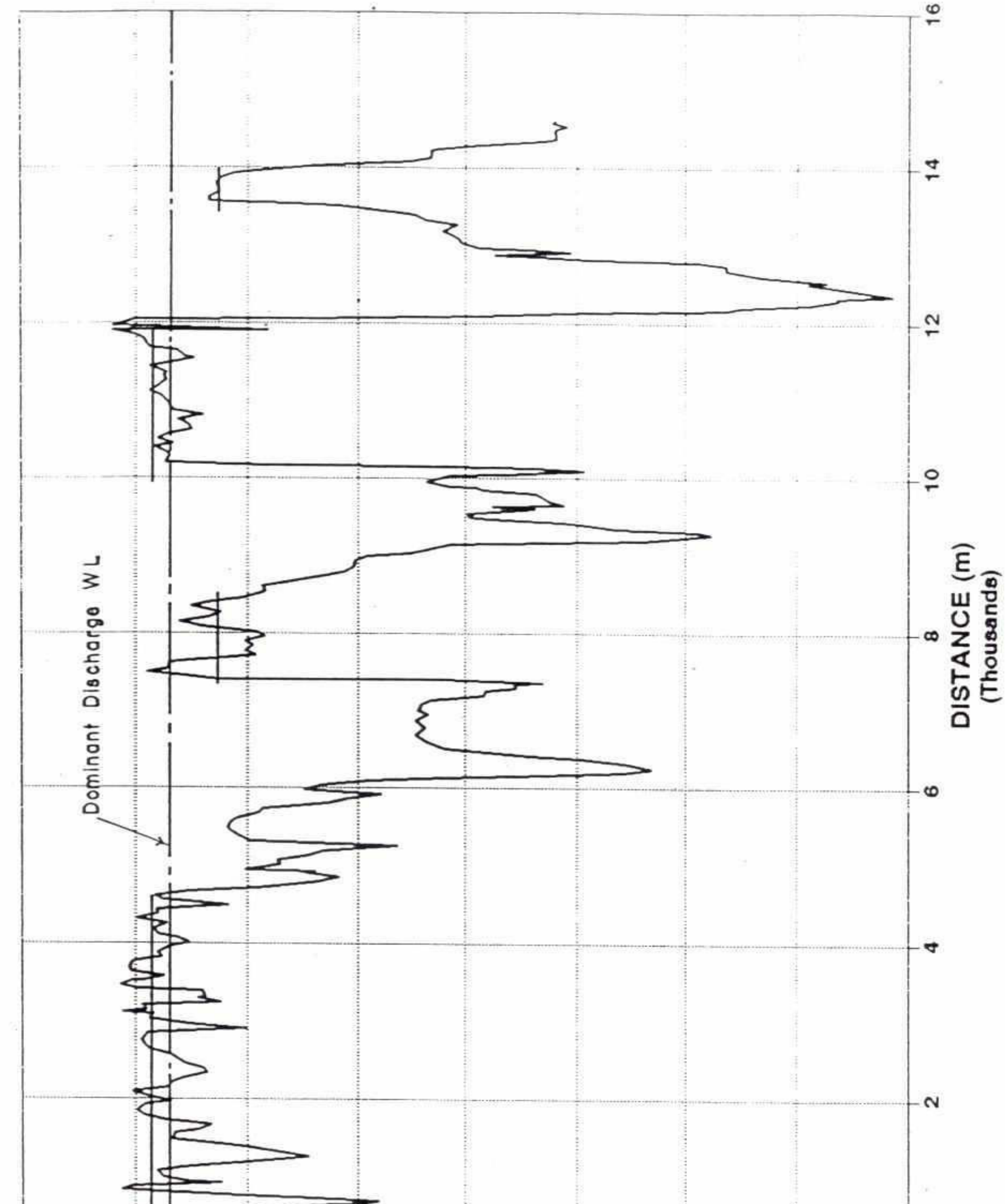
Total Sand/Sediment Transport Vs. Discharge Curves at Bahadurabad

Halcrow/DHI/EPC/DIG	*May 1993*	Figure 5.16

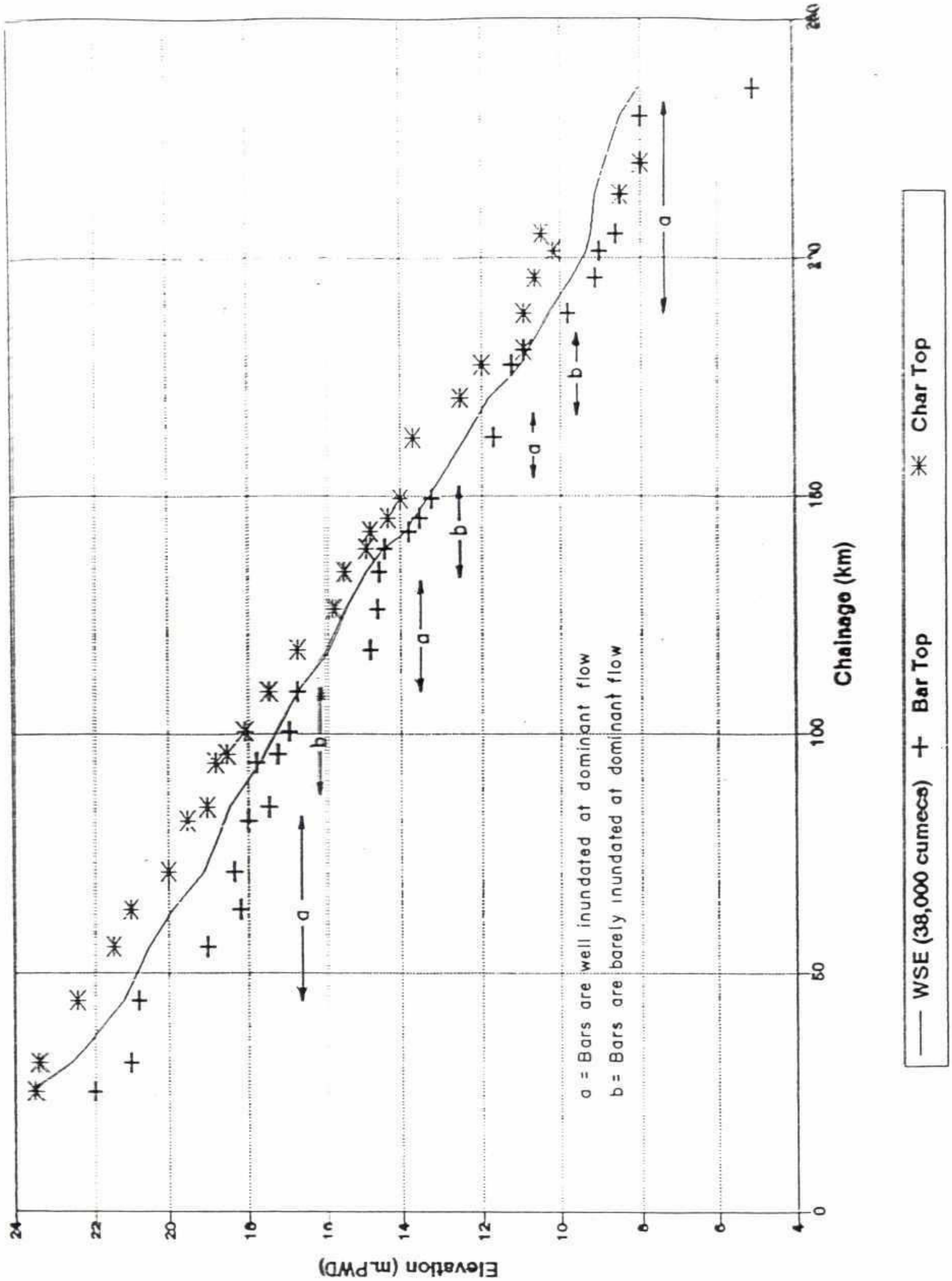


Flow Duration Curve at Bahadurabad, Brahmaputra River

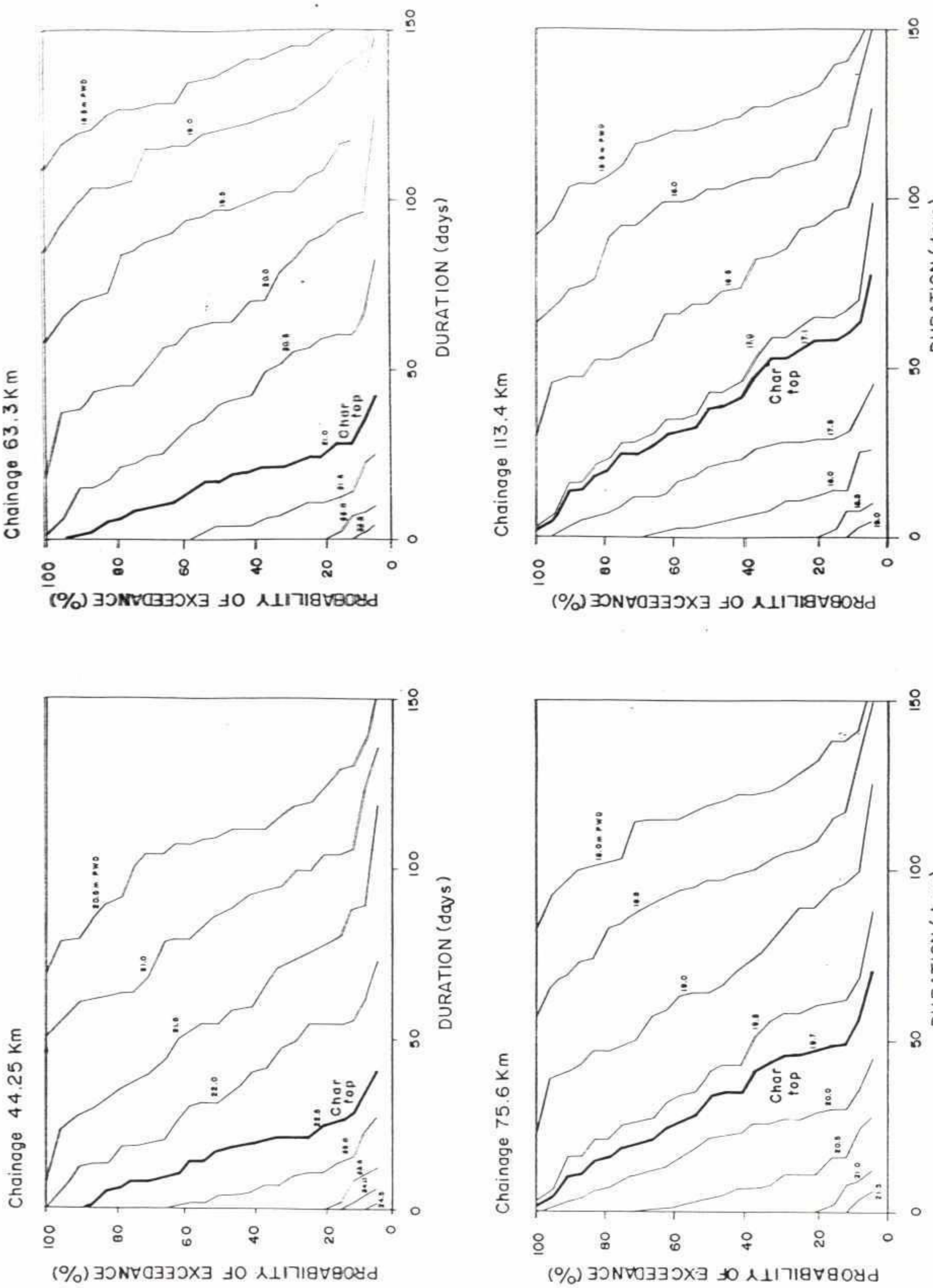
Halcrow/DHI/EPC/DIG	***May 1993***	Figure 5.17



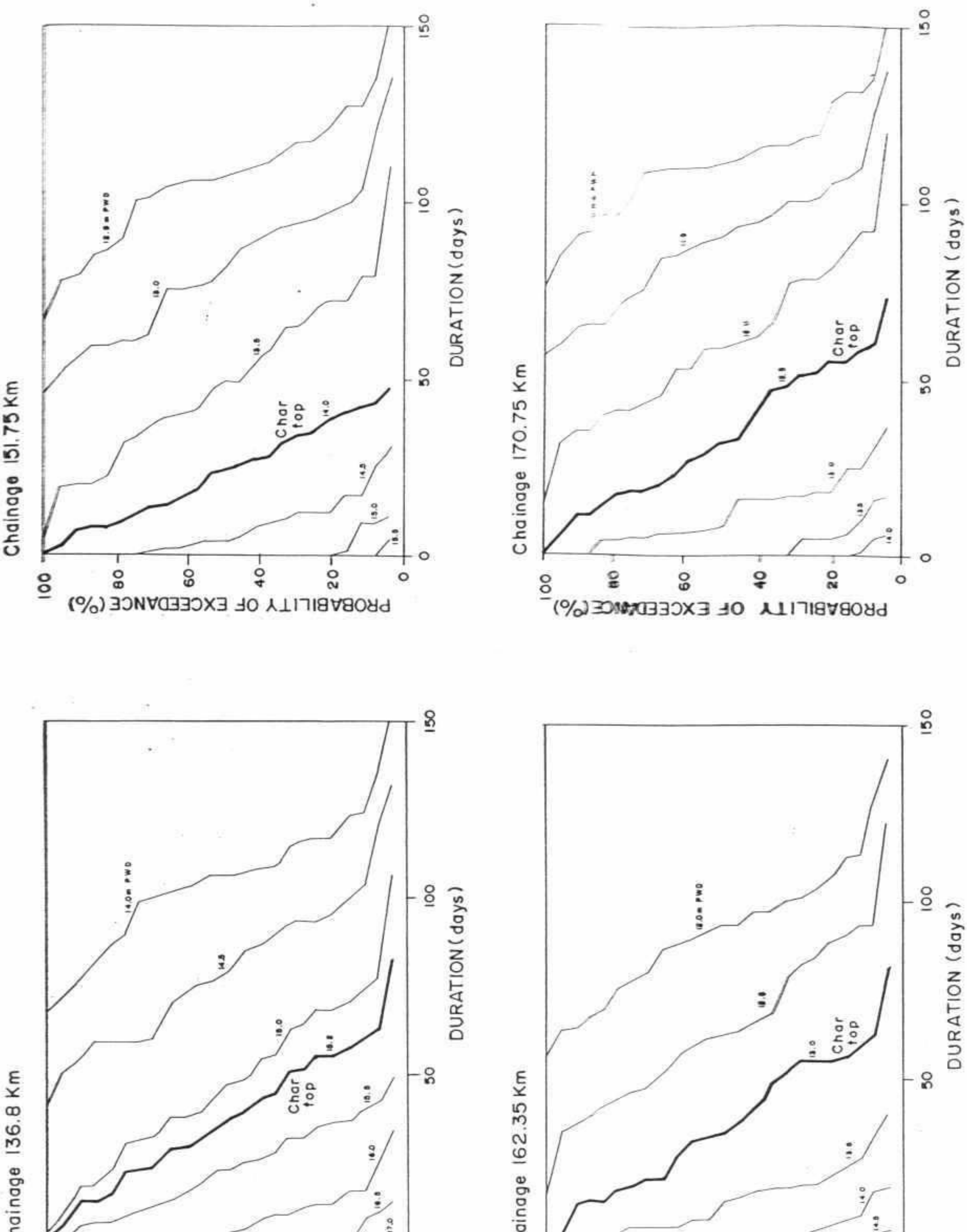
Typical River Cross-Section Showing Upper and Lower Char Top Levels



Long Section Showing Levels of Lower and Upper Chars



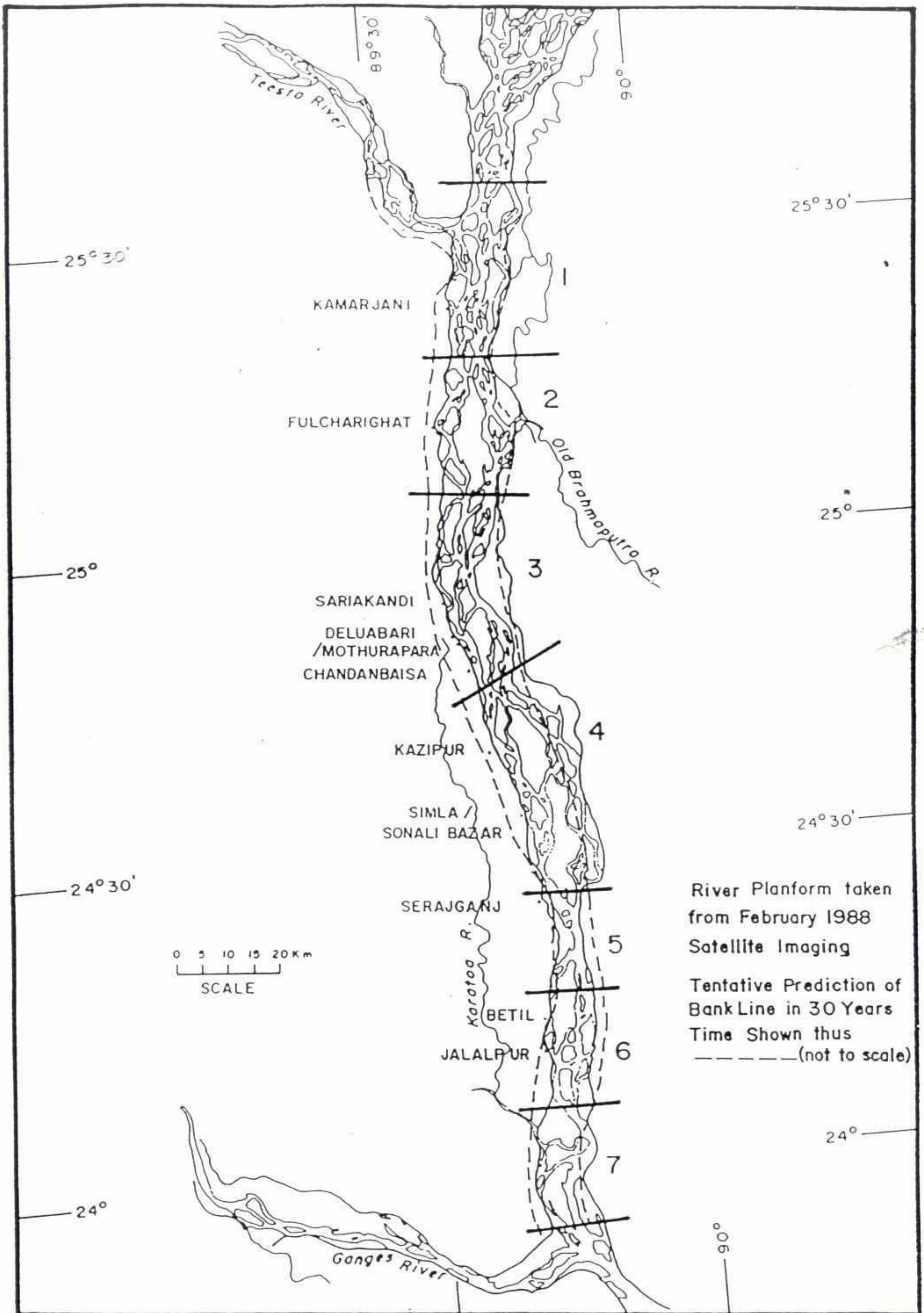
Inundation of Chars, Existing Situation - Sheet 1



Inundation of Chars, Existing Situation - Sheet 2

Halcrow/DHI/EPC/DIG *May 1993* **Figure 5.21**

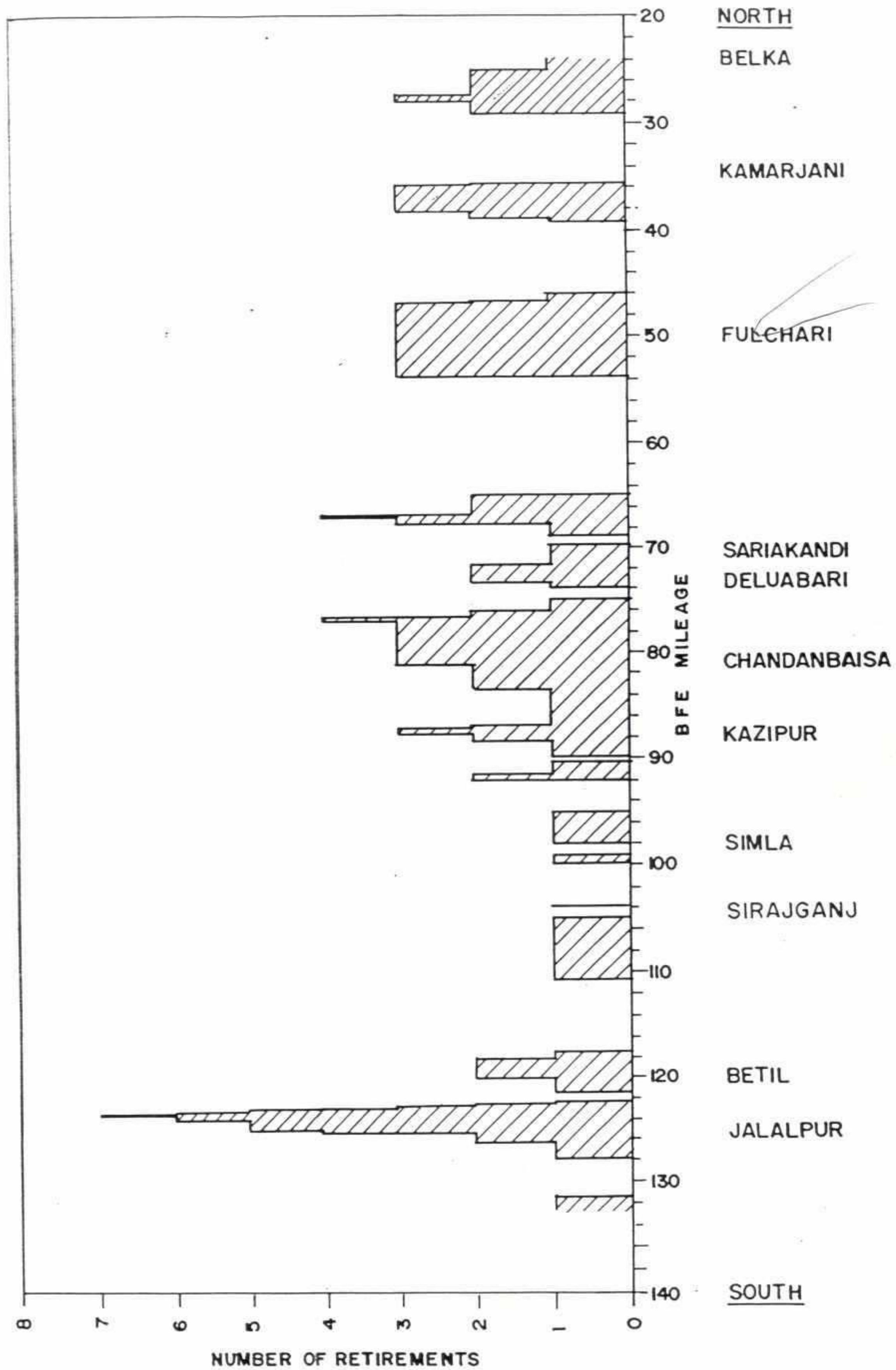
280



Definition of Reaches Used for Braiding Analysis

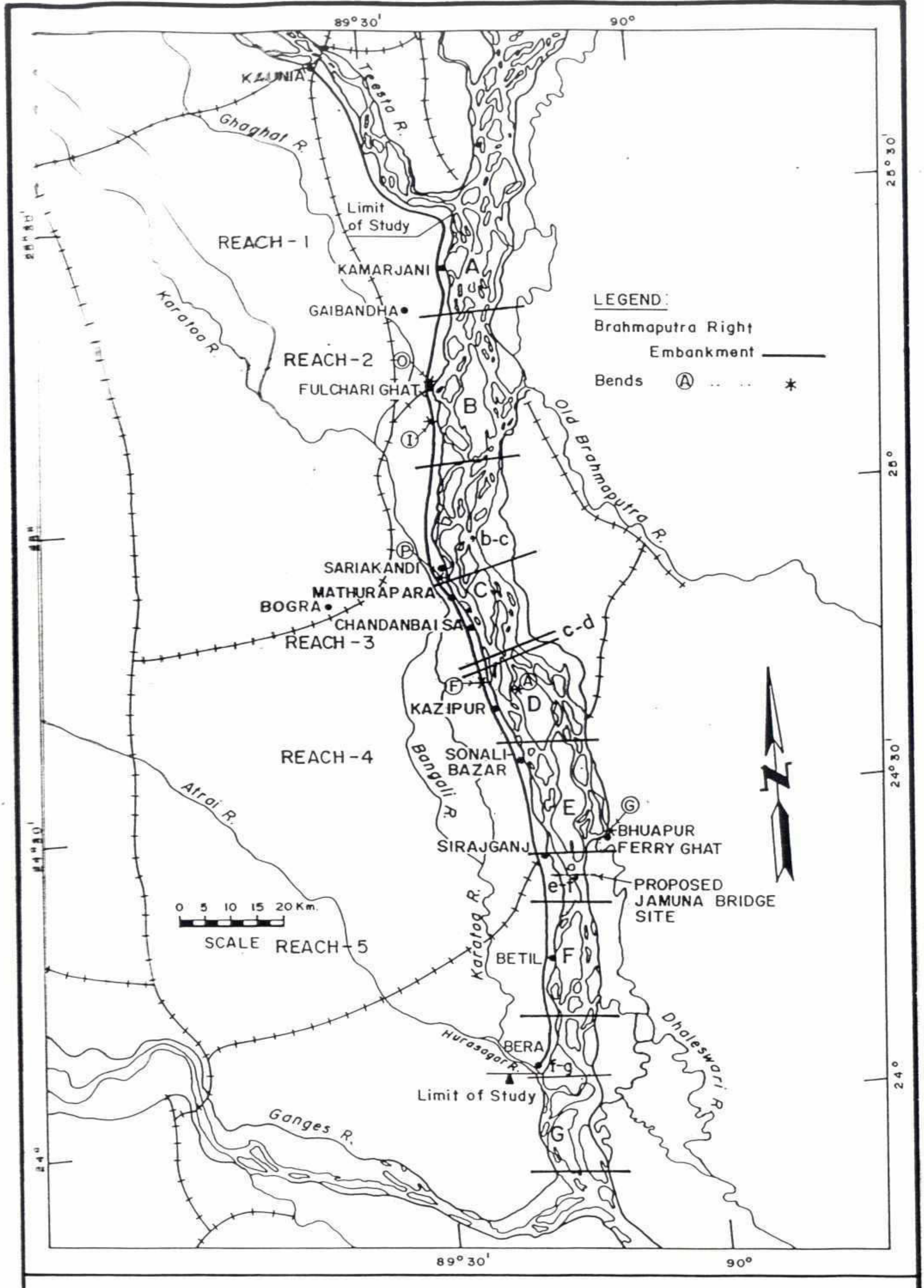
Halcrow/DHI/EPC/DIG *May 1993* **Figure 5.22**

282



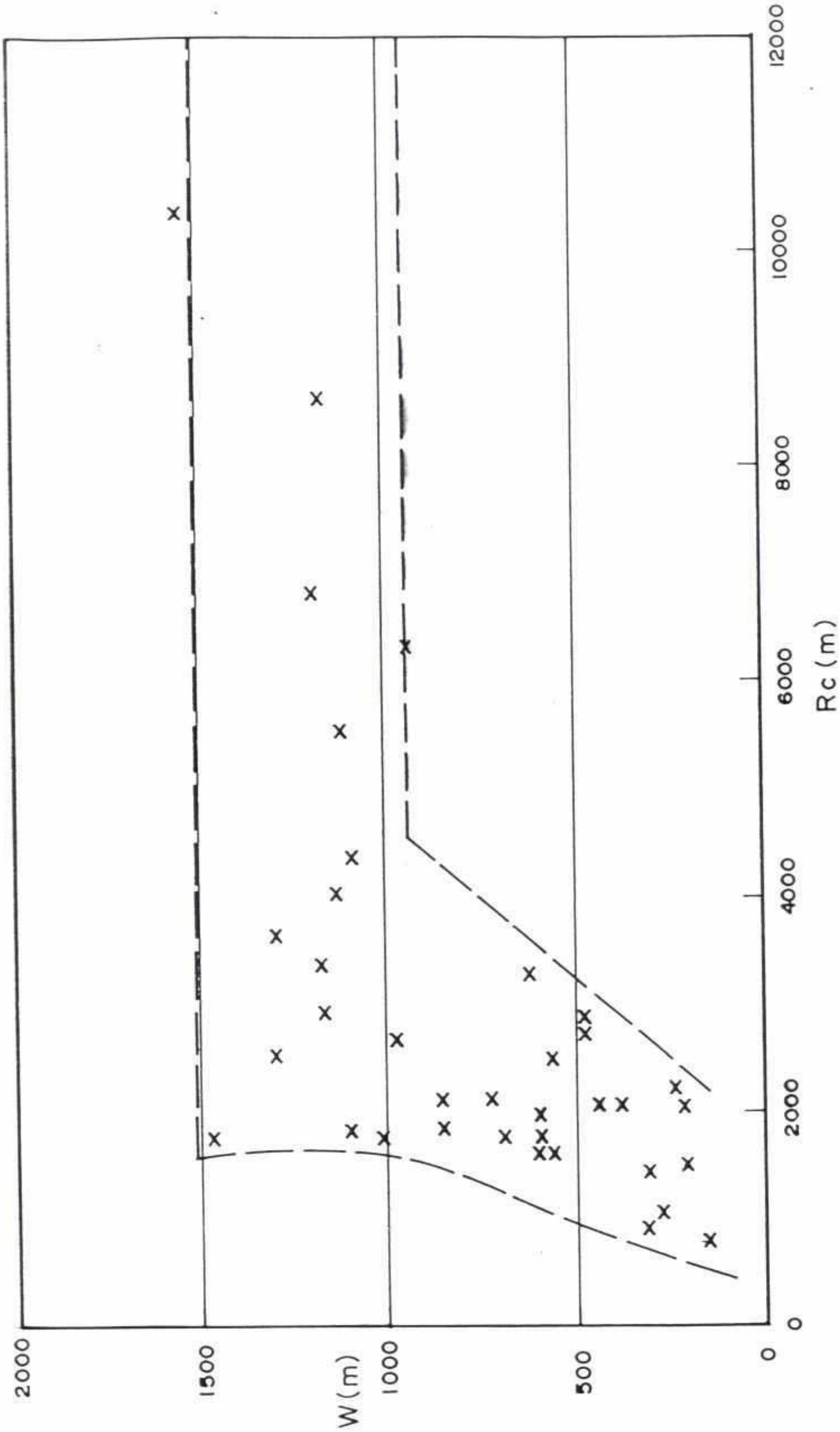
Number of BRE Retirements

Halcrow/DHI/EPC/DIG *May 1993* Figure 5.23



Location of Island Reaches and Selected Bends

Halcrow/DHI/EPC/DIG | May 1993 | Figure 5.24

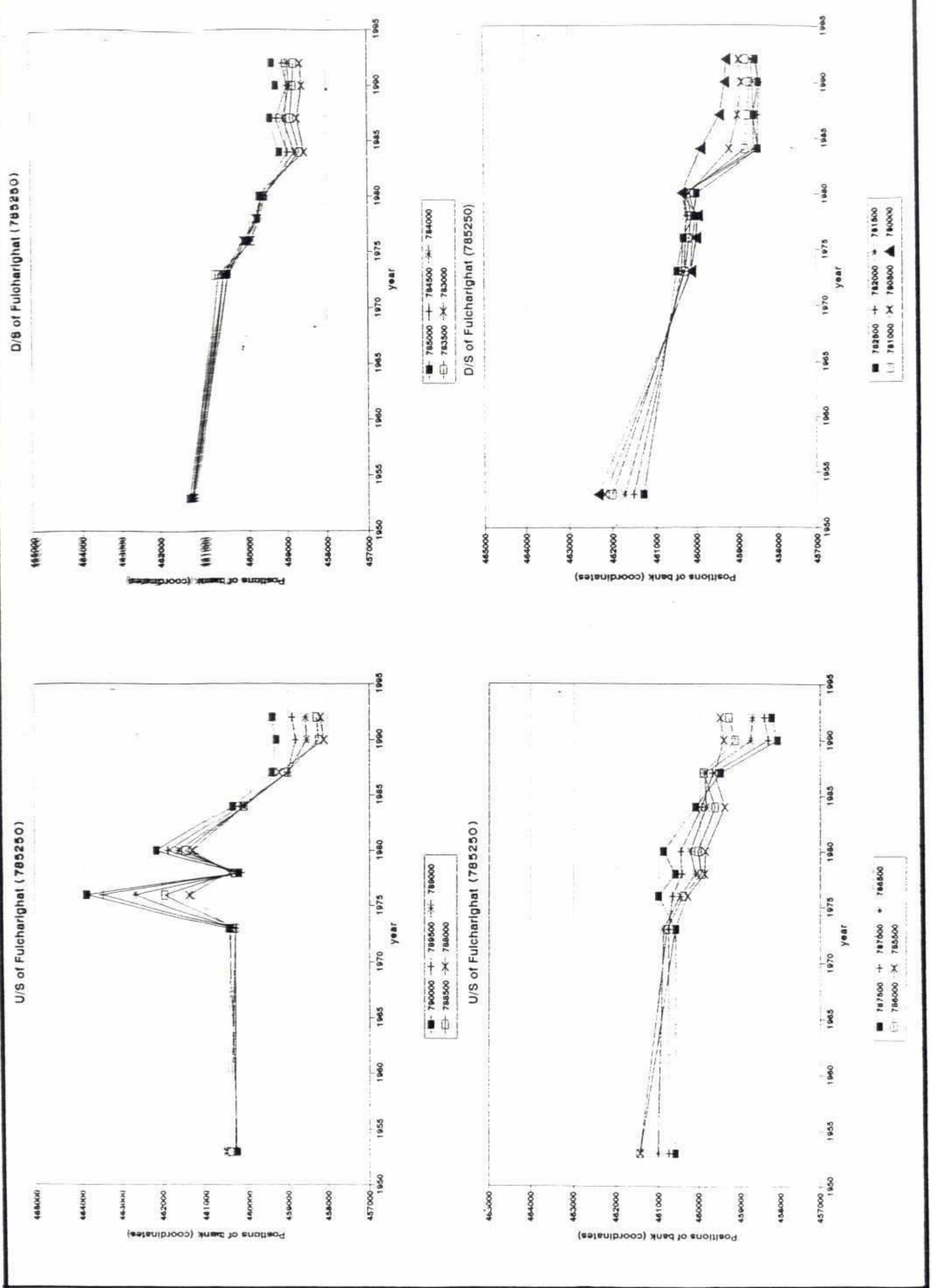


Notes: W = bend width

Rc = bend radius

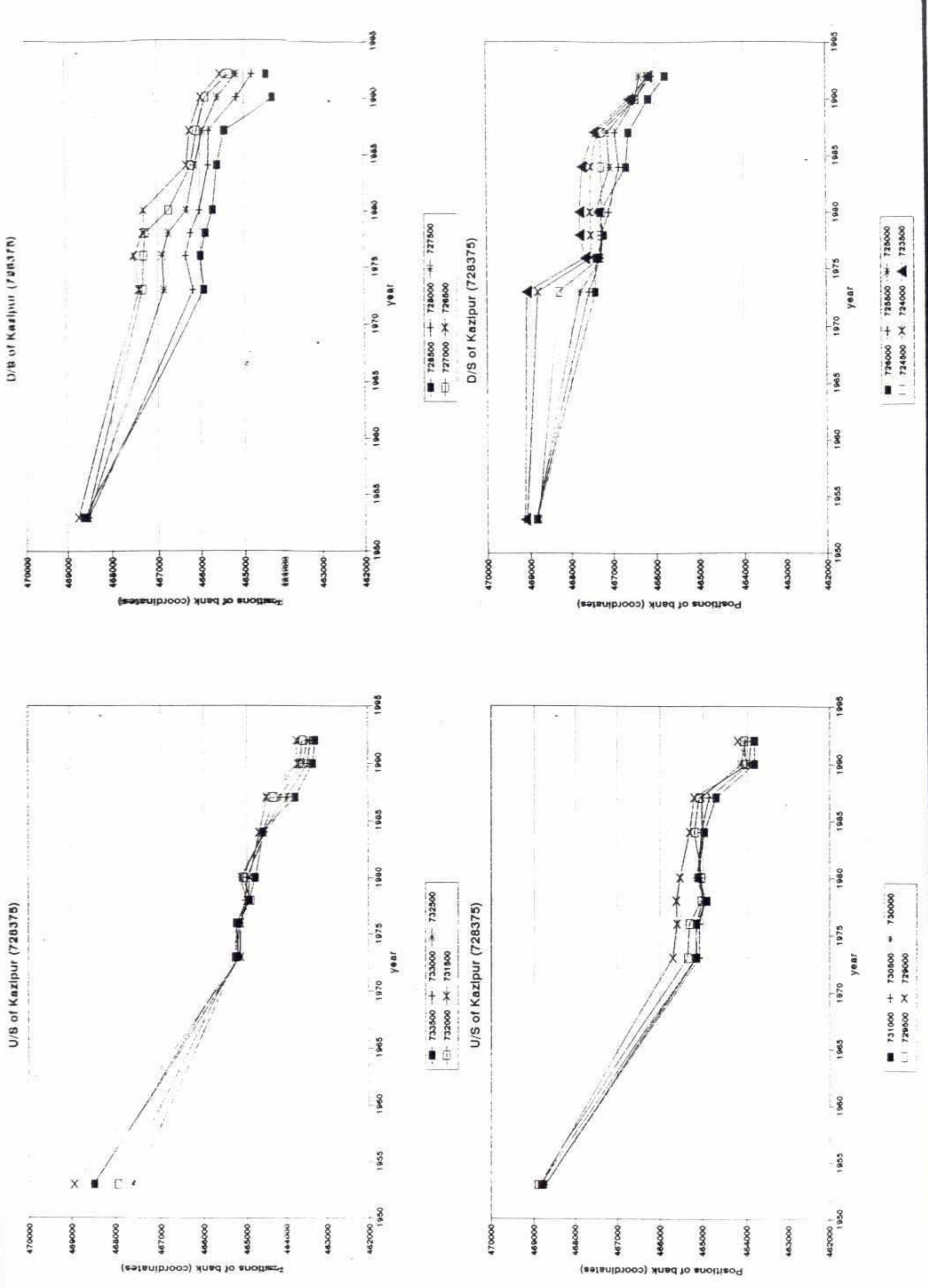
Relationship between Channel Width and Radius for Selected Aggresive Bends

Halcrow/DHI/EPC/DIG | *May 1993* | **Figure 5.25**



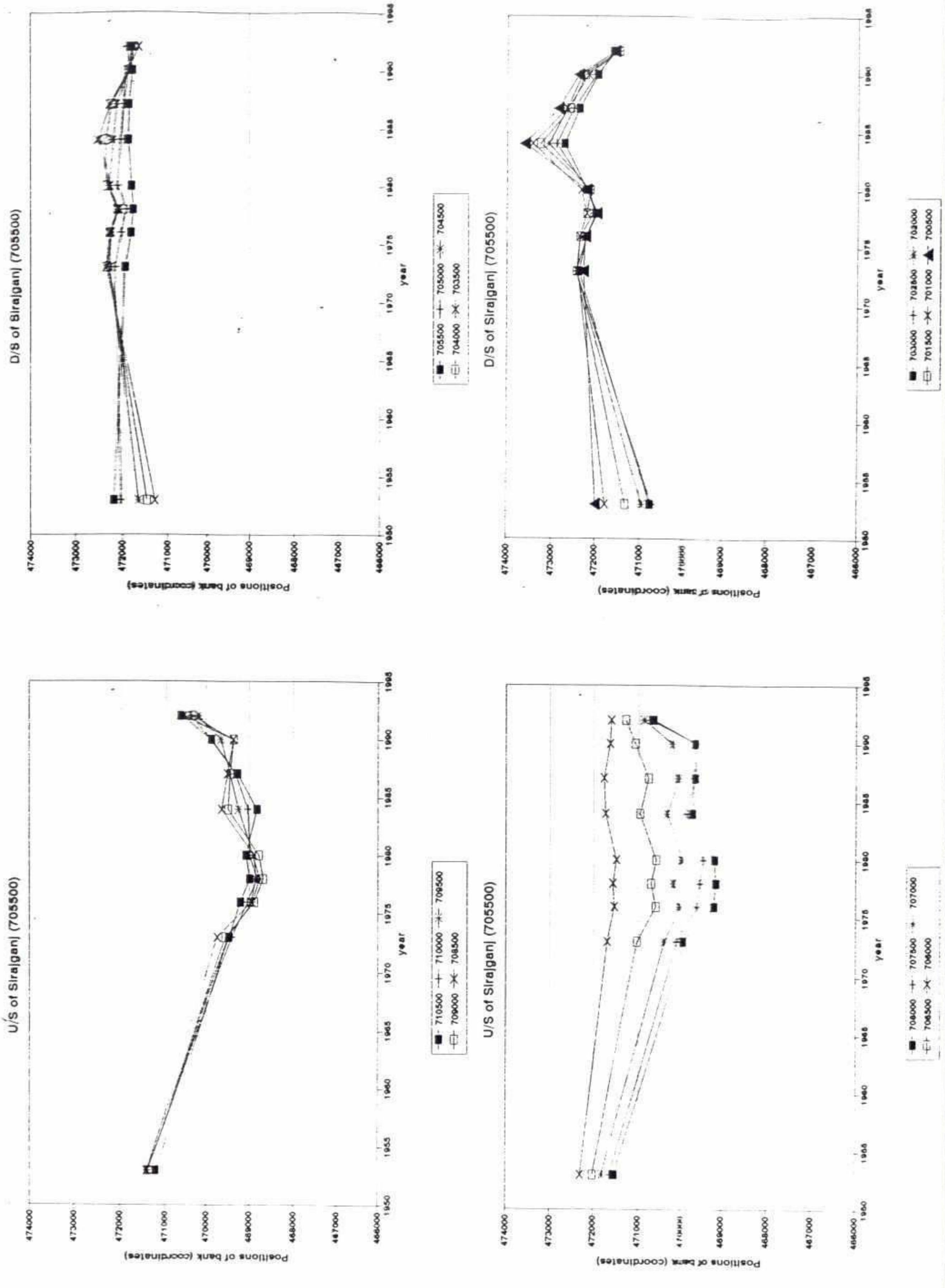
River Bank Erosion 1953-1992

Halcrow/DHI/EPC/DIG	*May 1993*	Figure 5.26 Sheet 1



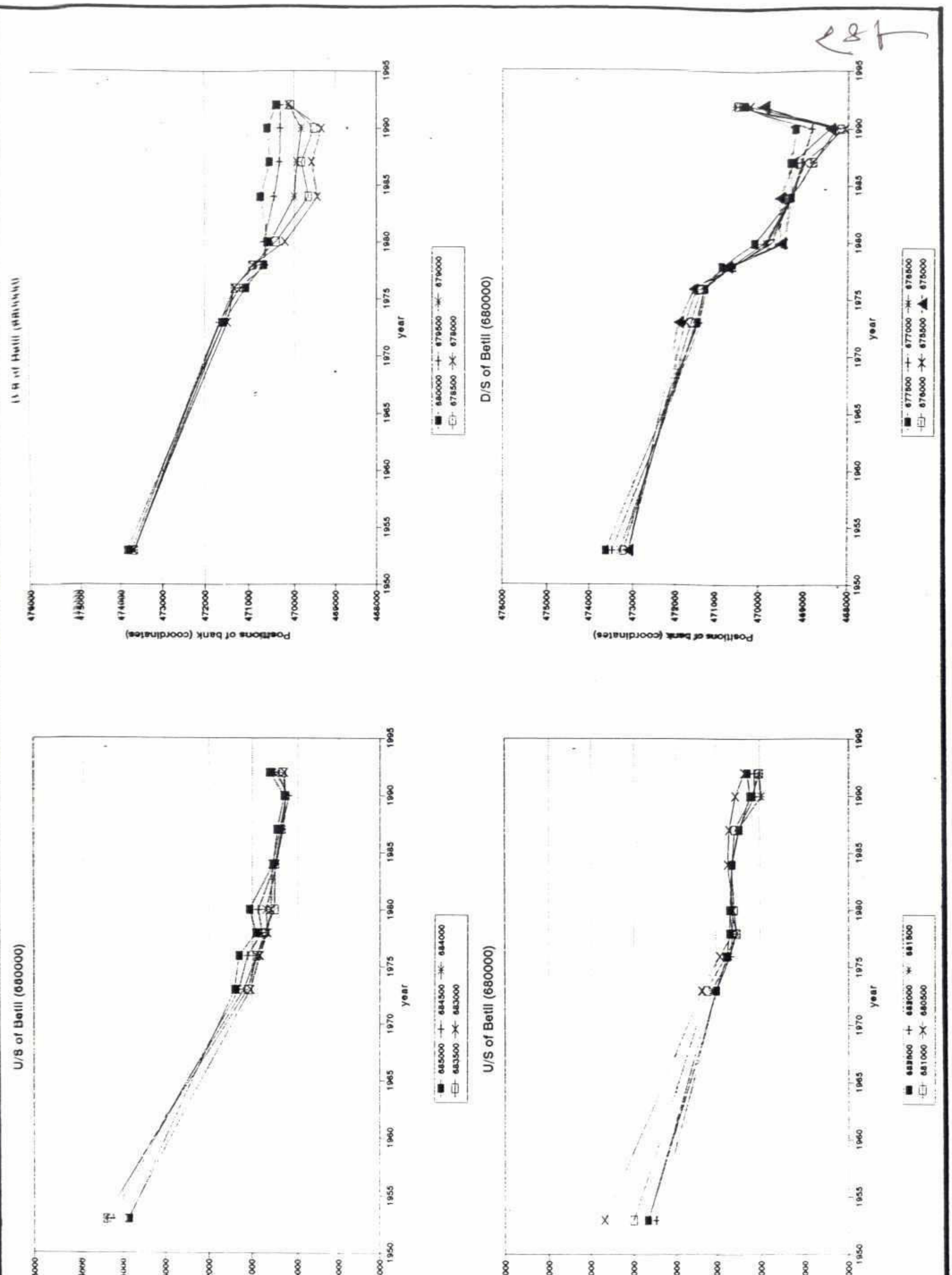
River Bank Erosion 1953-1992

Halcrow/DHI/EPC/DIG *May 1993* Figure 5.26 Sheet 2



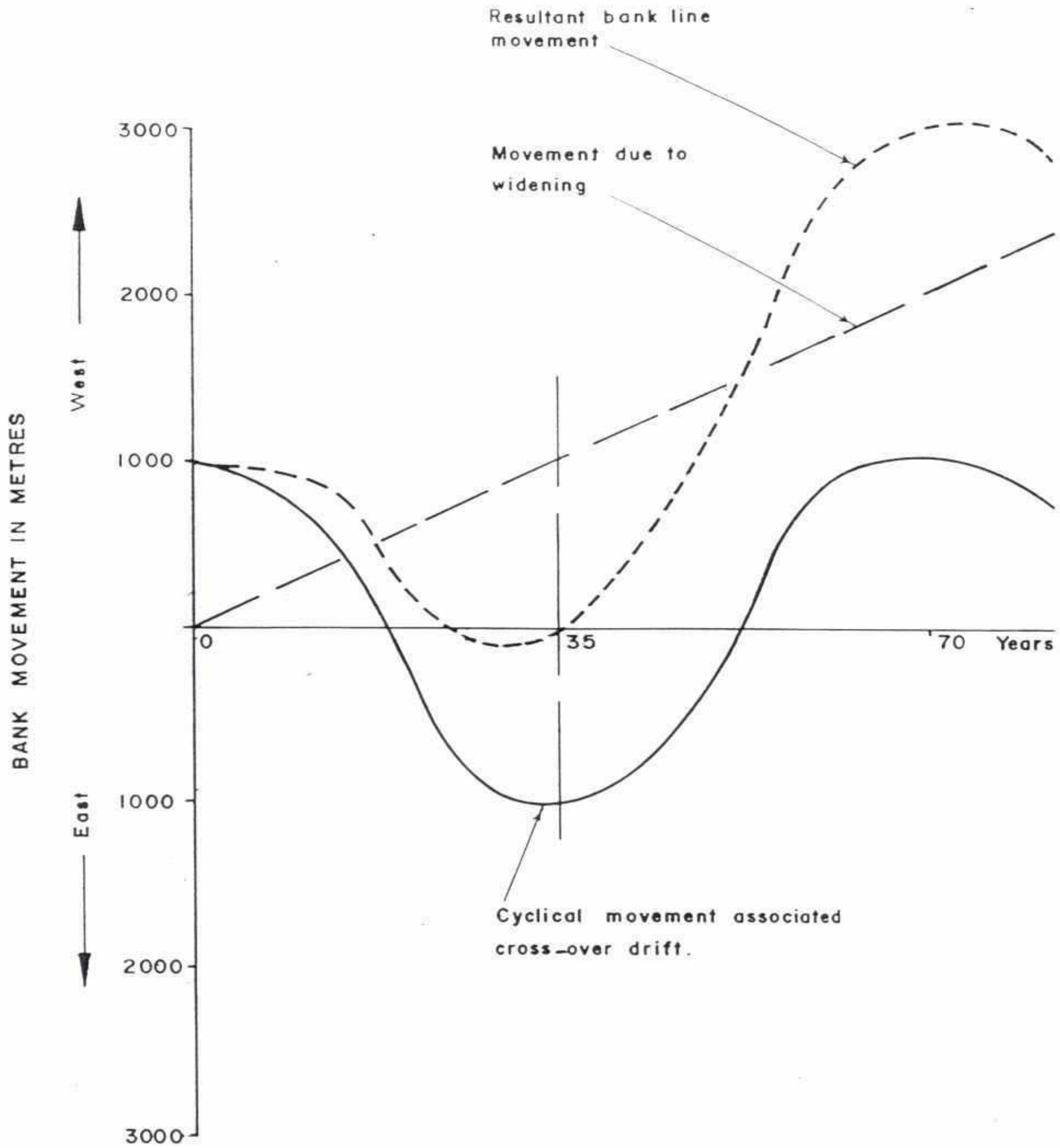
River Bank Erosion 1953-1992

Halcrow/DHI/EPC/DIG *May 1993* | Figure 5.26 | Sheet 3



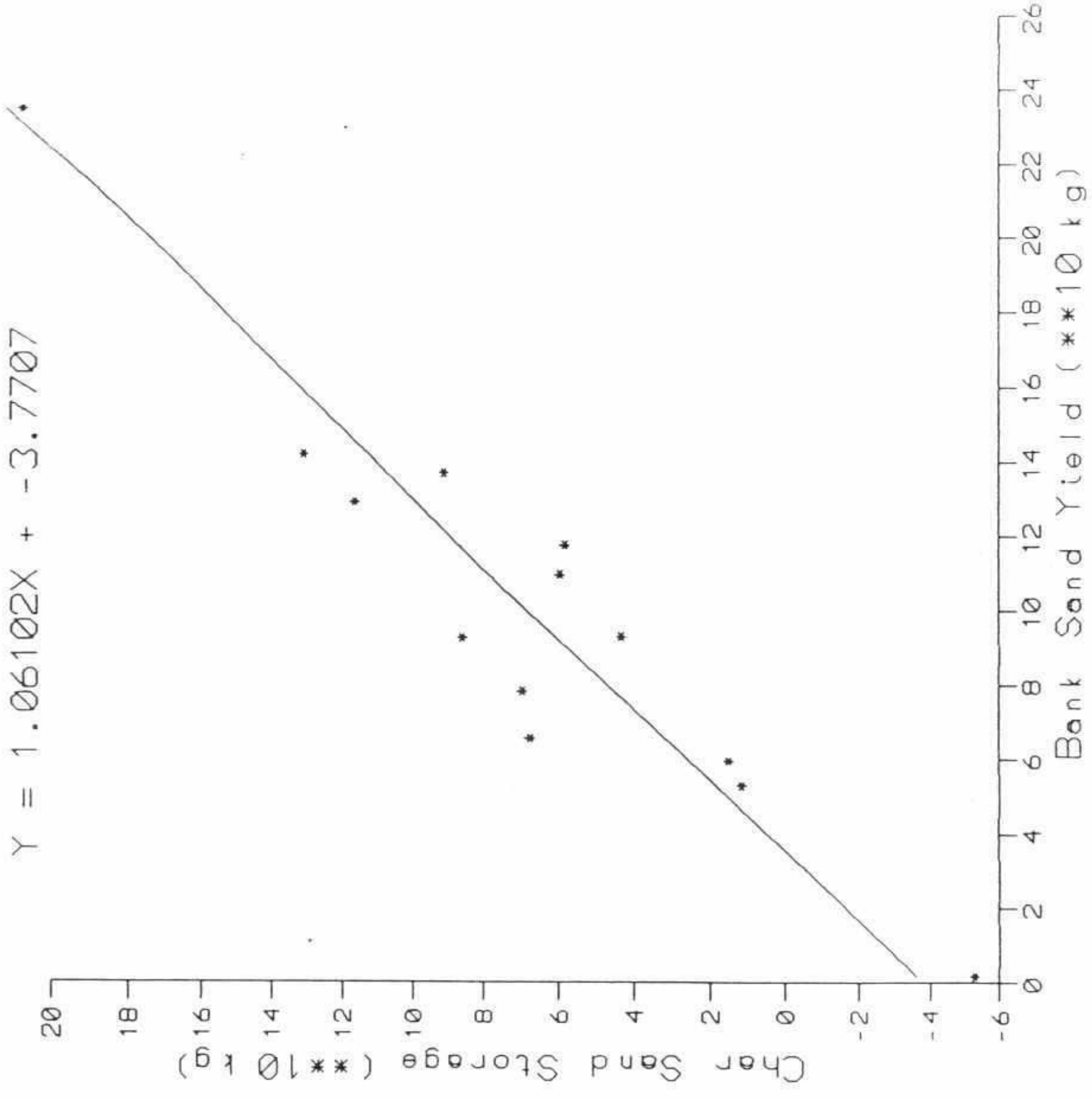
River Bank Erosion 1953-1992

Halcrow/DHI/EPC/DIG | *May 1993* | Figure 5.26 | Sheet 4



Conceptual Combination of Cyclical and Lateral Bank Movement

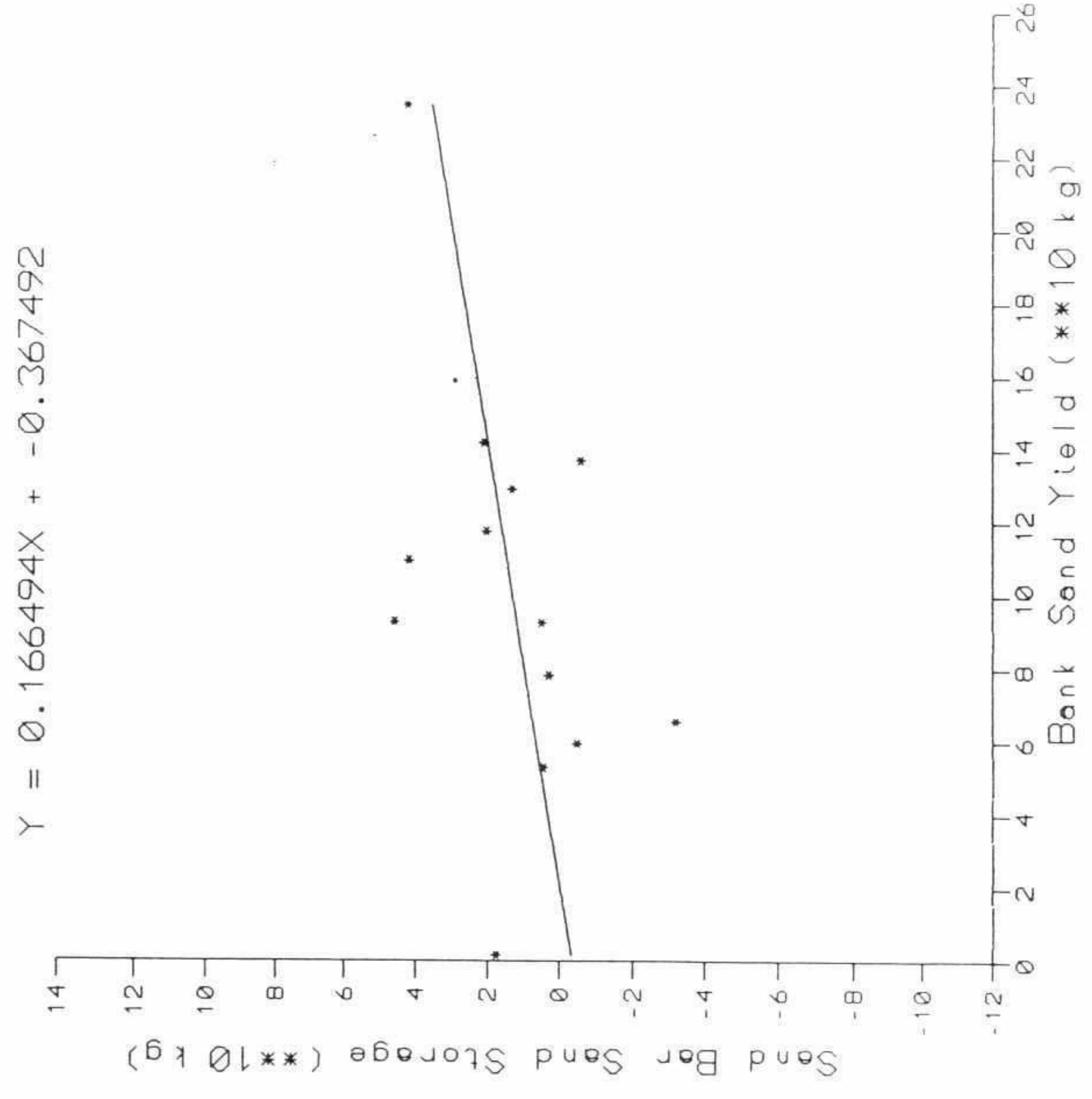
Halcrow/DHI/EPC/DIG *May 1993* **Figure 5.27**



Note : ** 10 Kg ≡ 10^{10} Kg

Relationship Between Floodplain and Char Sand Volume Change -Study Reach, 1973-92

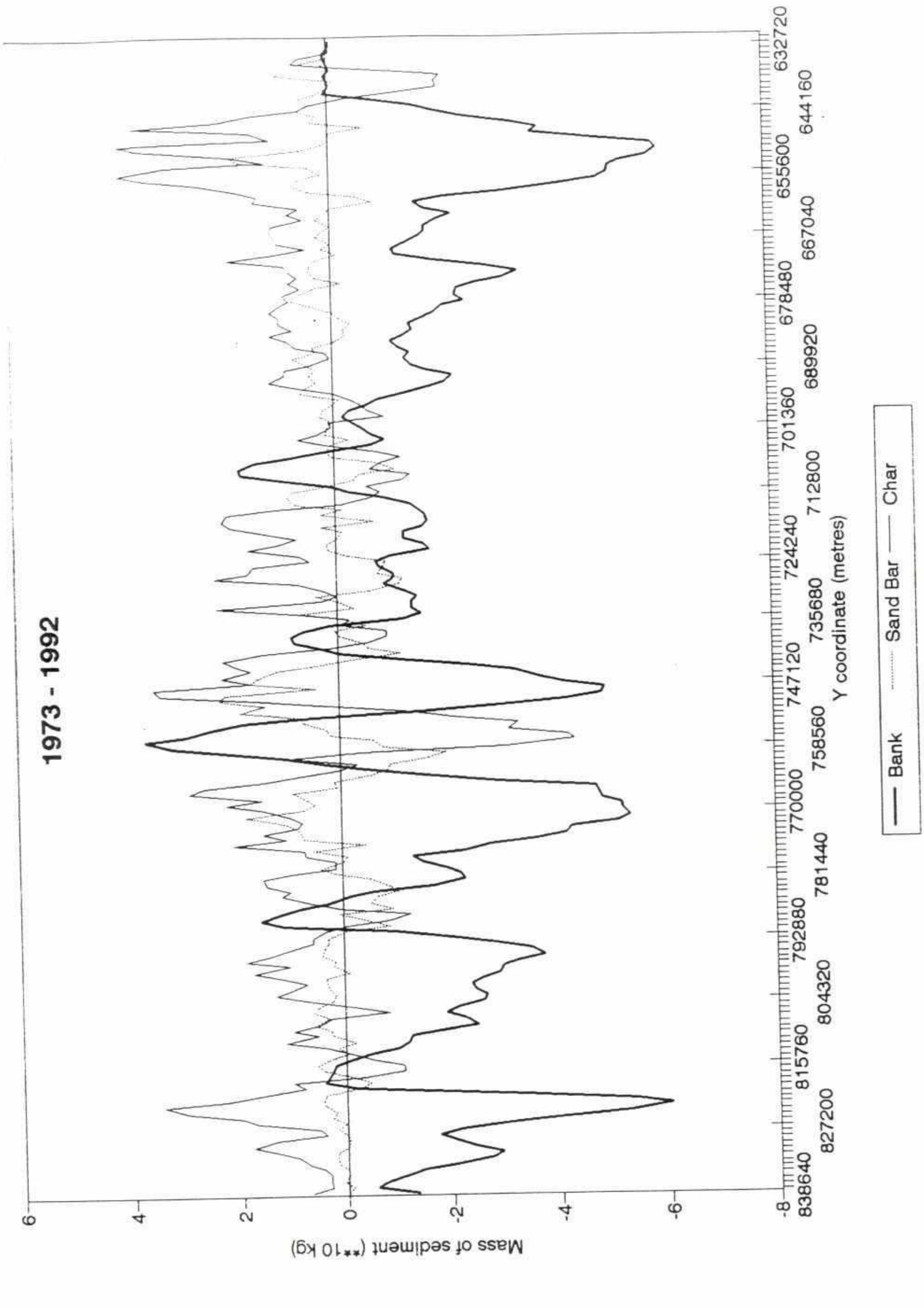
Halcrow/DHI/EPC/DIG	*May 1993*	**Figure 5.28**



Note : ** 10 Kg ≡ 10^{10} Kg

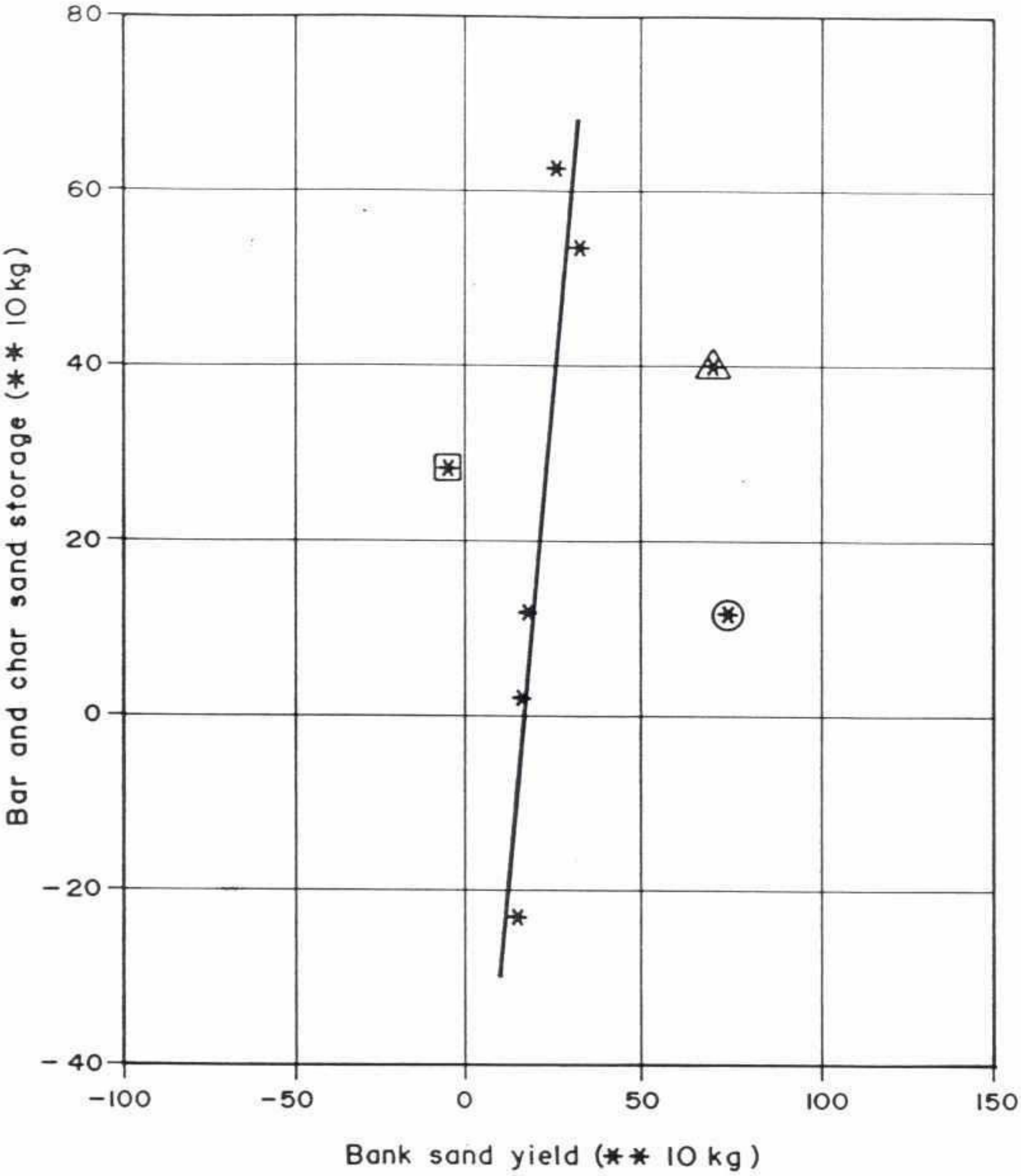
Relationship Between Floodplain and Sand Bar Sand Volume Change - Study Reach, 1973-1992

Halcrow/DHI/EPC/DIG	*May 1993*	**Figure 5.29**



Variation of Bank Erosion, Bar and Sandbar Change, Over Length of River

Halcrow/DHI/EPC/DIG	*May 1993*	Figure 5.30

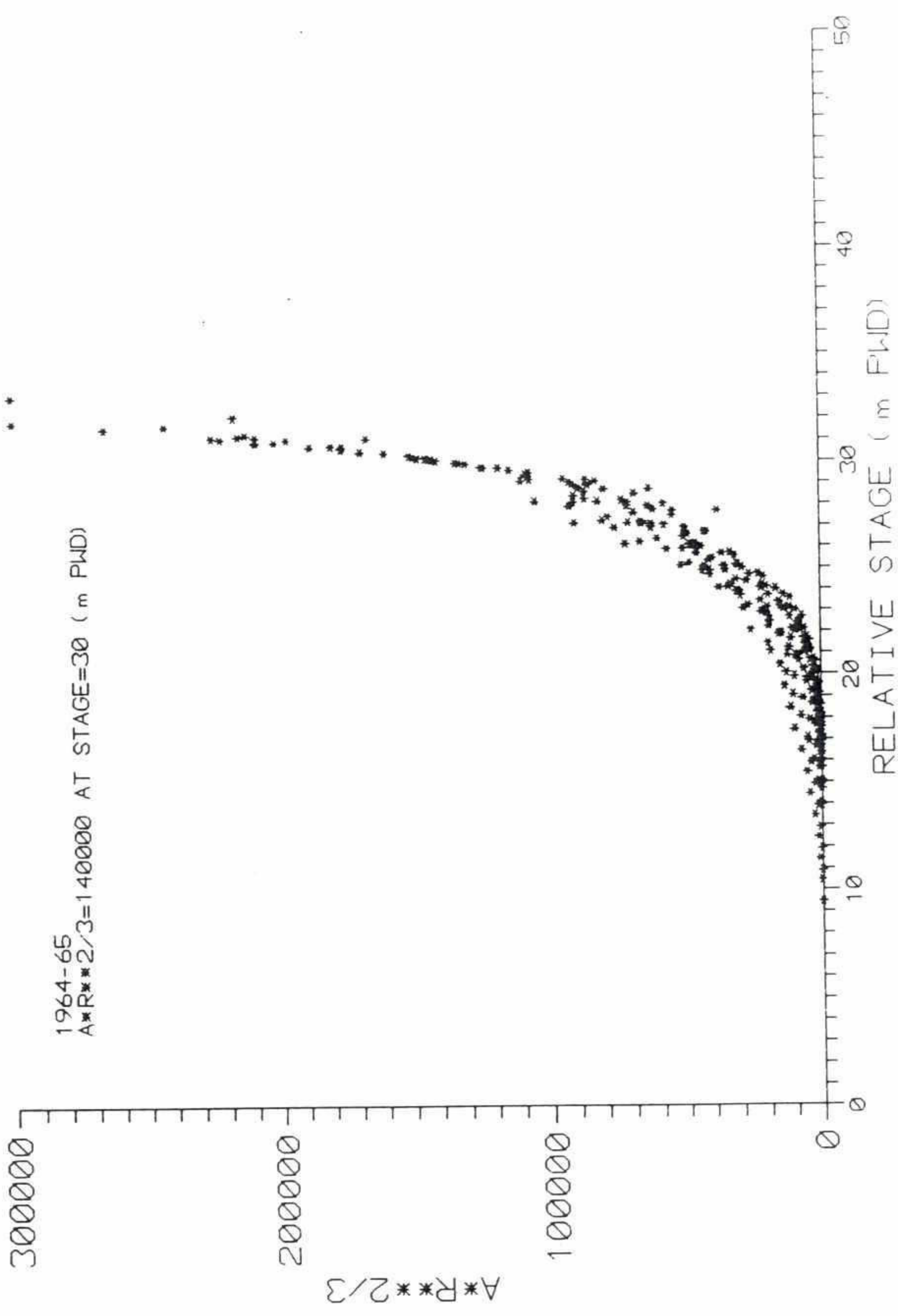


Notes:

- * Normal flow periods
- ⊛ 1987 − 1990
- ⊞ 1990 − 1992
- △ 1987 − 1992
- ** 10kg = 10^{10} kg

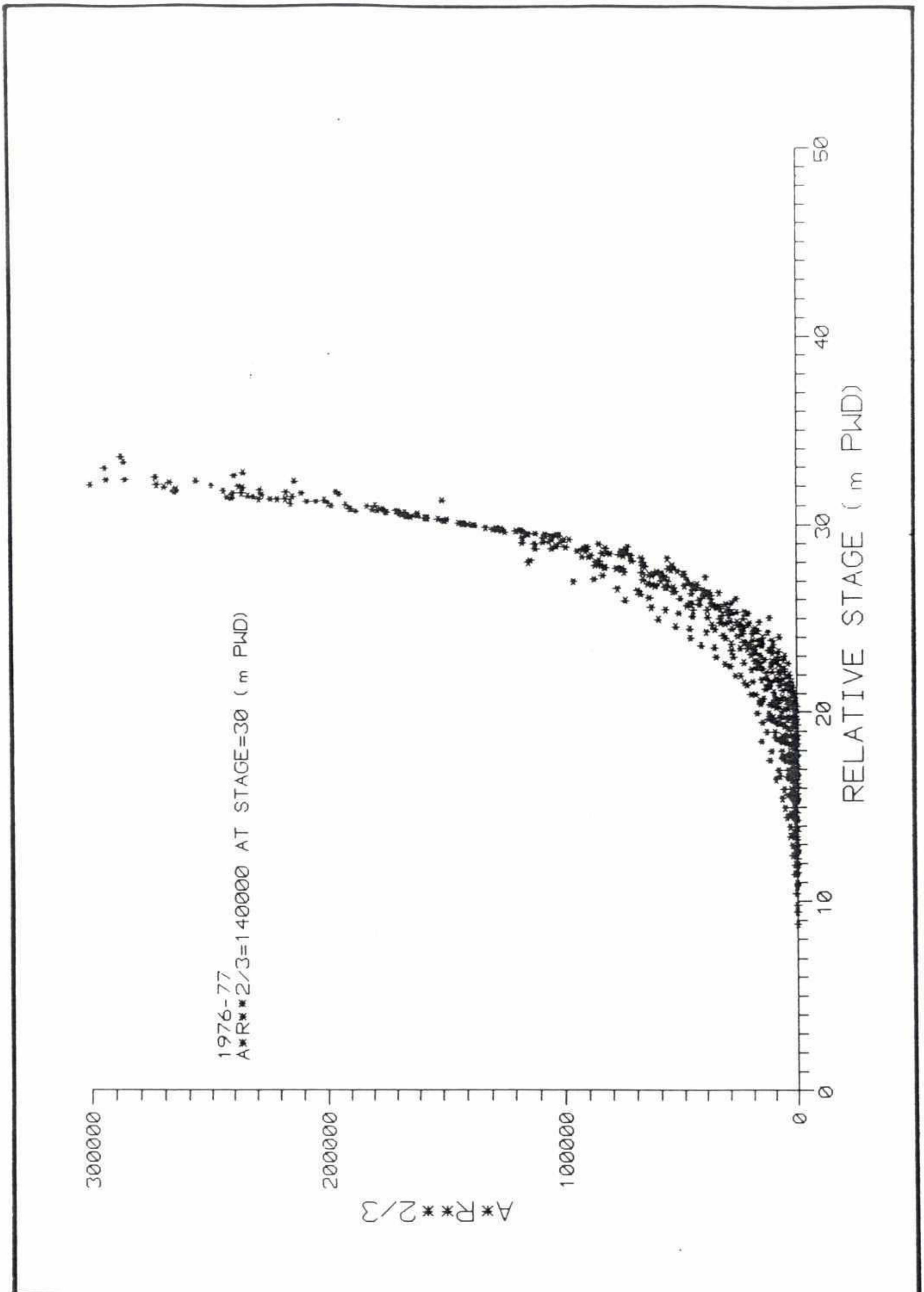
Relationship Between Bank Sand Yield and Char and Sand Bar Storage

Halcrow/DHI/EPC/DIG *May 1993* **Figure 5.31**



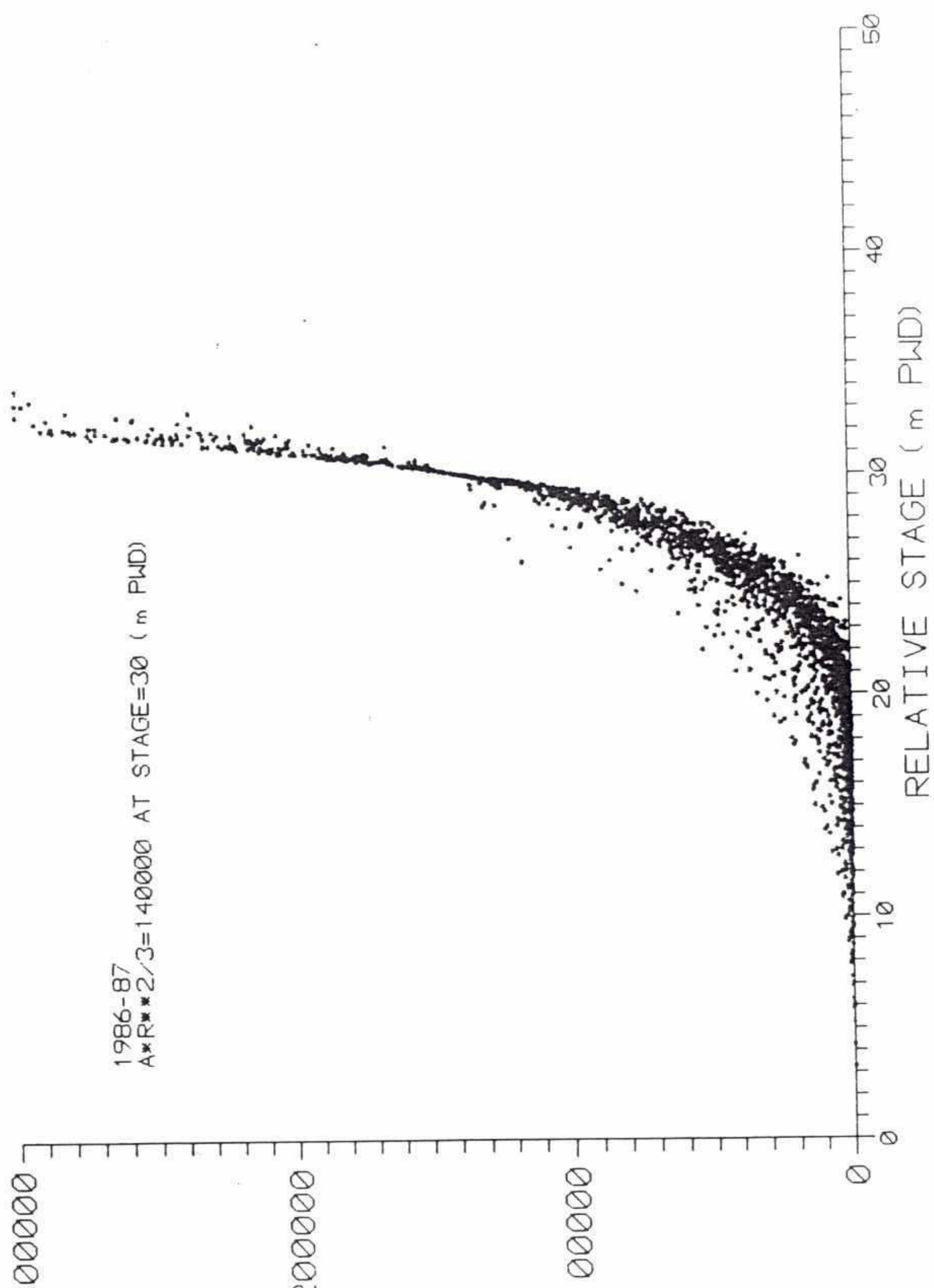
Conveyance Factor V Relative Stage 1964/65

Halcrow/DHI/EPC/DIG	*May 1993*	Figure 5.32



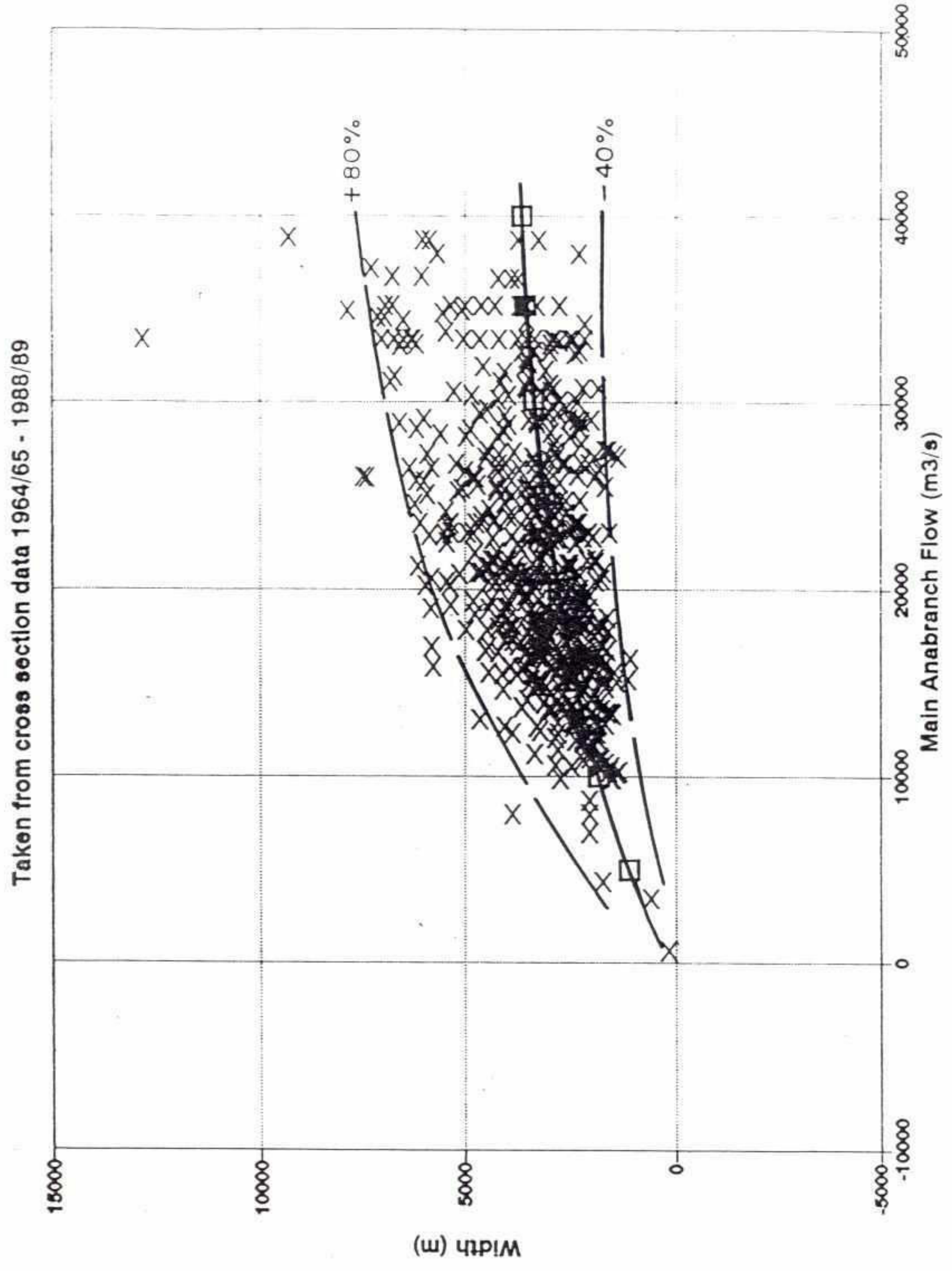
Conveyance Factor V Relative Stage 1976/1977

Halcrow/DHI/EPC/DIG *May 1993* **Figure 5.33**



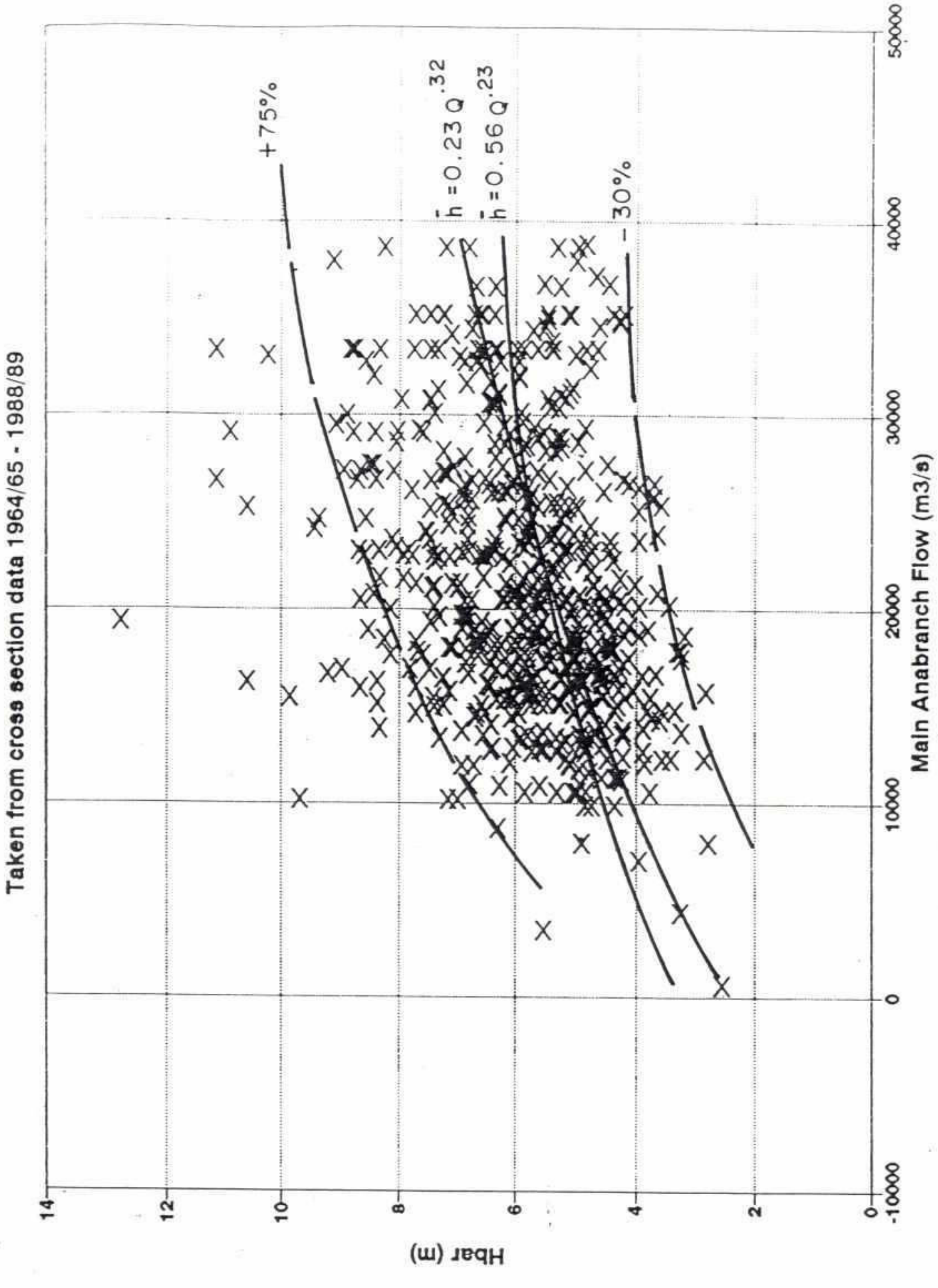
Conveyance Factor V Relative Stage 1986/1987

Halcrow/DHI/EPC/DIG	*May 1993*	Figure 5.34



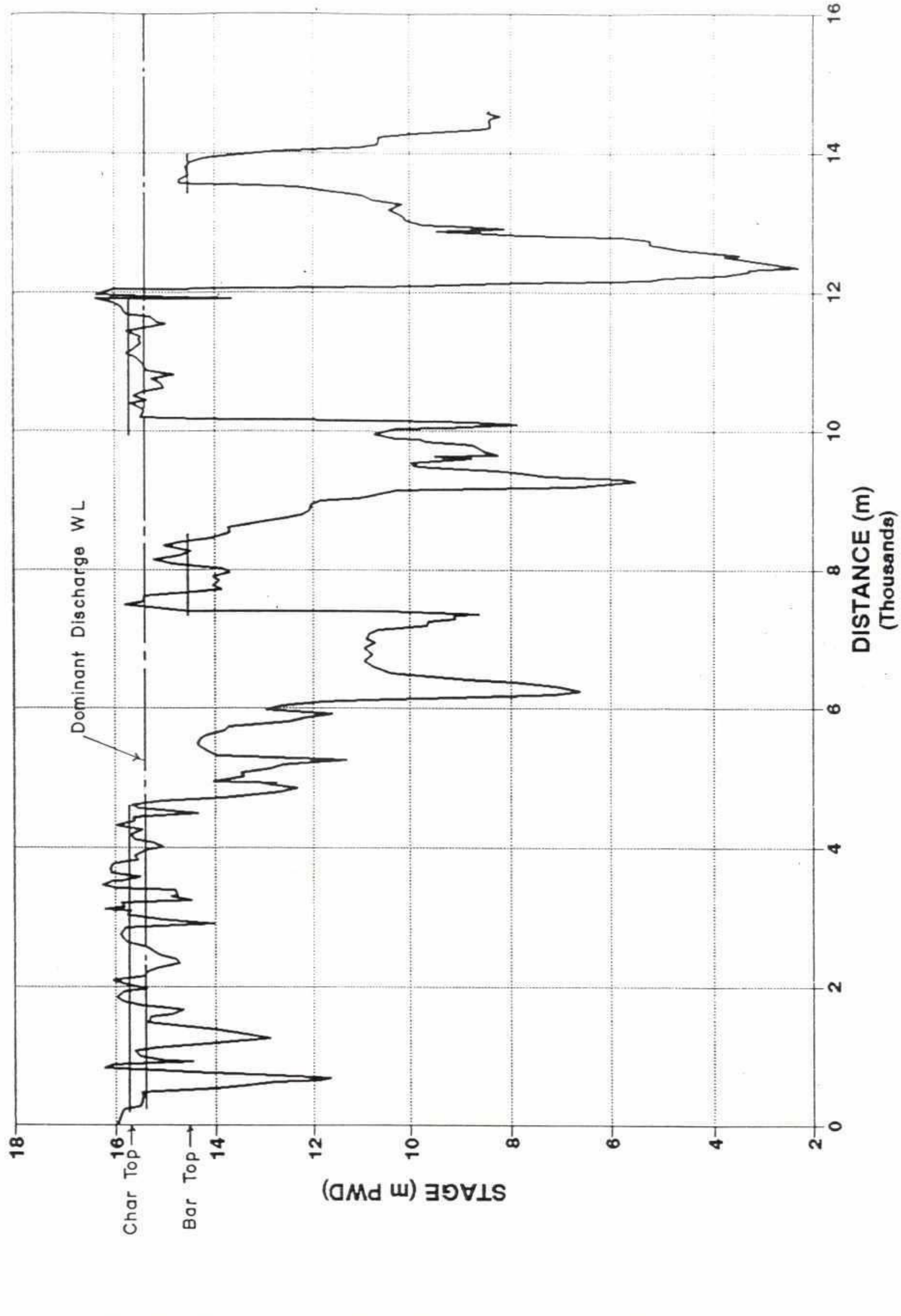
Relationship Between Anabranch Width and Discharge

Halcrow/DHI/EPC/DIG *May 1993* Figure 5.35



Relationship Between Mean Depth and Discharge

Halcrow/DHI/EPC/DIG	*May 1993*	Figure 5.36



Typical River Cross-section showing Upper and Lower Char top Levels

Halcrow/DHI/EPC/DIG *May 1993* **Figure 5.37**

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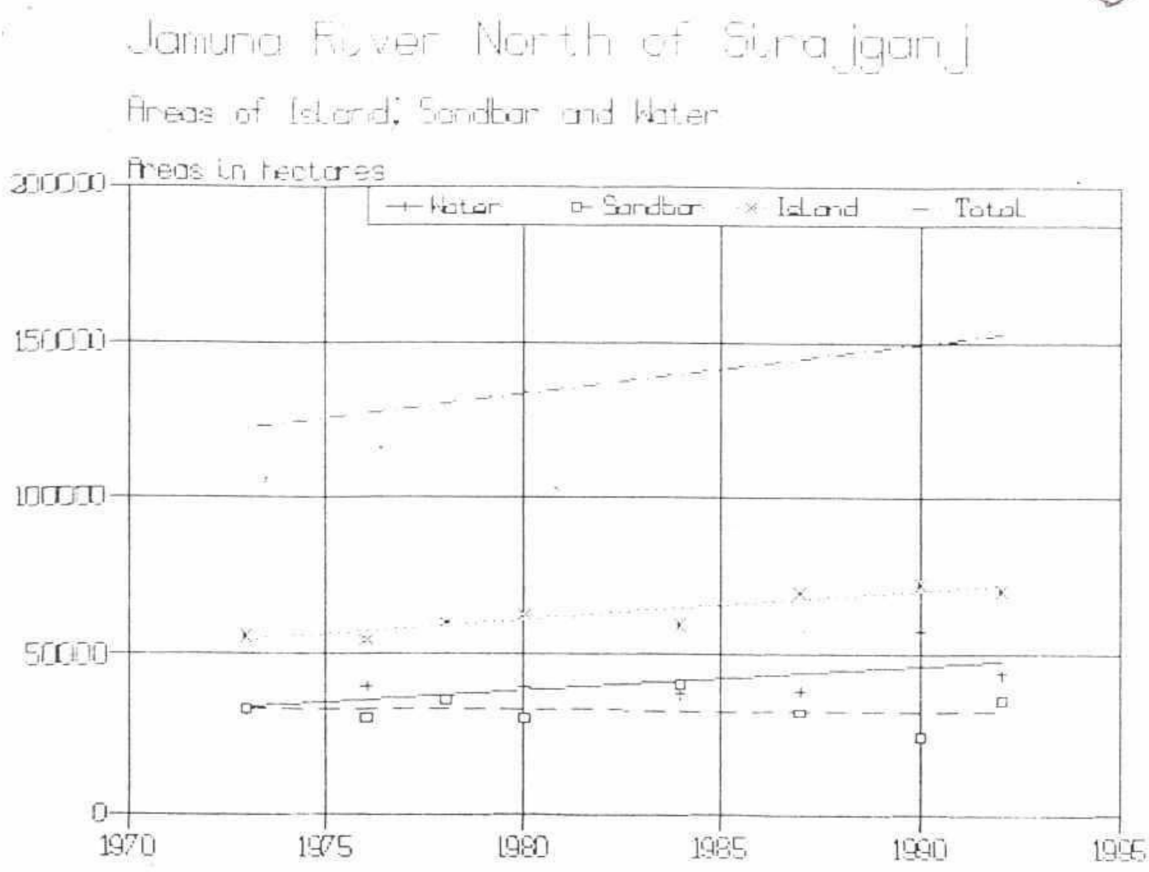
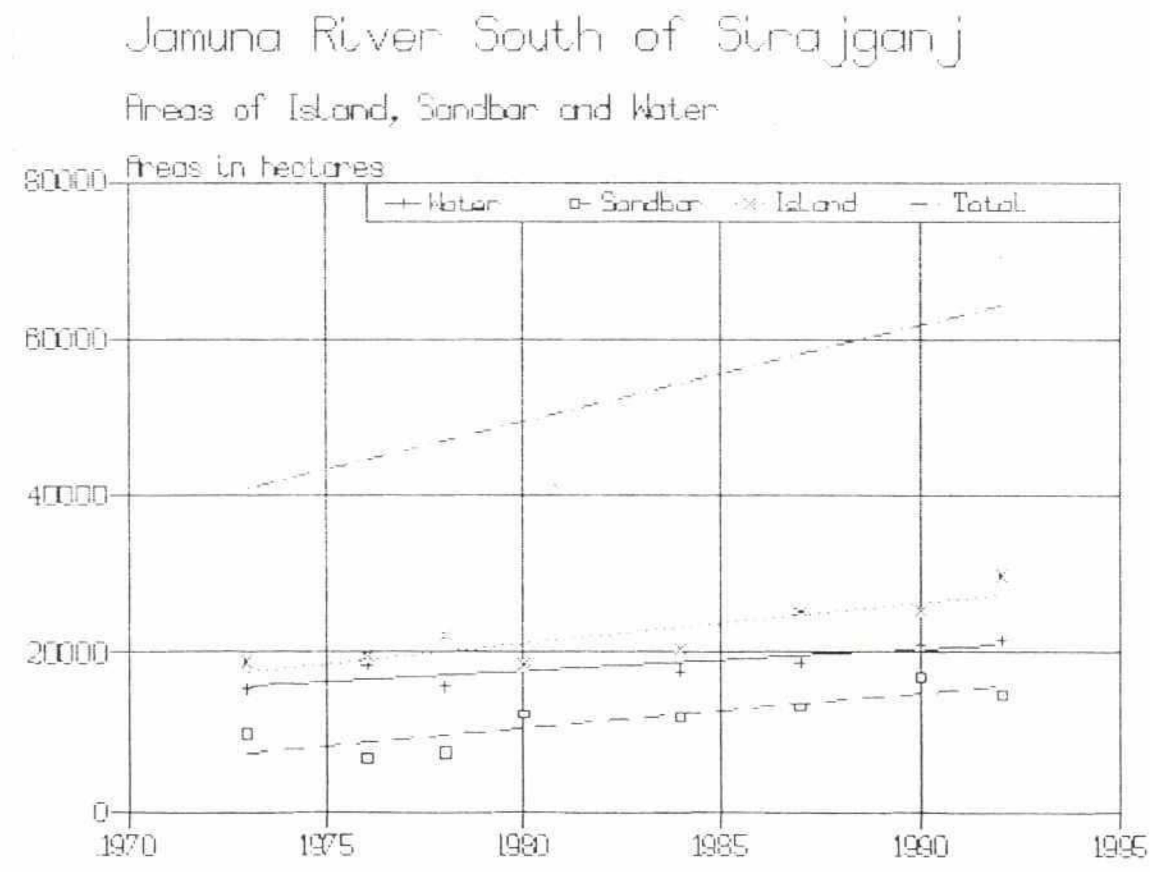
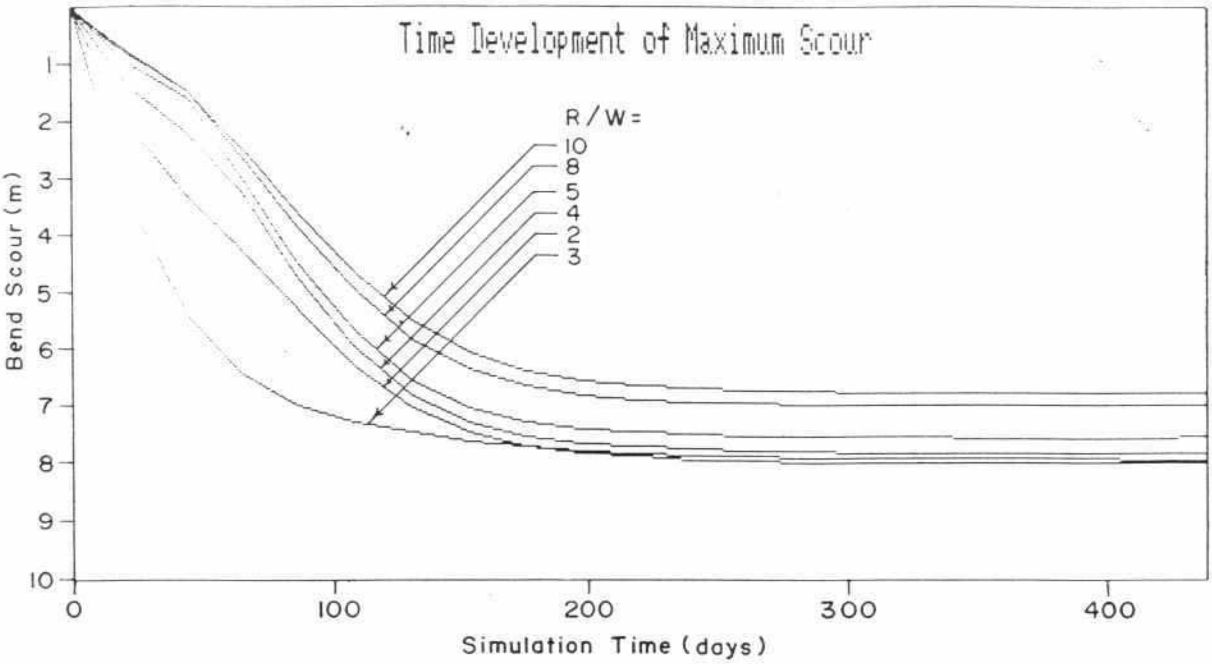
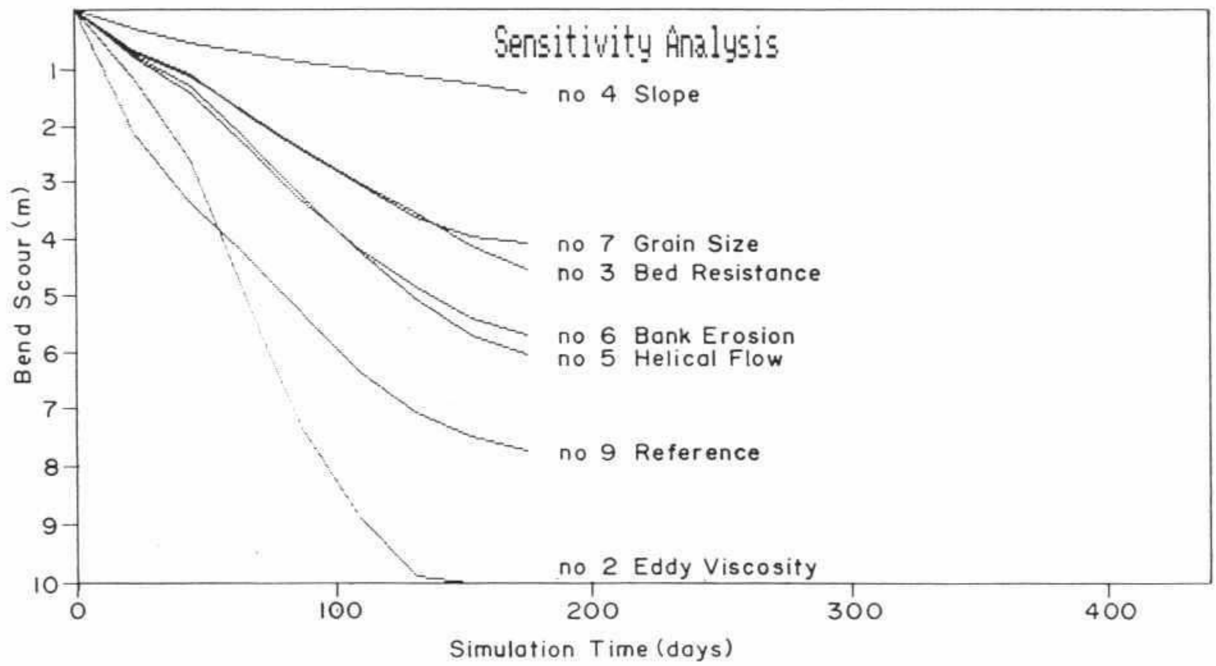




Increase of Bank to Bank Area With Time

Halcrow/DHI/EPC/DIG *May 1993* **Figure 5.38**





Sensitivity of Simulated Bend Scour and Development Time to Parameter Values

Halcrow/DHI/EPC/DIG *May 1993* Figure 5.39

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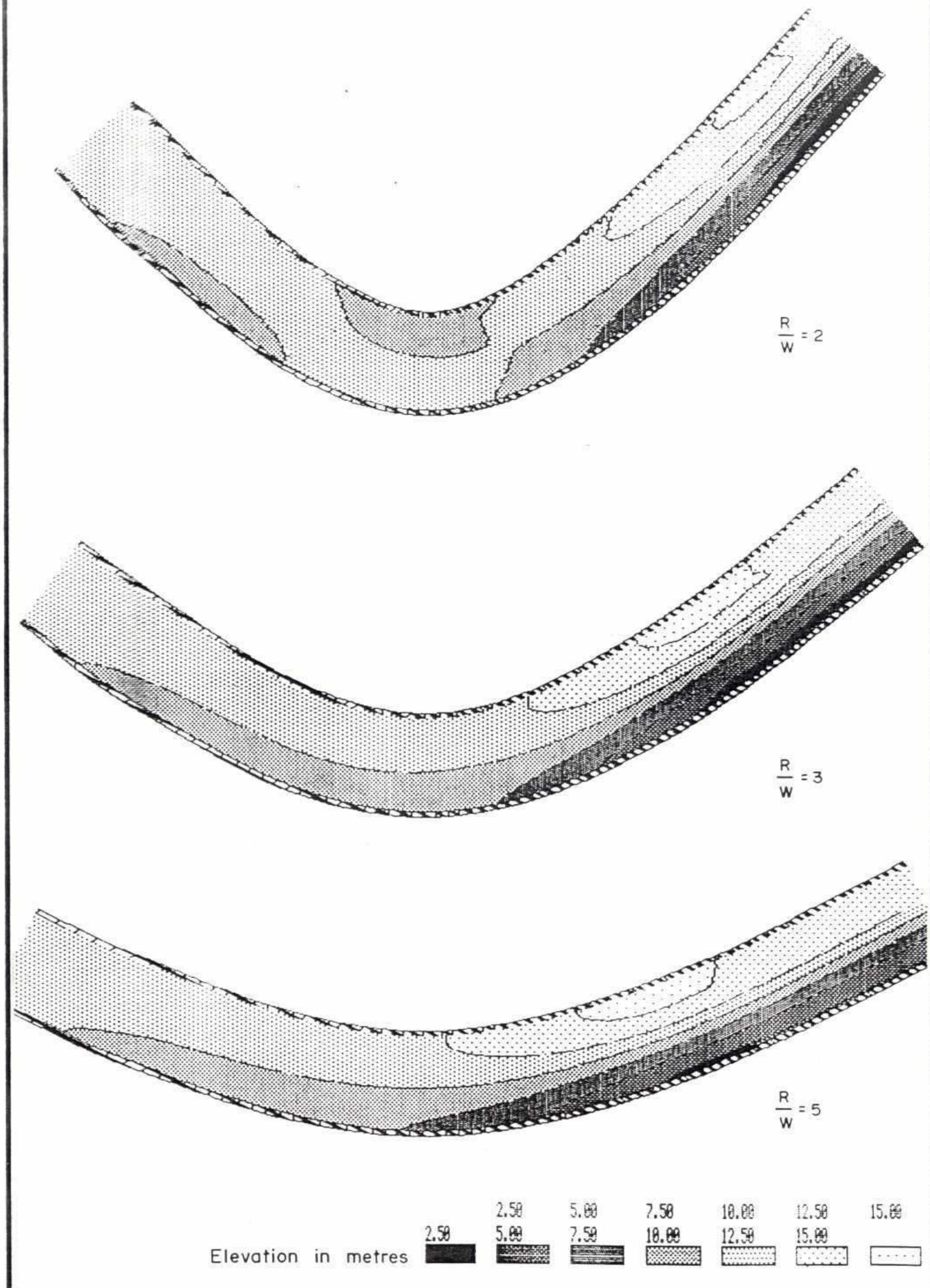
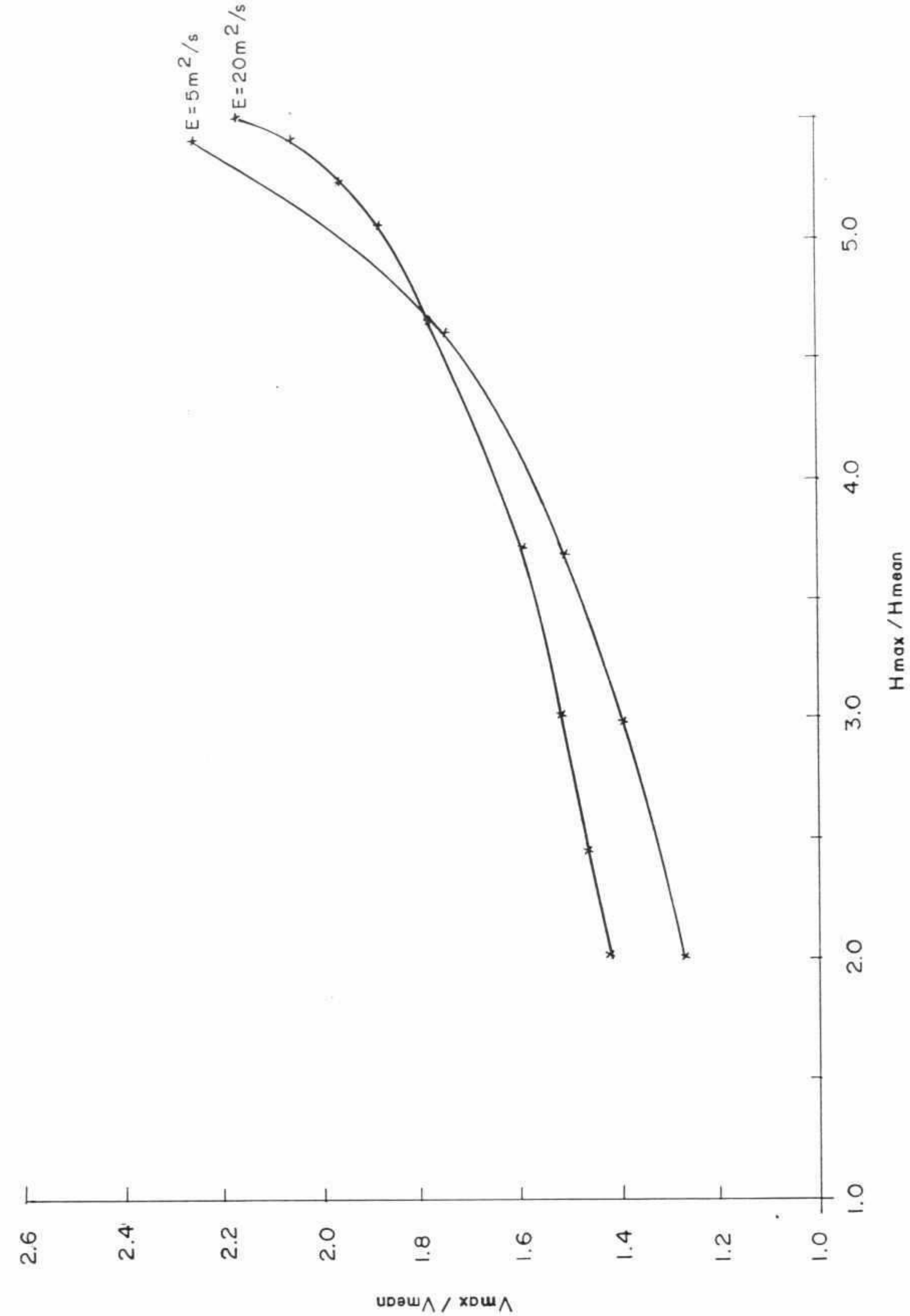


Simulated Bend Bathymetry for Varying Radius/Width Ratio

Halcrow/DHI/EPC/DIG

May 1993

Figure 5.40

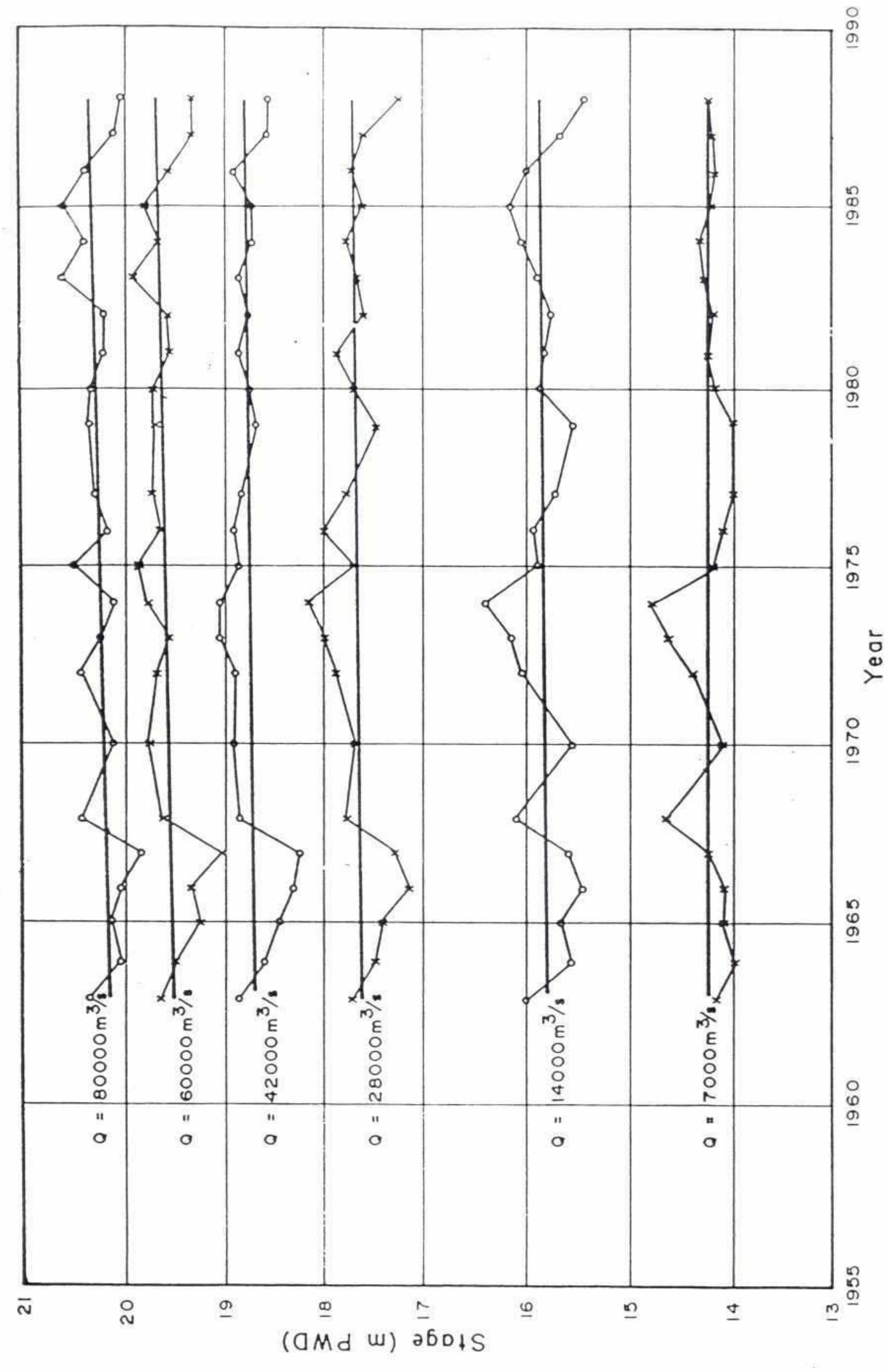


Notes: $\frac{R}{W} = 3$

E = Eddy viscosity

Relationship Between V_{max}/V_{mean} and H_{max}/H_{mean}

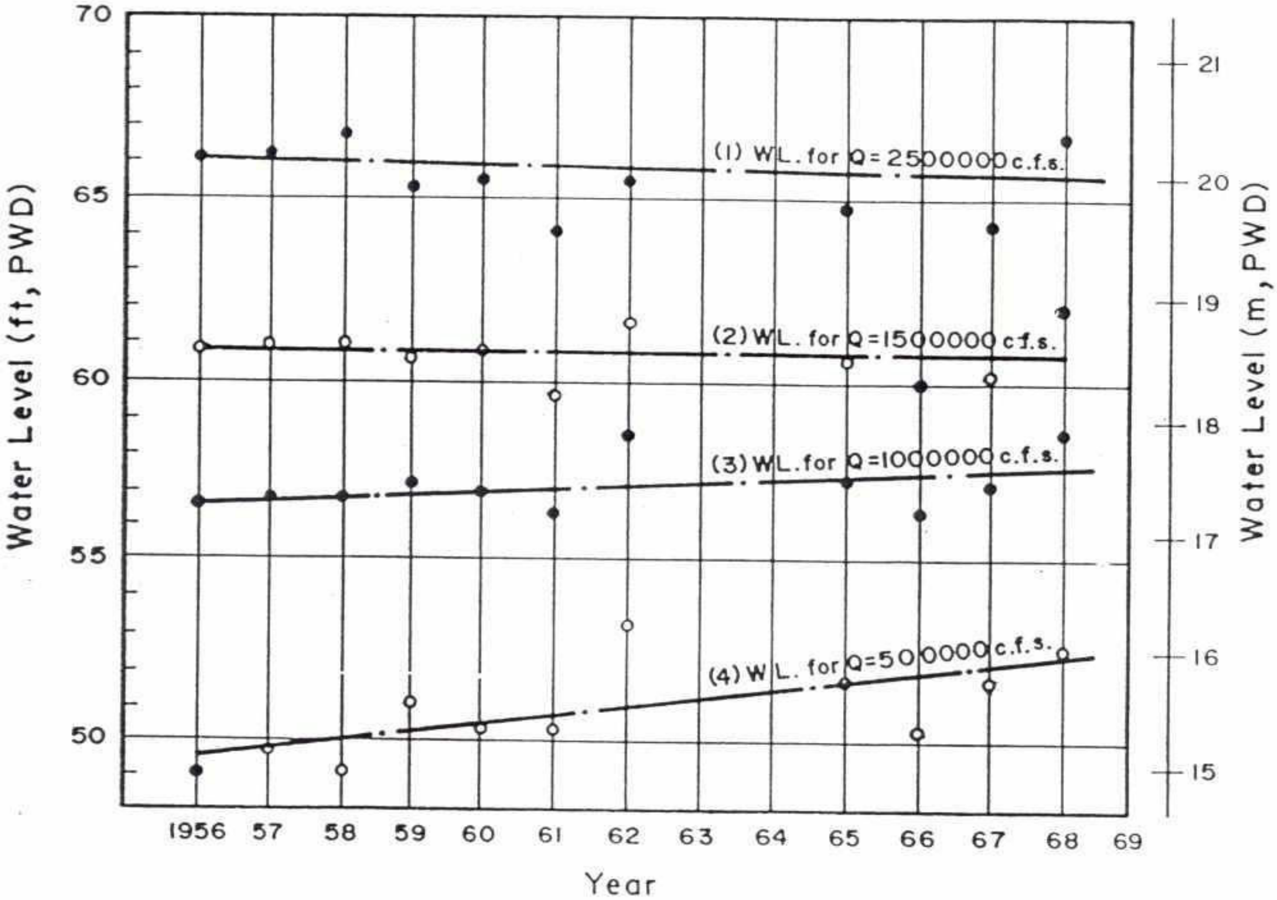
Halcrow/DHI/EPC/DIG | *May 1993* | **Figure 5.41**



Water Level Variation for six Discharges at Bahadurabad for 1963-89

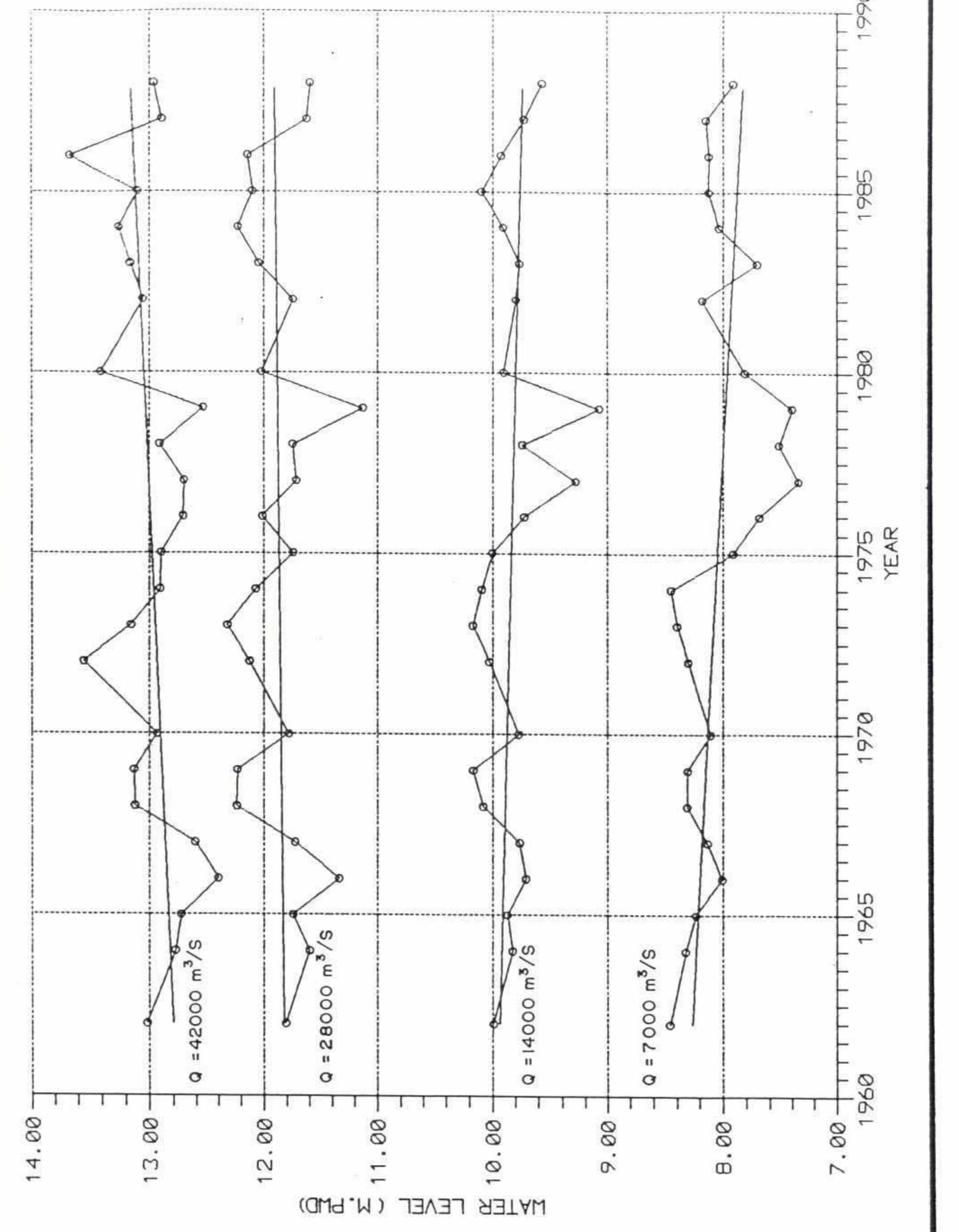
Halcrow/DHI/EPC/DIG	*May 1993*	Figure 5.42

(1) 70,236 m³/s; (2) 42,142 m³/s; (3) 28,094 m³/s; (4) 44,047 m³/s



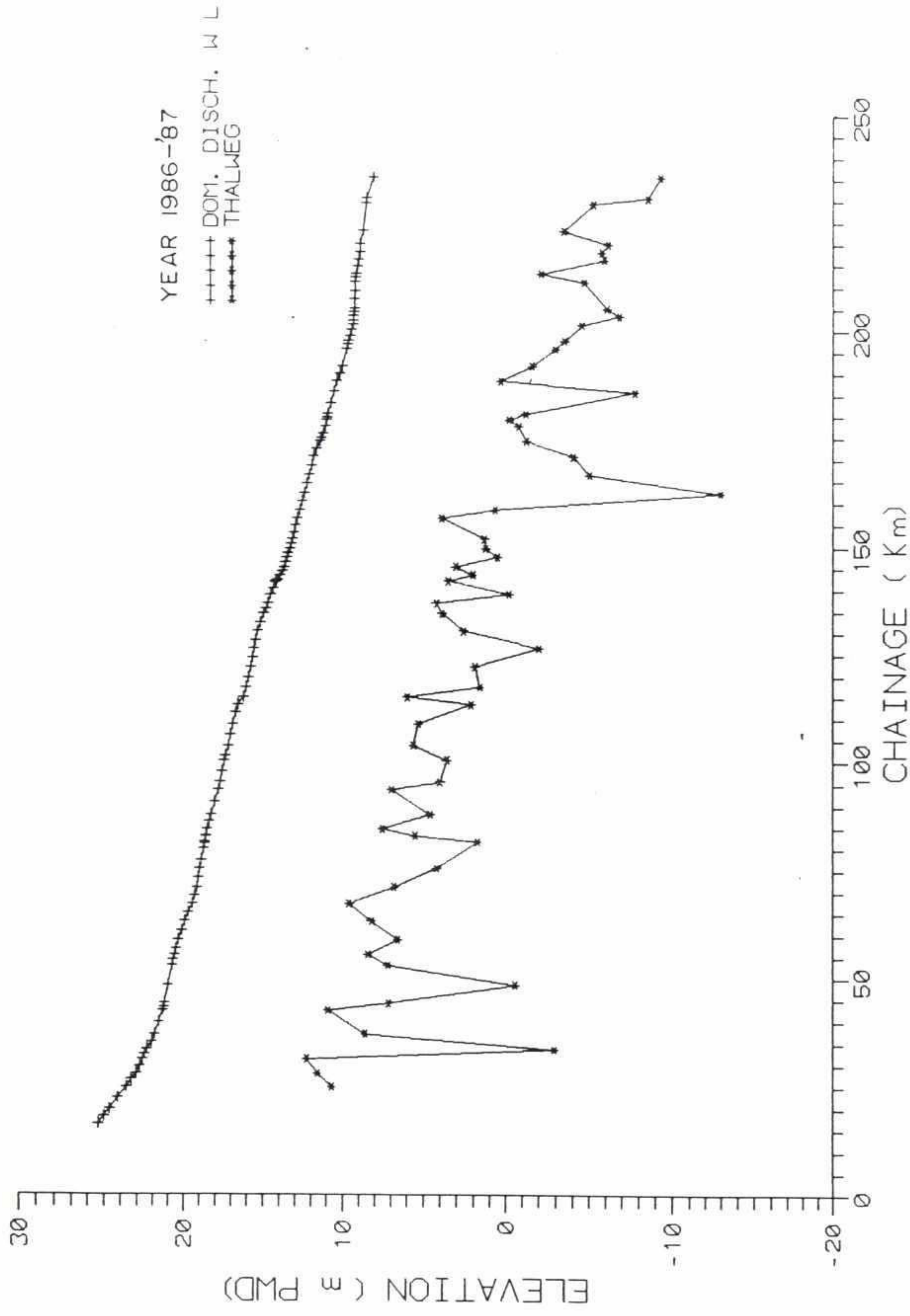
Water Level Variation for four Discharges at Bahadurabad for 1956-68 (After Lates, 1988)

Halcrow/DHI/EPC/DIG *May 1993* Figure 5.43



Water Level Variation for Four Relevant Discharges at Sirajganj for 1962-88

Halcrow/DHI/EPC/DIG | *May 1993* | **Figure 5.44**



Longitudinal Profile of the Brahmaputra River 1986-87

Halcrow/DHI/EPC/DIG	*May 1993*	Figure 5.45

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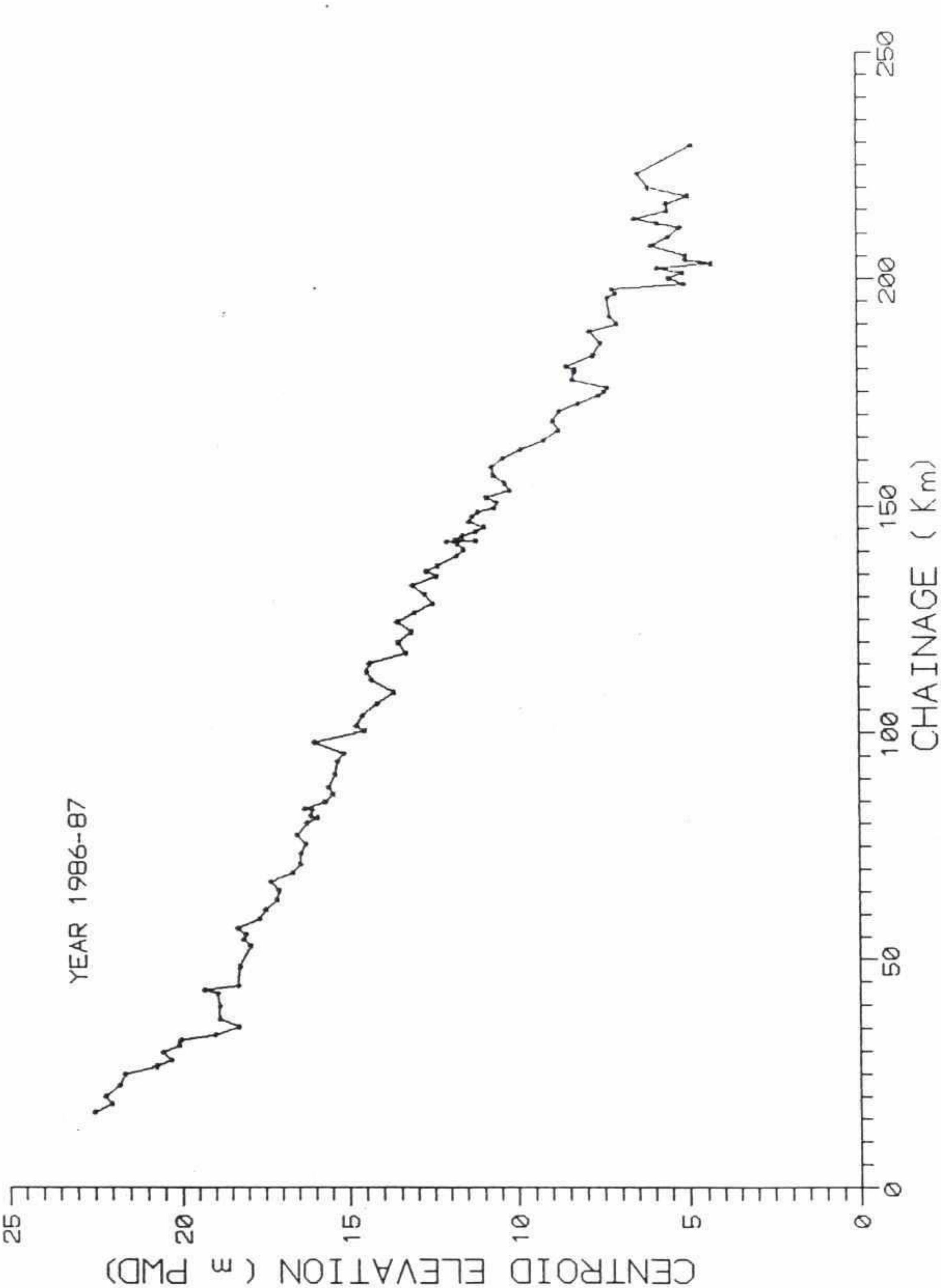
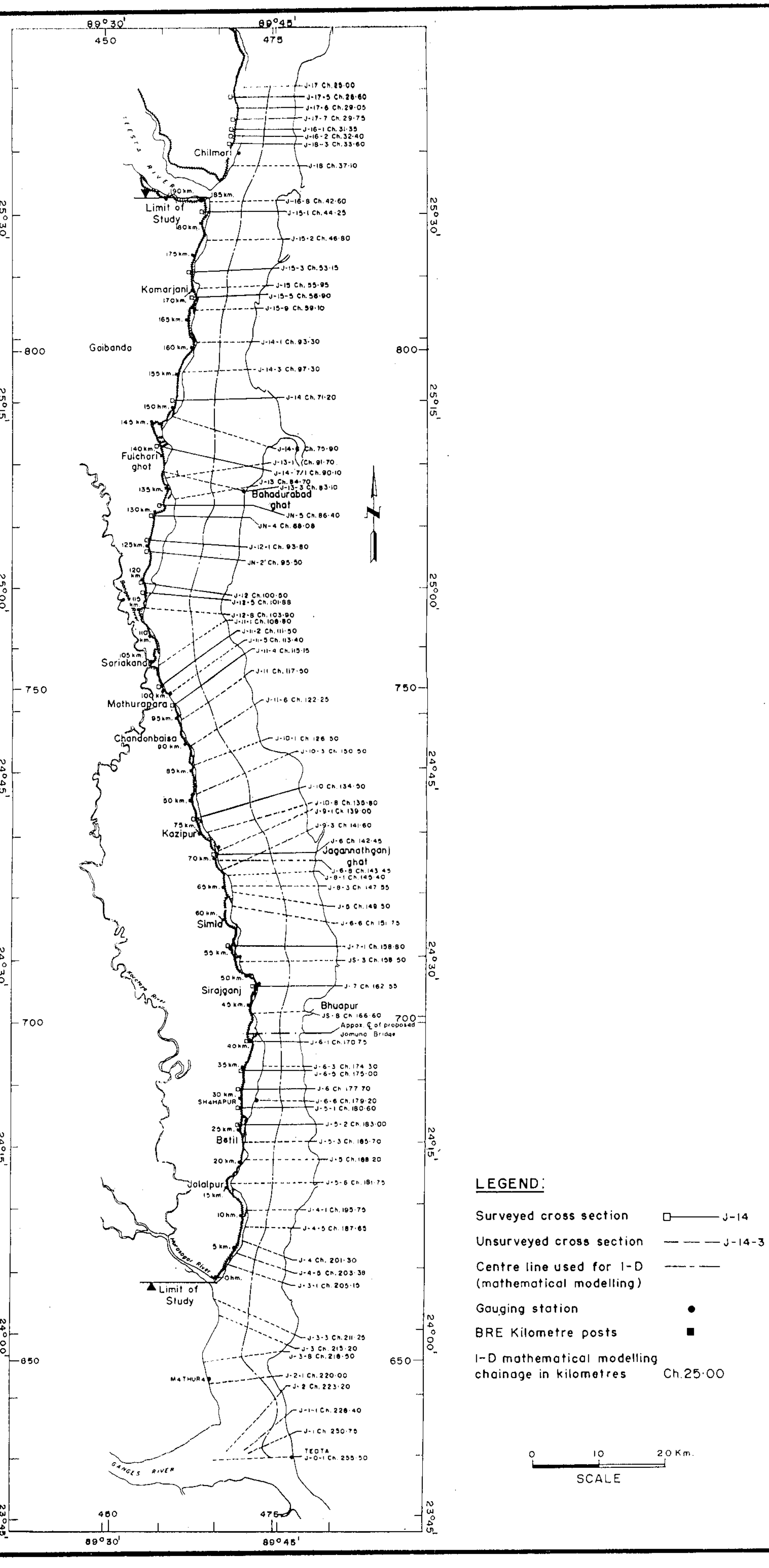


Variation of Vertical Elevation of Cross-sectional Centroid

Halcrow/DHI/EPC/DIG	*May 1993*	Figure 5.46

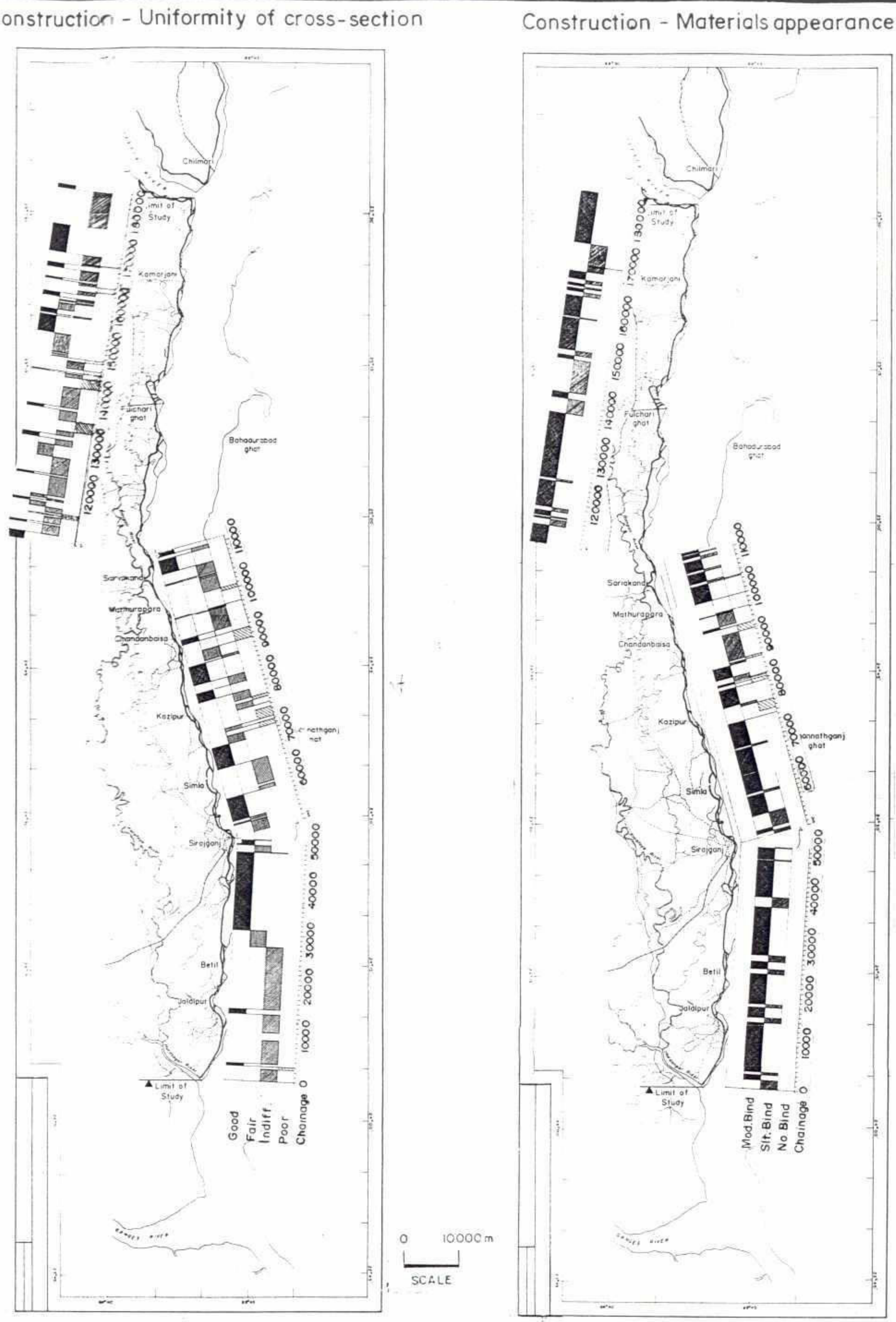


Location of Morphology Cross-Sections and Gauging Stations

Halcrow/DHI/EPC/DIG

May 1993

Figure 6.1



Note: Survey Undertaken May-August 1991

Characteristics of the BRE: Uniformity of X-Section/ Materials Appearance

Halcrow/DHI/EPC/DIG *May 1993*	Figure 6.2

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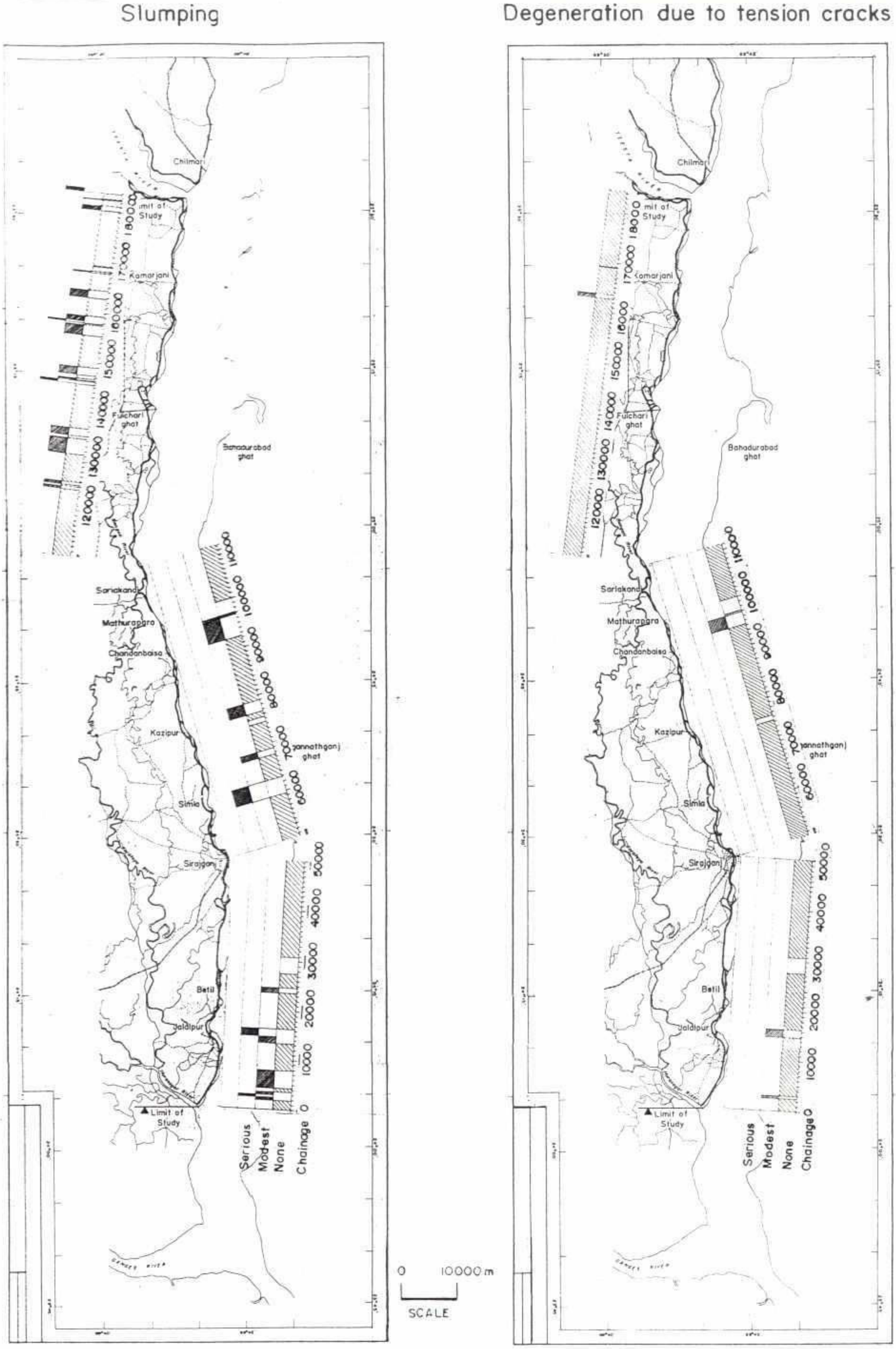
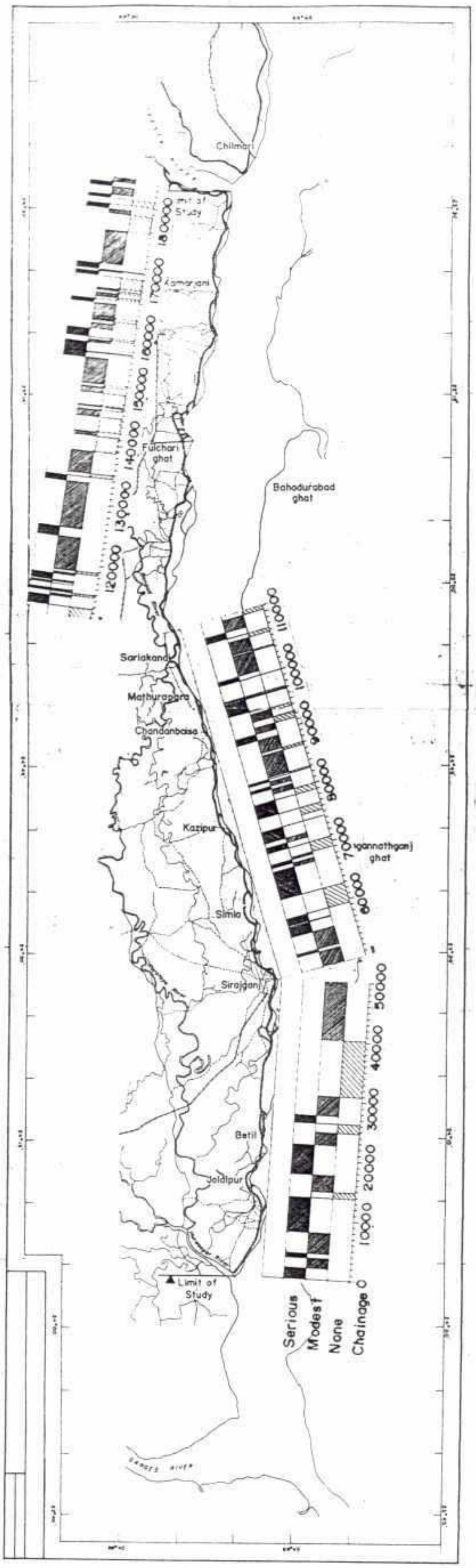


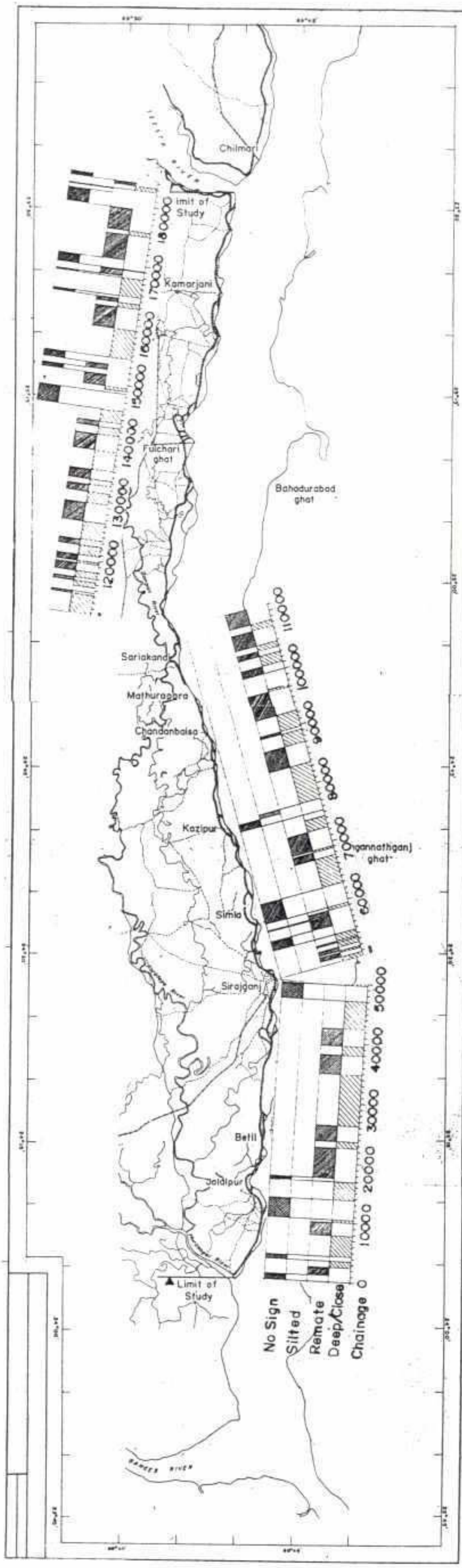
Note: Survey Undertaken May-August 1991

Characteristics of the BRE: Slumping/Tension Cracks

Degeneration due to benching



Borrow areas along BRE



0 10000 m

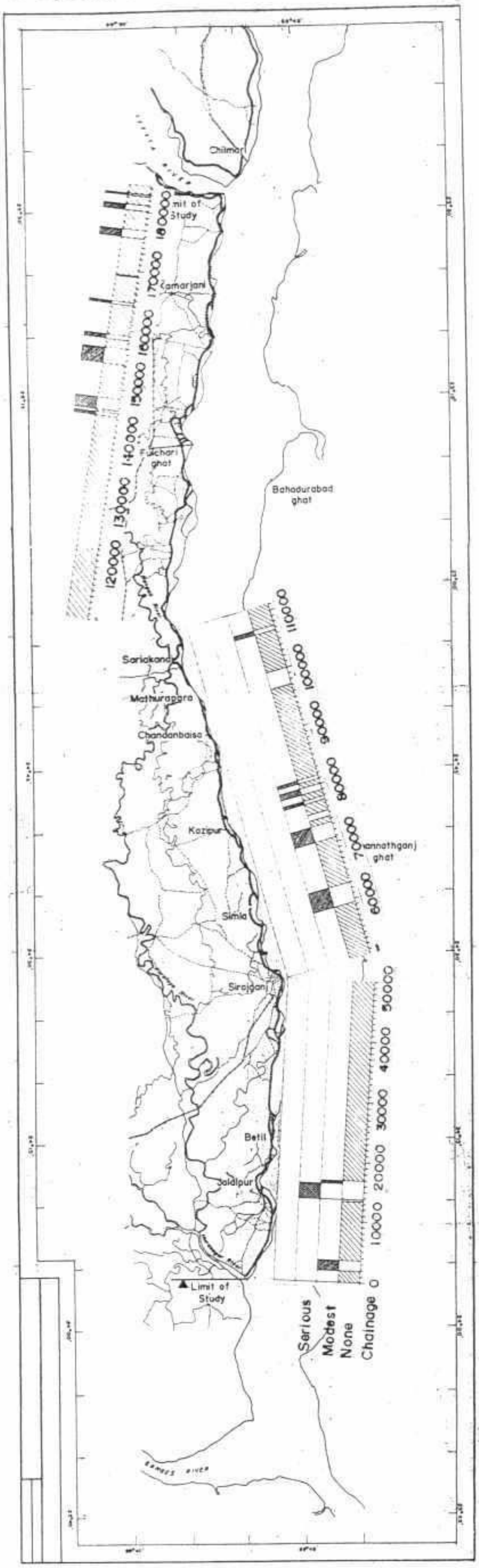
SCALE

Note: Survey Undertaken May-August 1991

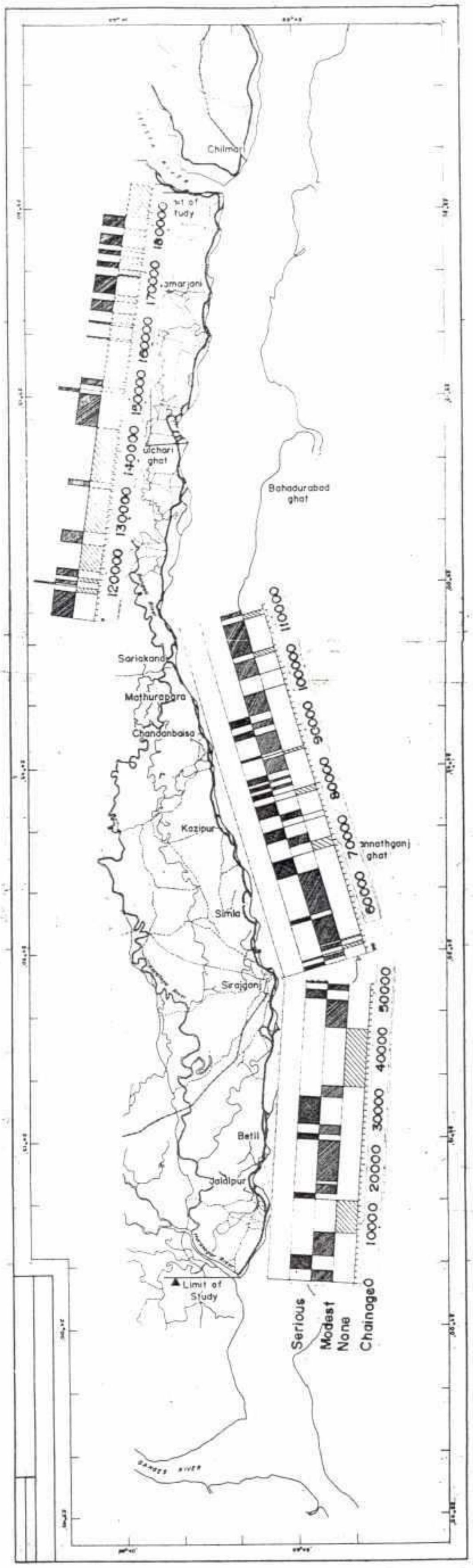
Characteristics of the BRE: Benching/Borrow Areas

Halcrow/DHI/EPC/DIG *May 1993* **Figure 6.4**

Degeneration due to wave action



Degeneration due to rilling

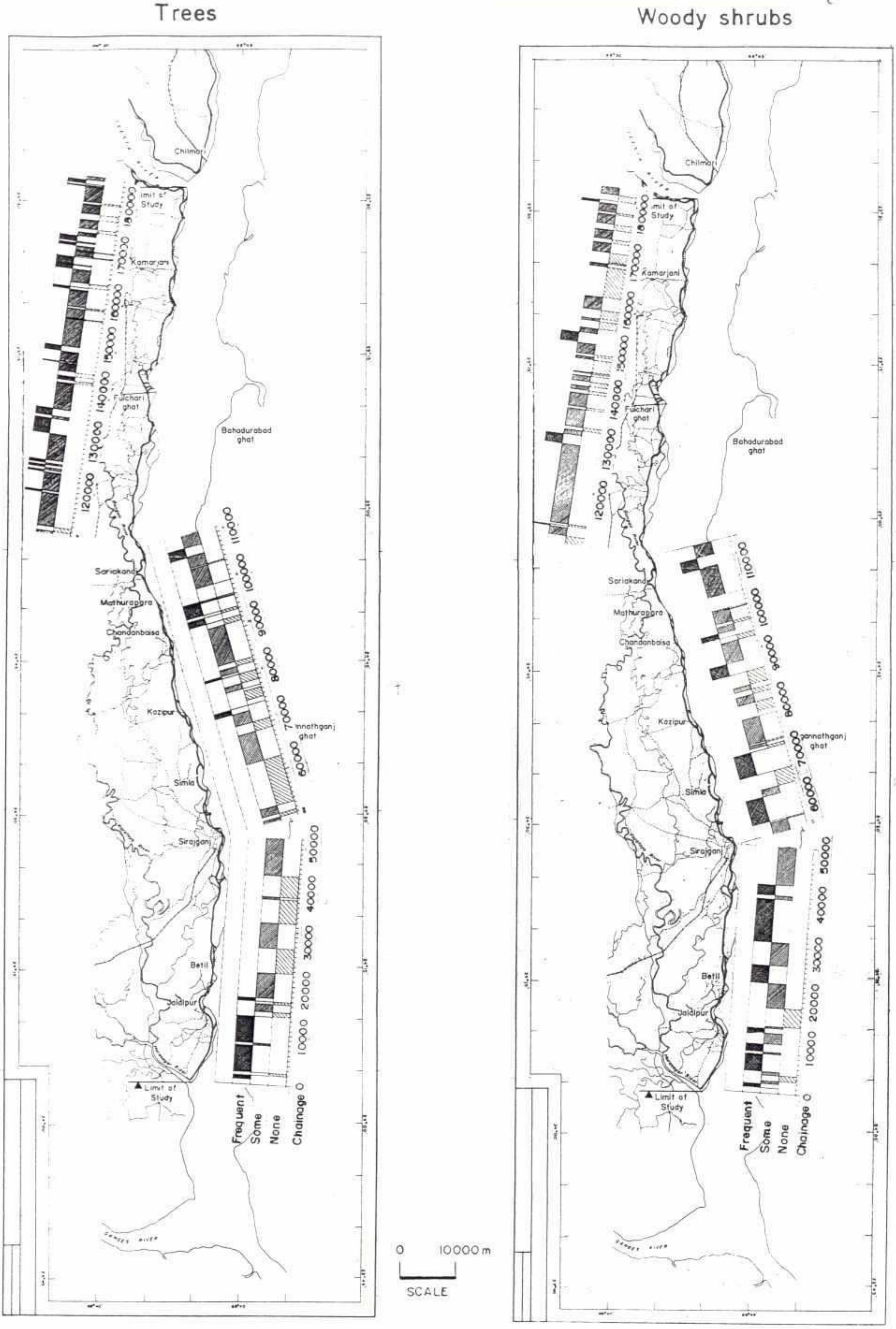


0 10000 m
SCALE

Note: Survey Undertaken May-August 1991

Characteristics of the BRE: Wave Action/Rilling

Halcrow/DHI/EPC/DIG *May 1993* **Figure 6.5**



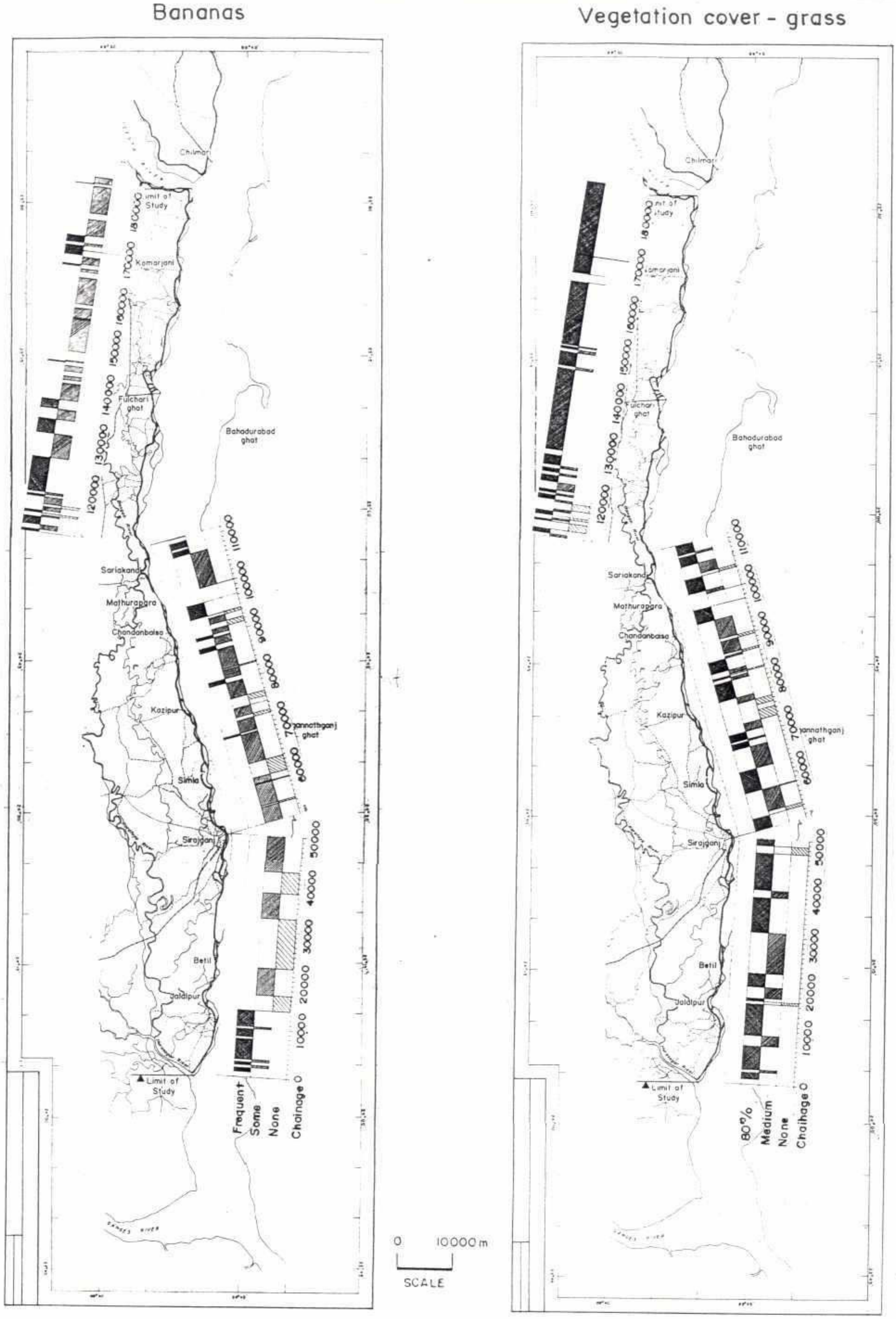
Note: Survey Undertaken May-August 1991

Characteristics of the BRE: Woody Shrubs/Trees

Halcrow/DHI/EPC/DIG

May 1993

Figure 6.6

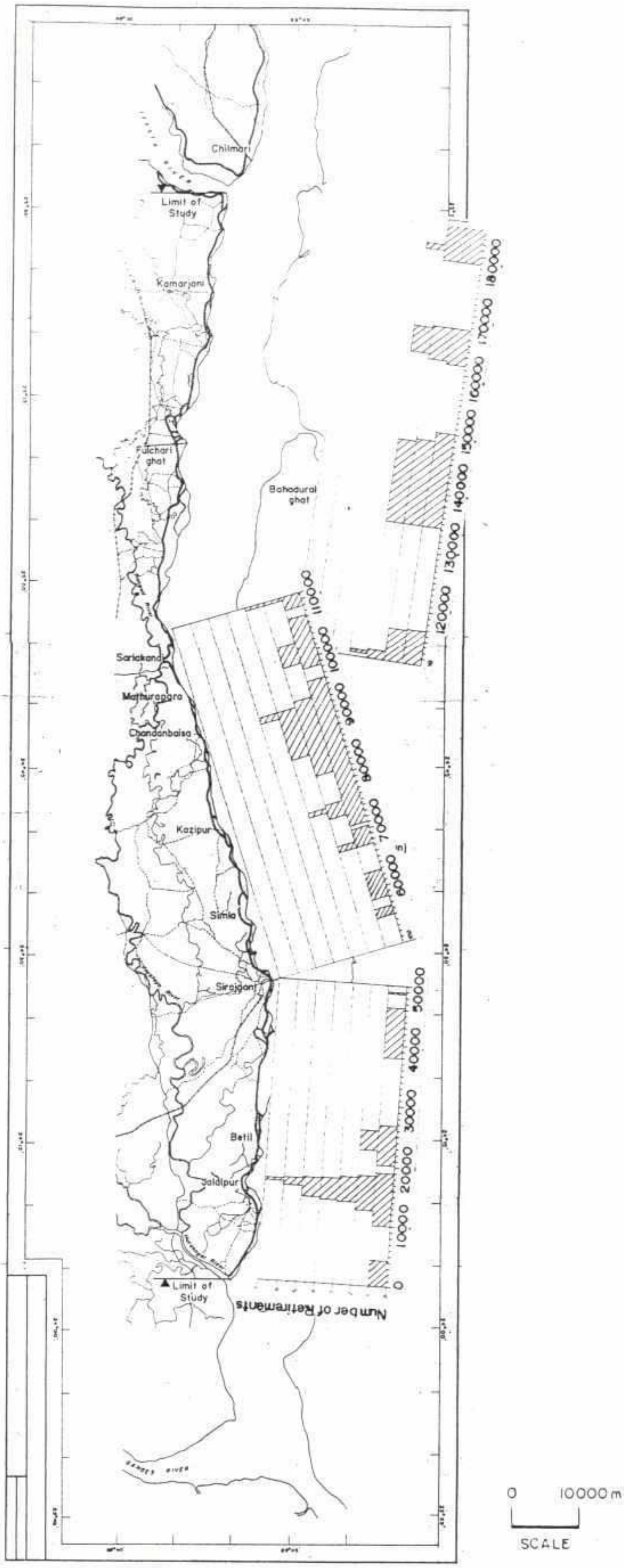


Note: Survey Undertaken May-August 1991

Characteristics of the BRE: Bananas/Grass

Halcrow/DHI/EPC/DIG *May 1993* **Figure 6.7**

BRE History



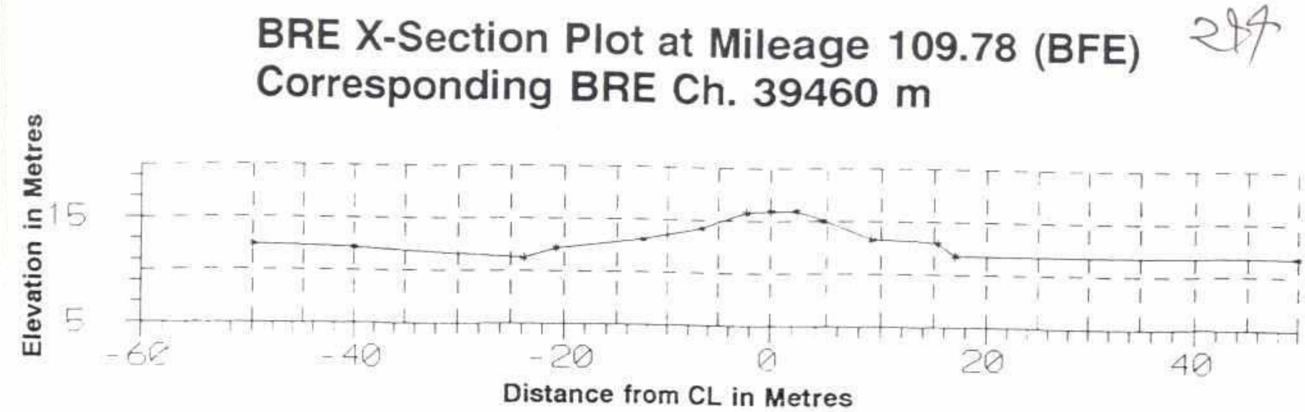
Note: Survey Undertaken May-August 1991

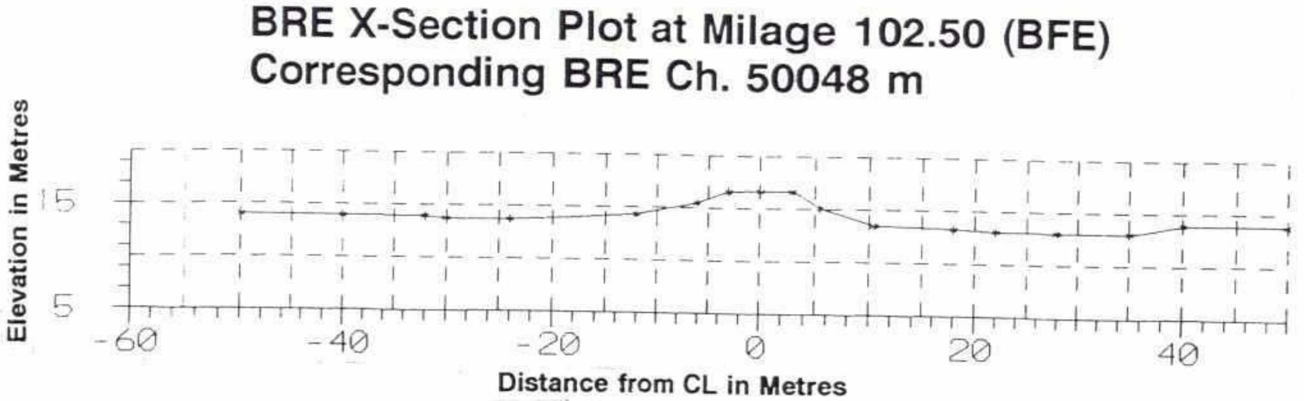
Characteristics of the BRE: Pattern of Retirements

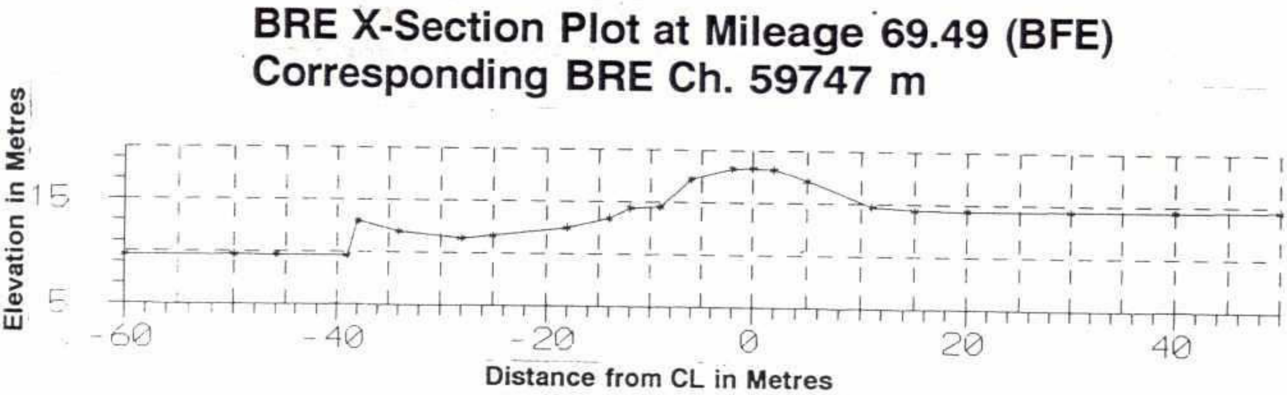
Halcrow/DHI/EPC/DIG

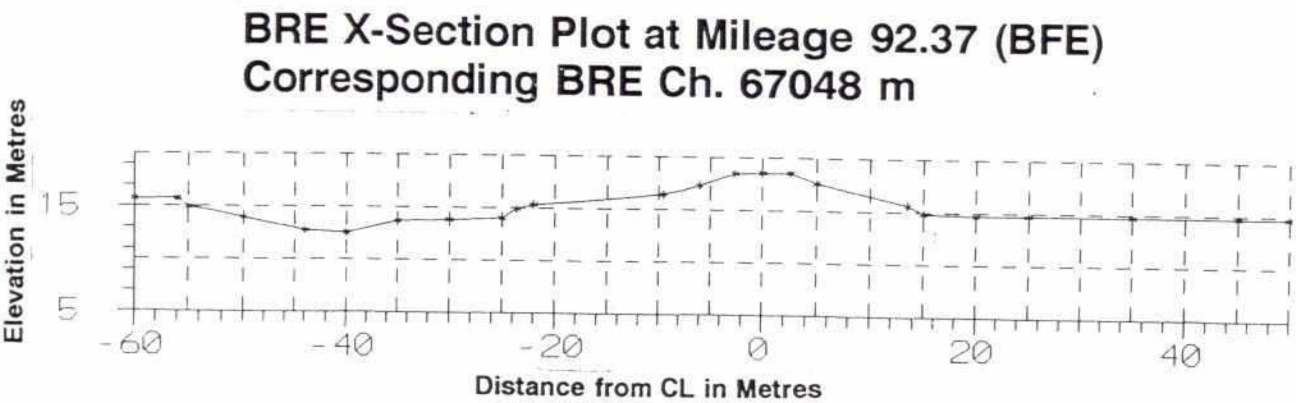
May 1993

Figure 6.8





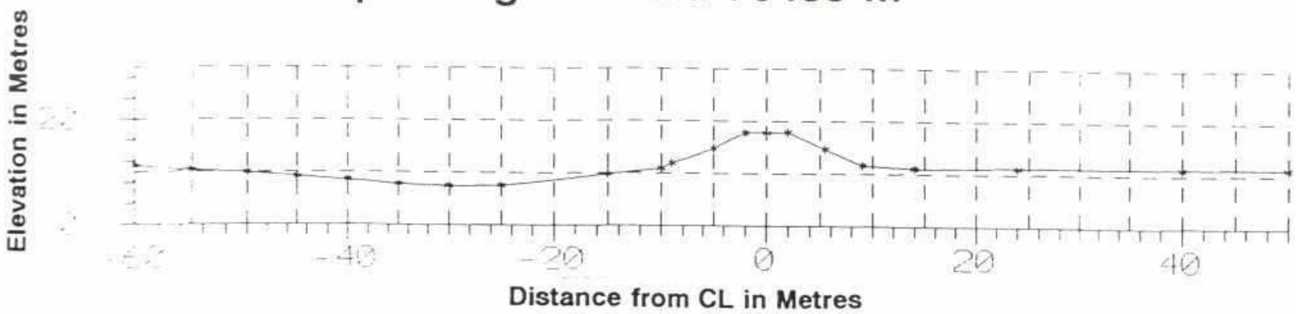




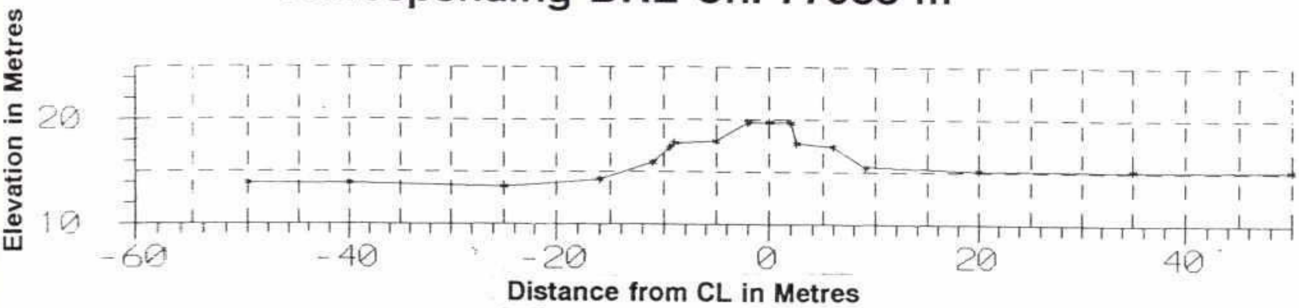
Typical Cross Sections of BRE, Sheet 1

Halcrow/DHI/EPC/DIG May 1993 Figure 6.9

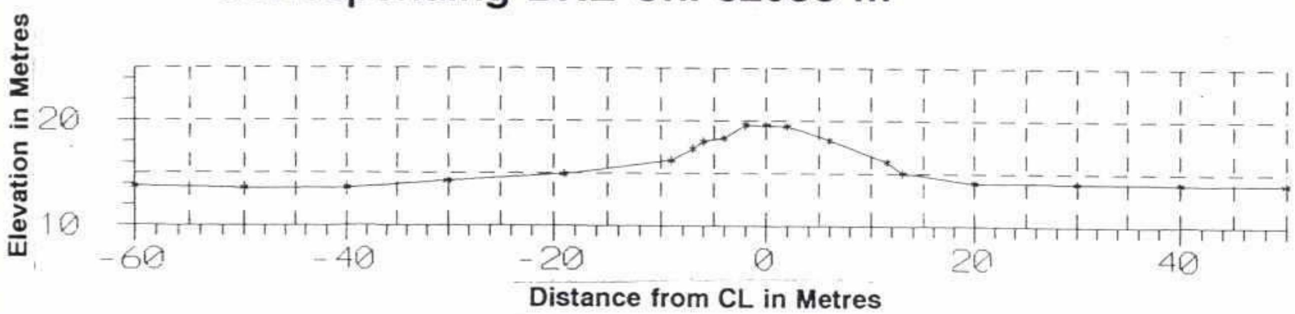
BRE X-Section Plot at Mileage 90.21 (BFE)
Corresponding BRE Ch. 70488 m



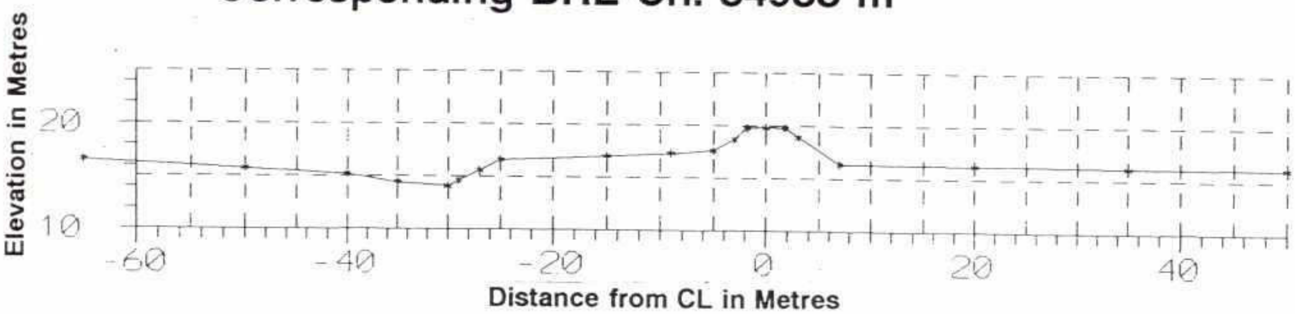
BRE X-Section Plot at Mileage 85.43 (BFE)
Corresponding BRE Ch. 77988 m



BRE X-Section Plot at Mileage 82.44 (BFE)
Corresponding BRE Ch. 82938 m



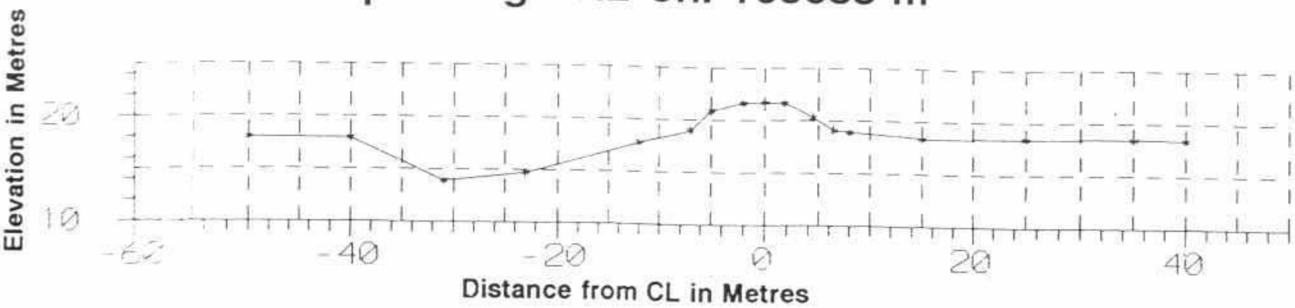
BRE X-Section Plot at Mileage 81.03 (BFE)
Corresponding BRE Ch. 84988 m



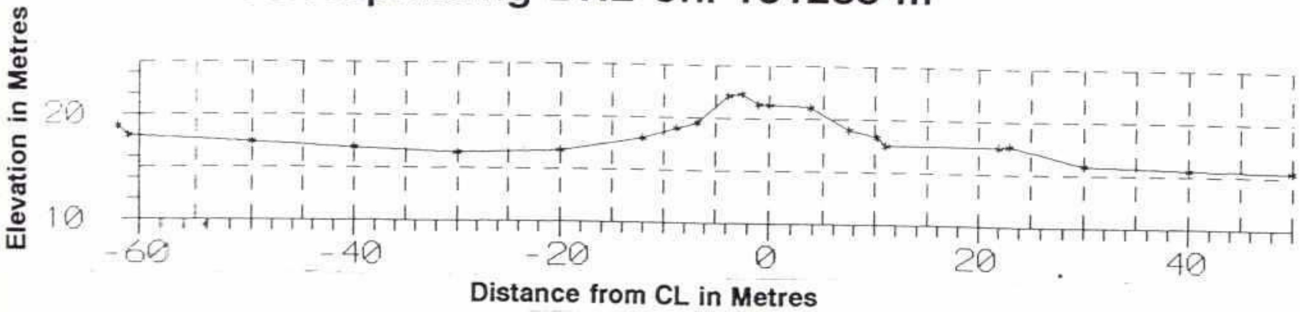
Typical Cross Sections of BRE, Sheet 2

Halcrow/DHI/EPC/DIG | *May 1993* | Figure 6.10

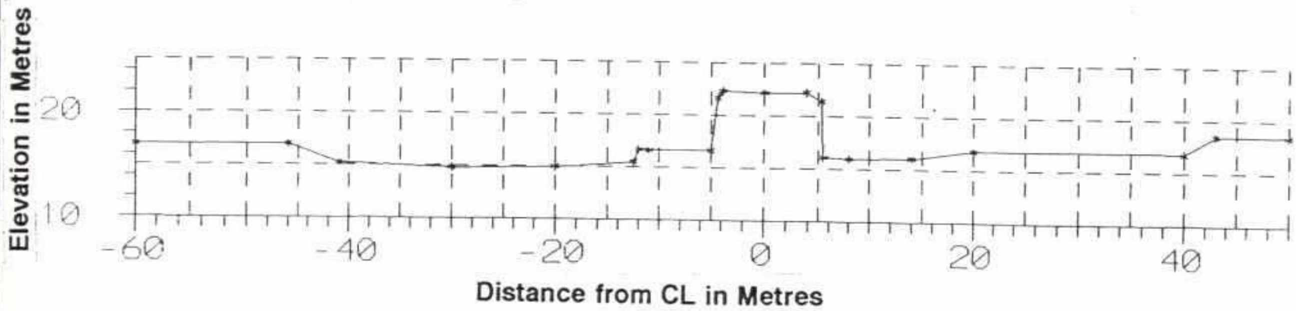
BRE X-Section Plot at Mileage 71.54 (BFE)
Corresponding BRE Ch. 103688 m



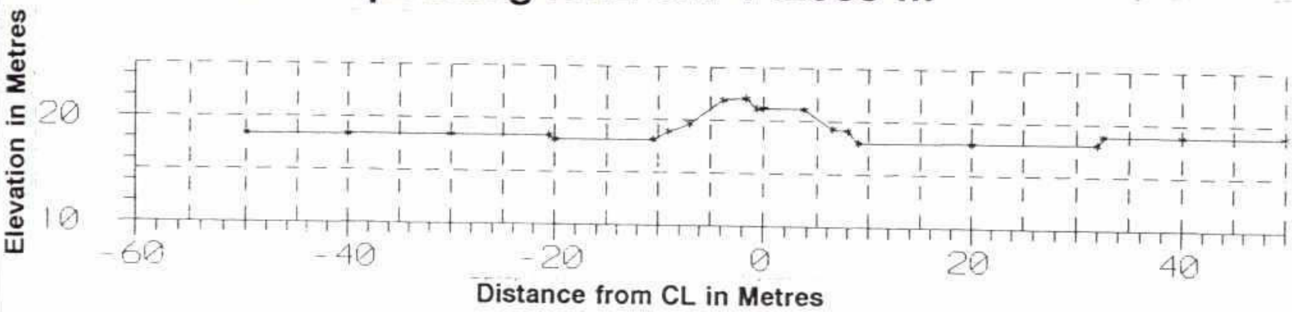
BRE X-Section Plot at Mileage 56.01 (BFE)
Corresponding BRE Ch. 131288 m



BRE X-Section Plot at Mileage 55.26 (BFE)
Corresponding BRE Ch. 132708 m



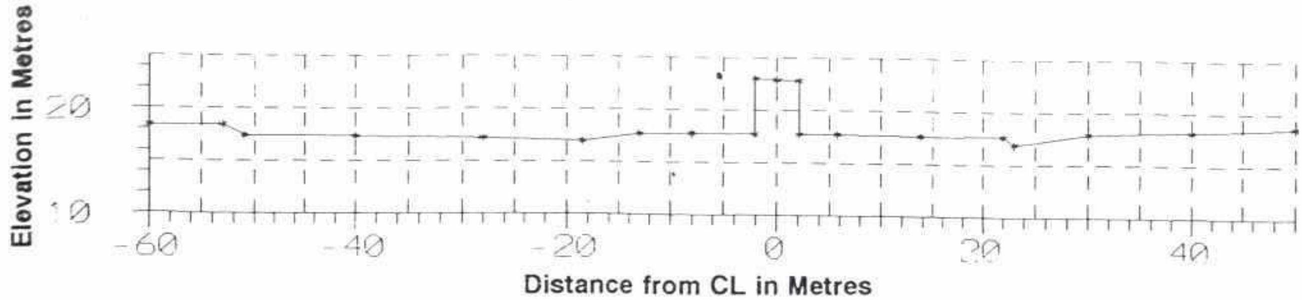
BRE X-Section Plot at Mileage 49.91 (BFE)
Corresponding BRE Ch. 142988 m



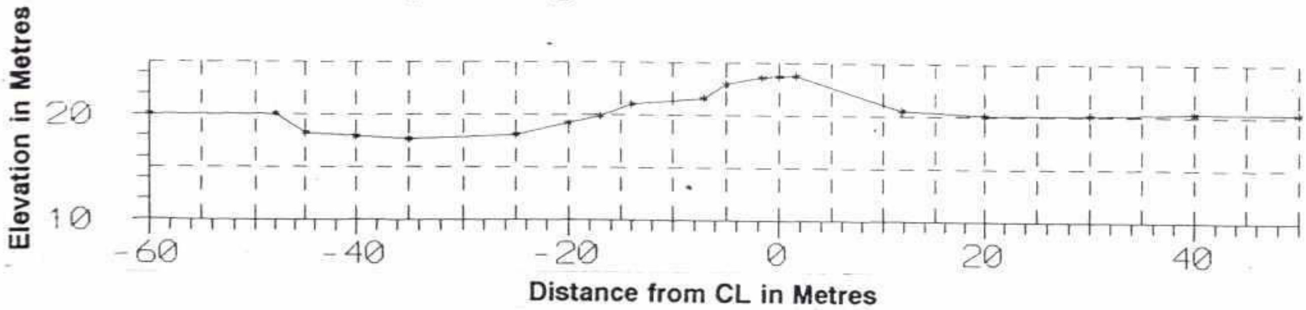
Typical Cross Sections of BRE, Sheet 3

Halcrow/DHI/EPC/DIG *May 1993* Figure 6.11

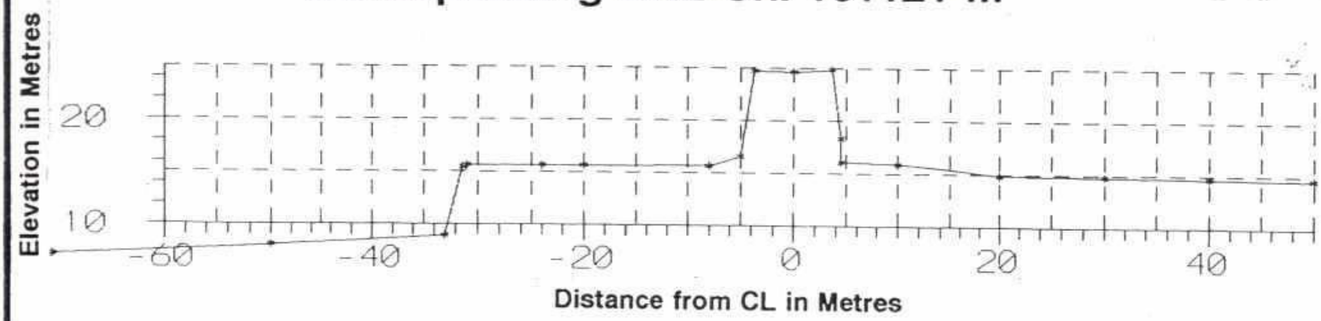
BRE X-Section Plot at Mileage 45.13 (BFE)
Corresponding BRE Ch. 151918 m



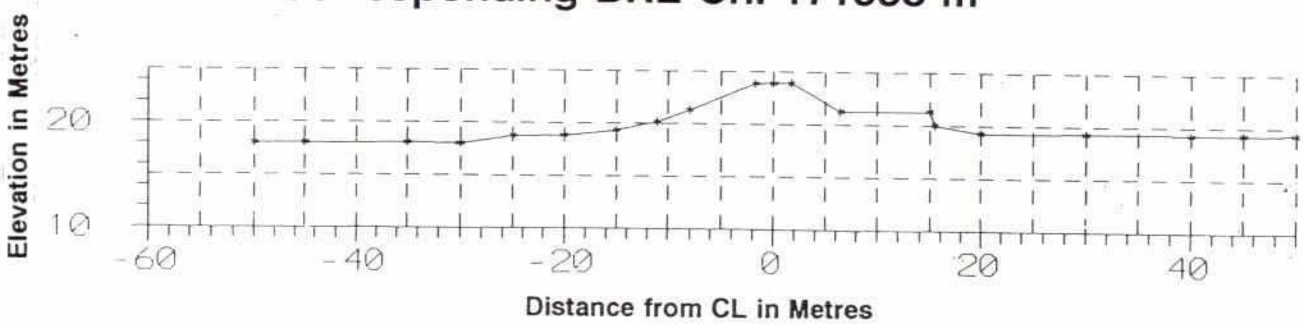
BRE X-Section Plot at Mileage 40.30 (BFE)
Corresponding BRE Ch. 160138 m



BRE X-Section Plot at Mileage 39.68 (BFE)
Corresponding BRE Ch. 161121 m

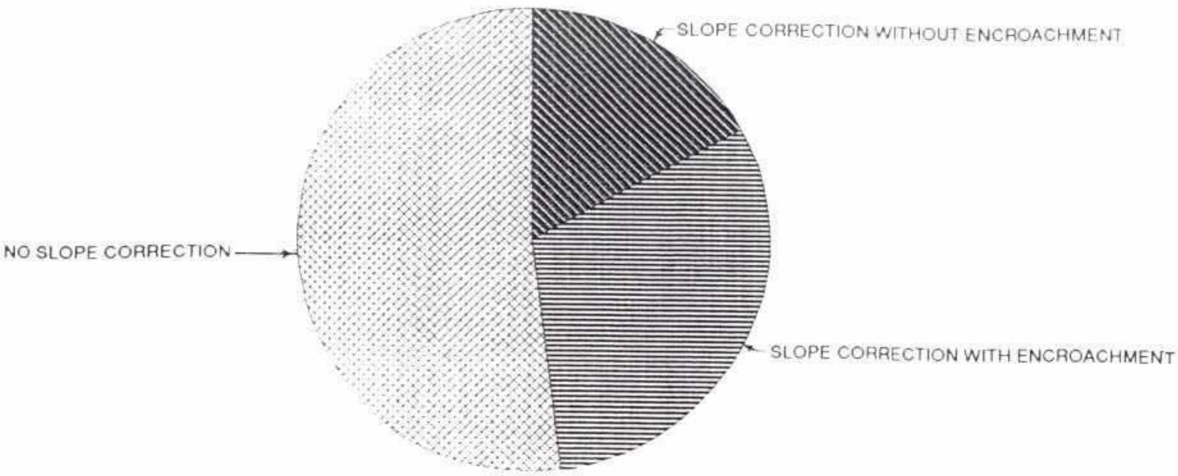


BRE X-Section Plot at Mileage 33.33 (BFE)
Corresponding BRE Ch. 171538 m

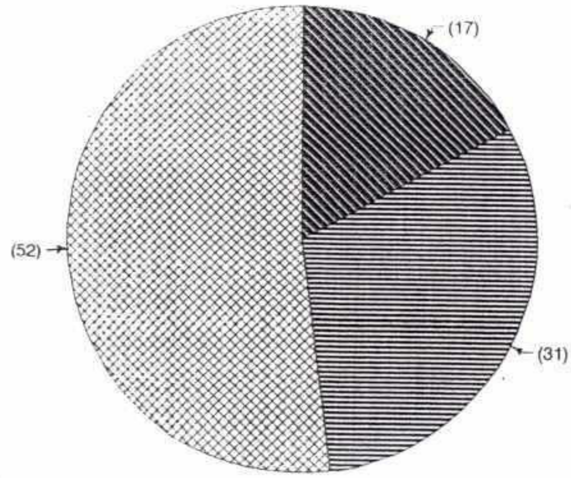


Typical Cross Sections of BRE, Sheet 4

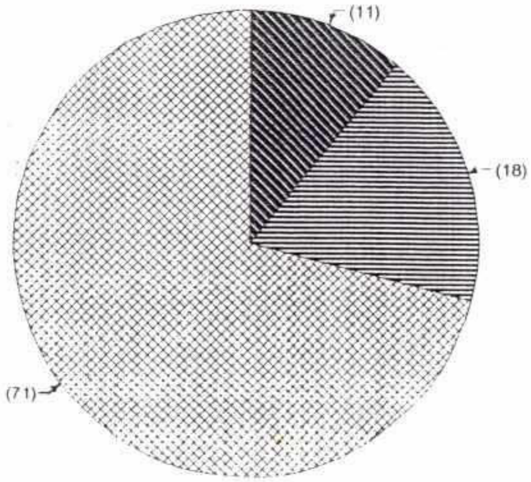
Halcrow/DHI/EPC/DIG *May 1993* Figure 6.12



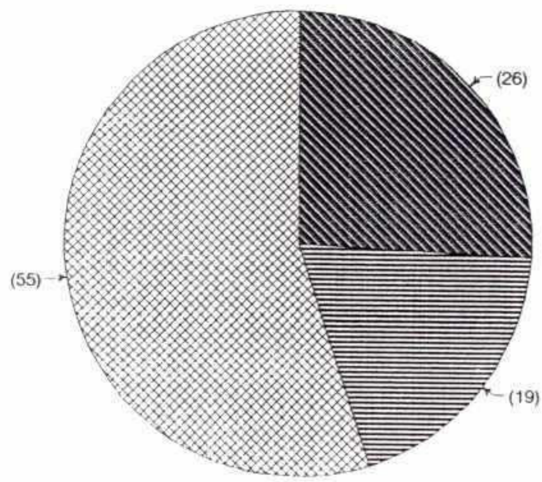
SLOPE CORRECTION REQUIRED (RIVERSIDE)
(KEY)



(MILEPOSTS 24 TO 134)



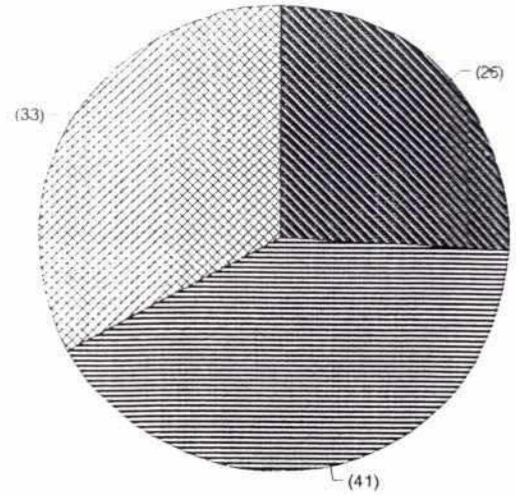
(MILEPOSTS 24 TO 45)



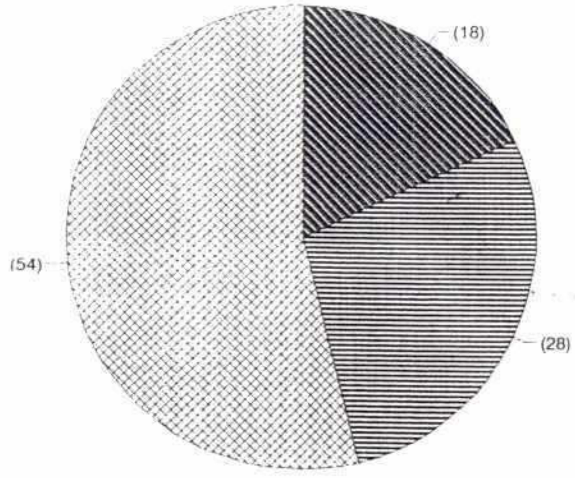
(MILEPOSTS 45 TO 60)

Slope Correction Diagrams, Sheet 1

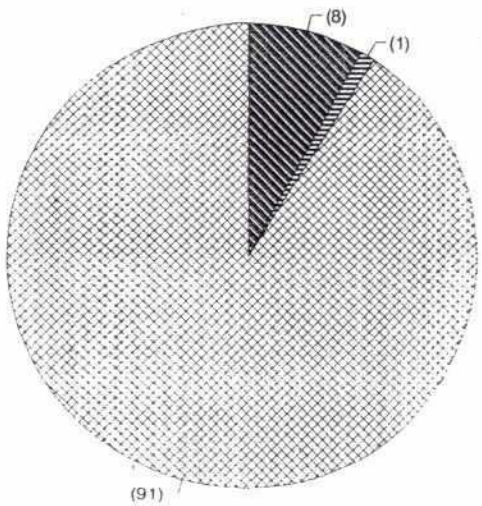
Halcrow/DHI/EPC/DIG | *May 1993* | Figure 6.13



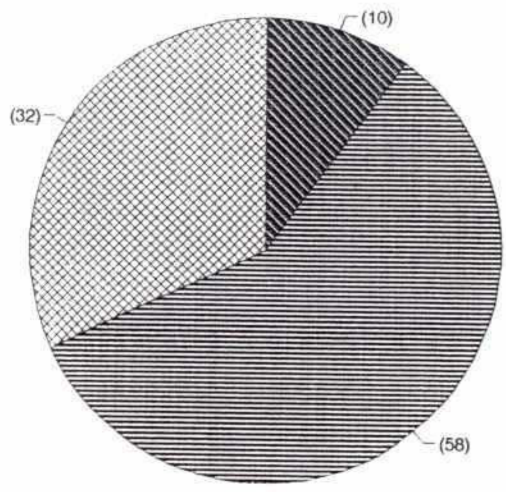
(MILEPOSTS 60 TO 83)



(MILEPOSTS 83 TO 105)



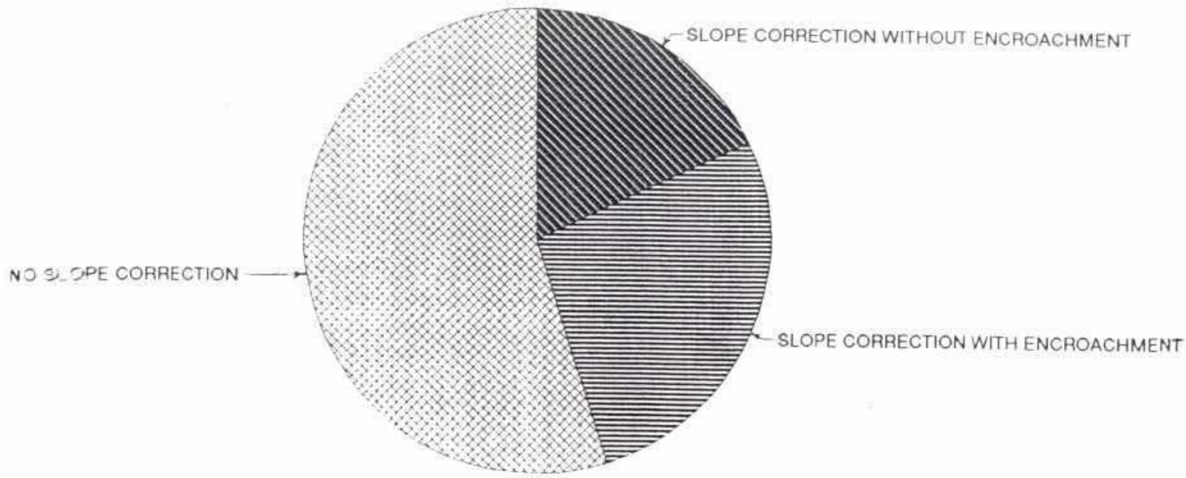
(MILEPOSTS 105 TO 115)



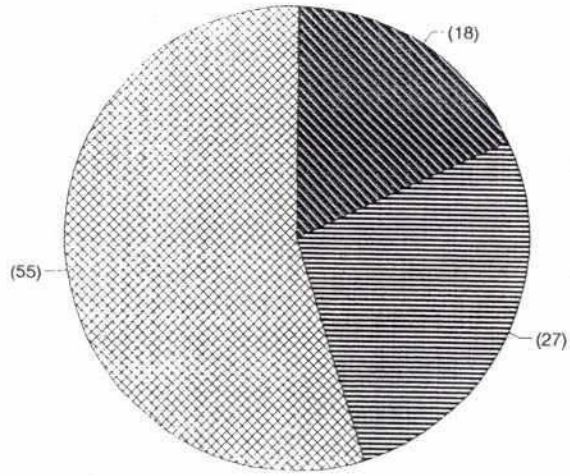
(MILEPOSTS 115 TO 134)

Slope Correction Diagrams, Sheet 2

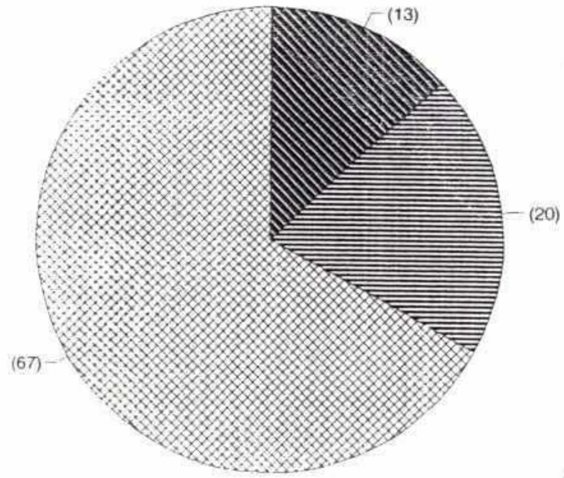
Halcrow/DHI/EPC/DIG *May 1993* Figure 6.14



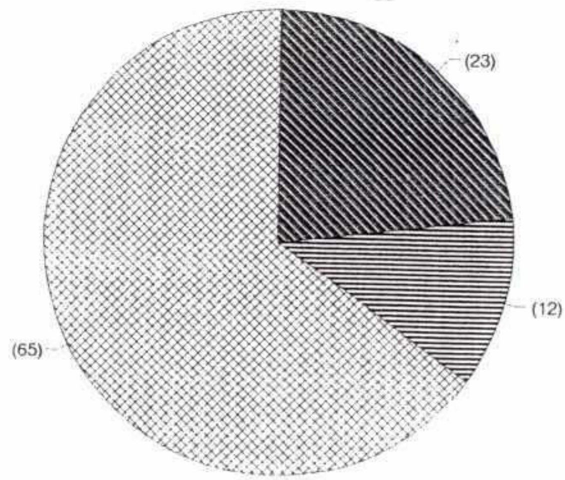
SLOPE CORRECTION REQUIRED (COUNTRYSIDE)
(KEY)



(MILEPOSTS 24 TO 134)



(MILEPOSTS 24 TO 45)

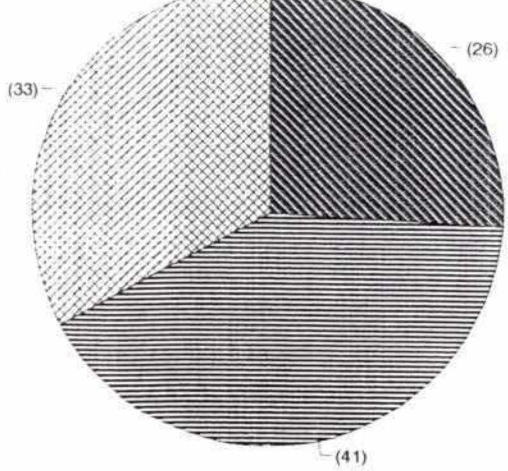


(MILEPOSTS 45 TO 60)

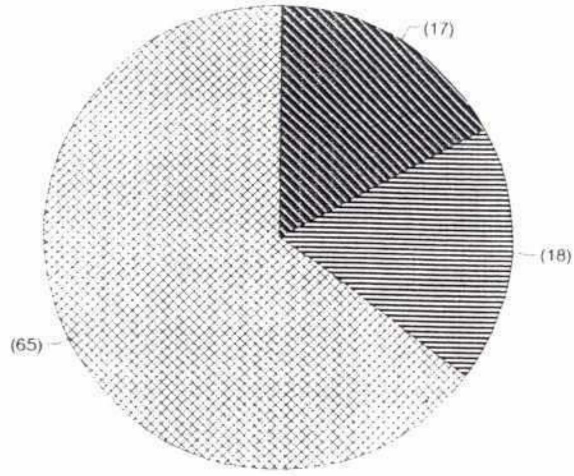
Slope Correction Diagrams, Sheet 3

Halcrow/DHI/EPC/DIG *May 1993* Figure 6.15

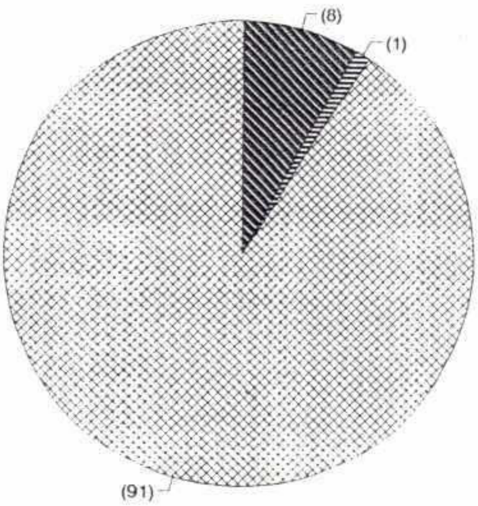
2f8



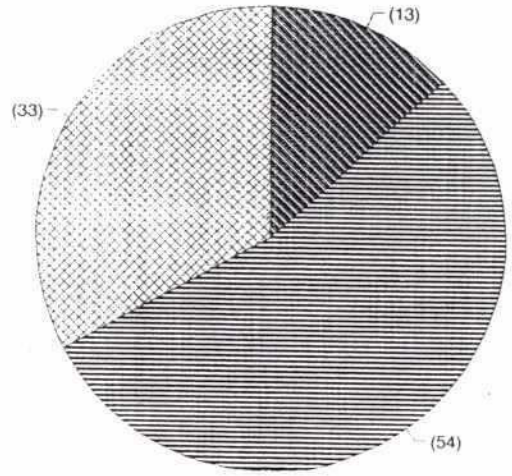
(MILEPOSTS 60 TO 83)



(MILEPOSTS 83 TO 105)



(MILEPOSTS 105 TO 115)



(MILEPOSTS 115 TO 134)

Slope Correction Diagrams, Sheet 4

Halcrow/DHI/EPC/DIG *May 1993* **Figure 6.16**

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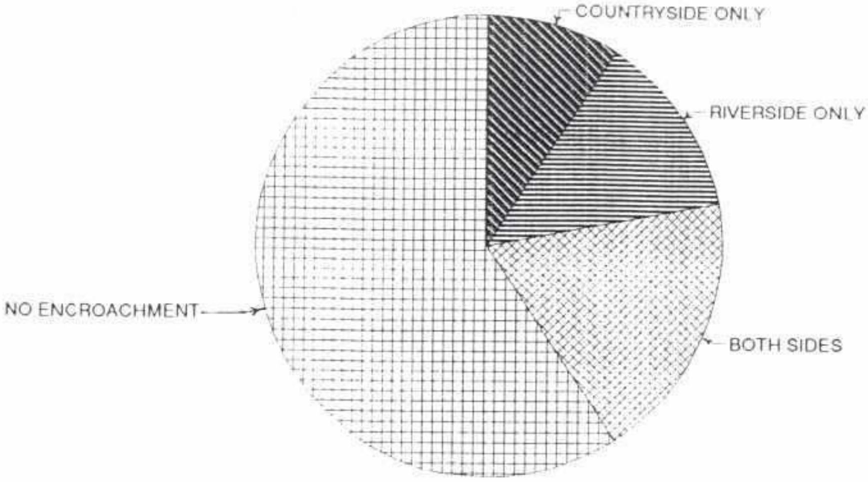
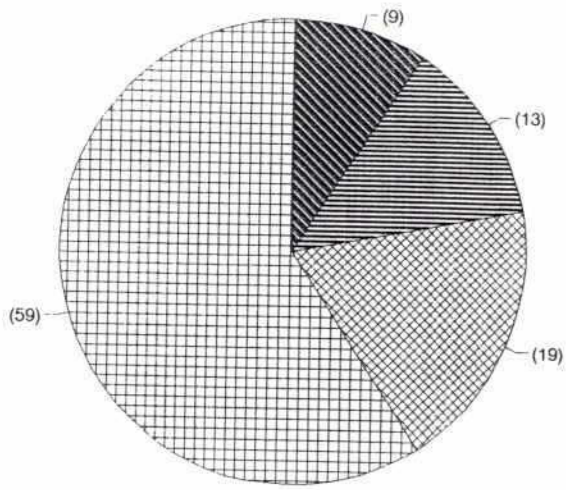
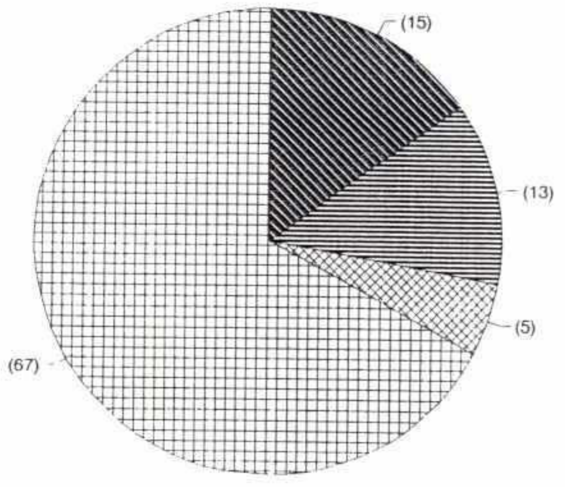


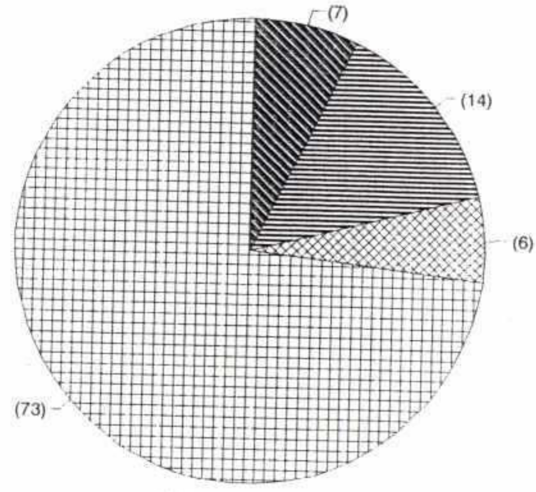
PERCENTAGE OF ENCROACHMENT (KEY)



(MILEPOSTS 24 TO 134)



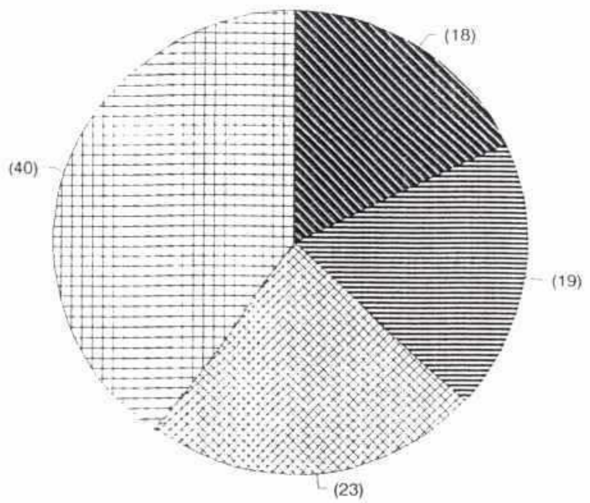
(MILEPOSTS 24 TO 45)



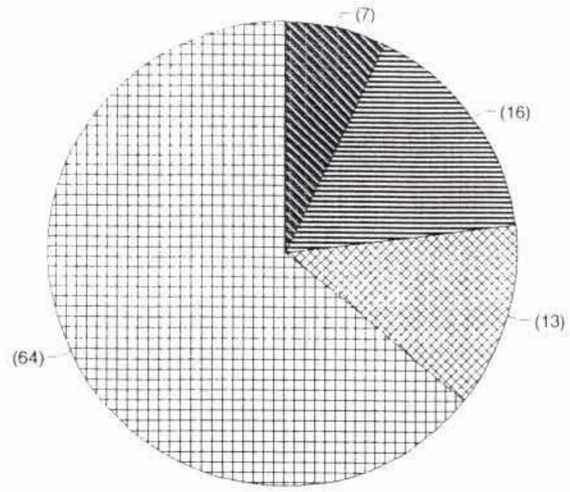
(MILEPOSTS 45 TO 60)

Encroachment Diagrams, Sheet 1

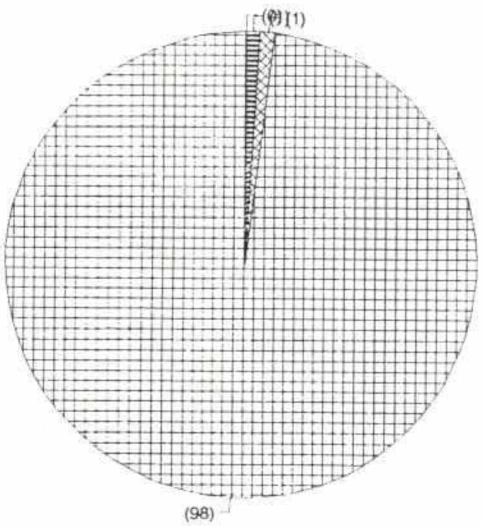
Halcrow/DHI/EPC/DIG	*May 1993*	**Figure 6.17**



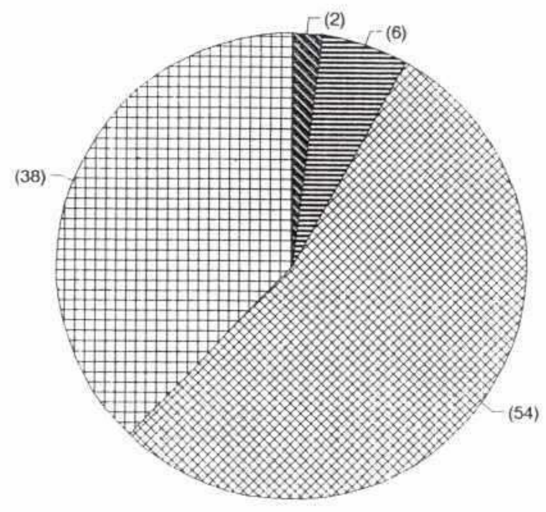
(MILEPOSTS 60 TO 83)



(MILEPOSTS 83 TO 105)



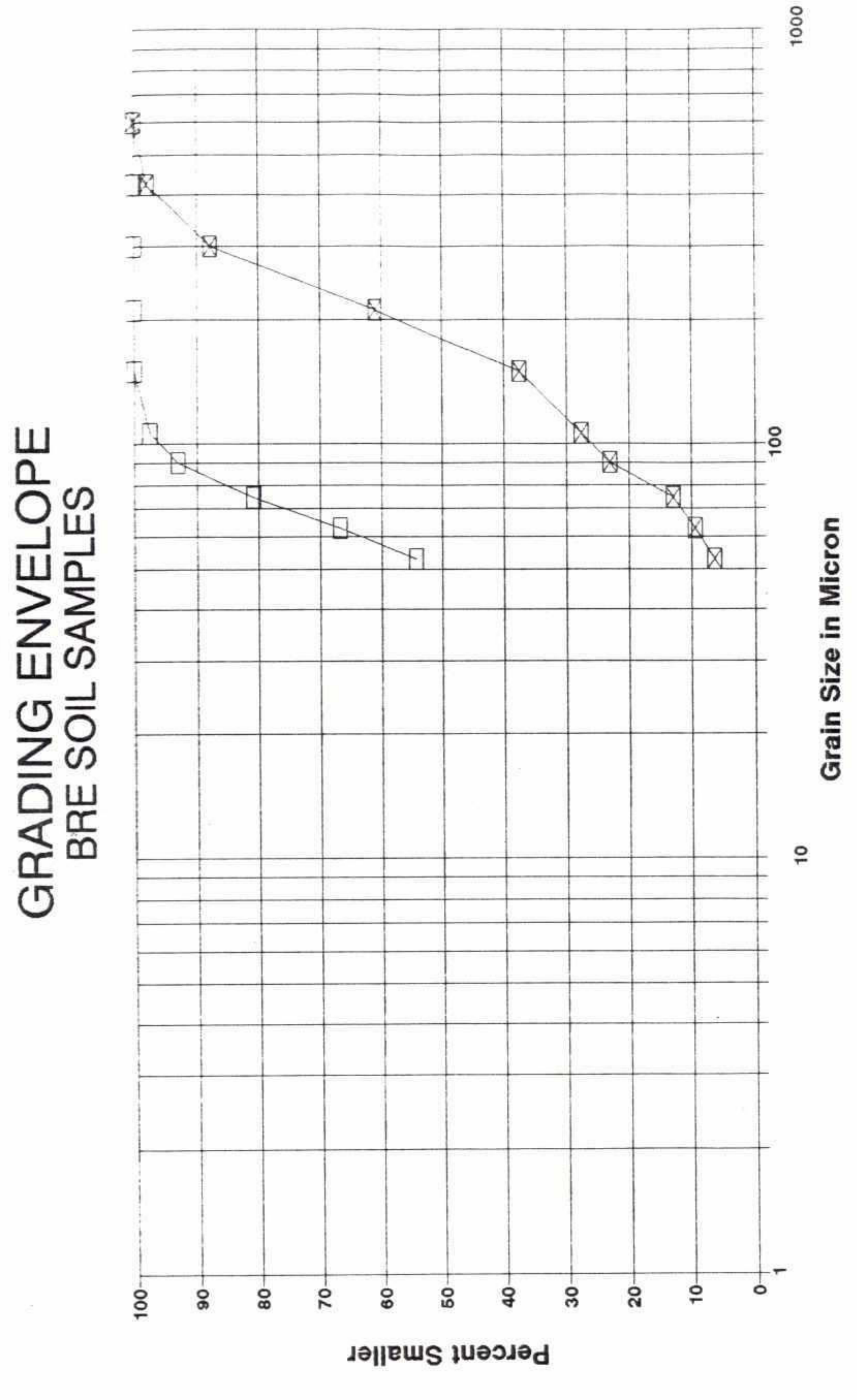
(MILEPOSTS 105 TO 115)



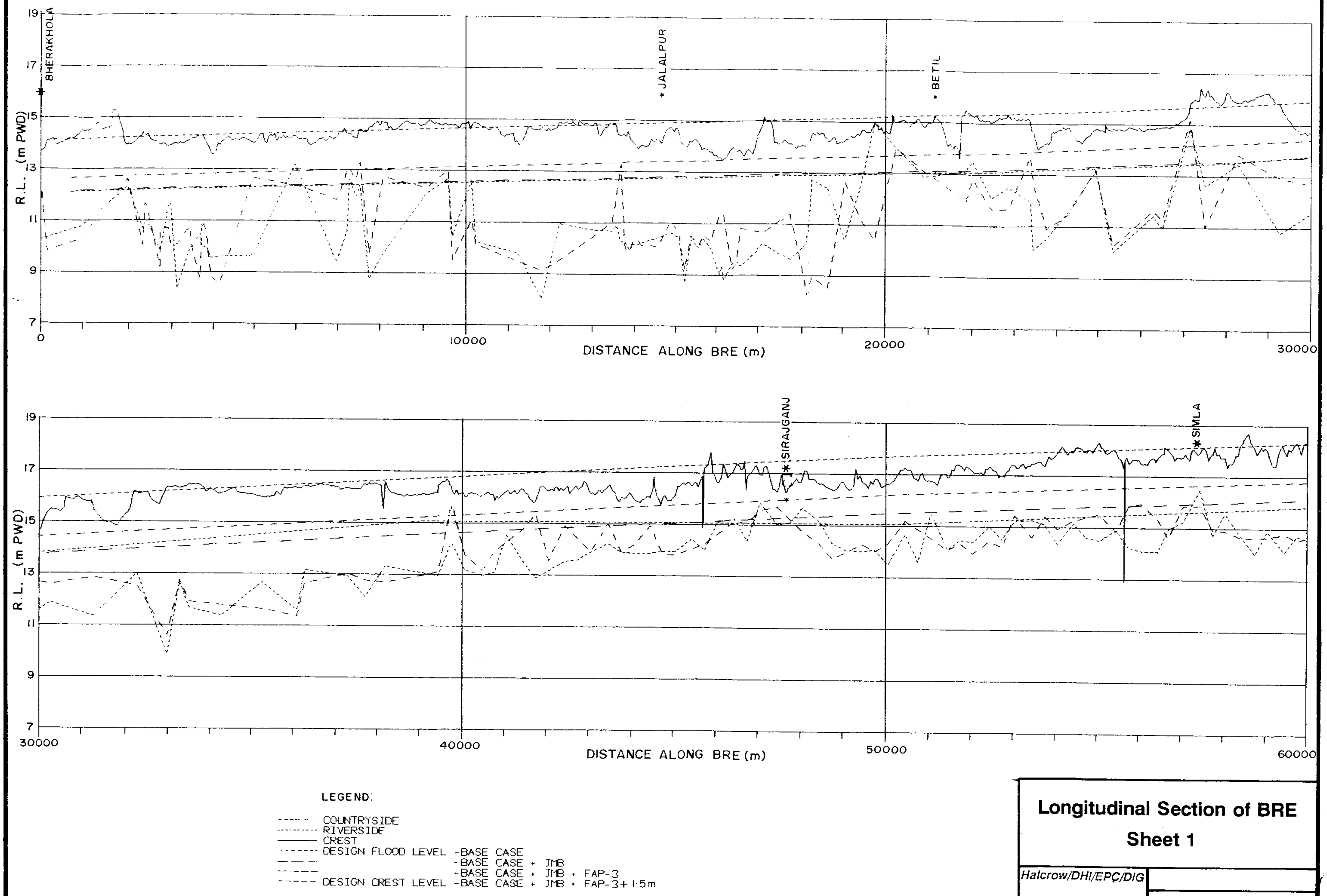
(MILEPOSTS 115 TO 134)

Encroachment Diagrams, Sheet 2

Halcrow/DHI/EPC/DIG *May 1993* Figure 6.18



Grading Envelope of BRE Soil Samples



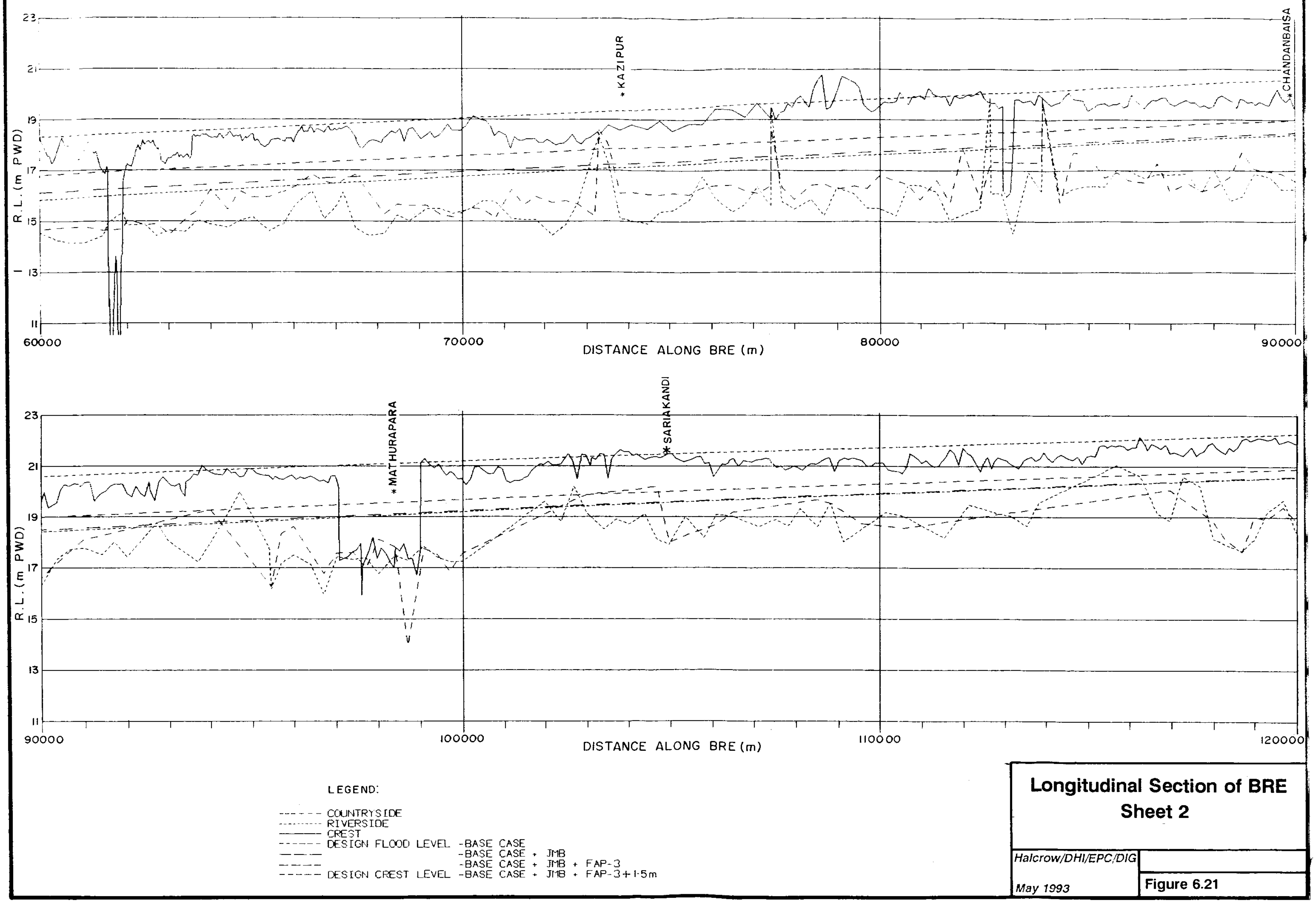
Longitudinal Section of BRE

Sheet 1

Halcrow/DHI/EPC/DIG

May 1993

Figure 6.20

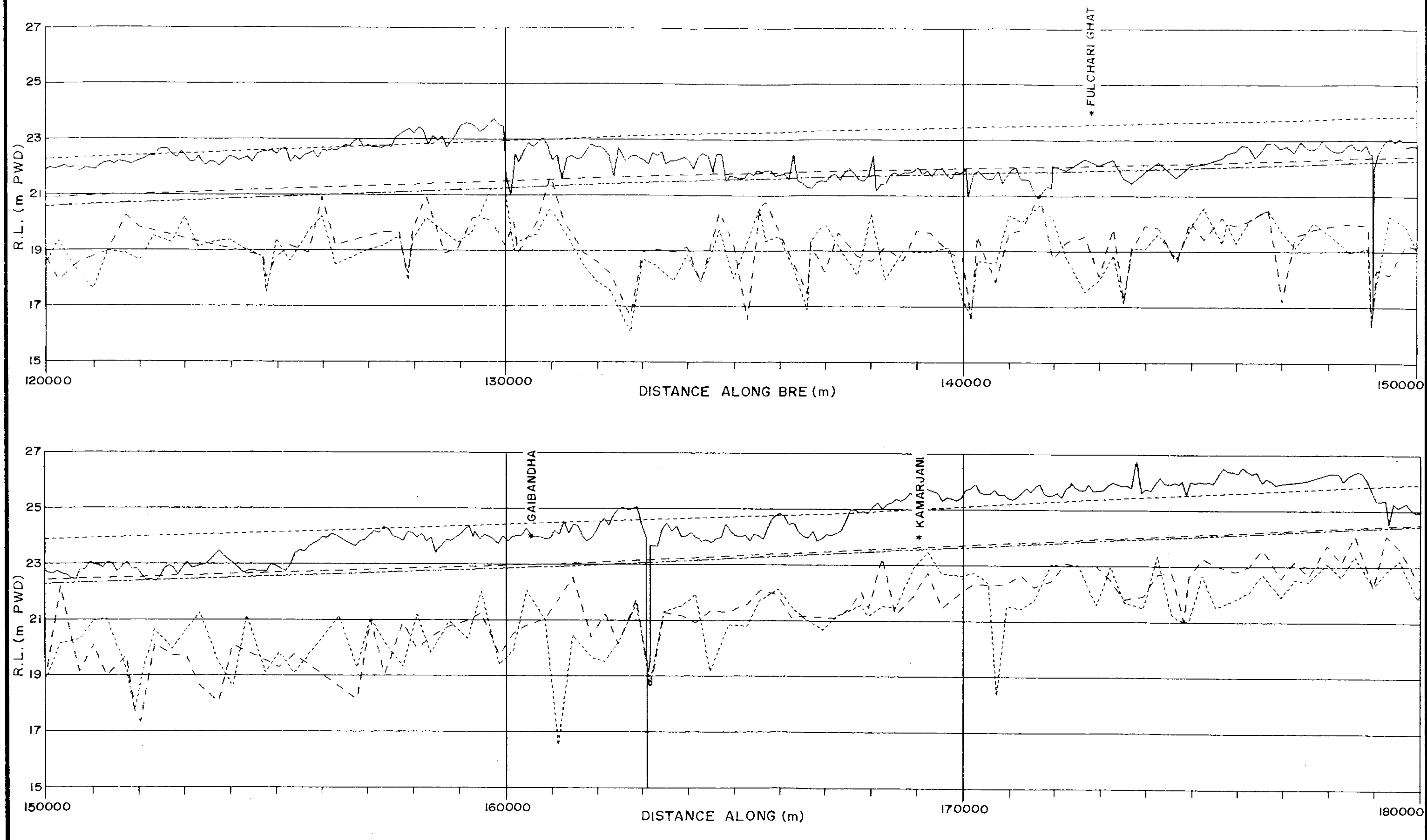


Longitudinal Section of BRE
Sheet 2

Halcrow/DHI/EPC/DIG

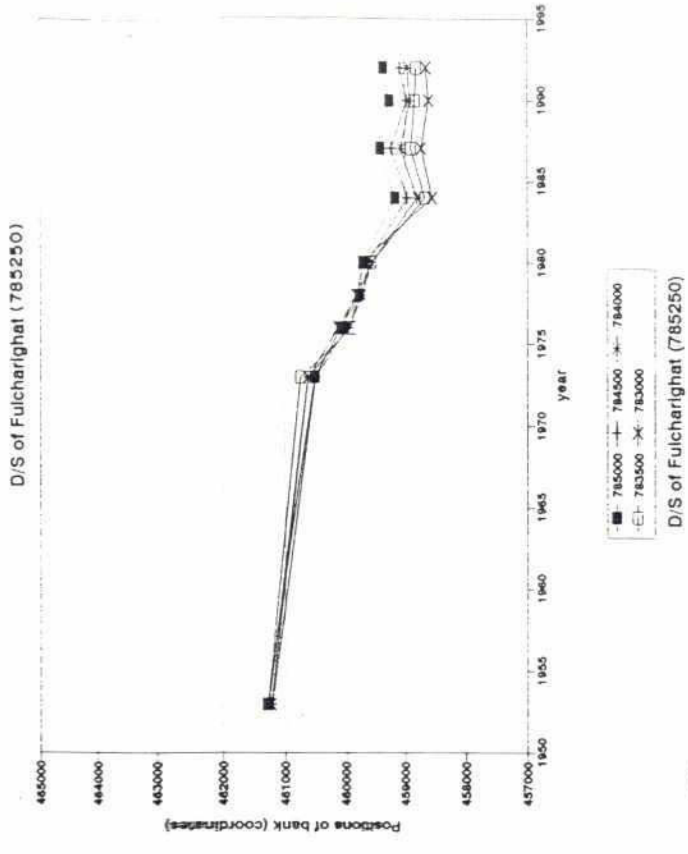
May 1993

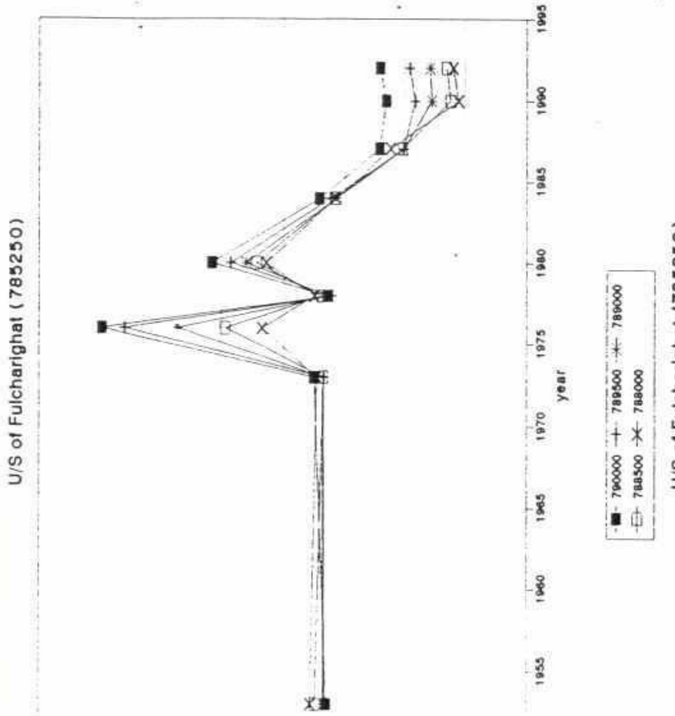
Figure 6.21

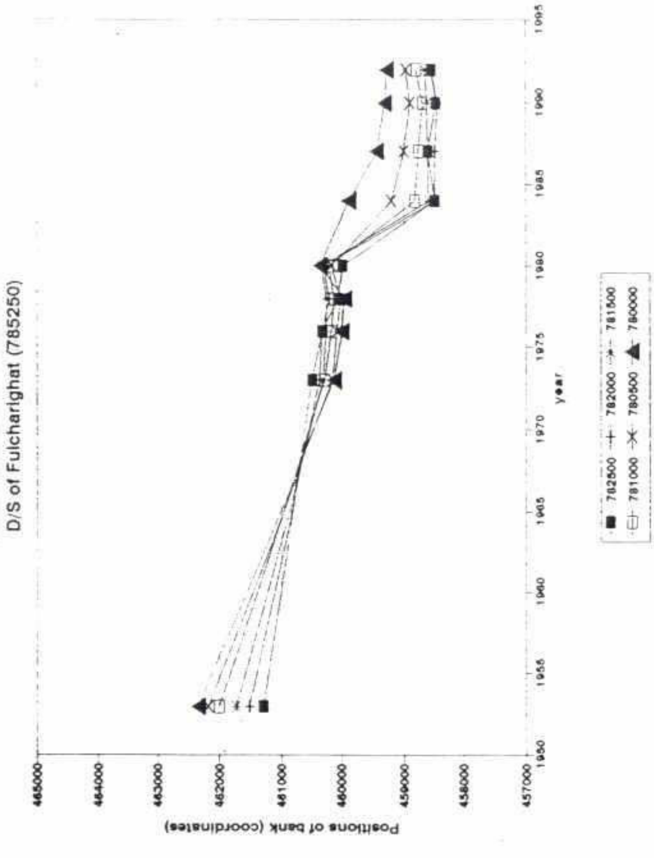


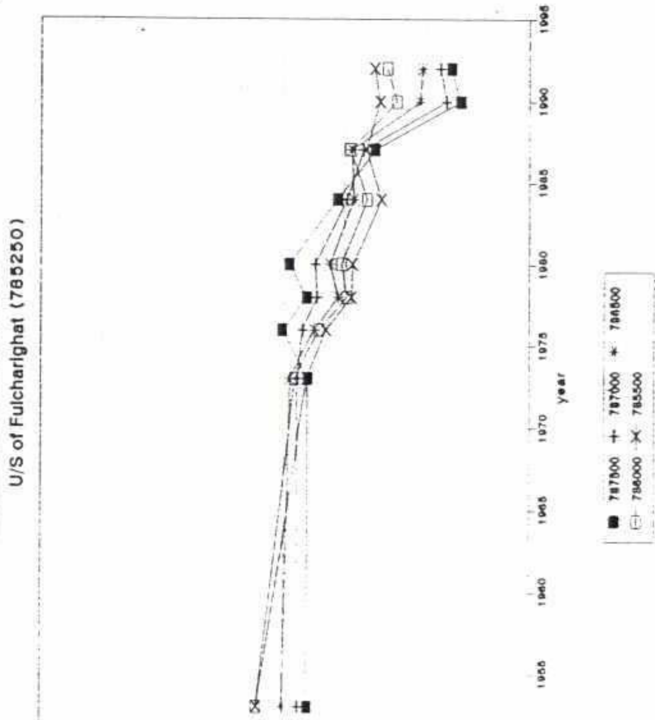
Longitudinal Section of BRE
Sheet 3

Halcrow/DHI/EPC/DIG	
May 1993	**Figure 6.22**



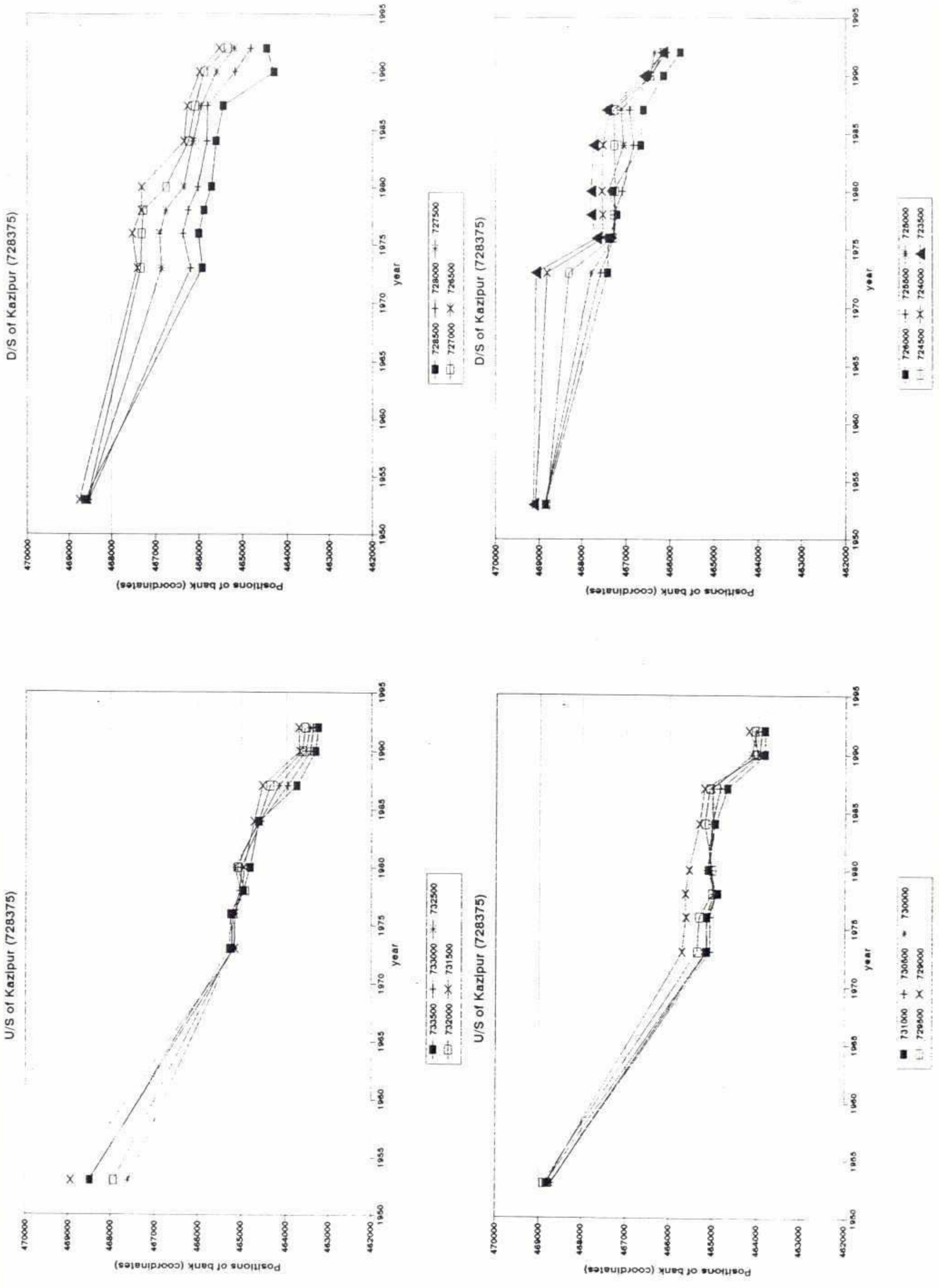






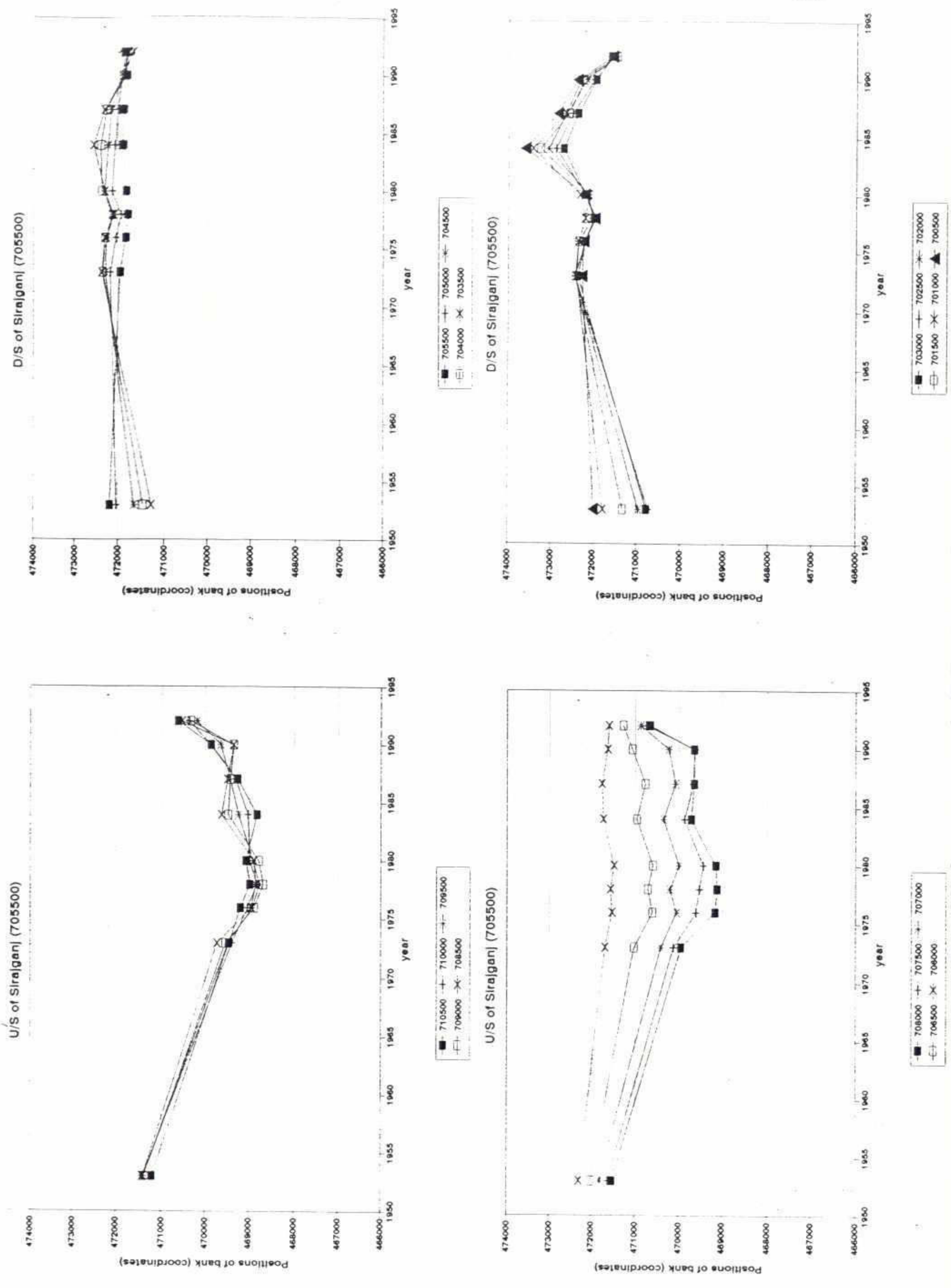
River Bank Erosion 1953-1992

Halcrow/DHI/EPC/DIG | *May 1993* | Figure 7.1 | Sheet 1



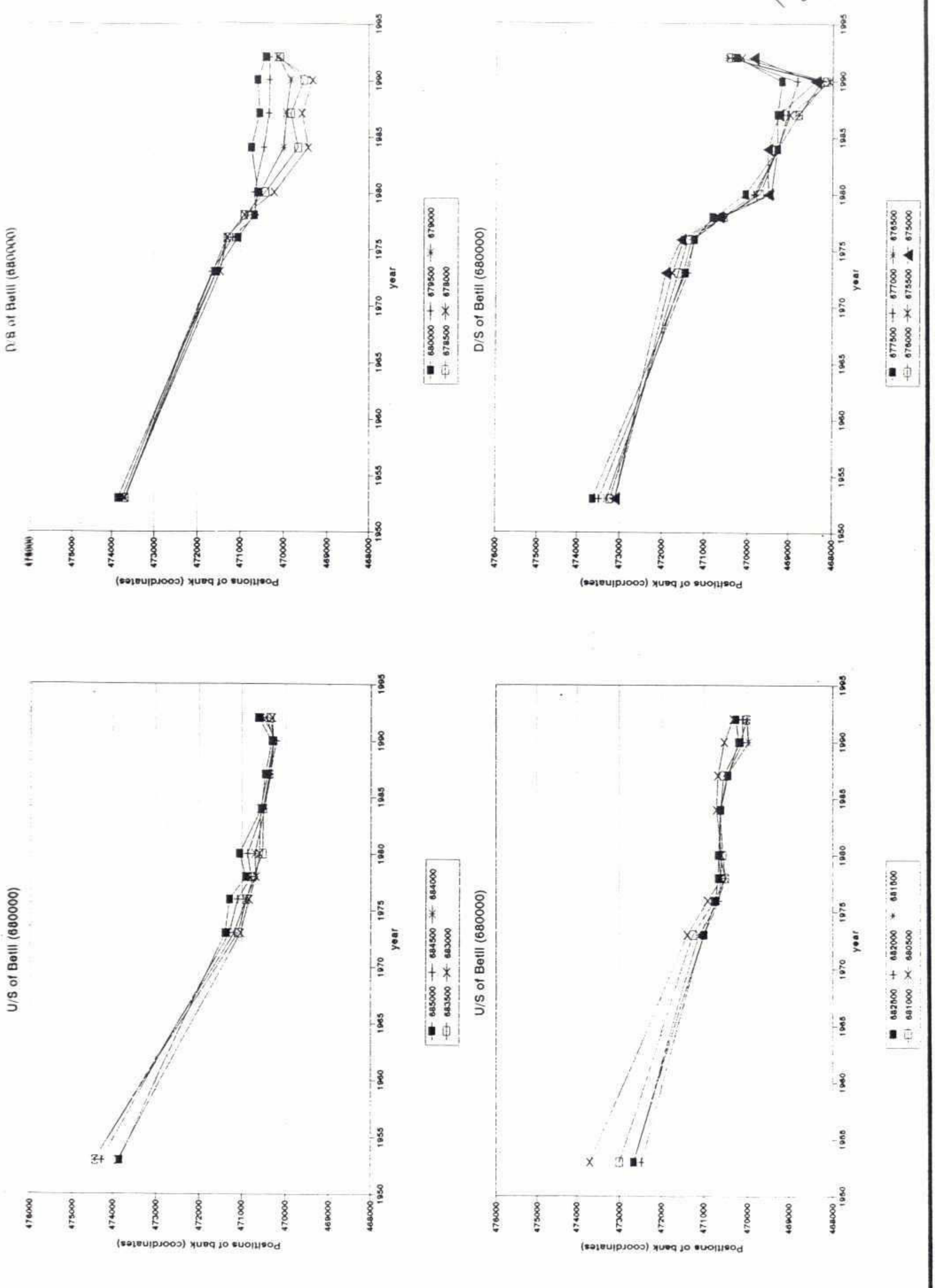
River Bank Erosion 1953-1992

Halcrow/DHI/EPC/DIG	*May 1993*	Figure **7.1** Sheet 2



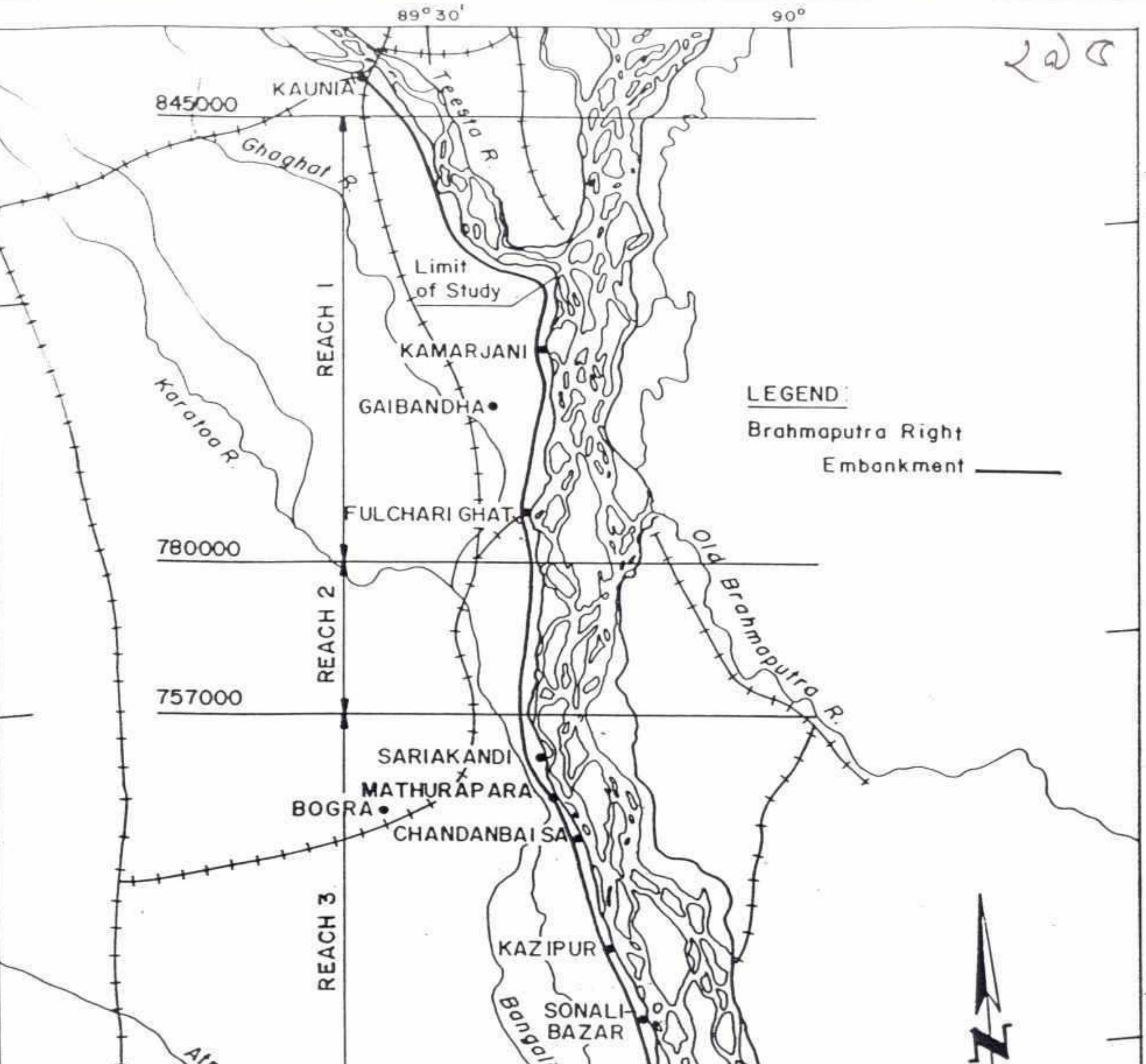
River Bank Erosion 1953-1992

Halcrow/DHI/EPC/DIG	*May 1993*	Figure 7.1 Sheet 3



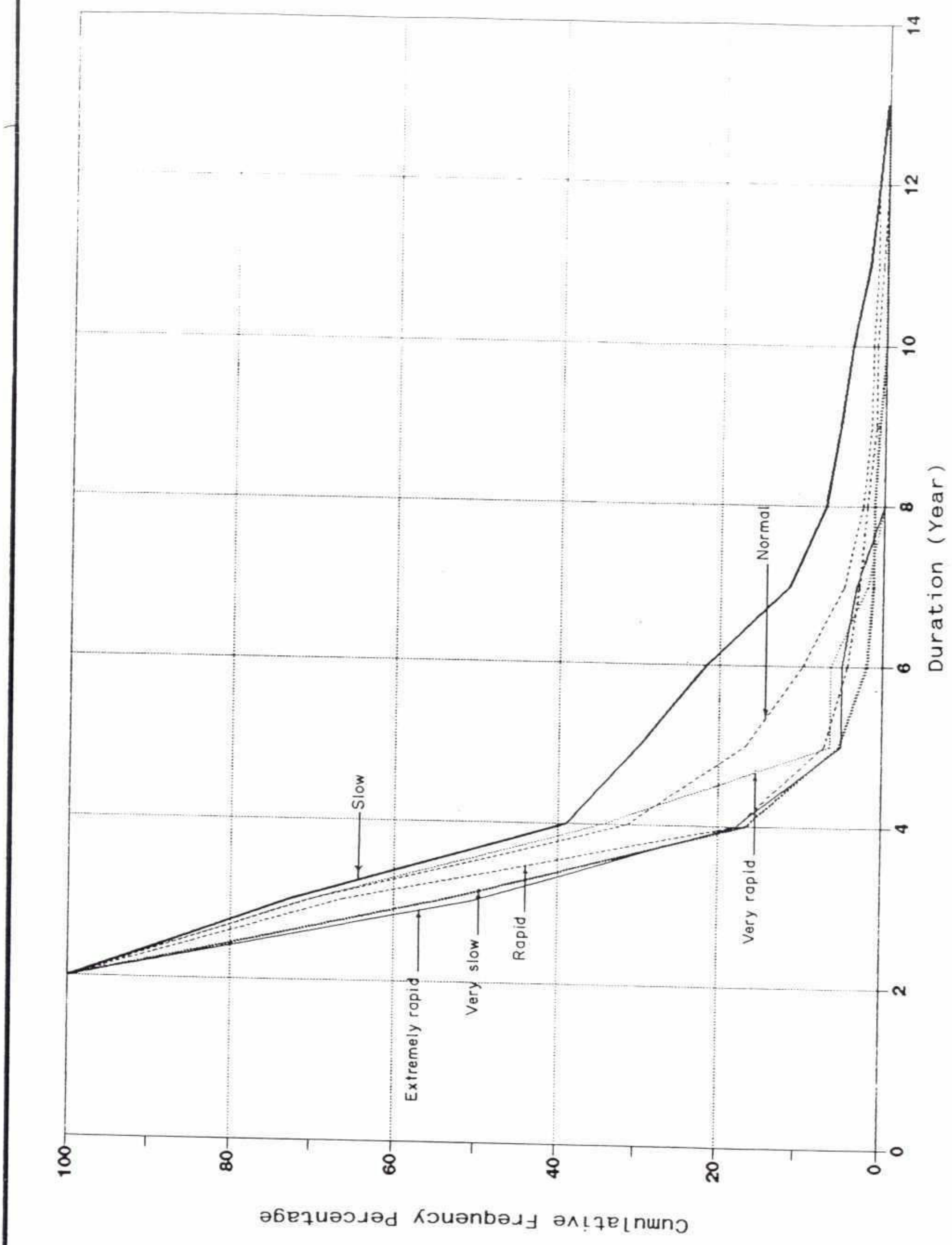
River Bank Erosion 1953-1992

Halcrow/DHI/EPC/DIG *May 1993* Figure 7.1 Sheet 4



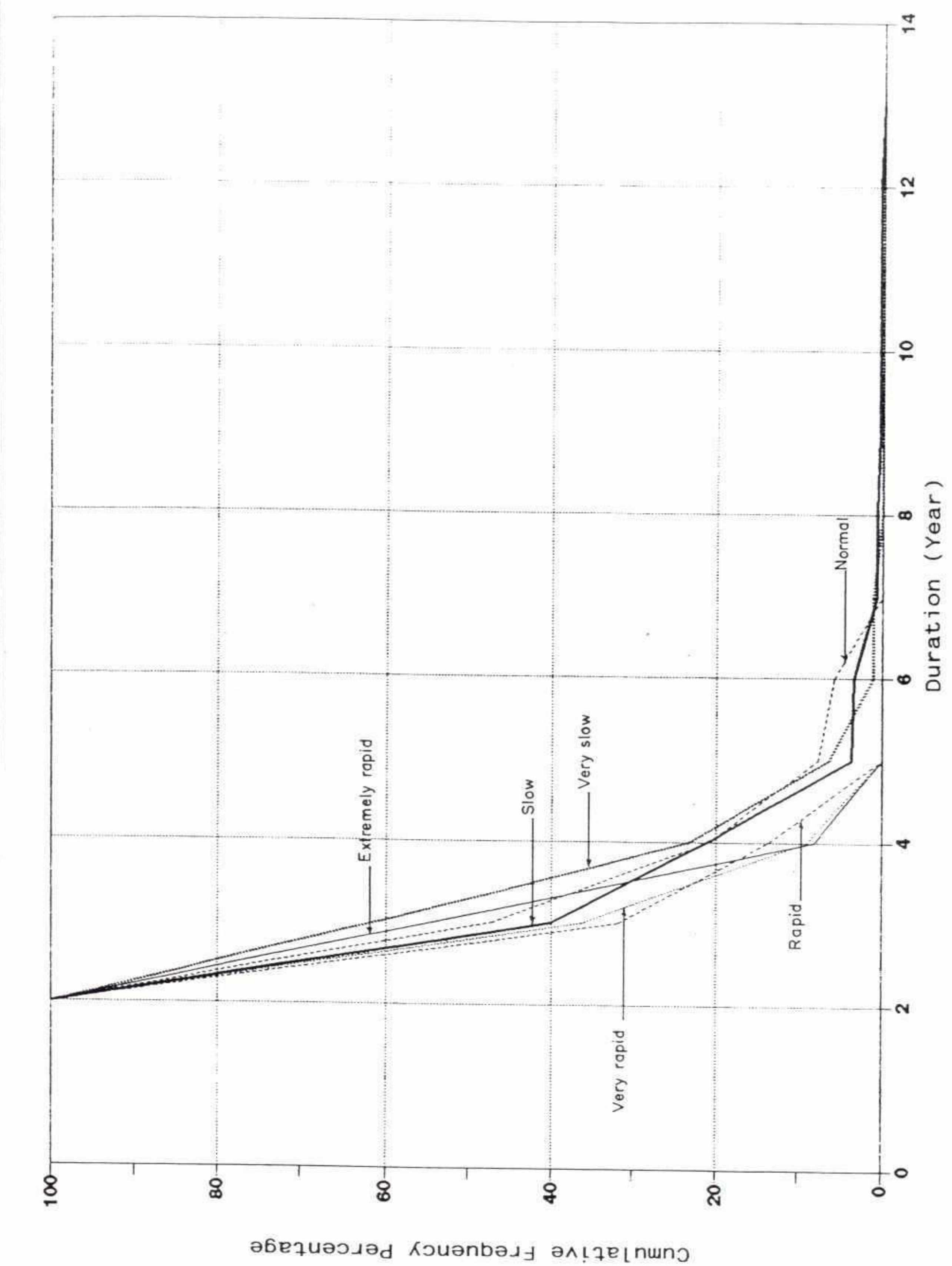
Definition of Reaches for Study of Rates of Erosion

Halcrow/DHI/EPC/DIG *May 1993* **Figure 7.2**



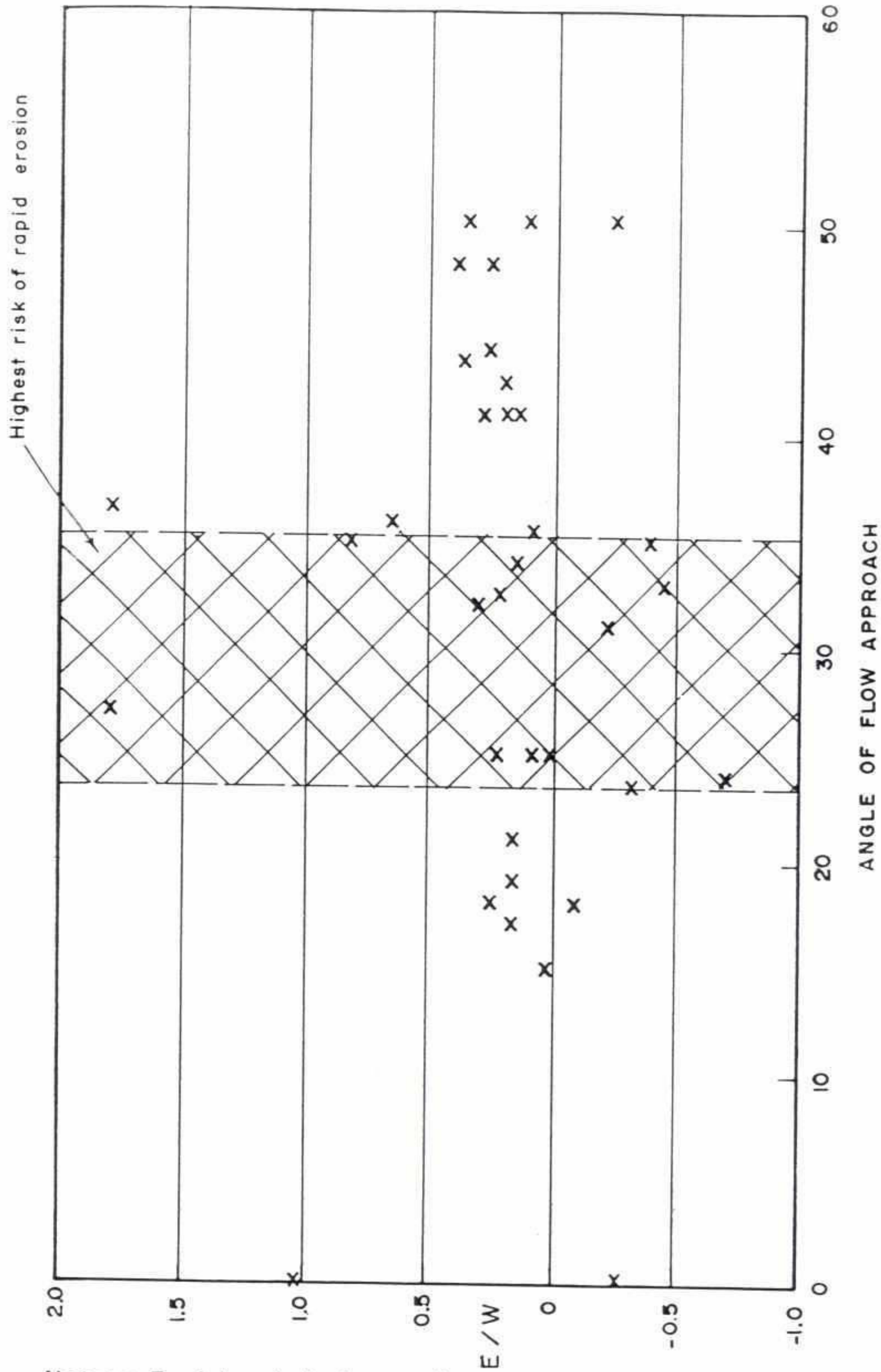
Duration of Erosion, Whole Study Area

Halcrow/DHI/EPC/DIG | *May 1993* | **Figure 7.3**



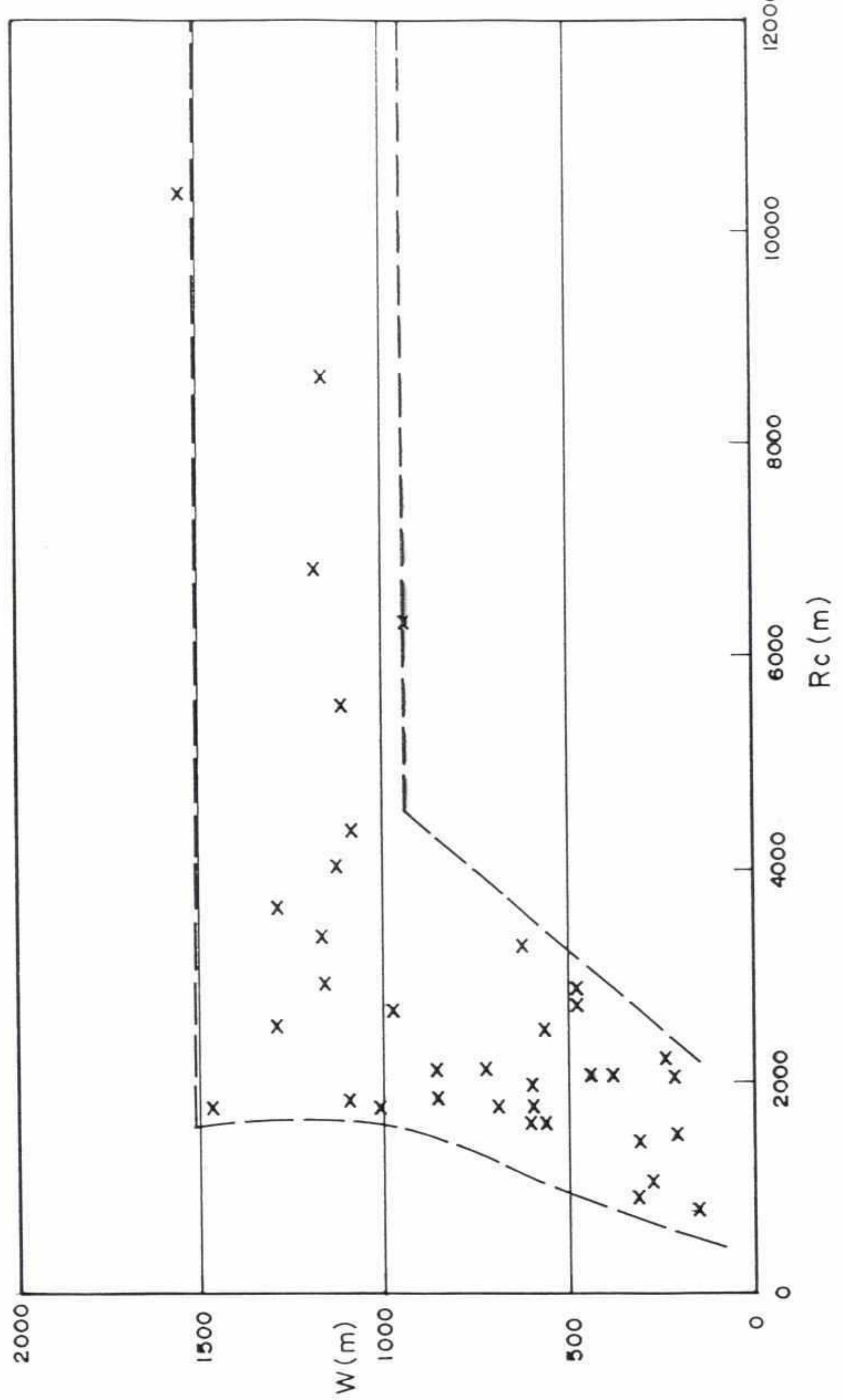
Duration of Accretion, Whole Study Area

Halcrow/DHI/EPC/DIG *May 1993* **Figure 7.4**



Notes : E = lateral displacement
W = bend width

Relationship between Bank Erosion and Angle of Flow Approach

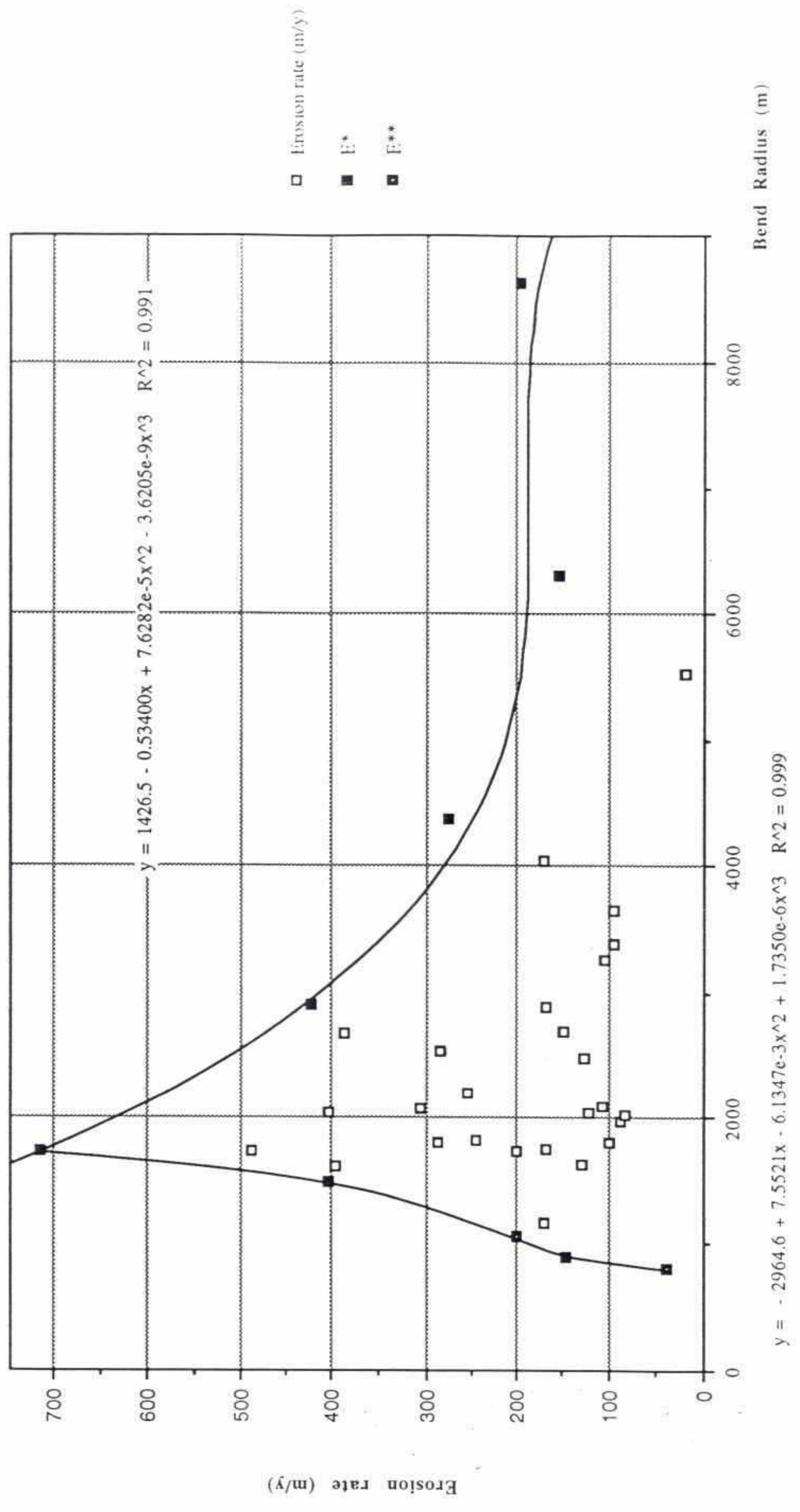


Notes: W = bend width

Rc = bend radius

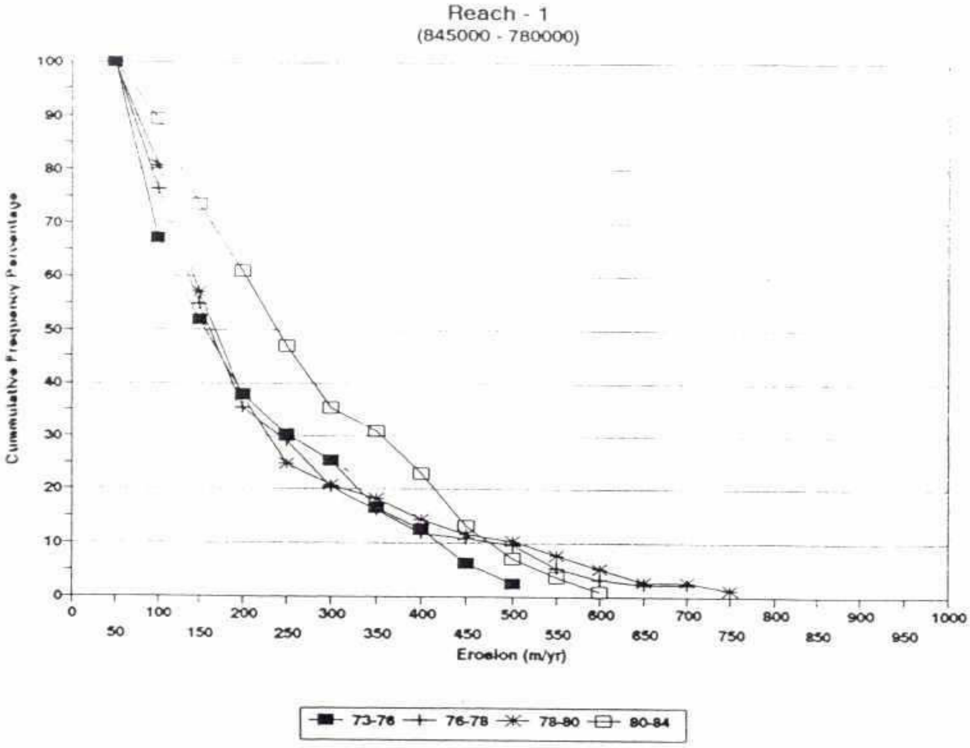
Relationship between Channel width and Radius for selected Aggresive Bends

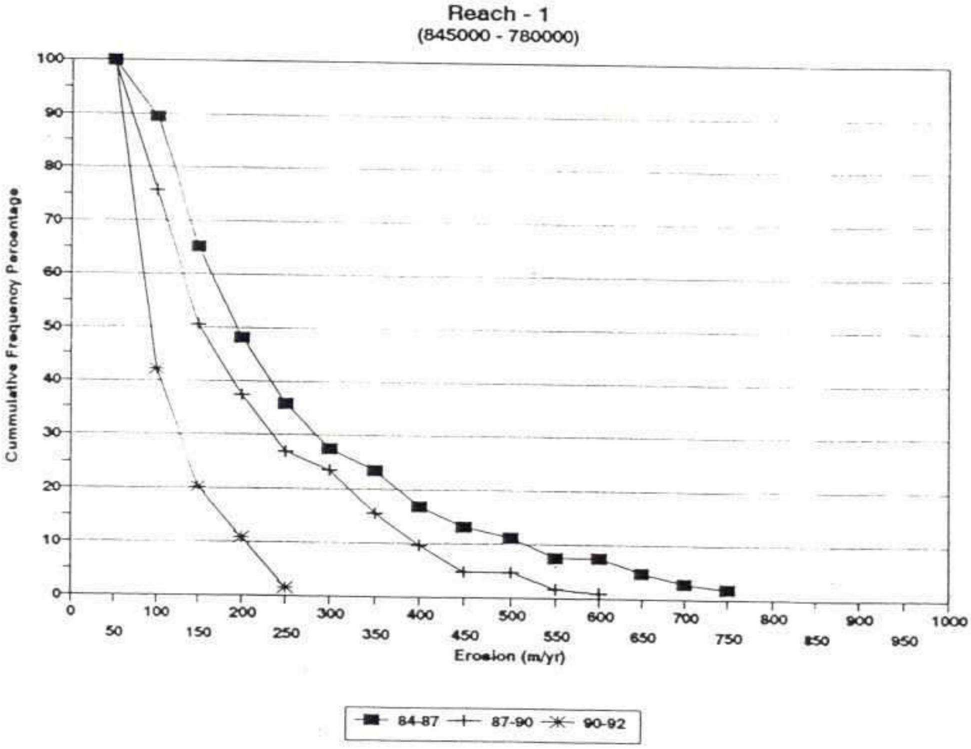
Halcrow/DHI/EPC/DIG	May 1993	Figure 7.6



Bend Erosion Predictor for Brahmaputra Anabranches

Halcrow/DHI/EPC/DIG	*May 1993*	Figure 7.7



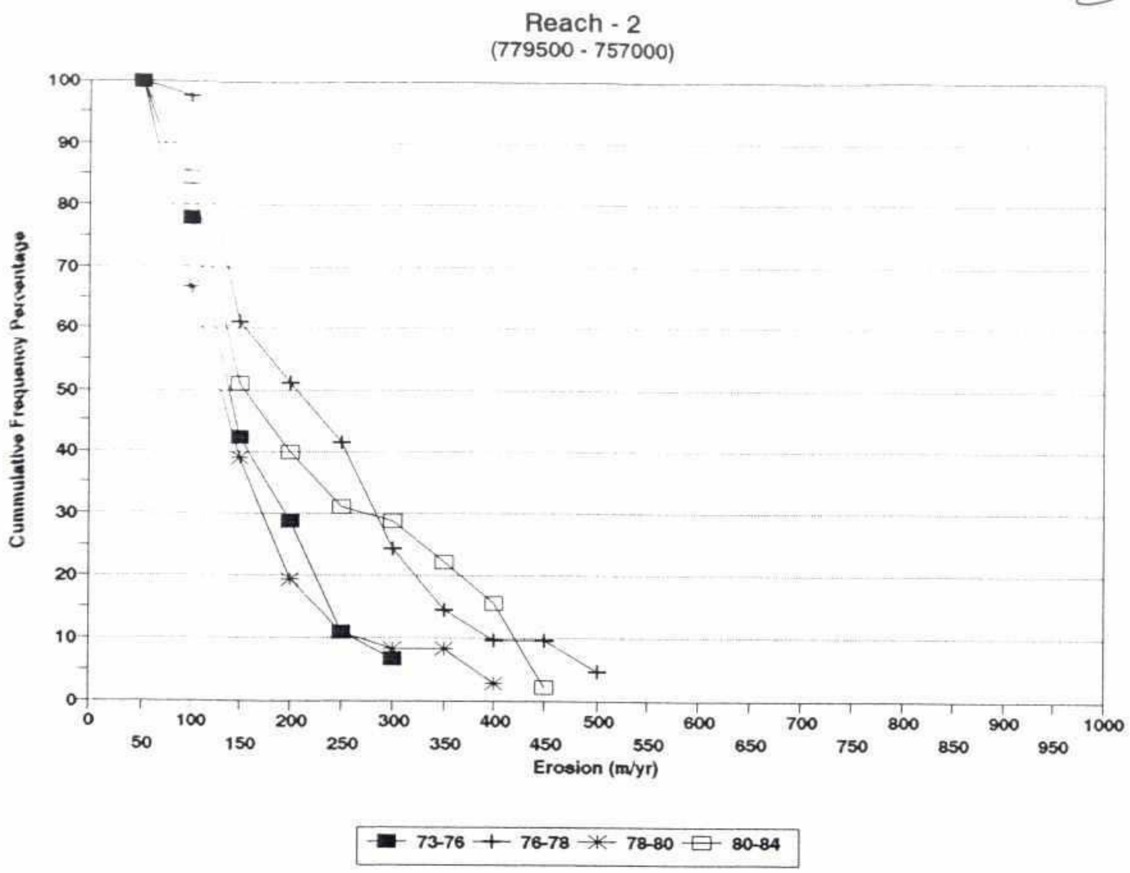


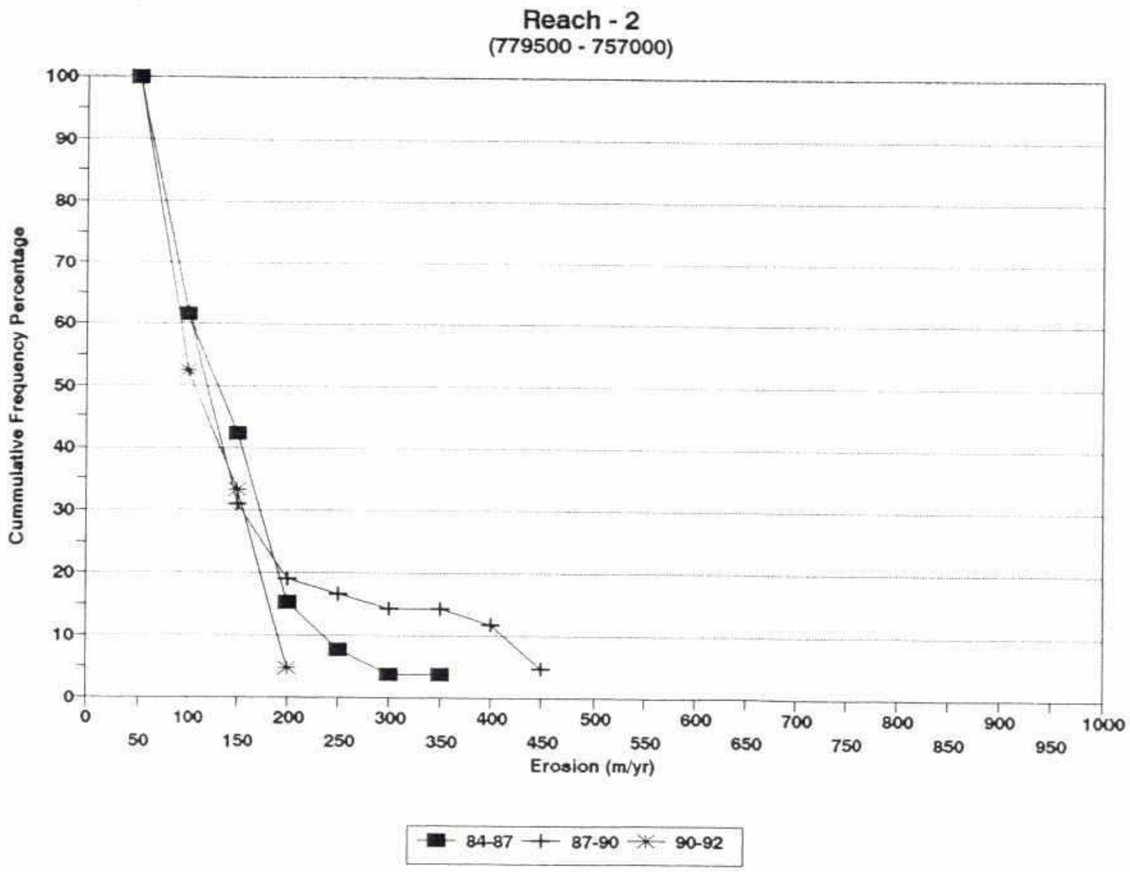
Frequency of Rates of Erosion, Reach 1

Halcrow/DHI/EPC/DIG

May 1993

Figure 7.8

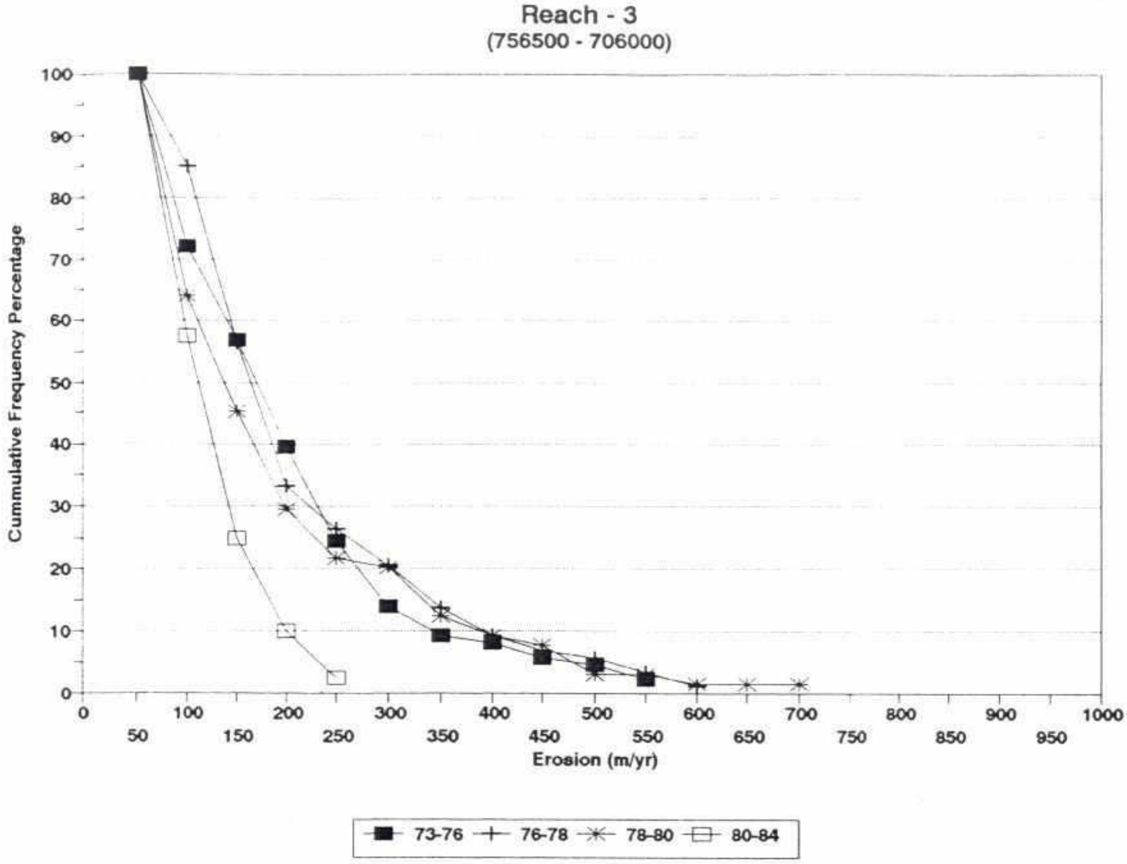


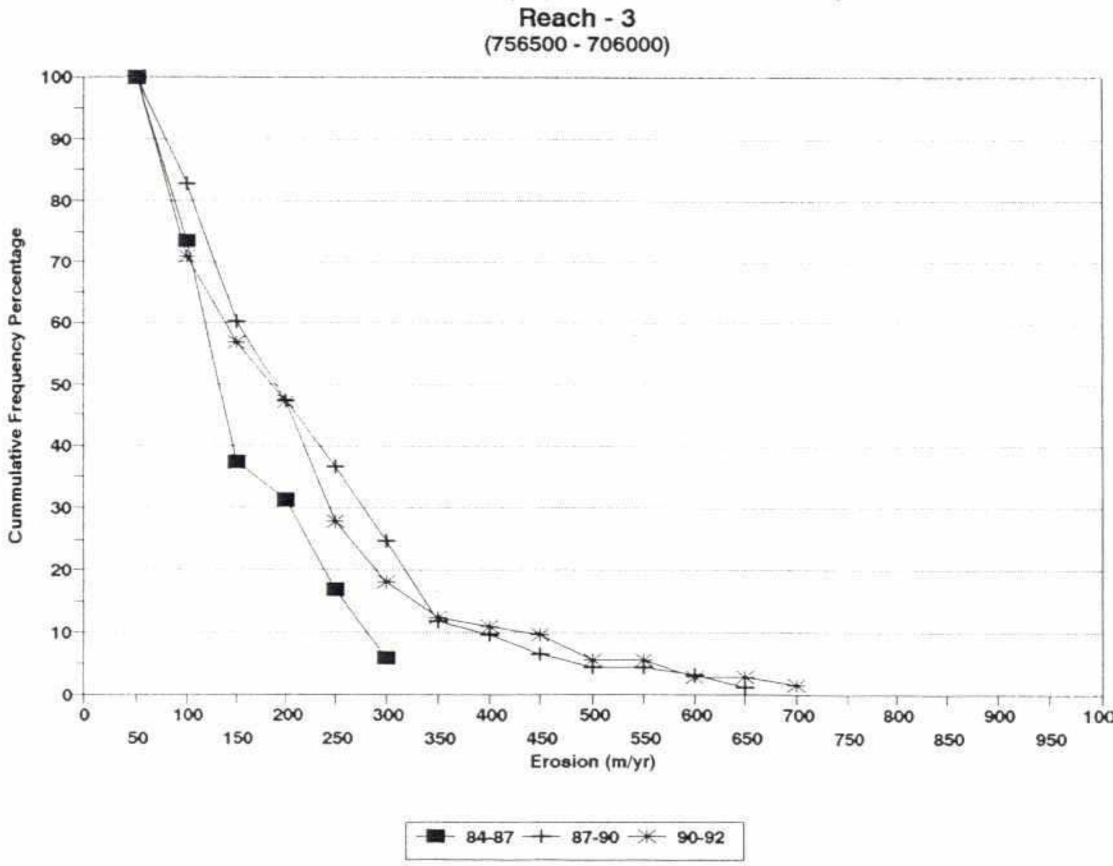


Frequency of Rates of Erosion, Reach 2

Halcrow/DHI/EPC/DIG | *May 1993* | Figure 7.9

C38





Frequency of Rates of Erosion, Reach 3

Halcrow/DHI/EPC/DIG | May 1993 | Figure 7.10

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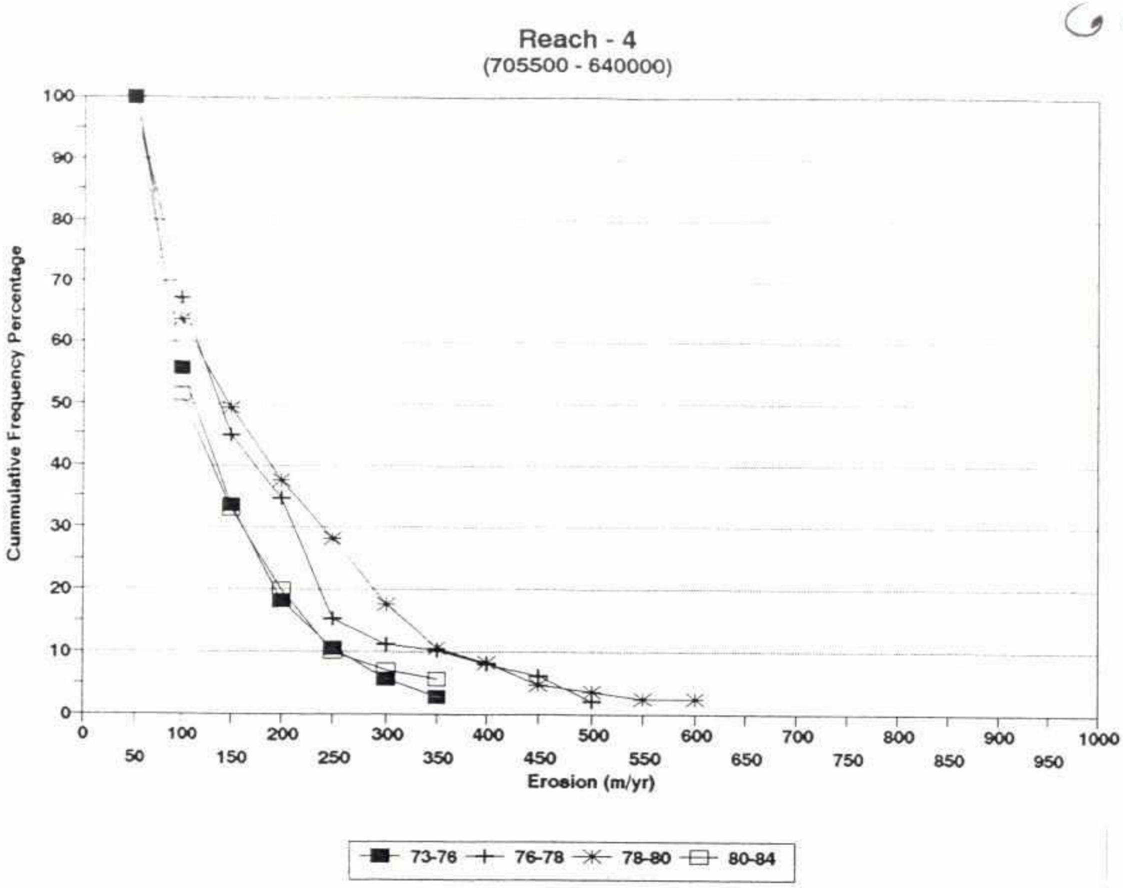
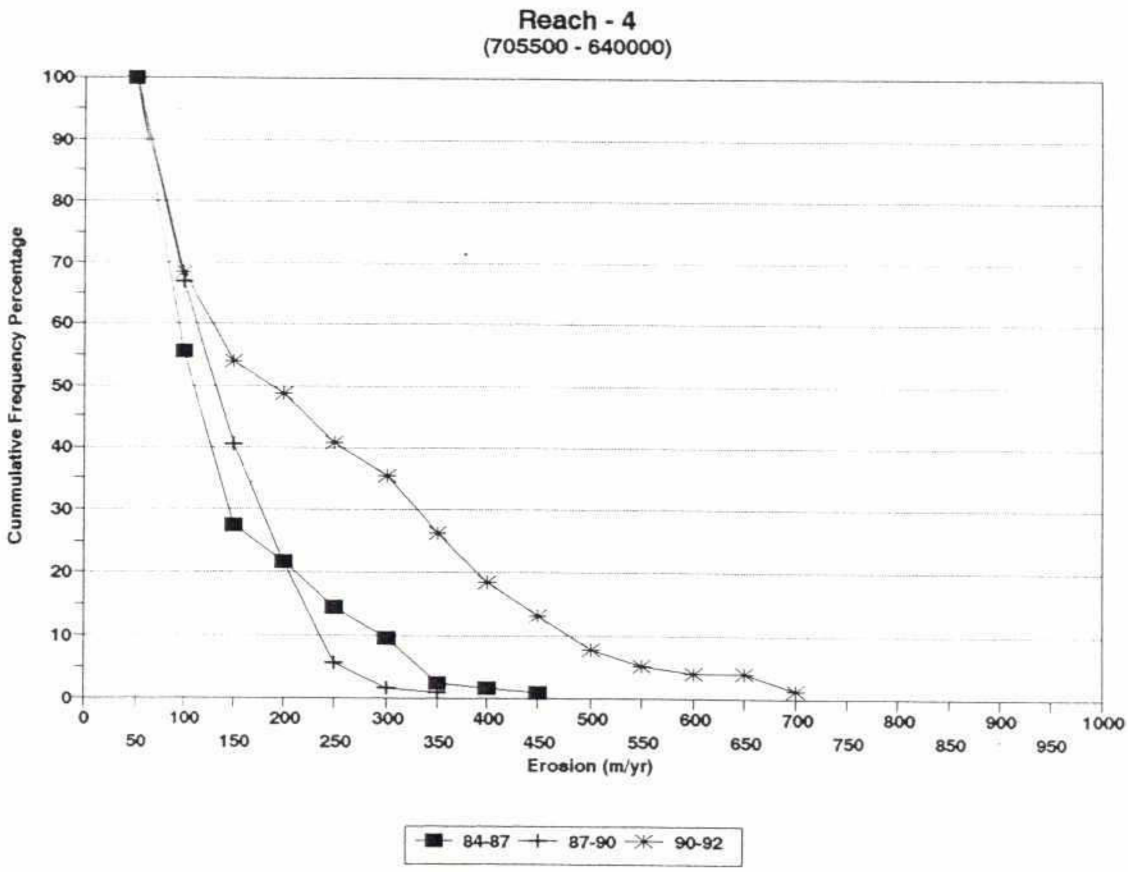


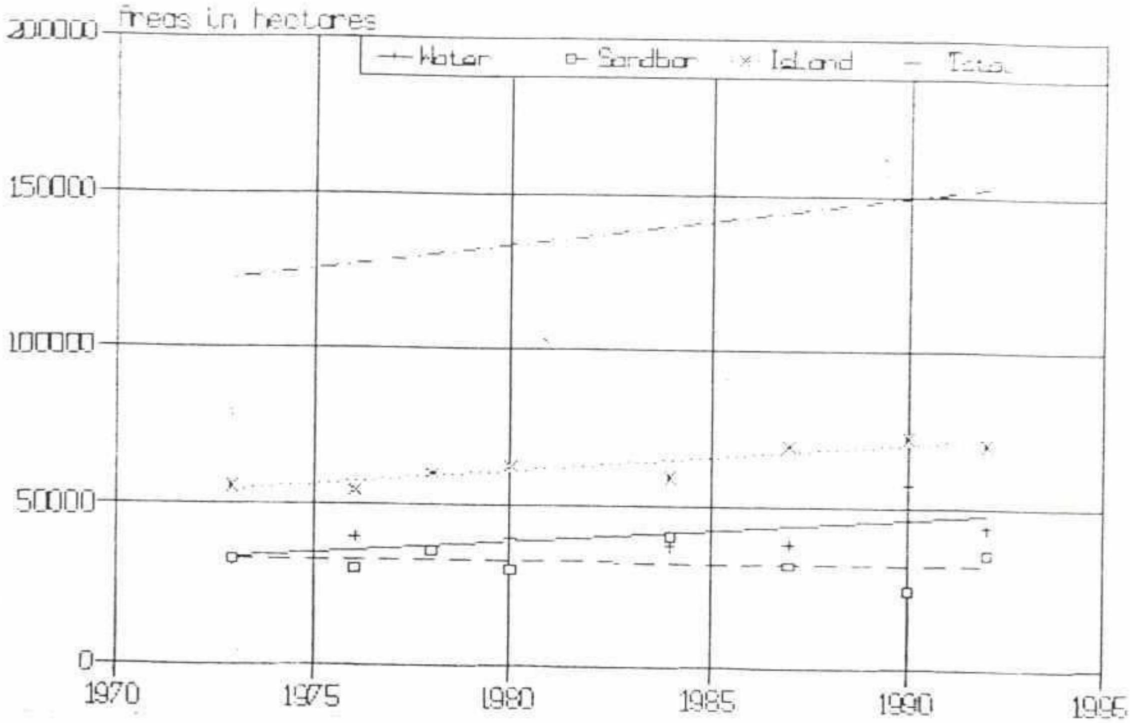


Frequency of Rates of Erosion, Reach 4

Halcrow/DHI/EPC/DIG	*May 1993*	Figure 7.11

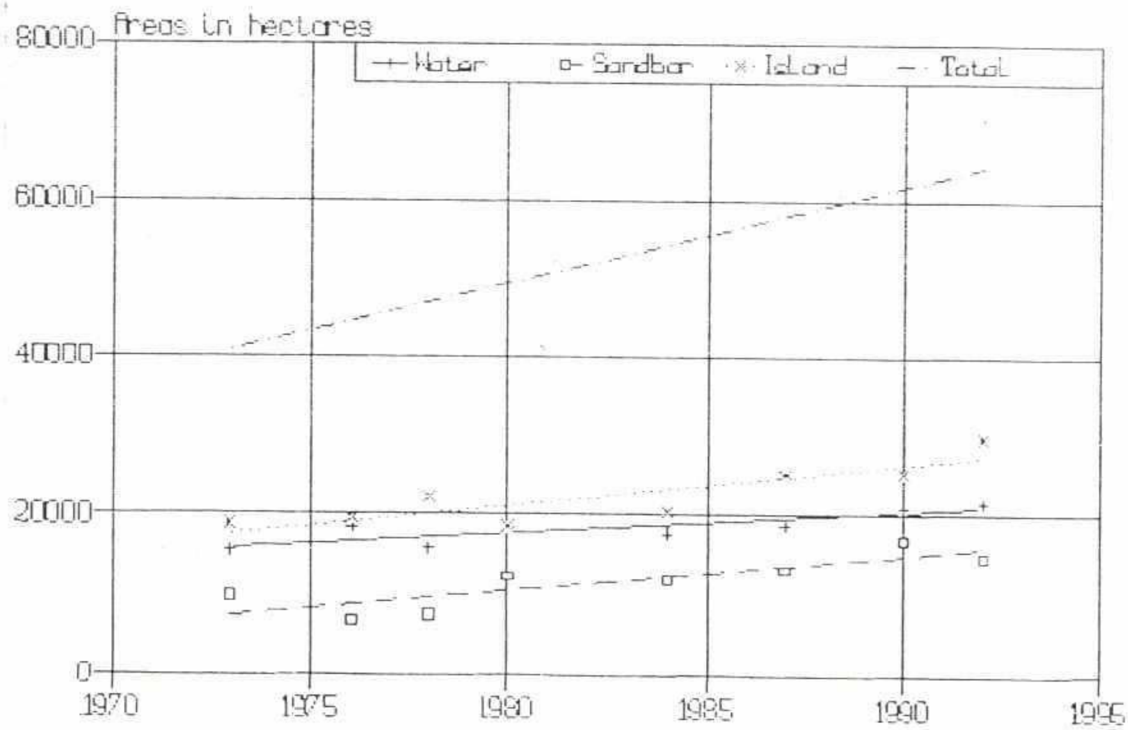
Jamuna River North of Sirajganj

Areas of Island, Sandbar and Water



Jamuna River South of Sirajganj

Areas of Island, Sandbar and Water



Increase of Bank to Bank Area With Time

Halcrow/DHI/EPC/DIG	*May 1993*	**Figure 7.12**

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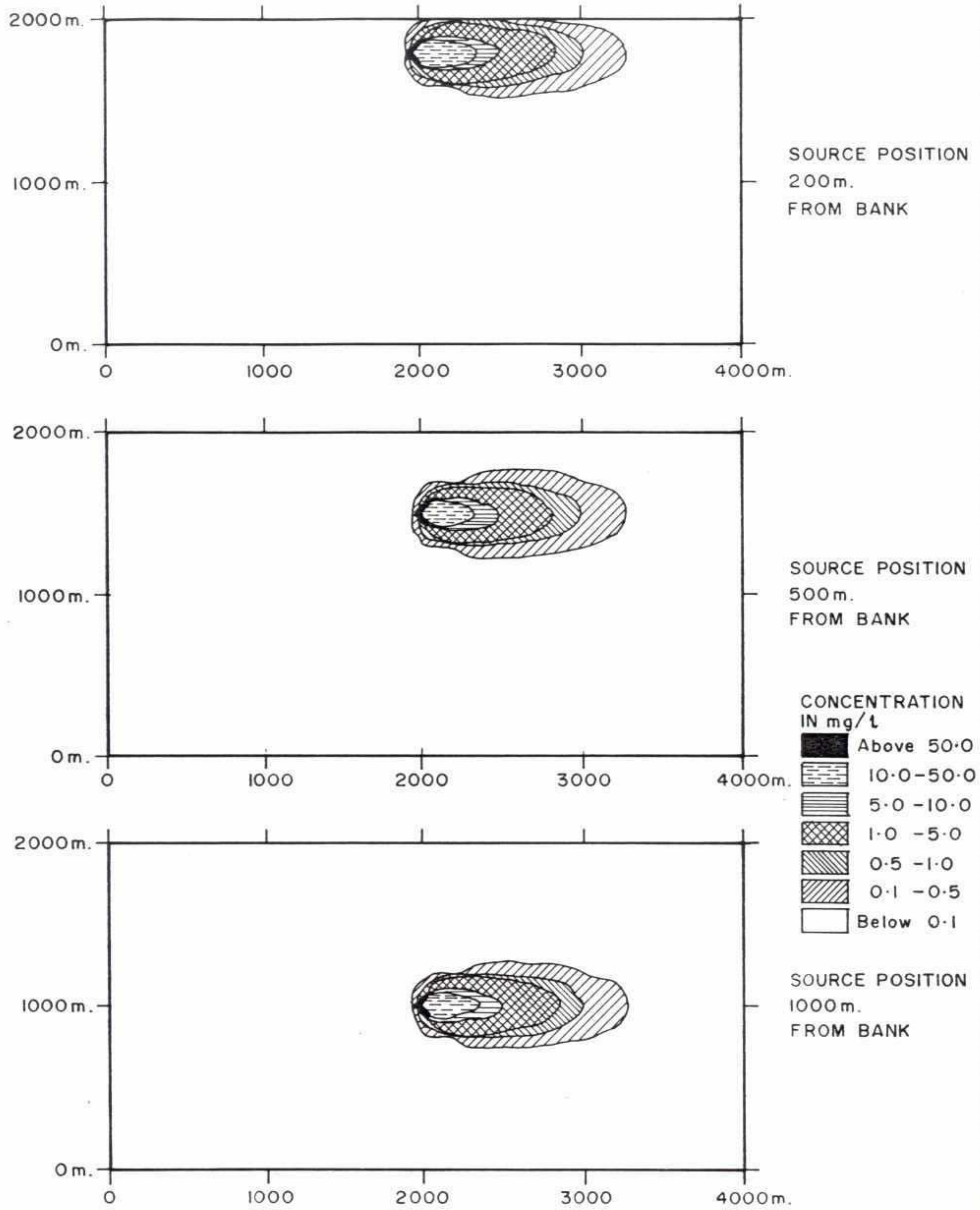


ASSUMPTIONS:

Discharge : Continuous single point discharge, rate 60/m³/ hour (44·2 kg/s at density 2·65 t/m³).

Flow velocity : 1 m/s across the entire section.

Channel cross-section

Rectanguar, Width 2000m, Depth 8m.

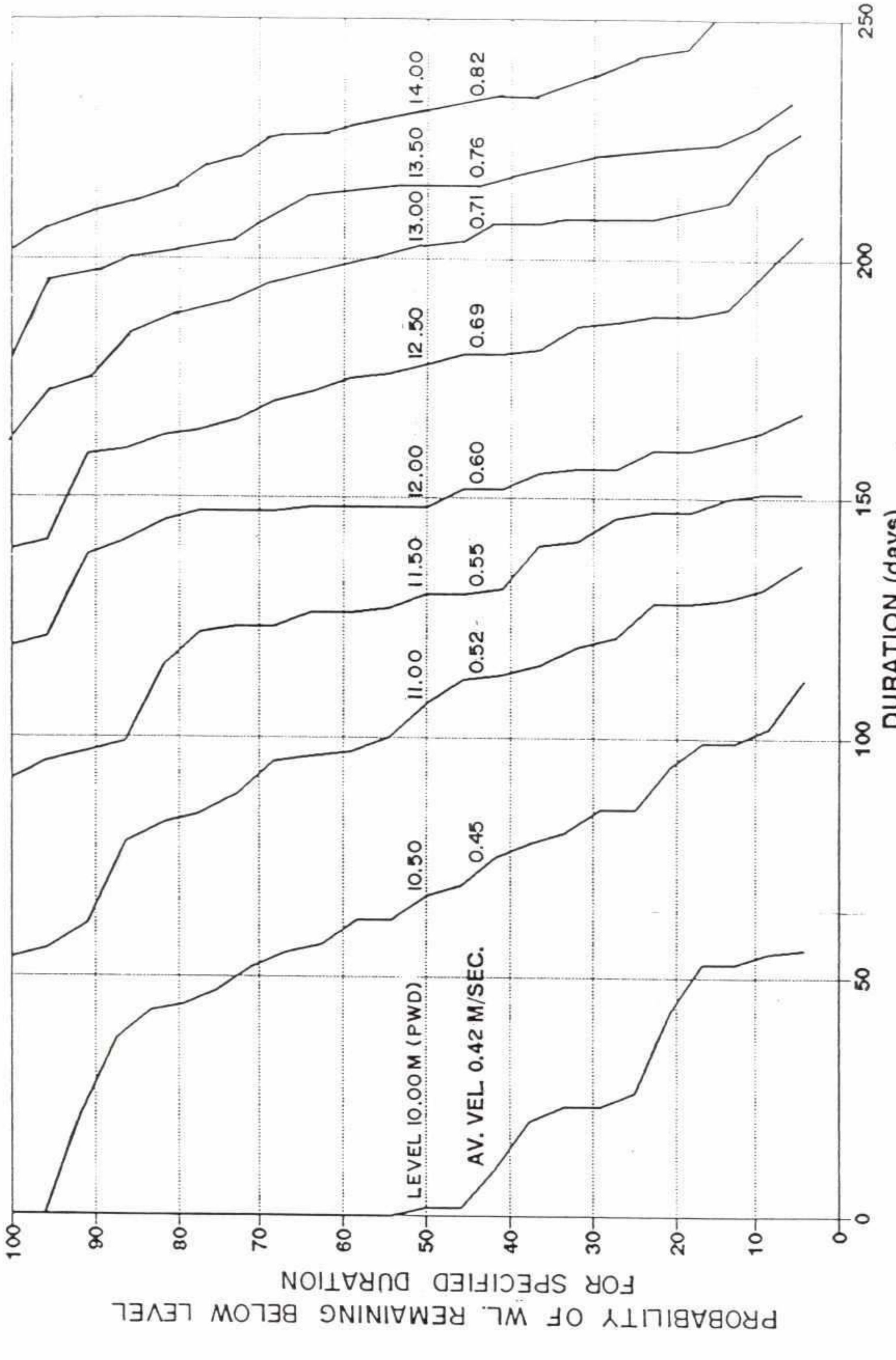
Settling velocity :

0·025 m/s (Fine sand, d50 = 0·18 mm).

SOURCE : DANISH HYDRAULIC INSTITUTE MARCH 1992

Silt Plume Estimate

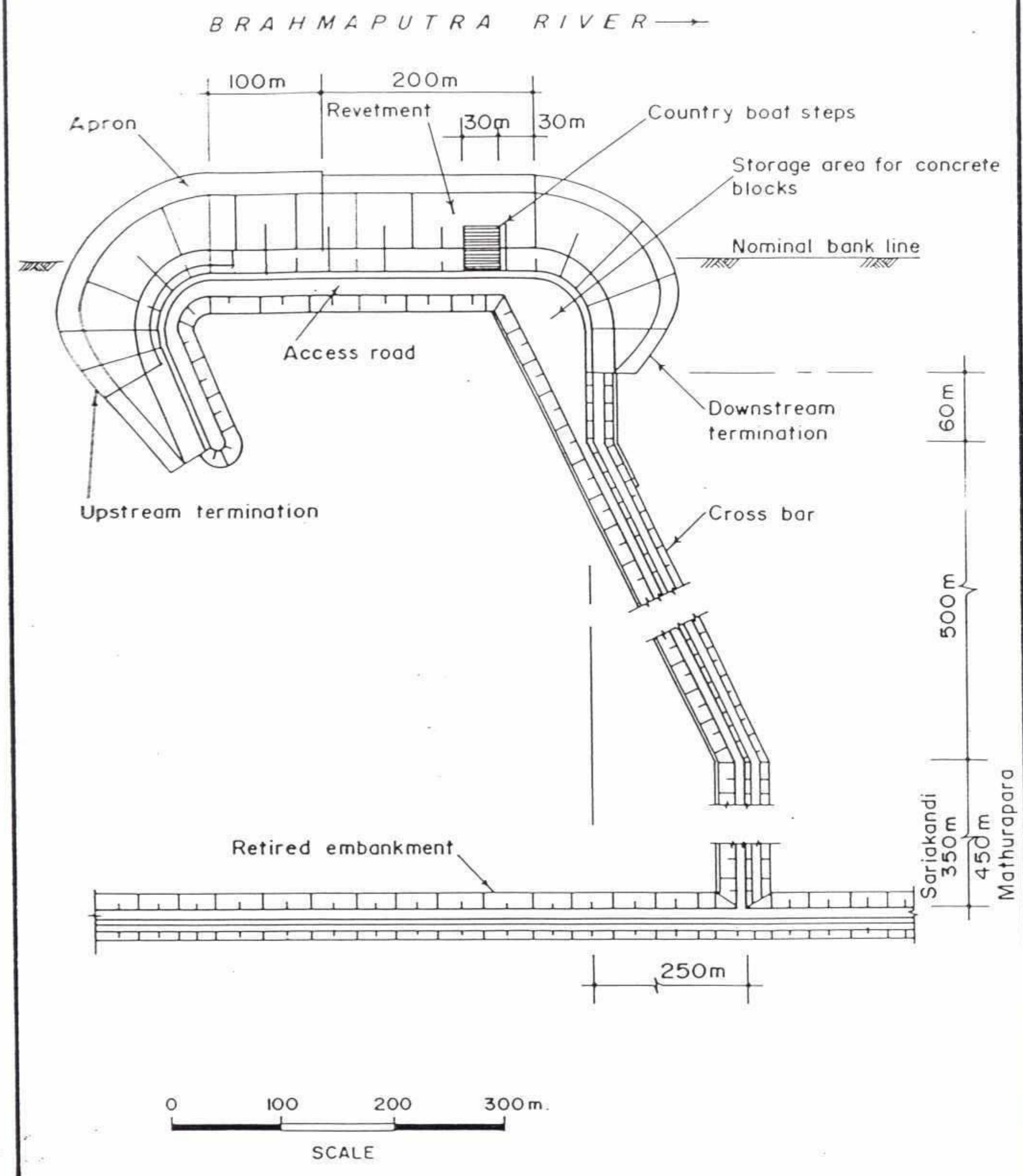
Halcrow/DHI/EPC/DIG | *May 1993* | **Figure 12.1**



Section J-10

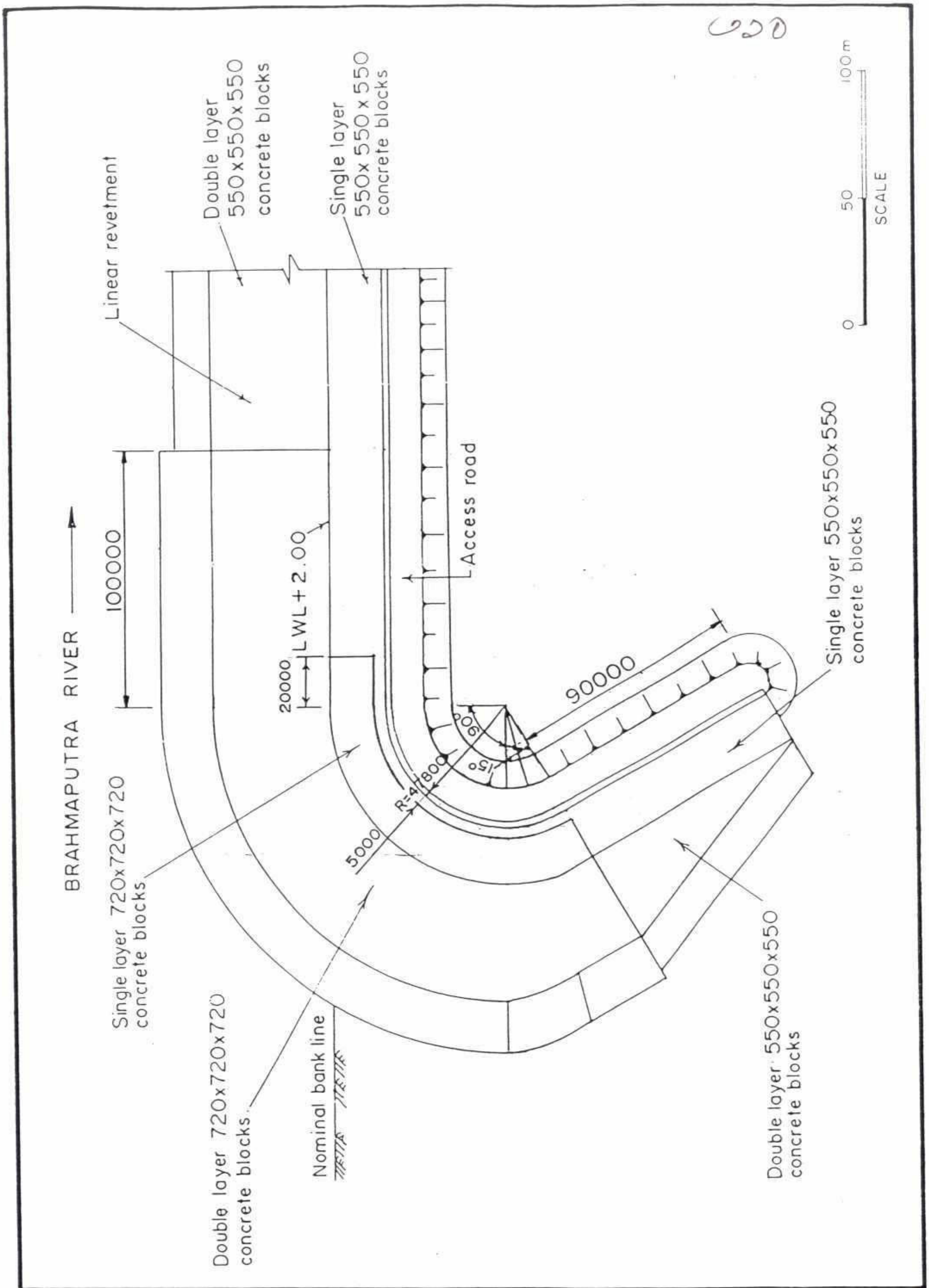
Probability of a Construction Window

Halcrow/DHI/EPC/DIG | May 1993 | **Figure 14.1**



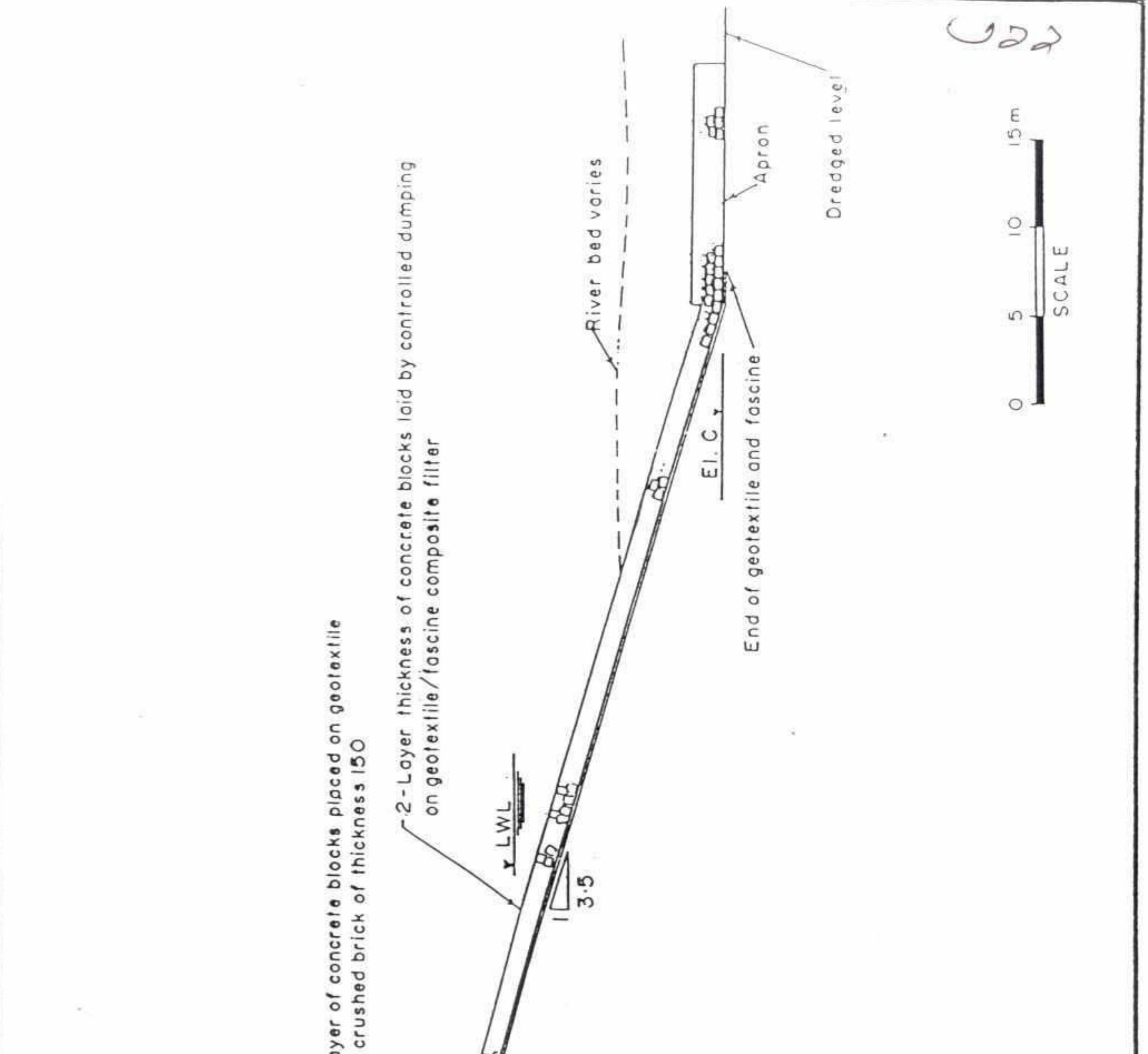
Typical Hard-Point and Cross-Bar

Halcrow/DHI/EPC/DIG May 1993 Figure 14.2

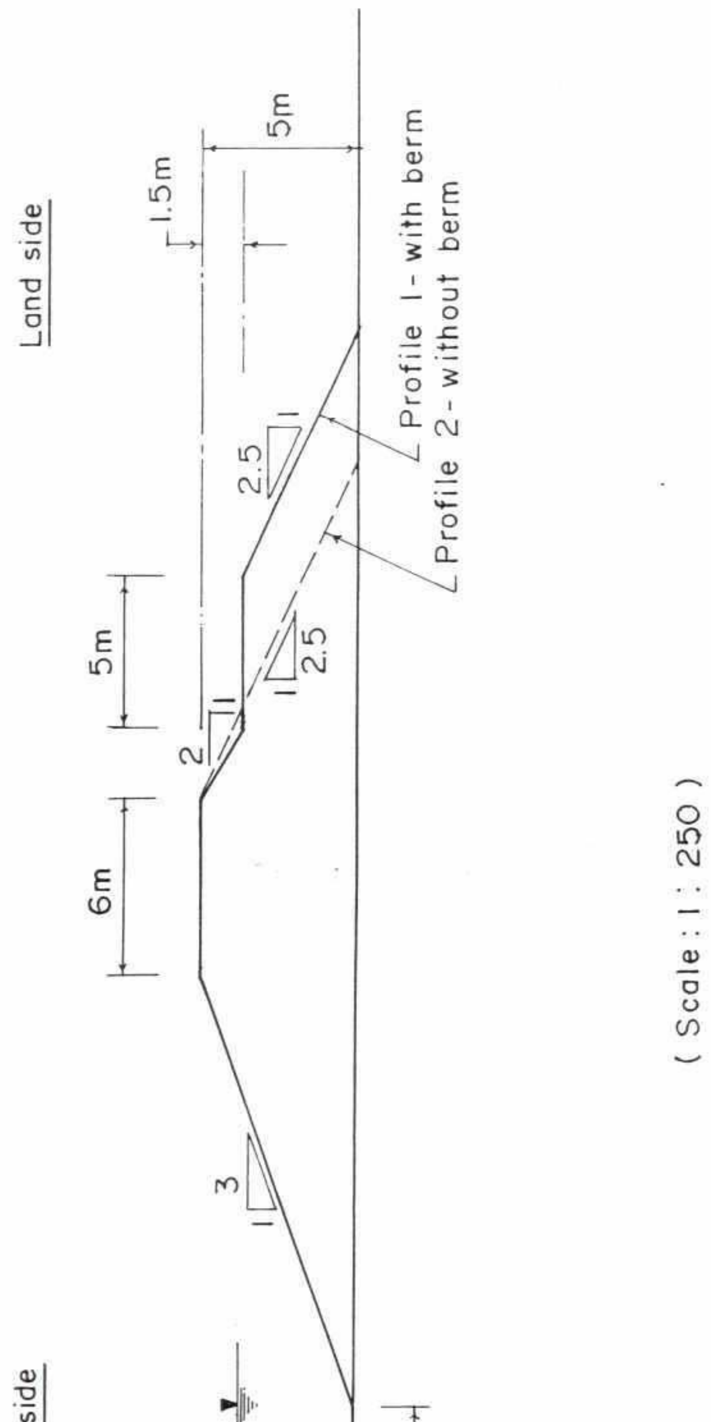


Plan of Upstream Termination

Halcrow/DHI/EPC/DIG *May 1993* **Figure 14.3**

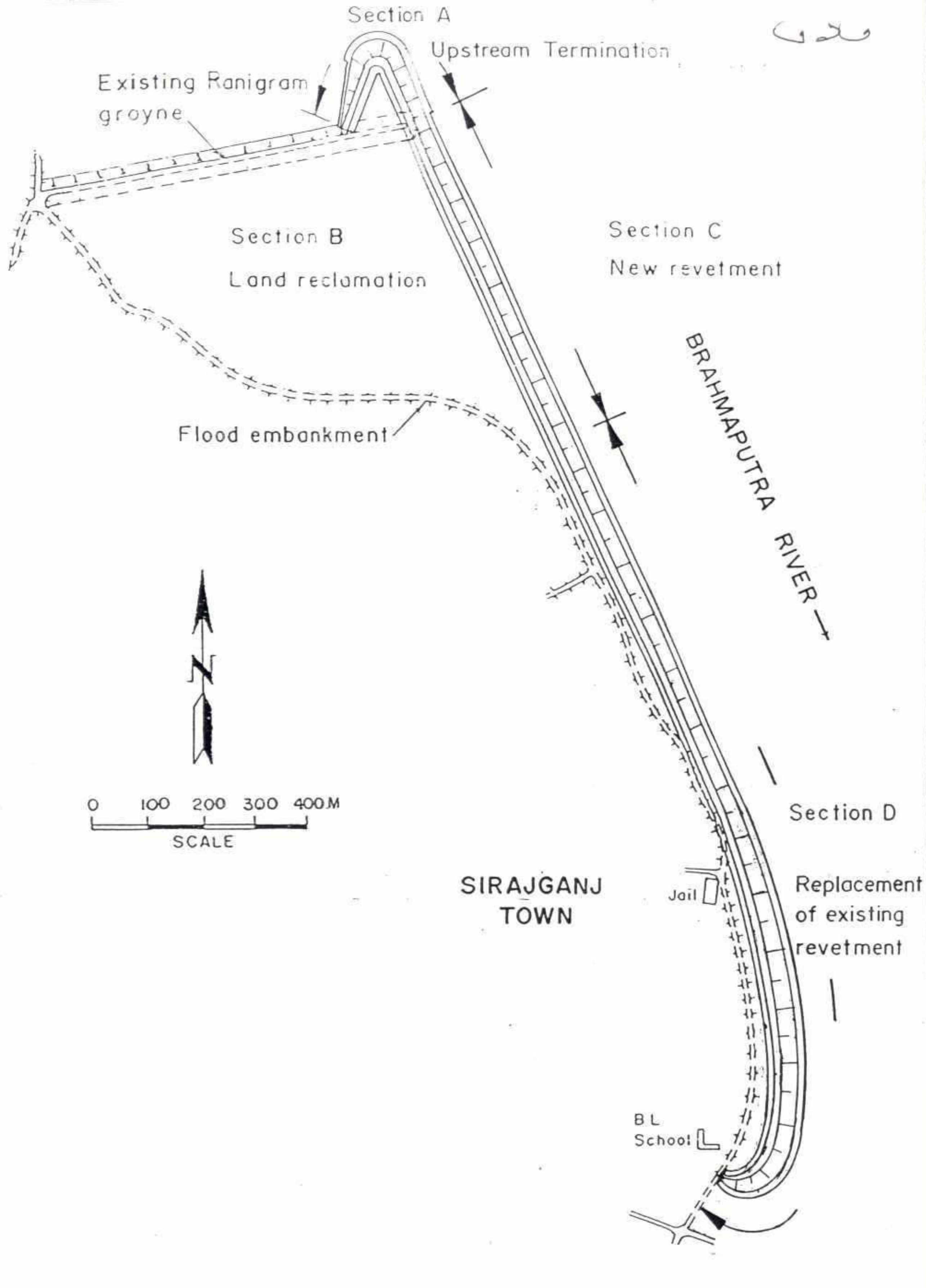


Typical Revetment Section



Design Section of BRE

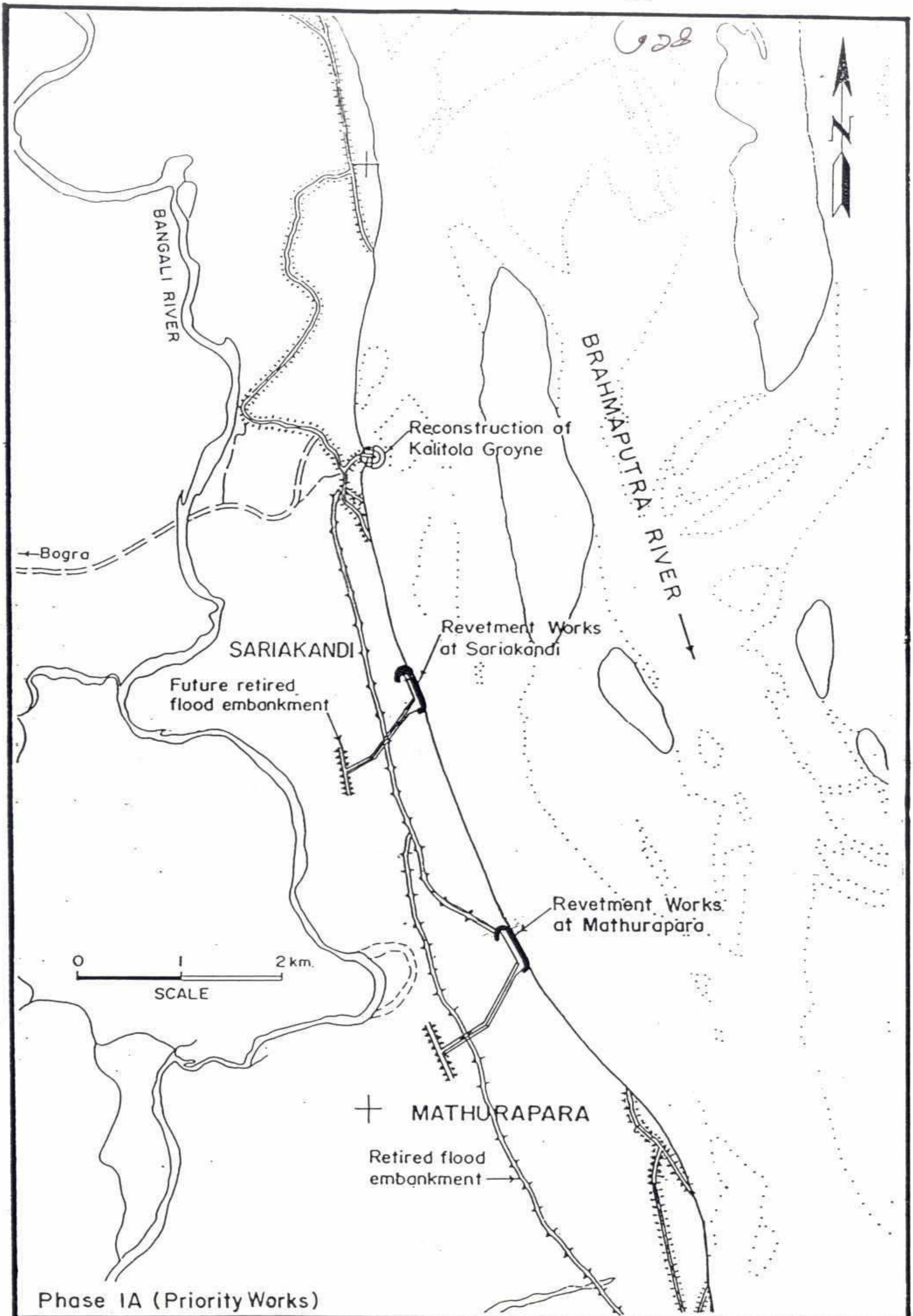
Halcrow/DHI/EPC/DIG *May 1993* **Figure 15.1**



Phase 1A (Priority Works)

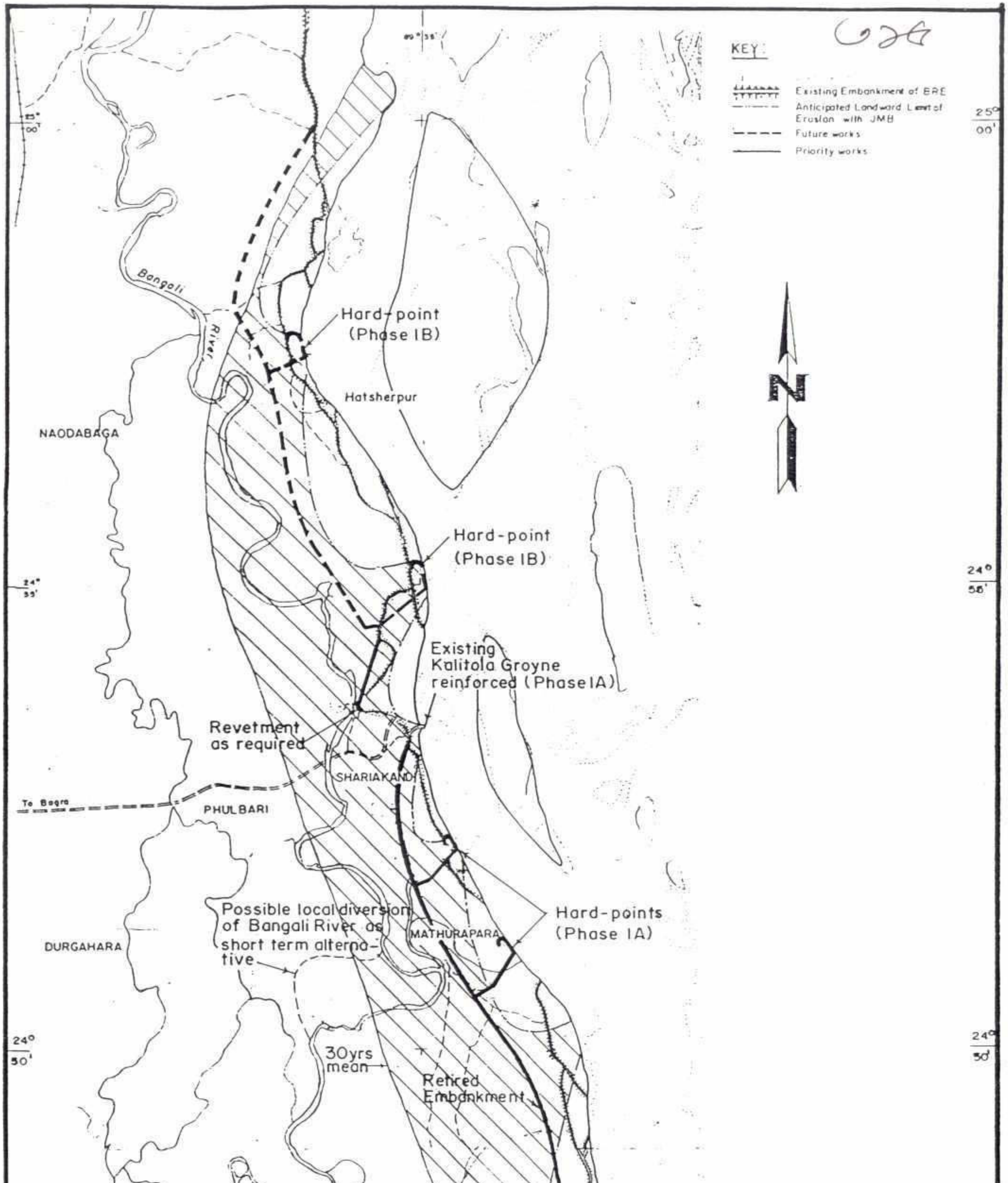
Layout of Works at Sirajganj

Halcrow/DHI/EPC/DIG *May 1993* **Figure 16.1**



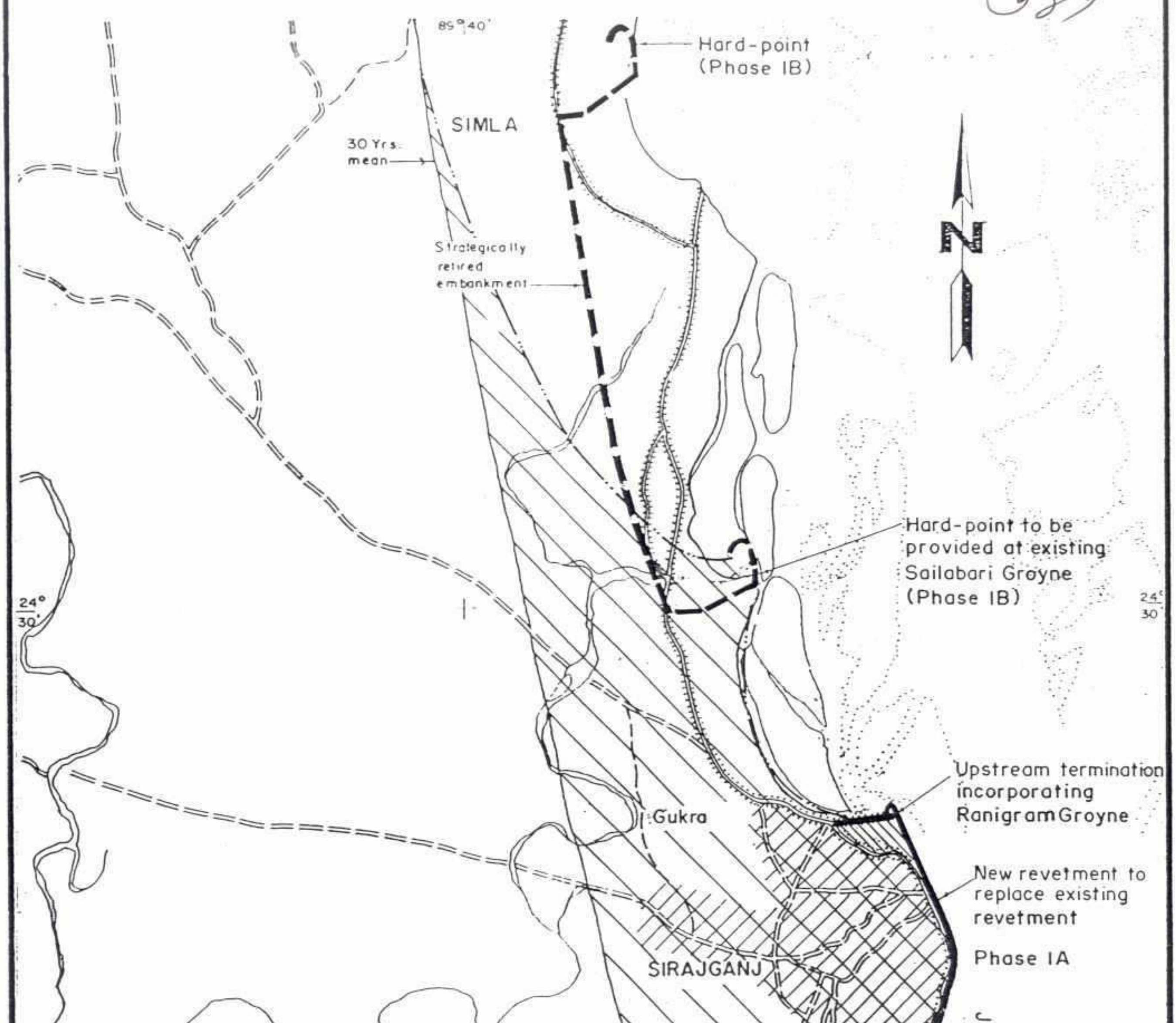
Layout of Works at Sariakandi & Mathurapara

Halcrow/DHI/EPC/DIG *May 1993* **Figure 16.2**



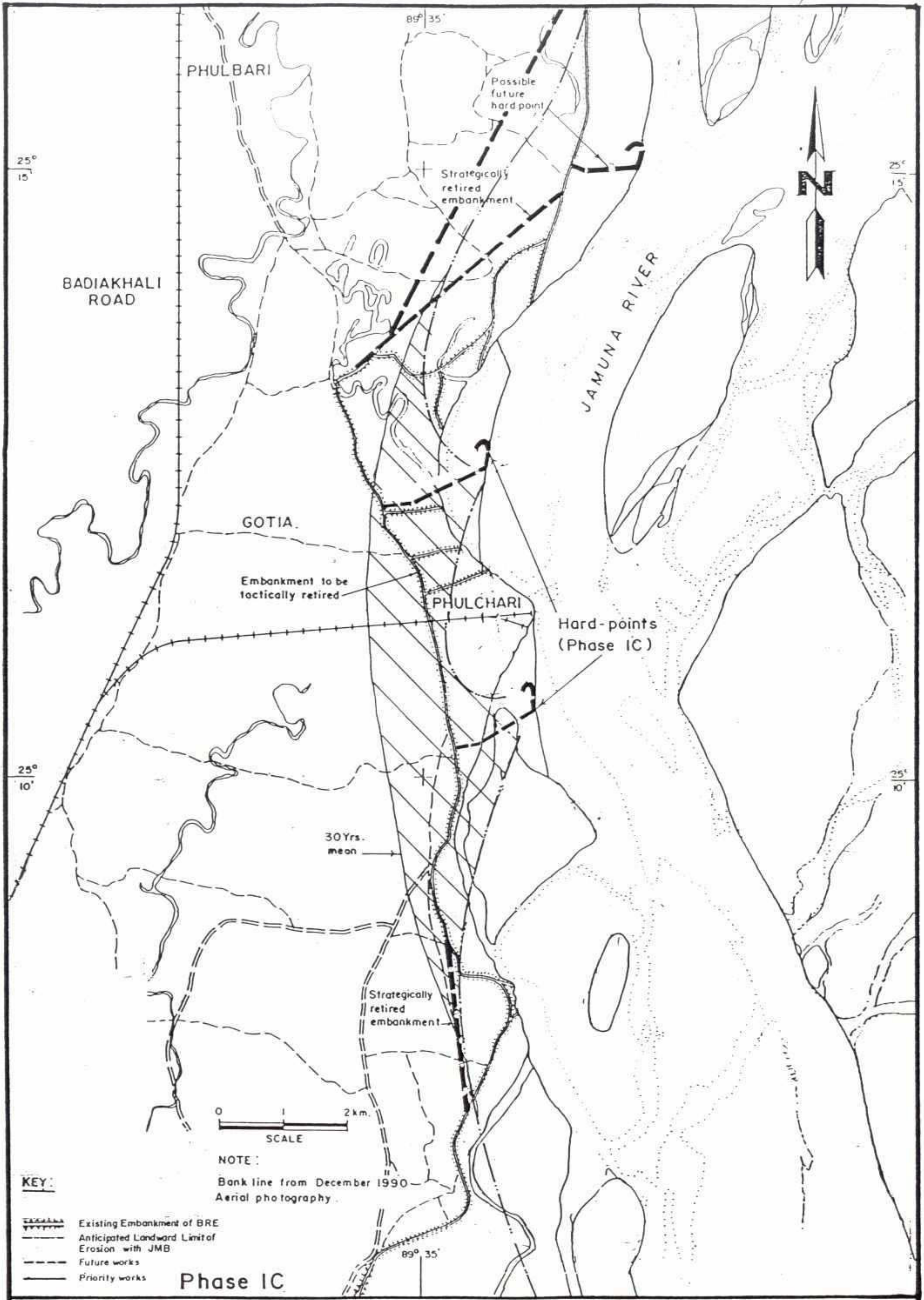
Priority and Future Works at Sariakandi and Mathurapara

Halcrow/DHI/EPC/DIG | *May 1993* | **Figure 16.3**



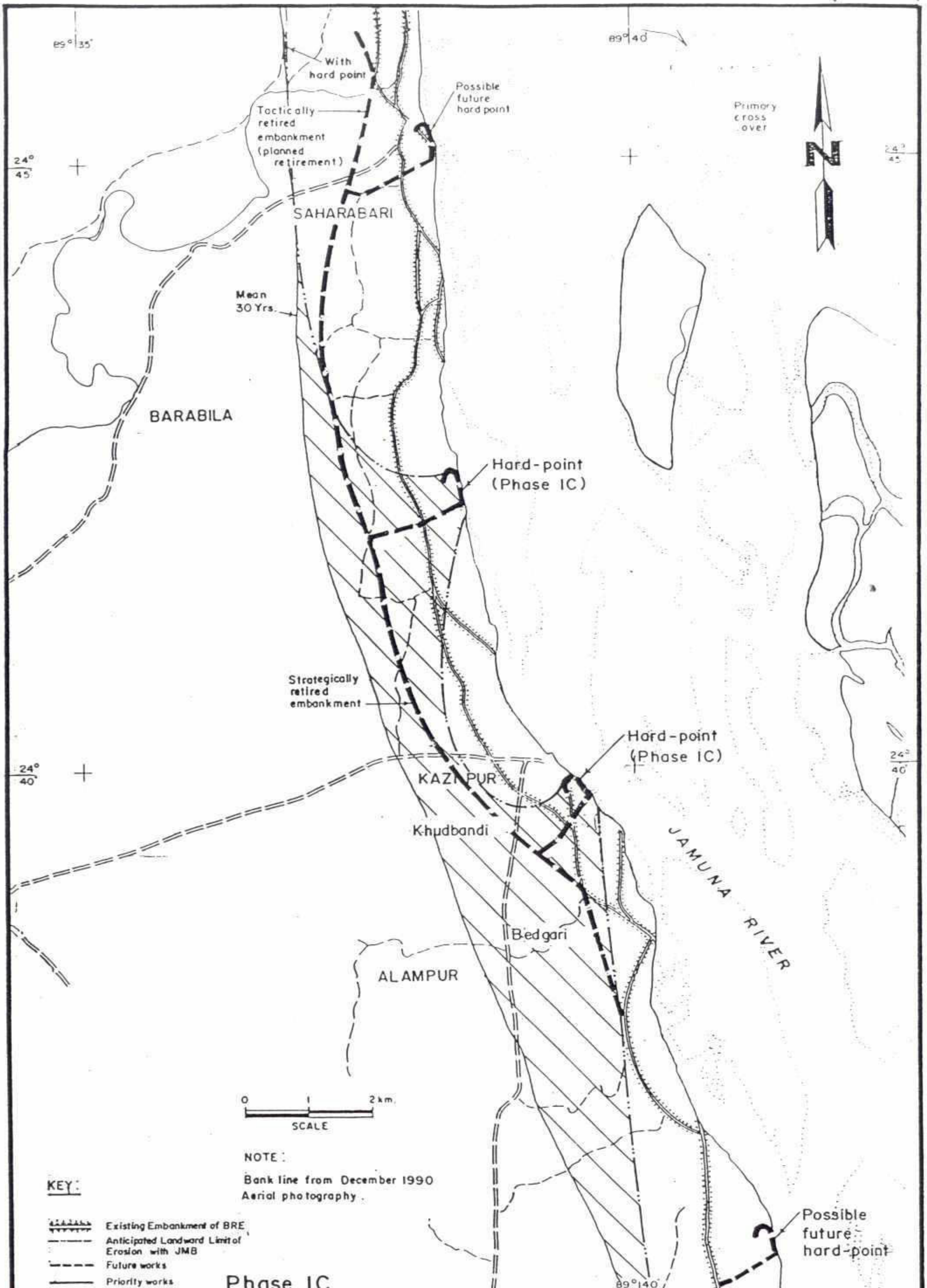
Priority and Future Works at Sirajganj

Halcrow/DHI/EPC/DIG *May 1993* **Figure 16.4**



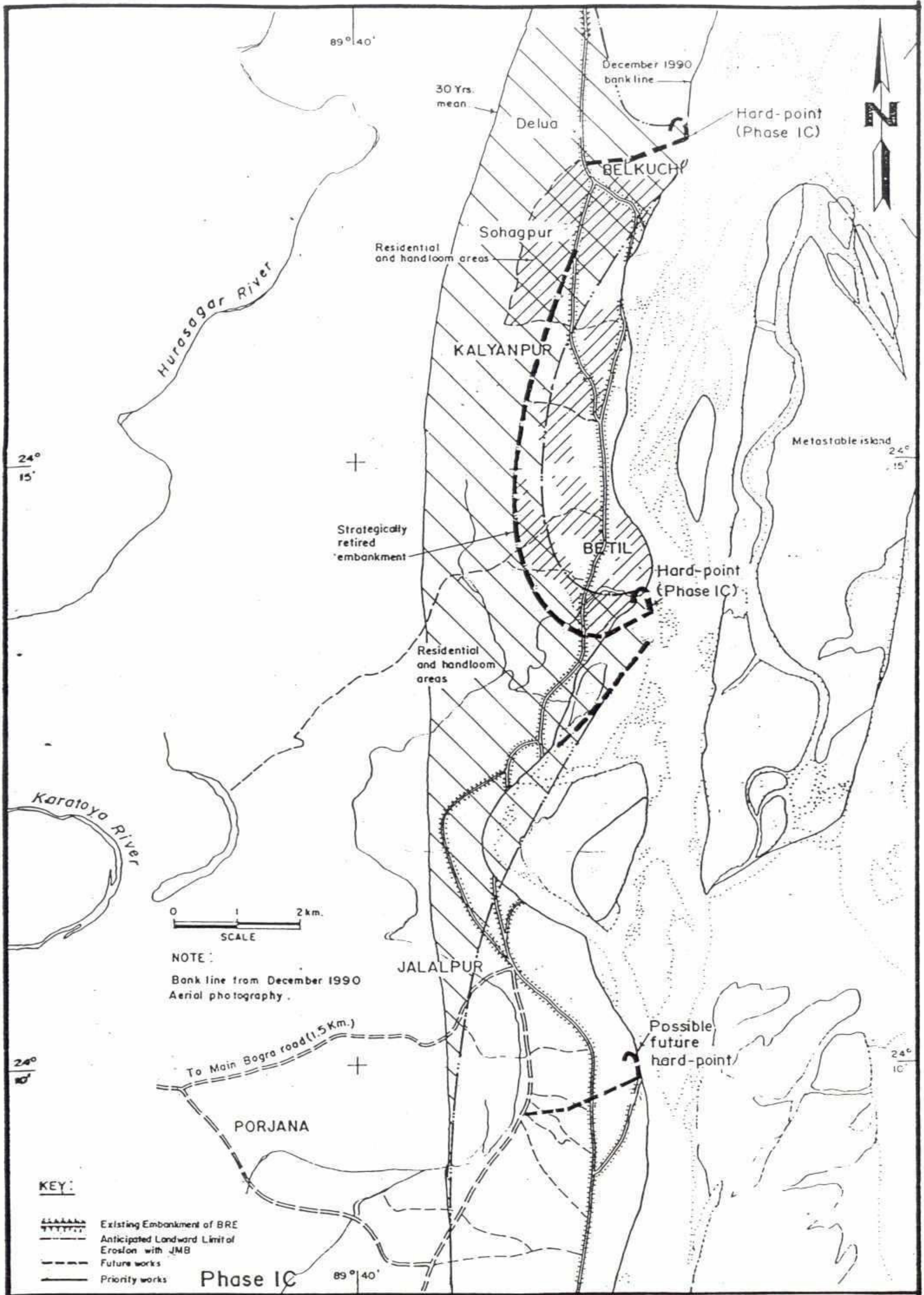
Priority and Future Works at Fulchari

Halcrow/DHI/EPC/DIG | *May 1993* | **Figure 16.5**



Priority and Future Works at Kazipur

Halcrow/DHI/EPC/DIG | May 1993 | Figure 16.6



Priority and Future Works at Betil

Halcrow/DHI/EPC/DIG | May 1993 | Figure 16.7

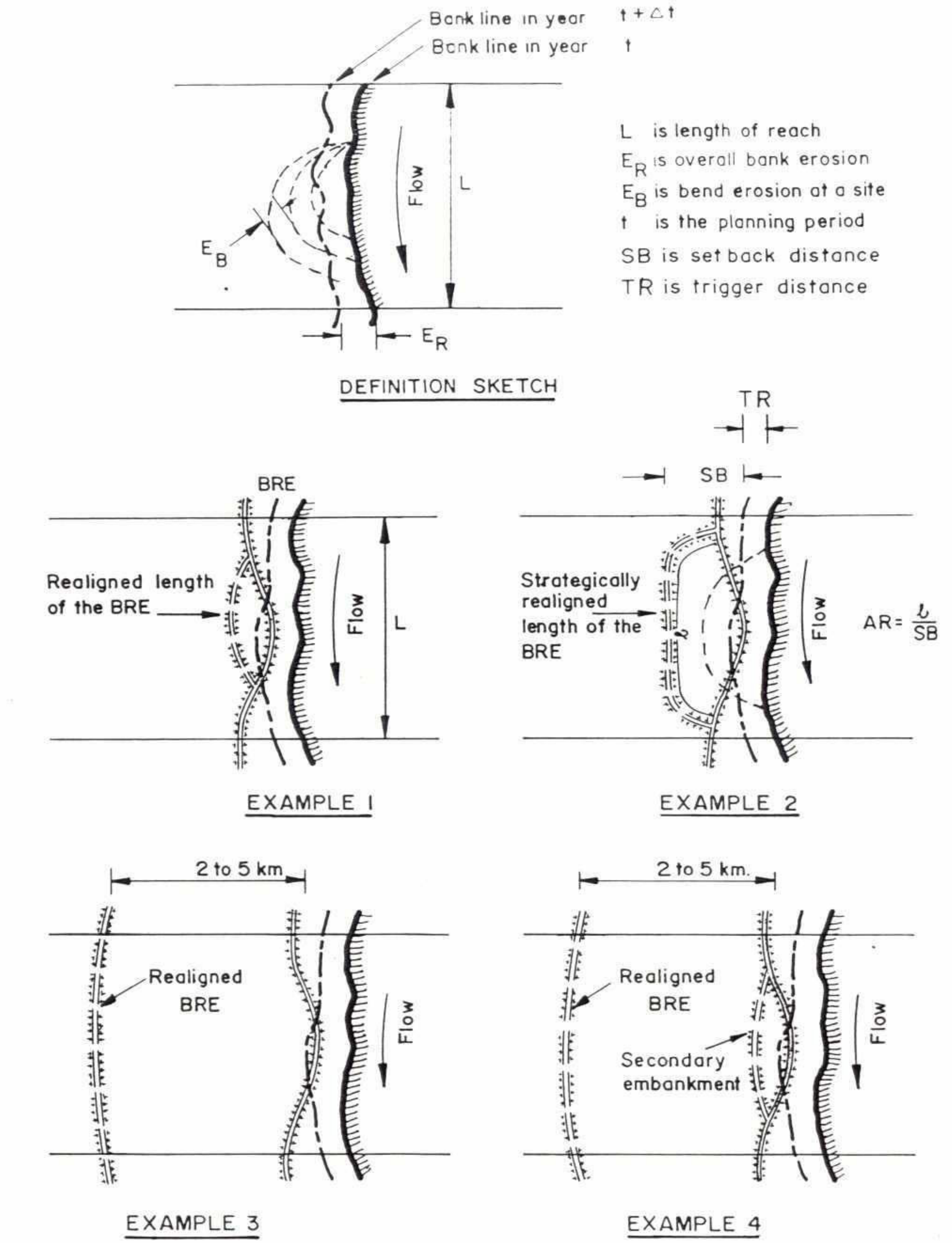
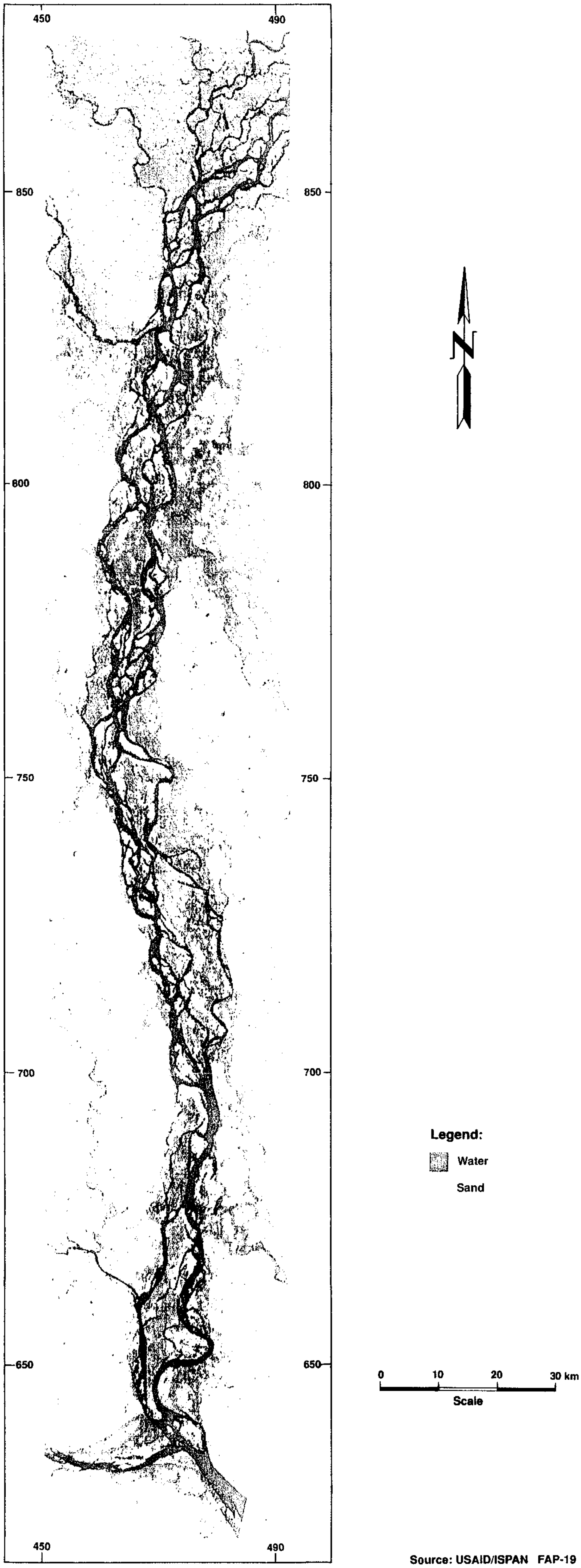


Illustration of Strategies for Embankment Retirement

Halcrow/DHI/EPC/DIG	*May 1993*	**Figure 21.1**

PLATES

Jamuna River Planform, March 1992

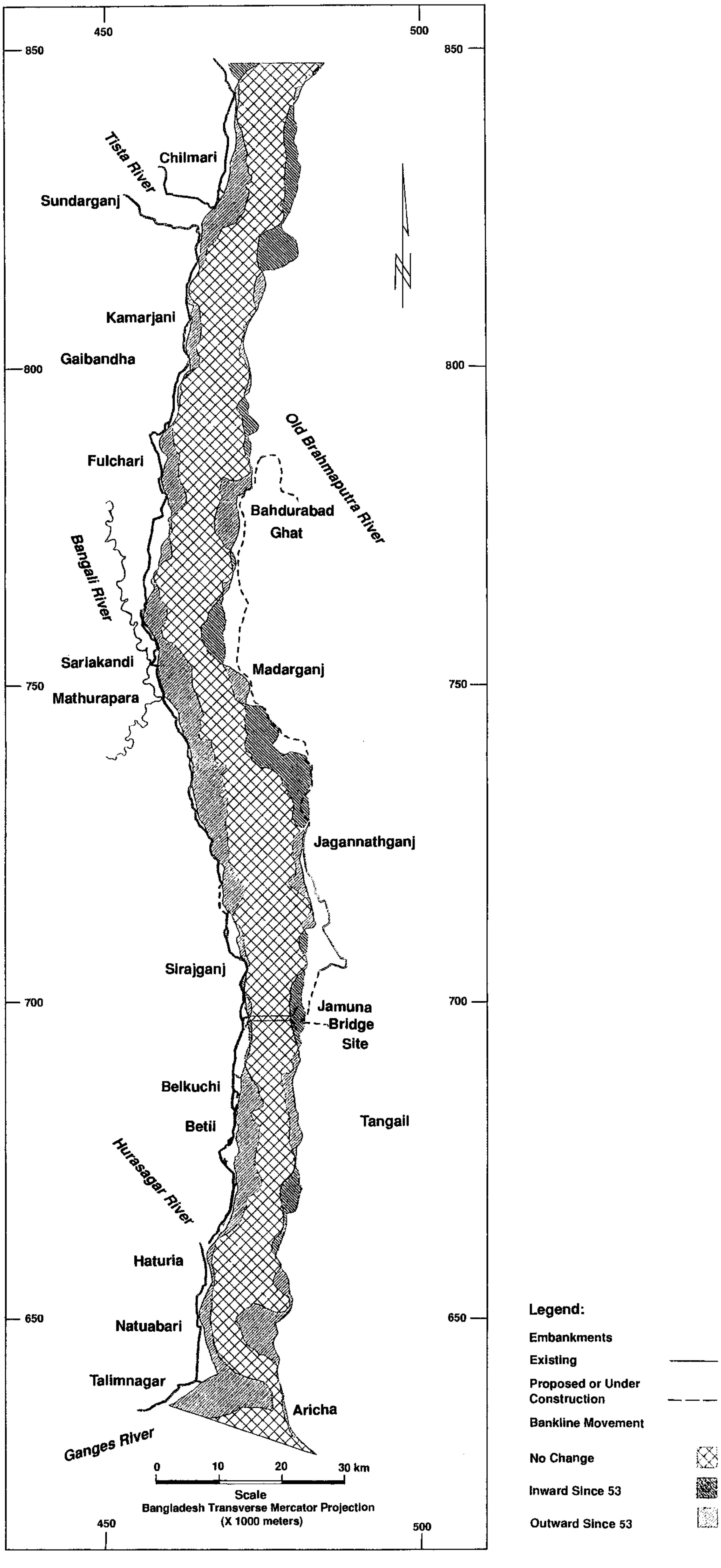


Source: USAID/ISPAN FAP-19

Halcrow/DHI/EPC/DIG

November 1992

Plate 1



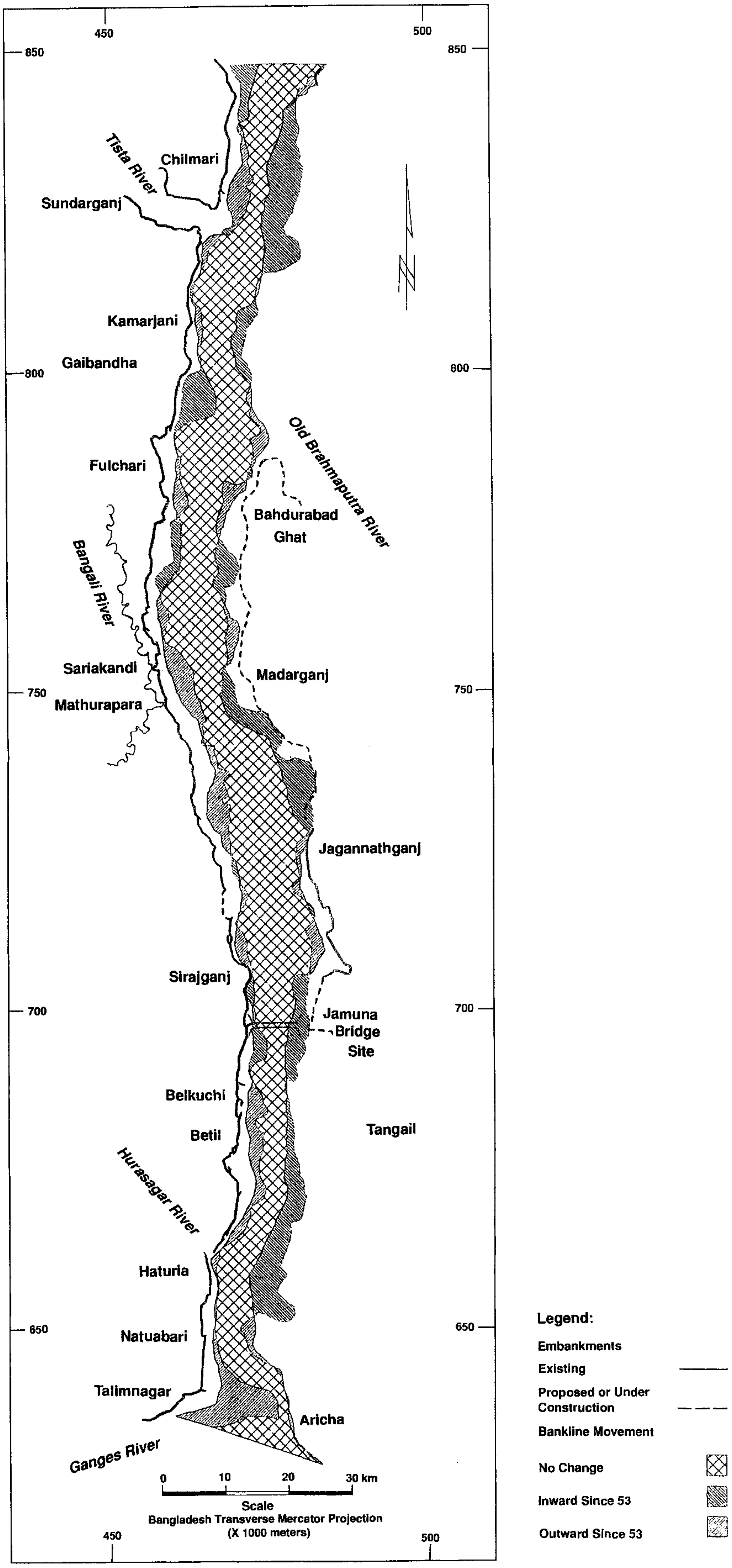
Jamuna River Bankline Movement 1953-1992

Halcrow/DHI/EPC/DIG

November 1992

Plate 3

Source: USAID/ISPAN FAP-19



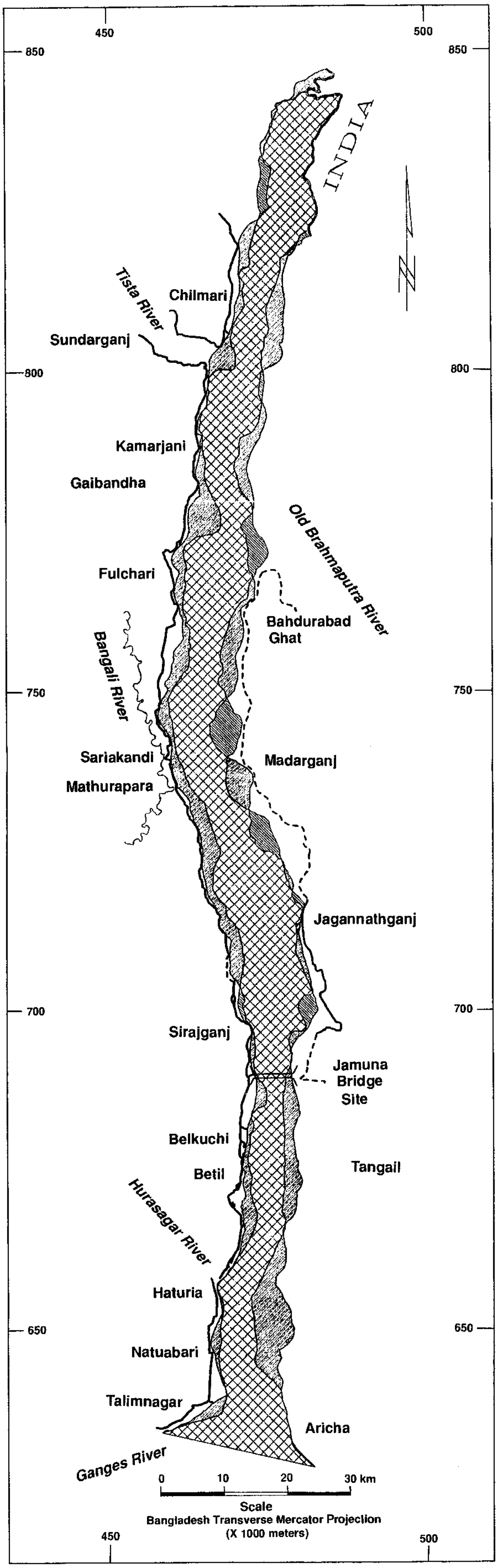
Jamuna River Bankline Movement 1953-1973

Halcrow/DHI/EPC/DIG

November 1992

Plate 4

Source: USAID/ISPAN FAP-19



Legend:

Embankments

Existing

Proposed or Under Construction

Bankline Movement

No Change

Inward Since 73

Outward Since 73

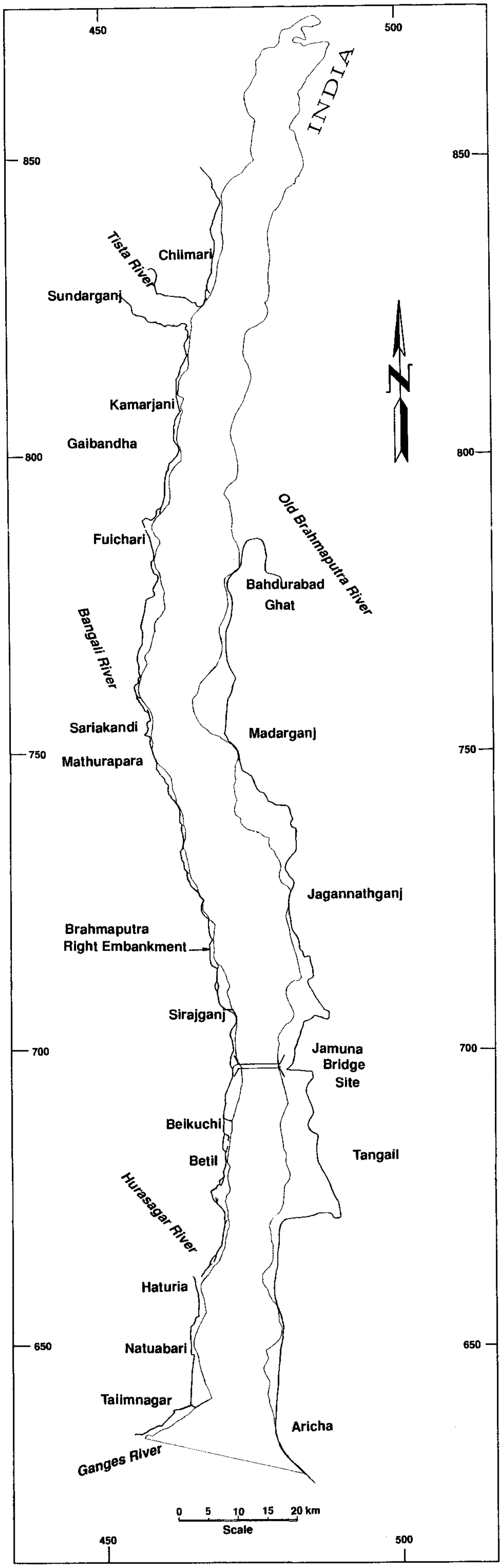
Source: USAID/ISPAN FAP-19

Jamuna River Bankline Movement 1973-1992

Halcrow/DHI/EPC/DIG

November 1992

Plate 5



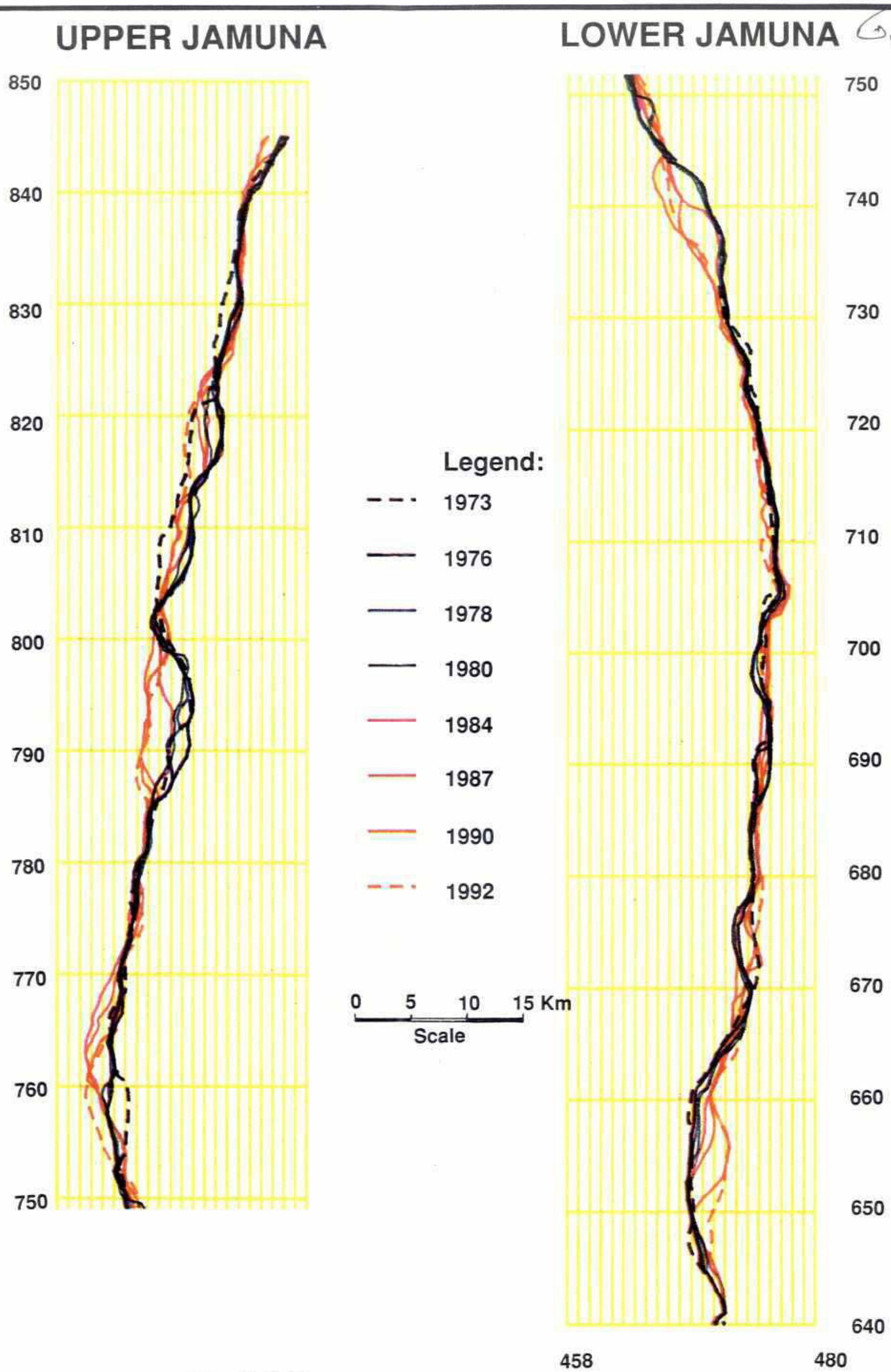
Jamuna Bankline 1992

Halcrow/DHI/EPC/DIG

November 1992

Plate 6

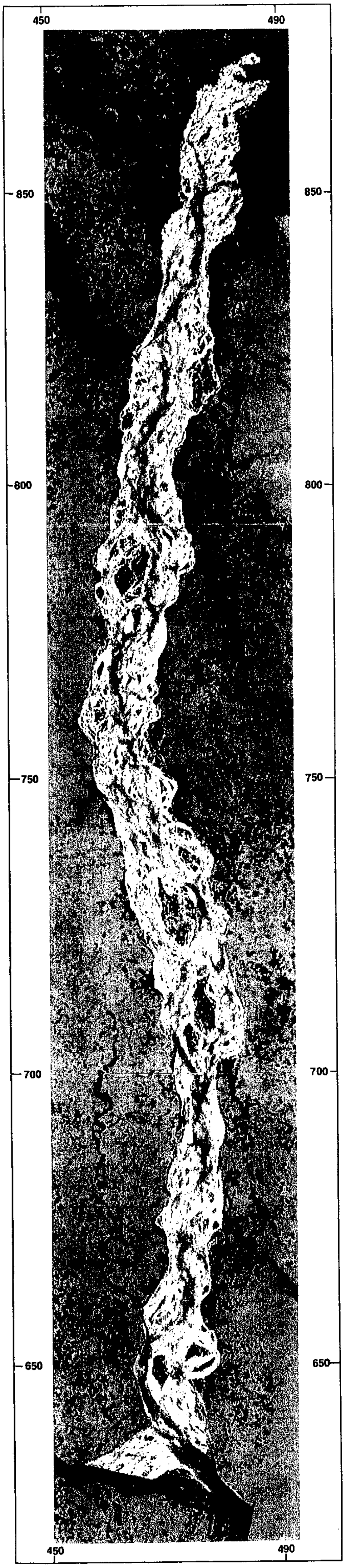
Source: USAID/ISPAN FAP-19



Source: USAID/ISPAN FAP-19

Centre Line Migration

Halcrow/DHI/EPC/DIG *November 1992* Plate 10



Legend:

Ferquency of Occurrence From 8 Dates

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8

0 10 20 30 km

Scale

Source: USAID/ISPAN FAP-19

Incidence of Dry Season Channels

Halcrow/DHI/EPC/DIG

November 1992

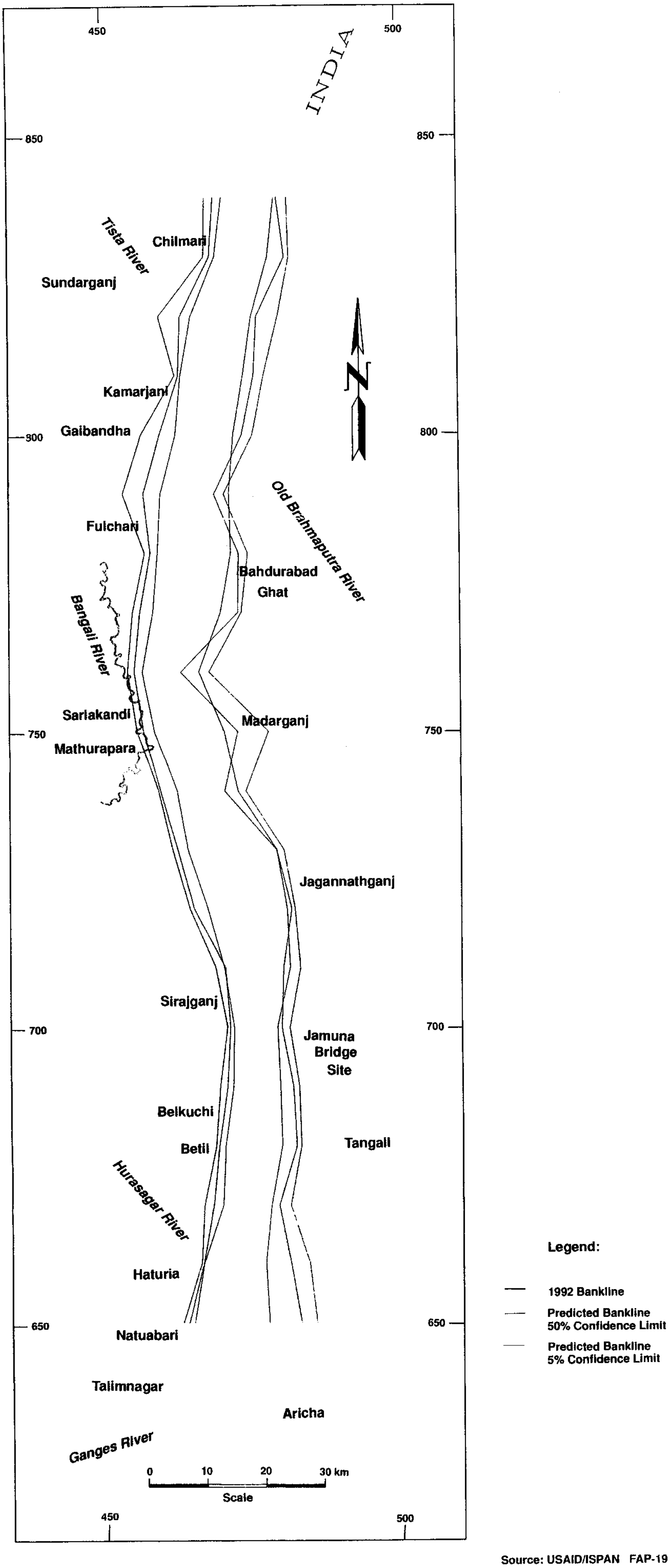
Plate 12

Predicted Jamuna Bankline in the Year 2011

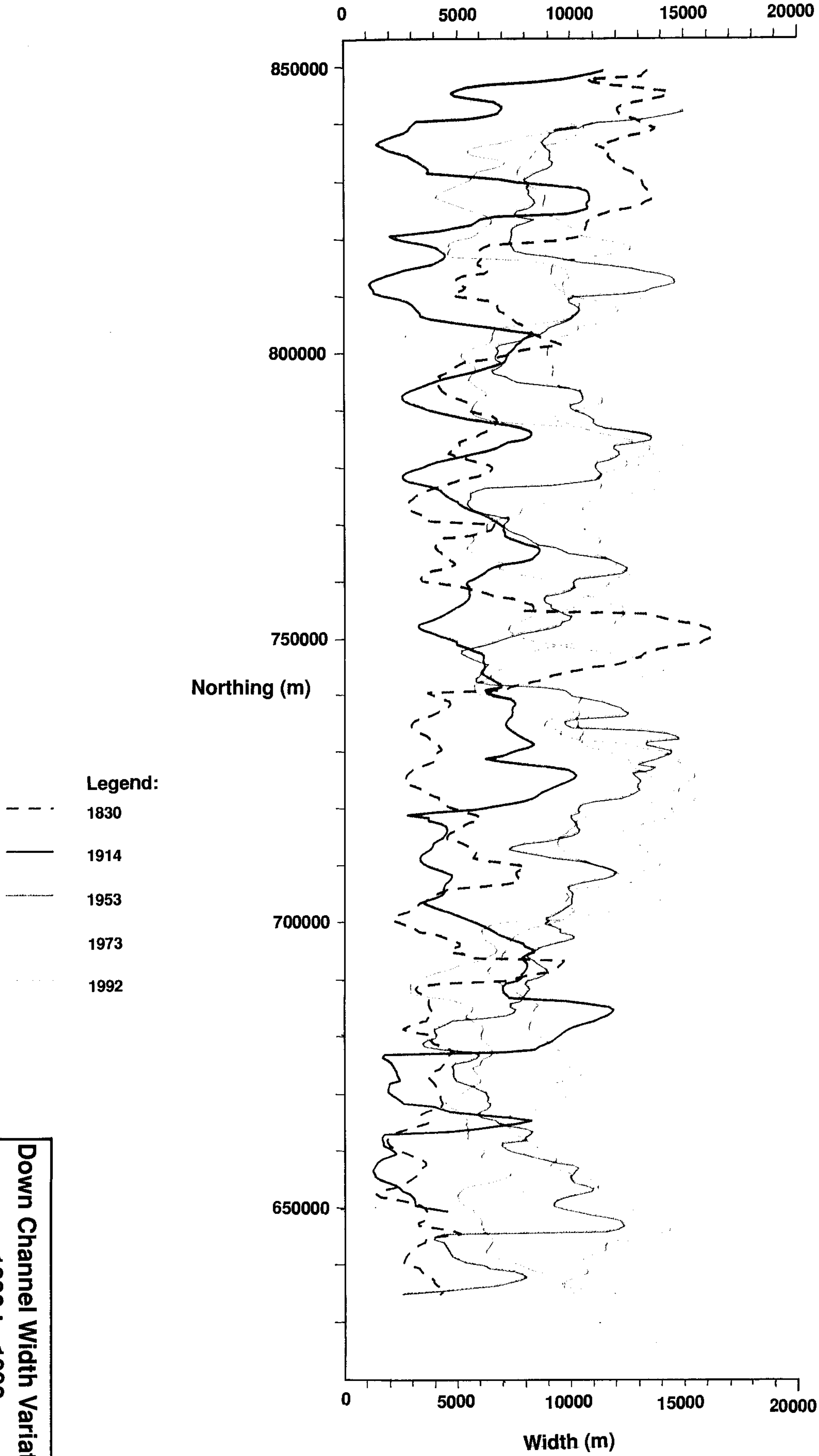
Halcrow/DHI/EPC/DIG

November 1992

Plate 13



Source: USAID/ISPAN FAP-19



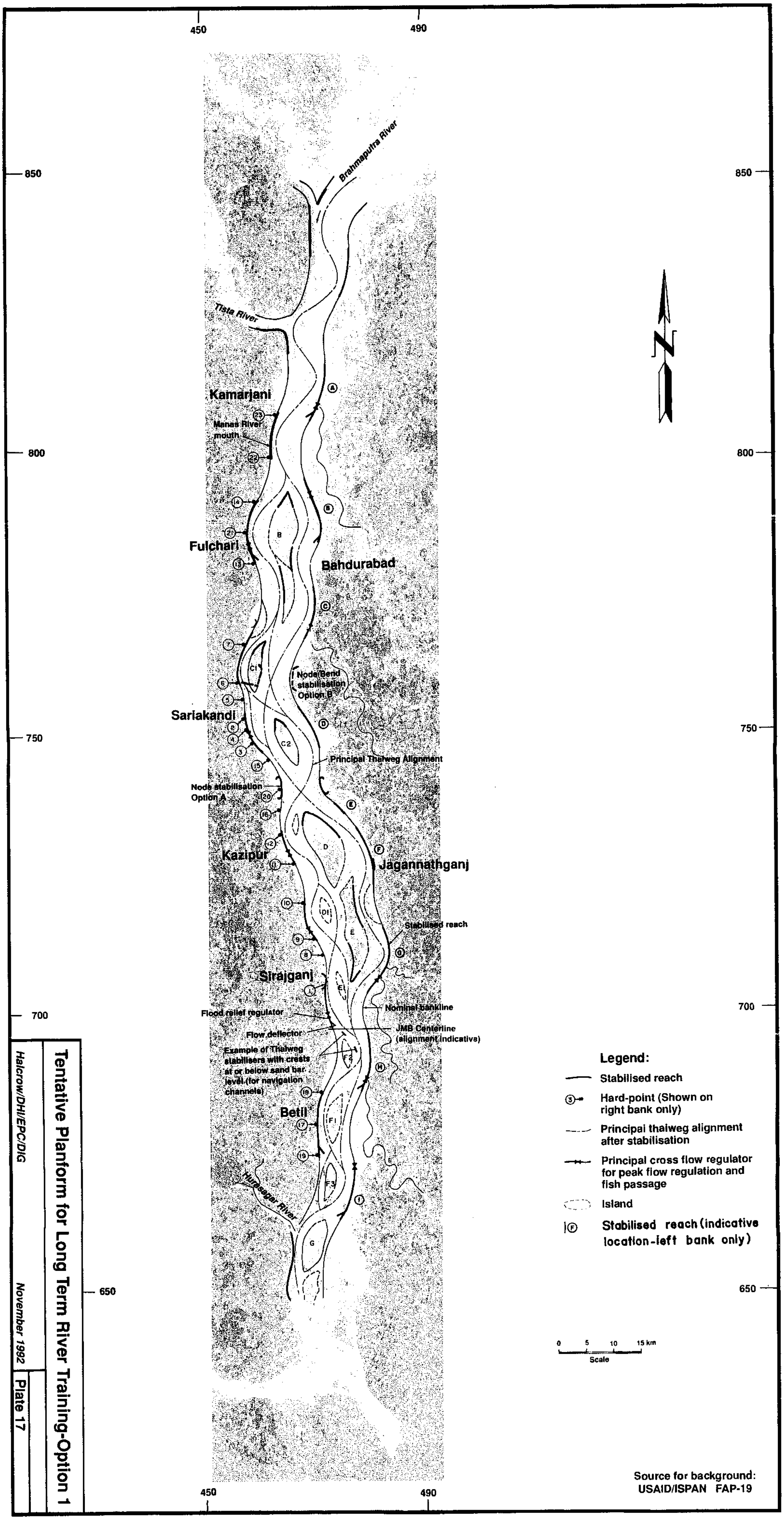
Down Channel Width Variation 1830 to 1992

Halcrow/DHI/EPC/DIG

November 1992

Plate 16

Source: USAID/ISPAN FAP-19

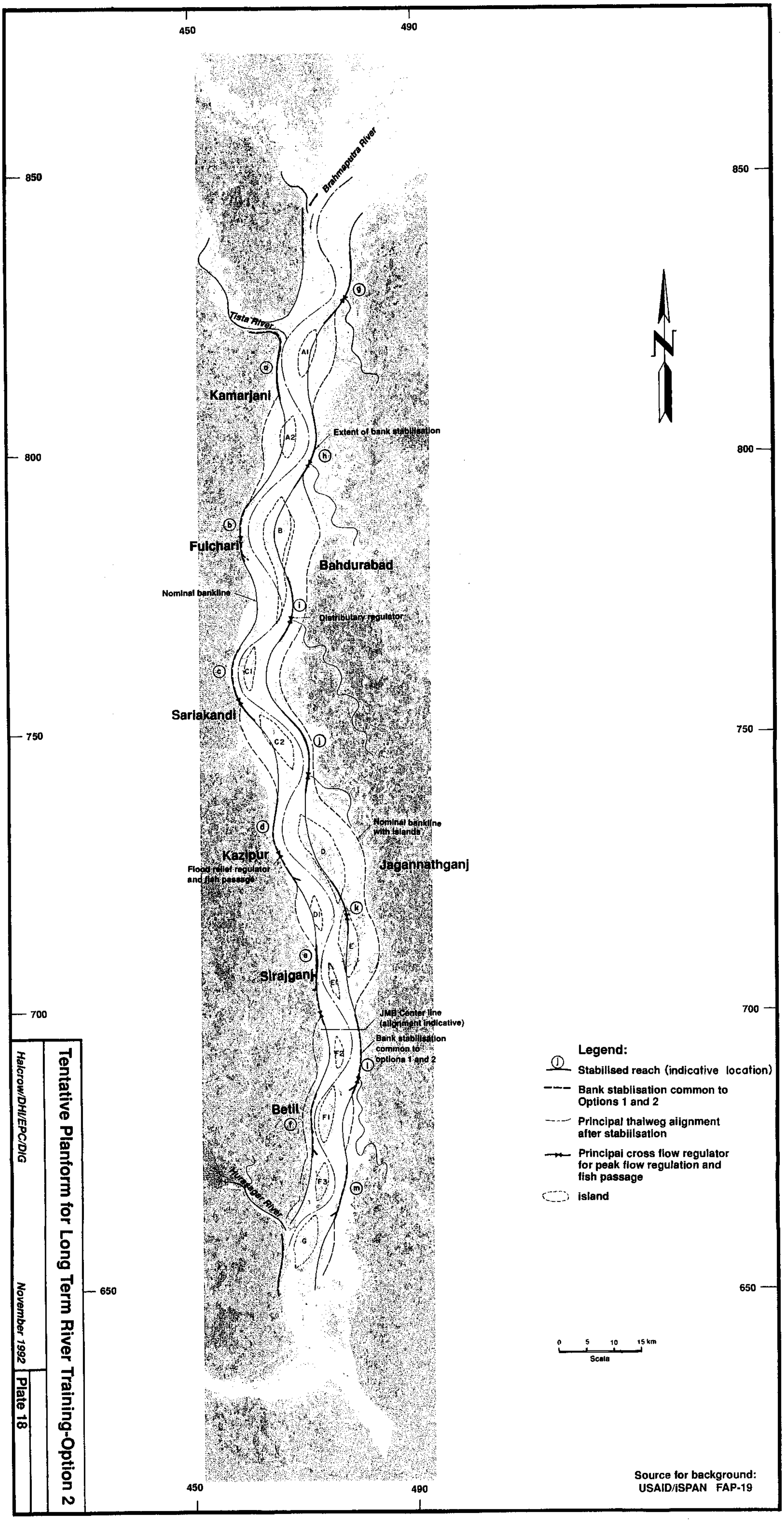


Tentative Planform for Long Term River Training-Option 1

Halcrow/DHI/EPC/DIG

November 1992

Plate 17



Tentative Planform for Long Term River Training-Option 2

Halcrow/DHI/EPC/DIG

November 1992

Plate 18

APPENDICES

HALCROW

J08

APPENDIX A

BRTS Reports and Technical notes

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MASTER PLAN REPORT - MAIN REPORT

APPENDIX A

BRTS REPORTS AND TECHNICAL NOTES

Inception Report	May 1990
Working Paper on 2-D Modelling Report	December 1990
Selection of Locations for Priority Engineering Works	December 1990
First Interim Report	April 1991
Design of Model for Sirajganj	April 1991
Physical Modelling Component Review	September 1991
Report on Priority Works	October 1991
Preliminary Draft Tender Documents	October 1991
Second Interim Report	December 1991
Review of BRTS Revetment Design	January 1992
Review of Priority Location Ranking	January 1992
Selection of Geotextile for Bank Slope Protection	February 1992
Physical Modelling Programme - Falling Apron Design: Discussion Note	February 1992
User Guide 1-D Hydrodynamic Model	February 1992
User Guide Database Report	March 1992
Design Note on Revetments for Priority Works	April 1992
Provisions for Operation and Maintenance	June 1992
Brahmaputra Right Bank Priority Works: Ferry Ghat at Sirajganj	June 1992
Tender Documents for River Bank Protection Project, Brahmaputra Right Bank Priority Works	July 1992
Environmental Impact Assessment	July 1992

Design and Construction Management Report	August 1992
Prequalification Document	November 1992
Resettlement Plans	December 1992
Final Report on Physical Model Studies (BRTS/RRI)	January 1993
Draft Final Report	January 1993
Notes on Design	March 1993
Review of Cost Estimates	March 1993
Report on Model Studies	March 1993
Master Plan Report	May 1993
Prequalification Document	July 1993
Master Plan Report (Approved Edition)	December 1994
Final Report (Approved Edition)	December 1994

APPENDIX B

Layout of Bank Stabilization Works for Sariakandi/Mathurapara Reach

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APPENDIX B - LAYOUT OF BANK STABILIZATION WORKS FOR SARIAKANDI/MATHURAPARA REACH

1. OBJECTIVES

(a) to prevent the strip of land between the Brahmaputra and the Bangali from reducing to less than 300 m (allow minimum set-back of the BRE on the Brahmaputra side of 200 m and on the Bangali side of 100 m).

(b) To protect the township of Sariakandi.

2. PRESENT SITUATION

The Bangali runs parallel to the Brahmaputra and within 1 to 2 km of it over a length of about 15 km (9 km to the north and 6 km to the south of Kalitola Groyne, Sariakandi). There are three characteristic zones: (a) the embayment with apex about 7 km north of Kalitola Groyne, (b) the Mathurapara embayment with its apex currently approximately 3 km south of Kalitola and (c) the "cusp" between these two embayments which is centred about 3.5 km north of Kalitola Groyne (Figure B1).

The two embayments are persistent features of the river although there are periods when the cusp between them is eroded and they are temporarily obliterated. The upper embayment has been consistently the most westward progression of the river since 1973 and may be expected to retain this leading role for the foreseeable future.

Bank movement in the north embayment eased around 1978 after a five year period of erosion rates of the order of 400 m/y to the long term mean rate of 85 m/y (measured east-west); since 1985/6 the rate has further dropped to an almost negligible level (Figure B2); the imagery shows strong sand bar development in the bay. From a simple extrapolation, there would appear to be high probability that this quiescent period will last until at least 1995 and quite possibly to 2000.

Movement at the present cusp ceased in 1978 and has been effectively zero since then (Figure B3). Prior to 1978 the long-term average rate of movement was around 120 m/y. In contrast, the rate of movement in the Mathurapara embayment, which has been running at around 300 m/y for three years, may be accelerating (Figure B4); the March 1992 LANDSAT imagery shows an ominous sandbar development that may be indicative of a tightening of the bend radius to close to the 4 km value at which bends have historically tended to become aggressive.

The seriousness of the situation has been somewhat eased by the natural partial cutoff, during the 1991 monsoon season, of the pronounced loop of the Bangali opposite the Mathurapara embayment. This is the point of minimum separation at present and in March 1992 the shortest distance between the rivers was 1,200 m.

3. **PREDICTION OF FUTURE BANKLINE MOVEMENT**

The most immediately threatening scenario would be the development of an aggressive bend in the Mathurapara embayment. In March 1992 the depth of the embayment was 1.5 km and the radius was 9.0 km but there are indications on the image that the radius could be reducing. If this were confirmed then there would be a significant probability that the rate of bank erosion would accelerate; at best it would be likely to remain at around 300 m/y (Case 1a) but under the worst scenario it would increase to more than 600 m/y (Case 1b) and be sustained at a high level until the embayment depth peaks at around 2 to 2.2 km (examples of such developments of aggressive smaller radius bends in typical 8 to 9 km chord length embayments are Fulchari and Jalalpur). There is also the possibility that upstream channel planform changes will causes the anabranch to decline in size, in which case bank erosion could decline. Analysis of historic bends suggests that aggressive bends typically have low flow channel widths of between 1,000 and 1,500 m; if the width falls below this the bend is unlikely to survive.

If the Mathurapara bank erosion were to continue at around 300 m/y for another three seasons beyond March 1992 (i.e to September 1994) then the embayment planform could be as shown in Figure B5. The extreme scenario involving the development of an aggressive bend is also shown.

The cusp area has experienced no significant erosion since 1978, which is close to the maximum recorded continuous quiescent period anywhere in this reach of the river since 1973. Since the north embayment has reached the normal maximum depth of about 2.2 km and the Mathurapara embayment is likely to reach that value by 1993 or 1994 (unless an aggressive bend develops) then the probability of erosion starting in this area within the next three or four years would appear to be high. The island char immediately to the north has been a strong feature for the past 20 years and this will limit the ways in which the erosion can take place; two possible ways (Cases 2a and 2b) are shown in Figure B5. The more northerly is similar to the pattern that developed during the period 1981 to 1984 and also has a similarity to the sequence that followed the decline of the aggressive Fulchari bend after 1989. It is therefore perhaps the more likely of the two.

Reoccupation of the more northerly embayment prior to the erosion of the cusp is a less likely scenario but it cannot be ignored. If it did occur it would be more likely to be in the form of an aggressive end, as happened in this vicinity between 1984 and 1987 (Cases 3). A possible alignment is shown on Figure B5.

4. **RESPONSE TO FUTURE BANKLINE MOVEMENT**

Case 1a

Presuming that contract award could be made in March 1994 and that construction in the river could commence in September 1994 (a very optimistic programme unlikely to be achieved in practice) then the layout of stabilization works as shown on Figure B5 would be appropriate. If construction were not started until September 1995, then it might be necessary to realign the Bangali river as shown.

Case 1b

With the same assumptions as above, but with the development of an aggressive bend, realignment of the Bangali would definitely be necessary and should be undertaken in advance of the commencement of construction of the bank stabilization works in order to maintain the continuity of the BRE.

Case 2a

Under this scenario it is assumed that the Mathurapara embayment erosion has reached its temporary limit in 1993 and that erosion has shifted to the cusp area where it is running at between 200 and 300 m/y. The immediate concern in this case is to prevent Kalitola Groyne from failing through a flank attack and in the process threatening the security of the town of Sariakandi. The longer term objective is to prevent a breakthrough into the Bangali to the north of Sariakandi. This could be achieved with the works shown on Figure B5.

Although arguably not strictly necessary at this time, it would be prudent also to provide the stabilization works in the Mathurapara embayment. The very narrow remaining strip of land means that when erosion did recommence a breakthrough would be likely to occur before a contractor could be mobilized for the construction of these works (the alternative would be to plan for realignment of the Bangali river).

Case 2b

This scenario presents a lower short-term risk, and therefore more scope for planning the defences, but threatens a breakthrough over a greater length of the bankline. The location of stabilization works will depend very much on the bend pattern that develops and those shown can only be broadly indicative.

Case 3

Simultaneous active erosion in adjacent embayment is very unusual and it is therefore unlikely that bank erosion will be taking place concurrently in the northern and the Mathurapara embayments. Nor could it occur if either of the bends associated with Case 2 developed.

It seems most likely that Case 3 would follow on from a Case 2 scenario but there is the low probability chance that an aggressive bend could become established in the embayment within the next two to three years.

In the former case the bank stabilization works could be take the form shown in Figure B5 and, from a planning point of view, could be considered as follow-up works under Phase 1B. In the latter case it would be necessary to respond rapidly since the separating strip of land is only 1,000 m wide and an aggressive bend could break through within two years. In such an event first priority would have to be given to stabilizing this bend and, because erosion of the cusp area would almost certainly follow, second priority to safeguarding Kalitola Groyne and Sariakandi town. With this scenario the Mathurapara embayment would most probably experience temporary accretion (viz Fulchari) and stabilization works in that vicinity could be postponed until Phase 1B.

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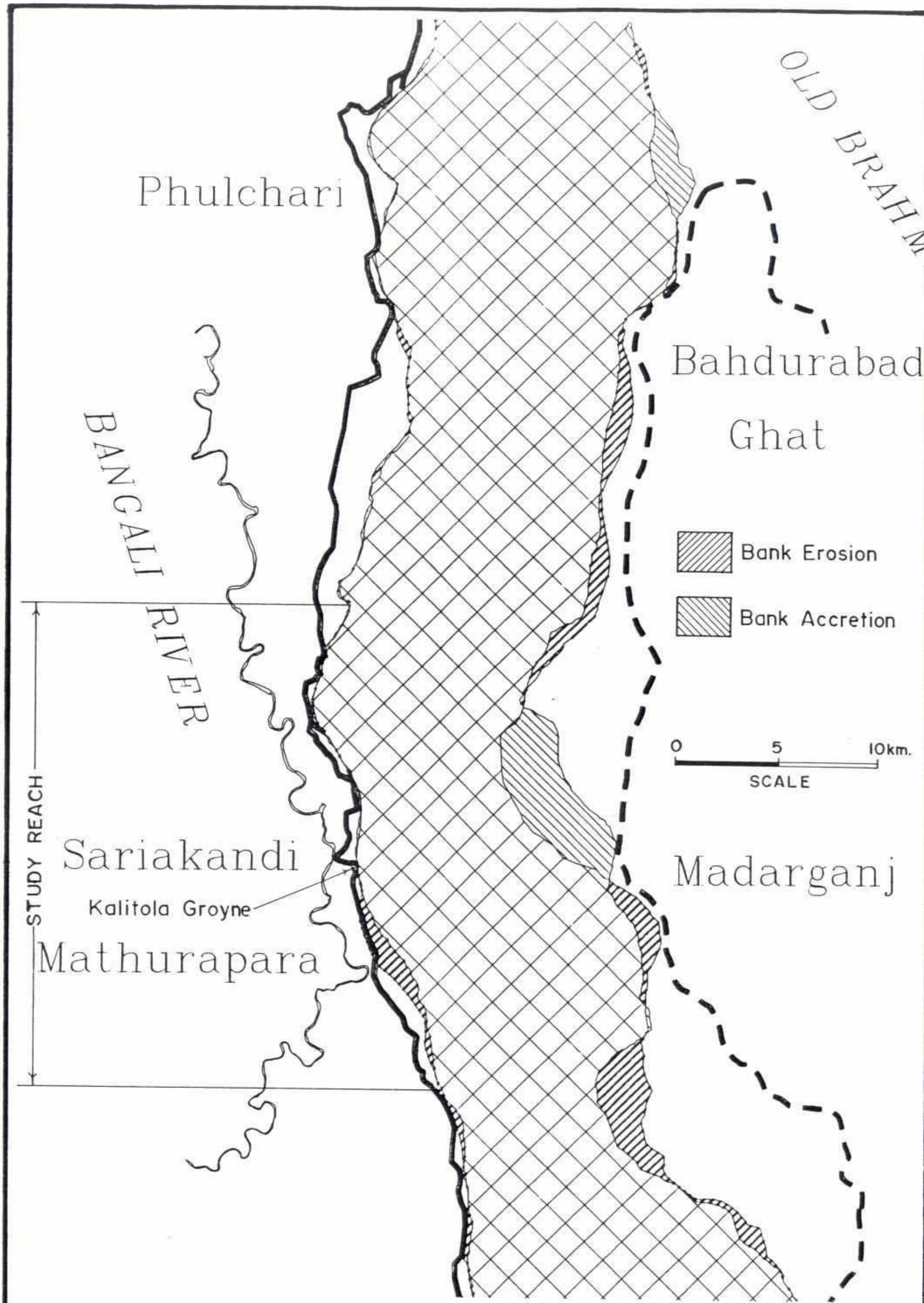
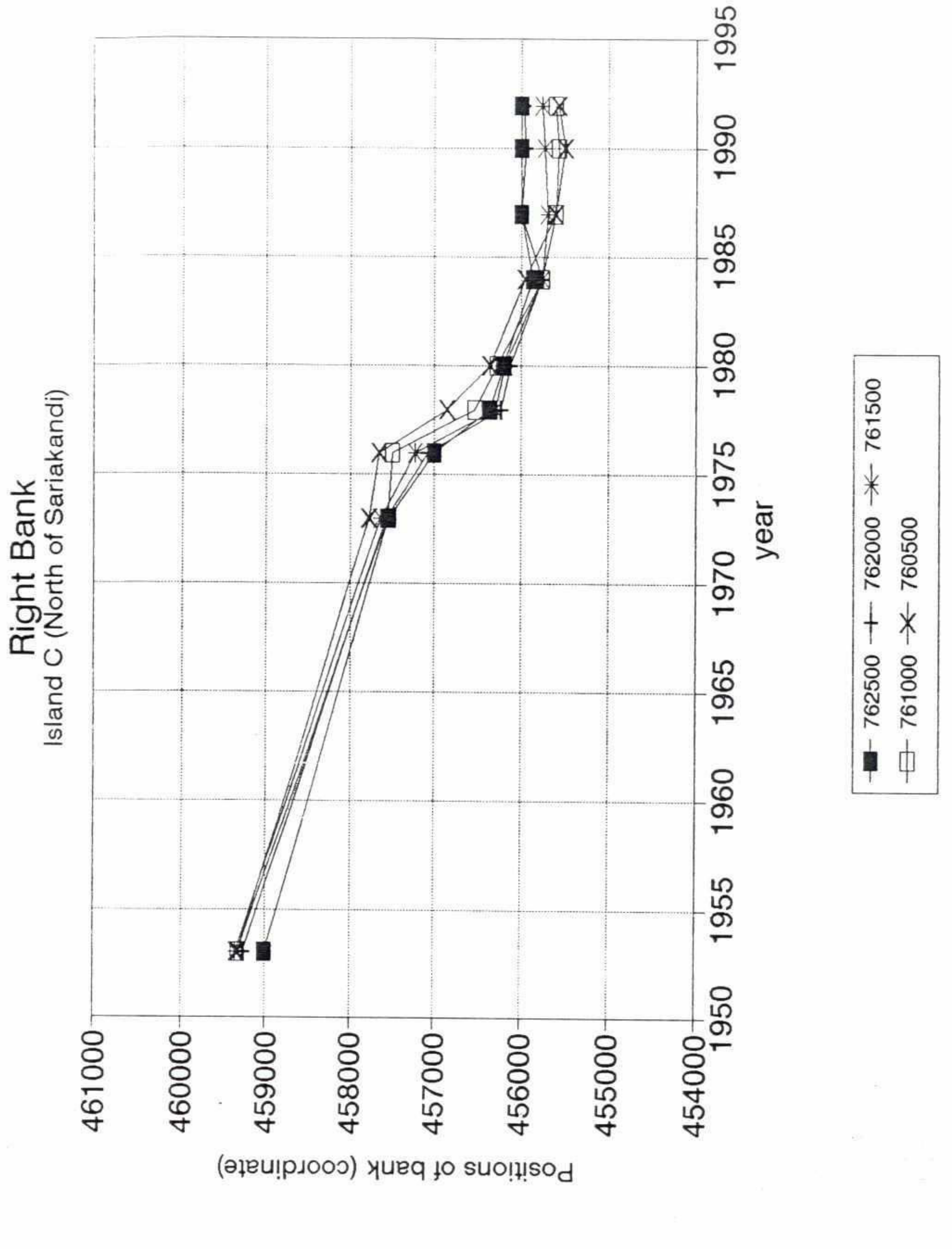


Bankline Movement Near Sariakandi, 1990-1992

Halcrow/DHI/EPC/DIG *May 1993*	**Appendix B** **Figure B1**

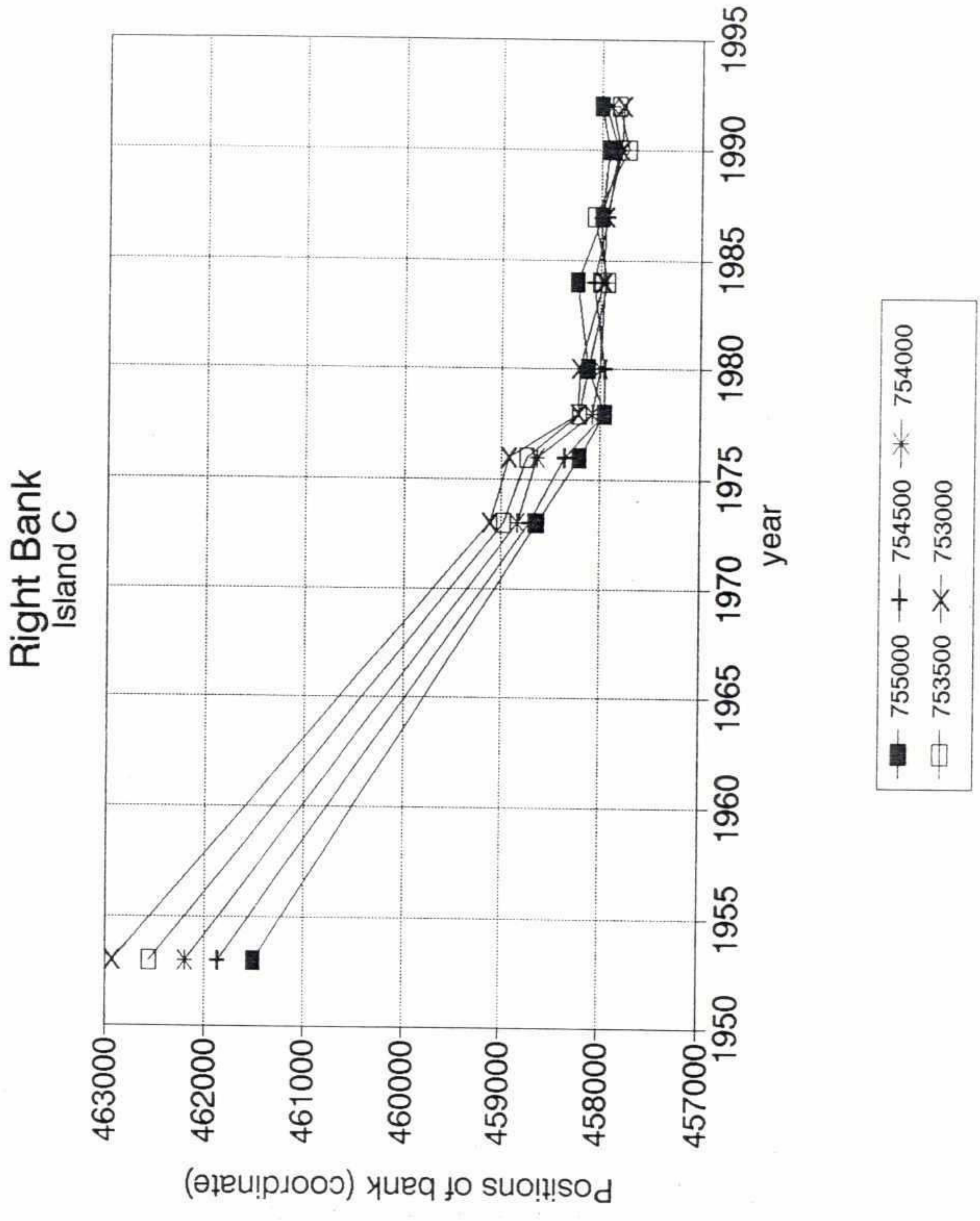
G82



Bankline Movement, Embayment North of Sariakandi, 1953-1992

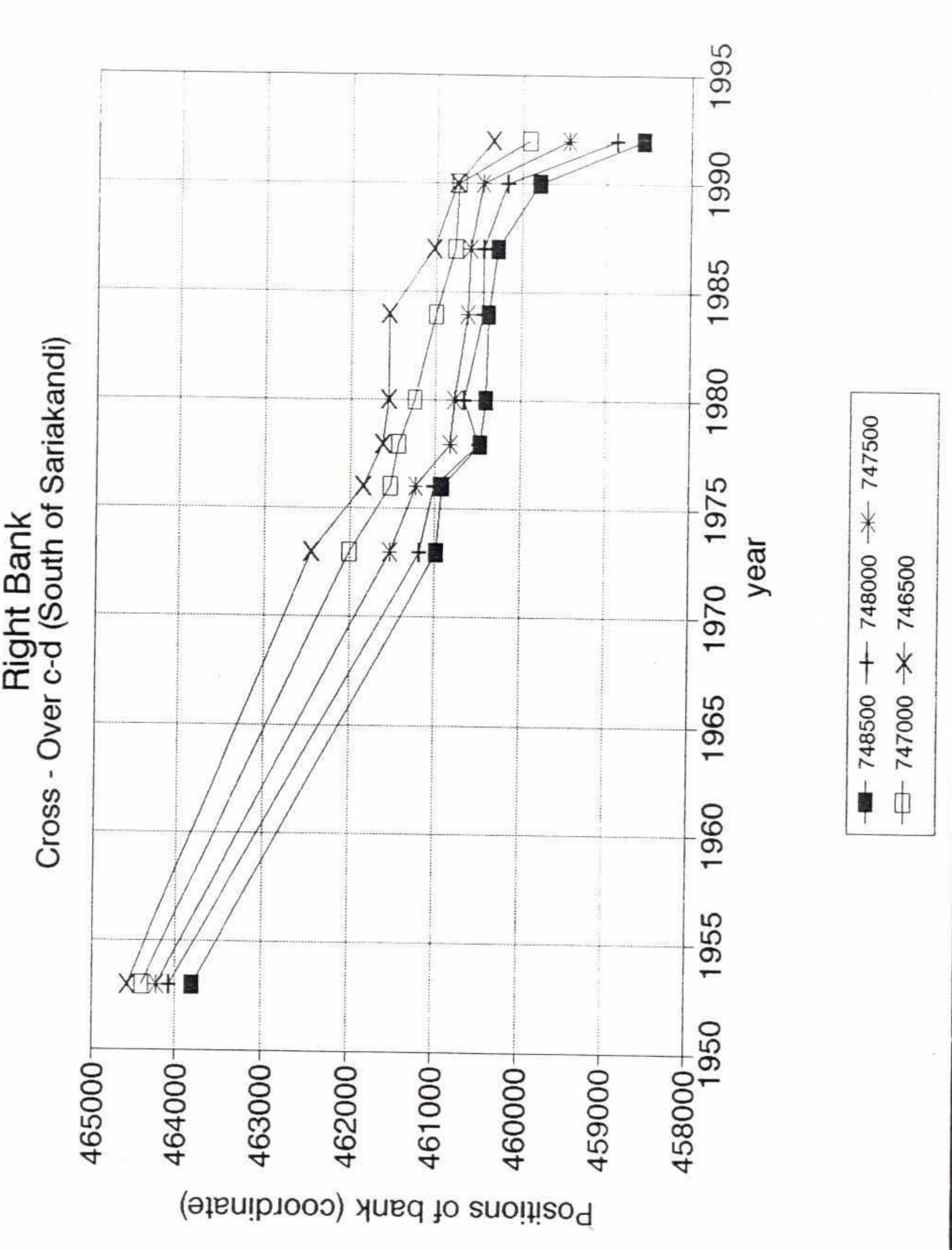
	Appendix B
Halcrow/DHI/EPC/DIG *May 1993*	**Figure B2**

G86



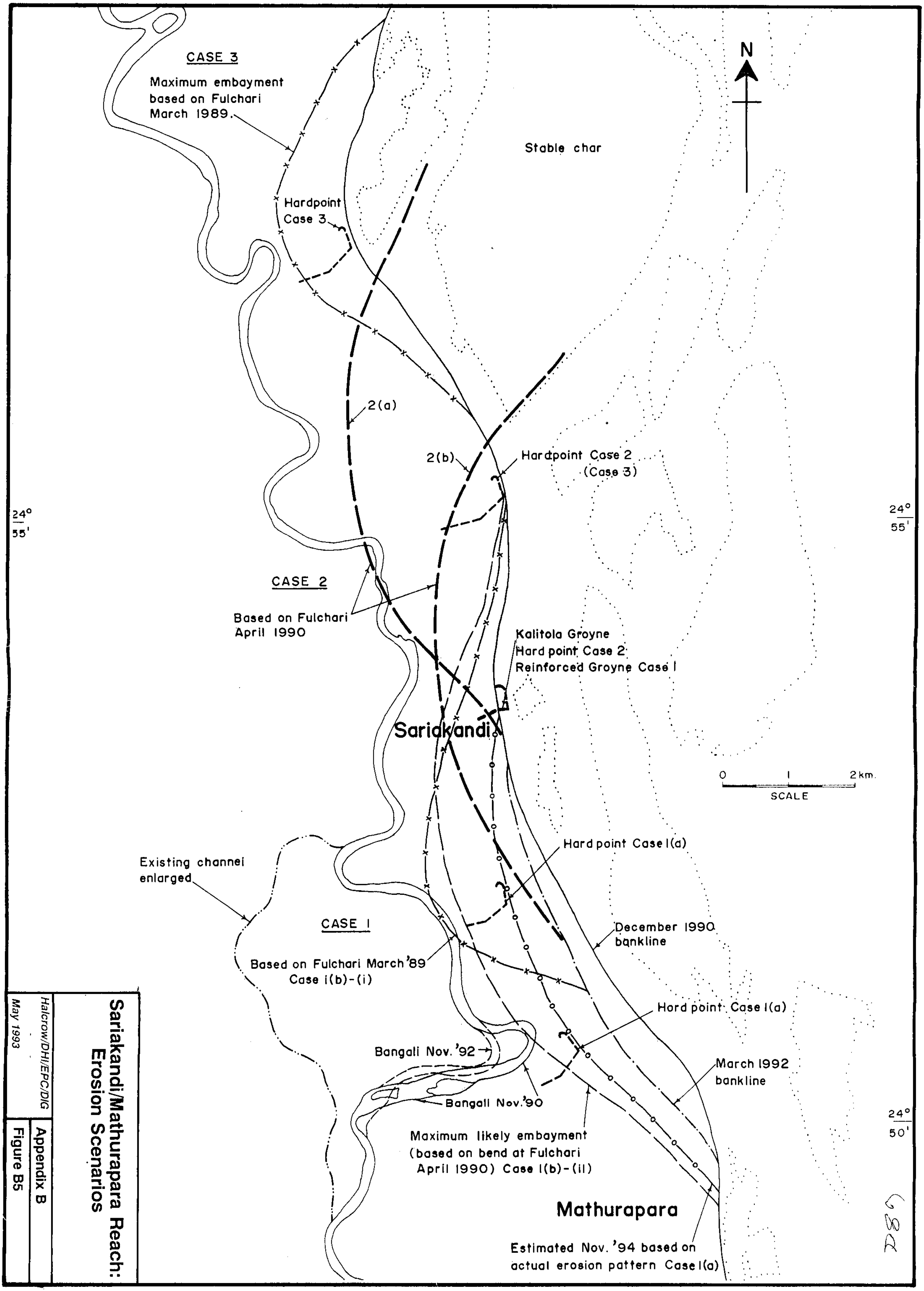
Bankline Movement, Cusp North of Sariakandi, 1953-1992

Halcrow/DHI/EPC/DIG *May 1993*	Appendix B Figure B3



Bankline Movement, Mathurapara Embayment, 1953-1992

Halcrow/DHI/EPC/DIG *May 1993*	Appendix B
	Figure B4



Sariakandi/Mathurapara Reach: Erosion Scenarios

Appendix B

Figure B5

Halcrow/DHI/EPC/DIG

May 1993

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APPENDIX C

Main River Engineering Observations (Yangtze and Huang Ho)

MASTER PLAN REPORT - MAIN REPORT

APPENDIX C

MAIN RIVER ENGINEERING OBSERVATIONS (YANGTZE AND HUANG HO)

THE YELLOW RIVER (HUANG HO)

The very high sediment load, ranging from 35 to 400 kg/m^3, is derived mainly from the loess plateau of the autonomous regions of inner Mongolia. Even in the dry season the water has a high turbidity. The sediment generally is considerably finer than the Brahmaputra and the bed material is a silty very fine sand. Both the suspended bed load and the wash load are considered to be significant with regard to the river morphology.

The width of the river varies from 3.5 to 9.5 km and although it is considered to be braided there is a discernible "meander" wavelength of around 12 km. Average depth is shallow at and the maximum scour depth at the nose of a long groyne-like structure was stated to be 18 m below LWL. This is consistent with the design of the older revetment works in the vicinity of the "vulnerable spot" near the highway bridge where the apron has been taken down to 23.5 m below the crest of the masonry wall, which is set about 5.5 m above LWL (see attached sketch - Figure C1).

Low flow is around 1,000 m^3/s and "formative flow" (equivalent of dominant discharge) about 5,000 m^3/s. The flood plain is inundated at between 6,000 and 7,000 m^3/s. Peak flows in 1843 and 1958 were 33,000 and 22,000 m^3/s respectively; the latter is the design discharge, which is less than the 100 year peak (27,000 m^3/s). To cope with floods in excess of the design value, two massive temporary detention ponds have been established with inlet structures designed to take 10,000 m/s each. Large areas of farmland would be inundated but this is considered preferable to the damage that would result from breaching of the flood embankments. There was no firm data available on velocities but it was thought that the mean velocity during floods was around 2.5 to 3.0 m/s and that maximum velocities reached about 4.0 m/s.

The Yellow River has a long history of instability and devastating floods when the levees are overtopped or eroded during high flows. Efforts to stabilise key reaches by use of bundles of brushwood (willow and other species) and rock ballast have been carried out over many centuries. The reach extending about 5 km upstream and downstream of the bridge carrying the Zhengzhou to Beijing highway has long been considered to be a key "vulnerable spot", where stabilization work has been concentrated. The present massive masonry walls forming a series of spur dykes (143 in all), and closely resembling the walls of European mediaeval fortified cities, were constructed starting in 1949 but these were founded on earlier works, which date back probably to the Ming period (perhaps 400 to 500 years old). It is reported that the works required 230,000 m^3 of rock and large quantities of brushwood.

Rock protection consists of 30-75 kg rocks that are quarried nearby and are placed by hand. Placing consists largely of dumping from the bank, which may explain the relatively steep slopes of the apron. No filters are used (although brushwood may to some extent perform in this role) but regular topping up of the slope protection and apron is carried out during the flood seasons; neat stockpiles of rock are to be seen all along the crest of the flood embankment and 20,000 personnel are employed for this purpose by the two Provinces, who are responsible for maintenance, under the direction of the Yellow River Authority. Average pay is between 250 and 500 yuan per month (roughly US$40 to US$80 per month).

In recent years the emphasis has moved from the masonry and dumped rock multiple spurs to series of earthfill groynes with rock protection. The intention is to train the primary thalweg to follow a meandering course and the training works are designed so that the flow is guided in concave bends with radius of between 4,000 and 7,000 m. Training works are thus concentrated along the concave faces of these bends and at the downstream limit the flow is encouraged to crossover to the next protected reach on the opposite bank. This is the main focus of the massive physical models that are in regular use both in Zhengzhou and Beijing (scale 1:800 horiz and 1:60 vert). No attempt has been made to stabilise nodal points, although these are recognised as being significant features of the river. The groynes are orientated at about 30° to the direction of flow and are spaced so that they effectively overlap (see sketch - Figure C2); I was told that this arrangement had been arrived at as one that produced negligible reverse eddy between the groynes. From other indications, I tentatively inferred that this arrangement has arisen from the practical requirements of construction using simple labour intensive techniques and readily available materials; by constructing the groyne in the lee of the upstream structure and at a shallow angle to the bank, nose velocities are probably minimised. At one point where velocities had been too high, a permeable groyne of 500 mm dia reinforced concrete piles with a massive concrete capping beam had been constructed. This was said to have been very successful in reducing flow velocity and encouraging accretion, enabling construction of the next groyne to be completed the following year.

The river bed is said to be rising at a rate of between 40 and 70 mm a year. The construction of major hydroelectric dams upstream was expected to reduce the sediment load and even result in some bed degradation. This did not happen and an earthen dam with gated regulator built across the river in the early 1980's to control the anticipated degradation at the Beijing/Nanjing bridge was abandoned a few years later because of the continuing rise in the bed level. The policy for the short-term is to build more dams to store the sediment and to steadily raise the embankments to keep abreast of the aggrading bed. In the longer term the only solution appears to be the expansion of effective erosion control measures in the loess area.

THE YANGTZE RIVER (CHANG JIANG)

In many respects the Yangtze is closer in character to the Brahmaputra than the Yellow River. The main differences between Yangtze and Brahmaputra being:

- the generally slower rate of morphological change (although sustained bank erosion at a rate as high as 100 m/y has been known);
- the absence of the large number of sandbars exposed at low flow that characterize the Brahmaputra.

- a generally narrower (1.1 to 1.3 km) and deeper main channel, although at bankfull it can be as wide as 5.5 km.

- a flatter bed slope (2.10^{-5})

Features in common are:

- island reaches of about 20 km in length;

- annual sediment load of around 450 million tonnes;

- wash load concentration about 0.55 kg/m^3;

Industrialisation of Nanjing started at the beginning of this century with the arrival of the railway and the construction of river port facilities, which tended to fix the planform of the river for a length of about 5 km upstream of the present bridge. This reach became the focus of river planform stabilisation efforts during the war of liberation when it was a key crossing point for the army and reliable wharfage facilities were essential. Subsequently, the equally strategic coal depot became the main area of concern. The problem was that deep scour developed in an unpredictable manner leading to fairly rapid erosion of the river bank and loss of the wharfs and associated infrastructure. Russian specialists identified the cause of the scour as a low level island, submerged at high flows, that had formed a short distance upstream of the coal depot and which was concentrating the flow. They recommended that it be removed and a massive dredging operation was accordingly undertaken. At the same time the vulnerable reach was stabilised by means of 1m thick willow and bamboo fascine mattresses, ballasted with large rocks.

The fascines continued to perform satisfactorily, although pieces of brushwood were found floating in the river after the unusually high flows of 1962-64, when surface velocities exceeded 3 m/s, causing some concern. However in course of time the island grew back again and the problem recurred; the scour developed in new locations and it was recognised that a more appropriate long-term approach would be stabilisation of the island together with key lengths of the river bank, thereby controlling the angle of approach to the bifurcation and limiting the variation in division of flow. Implementation of this policy was started some 20 years ago and the location and extent of scour has apparently remained static since then. This bank and island stabilisation is achieved solely by means of dumped rock revetment.

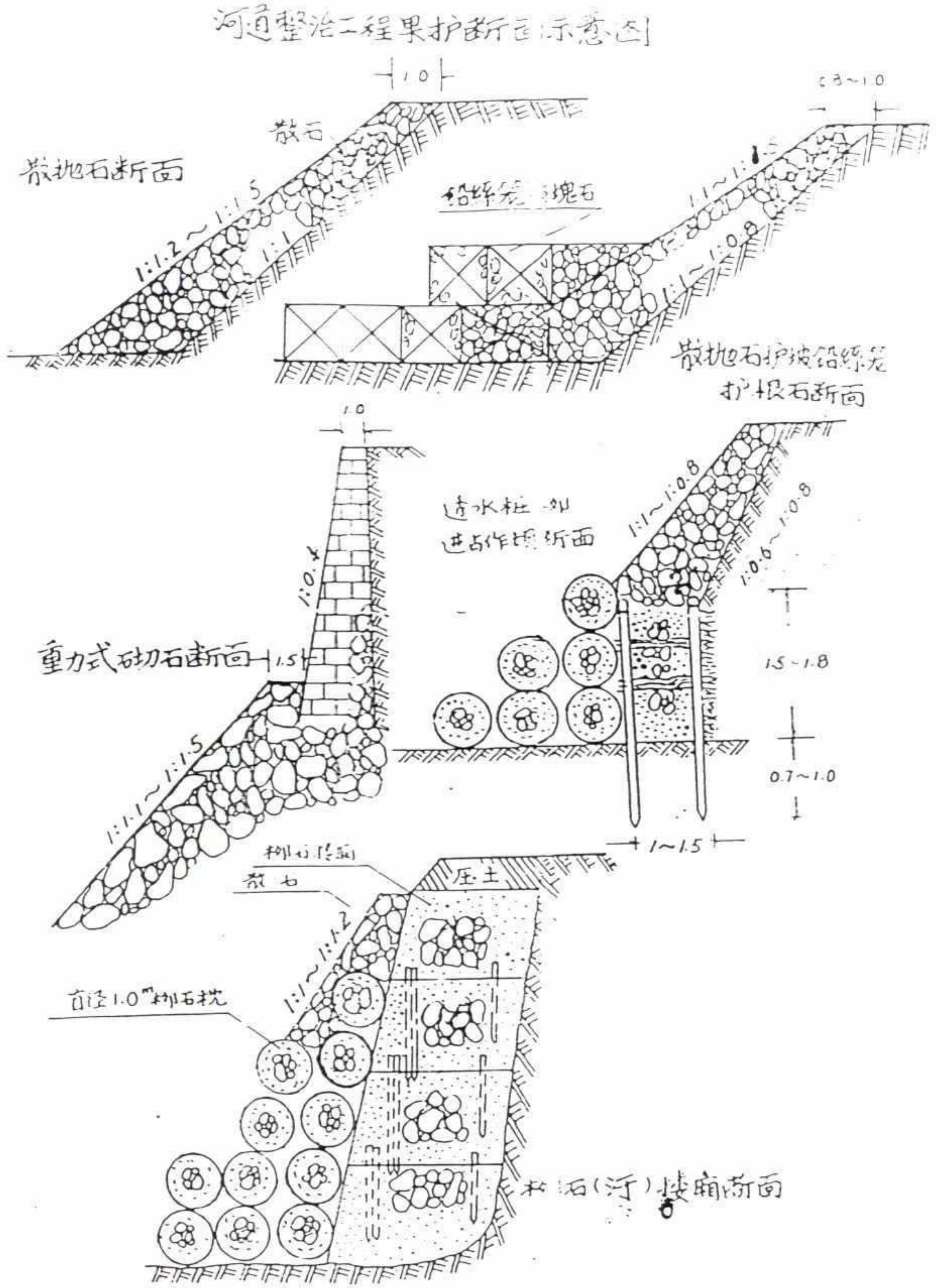
Downstream of the combined road and rail bridge there is another problem. A cutoff channel which formed many decades ago across the neck of a large meander loop is steadily capturing the river flow. From the point of view of the main river navigation the immediate impact is beneficial but while the loop was the main navigation channel, taking 70 percent of the flow, a power station and numerous chemical and other heavy industrial units were built along the outer bank; these are dependent on the river for both water supply and water borne transport.

Again, stabilisation of the island bifurcation is seen as the key to controlling the division of flow and the nose of the island has recently been stabilised by means of dumped rock revetment. No particular shaping of the nose was carried out and the rock was placed on the natural slope, which is of the order of 1 vert: 3 horiz. Where the velocity is not too high (not quantified) geotextile fabric is laid below the rock armour layer but not to the full depth. The thickness of the armour is designed according to a complex set of empirical guidelines that have been developed through experience; there is no apron as such, but the probability of additional scour development is one of the parameters for thickness determination and the end result is much the same - in fact it is probably more realistic than the highly stylised section, based mainly on Indian practice, that we tend to use.

Further downstream another island has been artificially attached to the left bank by the construction of two closure dams in order to create an ash lagoon. Although the branch that was closed had become relatively small, it seems that this has resulted in increased scour depth and bank erosion on the right bank and this is causing severe problems along a reach where there is a high density of heavy industrial infrastructure. Bank erosion to a depth of 2 km was experienced between 1950 and 1970, prior to the closure, and further erosion at even a more modest rate would result in major problems. In this case there is little choice but to stabilize the right bank by means of revetment over a length of about 10 km, much of which has already been completed.

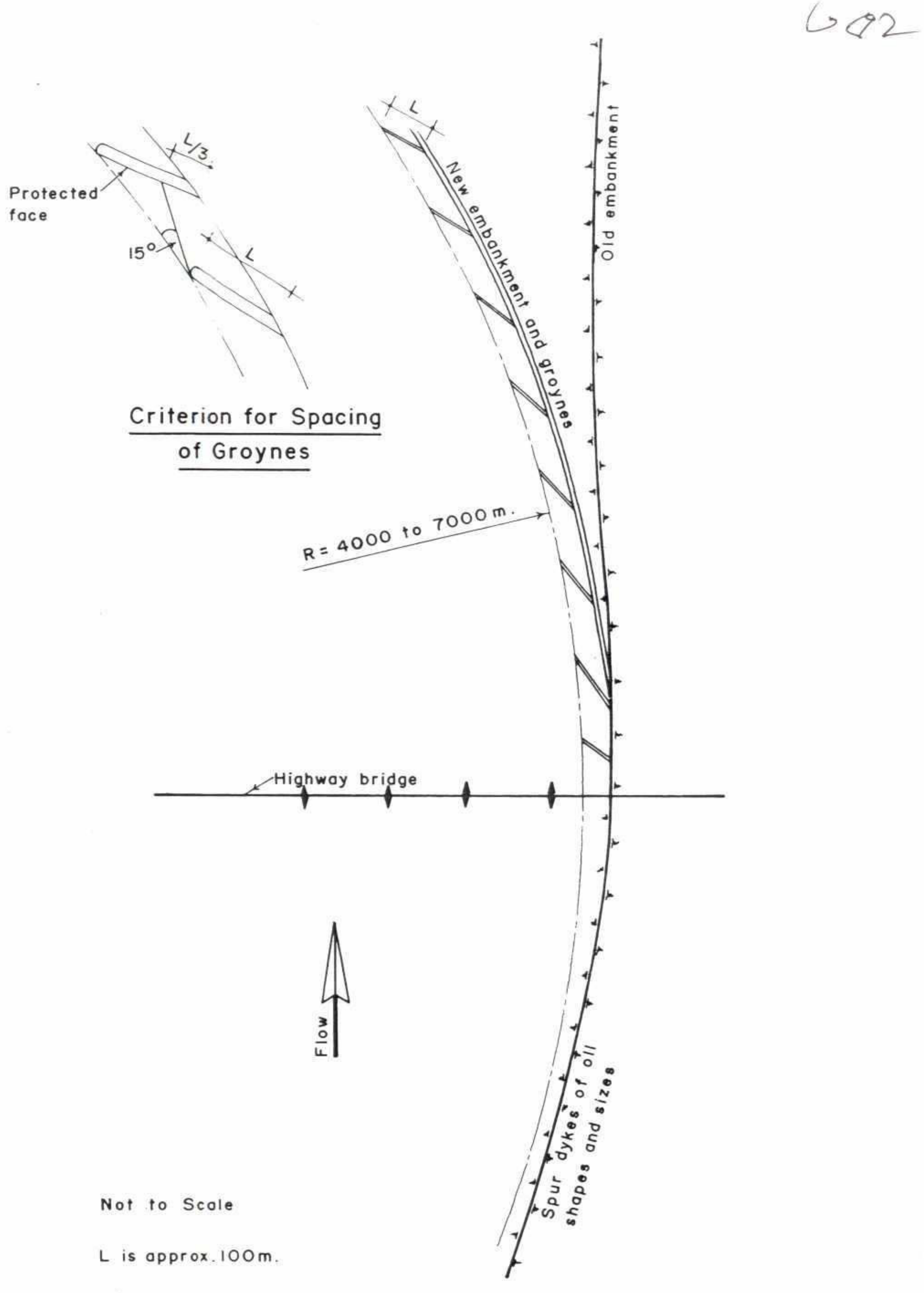
Placing of the rock revetment is done by hand from barges that are held in position by cables to four anchors and two shore based blocks, all of which are controlled by winches. Through a combination of laboratory model tests and field measurements (as simple as attaching a line to a rock and dropping it into the river) they have developed formulae for calculating the offset required in order to allow for drift as the material falls through the flowing water. There is inevitably segregation of the quarry run material but this does not appear to cause any problem in practice. Experience has also shown that revetment need not be taken down to the deepest point of the thalweg if this exceeds about 35 m. The thickness of the revetment varies depending on the depth of the channel and several other (unspecified) parameters. The minimum is 2 layers (about 0.5 m) and the maximum 8 layers (about 2.0 m).

A P G Russell, BRTS Technical Director
December 1992



Huang Ho River Bank Stabilisation

Halcrow/DHI/EPC/DIG *May 1993*	**Appendix C** **Figure C1**



Huang Ho River Training

Halcrow/DHI/EPC/DIG	May 1993	Appendix C Figure C2