GOVERNMENT OF PEOPLE'S REPUBLIC OF BANGLADESH
MINISTRY OF WATER RESOURCES
WATER RESOURCES PLANNING ORGANIZATION

FEDERAL REPUBLIC OF GERMANY

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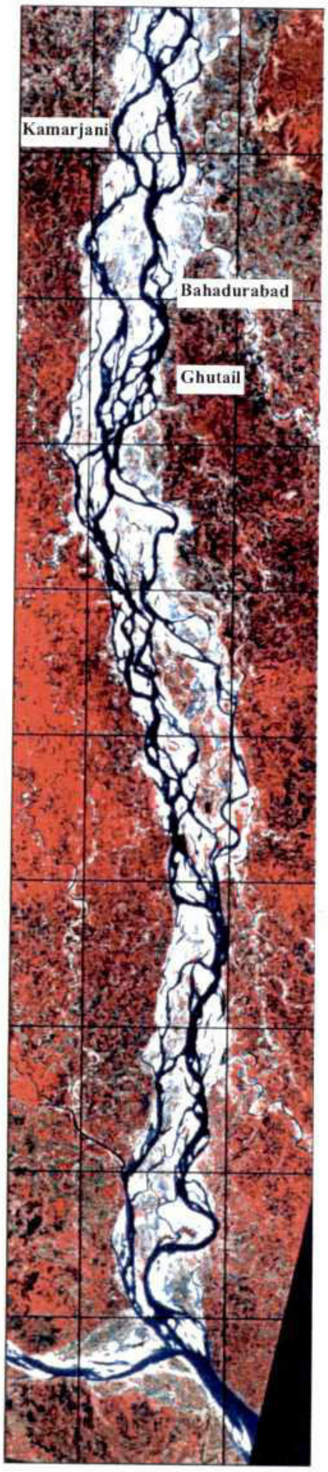

BANK PROTECTION AND RIVER TRAINING (AFPM) PILOT PROJECT FAP 21/22

FINAL PROJECT EVALUATION REPORT

VOLUME II

Annex 1: Morphological Investigations
Annex 2: Socio-Economic Aspects
Annex 3: Ecological Assessment

DECEMBER 2001

JAMUNA TEST WORKS CONSULTANTS, JOINT VENTURE
CONSULTING CONSORTIUM FAP 21/22

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In association with:
BANGLADESH ENGINEERING & TECHNOLOGICAL SERVICES LTD. (BETS)
DESH UPODESH LIMITED (DUL)

BANK PROTECTION AND RIVER TRAINING (AFPM)
PILOT PROJECT FAP 21/22

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MAY 2001

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BANK PROTECTION PILOT PROJECT
FAP 21/22

Important General Remark

The results presented and discussed in the Annexes of the Final Evaluation Report of the Bank Protection Pilot Project provides the state of the studies during the course of analysis and writing by the individual project partners. After a final review subsequent to the completion of the Annexes during the concluding stages of the Main Reports and the Guidelines and Manual some modifications and adjustments were felt necessary, also for covering more generalized structural measures in addition to the given case studies. For that reason, with respect to design formulae, recommended structure types, etc., reference should be made to the Main Reports and the Guidelines and Design Manual only.

DECEMBER 2001

BANK PROTECTION PILOT PROJECT

FAP 21

FINAL PROJECT EVALUATION REPORT

ANNEX 1

MORPHOLOGICAL INVESTIGATIONS

MAY 2001

FAP 21 - BANK PROTECTION PILOT PROJECT

FINAL PROJECT EVALUATION REPORT

ANNEX 1

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LIST OF ACRONYMS

BIWTA	-	Bangladesh Inland Waterways Transport Authority
BUET	-	Bangladesh University of Engineering and Technology
EGIS	-	Environmental and GIS Support Project for Water Sector Planning
FAP	-	Flood Action Plan
GIS	-	Geographical Information System
GPS	-	Global Positioning System
PWD	-	Public works Department datum
RRI	-	River Research Institute
SWMC	-	Surface Water Modelling Centre

GLOSSARY

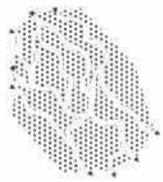
TERM | **DEFINITION**

aggrading — an alluvial river is "aggrading" when its bed rises because more sediment enters the river than the river can transport

alluvial — related to deposits of sediments left by the flow of rivers. The territory of Bangladesh consists mainly of alluvial plains. In river morphology, the term is often reserved to sediments which continue to be eroded and deposited by the rivers

altimetry — technique to measure altitudes (heights, elevations)

anabranching — formation of a river course with multiple channels, divided by islands, or sometimes bars, that are large in relation to channel width



avulsion — abrupt change in river course (e.g. the Brahmaputra avulsed from the Old Brahmaputra course to the present-day Jamuna course)

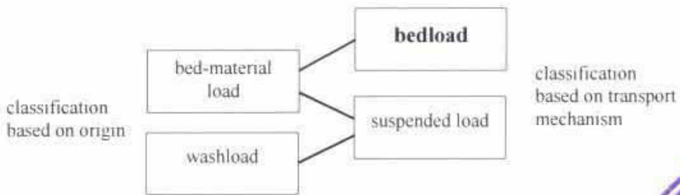
axisymmetrical — related to idealised bends with uniform curvature

bar — form of the river bed which scales with channel width

bathymetry — spatial depth distribution, usually defined as the submerged bed topography with respect to a sloping idealised water level surface for a certain specified constant discharge

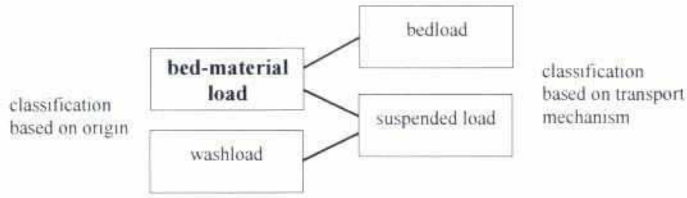
bedform — form of the river bed which scales with water depth (dune) or viscous sublayer (ripple)

bedload — sediment transport through rolling, sliding and saltation over the river bed



TERM — **DEFINITION**

bed-material load — transport of bed material, over the bed or in suspension

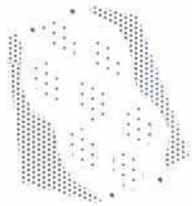


bed topography — spatial bed level distribution with respect to a horizontal datum

bend scour — scour in outer bend

bifurcation — point where a channel or river splits into two channels or rivers

braiding — formation of a river course with multiple channels, divided by bars that have a size on the order of the channel width



Bulle effect — disproportionate sediment transport into offtake channels due to helical flow

catkin — reed grass (Saccharum spontaneum)

certainty of attack — *see Section 5.2*

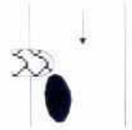
char — generally any accretion in a river, in particular islets in the rivers (Rashid, 1991)

Chézy coefficient — coefficient for hydraulic roughness

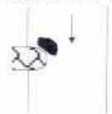
confluence — point where two channels or rivers join

confluence scour — scour occurring where two channels or rivers join

TERM	DEFINITION
constriction scour	scour occurring in narrower channel or river sections 
crossing	shallow area between two consecutive bends
cut-off	formation of a new channel which shortens the channel bend
degrading	an alluvial river is "degrading" when its bed goes down because less sediment enters the river than the river can transport
deterministic	related to models predicting the time evolution of certain parameters in terms of single numbers (as opposed to "probabilistic")
dimension	(1) extent or size, (2) the number of measures needed to describe the size of an object in a certain space. In mathematical modelling, the number of dimensions is equal to the number of space co-ordinates to which partial derivatives appear in the underlying differential equations
distributary	river taking off from another river (e.g. the Old Brahmaputra is a distributary of the Brahmaputra-Jamuna)
dune	bedform which scales with water depth
Exner's Principle	principle that erosion occurs in areas of accelerating flow and sedimentation in areas of decelerating flow
float tracking	measurement of surface flow velocities and flow lines by recording subsequent positions of floating objects
flow slide	bank erosion by means of relatively fast mass failure (liquefaction), resulting in deep bays in the bankline with a narrow neck
geomorphology	systematic study of landforms and their origin
ghat	quay, ferry landing
hardpoint	local inerodible bankline, assumed to prevent a longer river reach from lateral migration (control point in river planform development)

TERM	DEFINITION
hydrograph	graph representing discharges or water levels at a given station as a function of time
impingement	flow collision on a bank
interferometry	measurement technique based on differences in arrival times for signals from a point source which travel along different paths
isobath	equal-depth contour line
kaisha	catkin, a reed grass (Saccharum spontaneum)
kash	catkin, a reed grass (Saccharum spontaneum)
lineament	straight line representing abrupt changes in patterns and colours on satellite images and aerial photographs
local scour	scour downstream of a local structure or obstruction 
long term	time span of 3 to 30 years (for morphological predictions of the Brahmaputra-Jamuna)
mass failure	bank erosion process in which large portions of the bank collapse into the river during short events
meanders	sinuous rivers, sinuous channels
meandering	formation of a sinuous river course through bank erosion 
medium term	time span of 1 to 3 years (for morphological predictions of the Brahmaputra-Jamuna)
morphodynamics	study of the time-dependent changes in the forms of alluvial beds and their underlying processes. The term is also used as a synonym for morphological behaviour
morphology	branch of geomorphology, studying the forms of alluvial beds of water bodies and their ongoing changes by erosion and sedimentation. The term is also used as a synonym for the bed topography or the shape of a river

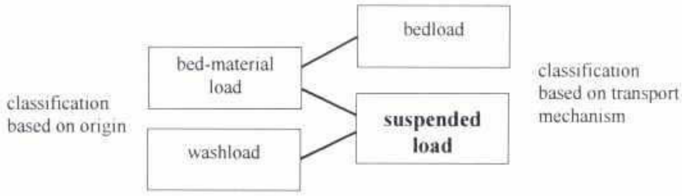
TERM	DEFINITION
mouza	plot, smallest revenue unit for land tax
overdeepening	additional bend scour due to non-uniform channel curvature
oversteepening	process by which erosion at the bank toe makes the bank so steep that it becomes unstable
photogrammetry	method of surveying or map making by photography
piping	process by which seepage flow carries away bank material from sublayers
pixel	picture element
planform	shape on map of banklines or water lines
point bar	bar at inner bend
pool	deep outer bend
plate	separate unit of the earth's crust
probabilistic	related to models predicting the time evolution of certain parameters in terms of a range of possible values and corresponding probabilities of occurrence (as opposed to "deterministic")
probability of attack	*see Section 5.2*
protrusion scour	scour immediately upstream of a local structure or obstruction



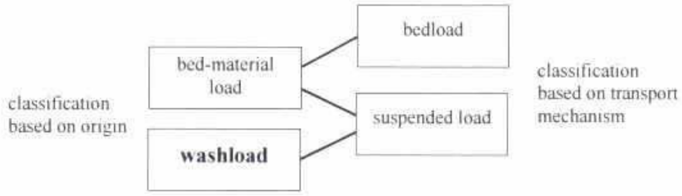
TERM	DEFINITION
regime	statistically averaged properties ("climate") of a river. A river is "in regime" if its statistically averaged properties remain constant, i.e. if the river is stable
relaxation	slow (oscillation-free) adaptation to an equilibrium state
remote sensing	observation or measurement without direct contact. In its broadest sense, the term includes hearing and seeing. In its more restricted operational meaning, it refers to gathering information from great distances and over broad areas, usually through instruments mounted on aircraft or orbiting space vehicles
resolution	size of smallest discernable detail

TERM	DEFINITION
retarded scour	scour occurring during the fall of the flood
retrogressive erosion	bank erosion by means of relatively slow mass failures (shear failures), resulting in a crescent-shaped line of bank retreat
ripple	bedform which scales with viscous sublayer
river morphology	branch of geomorphology, studying the forms of the river bed and their ongoing changes by erosion and sedimentation
scour	deepening of the bed by erosive action of water
secondary flow	flow phenomena related to deviations from standard vertical profiles (spiral flow, accelerating-flow deformation, decelerating-flow deformation)
sediment	solid material eroded, transported and deposited by the river
seepage	groundwater flow out of a bank face
shear stress	force exerted by the flow on a lateral interface of unit area
Shields parameter	parameter expressing the mobility of particles of a given size under given flow conditions (defined by Equation 2.3-8)
short term	time span of week to months (for morphological predictions of the Brahmaputra-Jamuna)
sinuosity	ratio between distance along the river or channel and distance along a straight line
sliding	bank erosion process in which large portions of the bank collapse into the river during short events
sloughing	bank erosion process in which thin layers of bank material are washed away particle by particle more or less continuously
specific gauge analysis	analysis of the development in time of the relation between certain discharges and the corresponding water levels
stable	an alluvial river is "stable" when its bed remains at the same level because the sediment entering the river equals the transport capacity of the river
statistical	related to application of mathematical functions to collections of data in order to summarize or to extrapolate those data

TERM	DEFINITION
subduction	descent of a tectonic plate into the earth's mantle
sun glint	optical backscatter by solar radiation
suspended load	sediment transport through flow convection, not in contact with the bed but kept in suspension by turbulence



synoptic	giving an overview of spatial patterns and interrelationships, as opposed to the information obtained from isolated point measurements
tectonic	related to the structural features of the earth's crust
tectonic activity	breaking and bending of crustal rock
thalweg	line connecting the deepest points of consecutive cross-sections
thrusting	process in which great slabs and slices are sheared off the top of a subducted tectonic plate and stacked atop one another
tributary	river flowing into another river (e.g. the Teesta is a tributary of the Brahmaputra-Jamuna)
undermining	erosion at the bank toe under higher, overhanging parts of the bank
washload	throughput of sediment which does not depend on local sediment transport capacity (supply-limited instead of capacity-limited transport)



LIST OF SYMBOLS

A	-	factor for influence of secondary flow on direction of bed shear stress	(-)
B	-	river width	(m)
B_0		reach-averaged channel width	(m)
C	-	Chézy coefficient for hydraulic roughness	($m^{1/2}/s$)
D	-	sediment grain size	(m)
D_{50}	-	median sediment grain size	(m)
f	-	silt factor	(m^3/s)
$f(\theta_0)$	-	function for influence of gravity component along transverse bed slopes on direction of bed shear stress	(-)
g	-	acceleration due to gravity	(m/s^2)
h	-	water depth	(m)
h_0	-	average water depth	(m)
h_0	-	reach-averaged water depth	(m)
h_{01}	-	average water depth in approach channel 1	(m)
h_{02}	-	average water depth in approach channel 2	(m)
i		water level gradient along streamline	(-)
K	-	multiplication factor depending on the geometry of river and structure	(-)
Q	-	discharge	(m^3/s)
r	-	transverse coordinate and local radius of curvature	(m)
s	-	volumetric sediment transport per unit width	(m^2/s)
s_0	-	reach-averaged sediment transport per unit width	(m^2/s)
u	-	depth-averaged flow velocity	(m/s)
u_{bank}	-	near-bank flow velocity	(m/s)
u_0	-	average velocity of approach flow	(m/s)
u_0	-	reach-averaged flow velocity	(m/s)
y	-	extra deepening due to scour	(m)
y_1	-	extra deepening due to scour after bank stabilisation	(m)
y_0	-	extra deepening due to scour in previous situation without bank protection	(m)
α	-	scour depth correction factor	(-)
β	-	exponent	(-)
Δ	-	relative sediment density	(-)
ΔB	-	reduction of river width	(m)
ΔH	-	elevation difference between outer bank and inner bank	(m)
θ	-	Shields' mobility parameter	(-)
θ_0	-	reach-averaged Shields parameter	(-)
κ	-	Von Kármán constant	(-)
ψ	-	sediment transport parameter	(-)
φ	-	incidence angle of joining channels	(°)
π	-	3.14159..	
$\partial n_B/\partial t$	-	bank migration rate	(m/s)

Other symbols are explained in the text at their utilisation.

SUMMARY

River morphology is a key factor for bank protection structures along the Brahmaputra-Jamuna river and other rivers of Bangladesh. Studies during the planning, the design, the construction and the monitoring of the test structures at Kamarjani and Bahadurabad have extended and deepened the knowledge on river morphology. This annex presents a resulting state of the art. It highlights specific topics and is not meant as a complete compilation of all the relevant knowledge. In this sense, the annex be seen rather as a series of footnotes to the work of Coleman (1969) and the reports of the River Survey Project (Delft Hydraulics & DHI, 1996 a-k). Ample references to other relevant literature are included.

A main activity under FAP 21/22 was the development of a prediction method for morphological changes two to three years ahead. For the rapidly changing Brahmaputra-Jamuna river with its sensitive dependence on small perturbations, a prediction span of two to three years is too long to be covered by simple extrapolation or detailed two-dimensional or three-dimensional mathematical modelling. That is why a different type of prediction method had to be developed. The resulting method and guidelines for its application are presented in Subsection 5.5.3 ("channel network analysis"). Guidelines for other prediction methods are given in the rest of Section 5.5. The basic principles of the methods apply to all rivers of Bangladesh, but the quantitative relations in the methods are valid for the Brahmaputra-Jamuna only. Application to other rivers will require re-calibration of the quantitative relations against data.

Another important finding during the project period is that the presence of structures and the associated local scour holes affect the morphology of the river on a larger scale. This effect makes the approach conditions to a structure more severe than would be expected from a statistical analysis of the conditions in a natural river without structures. Channels near structures become deeper, assume a more oblique approach angle, become more curved and have a larger probability of producing confluence scour holes than channels unaffected by structures. This finding is presented in Section 6.2 and remains a topic for further research.

1 INTRODUCTION

1.1 OBJECTIVES AND SCOPE

The *objectives* of the morphological investigations under FAP 21 were:

- To provide the morphological information, which were needed for the planning, design and implementation of test structures for bank protection and river training, and
- To develop guidelines for morphological investigations in aid of future bank protection and river training works on the Jamuna river and other rivers of Bangladesh.

Morphological investigations for bank protection and river training works can be used for the strategy laid down in a master plan, the identification of priority plans, site selection, assessment of design parameters, monitoring during implementation and morphological impact assessment. A master plan is not considered here. The works executed under FAP 21 were not a part of a master plan but concerned test structures with a temporary character. Morphological impact assessment is excluded from FAP 21 because a separate FAP project was supposed to be defined for the assessment of the morphological impacts of all FAP projects. A first step in this direction had been made by the River Survey Project (Delft Hydraulics and DHI, 1996 e). The large-scale morphological impact of the test structures is negligible because they do not reduce the active width of the river. Some local morphological impacts are discussed in Chapter 6.

This demarcation leads to the following *scope* of the morphological investigations:

- *Identification of priority plans:*
  Priority plans are usually based primarily on the requirement of defending important infrastructure ('something-to-defend criterion'). The areas for the FAP 21 test structures, however, were selected primarily on the requirement that they had be attacked by the river during the project period to allow proper testing ('certainty-of-attack criterion');
- *Site selection:*
  The probability distribution of the expected bankline migration was determined for the selection of a construction site within a priority area;
- *Assessment of design parameters*:
  A key issue in the assessment of representative design parameters is the response of the river to the structure. This response produces higher flow velocities and deeper scour than those observed in untrained rivers. The response can be understood from the interaction between local scour and general morphology, and
- *Monitoring:*
  The morphological predictions were reviewed and updated biannually during the implementation phase in order to assess the continuation of attack and the risk of unforeseen developments. Disappearance of the attack or appearance of undesired attack (e.g. on the upstream end of the Groyne Test Structure) would necessitate additional measures.

As the project proceeded, the emphasis of the morphological investigations has been shifting gradually. The main goal in the initial phase was site selection based on predictions of bank erosion a few years ahead. Satellite images were the major source of information. After construction of the test structures, the morphological investigations became focused on monitoring and assessing the effect of the test structures on the morphology of the river. For these investigations on smaller temporal and spatial scales, bathymetry and float-tracking maps were major sources of information in addition to the satellite images.

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1.2 TYPES OF RIVERS AND THEIR CHARACTERISTICS

1.2.1 Alluvial and Other Rivers

Rivers can be divided, according to the topography of the river basin, into the upper reaches in the hills, the middle reaches on the alluvial plain and the lower reaches affected by the sea. The rivers in hilly regions are characterised by the steepness of the slope, the swiftness of the flow, the occurrence of landslides and the formation of rapids along their courses. The control of rivers in the upper reaches is known as 'torrent control' and the methods adopted are distinctly different from those applied on the alluvial rivers known as 'river training'.

Alluvial rivers flow through alluvia, which have been built up by the rivers themselves and which continue to be eroded and deposited by the rivers. The alluvial sediments may range from fine silt to gravel.

1.2.2 Classification of Alluvial Rivers

The alluvial rivers can be classified, according to their vertical stability, into three types: (a) the stable type, (b) the aggrading type and (c) the degrading type. A river on an alluvial plain is seldom of a single type, but all the three types may be found on the same river from its uppermost point on the alluvial plain to its mouth. The classification depends on the amount and the size of sediment entering the river and its transport capacity for the sediment load. As the sediment load and discharge vary in time, any particular section of the river may be aggrading, degrading and stable at different times.

A river section is stable when its transport capacity is equal to the incoming amount of sediment. Aggradation is caused by excessive sediment or a decrease in slope, which may be due to a sudden inrush of sediment from a tributary or the extension of the delta at the river mouth. Degradation is caused when sediment transport is hindered or when the slope increases, for instance below a dam or barrage or above a cut-off.

1.2.3 Rivers in Regime

Aggrading and degrading rivers are interim forms, which would eventually develop into a stable river if the boundary conditions would remain unchanged. Such a stable river is said to be 'in regime'. The regime of a river depends on the magnitude and the variation of its discharge and sediment load, the composition of its bed material, the topography and the composition of its surrounding floodplains and banks. However, the dependence on these boundary conditions is not single-valued, because the history of a river plays a role as well. Given certain constant boundary conditions, several river regimes are possible.

A stable river is by no means permanent, as any change in the balance of boundary conditions affects the river regime. If boundary conditions change relatively fast, rivers never reach their regime and remain in a constant state of retarded adaptation.

1.2.4 Meandering

Sinuous rivers or sinuous channels within a river are called 'meanders'. Their planforms change through erosion of their outer banks. The word 'meandering' refers to the process of forming a sinuous course through bank erosion, but is also used in other ways. Firstly, it is sometimes used for any shift of the bankline although, for instance, the widening of a river is not a form of meandering. Secondly, it is used to distinguish certain river planforms from those of straight and braided rivers (Leopold and Wolman, 1957), but a disadvantage of this usage is that the terms 'meandering', 'braided' and straight' are not mutually exclusive (Kellerhals et al, 1976).

Another difficulty of such a descriptive planform classification is that a pattern, which might be described as braided at low water stage, may not appear so at higher stages (Neill and Galay, 1967). A quantification of the sinuosity and the number of channels at certain water levels is more precise. Finally, the term 'meandering' is used for channels or rivers with a sinuosity larger than 1.25 (Brice, 1983) or 1.5 (Rust, 1978).

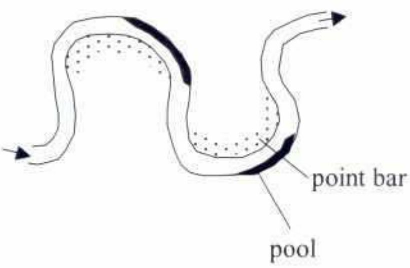


Fig. 1.2-1: Meandering river

1.2.5 Braiding and Anabranching

The multiple channels of the Jamuna river are partly related to braiding and partly to anabranching. Anabranching differs from braiding in that the flow is divided by islands, or sometimes bars, which are large in relation to the channel width. Each anabranch is a distinct and rather permanent channel with banklines, whereas braids are shifting and lie within the banklines of a single broad channel (Brice, 1983). In a braided river, the dominant process of channel shifting is bank erosion, deposition and the dissection of within channel-bars. The dominant process of channel shifting in an anabranched river is avulsion (Knighton and Nanson, 1993). Avulsions occur when the river captures a watercourse on the mainland, thus excising an island from the floodplain.

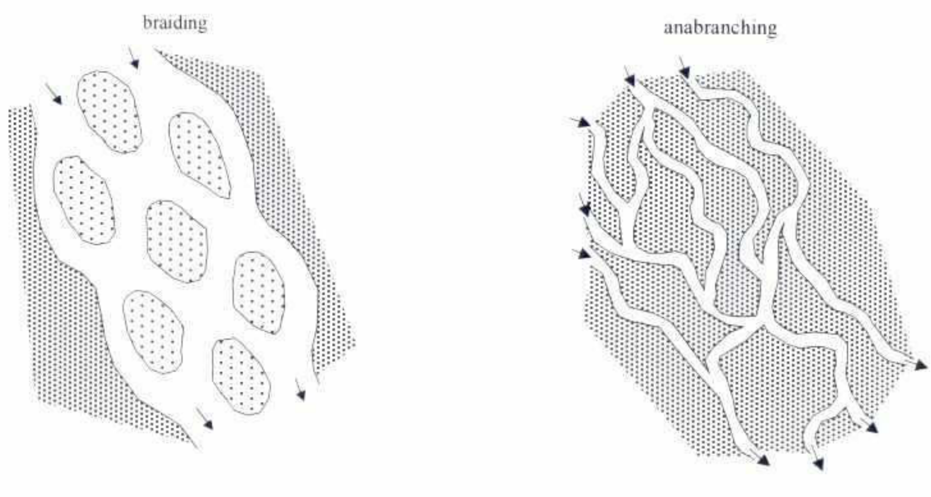


Fig. 1.2-2: Braided and anabranched rivers

Anastomosing rivers are also multi-channel rivers, but they are less relevant for Bangladesh because of their limited bank erosion. Makaske (1998) sees anastomosing rivers as a special type of anabranching rivers, corresponding to three of the six types of anabranching rivers distinguished by Nanson and Hickin (1996).

Braiding occurs when the width-to-depth ratio of a river is above a certain threshold. This condition is met when the banks of the river are easily eroded. Contrary to what is often believed, discharge variations and aggradation are not necessary conditions for braiding. Braided streams can be reproduced in flumes under steady flow conditions. Nonetheless, rapid discharge variations can promote braiding as they enhance bank erosion, and Germanoski and Schumm (1993) demonstrate that the number of braids increases with aggradation.

1.3 GEOLOGICAL SETTING

The general physiography and structure of the Bengal Basin is shown in Fig. 1.3-1. The basin is bounded to the west and to the north by shield areas and to the east by the fold zones of the Indo-Burma Orogeny. The western shield is the pre-Cambrian Indian Shield, the northern shield the Shillong Plateau with Cretacious and Tertiary shelf sediments on a pre-Cambrian basement. The Ganges and the Brahmaputra-Jamuna enter Bangladesh through the Shelf Zone between the two shield areas. Khan (1991), Rashid (1991) and Brammer (1996) provide comprehensive information on the geology, geography and pedology of the area.

The Ganges, Brahmaputra and Meghna rivers and their numerous tributaries and distributaries have filled the Bengal Basin with Quaternary sediments. The thickness of the sediment over the pre-Cambrian basement varies from a few hundred meters to about 18 km. The thickness is small in the Shelf Zone in the north but large in the Bengal Foredeep in the south. These two areas are divided from one another by the Eocene Hinge Zone, which crosses the Jamuna river in the reach immediately south of Sirajganj and has also been indicated in Fig. 1.3-1. The nature of this hinge zone is still subject of discussion (Khan, 1991).

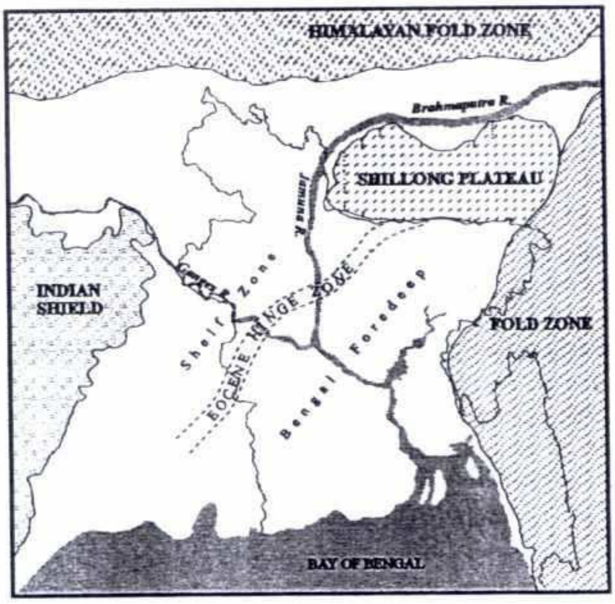


Fig. 1.3-1: General physiography and structure of the Bengal Basin
(source: EGIS,1997)

The tectonic structure of the Bengal Basin has influenced the courses of the rivers (Baker, 1986), but the effect of ongoing tectonic activity on present and future morphological changes of the Jamuna river is a source of debate. Bangladesh lies in one of the most active tectonic zones of the world. This tectonic activity is related to the ongoing collision of the Indian Plate against the main Eurasian Plate. The Indian Plate, carrying the Indian subcontinent, continues to move roughly north at a rate of about 5 cm per year. Its forward edge is subducted underneath the Eurasian Plate, thus elevating the Tibetan Plateau and creating the geologically still young and erodible Himalayan mountain range by 'thrusting': a process in which great slabs and slices are sheared off the top of the subducted plate and stacked atop one another. Further away from the forward edge, the advancing Indian Plate is broken into crustal blocks by internal stresses and deformations due to the collision. These blocks can be bounded by faults as well as by folds. The crustal blocks of the Bengal Basin have distinct rates of uplift and subsidence in the order of millimeters a year. The resulting tectonic structure has influenced the courses of the rivers, but the effect of ongoing uplift, subsidence and tilting on present and future bankline migration, river widths and braiding intensities is not clear. That ongoing tectonic activity could have any effect on the Jamuna river at all is even strongly debated, because the rates of uplift and subsidence are very small (order of millimetres per year) compared to the rates of local aggradation and degradation (order of meters per year). Tilting of crustal blocks might nonetheless have a great influence, as river planforms are very sensitive to small differences in slope.

Tectonic faults and crustal blocks can be identified on satellite images and aerial photographs by an analysis of lineaments. Lineaments are straight lines, which represent abrupt changes in patterns and colours. These changes can correspond to abrupt changes in geological units, elevation, vegetation, soil moisture or land use. One should be aware that man-made infrastructure may produce the same effect (e.g. blocking of drainage by a road) and that data transmission disturbances appear as straight lines on satellite images as well. Satellite images and aerial photographs can provide additional evidence that lineaments correspond to tectonic faults if the lineaments are aligned with nearby mountain valleys that are straight lines over a long distance, often making angles of 60° with other valleys (valleys in the Shillong Plateau for the Jamuna river). Lineaments are usually also derived from river courses, but that leads to a circular argument when tectonic faults are meant to explain those river courses. Lineaments persisting throughout the years are more likely to represent true physical features.

A lineament analysis was carried out under FAP 21 to assess the influence of tectonics on channel patterns in the Jamuna river (Hartmann et al, 1993; Mosselman et al, 1995). Without further field verification, however, the reported results remain highly speculative.

More-year change detection images reveal patterns of straight lines in the Brahmaputra river north of its entry into Bangladesh. This suggests that river channels regularly return to certain preferred courses, which are controlled by active tectonics. Preferred channel courses appear also further south in Bangladesh where the layer of sediment over the pre-Cambrian basement is thick. The latter might primarily be explained from the lower elevation and unconsolidated material of former river courses ('channel scars'). Gilvear and Harrison (1991) find evidence for the river Tay in Scotland that the sediment deposited in former abandoned channels is eroded more easily than the surrounding sediments.

1.4 RIVERS OF BANGLADESH

Besides the three mighty rivers Ganges-Padma, Brahmaputra-Jamuna and Meghna, more than 250 rivers flow through Bangladesh with a total length of about 24,000 km. The main hydrographic network is shown in Fig. 1.4-1. Some characteristics of the largest rivers are summarised in Table 1.4-1.

Name		Jamuna	Ganges	Padma	Old Brahma-putra	Dhales-wari	Gorai	Arial Khan	Upper Meghna
Catchment area (million km^2)		0.57	1.09	-	-	-	-	-	0.077
Gradient (m/km)		0.07	0.05	0.04	0.07	0.045	0.04	-	0 to 0.02
Average discharge (m^3/s)		19 600	11 000	28 000	500	600	1 400	2 600	4 800
Bankfull discharge (m^3/s)		48 000	43 000	75 000	-	-	-	-	-
Return period of bank-full discharge (year)		1.00	1.40	1.05	-	-	-	-	-
Width (m)		11 000	5 000	7 000	330	256	-	-	1 000
Average depth (m)		5.0	4.5	-	7.0	9.0	-	-	4.7
Seasonal water level variations (m)		6	8	6	-	-	8	-	5
Tidal influences		none	none	in winter	none	lower reach in winter	lower reaches	entire reach	in winter
Median bed-material grain size (µm)	overall	190	120	90	140	150	179	147	180
	active bed	200	140	-	180	-	-	-	-
	low-velocity areas	35	30	-	30	-	-	-	-
Vertical stability		stable	stable	stable	aggrading	-	aggrading	degrading	-
Meander wave length (km)		-	29	-	5.5	-	9.2	4.2	9.0
Channel sinuosity (-)		-	1.2	1.1	1.4	1.5	1.7	1.8	-
Brice braiding index (-)		4 - 6	-	-	-	-	-	-	-
Regime $B = aQ^b$	a	8.97	9.97	4.76	-	-	-	-	-
	b	0.57	0.555	0.62	-	-	-	-	-
Regime $h = aQ^b$	a	0.4	0.28	0.28	-	-	-	-	-
	b	0.26	0.29	0.30	-	-	-	-	-
Degree of nonlinearity in relation between sediment transport and flow velocity		3.66	5.0	-	-	-	-	-	-
Regime relations for individual channels: B = width (m), h = water depth (m), Q = bankfull discharge (m^3/s)									

Table 1.4-1: Characteristics of major rivers of Bangladesh

Most data of Table 1.4-1 stem from the Main Volume of the Final Report of the River Survey Project (Delft Hydraulics and DHI, 1996 a). According to this report, information and data of the Teesta river are very limited.

The bankfull discharges and the corresponding return periods have been taken from Special Report No.6 of the River Survey Project (Delft Hydraulics and DHI, 1996 f).

The seasonal water level variations stem from Annex 3 of the Final Report of the River Survey Project (Delft Hydraulics and DHI, 1996 b).

The bed material data for the Jamuna, the Old Brahmaputra and the Ganges have been taken from Special Report No.8 of the River Survey Project (Delft Hydraulics and DHI, 1996 h).

The vertical stability of the rivers represents the present situation. Changes in the vertical stability due to implementation of the FAP projects are assessed qualitatively in Special Report No.5 of the River Survey Project (Delft Hydraulics and DHI, 1996 e).

The regime relations for channel width and channel depth stem from Special Report No.7 of the River Survey Project (Delft Hydraulics and DHI, 1996 g).

The degree of non-linearity of the relation between sediment transport and flow velocity is explained in Section 1.5.

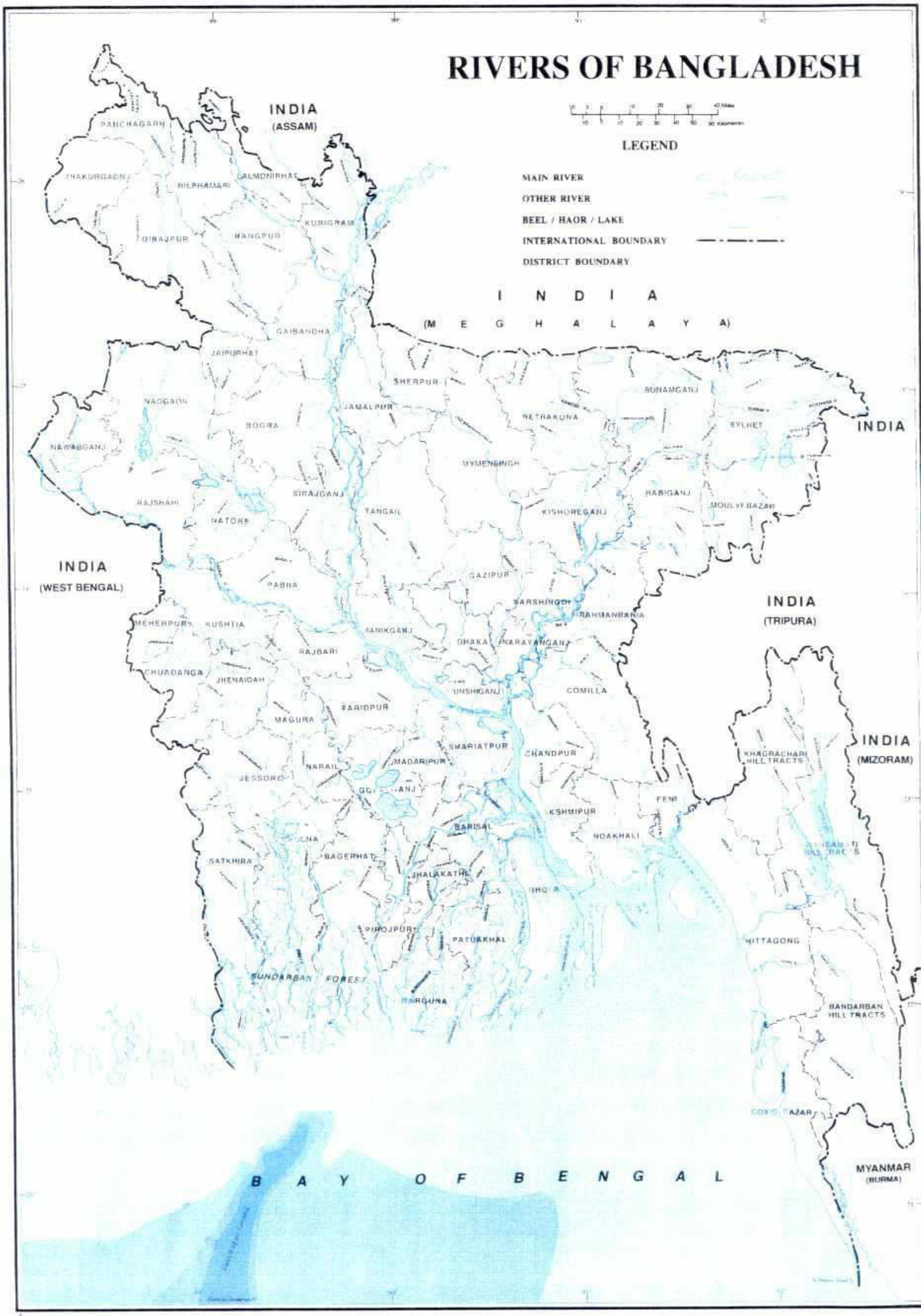


Fig. 1.4-1: Rivers of Bangladesh

(Source: Graphosman)

1.5 SEDIMENT TRANSPORT PREDICTORS FOR RIVERS IN BANGLADESH

The River Survey Project gives the following sediment transport predictor for the Jamuna (Delft Hydraulics and DHI, 1996 i):

$$\psi = 0.16\left(\frac{C}{\sqrt{g}}\right)^{1.45}\theta^{1.83} \qquad (1.5\text{-}1)$$

with

$$\psi = \frac{s}{\sqrt{g\cdot\Delta\cdot D_{50}^{3}}} \qquad (1.5\text{-}2)$$

$$\theta = \frac{u^2}{C^2\cdot\Delta\cdot D_{50}} \qquad (1.5\text{-}3)$$

in which,

C	=	Chézy coefficient for hydraulic roughness	$(m^{1/2}/s)$
D_{50}	=	median sediment grain size	(m)
g	=	acceleration due to gravity	(m/s^2)
s	=	volumetric sediment transport per unit width	(m^2/s)
u	=	depth-averaged flow velocity	(m/s)
Δ	=	relative sediment density	(-)
θ	=	Shields' mobility parameter	(-)
ψ	=	sediment transport parameter	(-)

For the Ganges, the River Survey Project gives the following sediment transport predictor (Delft Hydraulics and DHI, 1996 i):

$$\psi = 0.28\left(\frac{C}{\sqrt{g}}\right)^{1.7}\theta^{2.5} \qquad (1.5\text{-}4)$$

A key morphodynamic parameter is the degree of nonlinearity b in the relation between sediment transport and flow velocity. It is defined as

$$b = \frac{u}{s}\frac{ds}{du} \qquad (1.5\text{-}5)$$

The definition of b is illustrated in Fig. 1.5-1. As the Shields parameter is proportional to the squared flow velocity, b is equal to twice the exponent of θ in the sediment transport predictors. That is why b = 3.66 for the Jamuna and b = 5.0 for the Ganges in Table 1.4-1.

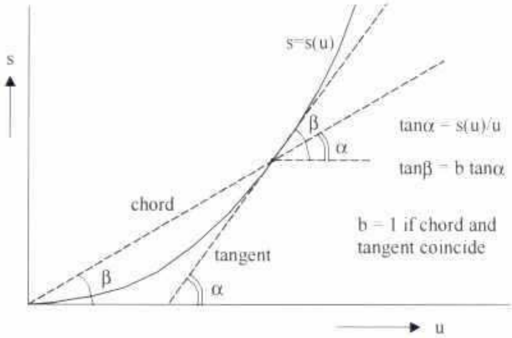


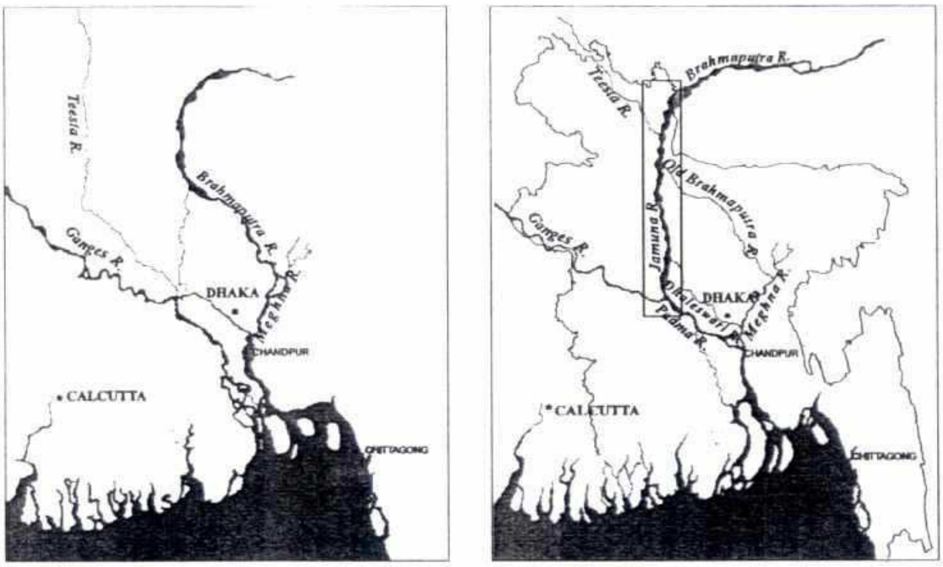
Fig. 1.5-1: Definition of degree of nonlinearity

1.6 JAMUNA RIVER

The FAP 21 test structures have been built along the Jamuna river, which is considered the most difficult river in Bangladesh to train.

Jamuna is the name of the new course for the lower end of the Brahmaputra river, which formed after a major avulsion about two centuries ago (see Fig. 1.6-1). The previous course is still called Old Brahmaputra. There has been dispute in the literature on whether the avulsion occurred gradually between 1720 and 1830 (Hirst, 1916) or rapidly after having been triggered by a major earthquake in 1762 (Coleman, 1969, p.139), a sudden increase in discharges due to the sudden appearance of the Teesta river as an upstream tributary in 1787 (La Touche, 1910) or the digging of a small channel by a farmer (Hunter, 1876). In the light of these hypotheses it is remarkable that as late as in 1810, the diversion was still seen as a threat rather than an accomplished fact (Fergusson, 1863, p.334). The rapid change proposed by La Touche (1910) had been generally accepted in the past as representing the opinion of the Geological Survey of India, but Morgan and McIntire (1959) argue that additional evidence from field studies supports the gradual change proposed by Hirst (1916). This also complies with the general observation that major river diversions are gradual. The gradual avulsion of the Brahmaputra-Jamuna may be ascribed partly to the gradual uplift (Fergusson, 1863) or tilting (Morgan and McIntire, 1959) of the Madhupur Tract by neotectonics. During the FAP 22 Expert Discussion, held in Dhaka in 1993, C.R. Thorne (University of Nottingham, UK) argued that aggradation and backwater effects associated with the build up of a great alluvial fan in the Sylhet Basin probably had as much to do with the diversion of the Brahmaputra-Jamuna to its present course as neotectonics.

The total length of the Brahmaputra-Jamuna is about 2,900 km. The length from its entry in Bangladesh to the confluence with the Ganges is about 240 km. This part is shown in Fig. 1.6-2. It is an anabranched and braided river, 5 to 15 km wide. From the entry to the confluence, its gradient decreases from 85 to 65 mm/km and its median bed-material grain size decreases from 0.22 to 0.16 mm. The bed consists of fine sand with considerable presence of silts. The content of mica in the sediment is relatively high. This mica is supplied by the Teesta river (Delft Hydraulics and DHI, 1996 j). The average annual sand transport (coarse fraction) amounts to 150 million tons per year, which is equivalent to 90 million m^3/year.



River course in 1767
Surveys by Major James Rennell

River course in 1991
Satellite Image, NOAA/AVHRR

Fig. 1.6-1: Brahmaputra river in 1767 and 1991
(source: EGIS, 1997)

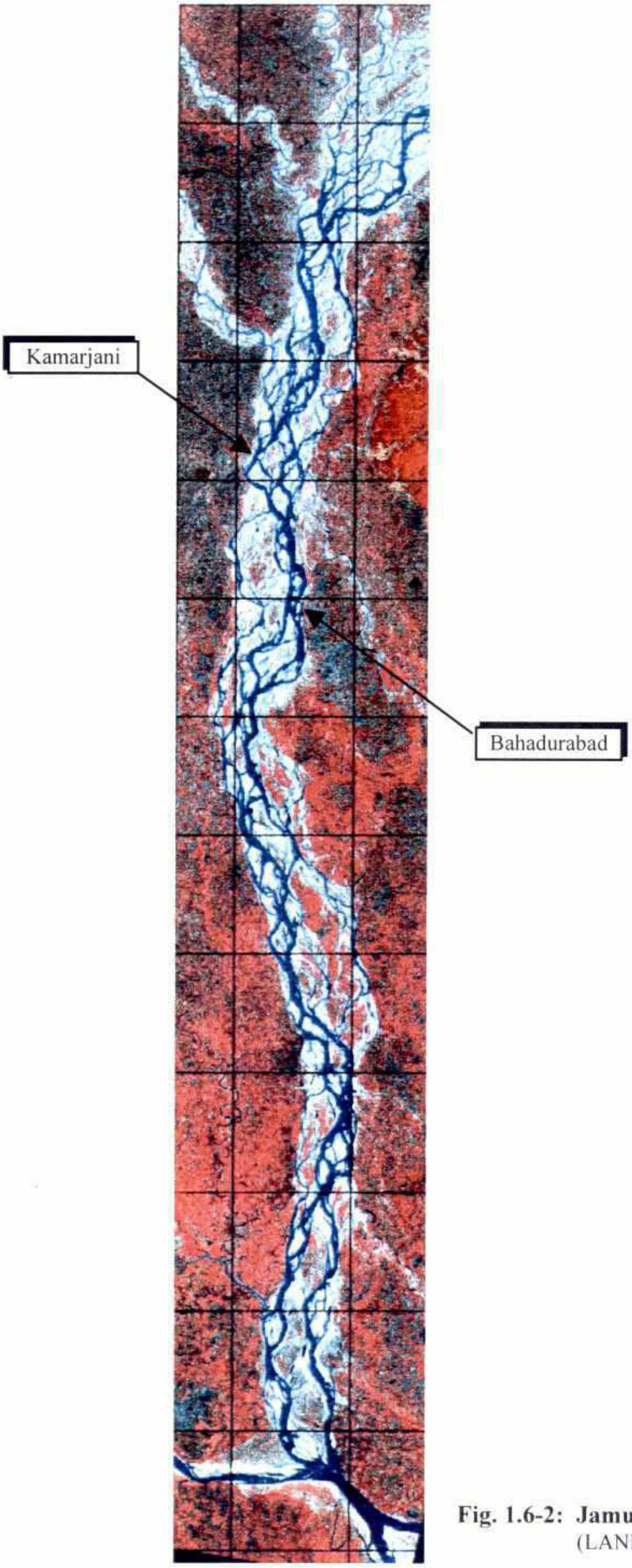


Fig. 1.6-2: Jamuna river in Bangladesh
(LANDSAT image of January 23, 1999)

2 MORPHOLOGICAL PROCESSES

2.1 INTRODUCTION

Morphological processes in the rivers of Bangladesh have been studied extensively during the Planning Study of FAP 21 and 22. This work, reported in the Final Report of the Planning Study, has been reviewed and updated by the River Survey Project (Delft Hydraulics and DHI, 1996 a-k; Delft Hydraulics, DHI and EGIS, 1996; Delft Hydraulics, DHI and University of Leeds, 1996; Delft Hydraulics, DHI and University of Nottingham, 1996). The pertaining reports form a good state-of-the-art of the morphology of rivers in Bangladesh, with ample reference to other important works such as the classical benchmark paper of Coleman (1969). Therefore, a detailed treatment of all morphological aspects is omitted here. Only the processes of bank erosion and scour, which have particular relevance for the work under FAP 21, are dealt with in Sections 2.2 and 2.3. The influence of human activities on the morphology of the rivers is treated in Section 2.4.

Morphological changes in the deeper, more active parts of the river are mainly related to the transport of coarser sediments (sand) as bed load and near-bed suspended load. Erosion occurs when the sand transport increases along a flow line, sedimentation when the sand transport decreases. The sand transport reacts quickly to changes in flow conditions, so that gradients in sediment transport can be correlated straightforwardly with gradients in water flow velocity. Thus, in the deeper, more active parts of the river one can apply *Exner's* (1925) *Principle* that erosion occurs in areas of accelerating flow and sedimentation in areas of decelerating flow. These areas are characterised by converging and diverging flow lines respectively, as shown in Fig. 2.1-1.

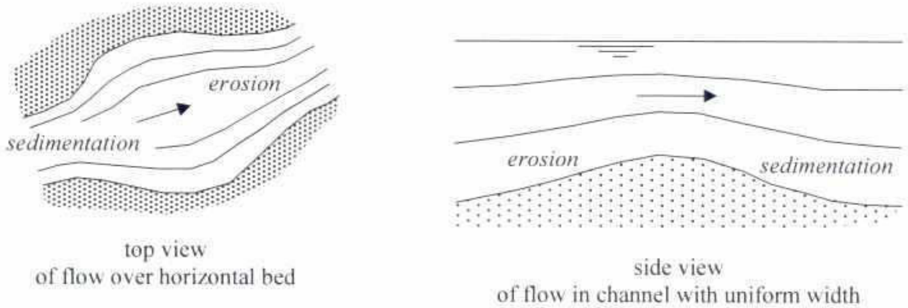


Fig. 2.1-1: Exner's Principle for coarse sediments

The finer sediments (silt) are transported as suspended load over the full depth of the river and do not respond quickly to changes in flow conditions. They can be treated as washload in the deeper active parts of the river, but they are deposited in areas of low flow velocities. Such areas are found on floodplains and chars, but also in deeper zones that are sheltered from the main flow. Banks erode where flow velocities are high, but mechanisms other than the exertion of flow shear stress may cause bank erosion as well.

The inflow conditions upstream, the water level downstream, the shape of banklines, channels and chars and the spatial distribution of the hydraulic resistance determine the flow field and hence the spatial distribution of flow velocity gradients. Following Exner's Principle, this yields the spatial distribution of erosion and sedimentation, which produce the changes in the shape of the river. These processes are complicated, however, by three-dimensional flow phenomena, such as spiral flow and large turbulent structures, and the occurrence of bedforms of different dimensions.

The average bed level is subject to seasonal changes. The left-hand side of Fig. 2.1-2 shows that, in principle, the bed is eroded during the rising limb of a flood hydrograph, when flow lines converge under the steeper water level. Conversely, the bed aggrades during the falling limb of the hydrograph. The result is a higher river bed elevation during the dry season. The opposite may be concluded, however, from the bed topographies derived from bathymetric surveys (e.g. Delft Hydraulics, DHI and EGIS, 1996). This is due to two effects. Firstly, some areas are submerged during the flood season but exposed during the dry season. As those areas are not covered by bathymetric surveys in the dry season, average bed levels seem lower. Secondly, the main channels tend to become incised more deeply in the dry season due to retarded scour across shallow crossings during the fall of the flood. This is shown in the right-hand side of Fig. 2.1-2.

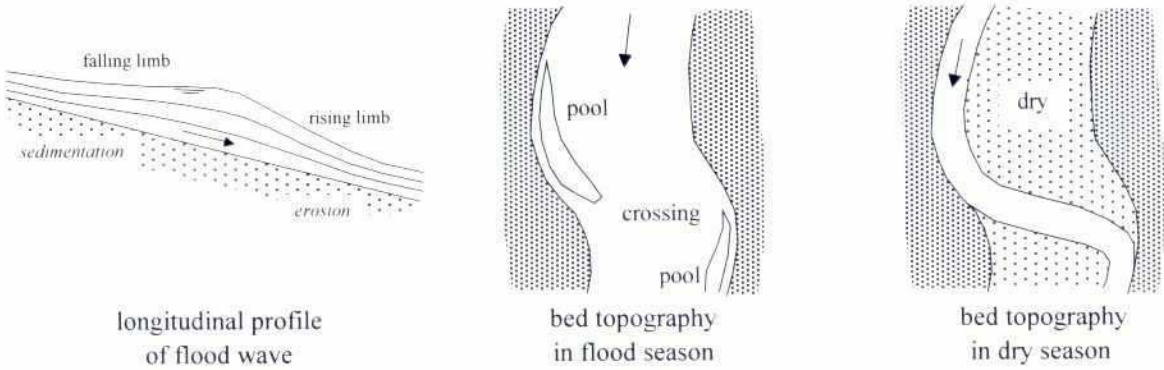


Fig. 2.1-2: Seasonal effects on river bed topography

2.2 BANK EROSION

Banks retreat by the erosive action of currents and waves, but also by other factors, which cause internal loss of stability. Thin layers of bank material may be washed away particle by particle in a more or less continuous process (*sloughing*) or large portions of the bank may collapse into the river during short events (*mass failure*, *sliding*). Strictly speaking, the term 'erosion' refers only to sloughing, but in the common broad operational use of the word it refers to mass failure as well.

Two particular types of mass failure occur along large alluvial rivers viz. retrogressive erosion and flow slides. *Retrogressive erosion* is a relatively slow process, which has been studied by Torrey (1995). It may take several hours and results in a crescent-shaped line of the retreated bank. *Flow slides* occur fast and produce deep bays in the bankline with a narrow neck. The different resulting banklines are shown in Fig. 2.2-1.

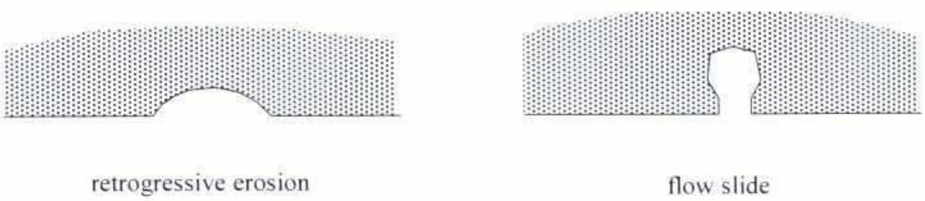


Fig. 2.2-1: Banklines after retrogressive erosion and flow slide

Mass failures are favoured by *oversteepening* and *undermining* of the bank due to scour at the toe. They are also favoured by fast decreases in water level when the banks are saturated with water. The weight of the saturated higher parts of the bank increase the shear stresses along potential slip faces, while the pressure of *seepage* flow out of the saturated bank decreases the internal shear strength. Bank stability is also reduced by groundwater flowing in sublayers towards the river. This flow may carry away material from the sublayers (*piping*).

The decrease in water level during flood recession favours also the bank erosion mechanism explained in Fig. 2.2-2. A river bend may have a rather uniform conveyance during a flood, despite differences in the shapes of consecutive cross-sections (left-hand side of the figure). When the water level decreases, however, the cross-section with the deepest pool will also have the highest point bar and the smallest conveyance (right-hand side of the figure). The resulting flow acceleration in this cross-section causes erosion, mainly along the outer bank due to the direction of flow impingement. The bank erosion may even promote further point-bar growth.

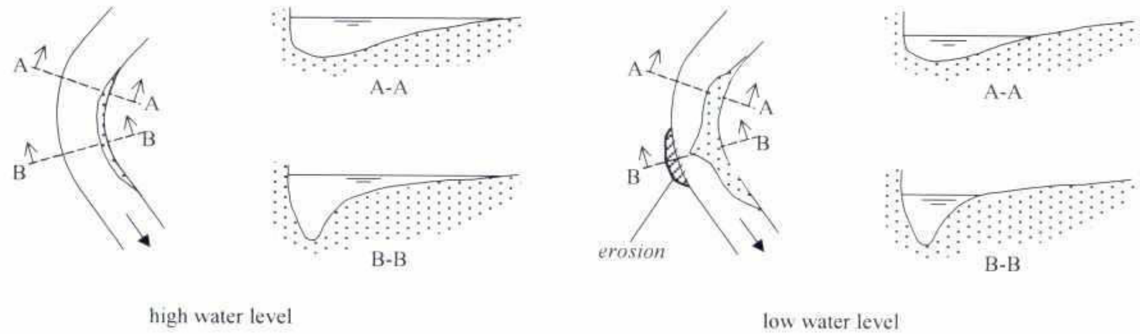


Fig. 2.2-2: Point-bar induced bank erosion after decrease in water level

Currently bank erosion is being included in two-dimensional mathematical models for river morphology. Mosselman (1992) proposes for these models a general bank erosion submodel in which the rate of bank retreat depends on:

- excess near-bank flow shear stress above a certain critical value;
- near-bank bed degradation rate;
- excess bank height above a certain critical value, and
- causes not related to the hydraulics and the morphology of the river.

The first dependence on near-bank flow shear stress is the most generally accepted one. A two-dimensional mathematical model applied to the Jamuna river (DHI and SWMC, 1996; Enggrob and Tjerry, 1999) contains a bank erosion submodel in which the rate of bank retreat depends on:

- near-bank bed degradation rate, and
- ratio of near-bank sediment transport capacity to bank height.

The first dependence is equal to the corresponding dependence from Mosselman (1992). The second dependence is questionable for two reasons. Firstly, the sediment transport capacity influences only indirectly the bank erosion mechanism and this indirect influence is already accounted for by the sediment balance (erosion being related to gradients rather than magnitude of sediment transport). Secondly, the inversely proportional relation between bank height and bank retreat implies that higher banks are less prone to erosion, despite their smaller stability. The background of selecting this relation may be that DHI and SWMC (1996) focus on the supply of bank erosion products for a given rate of bank retreat rather than on a mechanism of bank retreat. That this supply becomes greater as bank height increases can be described by a relation in which bank retreat is proportional to the ratio of volumetric bank material supply to bank height.

A semantic problem arises of whether only the upper part of the slope or the full slope from bank top to thalweg should be considered to be the bank. Hasegawa (1989) takes the full slope as bank. It is more consistent with morphological practice, however, to treat the lower part as a part of the bed, because its slope is less than 45° and because its erosion is basically determined by gradients in transport capacity. A different treatment could yet be justified when the processes between bank top and thalweg occur on subgrid scale, i.e. when the distance between thalweg and bankline is smaller than the size of the computational cells in the mathematical model.

2.3 SCOUR

2.3.1 Introduction

Different processes scour the bed at certain places below its average level (see Fig. 2.3-1). The River Survey Project (Delft Hydraulics and DHI, 1996 d,k) investigated these processes and the resulting scour depths in the major rivers of Bangladesh. The findings of that project are summarised and reviewed in the next subsections.

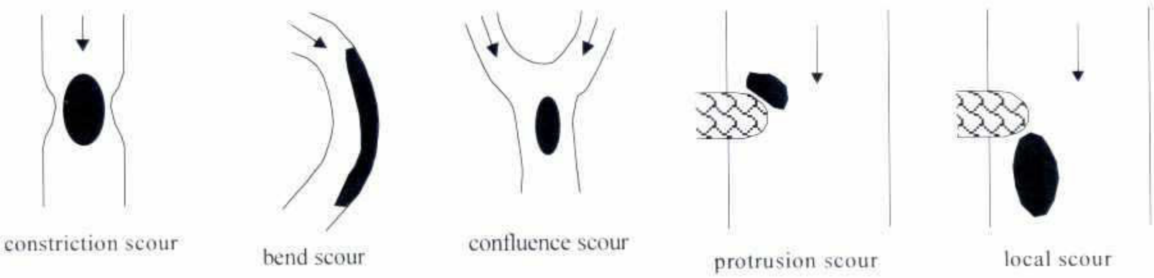


Fig. 2.3-1: Different types of scour holes

The scour occurring in reality is often a combination of different types, strongly depending on the local geometry of the river and its hydraulic structures. That is why simple scour formulas are not sufficient for the design of bank protection and river training works. More detailed methods are required. Physical modelling is still the primary method for scour assessment, but mathematical modelling can be expected to become a good alternative before 2010. The modelling serves not only the straightforward determination of design scour depths under given conditions. It is also an optimisation tool, which can be used to search the layout and shape of river training works which produce the least scour.

Traditional scour formulas on the Indian Subcontinent relate the scour depth primarily to the discharge, with some empirical factor to account for the geometry of river and structure. More recent scour formulas, however, relate the scour depth primarily to the average water depth in the approach flow. This is not contradictory, because a primary dependence on water depth can also be inferred from Lacey's discharge-dependent formulas. This is shown hereafter.

According to Lacey's regime relations, usually presented in British Imperial units, the average water depth is given by

$$h_0 = 0.47\left(\frac{Q}{f}\right)^{1/3} \qquad (2.3\text{-}1)$$

in which

	h_0	=	average water depth	(ft)
	Q	=	discharge	(cfs)
	f	=	silt factor	(cfs)
where	1 ft	=	0.3048 m	
	1 cfs	=	0.028317 m^3/s	

Lacey's scour equation reads:

$$h_0 + y = K \cdot 0.47\left(\frac{Q}{f}\right)^{1/3} \qquad (2.3\text{-}2)$$

in which

K	=	multiplication factor depending on the geometry of river and structure	(-)
y	=	extra deepening due to scour	(ft)

Combination yields

$$\frac{h_0 + y}{h_0} = K \qquad \text{and} \qquad \frac{y}{h_0} = K - 1 \qquad (2.3\text{-}3)$$

where the depths can be expressed in feet as well as meters. In this form, Lacey's formulas relate the scour depth primarily to the average water depth of the approach flow, with an empirical factor for the geometry of river and structure. Field evidence confirms the dependence on the average water depth of the approach flow (see Annex 7).

2.3.2 General Scour

General scour is related to the large-scale bed development of aggrading and degrading rivers. Ongoing aggradation and degradation can be inferred from the temporal development of the stage-discharge relationships at hydrographic stations. This is called 'specific gauge analysis'. The aggradation and degradation induced by changes in boundary conditions can be computed with zero- and one-dimensional mathematical models. Examples of such changes in boundary conditions are climate change, sea level rise, water extraction, dredging of off-takes and the construction of dams and reservoirs.

China-Bangladesh Joint Expert Team (1991) identified 0.25 m aggradation of the Jamuna in 23 years and ascribed this to sediment overloading due to the great Assam earthquake in 1950 when whole hill sides slipped into the river, causing 3 m bed aggradation far upstream in Assam. However, later specific gauge analyses under various FAP projects (Halcrow, 1991; ISPAN, 1993; Delft Hydraulics and DHI, 1996 b) found no significant trends of aggradation and degradation. Although the data still show inconsistencies due to benchmark problems, it can be concluded preliminarily that the Jamuna river is vertically stable. Specific gauge analyses by the River Survey Project (Delft Hydraulics and DHI, 1996 b) show that the Ganges and the Padma are also vertically stable, but that the Gorai river is aggrading.

The River Survey Project (Delft Hydraulics and DHI, 1996 e) gives a qualitative assessment of the effect of various scenarios on future aggradation and degradation in the rivers of Bangladesh. One of the results is that the construction of the Jamuna Bridge and the implementation of FAP 1, FAP 2 and parts of FAP 3 and FAP 5 will eventually cause a bed degradation of about 1 m in the Jamuna river upstream from the Dhaleswari river.

2.3.3 Constriction Scour

Constriction scour occurs when a river is narrowed by the bank protection or river training works. Laursen and Toch (1956) give the following general formula for constriction scour:

$$\frac{h_0 + y}{h_0} = \left(\frac{B}{B - \Delta B} \right)^{\beta} \qquad (2.3\text{-}4)$$

in which,

h_0	=	average water depth	(m)
y	=	extra deepening due to scour	(m)
B	=	river width	(m)
β	=	exponent	(-)
ΔB	=	reduction of river width	(m)

The equations of Jansen et al (1979) lead to the relation $\beta = 1\text{-}1/b$ for constrictions over a short distance, in which b is the degree of non-linearity of the sediment transport predictor. According to Section 1.5, b = 3.66 for the Jamuna (hence $\beta = 0.73$) and b = 5.0 for the Ganges (hence $\beta = 0.8$). Lim and Cheng (1998) give a value of $\beta = 0.75$ for constrictions over a long distance. For such a long constriction, also the time needed to develop the scour has to be taken into account in relation to the duration of floods (if only the flood width is constricted) and in relation to the design lifetime of the bank protection or river training works.

A different type of formula is proposed by Klaassen and Struiksma (1988), who explicitly include the contribution from protrusion scour in constriction scour. However, the FAP 21 test structures do not produce constriction scour because they do not reduce the width of the river.

2.3.4 Bend Scour

Bend scour developes near the outer bank in a curved channel. The corresponding scour depths can be predicted with empirical formulas, recently reviewed by Maynord (1996), or using theoretical models. The latter can be divided into axisymmetrical and non-axisymmetrical ones. Axisymmetrical models represent a single cross-section without considering streamwise interactions (van Bendegom, 1947; Engelund, 1974; Odgaard, 1981). Non-axisymmetrical models include streamwise interactions and reveal that for certain parameter ranges overdeepening occurs (Struiksma et al, 1985).

Maynord (1996) concludes from comparisons with a large data set that the empirical formulas of Watanabe et al (1990) yield the best predictions of scour. The River Survey Project (Delft Hydraulics and DHI, 1996 d,k) compares data from rivers in Bangladesh with a theoretical axisymmetrical model, neglecting overdeepening. As the latter work has been dedicated specifically to the rivers of Bangladesh, the same theoretical framework is followed here.

The axisymmetrical profile of the cross-section is described by:

$$\frac{dh}{dr} = A \cdot f(\theta) \cdot \frac{h}{r} \qquad (2.3\text{-}5)$$

in which

A	=	factor for influence of secondary flow on direction of bed shear stress	(-)
f(θ)	=	function for influence of gravity component along transverse bed slopes on direction of bed shear stress	(-)
h	=	water depth	(m)
r	=	transverse coordinate and local radius of curvature	(m)

The factor for the influence of secondary flow on the direction of bed shear stress is given by

$$A = \frac{2}{\kappa^2}\left(1 - \frac{\sqrt{g}}{\kappa \cdot C}\right) \qquad (2.3\text{-}6)$$

in which

C	=	Chézy coefficient for hydraulic roughness	($m^{1/2}/s$)
g	=	acceleration due to gravity	(m/s^2)
κ	=	Von Kármán constant	(-)

With $\kappa = 0.4$, $g = 9.8\ m/s^2$ and $C = 70\ m^{1/2}/s$, the factor becomes $A = 11$.

The following expression for the influence of gravity along transverse bed slopes was derived from experimental data with substantial scatter:

$$f(\theta) = 0.85\sqrt{\theta} \qquad (2.3\text{-}7)$$

in which θ denotes the Shields parameter defined as

$$\theta = \frac{h \cdot i}{\Delta \cdot D} \qquad (2.3\text{-}8)$$

where

D	=	sediment grain size	(m)
i	=	water level gradient along streamline	(-)
Δ	=	relative density of sediment	(-)

The River Survey Project found that these formulas overestimate bend scour with a factor 3 and report that similar overestimates were found during the Jamuna Bridge Study and the Meghna river Bank Protection Short Term Study. Recently, however, Talmon et al (1995) improved formula (2.3-7) by including the effect of the ratio between sediment grain size and water depth. They arrive at

$$f(\theta) = 9\left(\frac{D}{h}\right)^{0.3}\sqrt{\theta} \qquad (2.3\text{-}9)$$

With the values D = 0.2 mm and h = 12 m, which are representative for the Jamuna, this relation becomes

$$f(\theta) = 0.33\sqrt{\theta} \qquad (2.3\text{-}10)$$

which to a large extent resolves the factor 3 discrepancy of the River Survey Project (0.85/0.33 = 2.6).

The axisymmetrical model can be solved analytically and seems a suitable basis for the prediction of bend scour. However, the schematization to a uniform channel and the neglect of overdeepening remain major shortcomings. The experiences regarding assessment of design conditions using an axisymmetrical model are still limited, but the following points can be made:

- The curvature of a channel bend can still change when the structure does not stabilise the whole alignment of the bend. Therefore, it is recommended to use a design curvature radius, which is equal to 2.5 times the channel width. Hickin and Nanson (1984) find that this is the curvature, which produces the largest erosion.
- The assumption of vertical sidewalls in the axisymmetrical model leads to a severe overestimate of the bend scour. In reality, the presence of an outer bank slope will imply that the lowest bed level occurs some distance away from the outer bank. This reduces the predicted bend scour. The FAP 21/22 Guidelines account for this reduction.

Given the present state-of-the-art and the ongoing developments, it is likely that in the near future bend scour will be computed routinely with a two-dimensional mathematical model instead of a simple axisymmetrical model. A two-dimensional model does not have the shortcomings of uniform channel width and neglect of overdeepening.

The River Survey Project extends the axisymmetrical model for bend scour with the effect of bank erosion products, because the scour near an eroding outer bank is reduced by the continuous supply of eroded bank material. The River Survey Project uses a relation of Mosselman (1989), but without accounting for the sediment deposition on the opposite bank. This omission of inner-bank accretion from the sediment balance leads to results in which bank erosion products reduce the transverse bed slope over the full cross-section of a river. However, such a far-reaching effect is questionable and it is more plausible that the reduction of transverse bed slopes remains limited to a zone close to the bank. Indeed, Murshed's (1991) computations for the Dhaleswari River show that omission of inner-bank accretion from the sediment balance leads to unrealistic results. Mesbahi (1992) sees nevertheless a justification for the omission because bank erosion reduced in his laboratory experiments the transverse bed slopes over the full cross-section. Closer examination of his experiments shows, however, that the transverse bed slopes were reduced by the widening of the channel rather than by the input of bank erosion products. This confirms Mosselman's (1992) conclusion that bank erosion affects the morphology of rivers in alluvial plains mainly through widening and not through the supply of bank sediments, not even when the rivers are migrating fast.

The River Survey Project reports also that Shishikura (1996) finds bank erosion products to have a substantial effect on the cross-sections of channels in the Jamuna river. Closer examination of Shishikura's work shows, however, that this conclusion does not follow from his mathematical model, because the effect of bank erosion products cannot be isolated from the effect of width changes. Therefore, Shishikura has later withdrawn this conclusion (Mosselman et al, 2000).

Given these considerations, the River Survey Project approach to the effect of bank erosion products on bend scour is not recommended.

2.3.5 Confluence Scour

Confluence scour occurs where two channels meet. The River Survey Project proposes the formula of Klaassen and Vermeer (1988) for confluence scour in the Jamuna river:

$$\frac{\frac{1}{2}(h_{01}+h_{02})+y}{\frac{1}{2}(h_{01}+h_{02})}=1.292+0.037\varphi \qquad (2.3\text{-}11)$$

in which

h_{01}	=	average water depth in approach channel 1	(m)
h_{02}	=	average water depth in approach channel 2	(m)
φ	=	incidence angle of joining channels	(°)
y	=	extra deepening due to scour	(m)

This can be rewritten as

$$\frac{2y}{h_{01}+h_{02}}=0.292+0.037\,\varphi \qquad (2.3\text{-}12)$$

Other rivers may have another coefficient value than 0.292, depending on bed material properties, but the value of 0.037 seems to have a rather general validity (Hoffmans and Verheij, 1997).

The geometry of confluences changes easily, so that the design value of the incidence angle φ should not be measured from a temporary local situation. It is recommended to use a representative value of 45° for channels wider than 1 km and a representative value of 70° for channels narrower than 1 km.

2.3.6 Bedform Scour

The troughs between travelling bedforms represent an additional scouring. Bedform scour is therefore defined as the half of the bedform height. Since bedforms in the Jamuna river can be 6 or 7 m high, bedform scour can reach values of 3 to 3.5 m. It is likely that the heights of 15 m recorded by Coleman (1969) are not related to dunes but to the steep leeside faces of bars, possibly at tributary junctions (Klaassen et al, 1988).

The River Survey Project did not consider bedform scour because the 100 m interspacing of bathymetric survey lines was too large to identify the bedforms. Bedforms are clearly visible, however, on the FAP 21/22 survey maps of Bahadurabad.

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2.3.7 Protrusion Scour

Protrusion scour occurs when the flow impinges on a structure or a relatively resistant bank. The flow is then concentrated within a smaller width, increasing its velocity. The River Survey Project (Delft Hydraulics and DHI, 1996 d,k) recommends the following formula from the Mississippi river:

$$\frac{y}{h_0} = \frac{4 \cdot u_0^{0.33}}{(g \cdot h_0)^{0.165}} \qquad (2.3\text{-}13)$$

in which

g	=	acceleration due to gravity	(m/s^2)
u_0	=	average velocity of approach flow	(m/s)

The actual protrusion scour depends strongly on the local geometry and flow patterns. Hence modelling is needed to assess protrusion scour. This is elaborated further in the FAP 21/22 Guidelines.

2.3.8 Local Scour

Both protrusion scour and local scour occur in the vicinity of structures. The difference between the two is that 'protrusion scour' is caused by the flow acceleration along the structure, whereas 'local scour' is caused by the increased turbulence and the vortices in the decelerating flow downstream from the structure.

A recent state-of-the-art on local scour can be found in the Scour Manual (Hoffmans and Verheij, 1997). The application to bank protection and river training structures in the rivers of Bangladesh is elaborated further in the FAP 21/22 Guidelines.

2.3.9 Scour Enhancement due to Structure-Induced Morphological Changes

Bank protection and river training structures along migrating river channels do not only produce protrusion and local scour, but also morphological changes in a wider area. Channels become narrower, bends may become sharper and confluences of two or more channels may be formed close to the structure. These structure-induced morphological changes enhance the scour in several ways. The stopping of bank erosion prevents the reduction of bend scour by bank sediment supply. The narrowing of a channel, which may be due to retarded point-bar growth, increases h_0 and hence y in the scour formulas. The sharper bends, explained from flow attraction by scour holes or from the local prevention of channel migration, increase the curvature. The formation of a confluence, as a result of flow attraction by scour holes, produces confluence scour. The scour enhancement due to structure-induced morphological changes (interaction scour) is still largely unknown and has been the subject of special research under FAP 21/22 (Chapter 6).

2.4 ANTHROPOGENIC FACTORS

Proper interpretation of river morphology requires also an awareness of the effects which human activities have on the morphological processes in the rivers

(1) Land Use

The rapid population growth in the Brahmaputra basin leads to changes in land use through increasing extensive and intensive deforestation and cultivation of watershed areas, water management initiatives and floodplain development. These changes affect the runoff and the sediment yield to the river. Cultivation of the charlands in the river influences the hydraulic roughness and the trapping of sediment during floods. Charland dwellers plant catkin (*Saccharum spontaneum*) in order to protect char areas and to induce sedimentation. This type of reed grass, locally known as 'kaisha' or 'kash', becomes 4 m high and has 3 m long roots and stalks. It is applied in particular on lowlying areas at the upstream side of a char, to make the char grow upstream, and in minor channels (less than 300 m wide), to close these channels.

(2) Bank Protection

The enormous bank erosion along the Jamuna river is a continuous reason for human intervention, either by retiring embankments or by constructing revetments or groynes to protect the banks. Bank protection works may be washed away within a few years, but, for instance, the Sirajganj Town Protection has been functioning as a stable 'hardpoint' for decades. And even bank protection easily washed away may serve at least temporarily as a point of reduced erosion, though the opposite may also be true as scour holes due to bank protection may enhance the fluvial attack on the bank.

(3) Navigation

The effect of navigation lies not only in the erosion caused by the return current, the ship waves and the propeller race, but also in the surrounding activities to maintain the navigation channels and the ghats. The siltation of navigation channels is mitigated or prevented by dredging and bandalling as well as by the aforementioned return current and propeller race. Barges may be moored above shoals so as to have these shoals scoured by the resulting higher flow velocities. Furthermore, sunken ferries or lost cargo on the river bed affect the local patterns of flow, erosion and sedimentation.

(4) Construction of Infrastructure

Infrastructure in the river bed, such as barrages and bridges, affects the morphology. The guidebunds of a bridge may reduce the active river width and thus have a large influence on the channels and chars in their vicinity. These guidebunds may induce rapid morphological changes during an initial period of adaptation, but are expected to result eventually in a less capricious and more stable morphology. Barrages have even larger effects, because their operation also changes the discharge hydrograph of the river downstream.

(5) Operation of Barrages and Regulators

The operation of barrages and regulators has an effect on river morphology as well. Very pronounced effects may occur when large quantities of water are released in a short time. Rapid closure of a barrage at the end of the flood season may choke the dry-season river bed downstream by leaving insufficient time for retarded scour to form efficient low-water channels.

3 DATA COLLECTION

3.1 DATA NEEDS

Proper data collection involves the acquisition of ***relevant*** parameters with sufficient ***accuracy*** and with sufficient ***spatial resolution*** and ***temporal resolution***. Sufficient spatial resolution in the two horizontal dimensions allows ***synoptic*** mapping of the parameter values, thus revealing patterns and spatial interrelations.

Neill and Galay (1967) and Thorne and Baghirathan (1993) provide overviews of data to be collected for morphological studies. The relevance of certain data depends on the scope of the morphological investigations. Under FAP 21, the scope has been limited to identification of priority plans, site selection, assessment of design parameters and monitoring for bank protection and river training works. The corresponding data needs have been listed in Table 3.1-1. Only data indispensable for standard bank protection and river training works have been included in order to avoid an overabundance of data collection which would be difficult to sustain. For that reason sediment transports and bedforms have been omitted from the table. Sediment transports can be estimated from bed material properties, river flows and an appropriate sediment transport predictor. For the wider scope of national river management, however, sediment transport measurements do remain important, and studies for standard bank protection and river training works should make use of the knowledge derived from those measurements. The thorough measurements and analyses in the River Survey Project (Delft Hydraulics and DHI, 1996 c,h,i,j), for instance, have greatly advanced the knowledge on sediment transport processes and phenomena in the major rivers of Bangladesh. Furthermore, measurements of sediment transport and bedforms can be useful for the calibration and verification of the mathematical models which may be used for bank protection and river training works.

Data for morphological investigations	Method	Relevance for bank protection and river training project			
		priority plans	site selection	design parameters	monitoring
Climate (general type, with features which may effect river morphology, e.g. monsoon climate)	literature survey	+	-	-	-
Geological setting (maps with shield areas, mountain ranges, rock outcrops in alluvial plains, tectonic faults, areas of uplift and subsidence, etc.)	literature survey, existing geological maps, satellite images	+	+	-	-
Geographical mapping (tributaries, distributaries, names of towns and localities, bridges, hydraulic structures, valuable objects ("something-to-protect criterion"), river chainage, geographical co-ordinates)	existing maps, satellite images, surveying, mapping of valuable objects	+	+	-	-
Topographical mapping of river valley and alluvial plains (elevations, drainage pattern, potential pathways for channel avulsions, e.g. Bengali river as potential new course of Jamuna river)	existing maps, satellite images	+	+	-	-

Table 3.1-1: Data collection for morphological investigations in bank protection and river training projects

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Data for morphological investigations	Method	Relevance for bank protection and river training project			
		priority plans	site selection	design parameters	monitoring
Geomorphic mapping (significant geomorphic features and sediment deposits, clay plugs, landslides, etc.)	aerial photographs, field surveys	+	+	-	-
Channel confinement (unconfined, confined by embankments, inerodible banks, river training structures)	aerial photographs, field surveys	+	-	-	-
Historical river planforms	existing historical maps, satellite images, field interviews on local oral history	+	+	-	-
Actual river planforms (bankline positions, channel patterns - meandering, braiding, anabranching)	satellite images, bankline surveys using hand-held GPS, mouza maps combined with field interviews	+	+	+	+
Hydrological data (time series of water levels and discharges; results of routine analyses such as discharge duration curves and specific gauge analyses)	BWDB discharge records, readings from project water level gauges	-	+	+	+
Flow velocity field (magnitudes and directions)	float tracks, current meters, Hochschule Bremen drifter buoys, satellite images	-	-	+	+
Water surface topography mapping at a consistent stage of flow	water level gauges	-	-	-	+
Bathymetry mapping	echosounders, radar bathymetry assessment, qualitative optical remote sensing	-	+	+	+
Topographical mapping of chars and islands, including **vegetation** (elevations, vegetation cover, potential pathways for channel avulsions)	levelling, laser altimetry, photogrammetry, multitemporal observation of land cover and char age	-	+	-	+
Bed material properties (mineralogical composition, grain size distribution, sorting and armouring, consolidation of cohesive deposits)	laboratory analyses of samples	-	+	+	-
Bank properties (bank material weight and texture, shear strength and cohesive strength, physicochemical properties, bank height, bank profile, groundwater level and permeability, stratigraphy, tension cracks, vegetation [type, root depth, etc.], erosion processes and failure modes, structures)	field surveys (photographs), vertical soil profiles, laboratory analyses of soil samples	-	+	-	-

Table 3.1-1 (continued): Data collection for morphological investigations in bank protection and river training projects

The required spatial resolution depends on the scale of the map to be produced. Bathymetry maps of the Jamuna under FAP 21 have a scale of 1:50,000, but a scale of, say, 1:5,000 will be more appropriate for rivers which are only a few hundreds of meters wide. A common co-ordinate system should be selected with care when using spatial information from different sources. This is by no means trivial since different map projection parameters can cause errors of hundreds of meters in the field. In 1994, for instance, FAP 21 has been confronted with problems due to the differences between BTM (Bangladesh Transverse Mercator) and SPOT TM. Both systems are transverse Mercator projections (TM) with central meridian at 90° E, latitude of origin at the equator and a false Easting of 500 km. They are based on the same Everest ellipsoid. However, the scale factor of BTM is 0.9996 whereas the scale factor of SPOT TM is 0.9998. This difference caused a shift of 560 m for the area of Kamarjani lying 2800 km North of the equator ((0.9998-0.9996) × 2800 km = 0.56 km). The BTM and SPOT TM systems have also different false Northings, but that does not produce any errors. First recommended by FAP 19 and later strongly advocated by EGIS, the BTM system has become the national standard in Bangladesh. Its key parameters are listed in Table 3.1-2.

Parameter	Specification
ellipsoid	Everest 1830
projection	transverse Mercator
central meridian	90° E
latitude of origin	0° N
scale factor	0.9996
false Easting	+ 500 km
false Northing	- 2 000 km

Table 3.1-2: Specifications of Bangladesh Transverse Mercator map projection and co-ordinate system

The required temporal resolution depends on the scope of the morphological investigation as well as on the season. Monitoring will require more frequent measurements than the identification of priority plans. One or two measurements may be sufficient during the dry season, whereas the same parameter may need to be measured every month during the flood season.

Hand-held GPS (Global Positioning System) has proven to be a very useful instrument for data collection. It allows fast execution of bankline surveys, in particular when combined with an off-the-road motor cycle. A hand-held GPS provides also easy reference for boat trips on the river during floods, when there are no visual orientation points.

Water surface topography mapping is useful because local variations in water level slopes can provide clues on flow gradients and hence ongoing morphological developments (Peters, 1981; Peters and Wens, 1991). This is used on, for instance, rivers in India (Varma et al, 1989) and the Zaïre river in Africa (Peters, 1988). Local steep slopes indicate local strong currents, which may be eroding the shoal that caused them. As yet there are no operational methods for synoptic observation of water surface topography, but maybe radar altimetry could become such a method in the future. Hence, local slopes have to be derived from water level gaugings at carefully selected locations. Peters and Goldberg (1989) indicate some limitations to the possibility of measuring local water level slopes.

The separate treatment of bathymetry (submerged bed topography) and topography (exposed bed topography) in Table 3.1-1 may seem odd, because both represent parts of the bed topography of the river. The division between submerged and exposed parts of the bed is also ambiguous because it depends strongly on the water level in the river. Yet the distinction is useful because submerged and exposed parts of the riverbed require different survey methods. An additional difference between bathymetry and topography is the way in which they are usually mapped. Topography is usually represented by elevations with respect to a horizontal datum, whereas river bathymetry can often be represented by depths with respect to a sloping plane, the sloping plane being the idealised water level surface for a certain specified constant discharge. Equal-depth contour lines on bathymetry maps are called 'isobaths'. Under FAP 21, the results from bathymetric surveys were translated to bed topography maps representing bed elevations above PWD.

Synoptic bathymetry and topography maps are more useful than the traditional cross-sections, especially in complex braided rivers such as the Jamuna. The angle between local flow direction and any straight transverse line varies along this line and varies in time as well. This implies that a cross-section along such a line will usually not provide a good representation of the flow conveyance. At any rate, cross-sections perpendicular to certain channels can be derived easily from the bathymetry and topography maps.

Float tracks, Valeport current meters and drifter buoys have been used routinely under FAP 21 for measurement of the flow field in the river. Valeport current meters provide the mean magnitude and the direction of the main flow as well as the standard deviation of turbulent fluctuations. The Labor für Wasserbau of the Hochschule Bremen developed and operated the special drifter buoys of FAP 21, mounted with DGPS (differential GPS) and resistance bodies at optional depths.

Remote sensing and field interviews with the local population have received particular attention in the morphological studies under FAP 21. These special topics of data collection are treated in Sections 3.2 and 3.3 respectively.

3.2 REMOTE SENSING

3.2.1 Remote Sensing used under FAP 21

Optical satellite images from the period 1973-92 have been used in FAP 21 to study the morphological processes and to select the test areas (priority plans). From 1992 onward, the images have also been used to select construction sites, to monitor the ongoing developments and to evaluate previous predictions of morphological changes. Radar satellite images have been used only occasionally, but they might become more important in the near future, especially now that a small, mobile ground station (RAPIDS) has been installed at EGIS for the reception and processing of satellite data. Table 3.2-1 gives an overview of the satellite images purchased and utilised under FAP 21. The locations of the satellite imagery scenes are indicated in Fig. 3.2-1.

3.2.2 General Possibilities

There are numerous applications of remote sensing to rivers. Examples are rainfall-discharge predictions based on cold-cloud duration observations, sediment yield assessment based on observations of land use and landslides in mountain areas, river flood monitoring (real-time forecasting) and impact analysis (inundation areas, damage assessment), surface water temperature detection (industrial cooling water releases), detection of seepage through embankments during floods, etc. In this section only applications related to river morphology are addressed. The pertinent quantities are bankline positions (land-water separation), bathymetry, floodplain topography, current pattern (flow velocity field) and sediment transport. They are discussed below.

(1) Land-water separation

The separation between land and water can be detected by optical as well as radar remote sensors. The best contrast is found in the near-infrared band. Land-water separation with radar is based on the differences in surface roughness between water and land. This is not a matter of differences between average spectral intensities, but a matter of differences in the variance of spectral intensities.

(2) Bathymetry

Electromagnetic radiation is partly or, depending on the wavelength, fully reflected by the water surface. Therefore it is useful to make a distinction between bathymetry and floodplain topography, though both terms refer to the topography of the riverbed. The distinction is somewhat ambiguous in rivers where bars and chars with different elevations can emerge from the water level during part of the year. Nonetheless, it remains useful, also because submerged and exposed parts of the river bed require different survey methods.

The bathymetry of shallow water can be observed with *passive optical remote sensing* if the water is clear. In the Northsea in Europe, for instance, depths up to 10 m maximum have been determined optically with an accuracy of about 0.5 m. The best results are obtained when using wave lengths between 0.5 and 0.6 micrometre (yellow light). Differences in water depth are represented by differences in spectral intensity. The spectral intensity, however, is also affected by suspended sediment and haze, so that the method is mainly qualitative.

A more precise quantitative assessment of bathymetry is possible with (active) radar remote sensing, because radar is affected neither by clouds nor by suspended sediment. The technique of *bathymetry assessment by radar remote sensing* is operational for coastal areas and shallow seas, but could also have a high potential for large rivers like the Jamuna, the Ganges, the Meghna and the Padma in Bangladesh (Mosselman and Wensink, 1993). At first glance it may seem strange that radar can be used for the assessment of underwater features, since radar radiation is fully reflected by the water surface. The observation, however, is not direct but indirect, based on wave-current interactions at the water surface. Variations in bed level produce modulations in surface flow velocities. The latter cause variations in the spectrum of water surface waves and hence variations in water surface roughness. Radar backscatter is a function of this surface roughness. This chain of relationships implies that the bathymetry can be assessed by a data assimilation technique, starting from an assumed bathymetry. Numerical models for (1) water flow, (2) generation and advection of waves and (3) radar backscattering are used to compute a corresponding radar image. Evaluation of the differences between this simulated radar image and the real radar image reveals the required adjustments of the assumed bathymetry. A new radar image is computed in the same way from the adjusted bathymetry and this whole procedure is repeated until the differences between the simulated and the real image are smaller than a prescribed accuracy level. The bathymetry thus obtained represents the real bathymetry.

Another technique for bathymetry assessment by active remote sensing is the use of *laser*. This is still in an experimental stage and, being a form of optical remote sensing, only applicable in clear water.

Wave-current interactions can also be used for a qualitative assessment of bathymetry by optical remote sensing. Optical backscatter of solar radiation *(sun glint)* can locally produce similar results as radar backscatter. This is for instance visible in aerial photographs of the Brahmaputra-Jamuna river taken in 1990. Overlap areas are present on pairs of successive photographs taken only a few seconds apart. The area is often bright on one photograph due to sun glint, but of normal intensity on the other photograph because of the different angle of incidence. The bright reflection from the water surface displays submerged bed patterns that are not visible on its neutral counterpart. A quantitative assessment in this way is not possible, but sun glint can be used for a rough qualitative impression of the bathymetry while flying over the river. This is bound to remain a merely visual method, because only a small part of the area covered by routine photographs, exhibits sun glint. In Bangladesh, moreover, institutional problems related to military security severely limit the use of airborne remote sensing such as aerial photography. The strong dependence on the angle of incidence makes that sun glint is less likely to appear on satellite images, because they are taken with a narrower range of incidence angles than aerial photographs.

(3) Floodplain Topography

The three-dimensional structure of floodplains determines the flow patterns during floods and hence also the pathways of sediments, which are eroded from the top of the floodplains. Direct measurement of floodplain topography is possible with an airborne *laser altimetry* mapping system, based on the combined use of GPS, an inertial navigation system and accurate distance measurements with a laser range finder. It measures distances with 10 mm precision. Aerial photographs and satellite images are basically two-dimensional, but it is possible to derive three-dimensional information from them as well through *photogrammetry*, *radar interferometry*, *multitemporal observation of inundation contours* or *multitemporal observation of land cover and char age*. Aerial photographs have the advantage of a higher spatial resolution than satellite images, but their use is severely limited in Bangladesh due to institutional problems related to military security.

Photogrammetry can be used to map the topography of islands and floodplains from pairs of aerial photographs. *Radar interferometry* can be used in a similar manner for topographic mapping from pairs of radar images. The following problems, however, make the present applicability of radar interferometry to islands and floodplains in the rivers of Bangladesh questionable:

- The accuracy depends on vegetation. The relative effect of vegetation is negligible or absent in mountains and on ocean surfaces, but considerable on the relatively flat islands and floodplains;
- The accuracy is affected by atmospheric perturbations, and
- Successful application of the technique requires a high correlation between the two images, which is not ensured when the two images are taken several weeks apart.

In principle, the topography of floodplains can also be constructed by deriving elevation contours from inundation boundaries on a series of images, taken at different water levels. However, this *multitemporal observation of inundation contours* would require several images in a relatively narrow time window during the rising and the falling limb of the hydrograph, while overpass intervals of satellites are usually in the order of two or three weeks. Moreover, obstructions on the floodplains may back up water locally, producing more inundation, and may prevent water from flowing into low-lying areas elsewhere. Hence inundation contours are not necessarily equal to elevation contours.

Finally, floodplain topography can also be reconstructed roughly by *multitemporal observation of land cover and char age*, based on an empirical dependence of char elevation on these parameters (EGIS and Delft Hydraulics, 1997; Hassan et al, 1999).

(4) Flow Velocity Field

Streamlines and hence flow patterns are visible on optical images and radar images of the major rivers in Bangladesh. On the optical images, the streamlines are visualised by elongated plumes of suspended sediment. On the radar images, the streamlines are visualised by elongated areas of constant flow velocity, in particular by very bright zones, which represent the high flow velocities. These synoptic flow patterns give a good insight into the processes in the river. In addition, they are useful for the calibration of numerical models. The advantage of optical images over radar images is that the optical images are easier to interpret. They are less speckled, and the imaging mechanism is more or less the same as in the human eye. The advantage of radar images is that they allow a quantification of flow velocities through the radar bathymetry assessment system described in para (2).

(5) Suspended Sediment and Mixing

Optical remote sensing offers the best opportunities to observe relative concentrations of suspended sediment and related phenomena such as mixing. Like for bathymetry observation, the best results are obtained when using wavelengths between 0.5 and 0.6 micrometre (yellow light).

The spectral intensity, however, is not only related to the sediment concentration, but also to the type of sediment (mineral composition), the water depth and the presence of haze. This means that a quantification of suspended sediment concentrations on the basis of optical satellite images still requires thorough additional ground truthing.

In principle, radar remote sensing cannot be used to observe sediment concentrations, because radar radiation is fully reflected by the water surface and wave patterns are only influenced by suspended sediments when the concentrations are extremely high. It might be possible, however, to correlate higher sediment transports with zones of higher turbulence, which could be detected at the water surface.

Year of preceding flood	Date	Image	Water level at Bahadurabad [m+PWD]
1972	21-02-73 21-02-73	MSS 138-42 MSS 138-43	13.09 13.09
1973	-	None	-
1974	-	None	-
1975	10-01-76 10-01-76	MSS 138-42 MSS 138-43	13.54 13.54
1976	09-02-77 09-02-77	MSS 138-42 MSS 138-43	13.09 13.09
1977	22-02-78 22-02-78	MSS 138-42 MSS 138-43	13.07 13.07
1978	26-02-79 25-12-78	MSS 138-42 MSS 138-43	13.11 13.99
1979	16-01-80 16-01-80	MSS 138-42 MSS 138-43	13.78 13.78
1980	-	None	-
1981	-	None	-
1982	05-02-83 05-02-83	MSS 138-42 MSS 138-43	13.23 13.23
1983	23-02-84 23-02-84	MSS 138-42 MSS 138-43	13.12 13.12
1984	25-02-85 25-02-85	MSS 138-42 MSS 138-43	13.49 13.49
1985	20-02-86 20-02-86	MSS 138-42 MSS 138-43	13.38 13.38
1986	07-02-87 07-02-87	MSS 138-42 MSS 138-43	13.30 13.30
1987	-	none	-
1988	03-03-89 03-03-89 20-03-89 20-03-89	MOS 51.84W MOS 51.85W MOS 51.85E MOS 51.86E	13.94 13.94 13.77 13.77
1989	06-02-90 06-02-90 30-01-90	MOS 51.84W MOS 51.85W TM 148-43	13.75 13.75 13.69
1990	24-04-91 21-03-91	MOS 51.85W TM 148-43	15.07 13.70
1991	08-03-92 08-03-92	TM 148-42 TM 148.43	13.76 13.76
1992	21-01-93 21-01-93 01-12-92 01-12-92	MOS 51.84W MOS 51.85W MOS 51.85E MOS 51.86E	14.10 14.10 14.55 14.55
1993	25-01-94 25-01-94	TM 148-42 TM 148-43	13.61 13.61
1994	28-01-95 28-01-95	TM 148-42 TM 148-43	13.04 13.04
1995	28-11-95 28-11-95 31-01-96 31-01-96	TM 148-42 TM 148-43 TM 148-42 TM 148-43	14.92 14.92 13.53 13.53
1996	18-02-97 18-02-97	TM 148-42 TM 148-43	13.19 13.19
1997	03-12-97 03-12-97	TM 148-42 TM 148-43	14.26 14.26
1998	23-01-99 23-01-99	TM 148-42 TM 148-43	13.48 13.48

MSS = Landsat MSS, TM = Landsat TM, MOS = MOS-MESSR

Table 3.2-1: Satellite images 1973-99

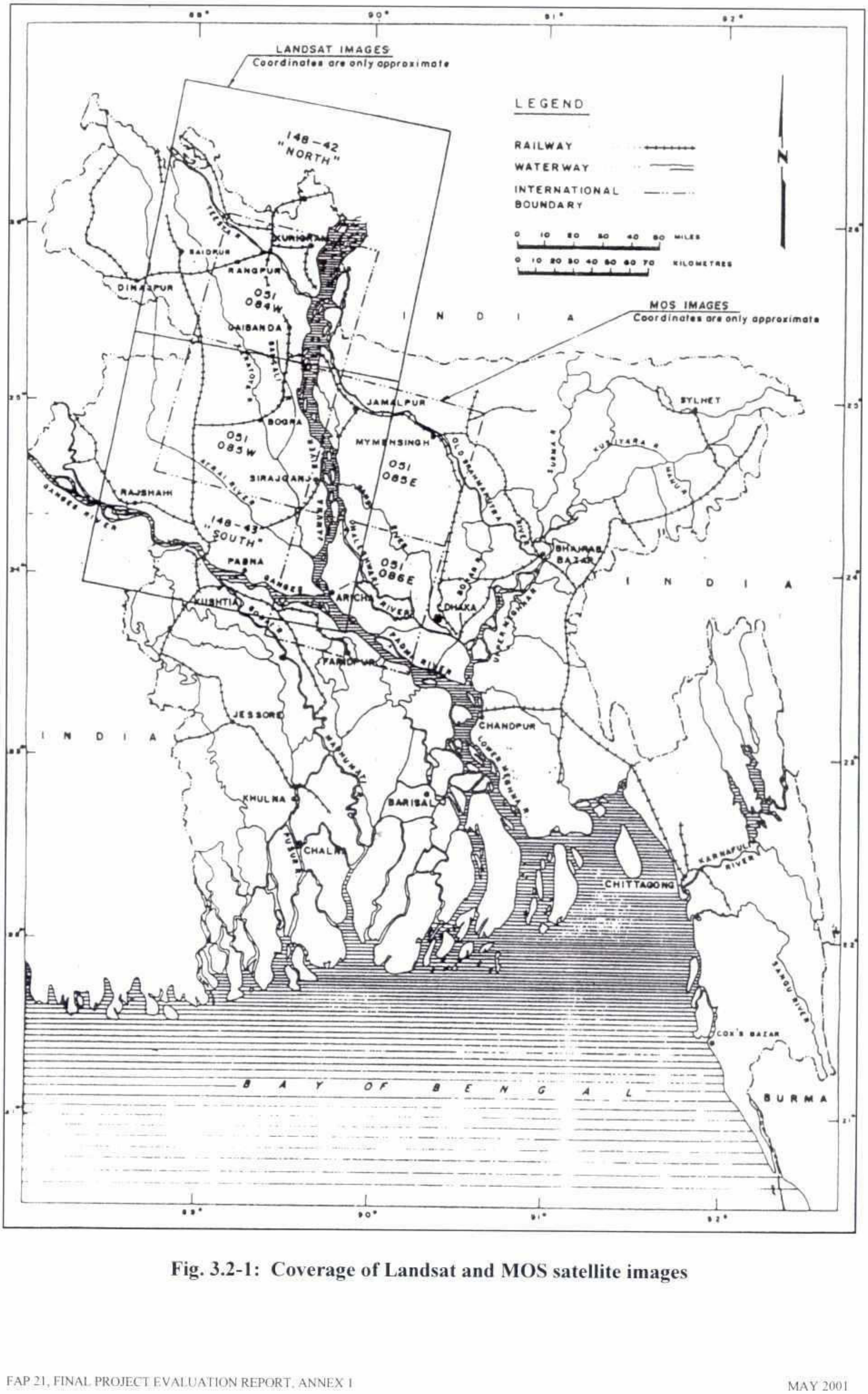


Fig. 3.2-1: Coverage of Landsat and MOS satellite images

3.3 FIELD INTERVIEWS

The life of millions of Bangladeshis is closely interwoven with the country's ever-changing rivers. Inevitably, many Bangladeshis have substantial knowledge of river behaviour and the ongoing morphological development. This holds for professionals at BIWTA, Bangladesh Railways (involved in bandalling for ferry operation), EGIS, SWMC and BUET, but also for the local population on the banks and the chars of the rivers. The local population usually knows which channels of the Jamuna are selected by large ships and, hence, which channels are the most navigable. Usually local people can also provide accurate figures on bank retreat, which can be very useful in circumstances where no results from bankline surveys are available. These accurate figures are derived from maps with plot numbers according to the mouza system set up by the British rulers before 1947, a "mouza" being the smallest revenue unit. The plot numbers are still in use and well known locally, thus allowing the identification of pieces of land of about 1 hectare in the field. Mouza maps are useful in particular for a quick assessment of bankline positions during a flood.

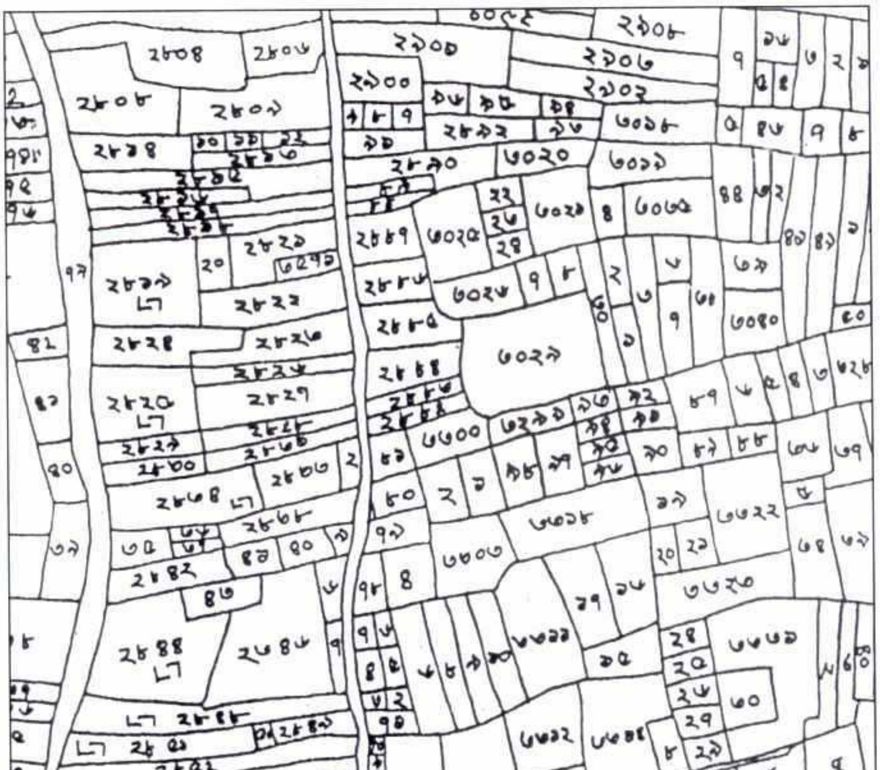


Fig. 3.3-1: Mouza map

Aware of the great potential, FAP 21 has sought to investigate the extent and the quality of the local knowledge. Field staff in the Kamarjani area had identified local representatives of the population who were said to have good knowledge and experience with the behaviour of the Jamuna. In September 1994 the FAP 21 Morphologist interviewed these representatives and came to the disappointing conclusion that the knowledge and insight of the local population was quite limited. The information that could be obtained from the representatives did not surpass the information from other sources. Three years later, however, it was finally understood that the interviewed people were mainland dwellers who had always been living far away from the river. Their first confrontation with the river had occurred only just before the interview, after the riverbank had retreated towards them more than one kilometre in 1993. Moreover, it took an anthropologist to explain that there is a great difference anyway between *mainland dwellers*, such as the ones interviewed, and *charland dwellers*, who live a life which is delicately tuned to the vagaries of the river (Schmuck-Widmann, 1996). The true river experts of the local population are to be found under the charland dwellers: village leaders, boatmen, fishermen, traders and local land surveyors.

The anthropologist brought FAP 21 engineers in contact with charland dwellers in 1997, thus creating conditions for a better assessment of local knowledge. In principle, the accuracy of observations by instruments and sensors is superior to the accuracy of observations by local people, but the local people observe the processes with a higher spatial and temporal resolution. Furthermore, local people derive a wider overview of the shape of the river by exchanging morphological information with people from other chars at the market place. The charland dwellers have good mental maps of the river. Remarkably, illiterate charland dwellers were found to be more capable in reading maps and satellite images than many of their educated compatriots. When explaining the physical processes behind the behaviour of the river, they make drawings in the sand in the same way as river engineers would do. They also have a system of knowledge generation based on empirical and theoretical methods, but the theoretical part is inevitably limited because they have no access to the accumulated knowledge of the international scientific community.

The knowledge of charland dwellers is in many respects complementary to the knowledge of the professional river morphologists involved in projects of bank protection and river training. It is a challenge for the future to pool this knowledge, but at the same time this is also very difficult, not in the least because charland dwellers have a very low status as 'choira' in the Bangladeshi society. Another difficulty is that charland dwellers and morphologists are interested in different aspects of river morphology. For instance, the identification of newly accreting land is of major importance for charland dwellers but without much relevance for morphologists. On the other hand, the large spatial and temporal scales relevant for river training have no meaning for charland dwellers. The different interests make a mutual understanding difficult. Nonetheless, the pooling of knowledge could be a core around which people's participation could be effectuated.

4 MORPHOLOGICAL DEVELOPMENTS AT TEST SITES

4.1 SATELLITE IMAGES

The evolution since 1980 of the dry-season planform of the Jamuna river between Northings 770 and 815 is shown in Figures 4.1 to 4.8.

4.2 SURVEYS

Bankline changes of the Jamuna river at Kamarjani are shown in Fig. 4.10. Maps of bathymetry and float tracks at Kamarjani since 1994 are shown in Figures 4.9 and 4.11 to 4.37.

Bankline changes of the Jamuna river at Bahadurabad are shown in Fig. 4.40. Maps of bathymetry and float tracks at Bahadurabad since 1993 are shown in Figures 4.38, 4.39 and 4.41 to 4.61. The morphological processes at Bahadurabad which are visible on the bathymetry maps from the period 1993-95 have been described and analysed extensively by the River Survey Project (Delft Hydraulics and DHI, 1996 k; Delft Hydraulics, DHI and EGIS, 1996).

4.3 RELATION WITH SITE SELECTION

In 1992, during the Planning Study, the areas of Kamarjani and Bahadurabad were selected for the sites of the test structures. One of the main reasons was the high certainty that the river would attack these areas within the project period. The morphological development of the river was further monitored and predicted to select more precisely the construction sites within those areas, based on the requirement that these sites should not be attacked by the river during construction, but needed to be subjected to river attack after completion of the test structures. This attack was required to persist at least one year within the project period of five years.

To verify subsequently that the selected sites remained suitable for the works, the morphological development was studied twice a year, once at the end of the monsoon and once in the dry season. The end of the monsoon was the period in which information about the morphological effects of the flood became available. In the dry season the latest satellite images became available.

4.4 SITE SELECTION AND MORPHOLOGICAL DEVELOPMENT AT KAMARJANI

The morphological investigations in 1993 confirmed that Kamarjani was a good area for the construction of a test structure. Initially the test structure was thought to protect the Manos Regulator, but huge erosion made this regulator collapse into the river on July 23, 1993. The bank at the regulator retreated 1000 metres in three months and the regulator, though initially on the bottom of the deep channel, ended up under metres of sand on the opposite side of the channel.

After the washing away of the Manos Regulator, the highest certainty of attack in the area of Kamarjani was in the downstream part of the bend near Rasulpur. Yet a more upstream site at Dhutichara, immediately North of the new mouth of the rivers Manos and Ghagot, was selected in 1994 after the following considerations:

a^a

(1) Short-term Certainty of Attack

The predicted range of possible bank erosion distances at Rasulpur was considered to be too large for a proper planning of the construction. In December 1994, the 1995 bank retreat with 90 % probability of exceedance was calculated to be 90 m and the bank retreat with 10 % probability of exceedance was calculated to be 510 m. Construction too close to the test structure would involve the risk that the structure would be washed away before its completion, whereas construction too far from the river would decrease the short-term certainty of attack. The risk that in 1995 bank erosion at Dhutichara would stop due to downstream migration of the bend was estimated to be low.

(2) Medium-term Certainty of Attack

The risk that the attack on the groynes would stop due to downstream migration of the bend was known to be higher in later years, but was still considered acceptable. It was thought that such a development would be mitigated with recurrent measures under FAP 22. A decrease of the attack at the upstream groynes was also preferred over the risk that the upstream groynes would come under full attack, for which the structure had not been designed.

(3) Something to Protect

The former Manos Regulator could no longer be protected, but the location at Dhutichara had the advantage of protecting the new Manos Regulator as planned by BWDB. It could also become the first element of a hard point to protect Gaibandha which otherwise would be expected to be attacked by the river after 80 years. The construction of a hard point would require a reinforcement of the upstream termination of the test structure.

Thus detailed site selection was optimised through a trade-off between increased short-term certainty of attack, decreased medium-term certainty of attack and increased fulfilment of the something-to-defend criterion.

The Groyne Test Structure was constructed at Dhutichara in the dry season 1994-95. Indeed it came under attack during the flood of 1995, but the certainty of attack in later years was considered to be declining. The flood of 1995 showed, however, that the effect of flow attraction by the scour hole in front of the groynes was stronger than expected. This mechanism deformed the channel bend, produced additional scour and decelerated the downstream migration of the bend. The downstream groynes were therefore estimated to have a fair probability of attack during the flood of 1996. It turned out that the downstream groynes were attacked in 1996 and 1997, but the attack ceased in 1998. The bend migrated downstream, away from the groynes, causing severe bank erosion at Rasulpur. Nevertheless, the requirement of no attack during construction and at least one year of attack within the project period had been fulfilled.

The initiation of a bend cut-off was identified in the bathymetry maps of June, July and August 1996. In June, the channel near the test structure was still eroding the thalweg towards the groynes. This erosion stopped in the first three weeks of July after a sharp rise in water level. The thalweg towards the groynes was filled with sediment and a cut-off channel between Kundarapara Char and Kharjani Char started to be excavated by the flow. When the water level dropped below 21 m+PWD again, the development of the cut-off stopped and in the first half of August the channel eroded again the thalweg towards the groynes. The cut-off channel was no longer actively scoured, but remained in existence.
The observed relation between the cut-off process and the water level demonstrated that a complete bend cut-off requires high water levels during a sufficiently long period. It was argued that it might take many years as long as floods are relatively small, but that a single large flood might cut off the bend at once. Indeed, the cut-off channel developed fully in 1998 when the flood was high and had an exceptionally long duration.

4.5 SITE SELECTION AND MORPHOLOGICAL DEVELOPMENT AT BAHADURABAD

Belgacha was initially chosen as a site for the Revetment Test Structure in the Bahadurabad area. Since 1990, an important channel had been impinging on the bank at Belgacha, South of the Railway Ghat, whereas the embayment immediately North of the Railway Ghat had been silting up. Rather unexpectedly, new channels were formed in the silted embayment during the flood of 1992, as was observed on a satellite image of the subsequent dry season in 1993. These channels were predicted to grow further and, indeed, one of them developed into a major bend cut-off channel during the flood of 1993. The resulting new major approach channel was more or less straight over a distance of 12 km, thus making many different morphological developments possible. This reduced the certainty of attack because, in the absence of a clear bend, capricious planform changes easily occur. It was therefore concluded in 1994 that it was not possible to indicate any site in the area where the banks had a high certainty of attack, which would be sustained during the first few years. Alternative areas were studied, but they often had disadvantages such as interference with ferry operations and the construction of FAP 1 hard points.

Bank erosion during the flood of 1994 occurred at the Railway Ghat and about 8 km downstream, but not at Belgacha. The conclusion that no site in the area of Bahadurabad had a high certainty of sustained attack during the first few years was confirmed in the morphological investigations after the floods of 1994 and 1995, though the long straight approach channel became more curved and hence more predictable. Despite the low certainty, continued erosion of the Railway Ghat and Kulkandi remained likely in the immediate future and therefore Kulkandi was selected as test site. The construction of the Revetment Test Structure at this site was started in the dry season 1995-96 and completed in the dry season 1996-97. The structure came under attack during the flood of 1997, thus fulfilling the requirement of no attack during construction and at least one year of attack within the project period. The attack continued in 1998, although the largest channel of the area did not impinge on the structure but on the bank 4 km downstream, causing severe erosion at Guthail. The development of a large bend upstream of the Railway Ghat was identified as a likely source of increased attack on the test structure before the year 2002.

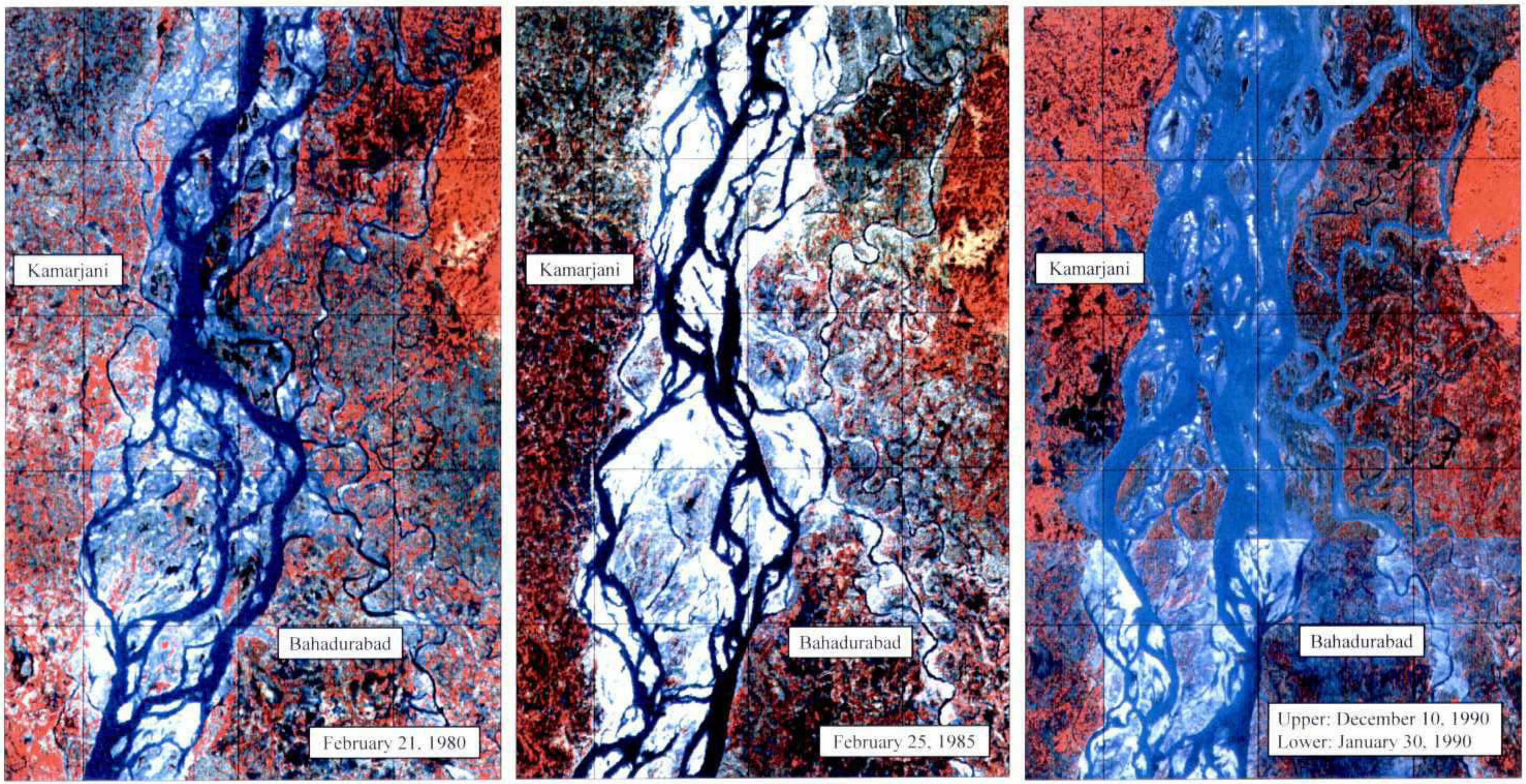


Fig. 4.1: **Planform Changes at Kamarjani and Bahadurabad inferred from Satellite Images of February 21, 1980, February 25, 1985**

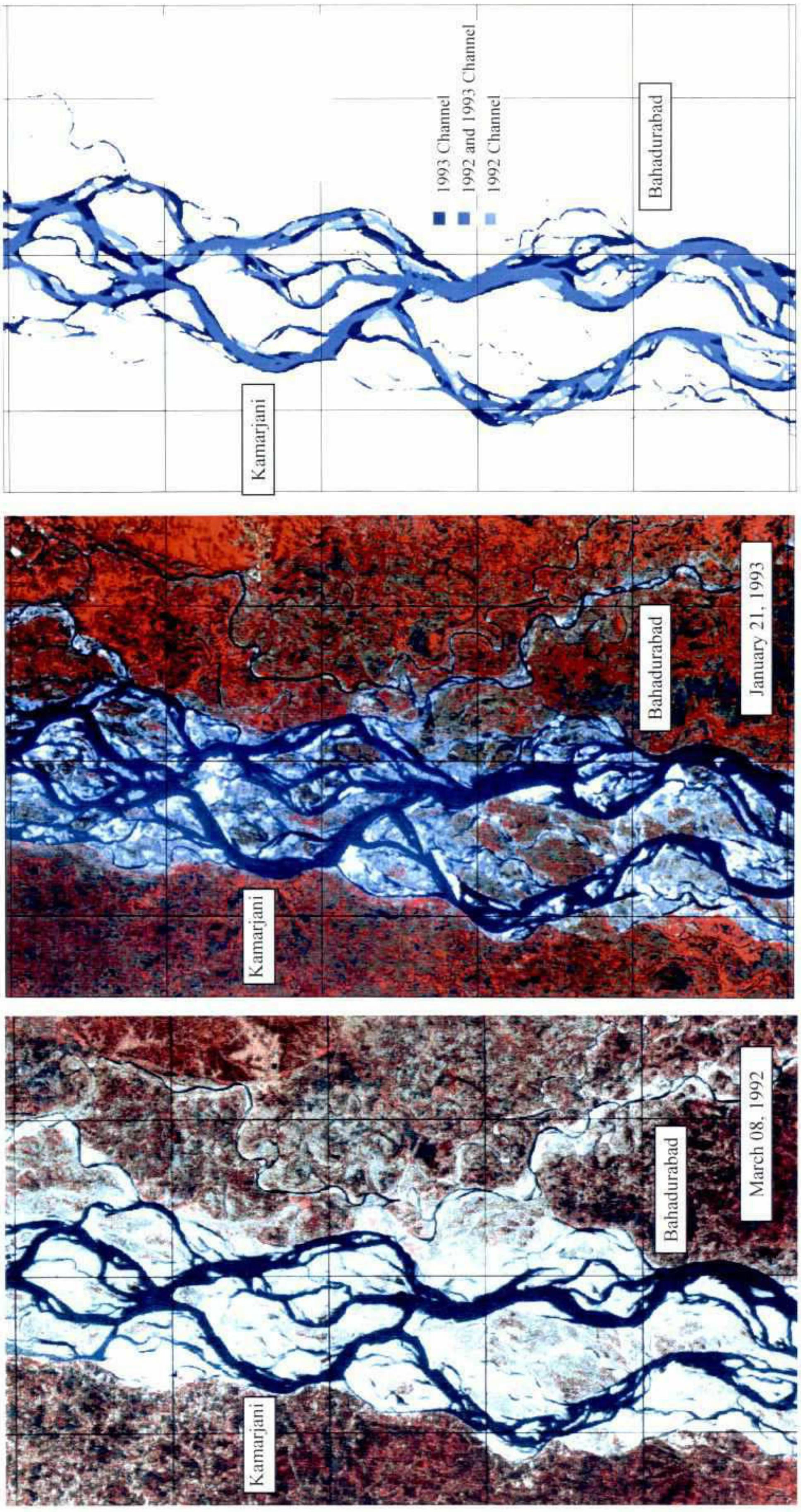


Fig. 4.2: Planform Changes at Kamarjani and Bahadurabad inferred from Satellite Images of March 08, 1992 and January 21, 1993

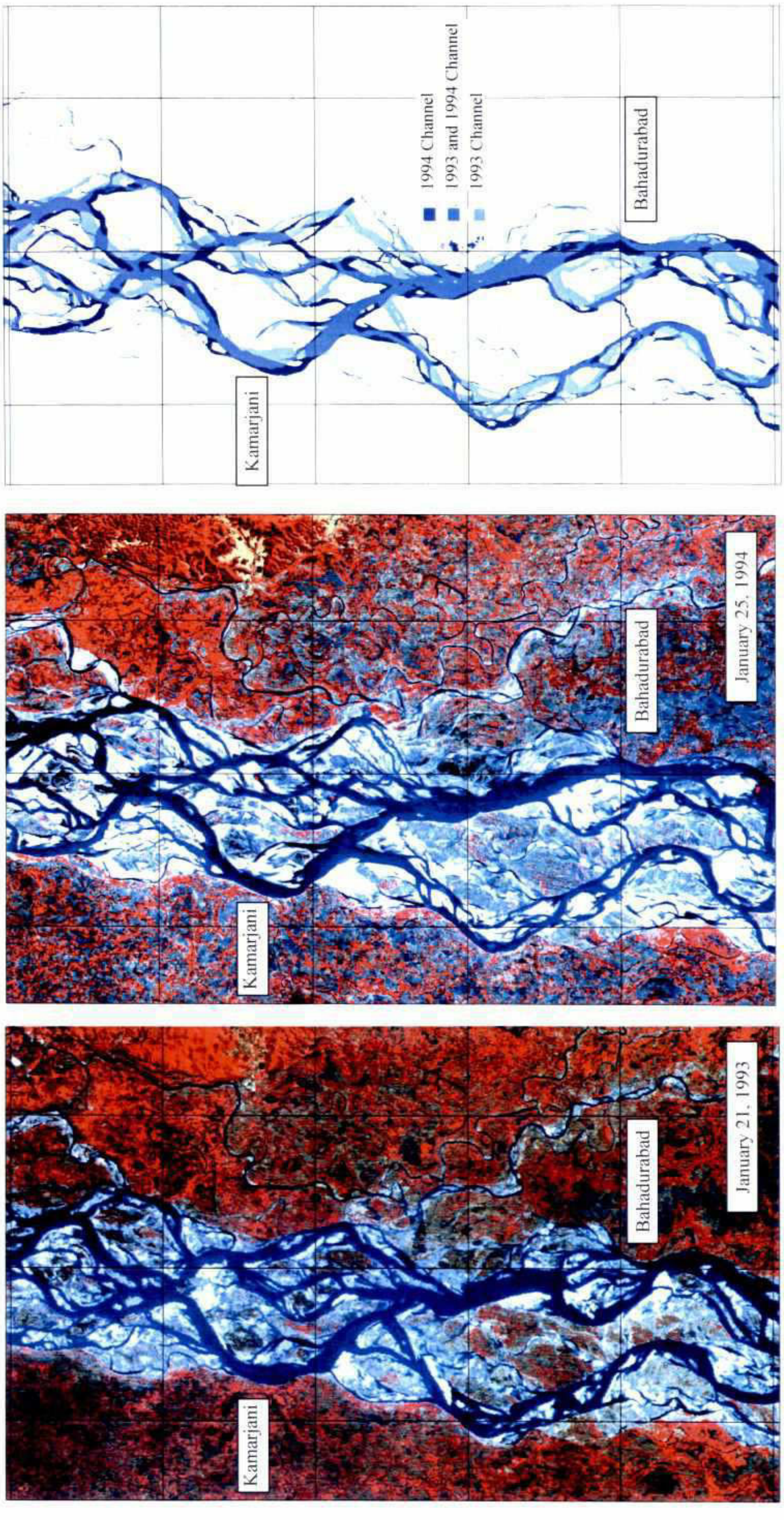


Fig. 4.3: Planform Changes at Kamarjani and Bahadurabad inferred from Satellite Images of January 21, 1993 and January 25, 1994

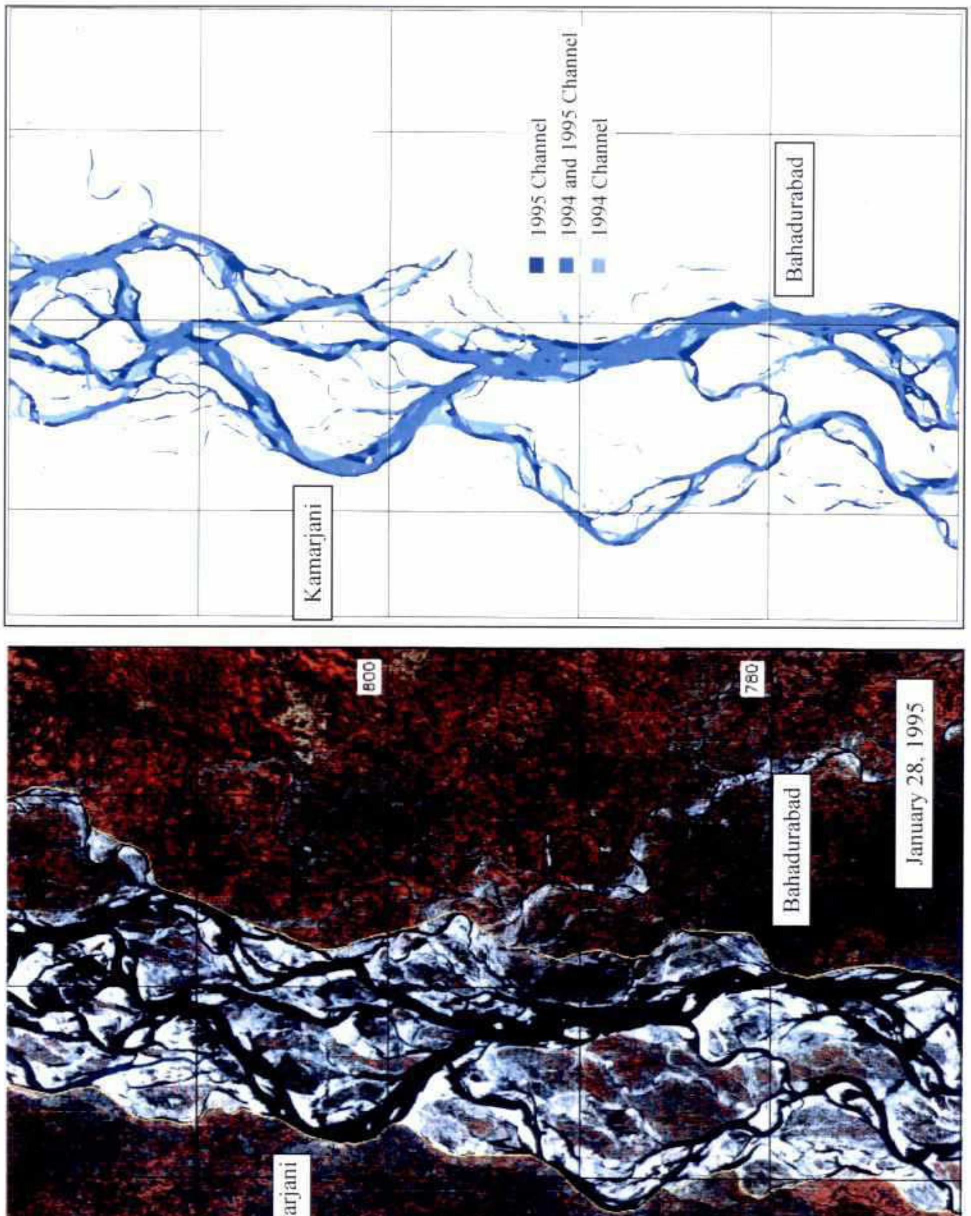


Fig. 4.4: Planform Changes at Kamarjani and Bahadurabad inferred from Satellite Images of January 25, 1994 and January 28, 1995

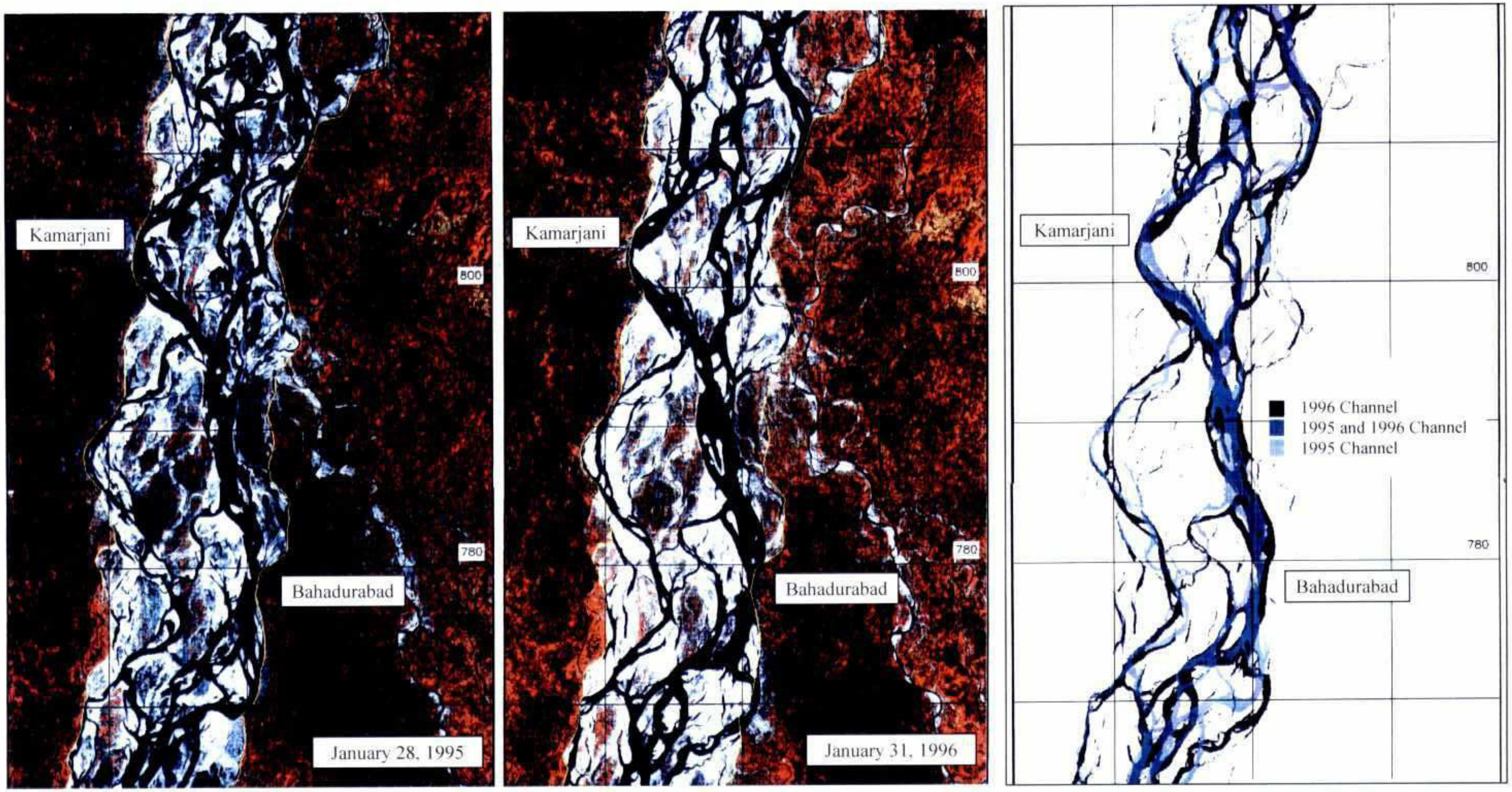


Fig. 4.5: Planform Changes at Kamarjani and Bahadurabad inferred from Satellite Images of January 28, 1995 and January 31, 1996

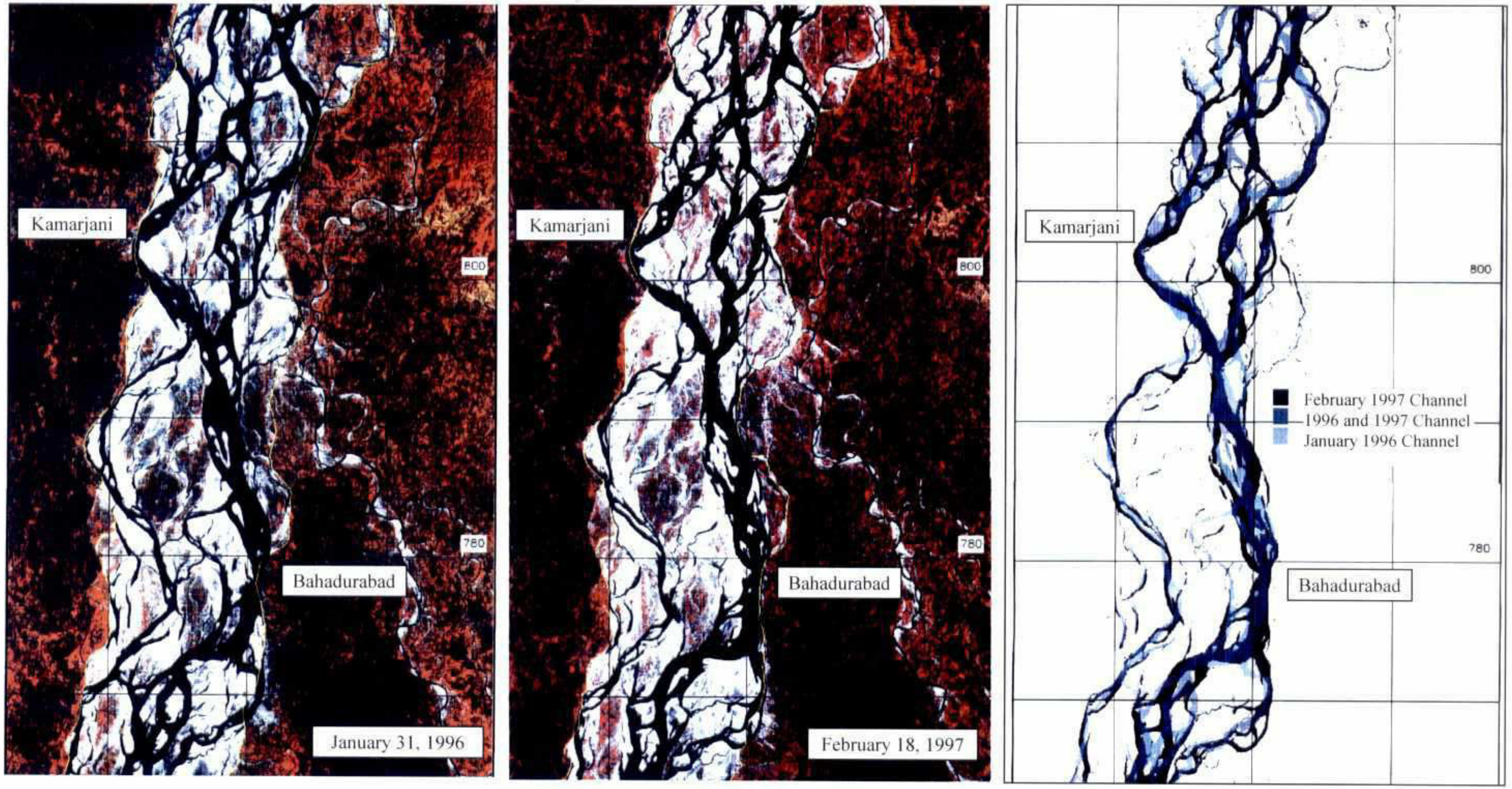


Fig. 4.6: Planform Changes at Kamarjani and Bahadurabad inferred from Satellite Images of January 31, 1996 and February 18, 1997

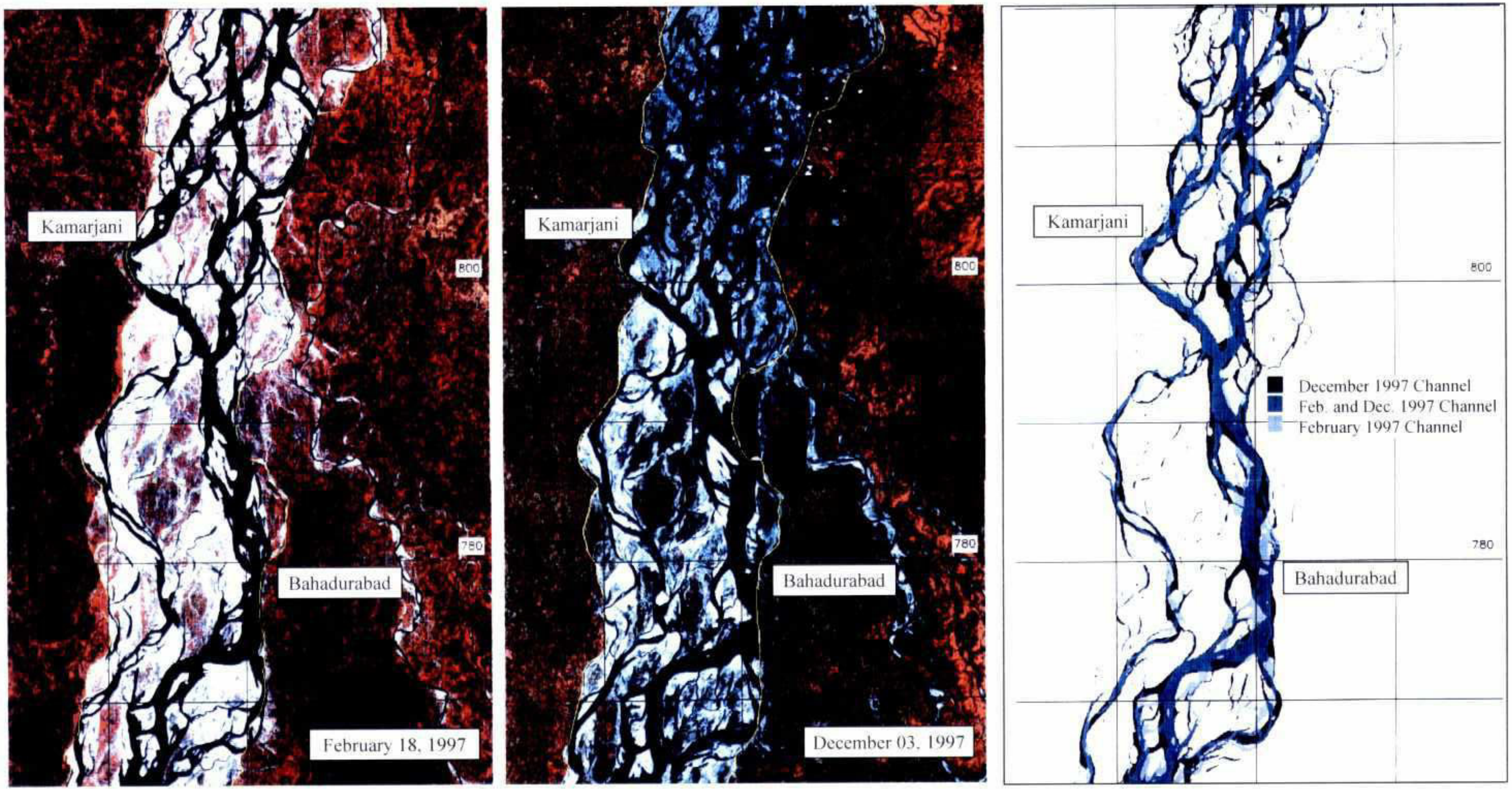


Fig. 4.7: Planform Changes at Kamarjani and Bahadurabad inferred from Satellite Images of February 18, 1997 and December 03, 1997

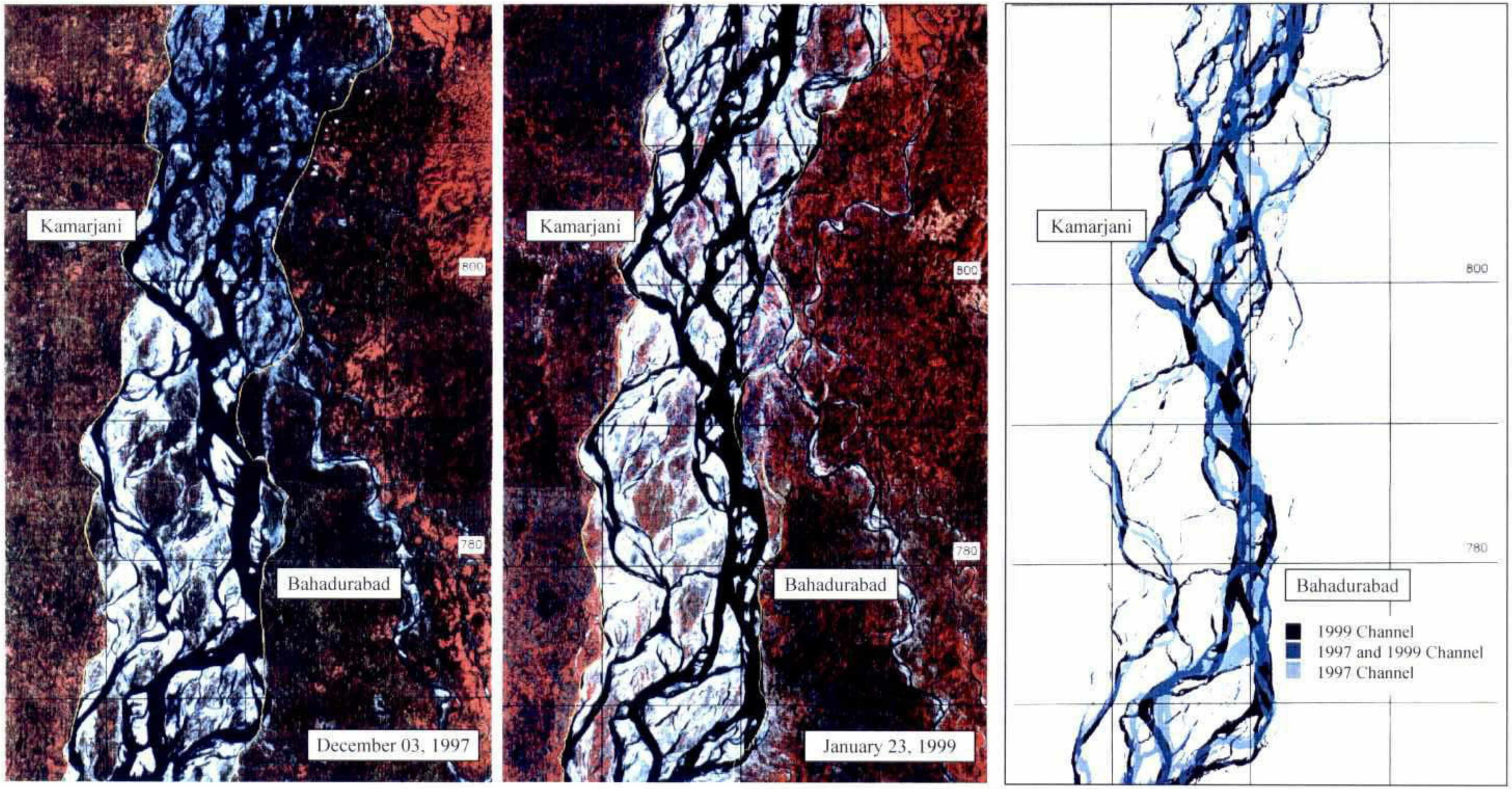
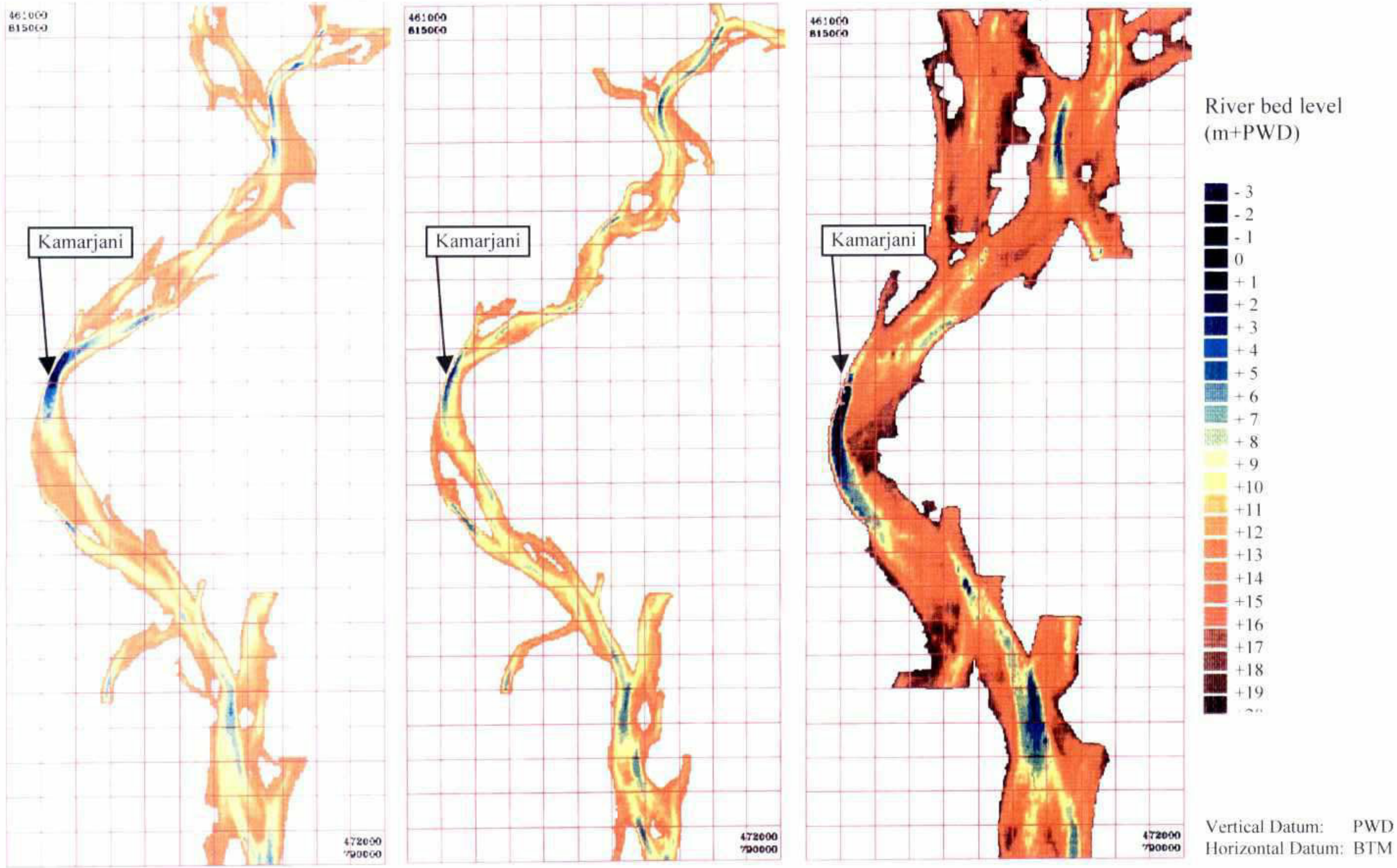


Fig. 4.8: Planform Changes at Kamarjani and Bahadurabad inferred from Satellite Images of December 03, 1997 and January 23, 1999



November 1994 | March 1995 | August 1995

Fig. 4.9: Bathymetry at Kamarjani
(Surveyed by FAP 24 and processed by EGIS)

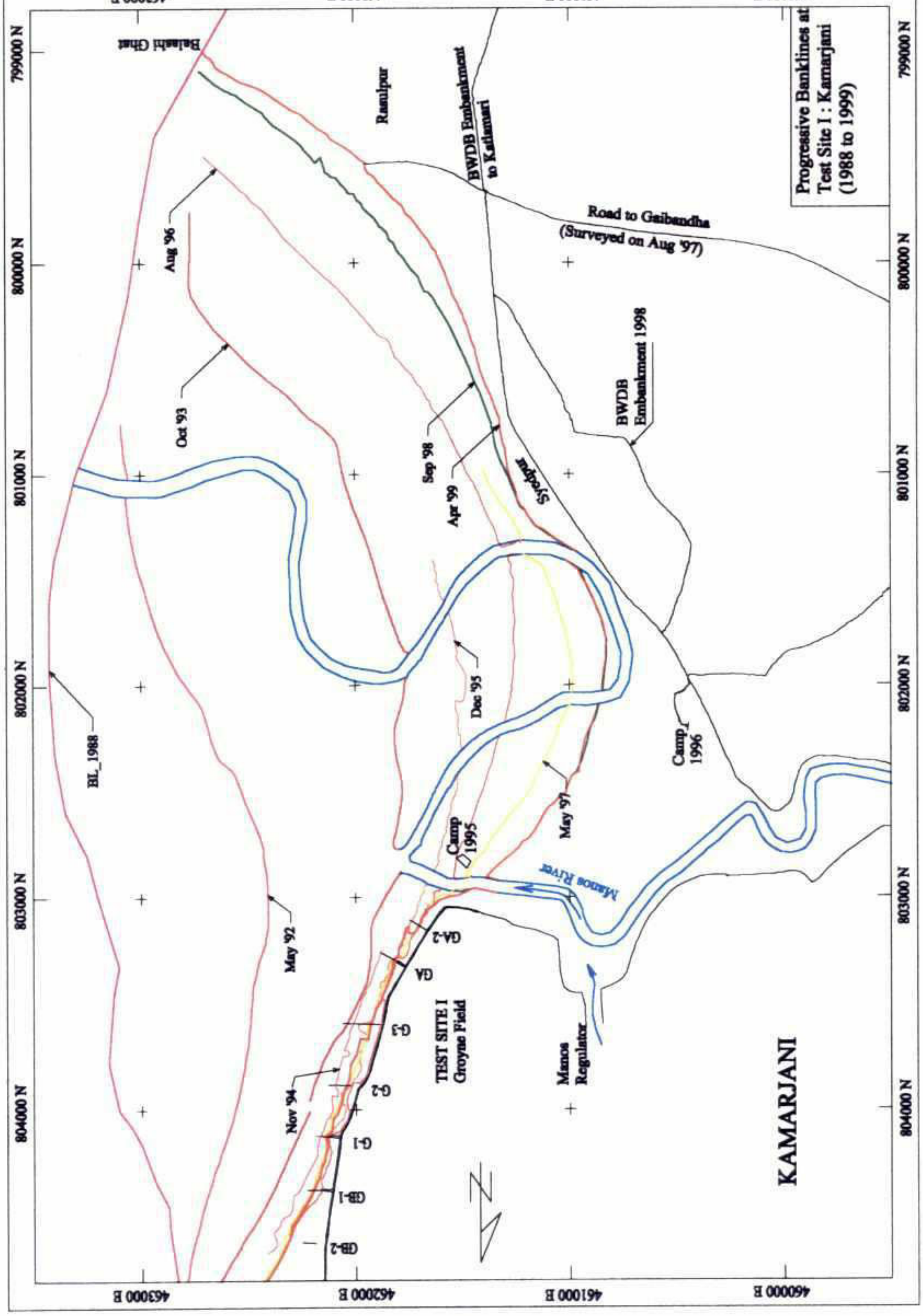


Fig. 4.10: Progressive Bankline

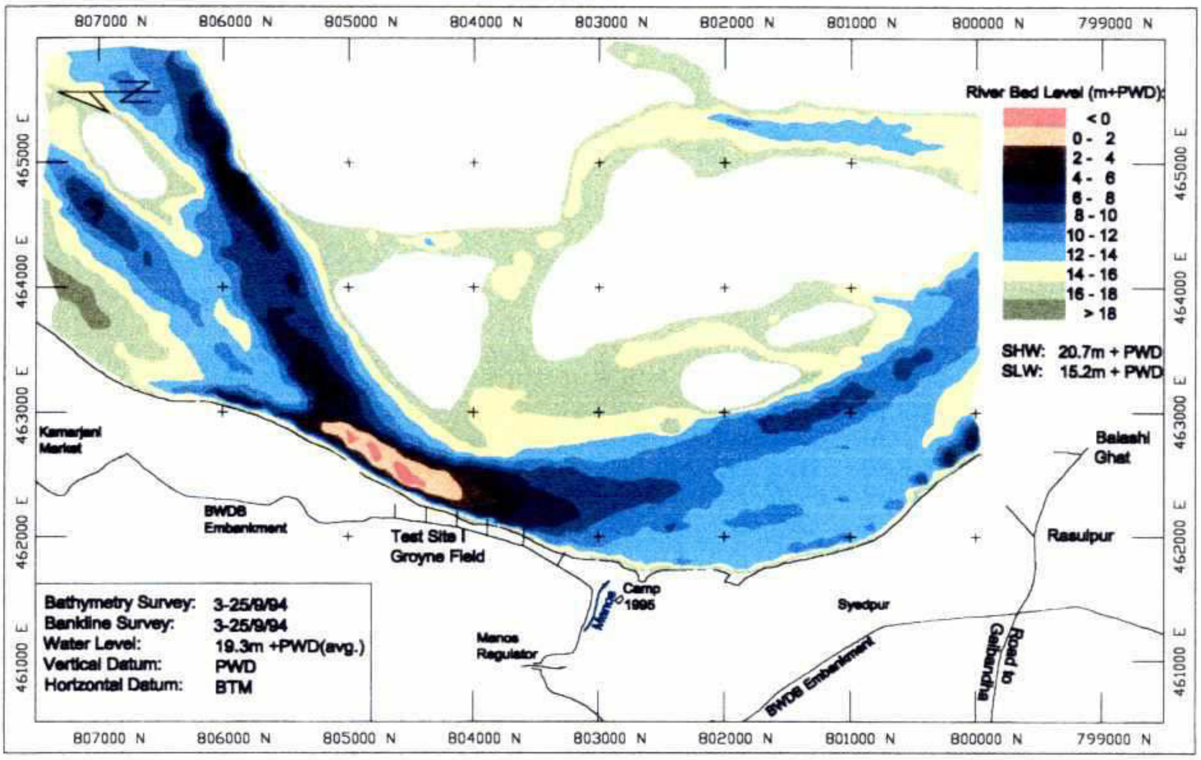


Fig. 4.11: Kamarjani September 1994
(Surveyed by FAP 24)

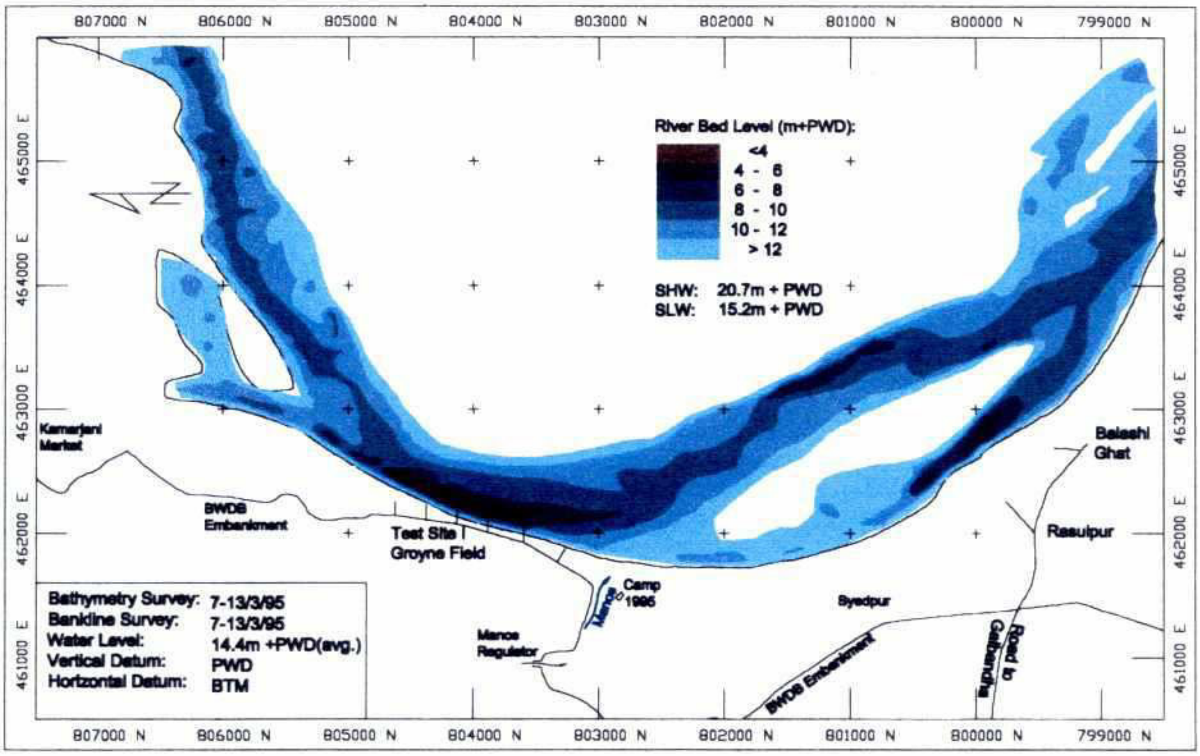


Fig. 4.12: Kamarjani March 1995
(Surveyed by FAP 24)

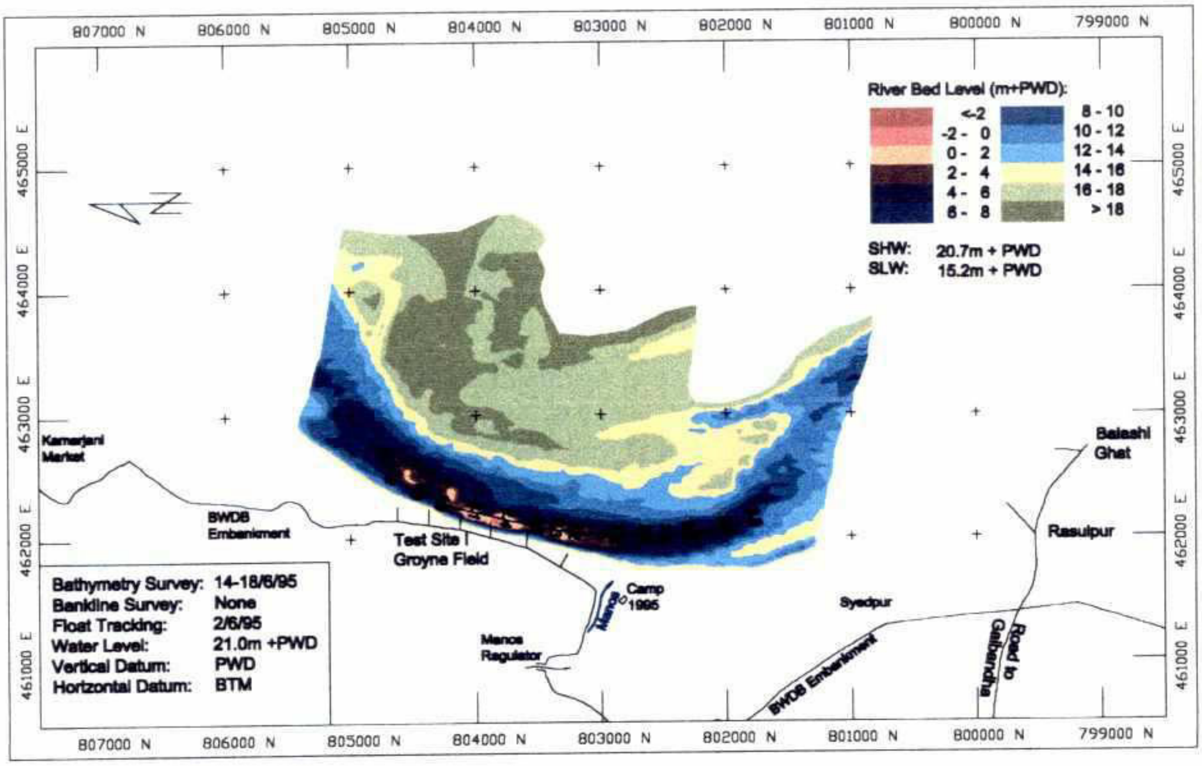


Fig. 4.13: Kamarjani June 1995

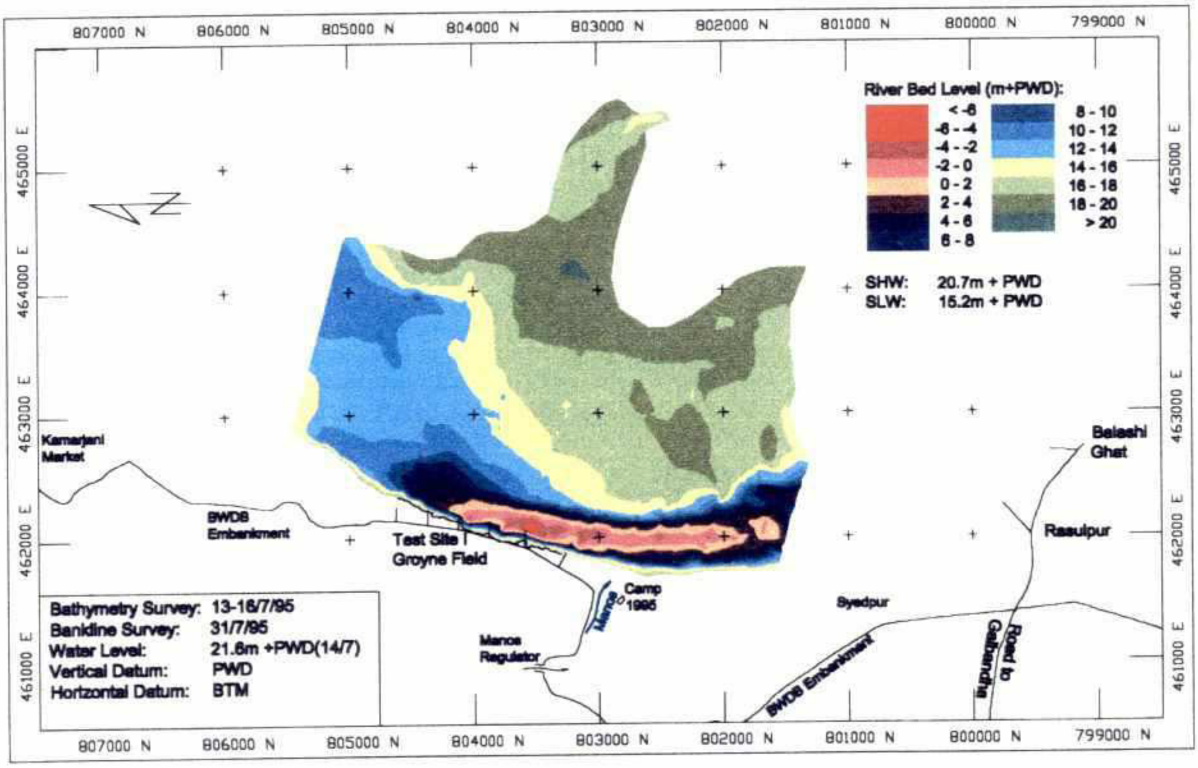


Fig. 4.14: Kamarjani July 1995

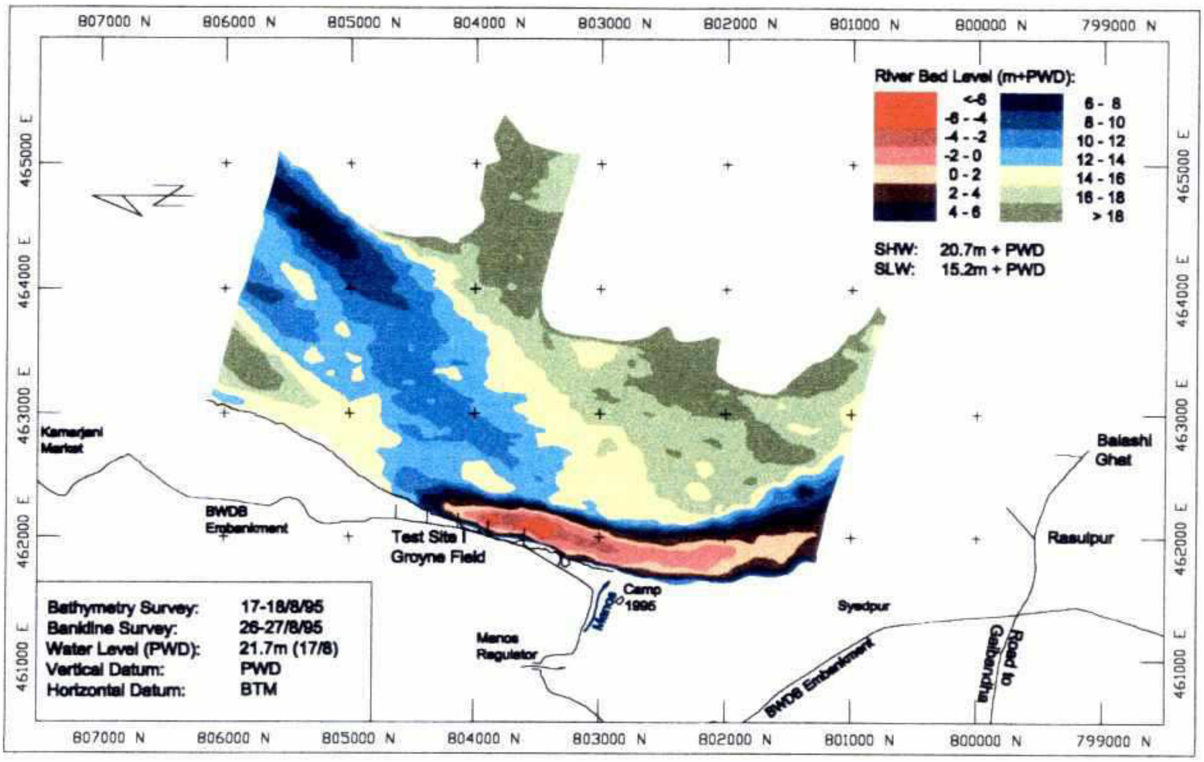


Fig. 4.15: Kamarjani August 1995

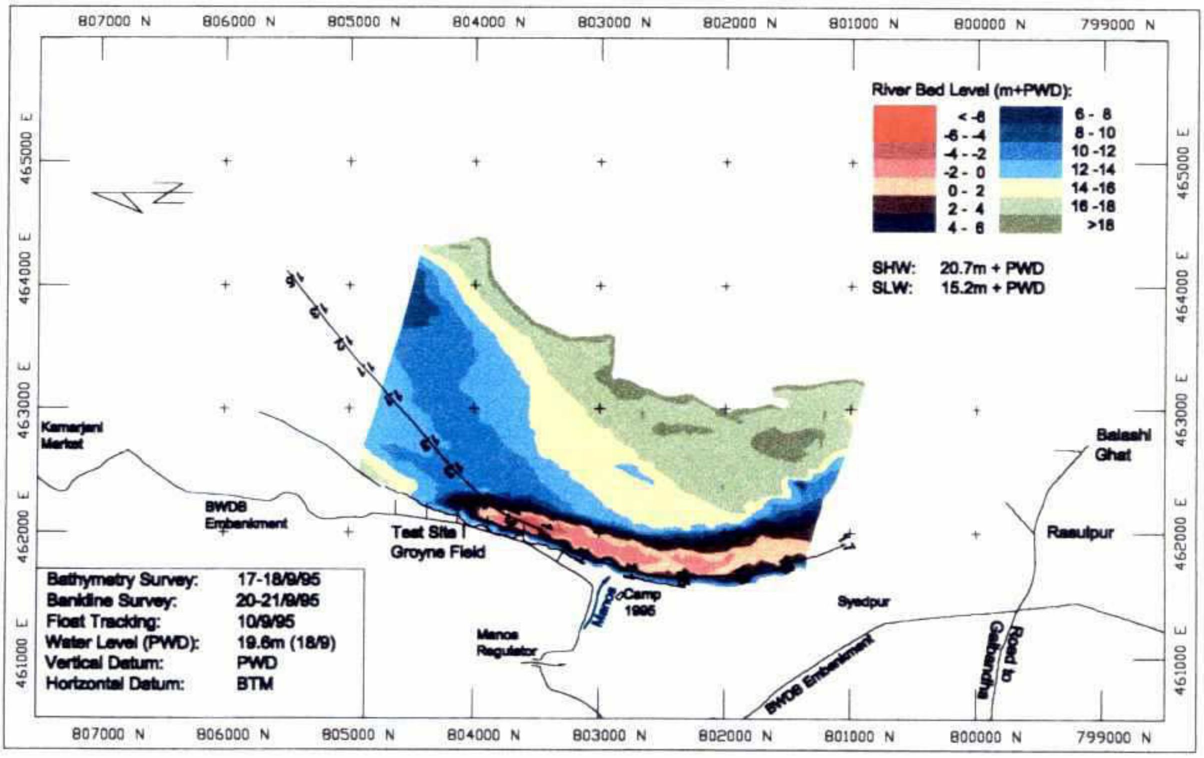


Fig. 4.16: Kamarjani September 1995

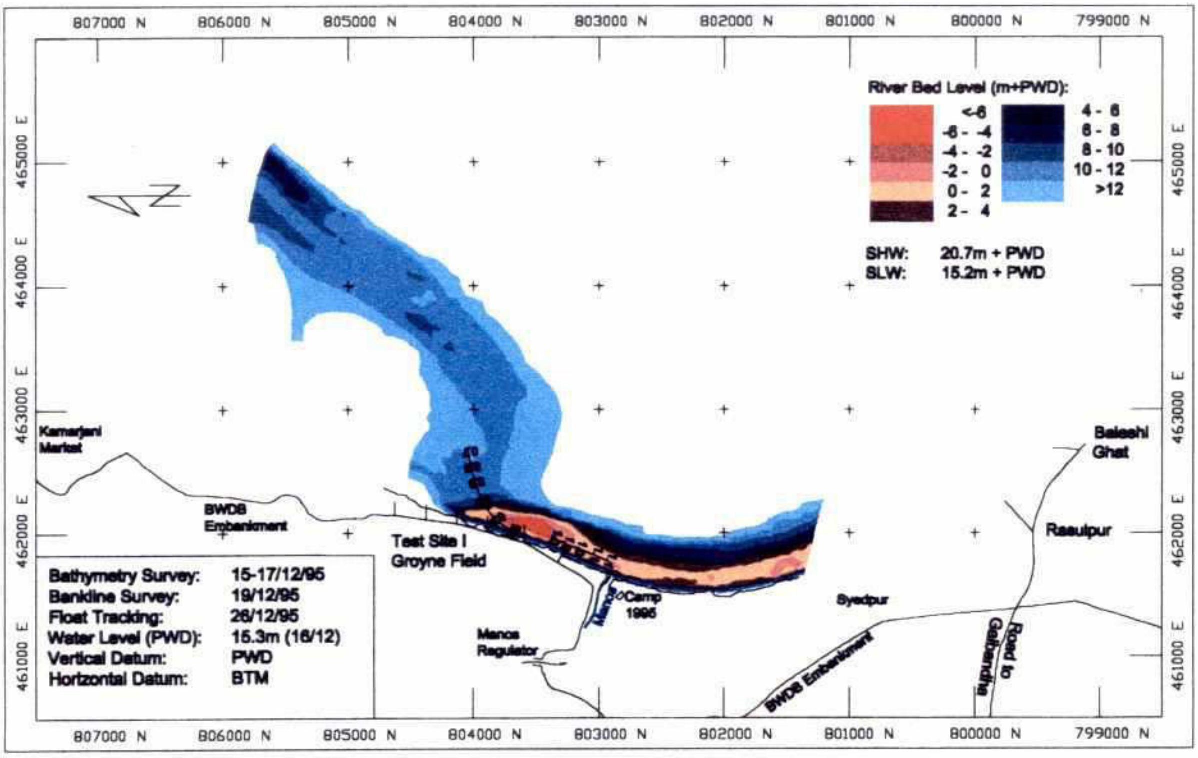


Fig. 4.17: Kamarjani December 1995

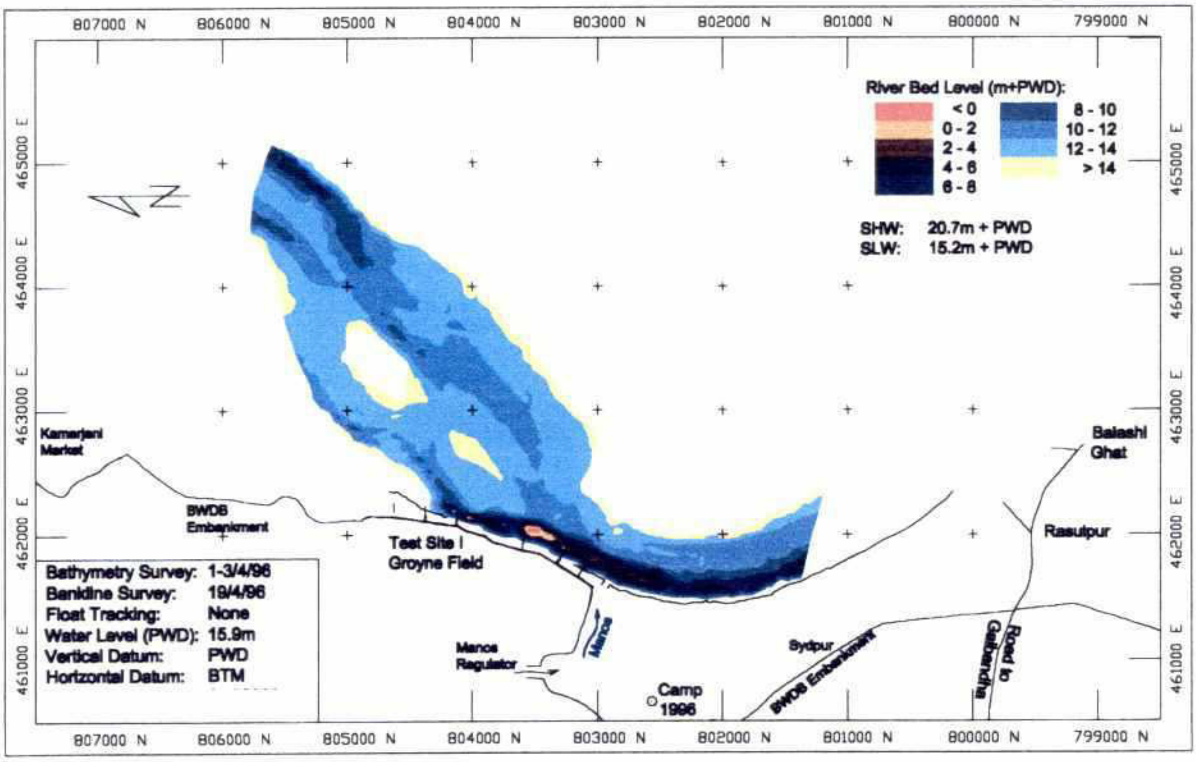


Fig. 4.18: Kamarjani April 1996

90

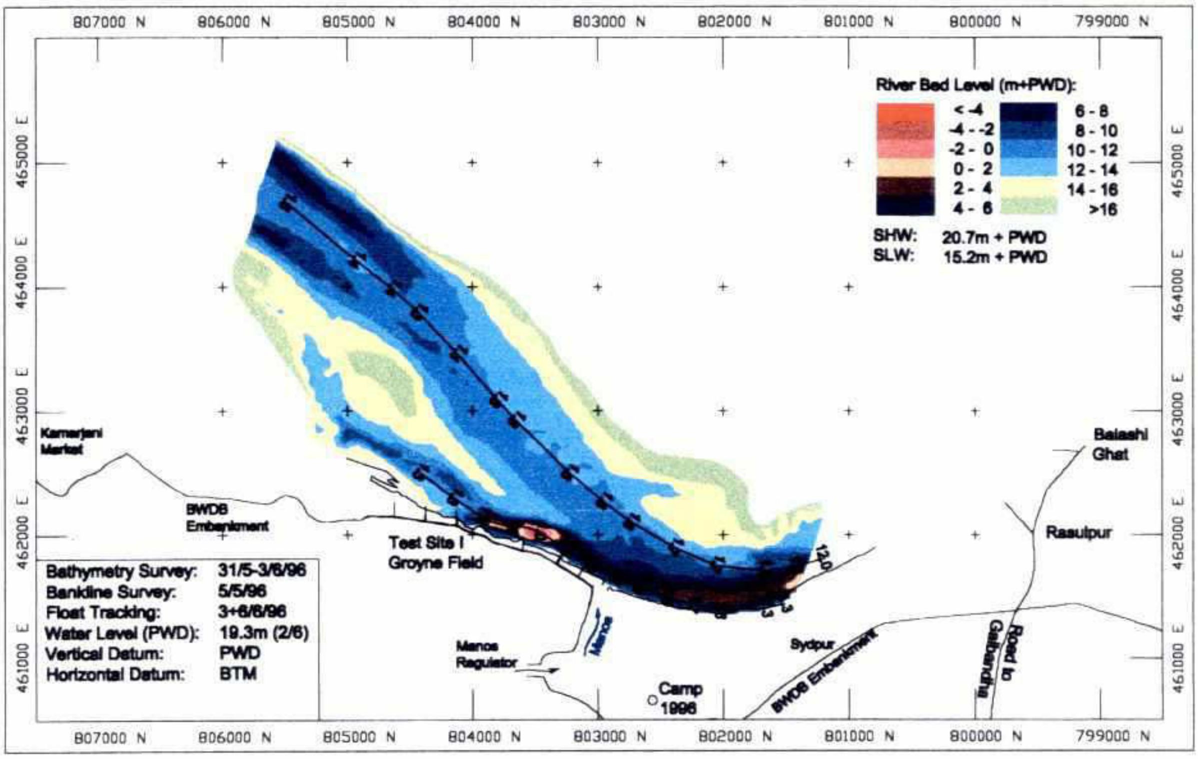


Fig. 4.19: Kamarjani May 1996

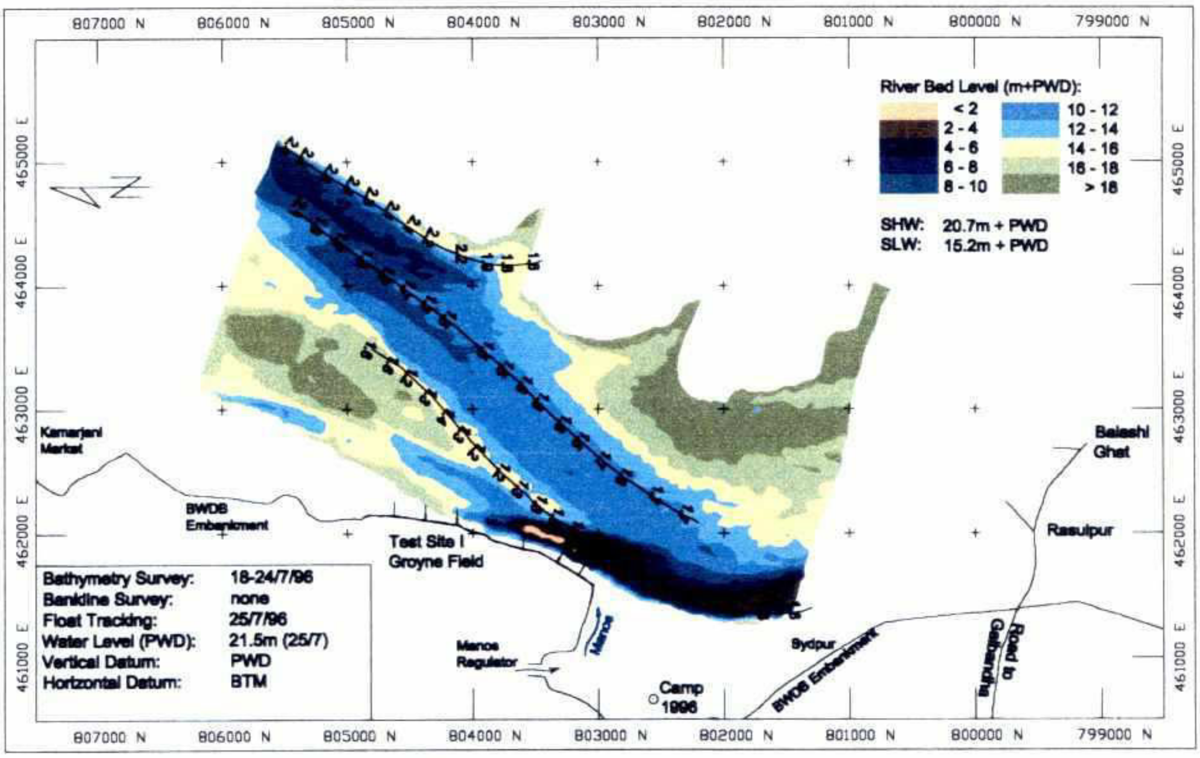
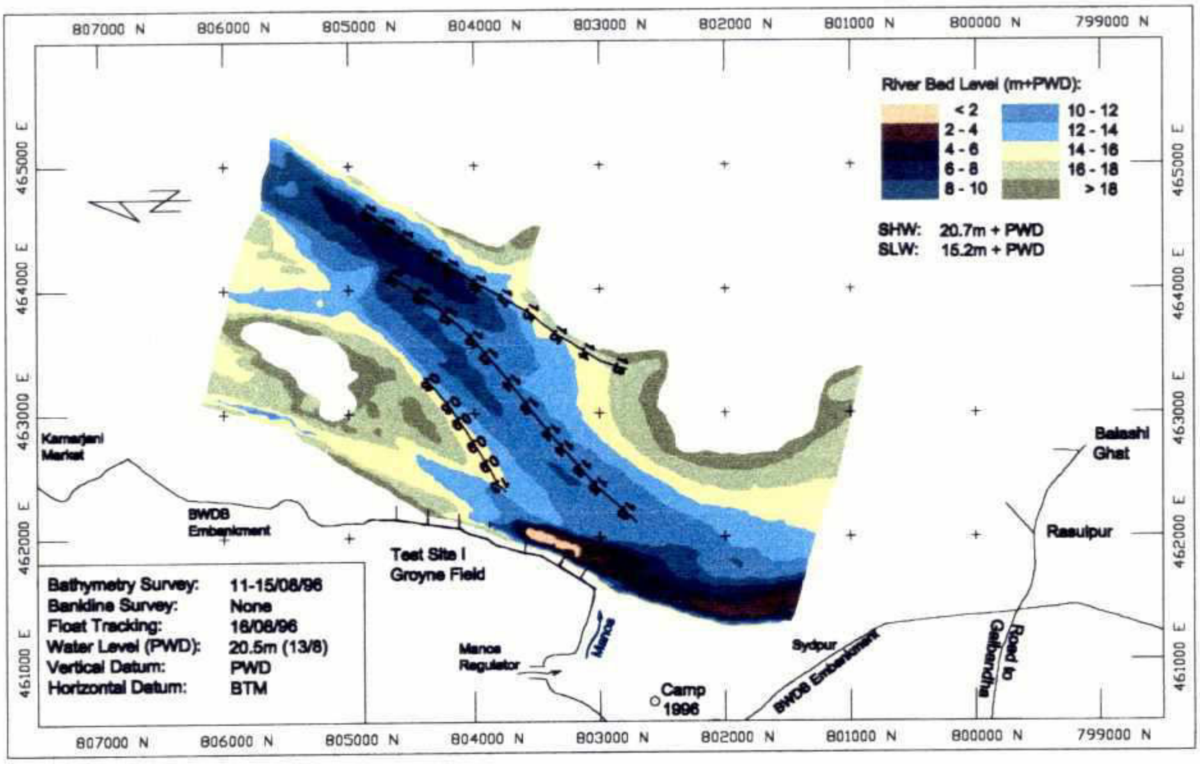


Fig. 4.20: Kamarjani July 1996



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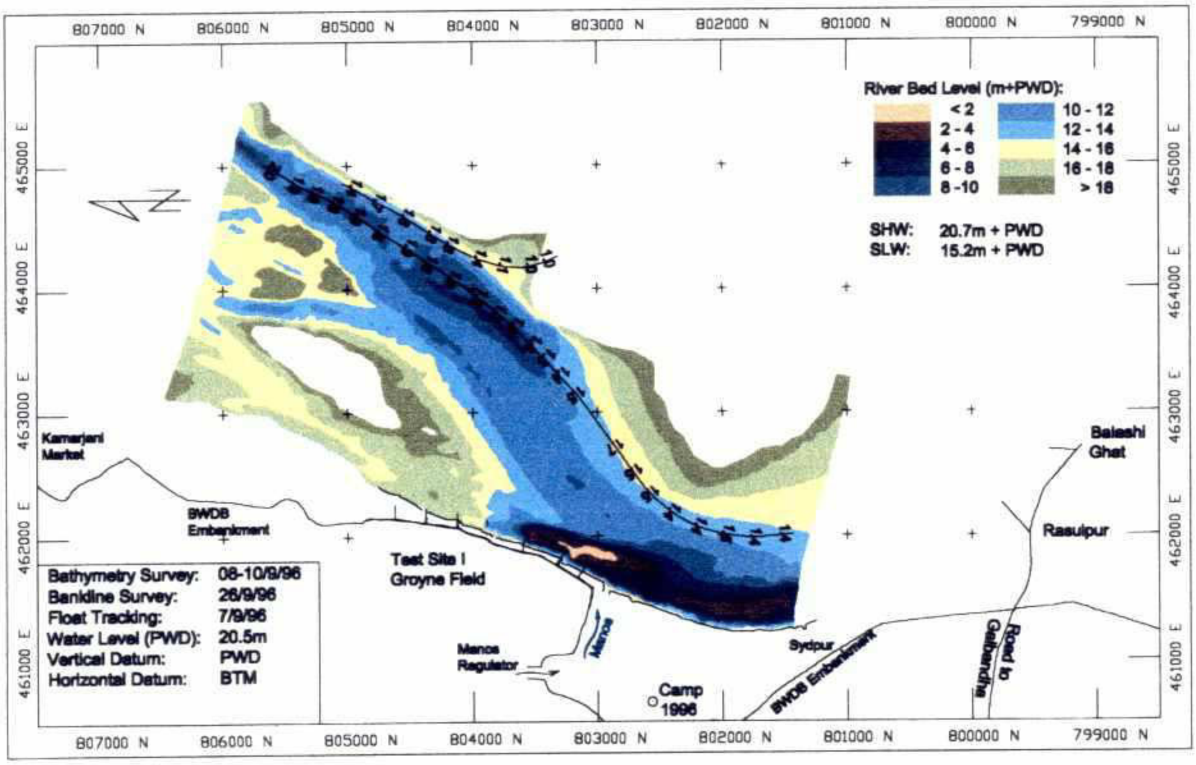


Fig. 4.22: Kamarjani September 1996

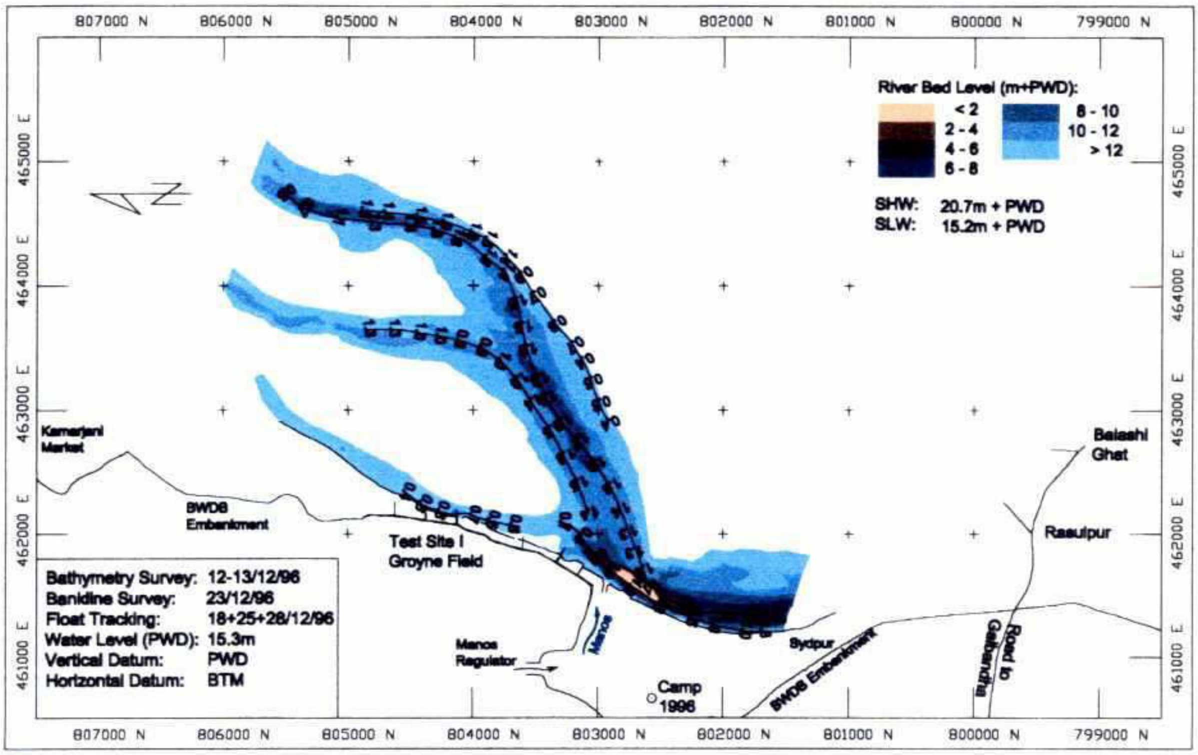
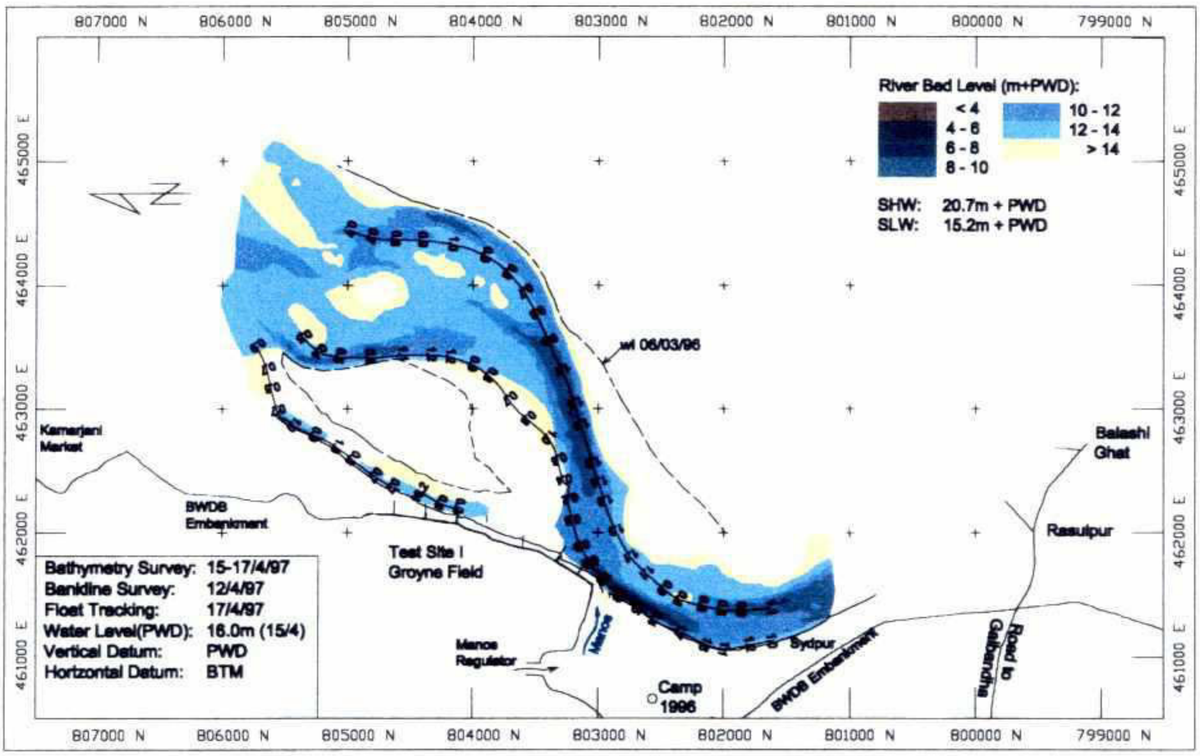


Fig. 4.23: Kamarjani December 1996



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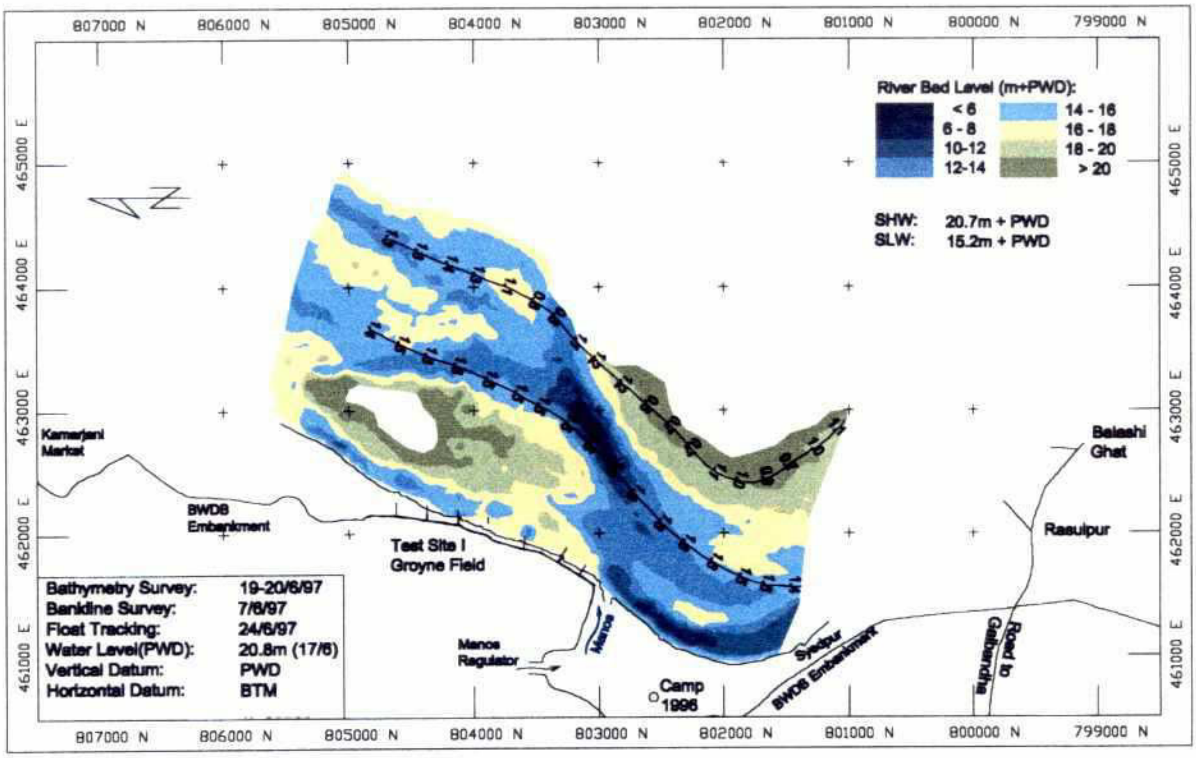

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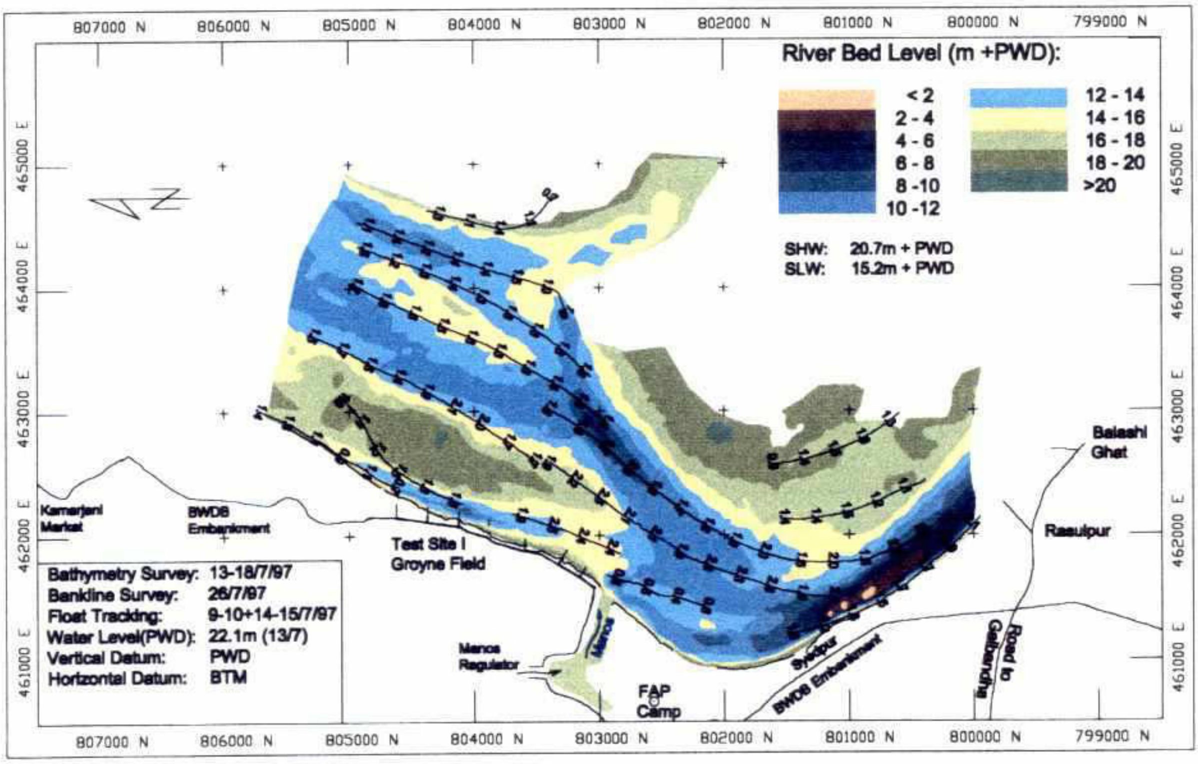

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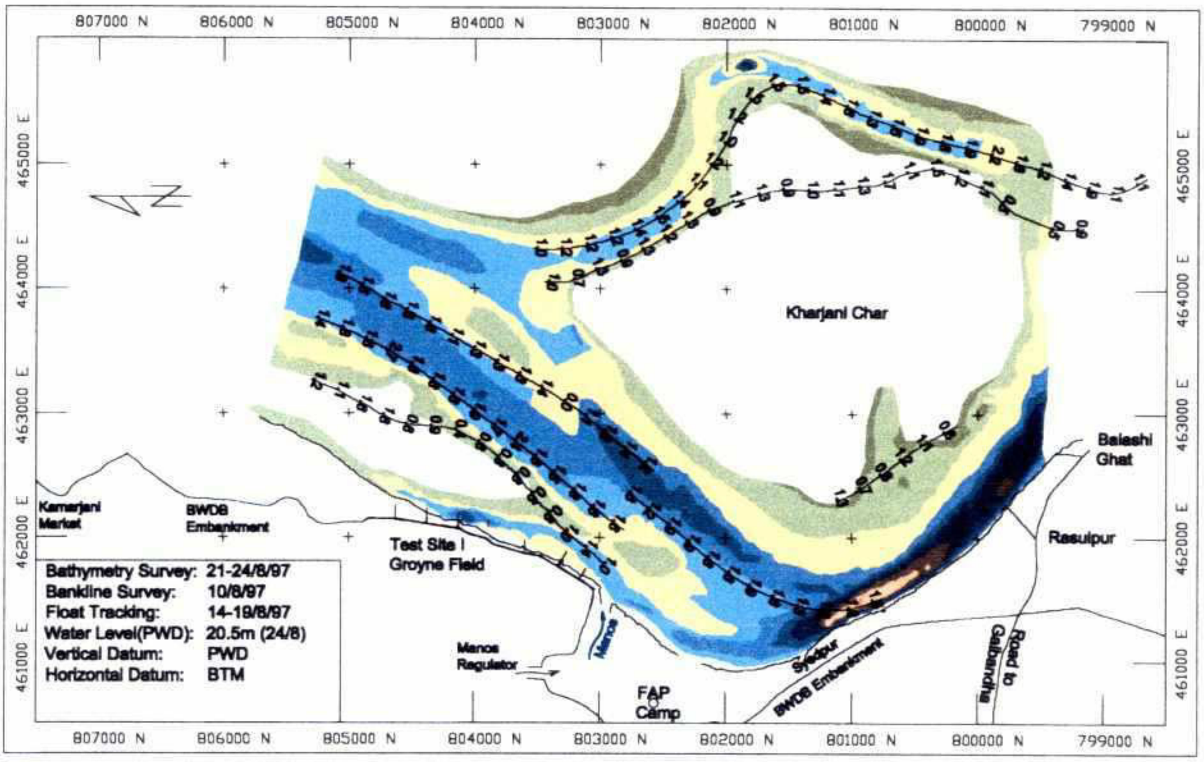


Fig. 4.27: Kamarjani August 1997

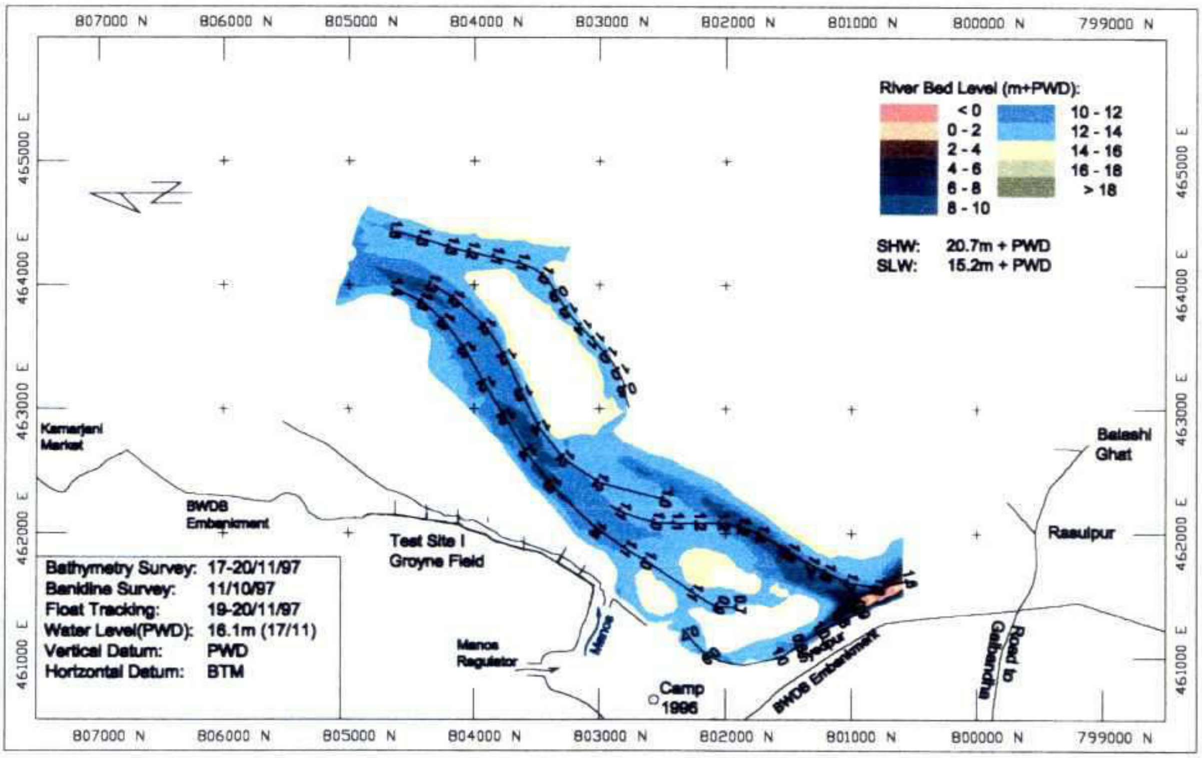


Fig. 4.28: Kamarjani November 1997

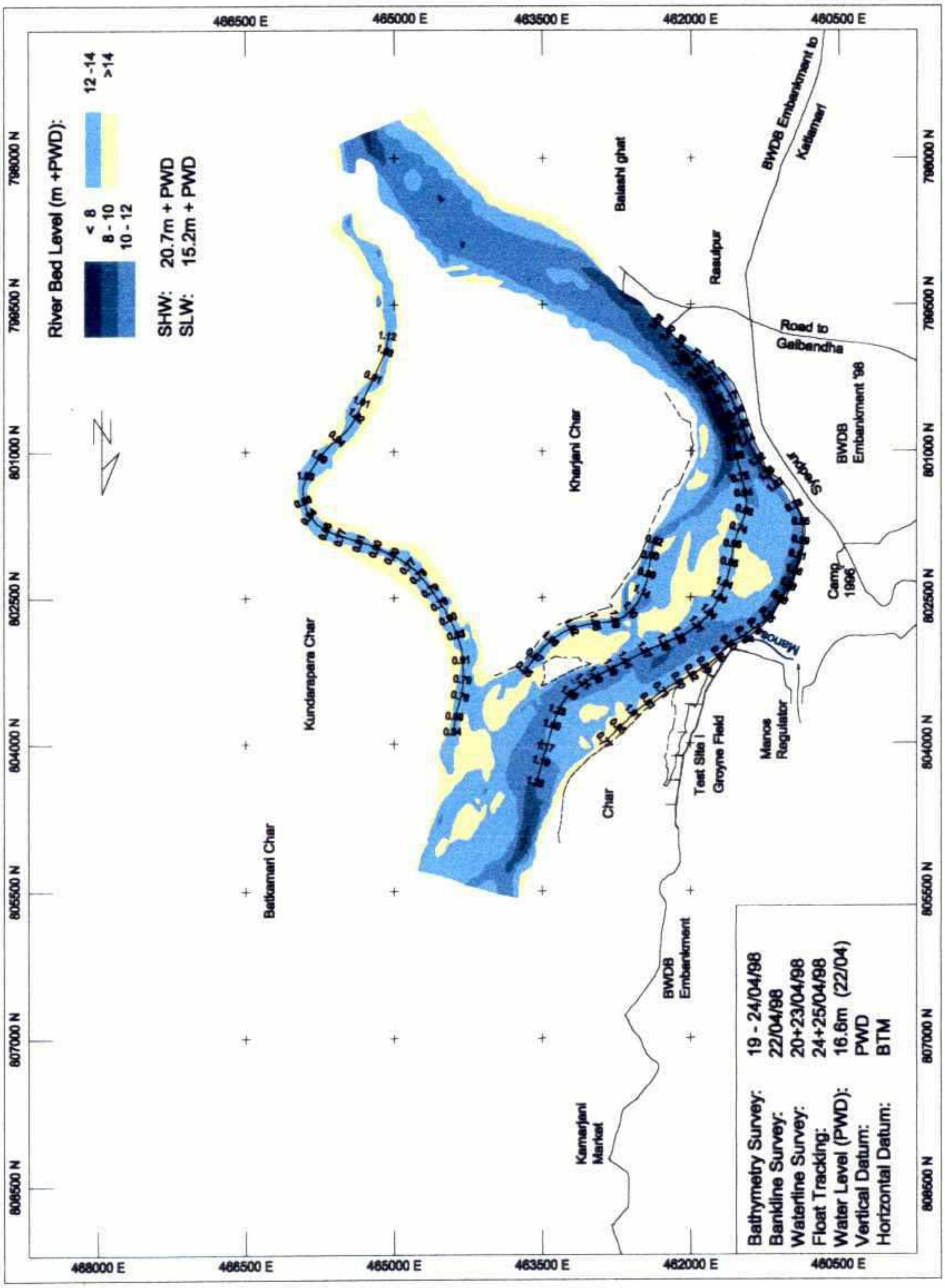


Fig. 4.29: Kamarjani April 1998

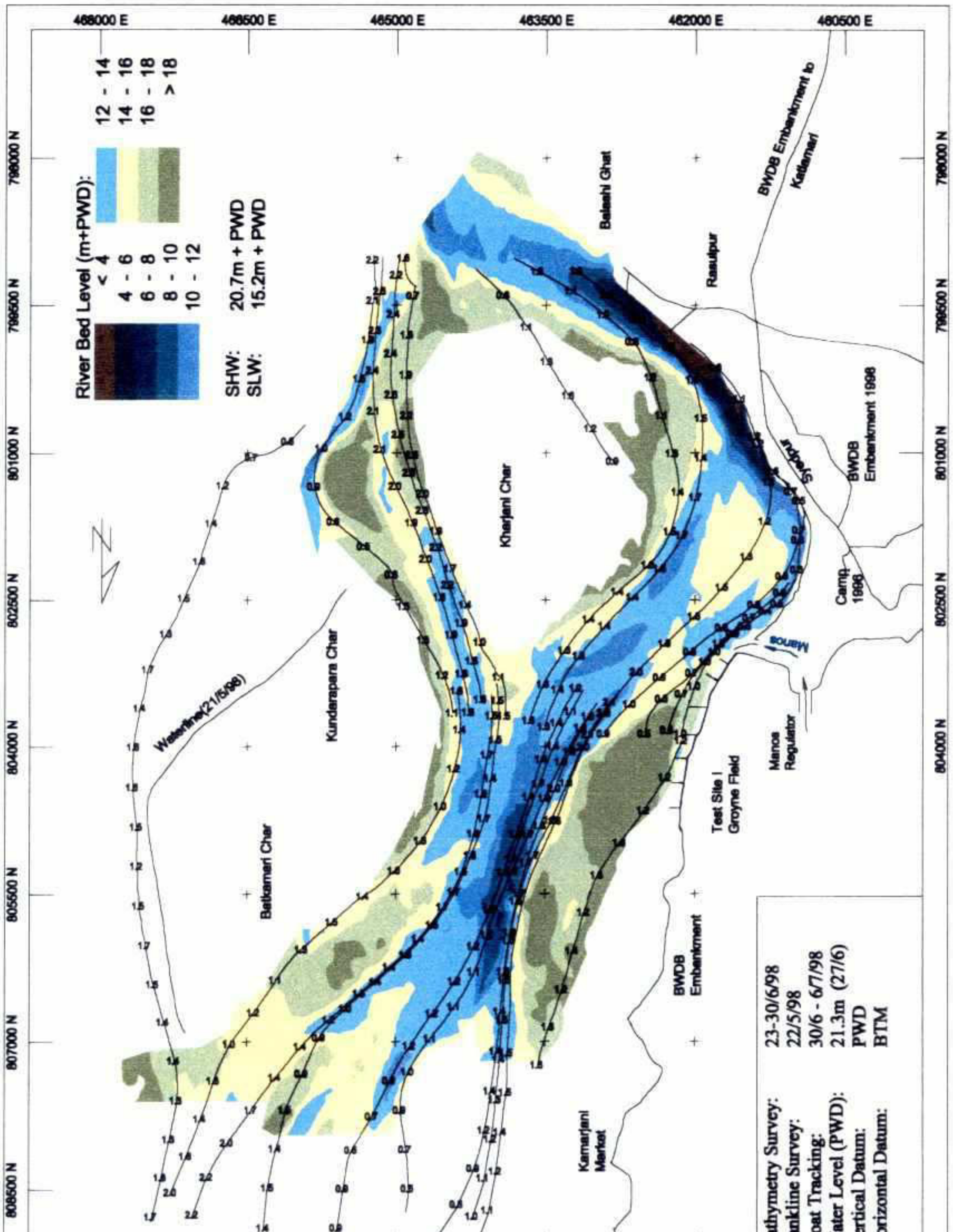
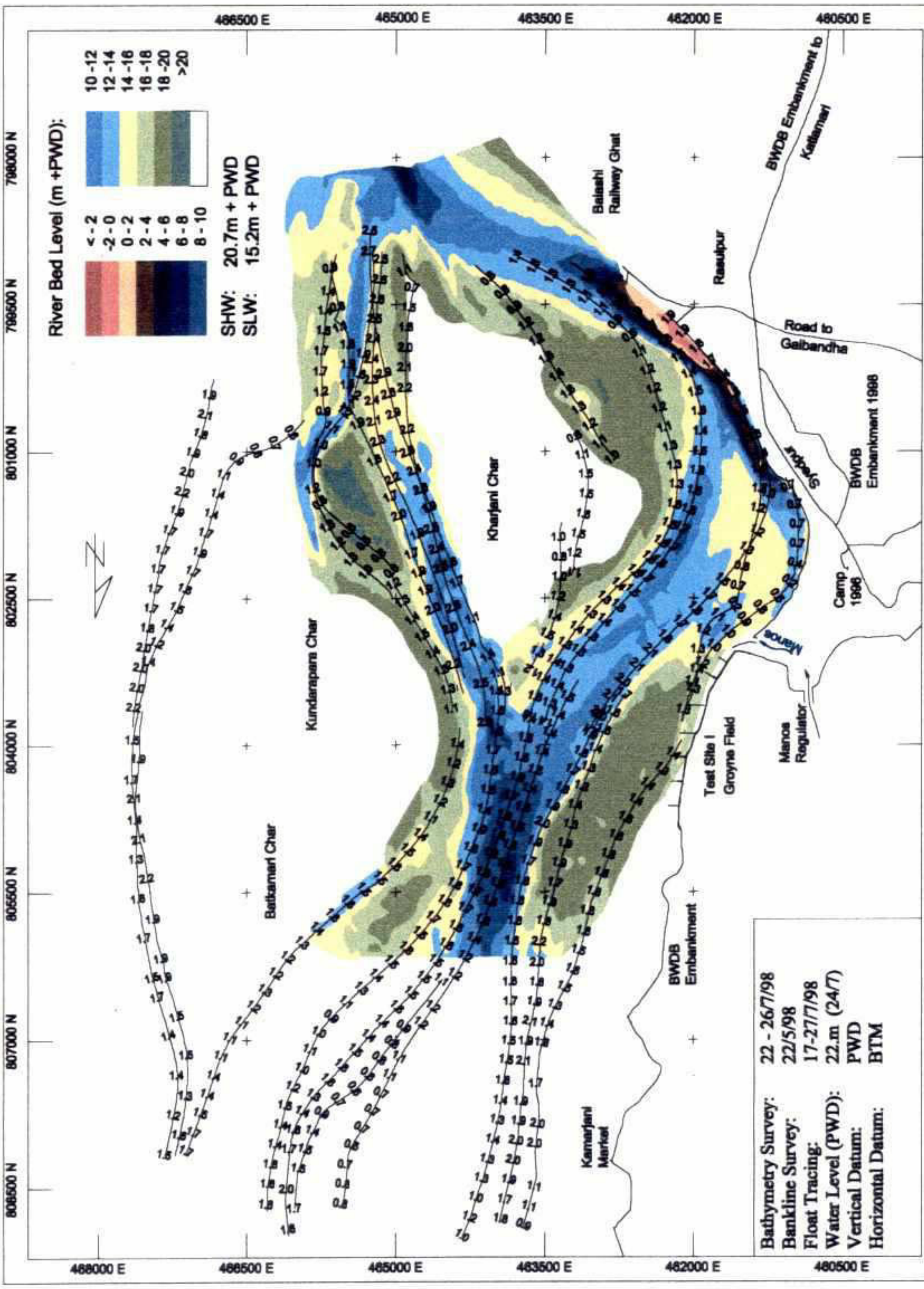


Fig. 4.30: Kamarjani June 1998



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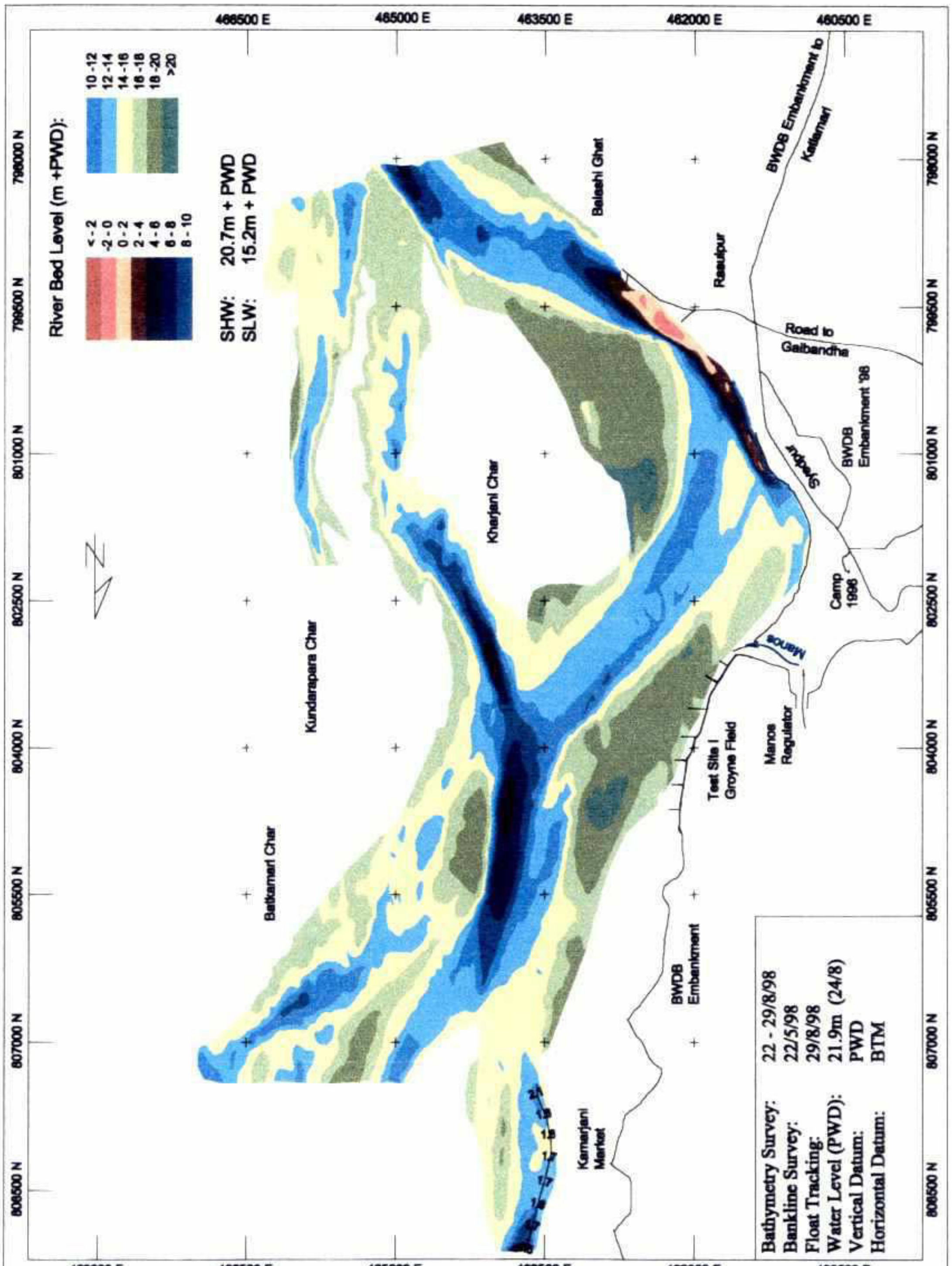


Fig. 4.32: Kamarjani August 1998

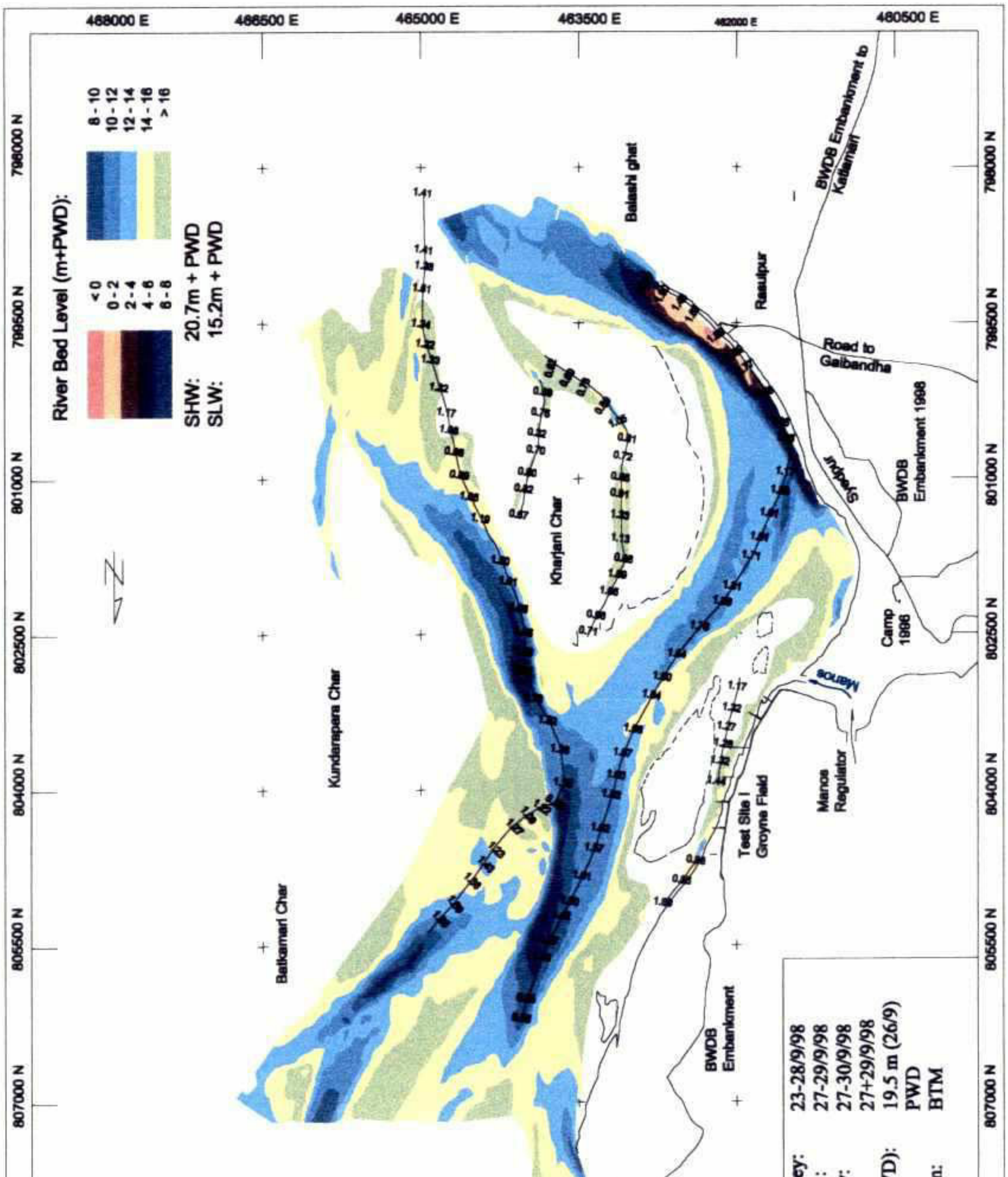


Fig. 4.33: Kamarjani September 1998

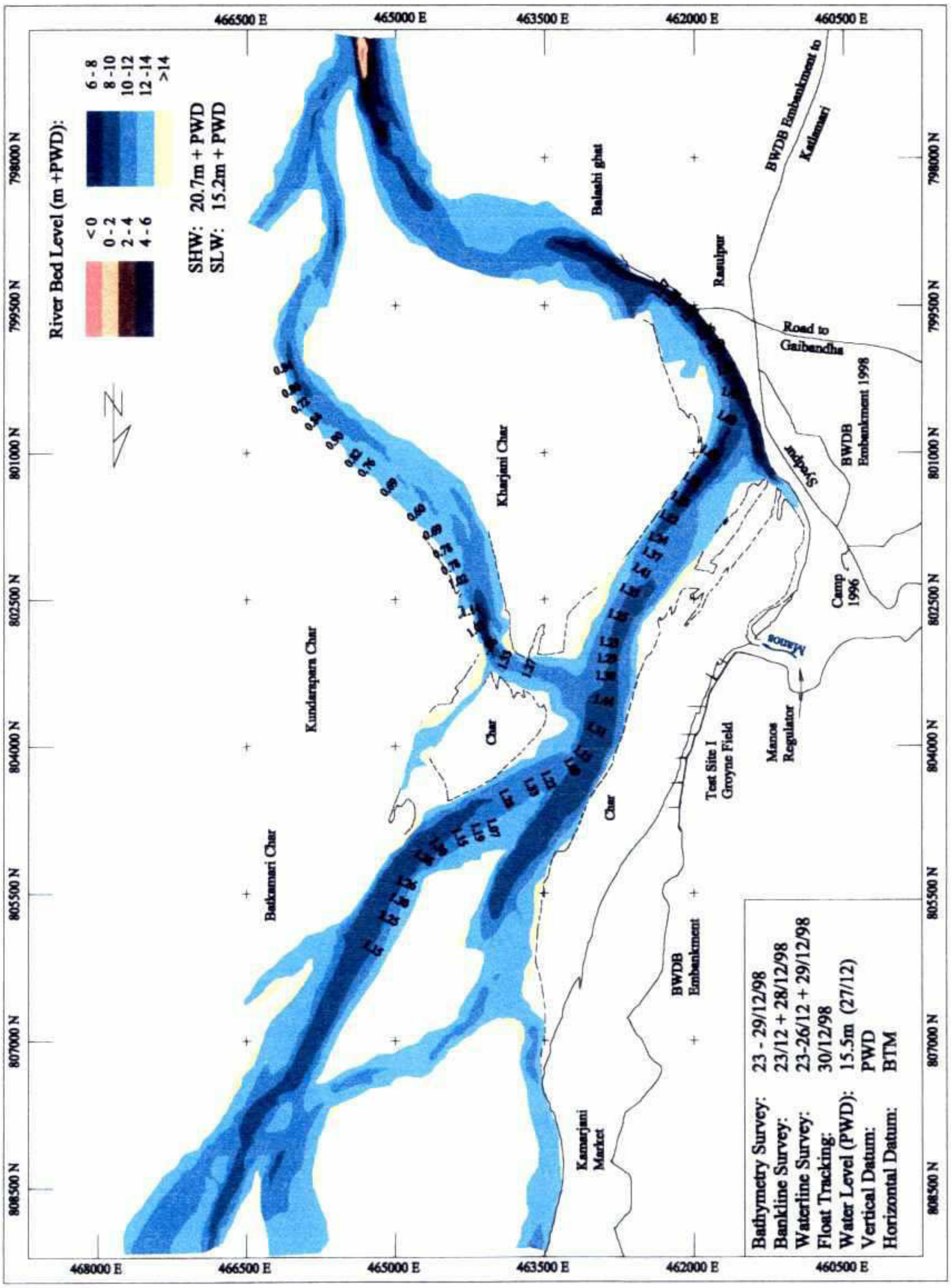


Fig. 4.34: Kamarjani December 1998

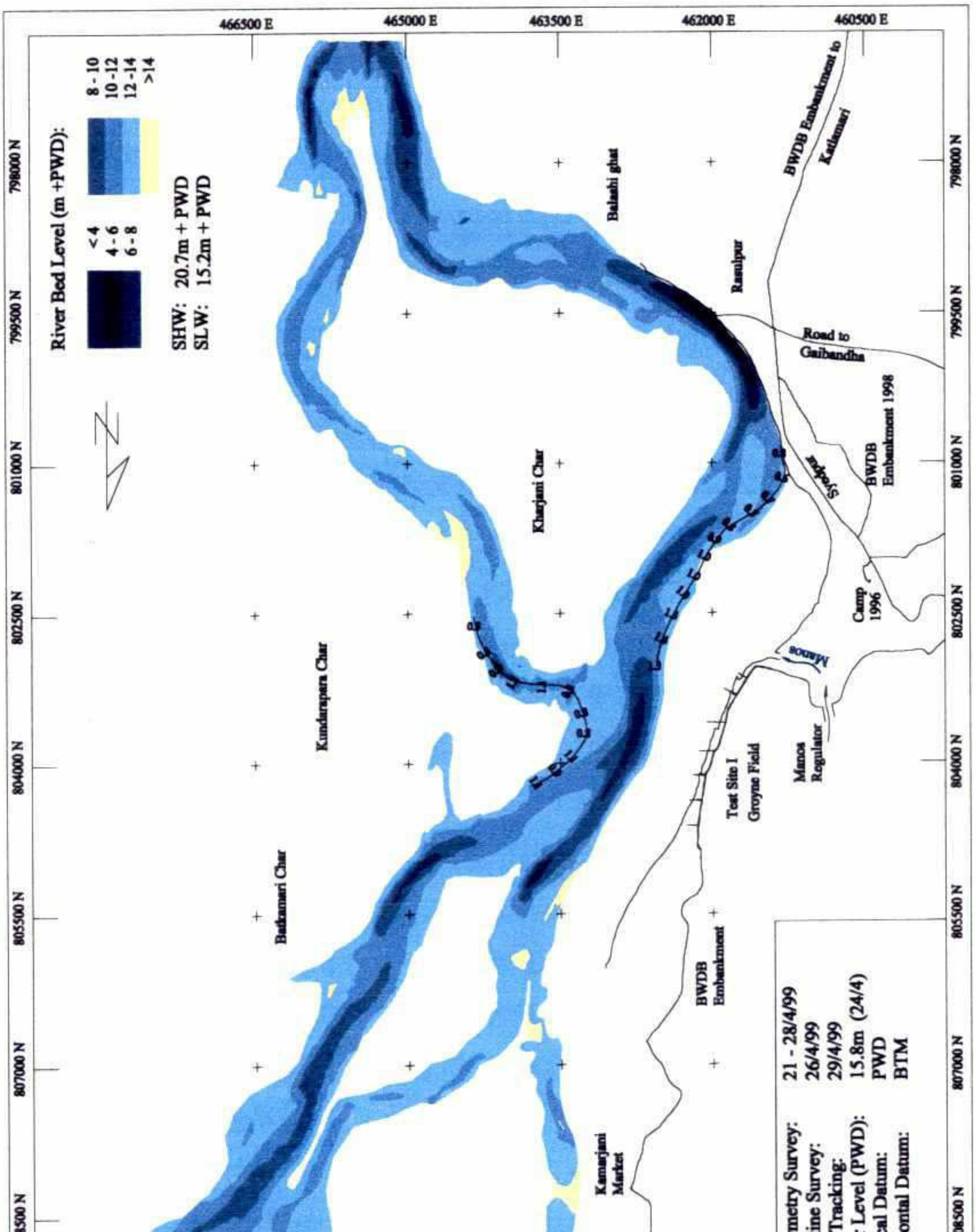


Fig. 4.35: Kamarjani April 1999

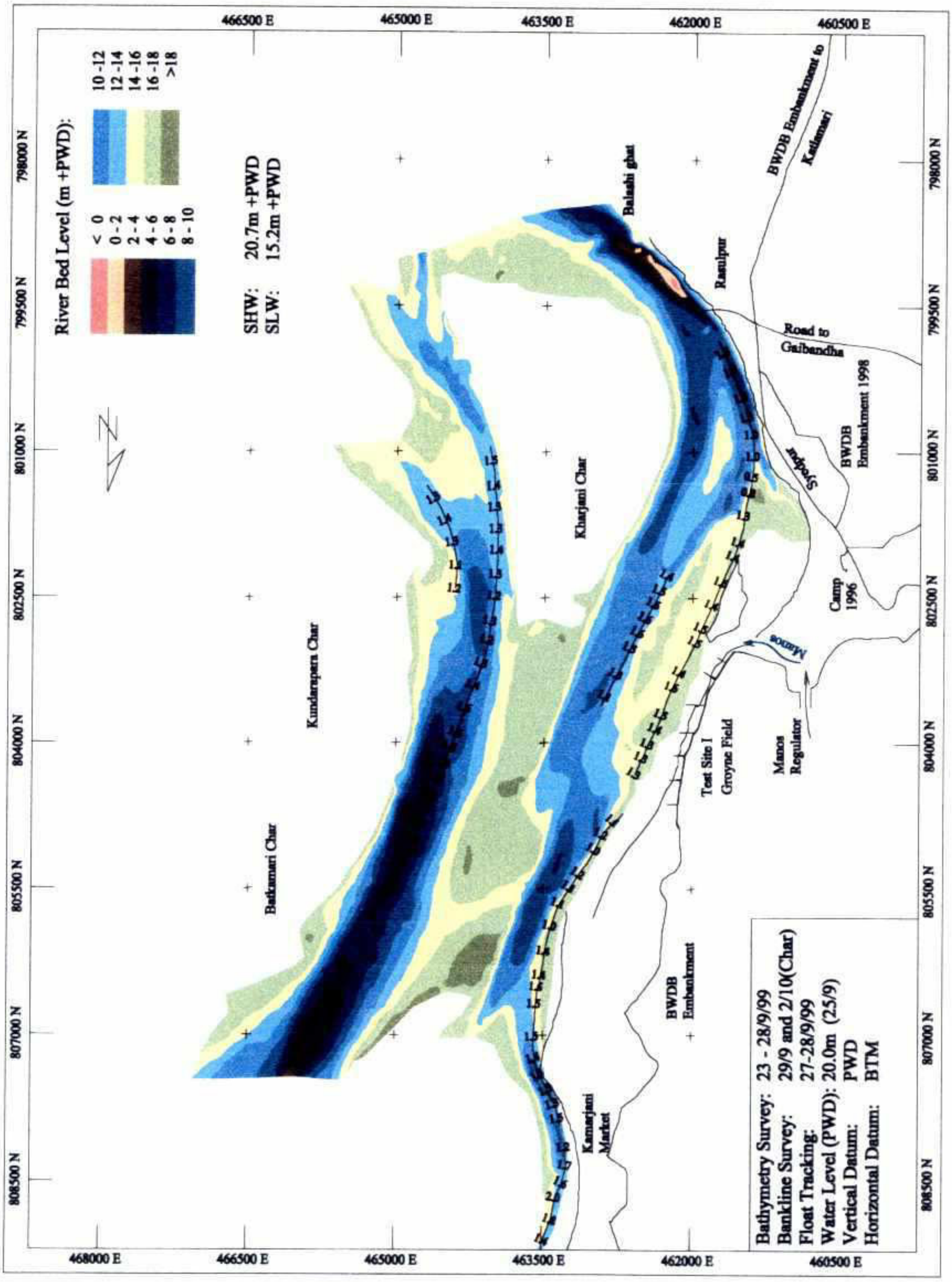


Fig. 4.36: Kamarjani September 1999

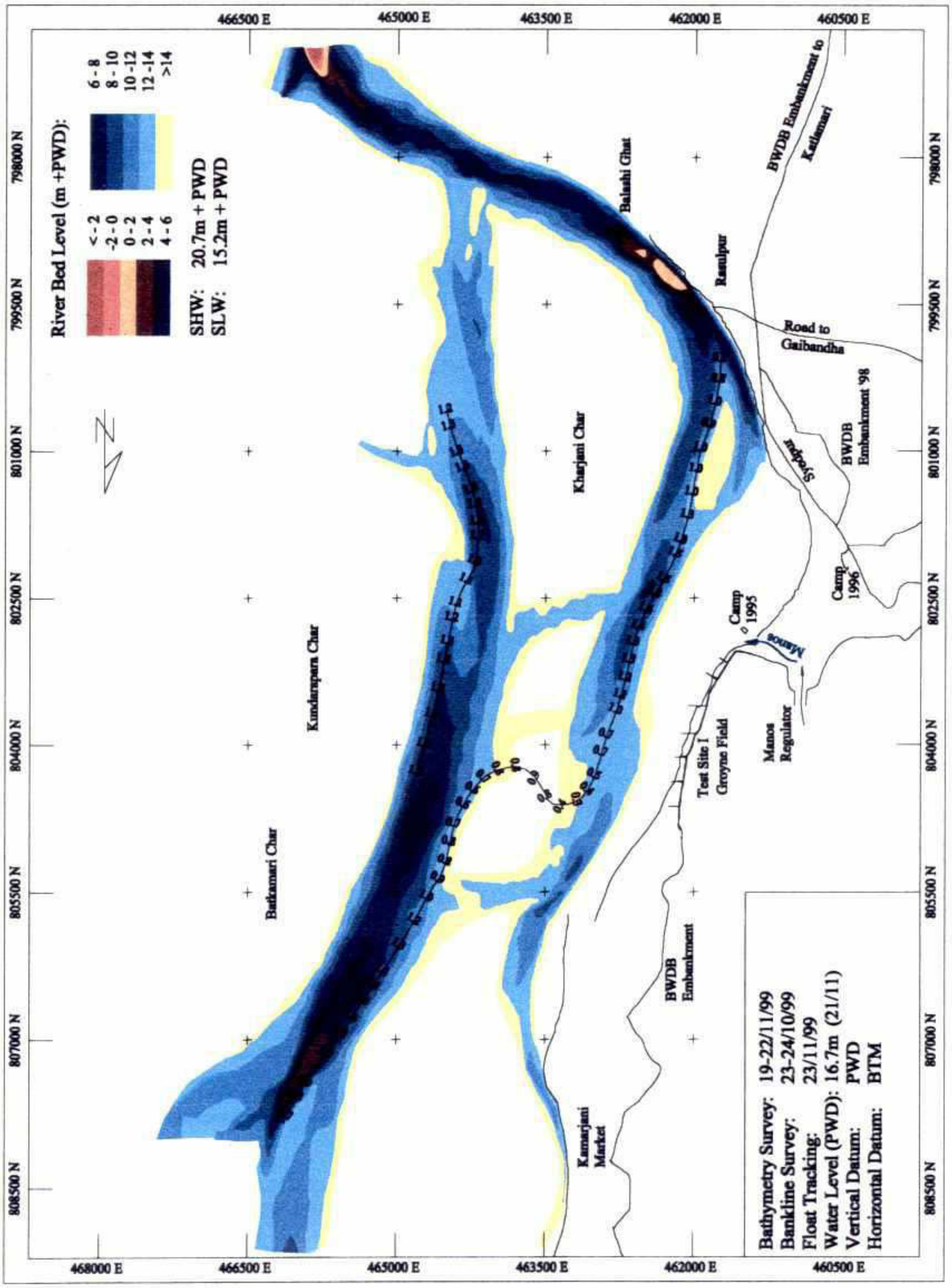


Fig. 4.37: Kamarjani November 1999

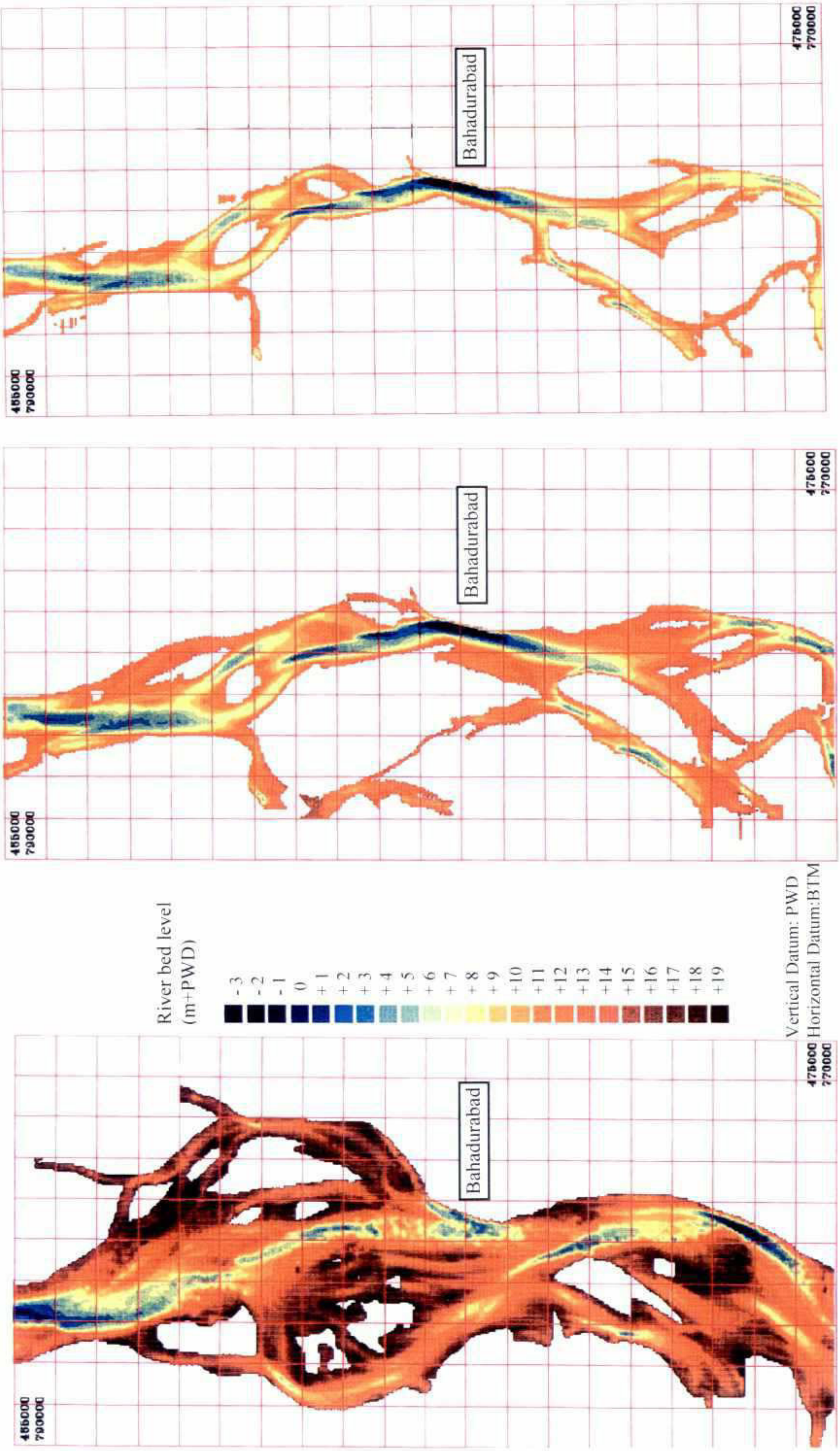
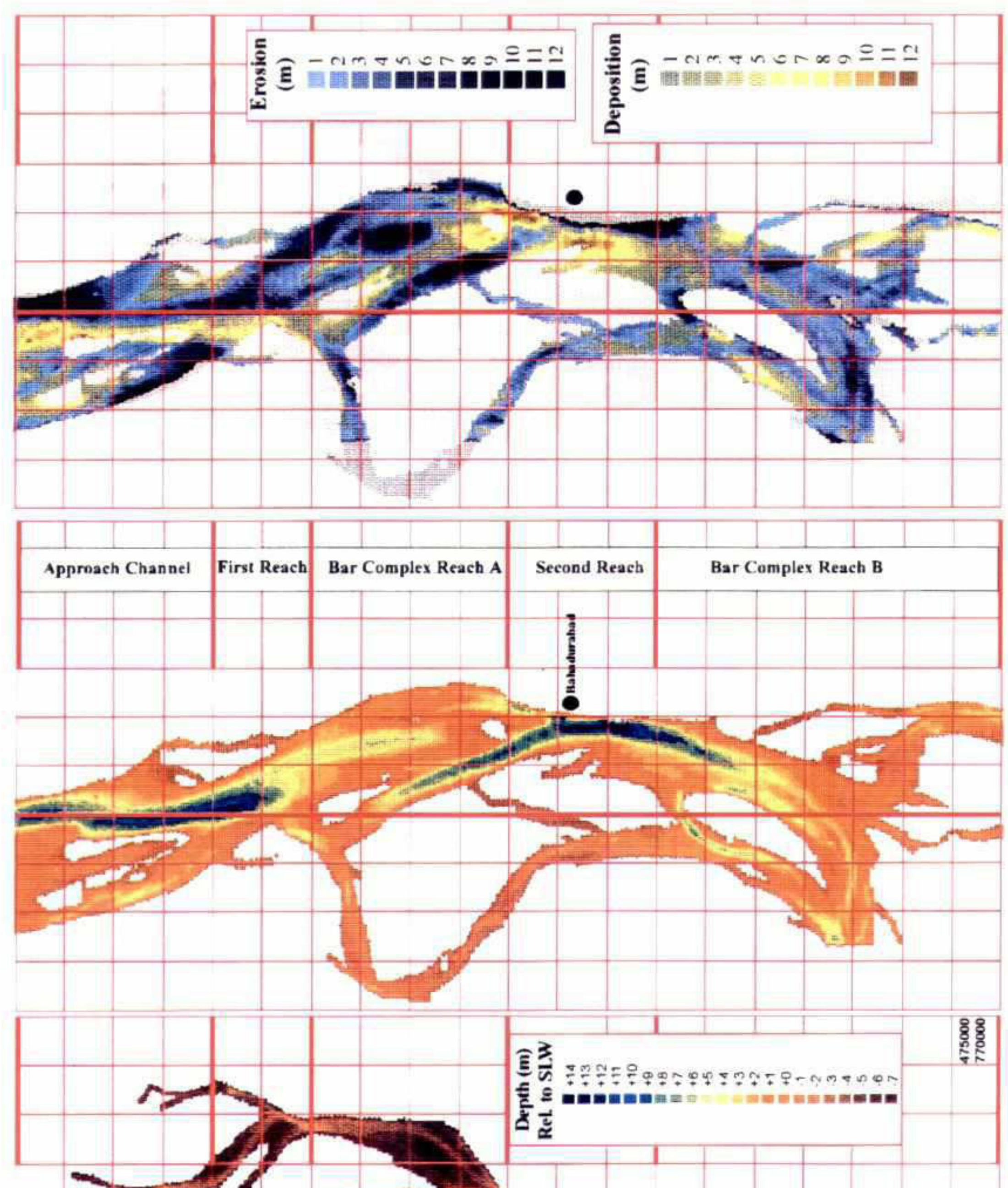


Fig. 4.38: Bathymetry at Bahadurabad
(Surveyed by FAP 24 and processed by EGIS)



A. Bathymetry contour slice of July 1995

B. Bathymetry contour slice of November 1995

C. Bed erosion and depositon, July to November 1995

Fig. 4.39: Bathymetry at Bahadurabad
(Surveyed by FAP 24 and processed by EGIS)

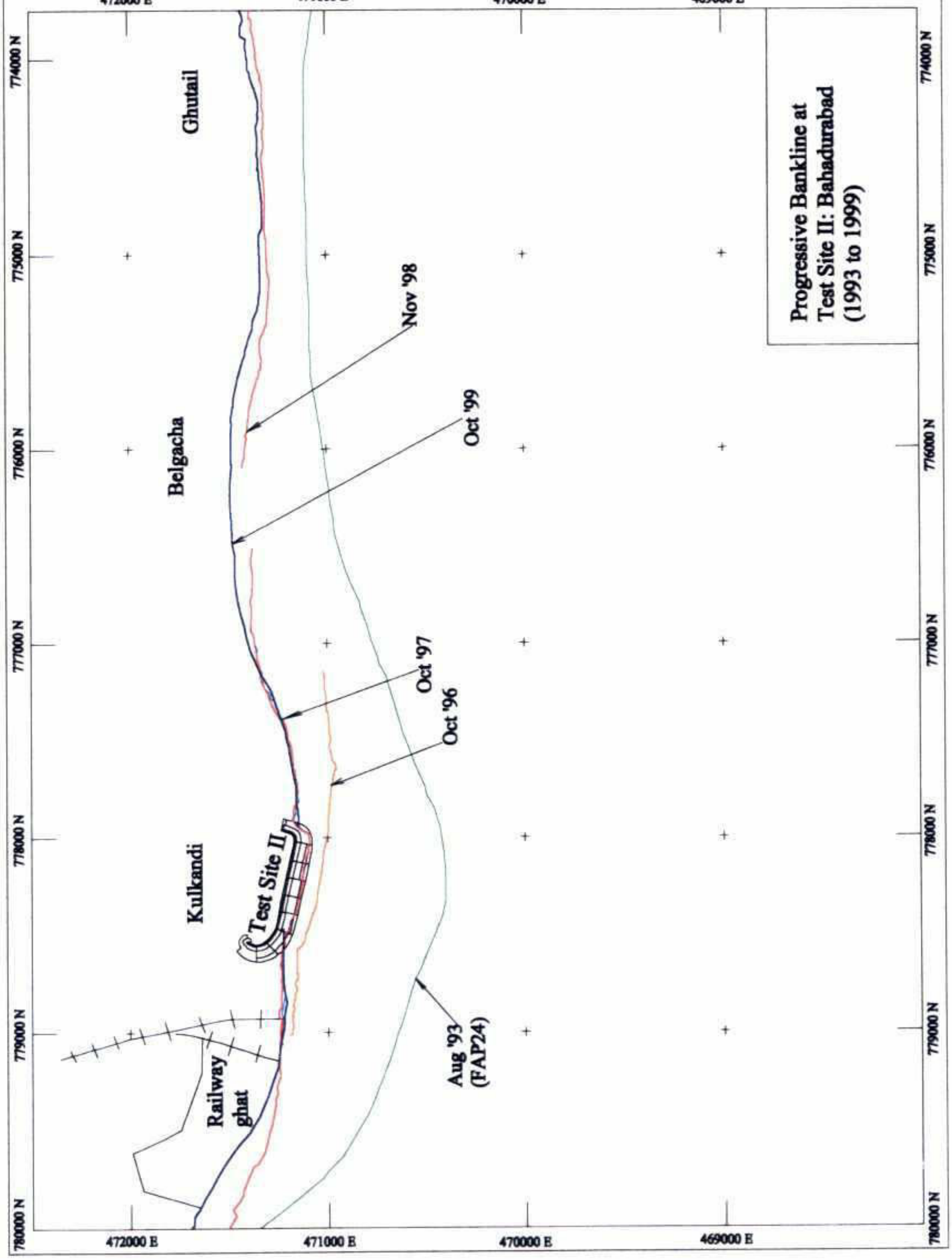


Fig. 4.40: Bahadurabad Progressive Bankline

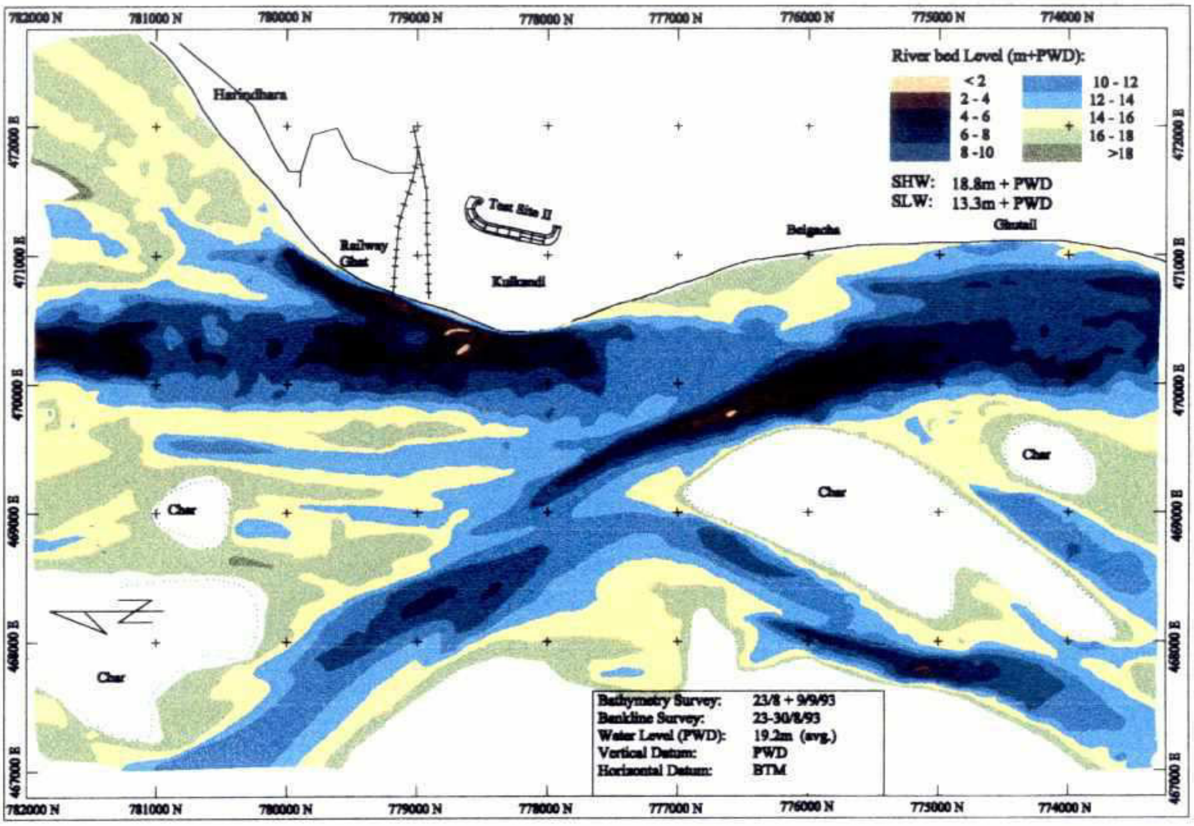


Fig. 4.41: Bahadurabad August 1993
(Surveyed by FAP 24)

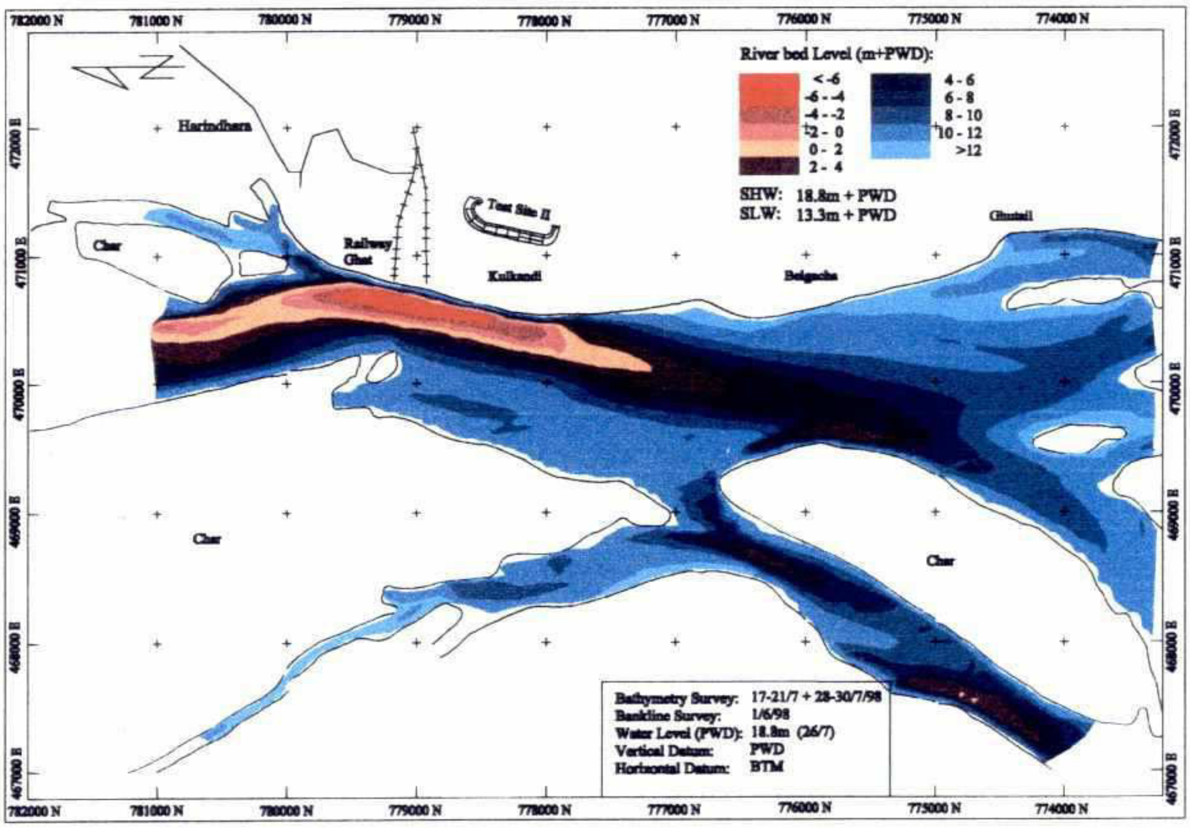


Fig. 4.42: Bahadurabad November 1994
(Surveyed by FAP 24)

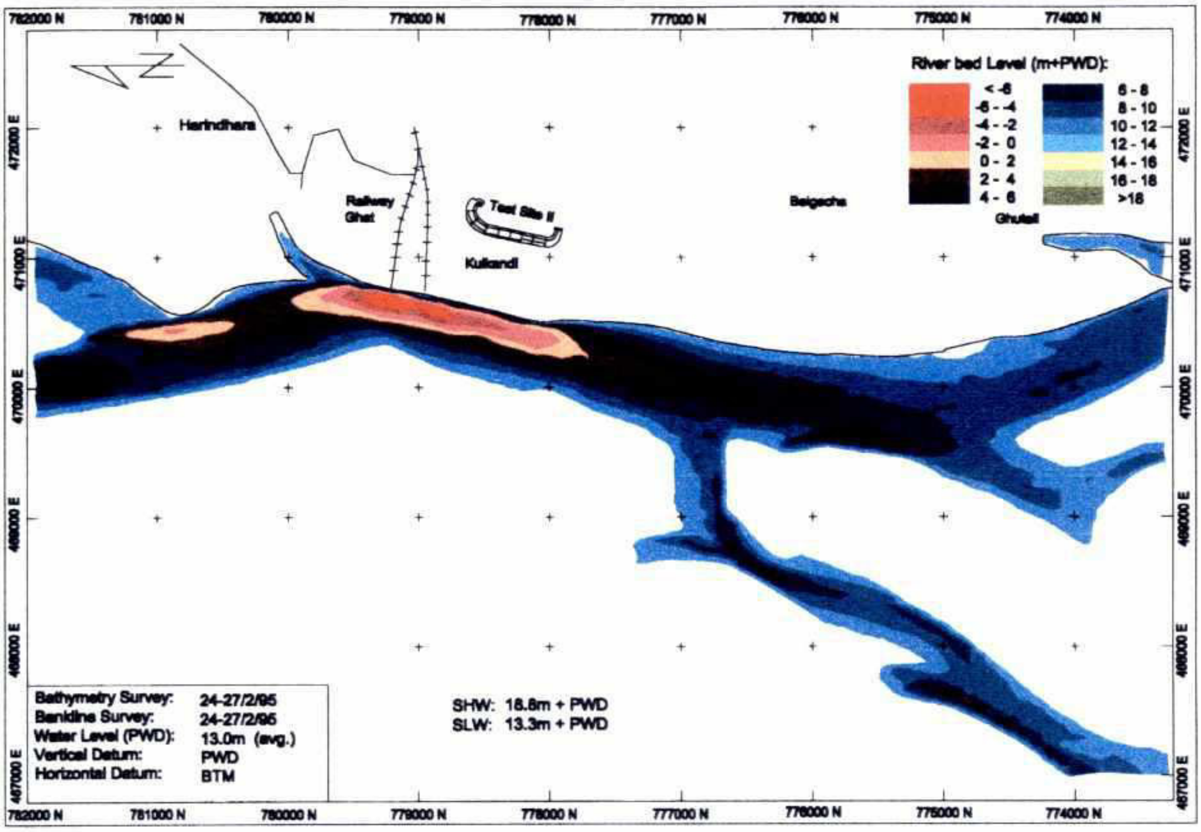


Fig. 4.43: Bahadurabad February 1995
(Surveyed by FAP 24)

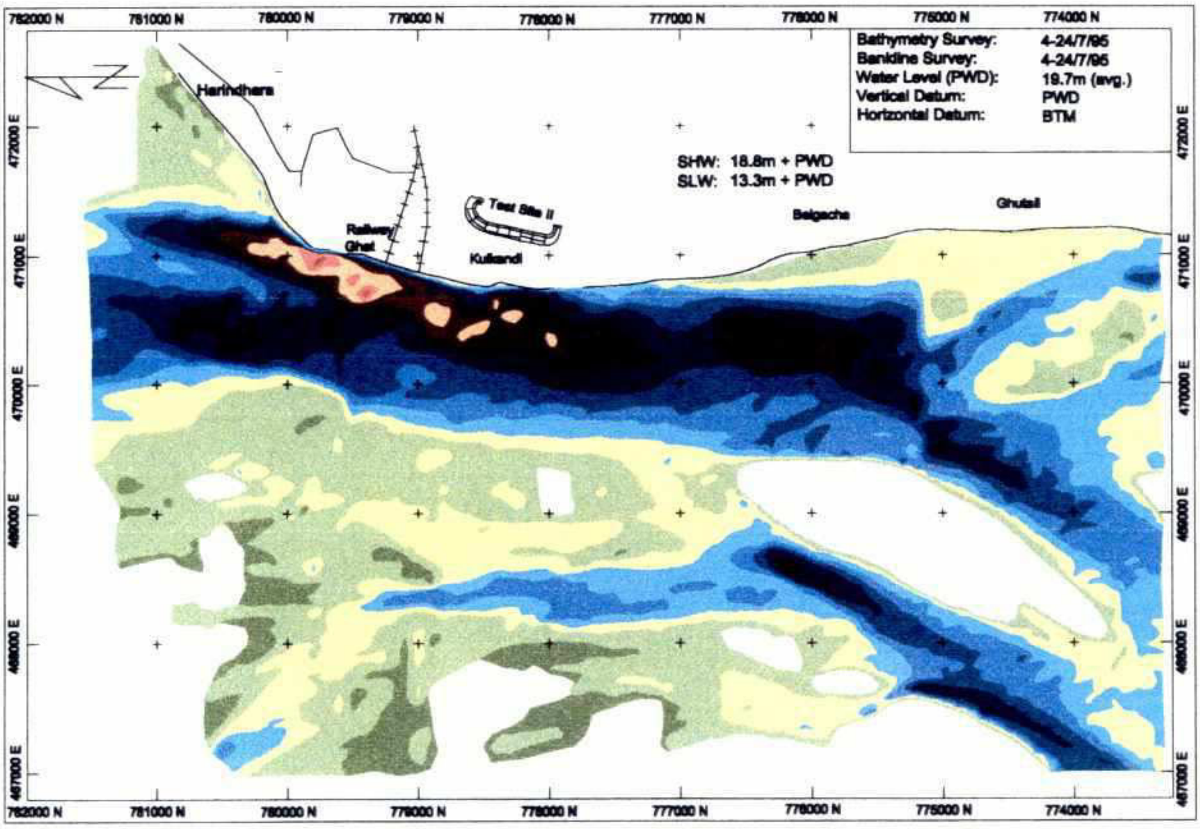


Fig. 4.44: Bahadurabad July 1995
(Surveyed by FAP 24)

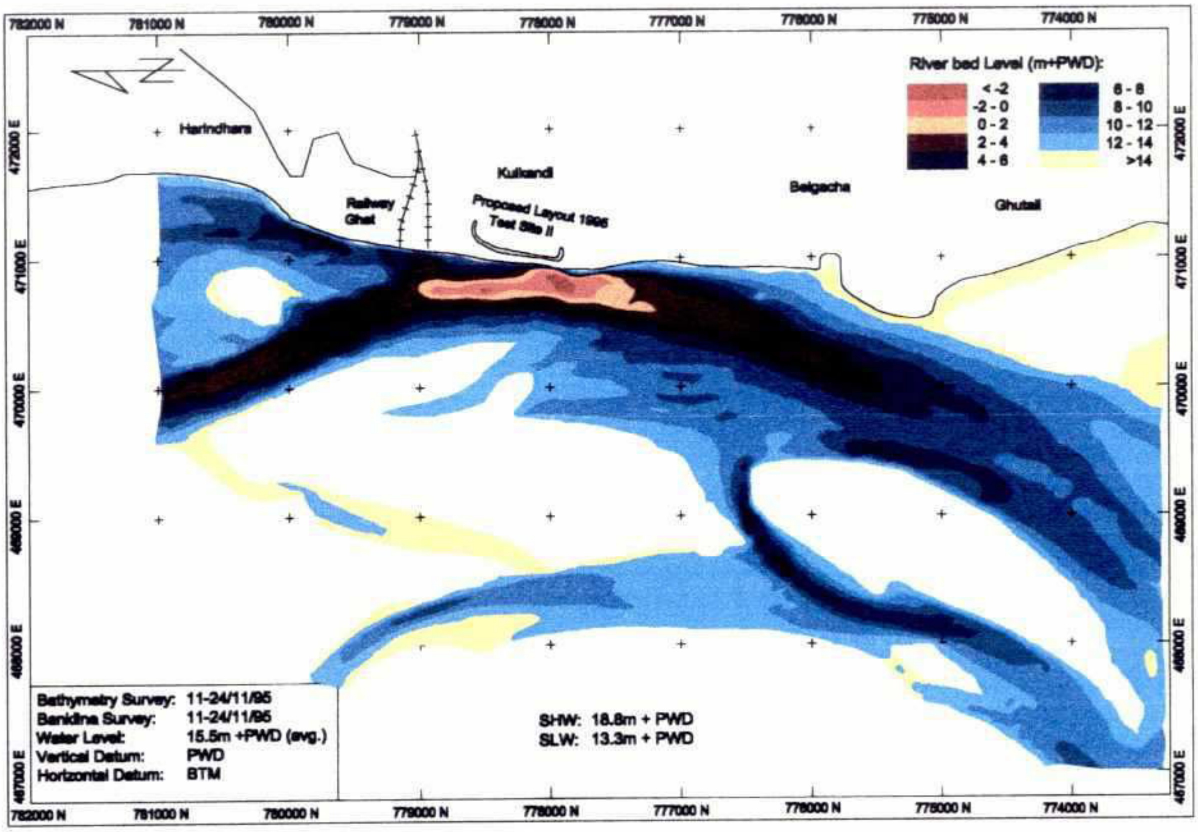


Fig. 4.45: Bahadurabad November 1995
(Surveyed by FAP 24)

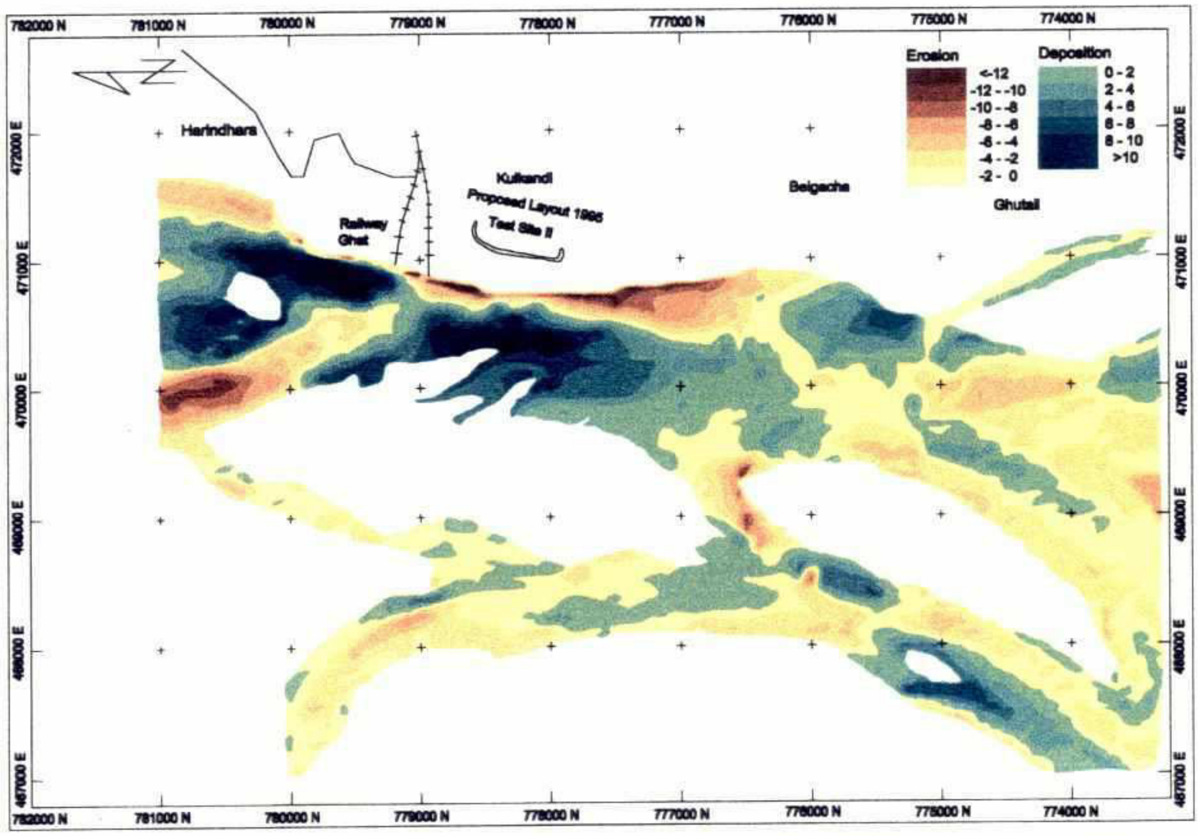


Fig. 4.46: Erosion and deposition at Bahadurabad from July 1995 to November 1995
(Surveyed by FAP 24)

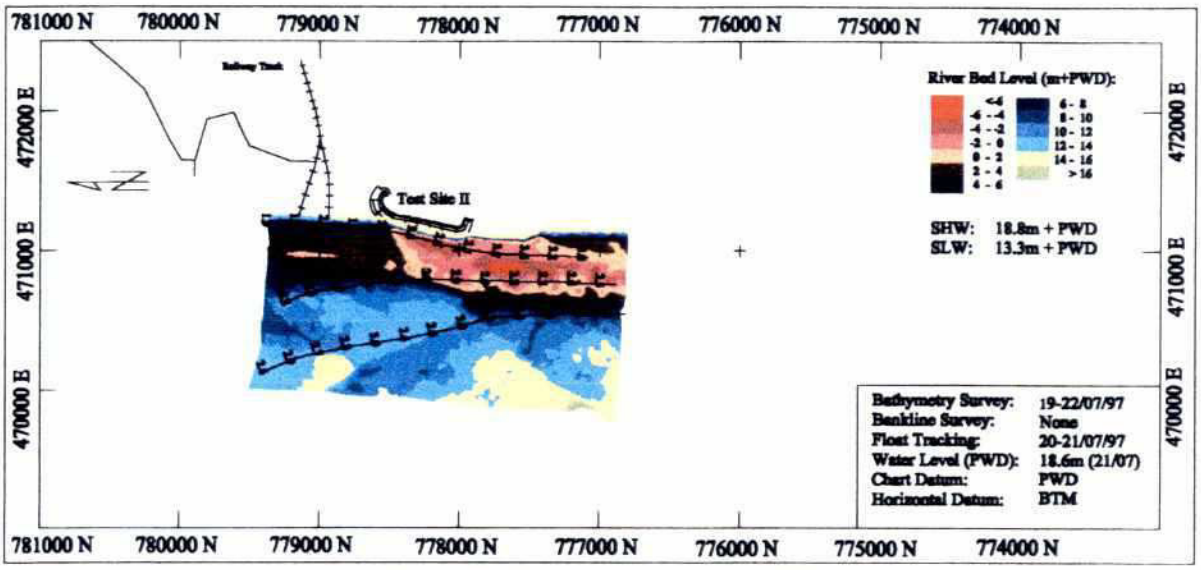


Fig. 4.47: Bahadurabad July 1997

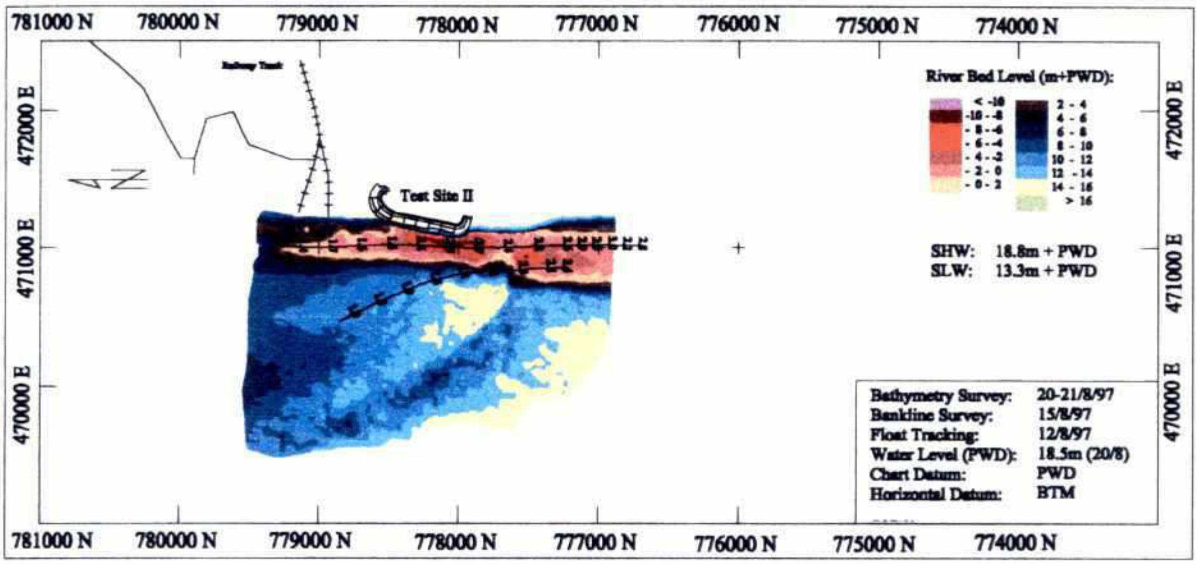


Fig. 4.48: Bahadurabad August 1997

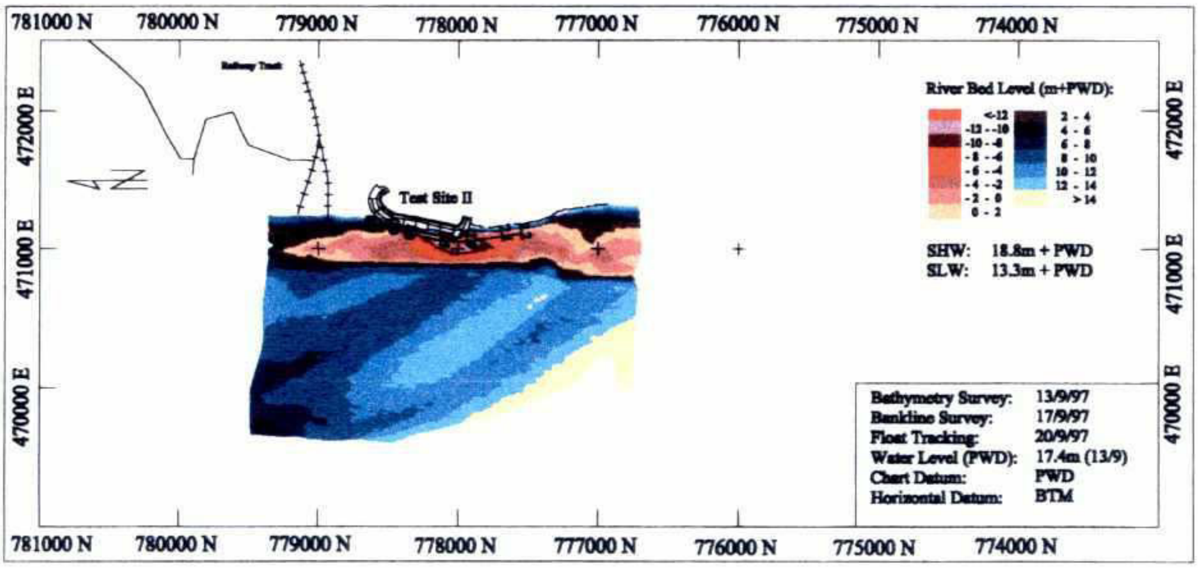


Fig. 4.49: Bahadurabad September 1997

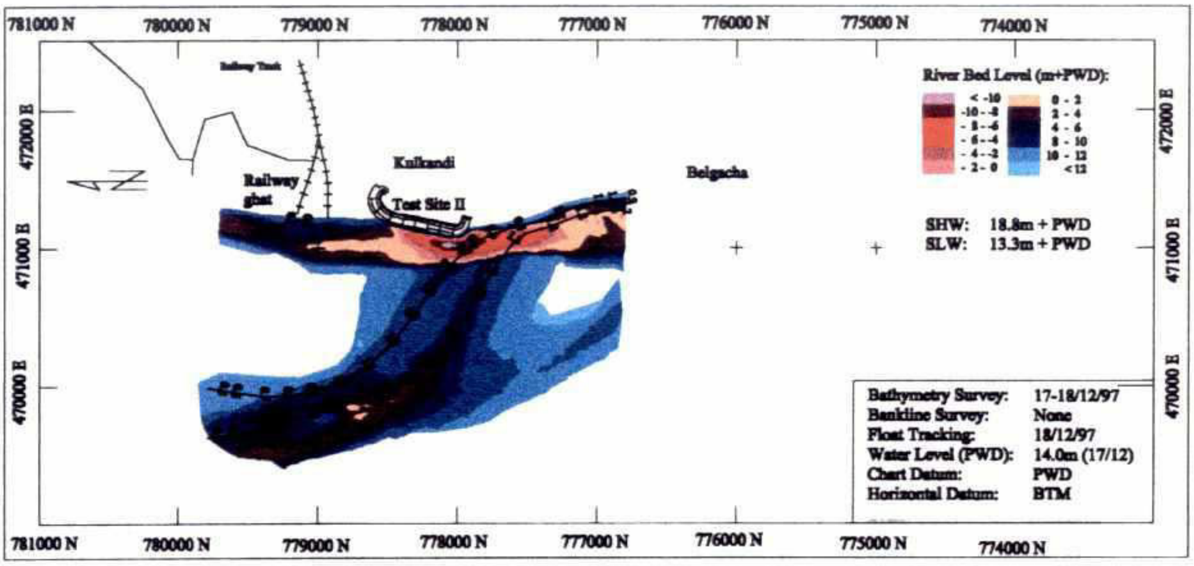


Fig. 4.50: Bahadurabad December 1997

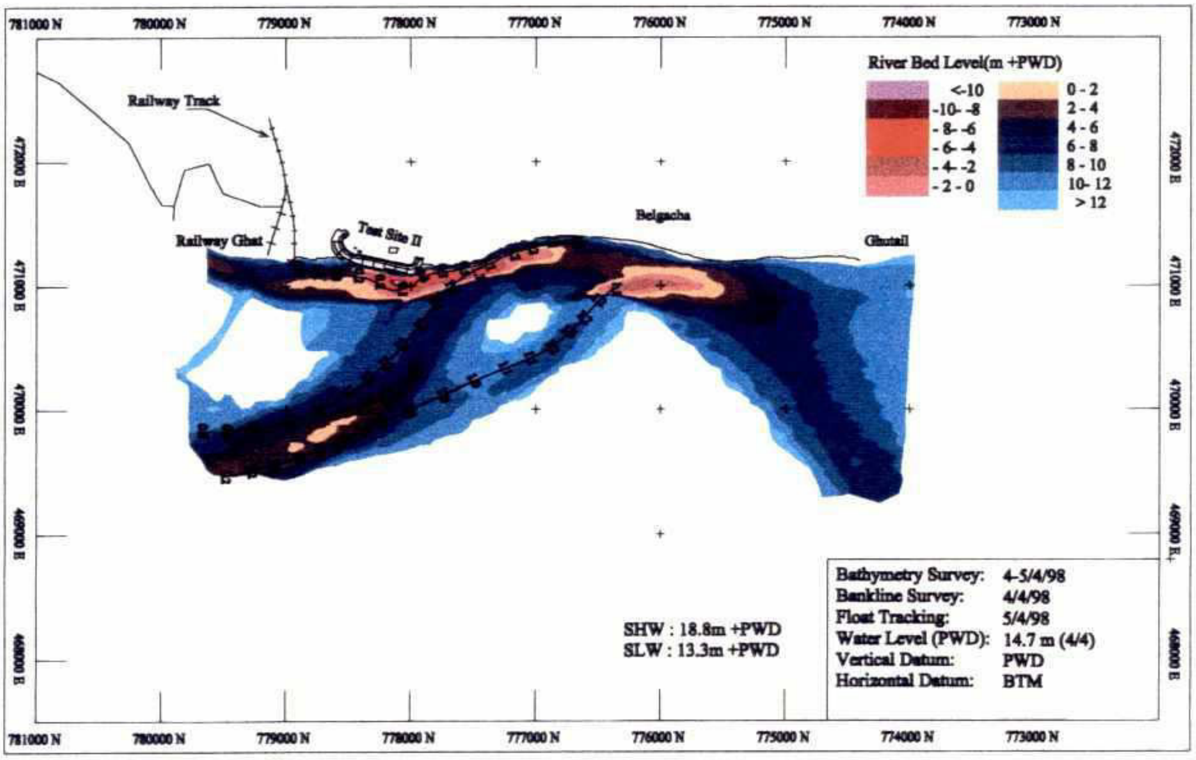


Fig. 4.51: Bahadurabad April 1998

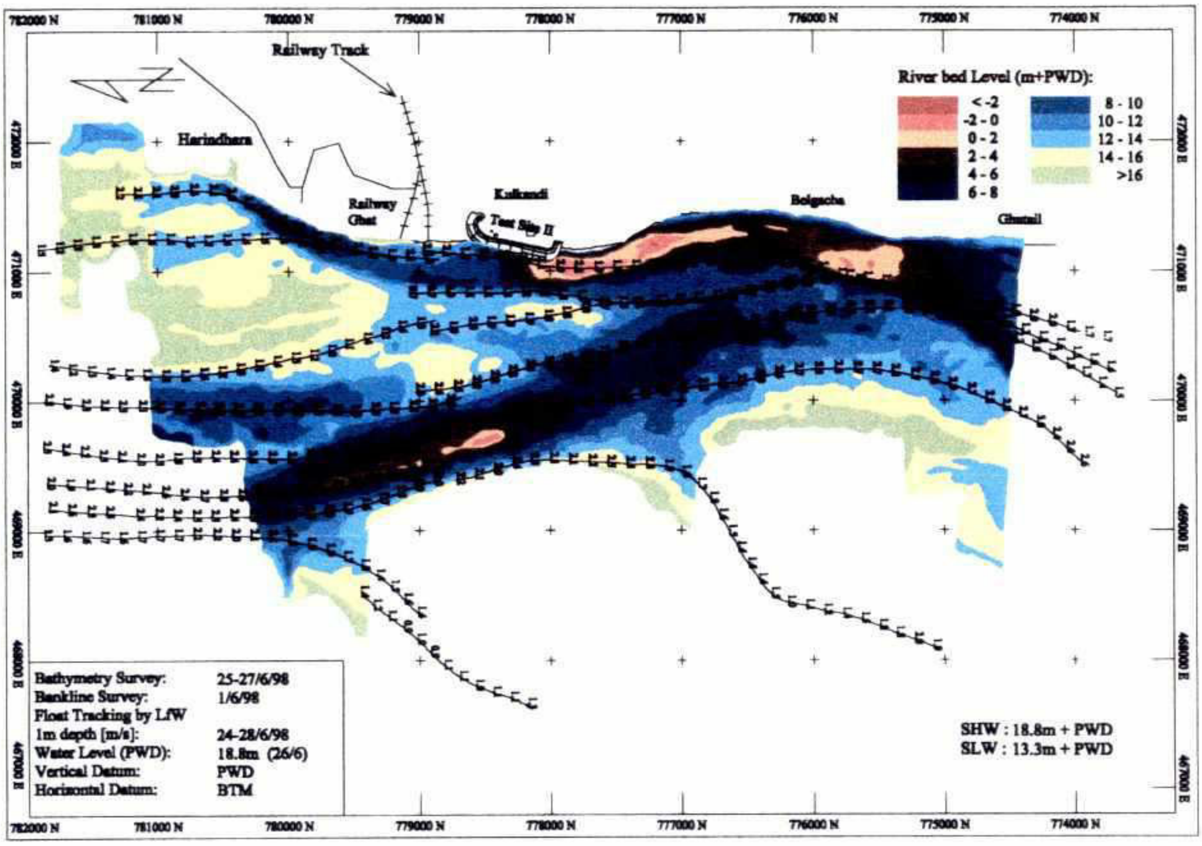


Fig. 4.52: Bahadurabad June 1998

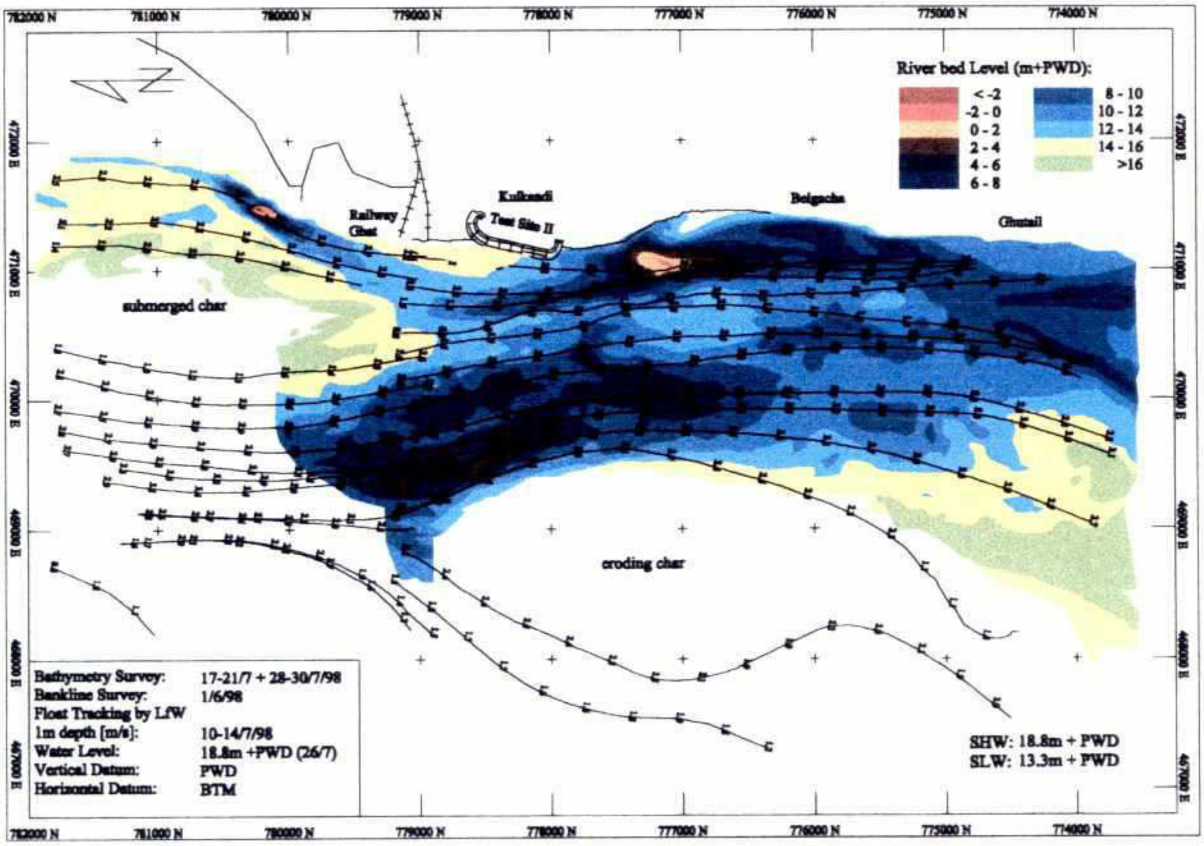


Fig. 4.53: Bahadurabad July 1998

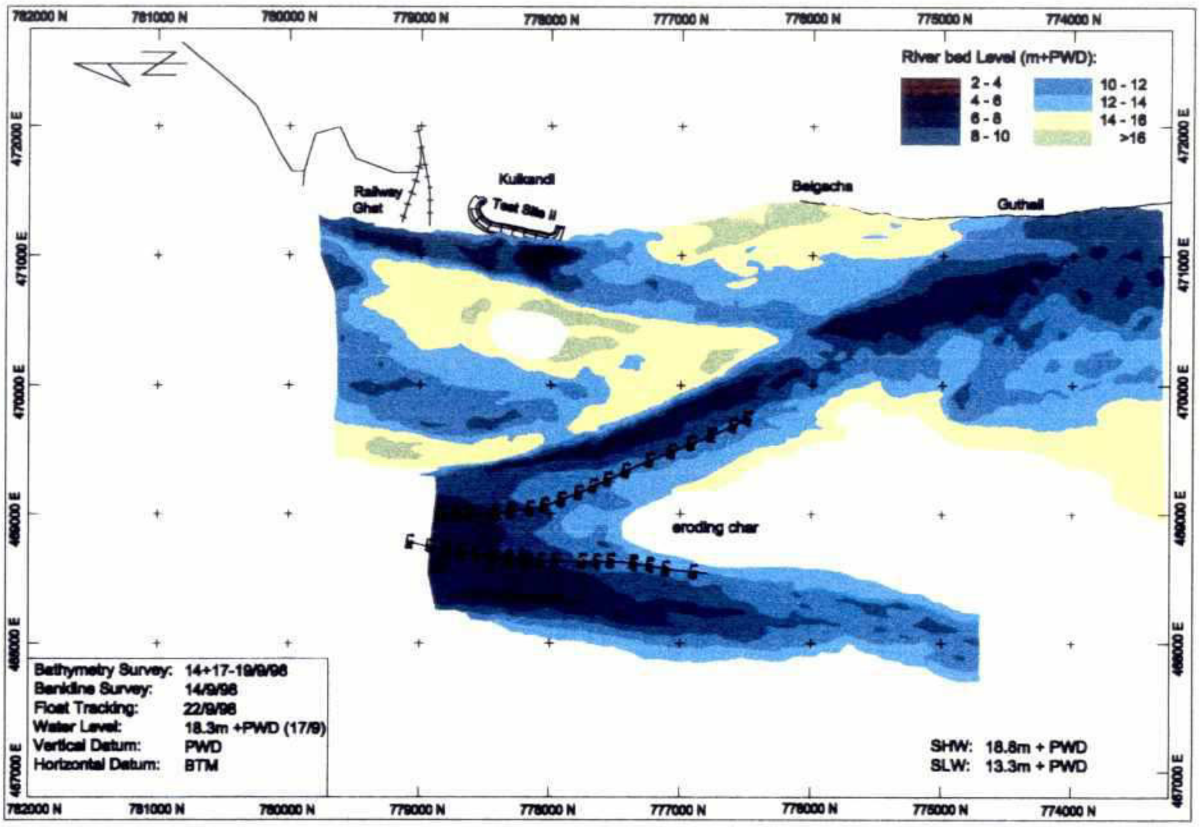


Fig. 4.54: Bahadurabad September 1998

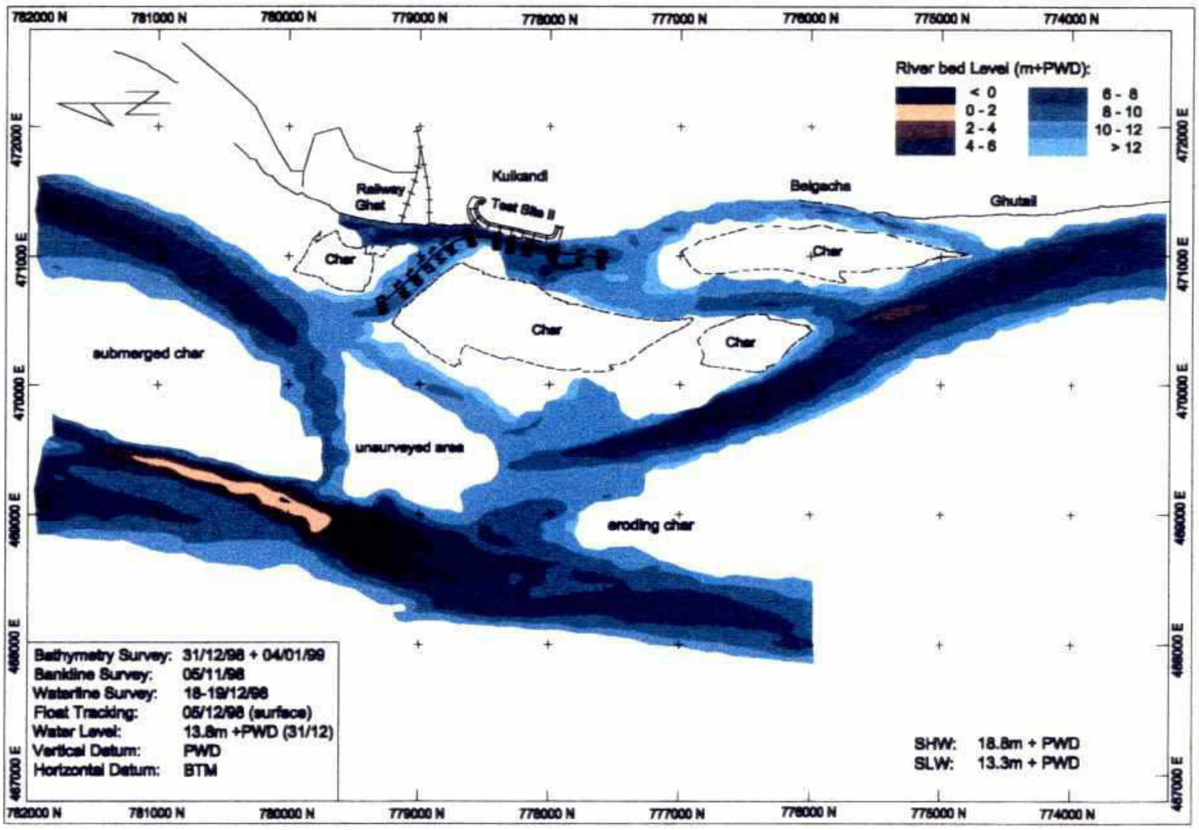


Fig. 4.55: Bahadurabad December 1998

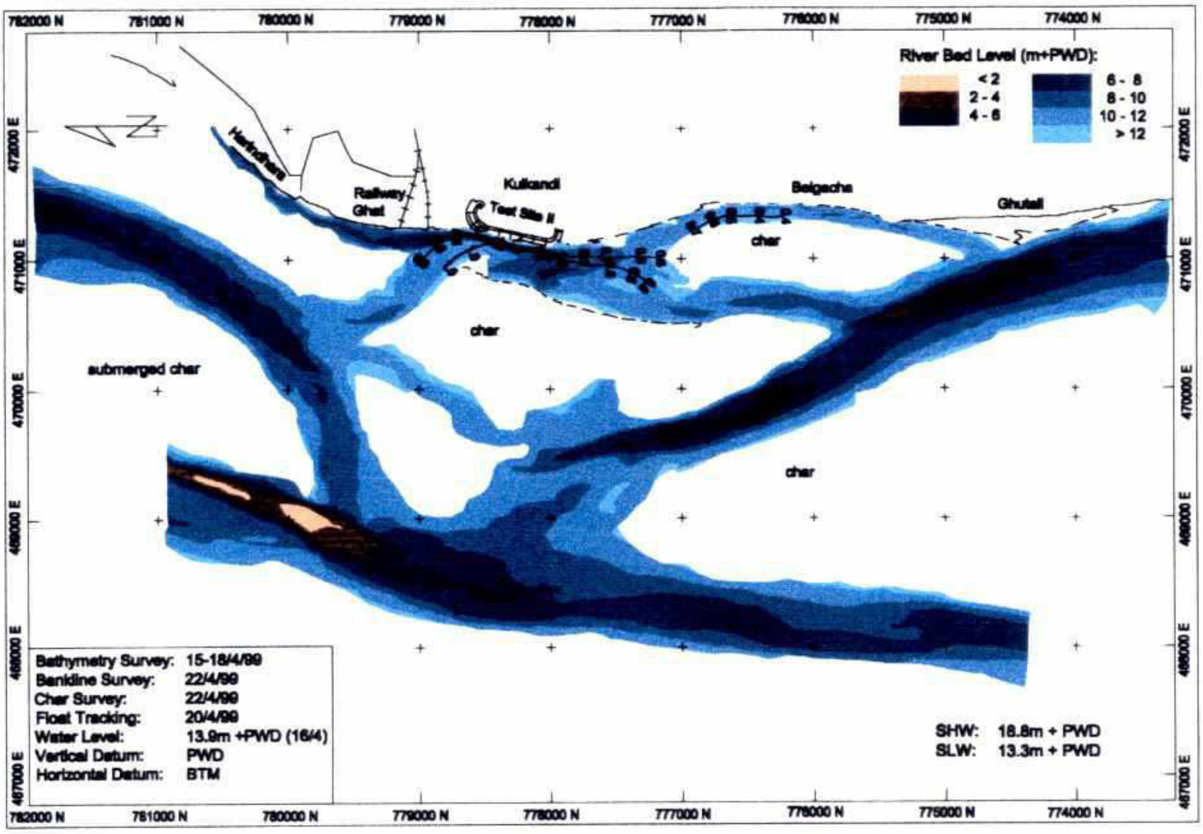


Fig. 4.56: Bahadurabad April 1999

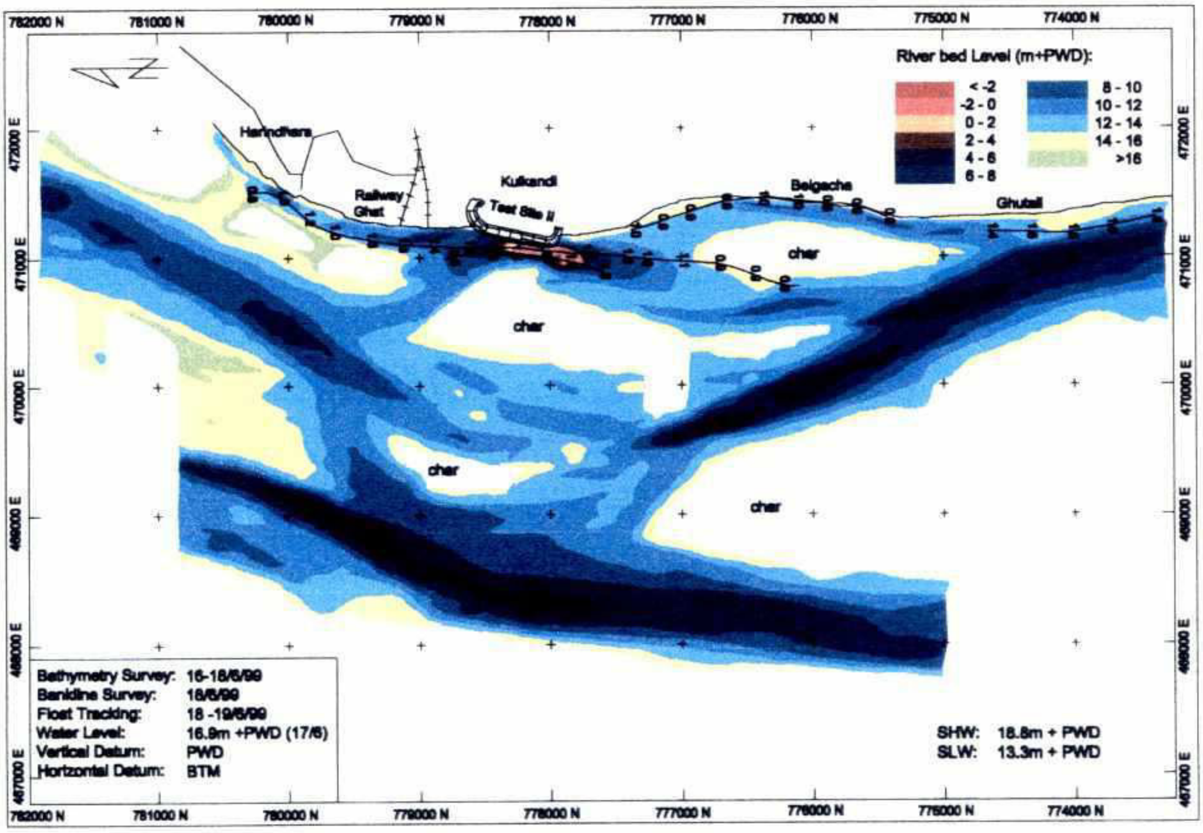


Fig. 4.57: Bahadurabad June 1999

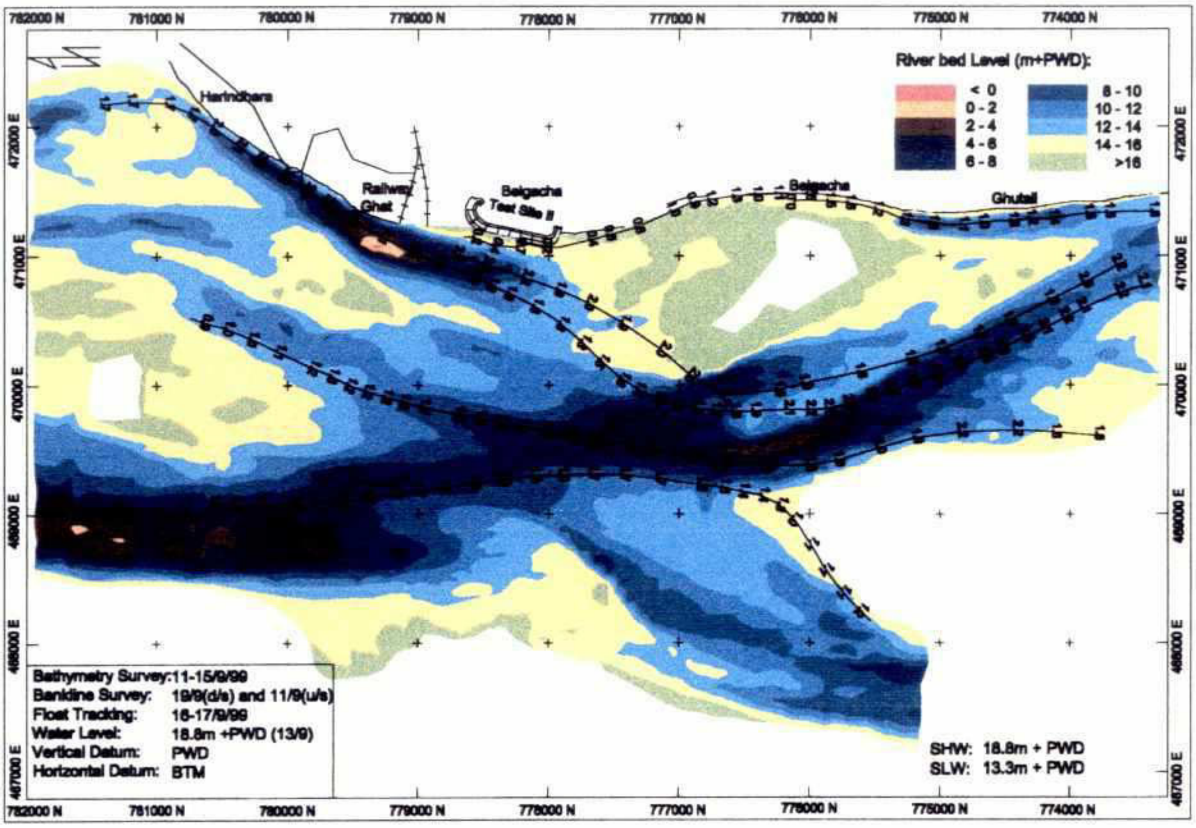


Fig. 4.58: Bahadurabad September 1999

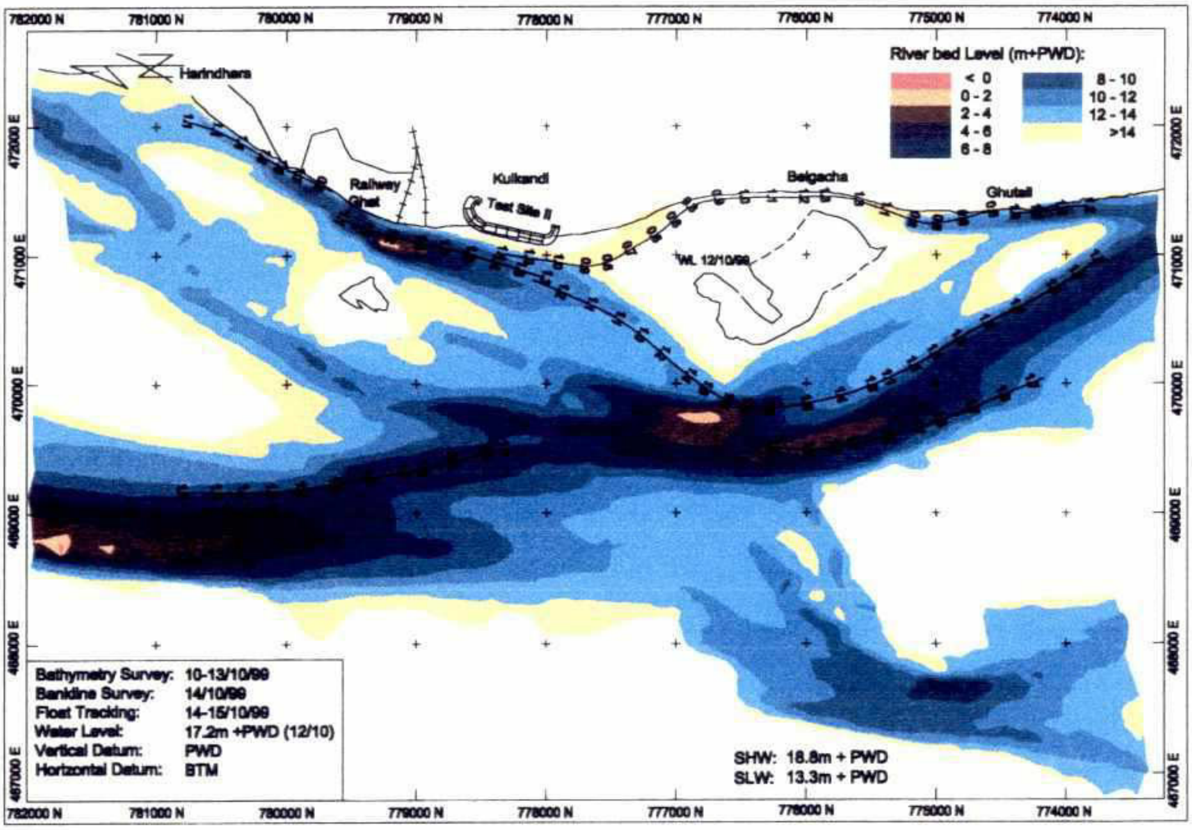


Fig. 4.59: Bahadurabad October 1999

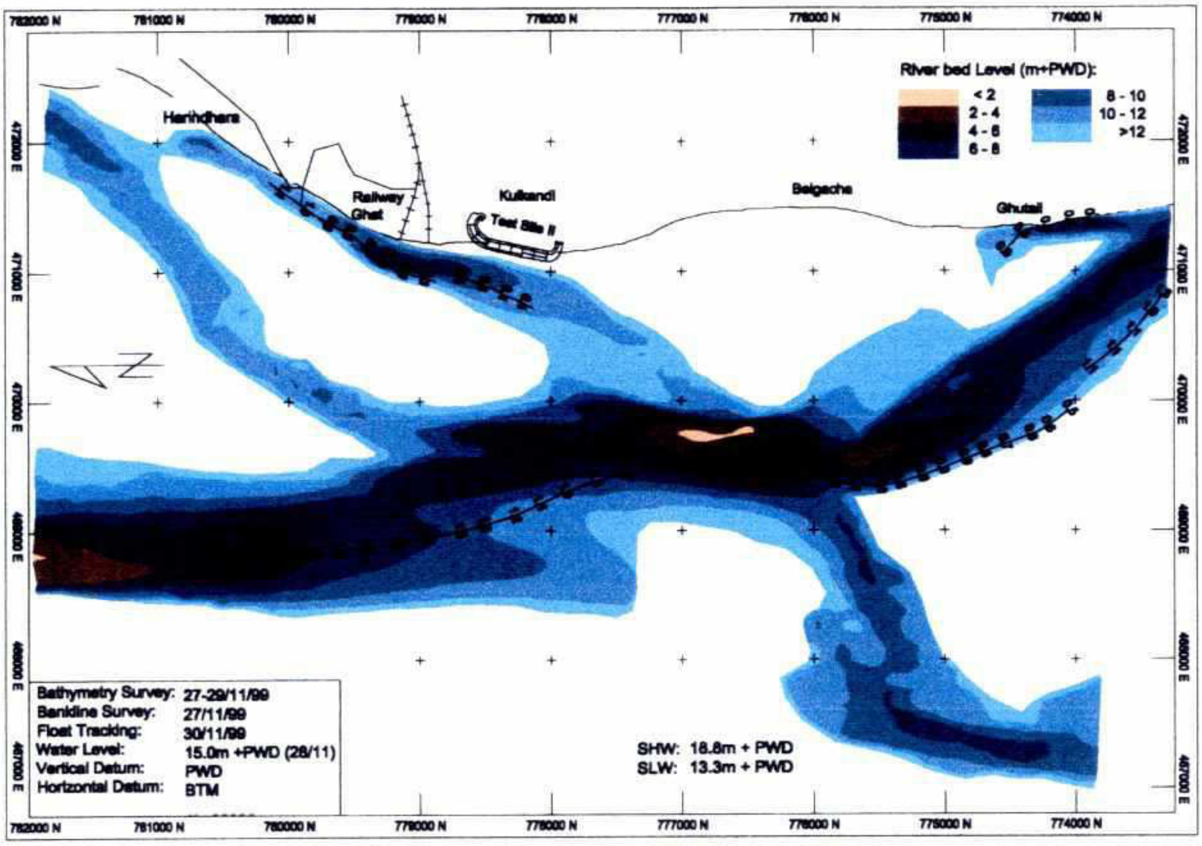


Fig. 4.60: Bahadurabad November 1999

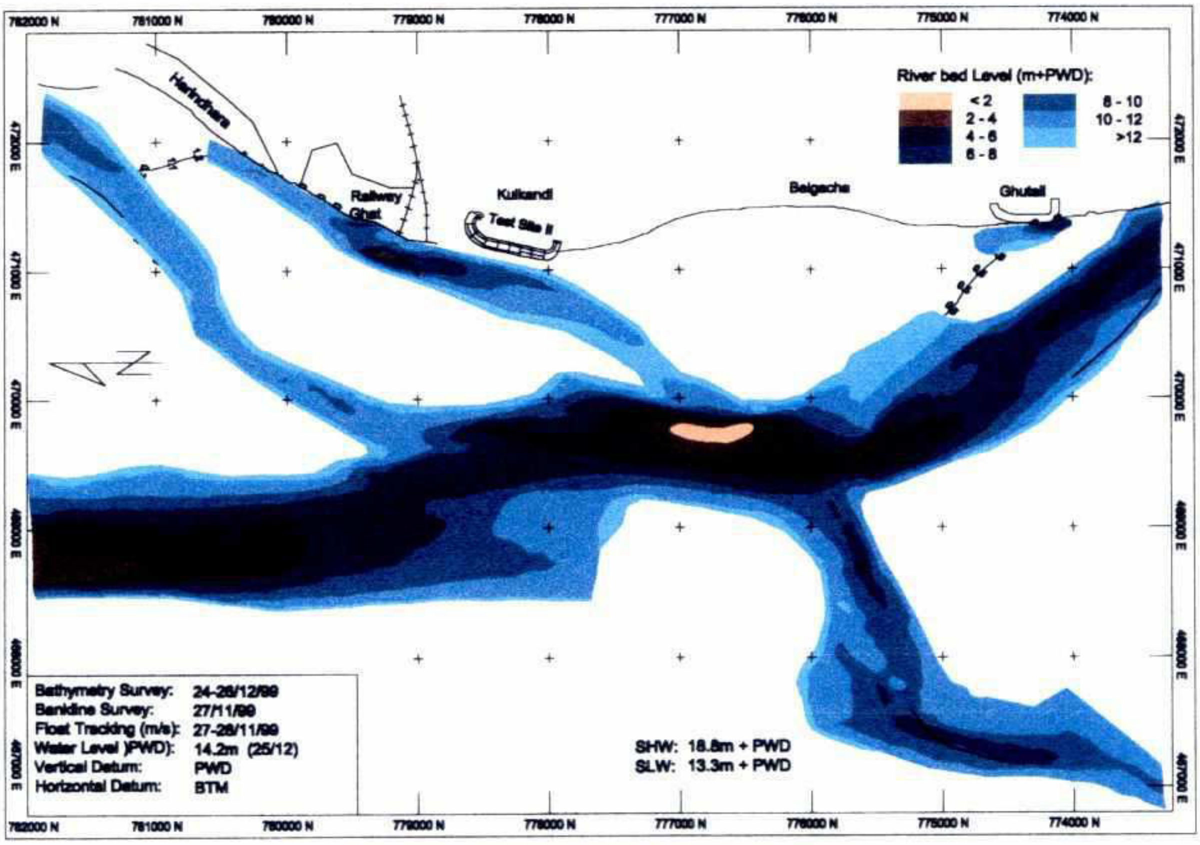


Fig. 4.61: Bahadurabad December 1999

5 PREDICTION METHODS

5.1 OVERVIEW OF METHODS

Morphological processes operate on different scales of time and space, each scale requiring a distinct approach to making predictions. A feasible treatment of larger scales requires descriptions on a higher level of aggregation. This is a general principle in science. When studying gases, for instance, practical descriptions are based on the 'emergent' concepts of volume, pressure and temperature instead of the positions and velocities of every individual molecule. Similarly, details of flow structure, sediment transport and bedforms, which are of primary importance for morphological processes on time scales of days or weeks, loose their significance in processes on time scales of years.

There is also another reason why accurate details are less relevant for larger time scales. The morphological system of the large rivers in Bangladesh depends sensitively on initial and boundary conditions (Klaassen, Mosselman and Brühl, 1993; Mosselman, 1992, 1995), which implies that the morphological system exhibits deterministic chaos. As a consequence, the predictability is inherently limited, no matter how good the fundamental processes are known and no matter how detailed and accurate the initial conditions are measured (Poincaré, 1908; Lorenz, 1963). It is estimated that a very detailed approach to morphological predictions for the Brahmaputra-Jamuna river makes sense up to prediction spans on the order of one year. For longer time spans, a probabilistic approach and the consideration of a sufficiently long river reach are more significant for the quality of the predictions than the use of a high level of detail. The fast morphological changes of the Brahmaputra-Jamuna river thus restrict the applicability of traditional deterministic approaches to much shorter time spans than for many other rivers in the world.

Prediction time span	Scope of morphological investigations	Character of Processes	Type of Model	Examples
short-term: week to months	detailed work planning, monitoring	Predictable with certain tolerance	Deterministic with accuracy and sensitivity analyses	• flow velocity gradient evaluation (Subsection 5.5.1) • relaxation towards equilibrium (Peters, 1988; Delft Hydraulics, DHI and EGIS, 1996; Sarker, 1996) • physical modelling (Section 5.3) • two-dimensional depth-averaged or three-dimensional mathematical modelling (Section 5.3)
medium-term: 1 to 3 years	area and site selection	Predictable for certain coherent structures, unpredictable elsewhere	Probabilistic	• channel network model (Klaassen et al, 1993; Jagers, 1996, 1997, 2000 (Subsection 5.5.3)
			Statistical	• probability distributions for arbitrary locations (Thorne et al, 1993; EGIS and Delft Hydraulics, 1997) (Subsection 5.5.4)
long-term: 3 – 30 years	area selection, assessment of design parameters	Autonomous development: random with secular trends	Statistical	• extrapolation of trends (Thorne et al, 1993; EGIS and Delft Hydraulics, 1997)
	assessment of response to strategies and scenarios	Response development: predictable with certain tolerance	Deterministic with accuracy and sensitivity analyses	• zero-dimensional and one-dimensional mathematical modelling (Jansen et al, 1979; Delft Hydraulics and DHI, 1996e)

Table 5.1-1: Methods for morphological predictions

Table 5.1-1 presents an overview of selected methods for morphological predictions in relation to the corresponding time scale or prediction time span. The relevant time scale depends on the scope of the morphological investigations. Under FAP 21, the scope has been limited to identification of priority plans (area selection), site selection, assessment of design parameters and monitoring for bank protection and river training works. The relation between scope and appropriate time scale has been indicated in Table 5.1-1 as well.

Some of the methods of Table 5.1-1 are presented in more detail in Sections 5.3 to 5.5. Physical and mathematical modelling require specialised expertise and are not treated in depth. Only some general remarks are made in Section 5.3. The development of a model for predictions one to three years ahead has been an important activity under FAP 21. This is presented in Section 5.4. Guidelines for a few selected prediction methods are given in Section 5.5.

5.2 CERTAINTY OF ATTACK AND PROBABILITY OF ATTACK

There is sometimes confusion about the terms probability of attack and certainty of attack. 'Probability' is a formal term with a well-defined meaning, whereas 'certainty' is a much looser term with a meaning, which has gradually evolved within FAP 21/22. The two terms are not mutually interchangeable, because, for instance, a *moderate probability* of attack is equivalent to a *low certainty* of attack. The relation between the two terms is shown in Table 5.2-1.

Probability of attack		**Certainty of attack**	**Certainty of no attack**
numerical value [%]	**Valuation in words**		
0 – 20	Low	low	high
20 - 40	Poor	low	moderate
40 - 60	Moderate	low	low
60 - 80	Fair	moderate	low
80 – 100	High	high	low

Table 5.2-1: Relation between probability and certainty of attack

The certainty-of-attack criterion is best satisfied in certain distinct settings where it is known that bank erosion usually persists for a number of years. These settings are discussed below:

(1) Major Channel Bends (Concave Banklines):
Major channel bends have a relatively predictable behaviour, similar to the behaviour of single-thread meandering rivers. They remain in existence for several years, though the period of the most aggressive erosion is usually restricted to a few years only. The Kamarjani Channel was an example of a major channel bend.

(2) Reaches of Unidirectional River Migration:
The mechanisms underlying unidirectional river migration are not well understood, but the reach between Shariakandi and Sirajganj exhibits a consistent trend of migration to the west on various time scales: over the last two centuries, over the last 20 years as well as over the last 5 years. Continuation of this trend is likely on empirical grounds.

(3) Exposed Promontories (Convex Banklines):
Promontories of mainland extending into the braid belt are likely to be eroded within a number of years. Whether this erosion starts soon or, when erosion already started, whether this erosion will continue uninterruptedly for three or four years, depends on the channel pattern upstream. In practice it means that the certainty of attack in a period of three or four years is only high when the promontory is located downstream from a major channel bend or along the eroding bank of a reach with unidirectional river migration. Bahadurabad Ghat is an example of an exposed promontory.

In general one can say that the certainty of attack within 3 years is higher for concave bank lines than for convex bank lines, whereas the certainty of attack within 10 years is higher for convex bank lines than for concave bank lines.

These considerations on concave and convex bank lines hold for the high banks of mainland, excised islands and old mature chars. The shape of the margins of low-lying chars does not have such a clear effect on the morphological evolution of the river and the certainty of attack.

5.3 PHYSICAL AND MATHEMATICAL MODELLING

Physical and mathematical modelling require specialised expertise. In Bangladesh, this expertise is covered by RRI (River Research Institute) and SWMC (Surface Water Modelling Centre), with support from international research institutes. Details on physical and mathematical modelling can be found elsewhere. Here only some general remarks are made.

Under FAP 21, physical modelling was only used for the details of flow and bed scour in the immediate vicinity of test structures. No mobile-bed physical model was made for the large-scale morphological development of the river. The design of a physical model and the proper assessment of scale effects in the model should be based on the mathematical equations which describe the physical processes of flow, sediment transport and bed evolution. De Vries (1993) presents Abdalla's (1990) intercomparison study of different scaling methods for mobile-bed river models. The Einstein-Chien method and the Delft method are found to give the best agreement between model and prototype. The Chatou method comes third in performance. The Wallingford method gives the largest differences between model and prototype, most probably because it utilises the controversial pre-Newtonian concept of extremal hypotheses. An interesting aspect of the long standing tradition of physical modelling on the Indian Subcontinent is the assessment of scale effects by constructing models for the same river reach on different scales (Varma et al, 1989).

Klaassen (1990) presents a large-scale mobile-bed physical model for the Brahmaputra-Jamuna river at the Jamuna Bridge. Typical problems of mobile-bed physical modelling include the difficulties in reproducing bank erosion mechanisms on scale (Friedkin, 1945), the sensitivity to floodplain roughness and topography (Peters, 1990) and the suppression of secondary braids and channels by model distortion.

No two-dimensional mathematical models for river morphology had been used in the Study Phase of FAP 21. Meanwhile, however, the developments in software, computer power and synoptic data collection have been so fast that the two-dimensional mathematical modelling of river morphology has become an ordinary tool in river engineering. The first model of this kind was developed for the Rhine river in the Netherlands by van Bendegom (1947), but its application without the modern computer devices of the present was very laborious. Subsequent work on helical flow in river bends (e.g. Kalkwijk & de Vriend, 1980) and forces on sediment grains on a transversely sloping bed (e.g. Engelund, 1974; Odgaard, 1981) resulted in the model of Struiksma (1985), Struiksma et al (1985) and Olesen (1987), from which the river morphology modules of the software systems Delft3D and MIKE21 have been derived. Similar models were developed by Shimizu and Itakura (1985, 1989) and Nelson and Smith (1989). The earlier flow and bed topography model by Kennedy et al (1983) does not fall into this class of models since it does not use the sediment balance. Enggrob and Tjerry (1999) apply a two-dimensional mathematical model for river morphology to the Brahmaputra-Jamuna river at the Jamuna Bridge. Fig. 5.3-1 shows a simulation of the flow around groynes based on LES (Large Eddy Simulation) with Delft3D.

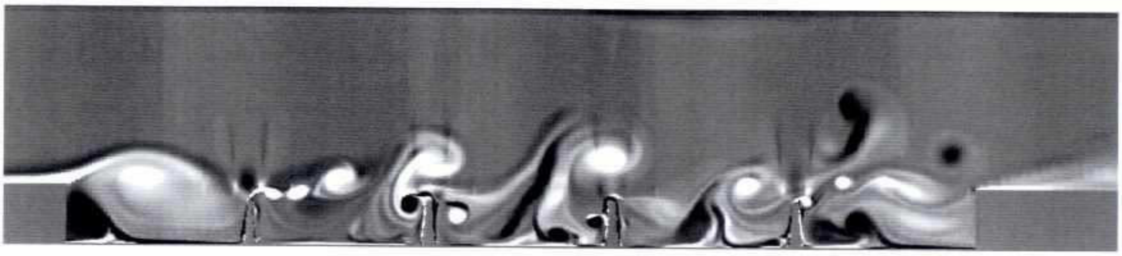


Fig. 5.3-1: Simulation of flow around groynes using Delft3D

The success of physical and mathematical modelling depends heavily on the availability of good boundary conditions from either measurements or a mixture of medium-term modelling and expert judgement.

5.4 DEVELOPMENT OF A MODEL FOR PREDICTIONS ONE TO THREE YEARS AHEAD

Klaassen, Mosselman and Brühl (1993) outlined the ideas for a model to predict the morphological development of the Brahmaputra-Jamuna river one to three years ahead. A functional design was elaborated jointly by FAP 21/22 and FAP 19 (now EGIS). This has been the starting point for an investigation by Jagers (1996, 1997, 2000), who developed the functional design into a working computer model and compared that model with two other models for the medium-term morphological development of the Brahmaputra-Jamuna river. The model based on the work of Klaassen et al is called *"branches model"*. The other two models are a *cellular model* after Murray and Paola (1994, 1997) and an *artificial neural network*.

The *branches model* is based on a representation of the braided river as a network of channels. These channels exhibit mid-channel bar formation, bend migration, abandonment and width adjustment (Klaassen and Masselink, 1992; Klaassen et al, 1993; Mosselman et al, 1995). The channel network is derived from a satellite image of the river in the dry season. The channel processes all include some randomness. The probabilities of erosion are therefore derived from the outcomes of many simulations, each representing a different possible realisation of river planform development. Mid-channel bars are formed when the width-to-depth ratio becomes large. The rates and directions of channel migration result from a combination of meander migration and downvalley shift due to overbank flow. The migration of bifurcations and confluences results from the migrations of their upstream and downstream channels. Channels may become abandoned when their upstream bifurcation angle is large. Changes in channel width are taken to be a completely random process with a mean equal to zero and a standard deviation derived from observations. A result of the model is given in Fig. 5.4-1. Some of the changes, which occurred in reality, are predicted reasonably well, but the prediction fails in many locations. The most important limitation seems to be that the channel network represents mainly aspects of the low-stage planform. Further improvements could hence be expected primarily from the inclusion of processes occurring during the flood season.

The *cellular model* (Murray and Paola, 1994, 1997) consists of a rectangular grid with some prescribed initial topography, such as a tilted surface with a uniform slope and some small local elevation perturbations. In this sense it resembles a two-dimensional mathematical for river morphology, but the underlying process equations are much simpler and solved in a different manner. Each computational step consists of releasing a certain amount of water at the upstream boundary. This water volume travels across the grid, each time dividing itself over neighbouring grid cells according to certain model rules. The resulting morphological changes are computed while following the paths of the water across the grid. These morphological changes are used to update the topography. Two types of sediment transport from one cell to another are included: sediment transported by the flow and sediment supplied by lateral erosion. The model reproduces several features of braided rivers, but it is found to be unsuited for predictions on real rivers.

An *artificial neural network* has been trained on the basis of a time series of Landsat satellite images. For each pixel, the neural network derives the probability that it will represent water on next year's satellite image from the following inputs:

- The distance of the pixel to the nearest channel;
- The angle between the direction to the nearest channel and the overall river direction (approximated by the North-South direction);
- The local width of the nearest channel;
- The water-covered fraction of the 11×11 pixels neighbourhood around the pixel considered.

Although the information comprised by these parameters is rather limited, the neural network appeared to be able to yield realistic predictions for locations of future bank erosion, as shown in Fig. 5.4-1. However, the results deviate significantly from the planform changes, which occurred in reality. The results suggest that a better neural network, with more input, could be more successful for the medium-term prediction of planform changes in braided rivers. Yet at least two important limitations arise in relation to the availability of data. First, much more data are needed for proper training of a model with more input. Second, the satellite images of the Jamuna river contain at any rate very few data on the effect of river training works. This implies that the capacity to predict responses to river training would remain very limited.

The general conclusion is that, despite some nice results, the overall performance of the medium-term models is poor. The development into good predictive tools would still require a lot of work. For that reason Jagers (2000) has abandoned this line of research, focusing more on short-term predictions using two-dimensional mathematical modelling, with special attention to the process of natural bend cut-offs. Nonetheless, the branches model is found to be the most promising, compared with the two other models. The basic concepts of the branches model are used in a manual evaluation procedure without computer, called *"channel network analysis"*. This has become the standard method for medium-term predictions under FAP 21/22. Subsection 5.5.3 gives more details.

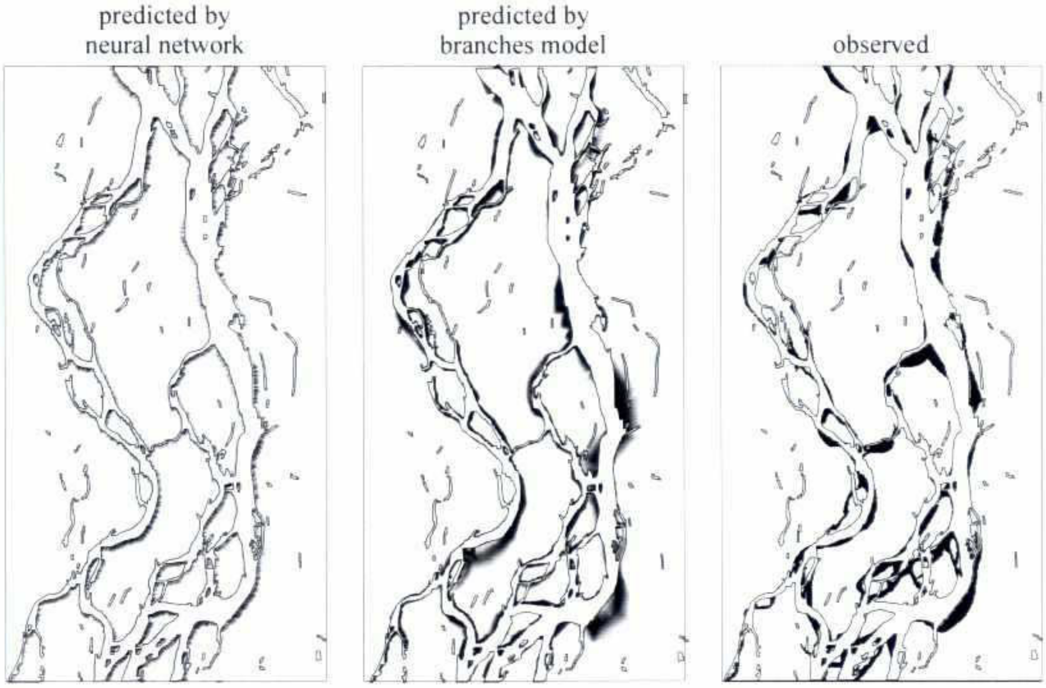


Fig. 5.4-1: Comparison of medium-term model results with observed river planform changes

5.5 GUIDELINES FOR SELECTED METHODS TO PREDICT MORPHOLOGICAL CHANGES OF THE BRAHMAPUTRA-JAMUNA RIVER

5.5.1 Flow Velocity Gradients on Float Track Maps

Exner's (1925) Principle, explained in Section 2.1, implies that erosion and sedimentation are related to gradients in flow velocity. Theoretically, the flow velocity gradients can be derived from float track maps and bathymetry maps, provided that each float track is sufficiently close to neighbouring tracks. If the discharges between two float tracks are uniform, without lateral exchanges, the flow velocities are inversely proportional to the cross-sectional area between the float tracks. Thus flow velocity gradients could be derived from gradients in the cross-sectional area. In reality, however, discharges between float tracks are not uniform, due to three-dimensional flow effects. The application of this method has not been satisfactory.

Better results are obtained when the flow velocities themselves are measured. This results in a method based on float track maps in combination with flow velocity measurements. The data for this method are provided by the routine float tracking of the Hochschule Bremen, Labor für Wasserbau, using their specially-developed drifter buoys mounted with drogue, GPS receiver, data logger and power supply.

Under FAP 21, the flow velocity gradient method for short-term prediction of erosion and sedimentation has been applied only qualitatively. It is recommended, however, to calibrate the method quantitatively on the basis of the measurements in the field. The prediction span amounts to a few weeks during the flood season.

5.5.2 Recognition of Sedimentary Features

Certain specific sedimentary features provide clues on ongoing morphological processes. Underwater features may also be visible on satellite images in the dry season, when ongoing developments are temporarily frozen and the corresponding sedimentary structures are exposed. The recognition of features is done best with a neural network, noting that the natural neural network of a human brain is far more powerful for this than any artificial neural network in a computer. Examples are given in Fig. 5.5-1 to 5.5-6.

Major channel bends have a relatively predictable behaviour. In the Jamuna they remain in existence for several years. Aggressively eroding bends can produce deep embayments into the mainland. As the maximum erosion rates occur in their downstream part, bends tend to migrate downstream. Only when their sinuosity is high, they extend laterally rather than migrating downstream.

Fig. 5.5-1: Major channel bend (Kamarjani, January 1995)

Promontories protruding into the braid belt are usually most likely to be attacked within 10 years. They may be formed by chance when upstream and downstream banks undergo more flow attack, or they may be formed because they are more resistant against erosion.

Fig. 5.5-2: Exposed promontory (Bahadurabad, January 1995)

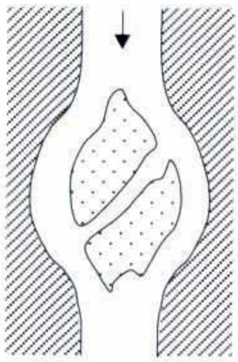


Fig. 5.5-3: Wider section with bars

A channel starts to braid if a threshold value of its width-to-depth ratio is exceeded. Thus mid-channel bars develop spontaneously in overwide channel reaches. Their growth pushes the channels on either side away, inducing bank erosion and hence further widening of the overwide reach. This positive feedback implies that widening and mid-channel bar formation are a common phenomenon, occurring frequently and fast.

A high braiding intensity can be an indication that the river reach undergoes overall sedimentation (Germanoski and Schumm, 1993).

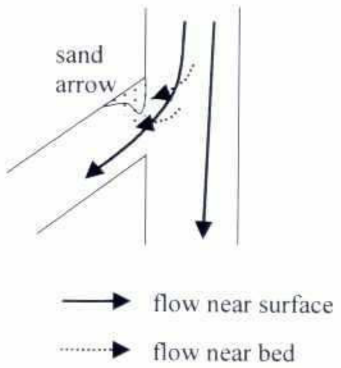
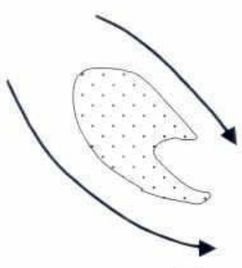


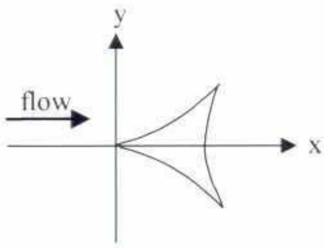
Fig. 5.5-4: Spit or sand arrow

Spits or sand arrows can be formed in areas of diverging flow or at the entrance of offtaking channels. The deviation of a part of the flow into an offtaking channel produces curved flow lines, which cause a helical water motion. This helical motion deflects the water near the surface towards the outer part of the curve and deflects the water near the bed towards the inner part. As near-bed load is dominant, a disproportionate part of the sediment transport is directed into the offtaking channel (Bulle effect). The resulting sedimentation forms a spit or sand arrow, and hence increases the angle between the offtake direction and the main channel. This enhances the flow curvature and the Bulle effect. The close relation between offtake angle and offtake entrance sedimentation corresponds to the dependence of channel abandonment on bifurcation angle in Subsection 5.5.3.



(a)

Mid-channel bars often exhibit two downstream wings. They may be asymmetrical if the channel on one side carries more water and sediment then the channel on the other side. The longest wing corresponds to the most active channel. The shape of the bars thus provides information on the distribution of water and sediment around them.



(b)

Fig. 5.5-5: Winged bars: (a) asymmetry, (b) theoretical star shape

The shape of winged bars corresponds to the barchane shape of desert dunes (Bagnold, 1978). Its development can be understood from the basic mathematical equations of flow, sediment transport and bed evolution. This is demonstrated by de Vriend's (1987) theoretical derivation of a star shape for incipient bars.

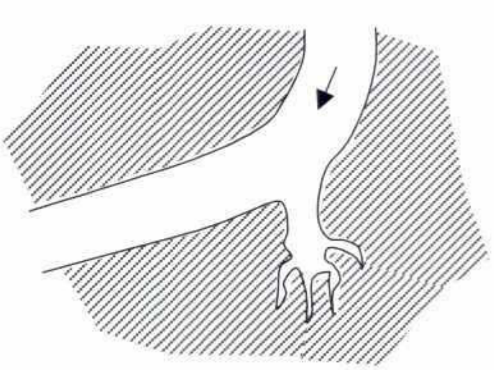


Fig. 5.5-6 Finger channels

The formation of new channels during floods may proceed from an upstream offtake in downstream direction. An actively growing new channel can often be recognised from its front where the channel breaks up into smaller, finger-shaped channels.

5.5.3 Channel Network Analysis

The channel network analysis is based on the concept of Klaassen et al (1993) for predictions one to three years ahead. It follows a probabilistic approach in which different possible developments are evaluated. It is carried out by elaborating a tree of events and associated probabilities of occurrence, similar to fault trees in risk analysis. This is illustrated in Fig. 5.5-7.

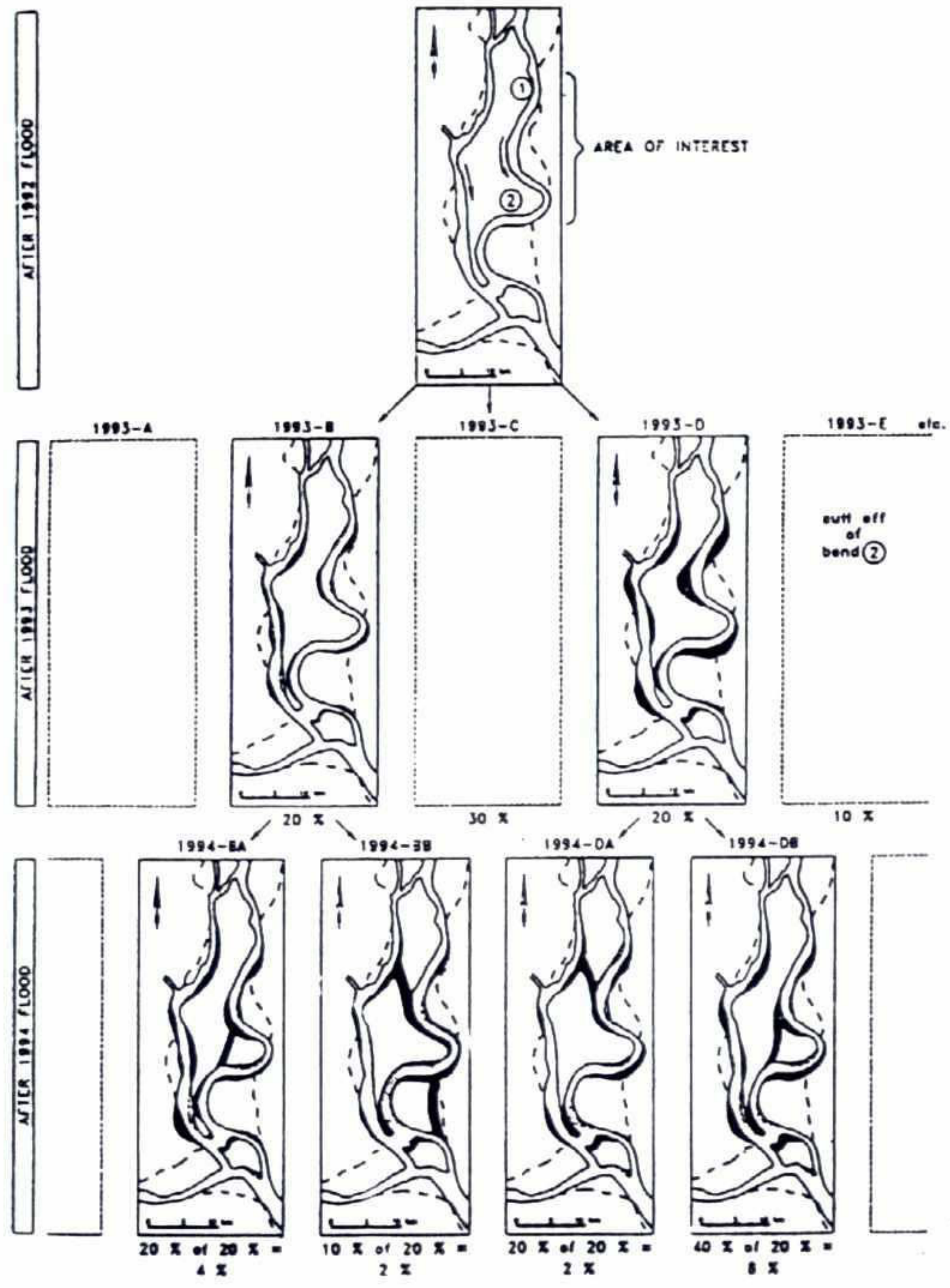


Fig. 5.5-7: Principle of elaborating a tree of events in probabilistic channel network analysis

The analysis is carried out for a particular site of interest along the Brahmaputra-Jamuna river. It consists of the following steps:

Step 1: Schematise Network

The channels in an approximately 20 km long reach of the Brahmaputra-Jamuna river upstream of the site of interest are schematised into a network. Satellite images recorded in the low-flow season provide the most convenient basis for this schematisation. Due to the large number of channels, the analysis is only feasible in a simplified form. Therefore only the main structure of channels influencing the site of interest is considered. Minor channels are ignored.

Step 2: Draw Thalwegs

Thalwegs are defined as the lines, which connect the deepest parts of consecutive cross-sections. They are drawn on a map or a satellite image for the schematised channel network. Without additional bathymetry information, this is rather subjective. An experienced morphologist can estimate the proper positions of the thalwegs from the river planform and the spectral intensities of the water pixels on the satellite image. In the absence of such indications, it is recommended to use channel centre-lines instead of thalwegs.

Step 3: Determine Bifurcation Angles

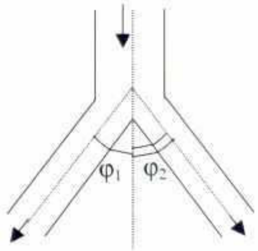


Fig. 5.5-8: Definition of bifurcation angles

The bifurcation angle, φ, of a channel is defined as the angle between the thalweg of the channel at the entrance and the virtual downstream extension of the thalweg of the upstream approach channel (Fig. 5.5-8).

All bifurcation angles of the schematised channel network are measured.

Step 4: Calculate probabilities of channel abandonment for each channel

A channel is usually abandoned by closure of its entrance due to sedimentation. The probability of channel abandonment, P {A}, is a function of the bifurcation angle, φ, according to the relations given in Table 5.5-1. These relations result from a 1997 update of earlier relations by using a larger dataset.

	Channel length ≤ 20 km	**Channel length > 20 km (major anabranch)**
$\varphi \leq 20°$	$P\{A\} = 0$	$P\{A\} = 0$
$20° < \varphi \leq 153°$	$P\{A\} = (\varphi - 20°) \cdot 1.1\ \%$	$P\{A\} = 0$
$\varphi \geq 153°$	$P\{A\} = 100\ \%$	non existent

Table 5.5-1: Calculation of channel abandonment probability from bifurcation angle

Step 5: Calculate the probability that the channel along the site of interest is abandoned

The probability that the channel along a site of interest is abandoned is calculated by evaluating all combinations of relevant channel abandonments in the schematised network, together with the corresponding probabilities. This is the actual elaboration of the tree of events indicated in Fig. 5.5-7. The influence of abandonment of channels upstream is assessed by using calculation rules for the combined effect of parallel channels and serial channels.

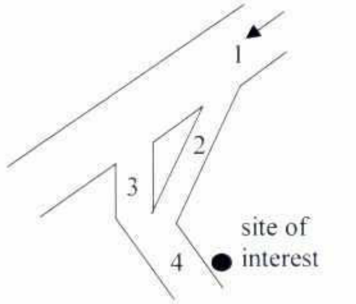


Fig.5.5-9: Parallel channels towards site of interest

The probability that the channel along the site of interest is abandoned is equal to the probability that the entrances of both channel 2 and channel 3 are closed. This is given by the relation

$$P\{A_{site}\} = P\{A_2\} \cdot P\{A_3\} \qquad (5.5\text{-}1)$$

in which $P\{A_{site}\}$ is the probability that the channel along the site of interest is abandoned, and $P\{A_i\}$ is the probability that the channel with number i is abandoned.

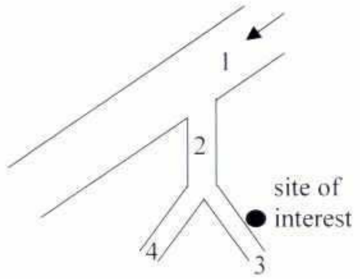


Fig.5.5-10: Serial channels towards site of interest

The probability that the channel along the site of interest is abandoned is equal to the sum of the probability that the entrance of channel 2 is closed and the probability that the entrance of channel 3 is closed, minus the probability that both entrances are closed (to correct the double-counting of this situation). This is expressed by the relation

$$P\{A_{site}\} = P\{A_2\} + P\{A_3\} - P\{A_2\} \cdot P\{A_3\} \qquad (5.5\text{-}2)$$

Step 6: Determine local channel width and radius of bend curvature

The following parameters of the channel along the site of interest are measured:

B = channel width (m)
R = smallest curvature radius of bend along site of interest (m)

Step 7: Calculate Hickin-and-Nanson reduction factor for outer bank erosion

The Hickin-and-Nanson reduction factor for outer bank erosion is calculated from the following relations:

$$f\left(\frac{B}{R}\right) = 2.5\frac{B}{R} \qquad for\ \frac{B}{R} \leq 0.4 \qquad (5.5\text{-}3)$$

$$f\left(\frac{B}{R}\right) = \frac{2 - 2\frac{B}{R}}{3\frac{B}{R}} \qquad for\ \frac{B}{R} > 0.4 \qquad (5.5\text{-}4)$$

Note that f(B/R) = 1 (i.e. no reduction), if the smallest curvature radius is equal to 2.5 times the channel width. This corresponds to the design curvature radius in Subsection 2.3.4.

Step 8: Calculate probabilities of exceedance of largest bank erosion rates under the condition that the channel is not abandoned

The largest bank erosion rates occur somewhat downstream from the apex of the bend. The probability distribution of these bank erosion rates is calculated from the relations in Table 5.5-2. The bank erosion rates of a certain probability level can be taken to decrease linearly in upstream direction to zero at the start of the bend. In downstream direction, the bank erosion rates remain equal to the largest rates over some distance.

probability of exceedance (%)	bank erosion rate in direction perpendicular to former channel (m/year)
90	$0.3 \cdot B \cdot f(B/R)$
75	$0.5 \cdot B \cdot f(B/R)$
50	$0.7 \cdot B \cdot f(B/R)$
25	$0.9 \cdot B \cdot f(B/R)$
10	$1.1 \cdot B \cdot f(B/R)$

Table 5.5-2: Probability of exceedance of bank erosion rates

Step 9: Correct the probabilities of exceedance by including the probability of local channel abandonment

Based on the previous step, lines of 90 %, 75 %, 50 %, 25 % and 10 % probability of exceedance of bank retreat can be mapped. These probability levels would hold if the probability of local channel abandonment would be zero. The proper values are obtained by multiplying all probabilities of exceedance with a factor (100 % - $P\{A_{site}\}$).

5.5.4 Probability Distributions of Bankline Migration

Predictions of bank erosion one to three years ahead can also be based on the general erosion probability of an arbitrary bank without the consideration of site-specific hydraulic and morphological conditions.

EGIS and Delft Hydraulics (1997) use satellite imagery of the period 1973-96 to make frequency distributions of bankline migration rates along the Brahmaputra-Jamuna river. The frequency distributions of past migration rates can be used as probability distributions for future migration rates. They are shown in Fig. 5.5-11 and 5.5-12. Simple guidelines derived from these Figures are given in Table 5.5-3.

Probability of exceedance (%)	Bank migration rate (m/year)		Probability of erosion or accretion (%)
	Right bank	Left bank	
90	-75	-175	accretion
70	0	0	30 %
50	50	50	
30	100	150	erosion
10	275	400	70 %
5	425	575	

Table 5.5-3: General probability distribution of bank erosion rates along the Brahmaputra-Jamuna river

Example: a house on the mainland is standing about 300 m from the left bank of the Brahmaputra-Jamuna river. The probability that it will be eroded within one year lies between 10 % and 30 %.

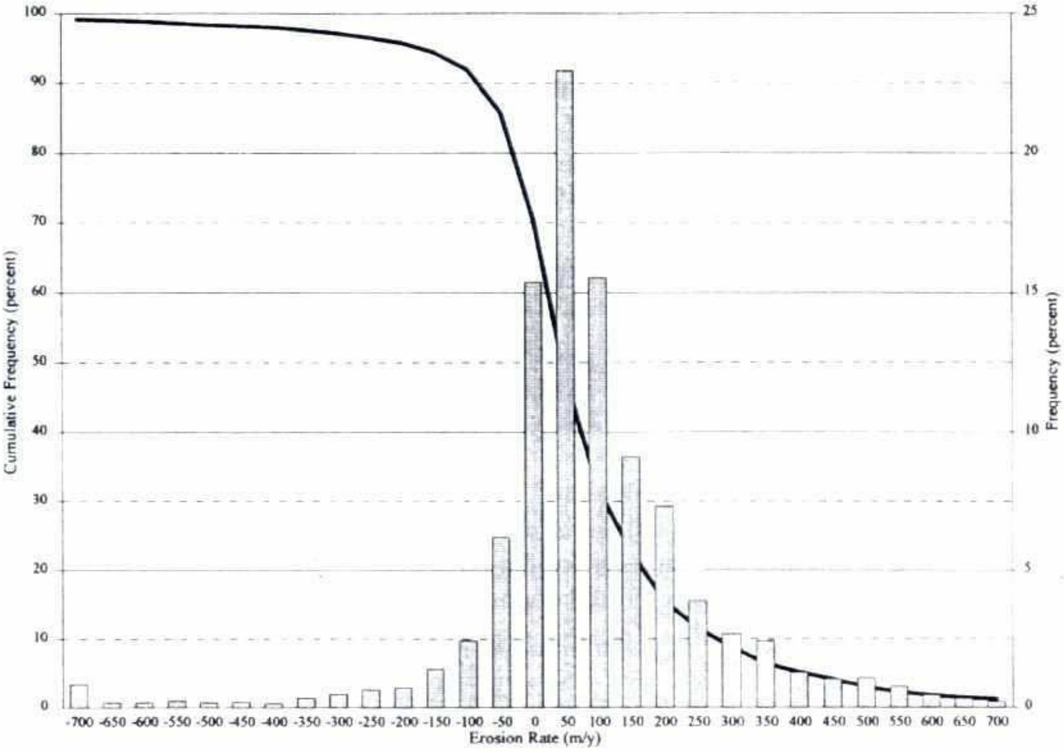


Fig. 5.5-11: Distribution of right bank erosion

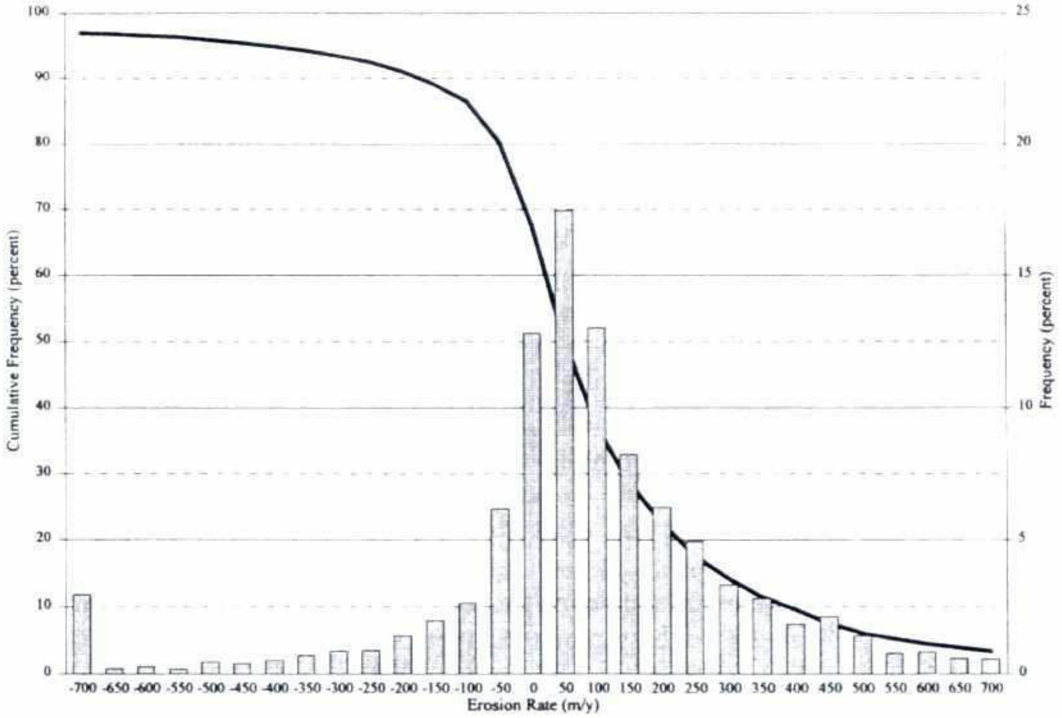


Fig. 5.5-12: Distribution of left bank erosion

6 EFFECT OF STRUCTURES ON RIVER MORPHOLOGY

6.1 INTRODUCTION

Bank protection and river training structures affect river morphology in several ways. Most quantitative methods for the prediction of structure-induced scour hold for relatively stable rivers where the bank lines are fixed and hence the geometry does not change. In unstable rivers where bed levels and bank lines change rapidly, however, bank protection structures may cause extra scour. Moreover, they also affect the morphology of a river on larger scales. Table 6.1-1 gives an overview, with references to a more detailed treatment in the subsequent sections. The emphasis is put on the morphology of larger areas, because local scour is treated in depth in Annexes 7 and 11. It is worth noting, however, that the local scour depends on the boundary conditions imposed by the morphology of larger areas. The local effect on bank erosion is trivial, because that effect is simply the stopping of bank migration at the structures.

Category of effect	Phenomena	Treatment in Chapter 6
Local effect on bank erosion	Stopping of bank erosion due to bank protection	None (trivial)
Local effect on river morphology and scour	Bank toe scour due to increased turbulence	None (concerns local scour, treated elsewhere)
	Deeper bend scour due to stopping of input of bank erosion products	Subsection 6.2.1
	Narrowing and deepening due to stopping of channel migration	Subsection 6.2.2
	Bend tightening due to hindered migration and flow attraction	Subsection 6.2.3
	Formation of channel confluences due to flow attraction	Subsection 6.2.4
Effect on nearby areas downstream from structure	Initial deceleration of bank erosion, possibly followed by accelerated bank erosion	Section 6.3
Effect on river morphology far away	Changes in morphological development, but no effect on statistical properties of morphological parameters such as the probabilities of bank erosion	Section 6.4

Table 6.1-1: Effects of structures on river morphology

6.2 LOCAL EFFECT ON RIVER MORPHOLOGY AND SCOUR

6.2.1 Deeper Bend Scour due to Stopping of Bank Material Supply

The scour near an eroding outer bank is reduced by the continuous supply of eroded bank material. Bank stabilisation puts an end to this supply and hence produces deeper bend scour. However, this effect of bank stabilisation on channel cross-sections is of minor importance compared to the narrowing and deepening of the channel which is also a result of bank stabilisation. The latter effect is treated in Subsection 6.2.2.

The minor importance of the input of bank erosion products was not recognised in the River Survey Project, because Shishikura (1996) concluded that bank erosion products do have a substantial effect on the cross-sections of channels in the Jamuna River. Closer examination of Shishikura's work shows, however, that this conclusion does not follow from his mathematical model (see Subsection

2.3.4). Therefore, Shishikura has later withdrawn this conclusion (Mosselman, Shishikura and Klaassen, 2000).

A quantitative substantiation of the minor importance of bank erosion products is given as follows. Bank erosion is assumed to be controlled by excess flow shear stresses over a critical value. The critical flow conditions for bank erosion are assumed to be equal to the reach-averaged flow conditions in the situation without bank protection. Channel curvature is assumed to remain unchanged during bank migration. All bank erosion products are assumed to have the same properties as the sediment of the bed (washload factor equal to zero). Then the following scour depth correction factor α arises from Mosselman's (1992) equations (2.73), (3.38), (3.120), (3.121), (3.122) and (3.138):

$$\alpha = \frac{y_1}{y_0} = 1 + \frac{1}{\pi^2} \cdot \frac{B_0}{h_0} \cdot \frac{\Delta H}{s_0} \cdot \frac{\partial n_B}{\partial t} \cdot \frac{u_0^2}{u_{bank}^2 - u_0^2} f(\theta_0) \qquad (6.2\text{-}1)$$

in which

B_0	=	reach-averaged channel width	(m)
h_0	=	reach-averaged water depth	(m)
$f(\theta_0)$	=	function for influence of gravity component along transverse bed slopes on direction of bed shear stress	(-)
s_0	=	reach-averaged sediment transport per unit width	(m^2/s)
u_{bank}	=	near-bank flow velocity	(m/s)
u_0	=	reach-averaged flow velocity	(m/s)
y_0	=	extra deepening due to scour in previous situation without bank protection	(m)
y_1	=	extra deepening due to scour after bank stabilisation	(m)
α	=	scour depth correction factor	(-)
ΔH	=	elevation difference between outer bank and inner bank	(m)
θ_0	=	reach-averaged Shields parameter	(-)
π	=	3.14159..	
$\partial n_B/\partial t$	=	bank migration rate	(m/s)

It is assumed that u_{bank} is about 40 % higher than u_0. Using a water surface gradient of 0.07 m/km, a Chézy coefficient of 70 $m^{1/2}$/s, a water depth of 12 m, a relative submerged sediment density of 1.65 and a median sediment grain size of 0.2 mm, one finds u_0 = 2.0 m/s (Chézy's equation), u_{bank} = 2.8 m/s (assumed 40% higher than u_0), θ_0 = 2.54 (Equation 2.3-8), $f(\theta_0)$ = 0.53 (Equation 2.3-10) and s_0 = $9.1 \cdot 10^{-4}$ m^2/s (Equation 1.5-1). Substitution of these numerical values into Equation 6.2-1 yields

$$\alpha = \frac{y_1}{y_0} = 1 + 5 B_0 \cdot \Delta H \cdot \frac{\partial n_B}{\partial t} \qquad (6.2\text{-}2)$$

A sample calculation with B_0 = 500 m, ΔH = 1.5 m and $\partial n_B/\partial t$ = 150 m/month (= 5 m/day = $0.058 \cdot 10^{-3}$ m/s) yields α = 1.2, which corresponds to a 20% increase of the bend scour. The increase of bend scour due to structure-induced narrowing and deepening is much larger.

6.2.2 Narrowing and Deepening of Channel Along Structure

Migrating rivers are overwide when point-bar deposition cannot keep up with bank erosion. The stopping of migration by a bank protection structure causes hence narrowing and associated deepening. No quantitative methods are available for the prediction of the structure-induced narrowing and deepening. Therefore a study based on simplified mathematical modelling was carried out under FAP 21/22 in co-operation with IHE Delft (Shishikura, 1996; Mosselman, Shishikura and Klaassen, 1997). The simplified mathematical model could reproduce the effects of bank stabilisation qualitatively, but the quantitative results were poor. Therefore, no readily applicable design formulae could be obtained. Nonetheless, the study has increased the insight in the phenomena and has revealed the most promising lines of further research.

The structure-induced deepening had been estimated pragmatically during the Planning Study through expert judgement. It was argued that the finding α = 1.2 in Subsection 6.2.1 must represent a lower limit, because channel narrowing and deepening is known to have a greater effect on bend scour than stopping of the input of bank erosion products. An upper limit was obtained by replacing the bank elevation difference ΔH by the full bank height H. It was expected that this would overestimate the amplification of bend scour, because Murshed (1991) found that replacing ΔH by H deteriorated his results for the Dhaleswari River. Substituting ΔH = H = 15 m into Equation 6.2-2, the scour depth correction factor becomes α = 3. The real value of α will lie somewhere between 1.2 and 3. The 10 m extra scour thus predicted for Kamarjani complied with the physical model tests at RRI Faridpur and the prototype observations at Kamarjani.

6.2.3 Tightening of Bend Along Structure

The phenomenon of structure-induced bend tightening is explained schematically in Fig. 6.2-1. River meander bends in homogeneous soils have smooth curvatures. Their migration can be decomposed into a transverse component (*extension*) and a downstream component (*translation*) (A). The extension is hindered when a bend meets a more resistant soil or a structure (B). The channel becomes narrower and deeper there, thus increasing the attack on the riverbank, but the resulting deep scour hole reduces the horizontal mobility of the riverbed. This has two effects. Firstly, the river channel along the resistant bank will not easily move away from the bank, but maintain a considerable depth along the bank. Secondly, the downstream translation of this part of the meander bend is slowed down, which leads to a characteristic deformation in which the meander bend becomes asymmetric, pointing upstream. This deformation rotates the approach channel which, as a consequence, impinges more perpendicularly on the bank. The resulting stronger flow impingement increases the structure-induced local scour as well. Eventually, the bend becomes so sharp that one can no longer speak of bend scour, because the bend becomes too short for the development of the typical helical flow pattern of river bends.

Continued deformation of the bend increases the sinuosity and hence the water surface elevation difference between the entrance and the exit of the bend. Thus the water surface slope of flood flows over the chars becomes steeper, which increases flow velocities and enhances erosion. Eventually this leads to the formation of a cut-off channel (see C in Fig. 6.2-1). Continued upstream meander bend translation deforms the geometry of the upstream channel bifurcation in such a way that the bifurcation angle of the long meander loop increases, thus promoting abandonment of this loop.

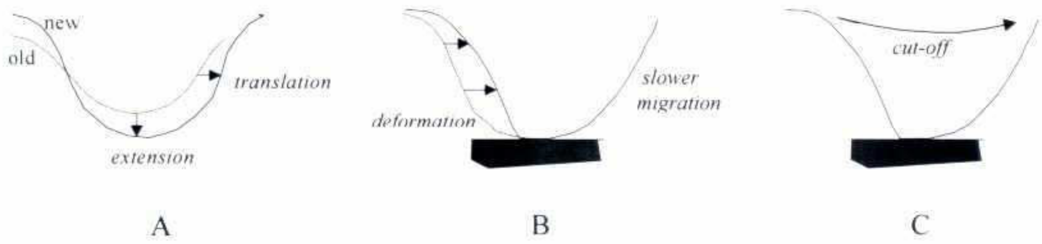


Fig. 6.2-1: River channel bend deformation due to local structures

6.2.4 Formation of Channel Confluences along Structure

Part of the deformation of bends in the previous subsection could be understood as a result of flow attraction by the structure-induced local scour hole. This flow attraction leads also to an apparent attraction of channels. In a braided river, this increases the probability that channels form a confluence close to the structure, especially when the structure protrudes into the river over distances which are long in relation to the width of the channels. During the project period of FAP 21, the Consultant was also involved in river training along the alluvial rivers of Pakistan under the Flood Protection Sector Project of the Federal Flood Committee. There he observed that long J-head spurs on the Chenab River and on the Ravi River attracted the flow strongly, due to deep scour and due to flow acceleration around the J-head.

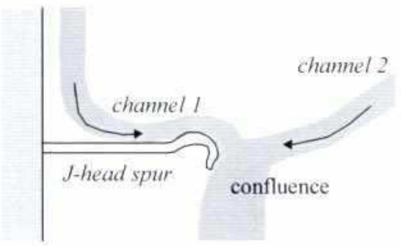


Fig. 6.2-2: General pattern of head-on attack, observed in the Punjabi Rivers of Pakistan

For braided river sections, this influenced the morphological evolution in such a way that most often two channels came to meet at the head of the spur, irrespective of the channel pattern before the spur was constructed. The resulting channel pattern has been sketched in Fig. 6.2. The confluence of the two channels leads to additional scour, thus aggravating the head-on attack of the spur.

6.3 EFFECT ON NEARBY AREAS DOWNSTREAM FROM STRUCTURE

The presence of a bank protection structure leads initially to a deceleration of bank erosion downstream, because the migration of the downstream channel is slowed down (see Fig. 6.2-1 B). Eventually, however, the point of flow impingement arrives at the downstream end of the structure, thus attacking the bank immediately downstream. The shift of the point of flow impingement can be observed when comparing the Kamarjani bathymetries of spring 1996 (Fig. 4.13) and spring 1997 (Fig. 4.16). The arrival at the downstream end enhanced the erosion immediately downstream from the groynes (in the area of the former course of the Manos River) while bank erosion further downstream remained weak (between Saidpur and Rasulpur).

The full bank erosion is resumed when the channel bend and the point of flow impingement have lost their contact with the structure, unless the bend has been cut off and subsequently abandoned (see Fig. 6.2-1 C). A bend cut-off did develop at Kamarjani, but could not prevent the resumption of severe bank erosion between Saidpur and Rasulpur.

6.4 EFFECT ON RIVER MORPHOLOGY FAR AWAY

Theoretically the morphology of the Jamuna River is so sensitive to disturbances that even the mooring of a country boat or the planting of catkin may change the future erosion of a bank many kilometres downstream. The effect of bank protection structures on river morphology far away does not differ from the effect of country boats or catkin. However, it is fundamentally impossible to assess this effect. This impossibility is not due to limitations in the present knowledge or the present level of technology, but due to the very nature of the river. This implies that a deterministic assessment of the effect on local bank erosion far away will also remain impossible in the future. Claims of specific losses of land many kilometres downstream from a bank protection structure can only be based on subjective opinions, not on hard technical or scientific facts.

However, changes in the *statistical* properties of bank erosion far away are more open to scientific assessment. According to the present knowledge, those statistical properties are not affected by the bank protection structures. The only way to verify this point of view is by studying trend breaks through statistical analysis, but that would require data from many years after the implementation of the structures.

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BANK PROTECTION PILOT PROJECT
FAP 21

FINAL PROJECT EVALUATION REPORT

ANNEX 2

SOCIO-ECONOMIC ASPECTS

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FAP 21 - BANK PROTECTION PILOT PROJECT

FINAL PROJECT EVALUATION REPORT

ANNEX 2

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ATTACHMENTS

Attachment-1: Questionnaire for Household Survey
Attachment-2: Report on Consultation Process Meetings

1 INTRODUCTION

1.1 PROJECT OBJECTIVES

The objective of FAP 21 Bank Protection Pilot Project is aimed to develop and optimise design criteria as well as cost effective construction and maintenance methods, which would ultimately serve as standard bank protection measures along the Jamuna and other erosion prone rivers in Bangladesh. For realization of the above objectives, two different types of full scale test structures have been constructed, one on the right bank of Jamuna and two on the left bank side.

1.2 TEST STRUCTURES

On the west bank of Jamuna, a Groyne Test Structure was constructed at Kamarjani in Gaibandha district. On the east bank of Jamuna, a Revetment Test Structure has been constructed at Bahadurabad under Jamalpur district. The construction of Groynes was done in 1994-1995 construction season. The construction of Revetment, although started in 1995-1996 construction season had to be abandoned due to various reasons, both technical and socio-political and has been completed in the season 1996-1997 before the monsoon. Another Revetment Structure is under construction at Ghutail and was completed in the construction window of 1999-2000.

1.3 SOCIO-ECONOMIC INVESTIGATIONS AT STRUCTURE SITES

Socio-economic investigations in the project area started as soon as the site has been selected for the construction of bank protection structures.

Household surveys were conducted to assess the people's benchmark condition in the erosion prone area selected for the bank protection work. Attachment-1 provides the form used for Household Surveys.

Participatory public meetings were organized to make the people understand the proposed project, obtain peoples suggestions and discuss probable pros and cons of the project to be experienced by the population in the project area. An especially developed format was used for reporting and evaluation of the public response later. The format 'Report on Consultation Process Meetings' as was used has been appended as Attachment-2.

Motivational works prepared the population for acceptance of the project and participate in the project work leading to making land available for the construction before formal Land Acquisition done by the District Authority.

Rehabilitation works were also undertaken in small scale for the public installations fallen and displaced in the alignment of the structure during construction works.

2 HOUSEHOLD SURVEYS

2.1 KAMARJNAI GROYNE FIELD SITE

Several field visits as part of household surveys were conducted to the proposed site at Kamarjani during May-June 1994. The surveys covered the site, area, people and organizations at Kamarjani and around. The household surveys were helpful in having ideas about benchmark condition of the people and helped in formulation of methodologies to proceed with other socio-economic activities in the area.

2.2 BAHADURABAD REVETMENT SITE

Household surveys at Bahadurabad site began covering a wider area from May 1995. Almost all activities of household surveys as carried out at Kamarjani were repeated at Bahadurabad. The surveys in Bahadurabad had two phases. The first phase survey started in May 1995 and the second phase in March 1996. This was required due to suspension of works in the first phase and subsequent erosion of major area of first phase. Then a second phase was required to complete the work.

2.3 GHUTAIL REVETMENT SITE

Household surveys at Ghutail started in April 1999. This test structure has been undertaken by popular demand. Understanding of the project socio-economic conditions was aimed and achieved through this reconnaissance survey.

3 PARTICIPATORY PUBLIC MEETINGS AND MOTIVATIONAL WORK

3.1 KAMARJANI GROYNE FIELD SITE

After monsoon 1994 the location of the groyne field was established at the Kamarjani area on the basis of bankline development prevalent at that time. The site comprised part of Dhutichara, Analerchara and Baguria Mouzas. Participatory public meetings (Consultation Process Meetings), both pre-arranged and impromptu, were organized covering cross-sections of the people.

Discussion of the meetings were mostly relating to:
- aim and objectives of the project;
- likely negative-positive impacts of the interventions;
- peoples attitude towards the project including issues of land acquisition particularly leasing-out of their land for the project work;
- their state of co-operation towards the execution of project work;
- exchanging idea about compensation package with payment procedure, and
- peoples view about the project and suggestions for the solution (if any) to the problems of river-bank erosion.

Formal reports in prescribed formats were submitted after each meeting.

Before the start of the project work (formally opened in the 1st week of October, 1994) it was possible to reach in a general consensus of the people in favour of the project through these meetings. They liked and welcomed the project. They also agreed to provide their land for the project (of Dhutichara and Analerchara). Finally, they agreed to lease-out their land and accepted the proposal of compensation money by the project against one year term lease, forgoing (for the time being) their legitimate demand of getting compensation money in full. This was the most challenging decision that the people took to allow project work without permanent acquisition of their land. Otherwise the project work could not be started there in due time or may be never.

3.2 BAHADURABAD REVETMENT SITE

Activities in respect of Participatory Public Meetings as carried out at Kamarjani were repeated for Bahadurabad as mentioned in discussion of the meetings above.

Further, two alternative site locations were presented in a meeting chaired by local UP-Chairman and was attended by a large cross-section of local people in October, 1995. The accepted location by the people was finalized as the Revetment site. The people were well informed about the aim, objective, purpose and method of realization of the objective. The consent of the people to provide land through lease for the project work was obtained during this participatory meeting prior to finalization of Bahadurabad as a test site.

3.3 GHUTAIL REVETMENT SITE

Although the project was undertaken by popular demand reflected by the request of GoB and agreement by the Donors, still motivational work through participatory public meetings at site were conducted. Since the structure had to be sized within limited funds, it was rather difficult to make the population agreeable to the siting of the structure and the area to be protected. However, since the remaining funds was the deciding factor in sizing the structure, the beneficiaries accepted the structure which could be done with the remaining funds and GoB decided to make an extension of the project downstream to cover the school and madrasha compounds.

4 LAND ACQUISITION

4.1 INITIAL PROBLEMS

Although the selection of the structure locations were dependent on different technical criteria, the most important and crucial aspect after the sites were fixed was the actual possession of land to start the work, because the question of making land available remained unsettled till then. It was unlike other projects, where land acquisition is done or the process has progressed substantially before the start of the project work. So a special formulation had to be evolved to have access to the land of the project alignment before the actual acquisition is done and physically handed over the land to the project by the appropriate authority.

The formulation worked fine at Groyne Test Structure site at Kamarjani. But was not very successful at the Revetment Test Structure sites at Bahadurabad and Ghutail. The reason may be the varying socio-economic condition of the people at two different sites.

4.2 CONTRACTUAL REQUIREMENT

All project costs except local taxes and land cost are covered by technical assistance of the Donors. Government of Bangladesh shall provide land for the structure site as per provision of the Contract Agreement.

FAP 21 - Bank Protection Pilot Project is being implemented by WARPO as Executing Agency. Since WARPO does not have any field unit to process the land acquisition for structure sites, the responsibility was given to BWDB field Division under whose jurisdiction the structure site is located.

Thus the requirement from GoB (WARPO and BWDB) in connection with acquisition of land for the structure was:

i) keeping ready requisite fund for payment compensation of land acquisition;
ii) collecting Mouza Maps of the area covered by the structure;
iii) preparing land plan and land schedule of the area under requirement of acquisition;
iv) preparing proposal of land acquisition as per approved format;
v) submitting the proposal to DC office, and
vi) following up all activities of the DC office in this respect up to end of the process of handing over the land to the user.

The Consultant assisted BWDB in performing the activities under items (ii) and (iii).

4.3 LAND ACQUISITION PROCEDURE

Bank Protection Works are very much related to the bankline at the time of construction. The necessary preparation for all other works including collecting materials, preparation of design, floating tenders - all could be done well ahead for a site area with probable bankline at the time of construction keeping in mind the erosion rate prevalent at the site. This site area provides and umbrella coverage where exact site would be located after the recession of flood. Hence, unlike other projects exact siting of the structure is not possible well ahead of the start of construction, rather it is done only a couple of weeks before the construction. This special feature called for some formulation to solve the problem.

The formulation had two aspects of activities. The first aspect would deal with:

(i) preparation of site plan with expected probable location of the structure at the time of construction. This site plan will provide an umbrella coverage of the area within which the actual alignment of the structure will be set after recession of flood, probably by mid-September.

(ii) Collection of relevant Mouza Maps and transferring the site plan into the Mouza Maps.

(iii) Preparation of schedule of land falling within the site plan drawn on the Mouza Map with exact area and ownership.

(iv) Preparation of the inventory of affected households covering mainly information about housing (type, size, materials used etc.) and other items (tubewells, latrines). Information about shops, business units, rural industry as well as trees, standing crops in the field etc. are also needed to be included in the inventory.

(v) After fixing the exact alignment of the structure the land plan, land schedule and the inventory are immediately modified from the umbrella coverage area to exact area.

(vi) The Land Acquisition Proposal is then prepared in the required format and submitted to Deputy Commissioner for formal acquisition of land.

Items (i) through (iv) were programmed to be completed during May through August month while items (v) and (vi) would be done during the months of September and October. Deputy Commissioner's office takes about 5 to 6 months for step wise notifications to the people having property in the proposed acquisition plan, making verification of inventory of houses, crops, trees and others and acquires land on payment to the affected people. The situation worsens sometimes in absence of proper funds to be placed by the requiring body to the Deputy Commissioner.

The second aspect of formulation dealt with the situation of making land available for the construction in November, when work should start precisely to complete the same by coming May or June at the latest. For this purpose, public participatory meetings early in September were convened. Project's pros and cons were thoroughly discussed with them and the population was convinced about the necessity of the project. The population were also, convinced that land should be made available to the project before the actual payment of compensation for land by the appropriate authority. Discussions revealed that the owners should handover the land at least one crop season ahead of the actual payment. Keeping in view the limitations of the affected people and the hardships they would suffer, it was mutually agreed that:

(i) project will bear the cost of house shifting as per agreed rate;

(ii) project will bear the compensation for trees and standing crops at some agreed rate, and

(iii) on receipt of the house shifting cost and compensation for trees and standing crops, the owners would vacate the land by beginning of November so that physical work of construction could begin immediately.

It was expected that the formulation would work fine and land would be made available for the construction as early as November, but in reality in did not happen so for the second test structure at Bahadurabad. In 1995-96 dry season, the planned construction work of Bahadurabad was delayed due to non-availability of land from the owners, even after adopting the formulation to pay house shifting cost and compensation for crops and others. This was one of the reasons to postpone the work till next season and necessitated a second phase of acquisition for the same structure.

4.4 APPROACH TO THE WORK

Possession of land for the construction is a pre-requisite in all project works. As permanent acquisition was not possible before the start of construction works due to insufficient lead time for formal acquisition, the land had to be arranged by taking lease (temporary acquisition) from the land owners by convincing them as per formulation already described.

In achieving the target the steps undertaken were:

a) field visits;
b) meeting and sitting with the local people;
c) scooping sessions and project briefing;
d) listen and pay attention to the problems / needs of the people;
e) motivate people towards the project;
f) formation of a land compensation committee, and
g) inventorization of assets (movable / immovable) of likely affected people.

Measures for preparing land plan/schedule and deal with process of permanent acquisition of land were also undertaken. The project having no provision of support staff at field, the service of contractors field workers were utilized as per construction contract in preparing land schedule and other related jobs of Land Acquisition. Later Consultant's surveyor was recruited to assist in above works.

Steps were also taken to arrange meetings of high officials of the Consultants, WARPO, WDB etc. with the people from time to time in view to grow confidence among the people about the project activities and to have successful Client-Consultant-Beneficiary interactions.

4.5 FORMULATION BASED ACTIVITIES

4.5.1 Groyne Test Field Structure at Kamarjani

The first test structure to be constructed was the Groyne Test Field at Kamarjani. The location was decided in the Planning Study Phase using selection criteria of test sites for the optimum condition. Sequential activities at Kamarjani are described below:

(i) Demarcation of a Gross Site Area

A gross site area map was prepared with tentative location of the structure based on predicted bankline in the next dry season with the help of Mouza Map. Demarcation of an umbrella coverage was done allowing possibility of any shift of the placement of the structure within it. The demarcation line was later refined considering the actual bankline only in September when the monsoon was over.

(ii) Listing of Affected Households in the Gross Site Area

An inventory of likely affected people within umbrella coverage area was launched immediately after demarcation of the site, but could not continue as the site was continuously changing due to bank erosion.

(iii) Committee for Determining Compensation Money and Payment

Following the understanding between the people and project personnel regarding arrangement of land through lease, the question of settling compensation package came up which would be dealt by a land compensation committee (L.C.C.). A 4 member panel (comprising 2 project personnel, 1 representative from the contractor and 1 from the people) was assigned to negotiate with the people to determine the compensation package for the affected people.

Meanwhile an estimate was submitted to the Consultant's project management about the total compensation money to be required for the compensation of the effected people. The estimate was prepared considering the market price of the crops, trees, land, house building materials, wage of labour etc. and by discussing local people.

By holding a few meetings the panel however, finalized the items to be covered under compensation payment and their rates. The items of compensation were: a) compensation for loss of two crops and b) cost of shifting of houses. The rate was fixed @ Tk. 6,000/- per bigha (0.1338 ha.) for loss of crops while the shifting cost of houses was determined to be as per market rate depending on size and materials used. But in any case the shifting cost should not be less then Tk. 500/- (for huts) as minimum. People were immediately informed about the decision and their acceptance obtained. (Table 4.5-1 presents details of compensation).

Beside fixing of rate of compensation and being present during payment of compensation the panel was also involved in handling minor disputes that emerged mainly from determining ownership of property and so on.

(iv) Preparation of Land Schedule for Permanent Acquisition of Land

Preparation of land plan/schedule was another important task that started with collection of Mouza maps, demarcation of site boundary, inventory of local people and their movable-immovable assets etc. All these tasks jointly helped in preparing the land schedule by WDB-Gaibandha Division for making the proposal of (permanent) land acquisition.

This job was hampered quite a few times as the site had shifts following bank erosion. After final fixing of the site boundary and setting layout of the structure, the land schedule was finalized (in November-December). The land schedule then jointly verified by WDB Gaibandha and the Consultant before it was finalized to be sent with the proposal of land acquisition. The land acquisition proposal for the groynes was submitted in early 1995.

Total amount of land was required to be acquired for the groynes and connecting embankment was 13.84 hectare (see Table 4.5-2). The acquisition plan of Kamarjani site on Mouza map is shown in Fig. 4.5-1.

(v) Formation of Committee by Local People

Steps also were taken to form two committees (one each for Dhutichara and Analerchara) to be owned by the local people. The idea was that the committees will act as media of the people to communicate with the project including the contractors and also a platform for the general people to voice their grievances in fulfilling their demand (if any) or settling disputes. Formation of these committees initially gave good results but did not last long.

(vi) Co-ordination with the WDB Gaibandha Division

Being the project at Kamarjani to be owned later by WDB, the project site was under the jurisdiction of Gaibandha division of WDB. This division of WDB also was responsible to construct the embankment part of the overall structure to which the groynes would be connected with.

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Site	Items of Compensation	Basis of Payment	Rate (Tk.)	Remarks
Kamarjani	a) House Shifting Shifting cost of houses	As per category of houses (big, medium, small and huts)	Fixed Tk. 2000-3000 for a Tin roof /Tin wall Big house (room) Fixed Tk. 1500-2000 for a Tin+Tin/Bamboo made medium house (room) Fixed Tk. 1000-1500 for a Tin+Bamboo made small house (room) Fixed Tk. 500 for a hut	In total Tk. 2.5 million (approx.) was spent as compensation money for Kamarjani
	b) Land Compensation Cost for loss of crops	On all types of land	Fixed Tk. 6000/ 0.33 acre for one year lease	
Bahadurabad	a) House Shifting Shifting cost of houses b) Land Compensation Cost for loss of crops	As per type and size of houses	As per government and local market rate	In total Tk. 3.7 million (approx.) was spent as compensation money for Bahadurabad (1st phase only)
	i. Cost for loss of crops	Cropped land	= @ Tk. 3000/ 0.33 acre (paddy/sugar cane etc.) for two seasons = @ 5000-12000 (for different type of vegetables etc.) for two seasons	
	ii. Rent for a vacant land	Non cropped Land	= @ Tk. 1000/ 0.33 acre (for fallow land/ low lying areas/ ditches etc.) for one year	
	c) Loss of fishery	For fish ponds	= @ Tk. 200/ decimal for one year	
	d) Cost of trees	As per type and size of trees	As per government rate	
Ghutail	House shifting cost	Assessment based on negotiation	Lumpsum	In total Tk. 200,000 (approx.) was spent as house shifting cost

Table 4.5-1: Details of compensation payment (items and rates)

Therefore, it was necessary to maintain a very close link with WDB Gaibandha for various needs of the project particularly for the matters relating to (permanent) land acquisition. Preparation of the initial land-schedule for the groynes part was done with project initiative but for its finalization and ultimate submission as proposal for land acquisition required co-ordination with the WDB Gaibandha. Submission of the proposal (to D.C. office) for land acquisition was not an end in itself, continuous follow-up was required to get approval of the proposal and for arranging quick payments to the affected people. Here also co-ordination with WDB Gaibandha division was needed. The project offered the co-ordination as and when required.

(vii) Follow-up of Progress of Land Acquisition

Though the proposal of land acquisition was processed through government rules and had its own way to proceed, yet the Consultant was obliged to follow-up the process for he promised to expedite the process and arrange for quicker payments of compensation money to the affected land owners.

Site	Structure Type	Amount of Land Required	Submission Date of L.A. Proposal	L.A. Case #	Present Status	Remarks
Kamarjani	Groynes	13.84 ha. (including embank-ment) For groyne = 2.70 ha.	January 1995 (for 12.14 ha.)	15/94-95	Notice # 7 has been served (Now ready for start of payment to the land owners)	The L.A. proposal for total land was submitted in two separate instalments by mistake of WDB Gaibandha
		For embank-ment = 11.14 ha.	& June 1996 (for 1.74 ha.)	05/96-97	Only notice # 3 has been served	
Bahadurabad	Revetment	14.65 ha. (1st phase)	04/3/96 & 08/5/96 (revised)	06/95-96	Notice # 7 has been served and partial payment of land is made *	The proposal sent first time was not a complete one. So, a second proposal had to submit making necessary corrections.
		15.98 ha. (2nd phase)	30/05/96	01/96-97	Notice # 7 has been served and payment of house-shifting cost is paid to the affected people *	* Because of fund constraints part payment was provided to the (affected) people
Ghutail	Revetment	6.21 ha. (1st proposal)	28/11/99	01/1999-2000	Notice # 3 & # 6 has been issued	1st proposal excluded few plots which have been included in the additional proposal
		0.29 ha. Additional	09/02/2000		DLAC meeting scheduled to be convened	

Table 4.5-2: Status of land acquisition

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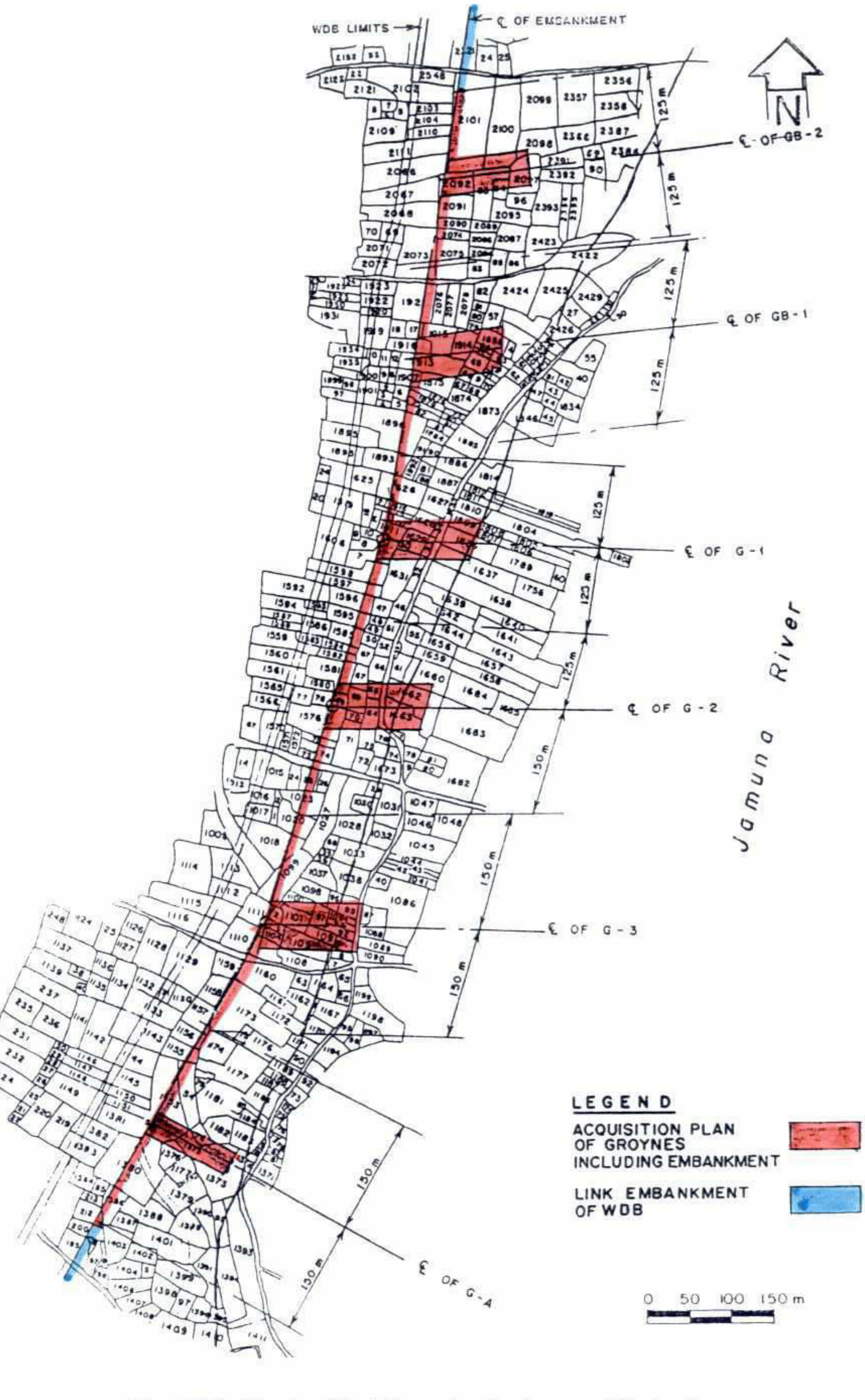

Fig. 4.5-1: Mouja: Dhutichara, Analerchara and Baghuria

4.5.2 Revetment Test Structure at Bahadurabad

The second test structure which included Revetment Sections was constructed at Bahadurabad. The first attempt to construct the test structure was taken during the dry season in 1995-96, but had to be postponed due to various reasons of which non-availability of land in time was an important one. The second attempt was taken during the dry season of 1996-97 and the structure was completed under very difficult social conditions.

The sequential activities in respect of land acquisition at Bahadurabad are described below:

(i) Inventory of affected Households

After finalization of site location in October '95 and having the consent of providing land by the people through lease, inventory of (likely) affected households began. The inventory covered mainly information about housing (type, size, materials used etc.) and other items (tubewells, latrines, etc.). In addition, information about shops/business units, rural industry and other structures also were included in the inventory. Inventory of trees (owned by affected households) also were required to be prepared at a later stage as demand raised from the local population to include trees under payment of compensation. The information recorded in the inventory was used for payment of compensation to the affected people.

(ii) Formation of Land Compensation Committee (L.C.C)

In view to provide a more realistic compensation package to the affected people and to take possession of land from the people in a systematic and peaceful way the land compensation committee (L.C.C) was formed (October '95) in Bahadurabad site in the first public participatory meeting.

Besides 3 members from the locality, one each from the Consultant and the contractors consortium represented in the committee. The local members in the committee (including local U.P. Chairman) were selected by the choice of the local people. The committee was assigned the task to determine compensation package for the affected land owners (including other relevant jobs linked to compensation payment), and to make land free to start project work in time.

The L.C.C functioned quite nicely at the beginning but ceased to function well at a later stage. Because all the local committee members ultimately turned as sub-contractors of the project and lost interest in fulfilling committee objectives.

After closing of the 1st phase, the committee was not revived to function in the 2nd phase. Because the provision for payment of compensation by the project was no more there (in the 2nd phase) for which the committee was required to form.

(iii) Determination of Compensation Rates

Items to be covered under compensation payment were decided earlier and a consensus was reached with the local people regarding that. Despite the fact, more new items and new issues came up as the committee proceeded to fulfil its objectives. The items however identified and rates were fixed to pay compensation for shifting of houses, loss of crops, vacant land, loss of fishery etc.. Compensation for trees also were included at a later stage. Several meetings were held for finalization of rates of various items at different times. (Table 4.5-1 give details of compensation).

The rates for shifting of houses/structures and cost of trees were determined by making a compromise between government rates and existing market rates by discussing with the people. While compensation money for land was determined on the basis of cropped and non-cropped land, a separate rate for the fish ponds was also determined.

(iv) Making Land Available for the Project

By payment of compensations as formulated and accepted by the people, process of making land available started but could not continue smoothly. A vested interest group hampered the project work for gaining in their ill motives of extracting undue benefits from the Project. The problems piled up further with the involvement of a large number of land owners as the subcontractors of the project who could pressurise the project implementation in a non-positive way. Site clearance was thus delayed and added with other factors ultimately contributed to the suspension of project until next working season.

(v) Arrangement of Meetings between WARPO Official and Local People

Following the postponement of project work until next working season for various unavoidable reasons a sense of insecurity was created among the people. Therefore, situation demanded exchange of views of WARPO high officials with local people. Following which a series of meetings between WARPO and local people were arranged where people urged to know about the fate of the project and progress of land acquisition while WARPO officials clarified their position and assured people about the completion of the project including payment of land compensation in time.

Arrangement also was made to bring representative from D.C. office (L.A. section) in some of these meetings so as to assure people their full co-operation as regards land acquisition.

(vi) Land Acquisition Proposal

The formal land acquisition proposal was prepared and submitted by Mymensingh O&M Division of BWDB to DC, Jamalpur. Besides preparing land plan/schedule of Land Acquisition, participation in joint verification for finalization of the schedule prior to submission of the Acquisition proposal and joint verification during the process of estimate finalization including other related field activities of land acquisition were under taken by the Consultant.

It may be mentioned here that two separate proposals (for two phases) of land acquisition were submitted for Bahadurabad site for a total of 30.63 hectare of land (see Table 4.5-2). The land plan of Bahadurabad site for the implemented structure on Mouza map is shown in Fig. 4.5-2.

As regards follow-up and monitoring of the process, extensive involvement was deemed necessary with the whole process for the Consultant as he was obligated to the people and WARPO as well to do the job.

The process from the beginning was not progressing as expected. There were lapses observed in all the stages of the process; from the preparation stage of the proposal (as happened to the proposal of 1st phase) by WDB (Mymensingh) up to the stage of obtaining approval from the ministry and subsequently in issuing notices from the D.C. office. People were aware about the happenings and got frustrated.

So, there was tremendous pressure from the people on the Consultant to expedite the process and arrange for compensation money for them as promised earlier. Particularly when the question of additional land arose, people pointed out the delay in acquisition process of the 1st phase land and demanded for a quick solution to that. As a result, follow-up and monitoring of land acquisition process was taken up by the Consultant by visiting D.C. office (Jamalpur) and maintaining a close link with WDB-Mymensingh, Land Directorate of WDB at Dhaka and WARPO on a regular basis.

After all those activities, payment for land compensation money could be arranged and Land Acquisition Section of DC Office started payment to the affected people. The land for the construction was then handed over to the project after seven weeks from the scheduled date. This delay caused hardship to complete the work in time.

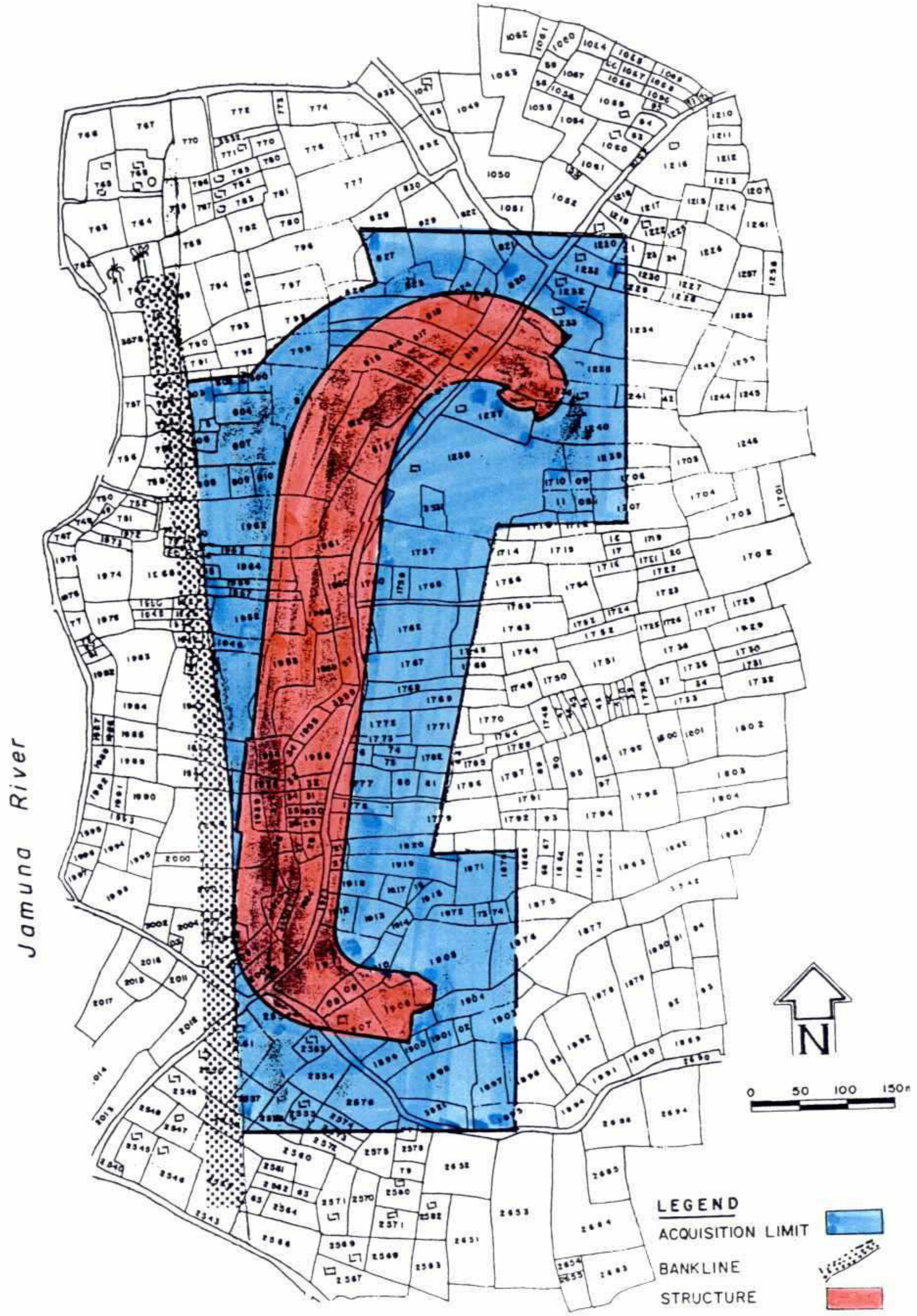

Fig. 4.5-2: Mouja: Kulkandi (Sheets 1 & 3)

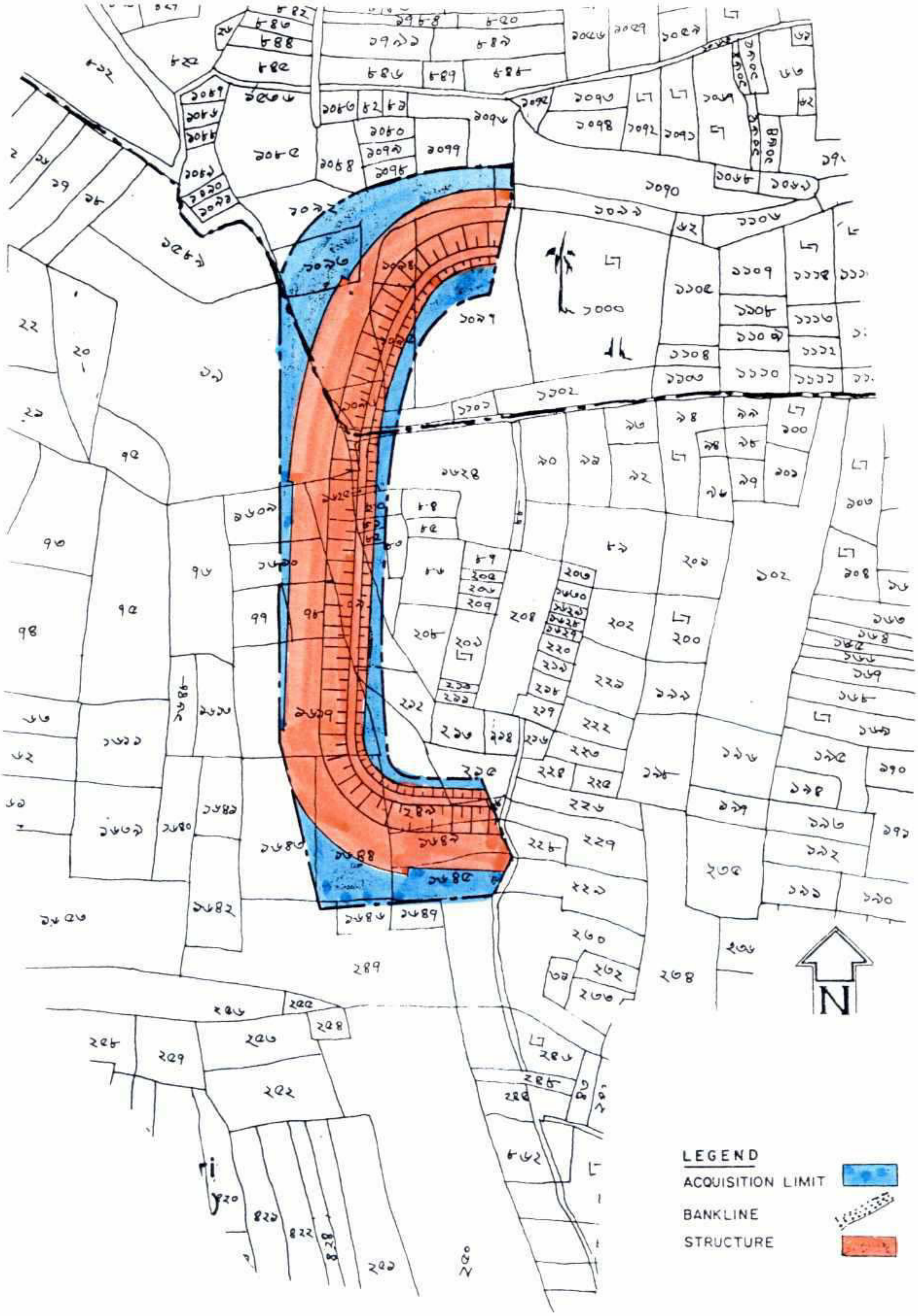

Fig. 4.5-3: Mouja: Belgacha and Gilabari (Sheets 1 & 3 old)

4.5.3 Revetment Test Structure at Ghutail

The third test structure which includes revetment sections is under construction at Ghutail. The structure was scheduled to be constructed in the construction window of 1998-1999. But the unprecedented prolonged flood of 1998 made it impossible to complete the construction before monsoon season 1999. The GoB and German authorities reviewed the situation in a bilateral meeting and decided to implement the structure during the dry season of 1999-2000.

The sequential activities in respect of land acquisition for the planned construction are described below:

(i) Formation of an Executive Committee
A preliminary committee having 51 members both from Belgacha and Chinaduli Unions were formed in June 1999 to assist the construction activities and making land available. The final committee having 22 members from among the 51 member preliminary committee came into existence in the same month for co-ordination of the construction and assisting in obtaining the land with the consent of the Hon'ble State Minister for Land who also the local MP. However, the committee was not successful in making land available for the construction.

(ii) Inventory of Affected Households
After fixing the preliminary alignment of the structure, the area of acquisition of land was marked and inventory of houses and other structures was made. The inventory covered informations mainly about types size and materials used in the housing and also other structures. Tube wells and latrines were also inventorized.

(iii) Land Acquisition Proposal
The first proposal was prepared by Jamalpur O&M Division of BWDB in October, 1999 for acquisition of 36.45 acre (14.75 hectare) and administrative approval from BWDB was taken in early November 1999. This proposal was prepared based on the preliminary design of the structure. The final design of the structure was completed in Mid-November 1999 and the proposal was revised in later November 1999 for a total land area of 15.22 acre to be acquired for the structure.

In order to avoid constructing the road directly on the embankment crest, a further land acquisition of 0.72 acre was proposed. The official procedure of acquiring land is underway. Meanwhile for construction land has been made available to the project on December 17, 1999 about 1.5 month later than the schedule time using formulation adopted for bank protection projects evolved by the Consultant.

5 SOCIAL DEVELOPMENT WORKS

In addition to erosion counter measures at Kamarjani, Bahadurabad and Ghutail the project also undertook efforts to improve the public infrastructure like schools, mosque, madrasha etc.

Besides, the project also undertook improvement of roads leading to the project sites. A Family Planning health Care unit was newly constructed and was threatened by the Jamuna at Bahadurabad. As this unit of health care centre had fallen in the alignment of the revetment test structure, the same had to be demolished and the project will construct a new Health Care Centre of the same size on the same plan at a safer place in near future. Meanwhile, the hospital services continued in a Porta-Cabin given by the project.

It is needless to mention that the schools and other installations rehabilitated by the project are new and semi-pucca structures with good workmenship as a replacement of very old and inferior structure. These rehabilitation works were appreciated by the people as welfare works to the society. List of such works are presented below site-wise.

At Kamarjani:

- Improvement and maintenance of link road from Gaibandha-Balashi metalled road to site.
- Construction of a primary school and a mosque.

At Bahadurabad:

- Improvement and maintenance of the earthen road connecting the site from Islampur/Dewangonj.
- Assistance to the construction of a high school, primary school and madrasha.
- Arranging supply of new school furniture for the high school by the German Embassy in Bangladesh.
- Supplying Porta-Cabin for continuation of health services.
- Committed to construct a Union Health Complex at a place given by the local Health authority.

The project also arranged site development of the newly located market place of Bahadurabad. Several individual residential plots were also developed by earth filling as per need from the project.

At Ghutail:

- Area development by earth filling behind the structure for locating new market place.

6 ASSESSMENT AND EVALUATION OF SOCIO-ECONOMIC ASPECT OF THE PROJECT

6.1 PRE-PROJECT CONDITION

For the assessment and evaluation of socio-economic effects of the project, pre-project conditions were obtained through a Rapid Sociological Appraisal (RSA) method of survey in the year 1992 during Planning Study Phase at two sites:

i) Kamarjani (Dhutichora and Analerchara), and

ii) Bahadurabad (Belgacha Mouza under Jamalpur district)

These survey data comprises:

- erosion condition in the preceding years;
- drainage;
- cropping pattern;
- livestock;
- occupational groups;
- land value, and
- Net Value Added (NVA).

Kamarjani data have been used for the assessment and evaluation of the groyne-field project while for the revetment sites at Kulkandi and Ghutail data recorded of Bahadurabad (Belgacha) located between both sites had been used.

6.2 POST-PROJECT CONDITION

A sample survey of the people living in the project areas was undertaken in March, 2000 to assess and evaluate post-project condition. The survey helped in assessing the following benefits:

- value of land protected from erosion;
- value of agricultural production;
- economic growth of the area;
- occupational activities, and
- charland development and its benefits.

These surveys were conducted in the areas protected by the Groyne Field and the Revetment Structures.

Results of pre-project and post-project survey are summarised in the following section.

6.3 PRESENTATION OF SURVEYED DATA

Summary results of pre and post project survey data are presented below:

Sl. No.	Item	Pre-project condition	Post-project condition
1	Erosion rate	150 m to 220m/year	No erosion. Accretion of 125-ha achieved
2	Drainage	congestion prevail	Congestion prevail
3	Cropping system	B. Aus, B.Aman, T. Aman, Boro, Jute, Wheat and Mustard	Irri/Boro, Aman, Wheat and Oil seeds
4	Livestock	Decreasing trend	Stable
5	Occupational group	Farmers: 37 %, Daily labour: 27 % Business 22% Others: 14 %	Around 70 % farmers and daily labours rest business, fishing and others
6	Land value/ha	Homestead: Tk. 59,300/= High land: Tk. 44,000/= Low land: Tk. 37,000/=	Average value: Tk. 123,550/=
7	Net Value Added/ha *	River side: Tk. 9,800/= Land side: Tk. 20,000/=	Average: Tk. 45,000/=
8	Infra-structural development	Negligible	Quite visible in the area
* Net Value Added (NVA): Gross product – Direct Production Cost – Labour Cost = Net Return			

Table 6.3-1: Kamarjani Groyne Field

Sl. No.	Item	Pre-project condition	Post-project condition
1	Erosion rate	100 m to 220 m/year	No erosion. Accretion of 15-ha achieved
2	Drainage	No congestion	No congestion
3	Cropping system	Rice, Wheat, Jute, Pulses, Sugarcane, Mustard vegetables and spices	Irri/Boro, Aman, Wheat and Oil seeds
4	Livestock	Decreasing trend	Stable
5	Occupational group	Farmers: 43 %, Daily labour: 52 % Others: 5 %	Farmers and daily labours: 60 % Business & Services: 40 %
6	Land value/ha	River side: Tk. 49,400/= Main land: Tk. 148,100/=	Average value: Tk. 207,564/=
7	Net Value Added/ha *	Tk. 17,400/=	Average Tk. 52,000/=
8	Infra-structural development	Slow	Rapid
* Net Value Added (NVA): Gross product – Direct Production Cost – Labour Cost = Net Return			

Table 6.3-2: Bahadurabad Revetment Structure

Sl. No.	Item	Pre-project condition	Post-project condition
1	Erosion rate	100 m to 220 m/year	Erosion arrested
2	Drainage	Normal	Normal
3	Cropping system	Rice, Sugarcane, Vegetables and Oil seeds	Irri/Boro, Aman, Wheat and Sugarcane
4	Livestock	Decreasing trend	Stable
5	Occupational group	Farmers and daily labours: 60 %, Business & Others: 40 %	Farmers and daily labours: 60 % Business & Services: 40 %
6	Land value/ha	Tk. 148,100/=	Tk. 506,048/=
7	Net Value Added/ha *	Tk. 17,400/=	Tk. 52,000/=
8	Infra-structural development	Slow	Very rapid
* Net Value Added (NVA): Gross product – Direct Production Cost – Labour Cost = Net Return			

Table 6.3-3: Ghutail Revetment Structure

The pre-project and post-project survey data on assessment and evaluation indicates that the Bank Protection Projects brought significant improvement in the area in terms of infrastructural development, land value and Net Value Added of the agricultural production. This definitely justifies the bank protection projects undertaken.

A detailed economic evaluation of the bank protection measures is given in the Final Project Evaluation Report (Main Report).

7 CONCLUDING REMARKS AND RECOMMENDATIONS

Bank Protection Projects are different from other types of projects in respect of land acquisition. Because, the lead time for preparation of the formal proposal leading to actual acquisition through various steps is only a couple of weeks - not at all sufficient for the whole process. In such project an emergency land acquisition procedure should be followed. For the success of such emergency land activities pre-requisites are:

(i) The project proposal should come from the affected people. The likely beneficiaries ought to understand that if the land is not given for the project, the same may be lost to the rivers by the process of erosion in future.

Requirement for the project did not originate among the local people in case of the projects under report. Consultants selected the sites for the bank protection work based on technical criteria. Although the local people welcomed the project, possibly they had a notion that the project was undertaken at the interest of the Consultant and in any case he shall have to complete the project. This negative attitude in the mind of the vested interest group provided significant hindrances to the implementation of the project.

The participatory meetings could not mobilize a general consensus about the absolute necessity of the project. For future bank protection projects, every step of formulation, planning, design and implementation procedure should be made clear to the beneficiaries by the implementing authority to ensure a close cooperation of the affected people including handing over the land falling in the alignment and required for other project works.

(ii) The original TAPP of the Project did not provide for any land acquisition cost. Therefore, there was no budgetary provision to pay for the compensation money to the affected people. For the first test site, project had to arrange for the temporary lease of the land by paying crop compensation, house shifting cost and like others. People were given assurance to pay land compensation as per GoB rules after approval of Revised TAPP and budgetary provision for the project in future. This arrangement, although was acceptable to the people but was not attractive. Therefore, there was chance that somebody could create hindrances for not having their legitimate demand.

(iii) Formation of land compensation committee did not have any legal basis. The committee acted only on good gesture of the people. So, anybody could defy the action of the committee if he did not want to obey. This situation arose particularly at Bahadurabad second test site. Land owners in some cases put pre-condition of offer of sub-contract to them for vacating land.

(iv) Payment of land compensation money of the budgeted amount in four quarterly instalment, the last quarter being in the month of June, does not carry any sense and created bottlenecks in the payment of compensation money to the land owner prior to handing over land by them to the project as early as in December of the previous year.

(v) Process of land acquisition is complicated and takes much time, which can not be afforded by a project having only about six weeks between the finalization of project alignment and actual construction. Payment procedure is also complicated too.

To overcome the situations as observed above, the following recommendations are given:

(i) Project formulation, planning and design needs to be taken up as per popular demand subject to the technical feasibility. Participatory meetings should be conducted to know the peoples mind, express the opinions of the implementing body, have consensus about the project formulation and planning. Likely affected people and the beneficiaries need to be consulted time and again in the process of finalization of the project planning. Affected people by the project should be mentally prepared to vacate the land and project executives and the beneficiaries should have an understanding of future fate of the displacees and measures taken, if possible, for the re-settlement.

(ii) Project Document should have a budgetary provision sufficient to cover the expenses of land compensation and the fund should be available in the budget of the year of implementation. The fund should be disbursed by the Finance Ministry totally by December of the execution season. The project being very special in nature shall have to be completed in one working season, preferably between Nov. 1 of the previous year to May 31 of the next year.

(iii) To deal with the situation of land compensation a committee with members drawn from local people, implementing body and GoB, personnel dealing with land acquisition should be formed. This committee should have legal basis to deal with the situation as per need. The committee should have role to facilitate, to control, to make arbitration (if necessary) and to followed up every step of the land acquisition and compensation procedures.

(iv) To minimise sufferings of the displaced population compensation money should be paid expeditiously by the DC office, preferably at site.

Attachment 1

Questionnaire for Household Survey

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JAMUNA TEST WORKS CONSULTANTS
FAP 21
QUESTIONNAIRE FOR HOUSEHOLD SURVEY

(of Households Affected through
Land Acquisition by Interventions of FAP 21)

Test Site:

Household Identification:
(Holding no.-Location)

Para : Interview No. : ☐☐☐

Village : Name of Interviewer : ________

Mouja : Date :

Structure Location : Time :

Q.1 Name of Respondent: ____________________

Age: ______ Sex: M ☐ F ☐

a) Marital Status:

Unmarried ☐ Married ☐ Divorced ☐

Widow/Widower ☐ Abandoned ☐

b) Are you head of household: Yes ☐ No ☐

If no, what is your relation with the head of the household and your position (tick most relevant one) in the family.

Relation:

Position:

Dependent ☐

Earning member ☐

Principal earner ☐

c) Principal occupation (tick most relevant one) of head of the household

Farmer ☐

Fisherman ☐

Weaver ☐

Landowner ☐

Businessman ☐

Others ☐ (specify) ____________________

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d) Secondary occupation (tick most relevant one)

Farmer ☐

Fisherman ☐

Weaver ☐

Landowner ☐

Businessman ☐

Others ☐ (specify) ____________________

e) Education

A	Cannot read and write	☐
B	Can read only	☐
C	Primary (1-5)	☐
D	Lower Secondary (6-8)	☐
E	Secondary (9-10)	☐
F	Higher Secondary (11-12)	☐
G	Graduate (13-14)	☐
H	Post Graduate (15+)	☐

f) Income

Income	Monthly	Yearly
Tk. 500 or less	☐	☐
Tk. 501 to 1,000	☐	☐
Tk. 1,001 to 1,500	☐	☐
Tk. 1,501 to 2,000	☐	☐
Tk. 2,001 to 3,000	☐	☐
Tk. 3,001 to 5,000	☐	☐
Tk. 5,001 to 10,000	☐	☐
Tk. 10,000 -	☐	☐

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Q.2 Household Information:

a) How many persons are there in the household ?

Total Nos. [ ]

Male [ ]

Female [ ]

Minor (under 15) [ ]

Major/Adult [ ]

b) How many are earning members ? ______________ Nos.

c) What is the total monthly earning of the household ? Tk. ______________

d) What is the total expenditure of the household (monthly) ? Tk. ______________

Q.3 Information of Member of Household:

No. of Members	Name	Relationship to head of household	Age	Education	Occupation (tick appropriate one)			
					Employed	Unemployed	Student	Housewife
01								
02								
03								
04								
05								
06								
07								
08								
09								
10								

Relation : SL = Self, F = Father, M = Mother, D = Daughter, B = Brother, S = Sister, O = Other

Age : 1. (0-15), 2. (16-25), 3. (26-35), 4. (36-45), 5. (46-55), 6. (56+)

Education : A = Can read and write, B = Can read only, C = Primary (1-5)
D = Lower Secondary (6-8), E = Secondary (9-10), F = Higher Secondary (11-12)
G = Graduate (13-14), H = Post Graduate (15+)

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Q.4 a) How long have you been in the area ? ____________ Year

b) Have you moved in recent time in the same area ? Yes ☐ No ☐

c) If, yes, reason of movement: ____________________

____

Q.5 Land ownership and area of land (Agri.) :

	Area in Decimal
a) Ownland	______
b) Tenant	______
c) Share Cropper	______
d) Others (specify)	______

Q.6 Type of house and size:

a) Housing Area: ________ sq.ft. (approx.)

b) No. of rooms: ________

c) Type of structure:

	No. of rooms	Size	
* Pucca	☐	sft.	(...........ft. x ....ft.)
* Semi-pucca	☐	sft.	(...........ft. x ....ft.)
* Kutcha	☐	sft.	(...........ft. x ....ft.)

d) Mode of ownership: (for owner only)

Inherited ☐ Purchased ☐ Constructed ☐

e) If constructed, year of construction ☐

f) Total area of homestead: ________ sq. ft. (...........ft. x ....ft.)

g) Total built-up area: ________ sq. ft. (...........ft. x ....ft.)

Q.7 Type of Services:

a) Water supply Yes ☐ No ☐

b) Toilet facilities Yes ☐ No ☐

If yes, Shared ☐ Private ☐

c) Electricity Yes ☐ No ☐

Q.8 For people affected directly : (land only)

a) Type of land: ______________

b) Area of land: ______________

c) Use of land: ______________

(in case of cropped land mention area only under crop and for Homestead garden/orchard mention, name, number and size of the affected trees if any).

Q.9 For people affected directly : (Business Concern)

a) Commercial / Industrial:

b) Type of activity:

c) Type of structure: Pucca ☐ Semi-pucca ☐ Kutcha ☐

d) Area: ______________ sft./Dec. ______________________________

e) Year of establishment: ______________

f) Type of machineries (specify): ______________________________

____

____

g) Amount invested: ______________________________ Tk. ______________

h) Monthly income: ______________________________ Tk. ______________

Q.10 Any other observation (specify): ______________________________

____

____

____

____

Attachment 2

Report on
Consultation Process Meetings

3aa

BANK PROTECTION AND RIVER TRAINING (AFPM) PILOT PROJECT; FAP-21/22

REPORT ON CONSULTATION PROCESS MEETINGS

Page 1 of 2

GENERAL INFORMATION	
Date: ______	Group: ______
Venue (Location): ______	Meeting #: ______
Village/Para: ______	No. of Participants: ______
Mouja: ______	# of FAP 21 Personnel Present: ______
Starting Time: ______	Facilitator: Mr. ______
Closing Time: ______	Reporter: Mr. ______
	Meeting Coordinator: Mr.

A — General Comments of the Participants:

______

______

______

______

______

A-I — Major Disagreement (if any):

______

______

______

A-II — Suggestions (if any):

______

______

______

______

______

B — Overall Remarks about the Meeting:

- No. of Participant took part in discussion: [|]
- Flavour of contribution: Poor [ ] Good [ ] Excellent [ ]
- Breadth of discussion: Narrow [ ] Medium [ ] Wide [ ]

LIST OF PARTICIPANTS

Group: ______________ Chairman of the Meeting: ______________

Meeting #: ______________

Sl. No.	Name & Address	Occupation	Signature	Remarks

Attendance taken by: ______________

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BANK PROTECTION PILOT PROJECT
FAP 21

FINAL PROJECT EVALUATION REPORT

ANNEX 3

ECOLOGICAL ASSESSMENT

MAY 2001

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FAP 21 – BANK PROTECTION PILOT PROJECT

FINAL PROJECT EVALUATION REPORT

ANNEX 3

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LIST OF ACRONYMS

AER	-	Agro-ecological region
BWDB	-	Bangladesh Water Development Board
EIA	-	Environmental Impact Assessment
EP	-	Environmental Post-Evaluation
FAP	-	Flood Action Plan
FCD	-	Flood Control and Drainage Project
FPCO	-	Flood Plan Coordination Organization
JTWC	-	Jamuna Test Works Consultants
TDS	-	Total Dissolved Solids
TS	-	Total Solids
TSS	-	Total Suspended Solids

GLOSSARY

TERM	DEFINITION
biophysical	part of natural environment, which includes physical, chemical and biological components such as air, soil, water quality, plants and animals
environment	totality of the natural and human environments on which the project will exhibit influence including: (a) all biophysical components of the natural environment of land, water and air, including all layers of the atmosphere, biological resources, and inorganic and organic matter both living and dead; (b) all socio-economic components of the human environment including, but not limited to, social, economic development, human resources, quality of life, administrative, cultural, historical, archaeological, architectural, structures, sites and things land and recourses usage, and human health, nutrition and safety.
environmental assessment	Process for making environmentally-sound decisions in regard to ensuring the concept of sustainable development is achieved in respect to projects and the plans leading to projects.
environmental impact	(a) any change that a project may cause to an environmental components; (b) any change to the project that may be caused by the environment, which then leads to changes in environmental components; (c) any cumulative effect caused or exacerbated by the project.
environmental impact assessment	Systematic study, quantified assessment and reporting of the impacts of a proposed plan or project;
mitigation	elimination, reduction or control of the adverse environmental impacts of a project;
significant environmental impact	Adverse residual environmental impact that is not justified in the circumstances;
socio-economic	refers to the human environment, which includes social and economic components that are not termed biophysical

SUMMARY

Already during the Study Phase of the Project investigations were undertaken to evaluate potential environmental consequences of the test structures. After completion of the works and during the monitoring phase these studies were continued in order to assess possible positive and/or negative impacts of the structures on the environment. Three categories of environmental issues and related impacts were considered viz. **physical, biological** and **human** aspects. A simplistic scaling of the degree of impacts shows for both test sites in general positive impacts and nil/negligible impacts. This assessment holds only for the test site areas, but not for reaches upstream and especially downstream from the new structures for bank protection against erosion, where the erosion of the unprotected river banks and attached land continued during the years following the construction of the groyne field and the revetment respectively.

Socio-economic investigations, which were carried out at the same time, show that the structures at both test sites are welcomed by the local population. They appreciate the benefits from the executed bank protection works with regard to the aspects mentioned above.

1 INTRODUCTION

In the course of the implementation of the Bank Protection Pilot Project three test structures have been built in the upper part of the Brahmaputra-Jamuna river, viz. a groyne field at Kamarjani on the right bank (Test Site I), and two revetments on the left bank downstream from Bahadurabad Ghat at Kulkandi (Test Site II) and at Ghutail Bazar (Test Site III) respectively. The area of Test Site I is located in Agro-ecological Region 3 (AER 3), which is known as Tista Meander Floodplain (FAO - 1988, see Fig. 1.1-1). The locations of the other two test sites are within Agro-ecological Region 7 (AER 7) known as the Active Brahmaputra-Jamuna Floodplain. Both regions comprise the belt of unstable alluvial land along the Brahmaputra-Jamuna river where the land is constantly being formed and eroded by shifting of river channels. AER 3 is closely similar to the Active Tista Floodplain (AER 2) and AER 7 similar to the Active Tista and Ganges Floodplains (AER 2 and 10). They differ, however, in having greater relief and a higher proportion of sandy alluvium and in having sediments derived from the Brahmaputra river. These regions also differ from the adjoining Karatoya Bengali Floodplains and young Brahmaputra and Jamuna Floodplains (AER 4 and 8 respectively) in having predominantly sandy and silty alluvial soils on unstable landforms.

The boundaries with adjoining regions vary from sharp to transitional in different places. They are liable to change as river channels encroach on older land, spilling active floodplain sediments ahead of them, but also when channels recede, allowing older char land soils – mainly on the eastern side – to develop properties like those on the young Brahmaputra and Jamuna Floodplains in AER 8.

Since1970 onwards it is necessary to plan an ecologically oriented landscape in order to protect and conserve the environment. Long term environmental changes/impacts should also be monitored to identify adverse impacts. Therefore, in the present project ecological and environmental studies were initiated during the planning process, which included the following:

- the examination of the ecological consequences of the demands made by a planned scheme, and
- the development of ecologically alternative solutions within the frame work of an overall spatial planning process.

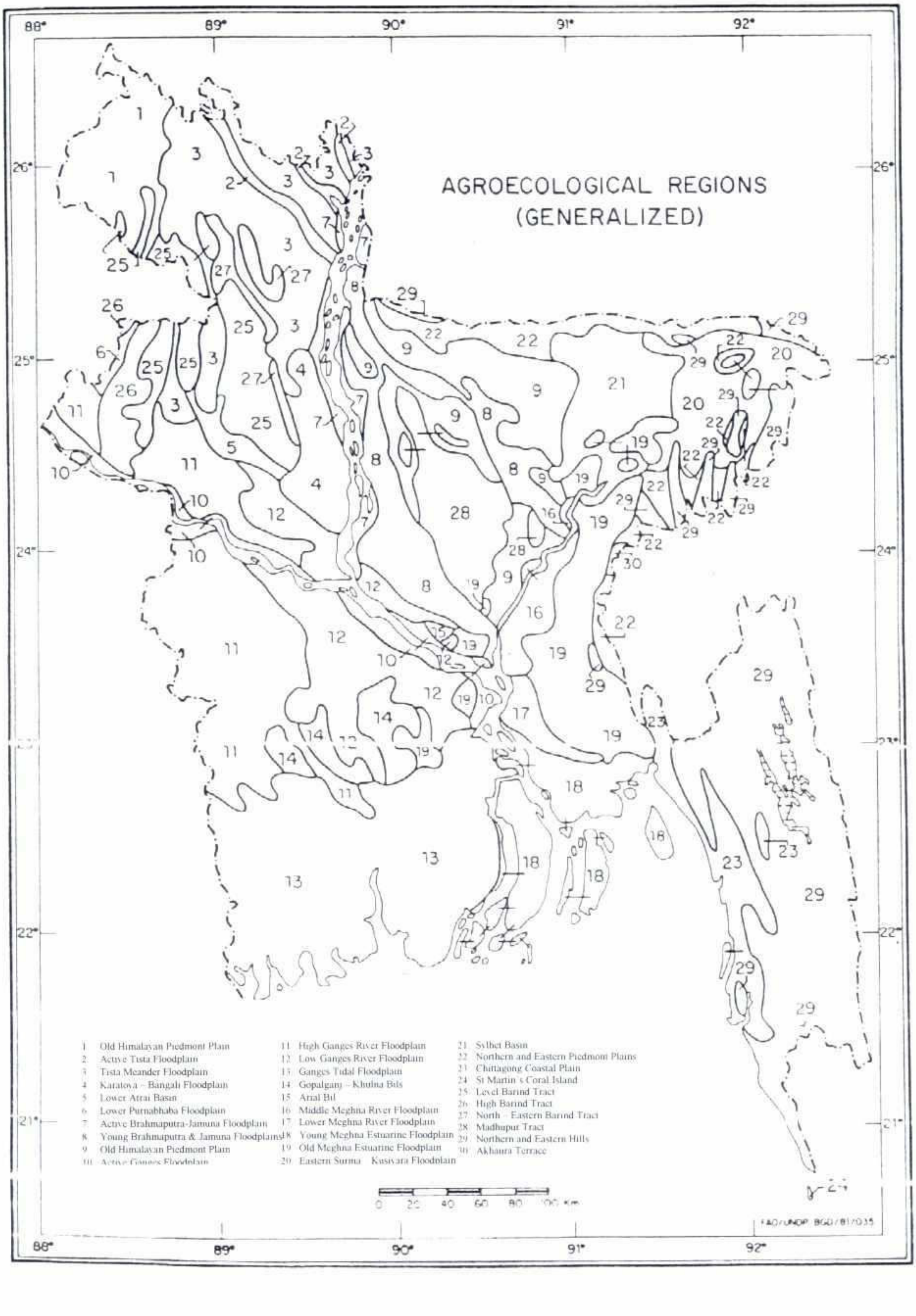

Fig. 1.1-1: Agro-ecological regions

2 PHYSIOGNOMY

The regions have an irregular relief of broad and narrow ridges and depressions, interrupted by cut-off channels and active channels. Both the outline and relief of char formations are liable to change each flood season due to bank erosion by shifting channels and to deposition of irregular thickness of new alluvium. Local differences in elevation are mainly 2 to 5 meters.

3 GENERAL INFORMATION

3.1 DRAINAGE

The whole area is virtually subject to seasonal flooding, which is shallow on highest parts, but deep on lowest parts. Depressions and thick new silty deposits remain wet through the dry season. The approximate percentage proportions occupied by the various depths of flooding classes are given below (FAO 1988):

- High Land 5 %
- Medium High Land 37 %
- Medium Low Land 20 %
- Low Land 8 %
- Very Low Land 0 %
- Homesteads and Water 30 %

3.2 CLIMATE

There are significant differences in climate between the north and south of the region. The main trends are given below:

- mean annual rainfall increases from about 1500 mm in the south to about 2500 mm in the far north;
- in the north, June has a mean rainfall exceeding 500 mm, whereas in the south no month has a mean rainfall exceeding 300 mm;
- the mean date when minimum temperature starts to fall below 20°C ranges from October 24 (or earlier) in the north to November 04 in the south;
- the mean length of the cool winter period increases from south to north.

Item	Station		
	North Kurigram	**Centre Pingna**	**South Tangail**
Rainfall			
Annual Total:	2325	1760	1547
* Annual Total: St.D.	480	427	291
No of months with mean rainfall > 200mm	5	5	4
No of months with mean rainfall > 500mm	1	0	0
Temperature			
Mean Annual (°C)	⊗24.6	**24.8	***25.8
Date when minimum falls < 20°C: mean	Oct. 24	Nov. 02	Nov. 04
* Date when minimum falls < 20°C: St.D.	8	3	5
Date when minimum falls < 15°C: mean	Nov. 25	Dec. 07	Nov. 25
* Date when minimum falls < 15°C: St.D.	7	14	9
Last date when minimum falls < 15°C: mean	Mar. 03	Mar. 02	Feb. 19
Last date when minimum falls < 15°C: St.D.	25	11	18
* Length 1 minimum < 15°C: mean (days)	97	84	85
Length 1 minimum < 15°C: St.D. (days)	28	25	17
No of days when maximum is 15>40°C: mean	2	2	3

* : Standard Deviation (the range (+/-) within about two-thirds of observations probably occur;
⊗ : All temperature data are for Rangpur
** : All temperature data are for Jamalpur; based on 6 years
*** : All temperature data are for Sirajgonj

Table 3.2-1: Climatic data (FAO 1988)

3.2 SOILS

Complex mixtures of sandy and silty alluvium occupy most char land, but these are some developed grey silty soils. On older areas of alluvium, especially along the eastern alluvium, vary from place to place and from year to year. Overall, silty deposits are more extensive than sandy deposits, especially in the south and on relatively older land. However, large areas of sand may be deposited in high flood years, especially in the north. The parent alluvium is rich in weatherable minerals, especially biotite, low in organic matter and neutral to moderate in alkaline reaction. The following table shows the area and proportions occupied by soils in different soil textural families.

General Soil Type	ha	%
Non-calcareous Alluvium	178173	56
- sandy	(60914)	(19)
- loamy	(117259)	(37)
Calcareous Brown Floodplain Soils	140	< 1
Calcareous Dark Grey Floodplain Soils	373	< 1
Non-calcareous Grey Floodplain Soils	42430	< 1
Non-calcareous Brown Floodplain Soils	58	< 1
Non-calcareous Dark Grey Floodplain Soils	2516	1
Total Soil Area	223690	71
River	81152	25
Homesteads + Water	14159	4
Total	319001	100

Table 3.3-1: Area and proportions of general soil types

4 PROJECT OBJECTIVES

The main objectives of the test structures were:

- to protect the bank at the relevant site from erosion, which ultimately will protect the adjacent areas and villages, and
- to stop the shifting of river diversion further to the west and to the east respectively.

Environmental aspects in the project preparation were strongly considered. The project appraisal based on economic analysis and a number of key issues that the holistic perspective of environmental evaluation would have considered. The issues include external areas affected/benefited by the Project, both adjacent as well as downstream and upstream from the structures, fisheries, livestock, wetland ecology, river behaviour and ecology.

5 APPROACH AND SOURCES OF INFORMATION

Environmental Post-evaluation (EP) has been defined here as the post evaluation of equivalent of environmental appraisal (ODA) or initial environmental examination (ADB). This is an intermediate level of post-evaluation, a main purpose of which is to identify the negative and positive impacts. In addition, identification of any mitigatory measures were suggested during the monitoring activities.

6 IDENTIFICATION AND ASSESSMENT OF ENVIRONMENTAL IMPACTS

In the Environmental Post-evaluation (EP) many significant environmental issues and impacts were identified and a scaling matrix was used. An attempt is made at scaling the positive (+) or negative (-) degree of impact as follows:

0 - nil or negligible impact;
1 - minor impact;
2 - moderate impact;
3 - major impact.

The simplistic scaling or scoring values reflect the essentially qualitative nature of EP. However, they do have advantages of:

- ensuring that each primary impact is individually considered, while taking into account its often complex linkages with other primary impacts and with secondary or tertiary impacts;
- presenting a clear and concise assessment, which is easily assimilated by the EP user, and
- avoiding voluminous written presentations with repetitions, which become confusing.

The environmental issues and related impacts are considered within **three** categories:

(i) physical;
(ii) biological, and
(iii) human.

7 SOURCES OF INFORMATION

The main existing sources of information have been the Feasibility Study and Initial Environmental Report (1995). In addition, the environmental evaluation, by its nature, depends mainly upon the work of the engineering, agricultural, livestock and sociological information.

8 ENVIRONMENTAL PROFILE

8.1 TEST SITE I AT KAMARJANI

8.1.1 Brief Description of Kamarjani Site after the Project

In the dry season 1994/95 six groynes of both impermeable and permeable nature were built at Kamarjani site on the right bank Jamuna river. Later, it was necessary to build another groyne (G-A/2) approximately 500 m downstream from Groyne G-A (Fig. 8.1-1). On the western side of the embankment, Dhutichara and Anelarchara villages are situated. In 1995 the number of homesteads were limited, but after building up the groyne the security and safety had become stronger than before and at present, the number of homesteads has increased substantially. The project site with the groynes and villages including other infrastructure as noted during the field visit of October 13-15, 1999 are given in Fig 8.1-1. The description of the conditions of the groynes and the areas between them is given in Table 8.1-1. The following details are noteworthy:

(i) A small crack (canal) has formed between G-B/2 and G-B/1 and water was draining out to the river;
(ii) Trees noted in 1995 between G-B/1 and G-1 are washed away. In addition, three new trees have come out;
(iii) River bankline between G-1 and G-2 was highly unstable and scouring very high;
(iv) Impermeable part of G-2 was fully washed away and G-2 was permeable;
(v) Big stones and boulders on the top and slope of groyne G-3 (noted in 1995) were removed;
(vi) Top of groyne G-A was covered with boulders and bricks;
(vii) A new groyne G-A/2 had been built 500 m downstream from G-A.

Since the initial environmental conditions including a detailed list of flora and fauna were given in the report of 1995, only the salient features are considered now to bring the information to a sharper focus.

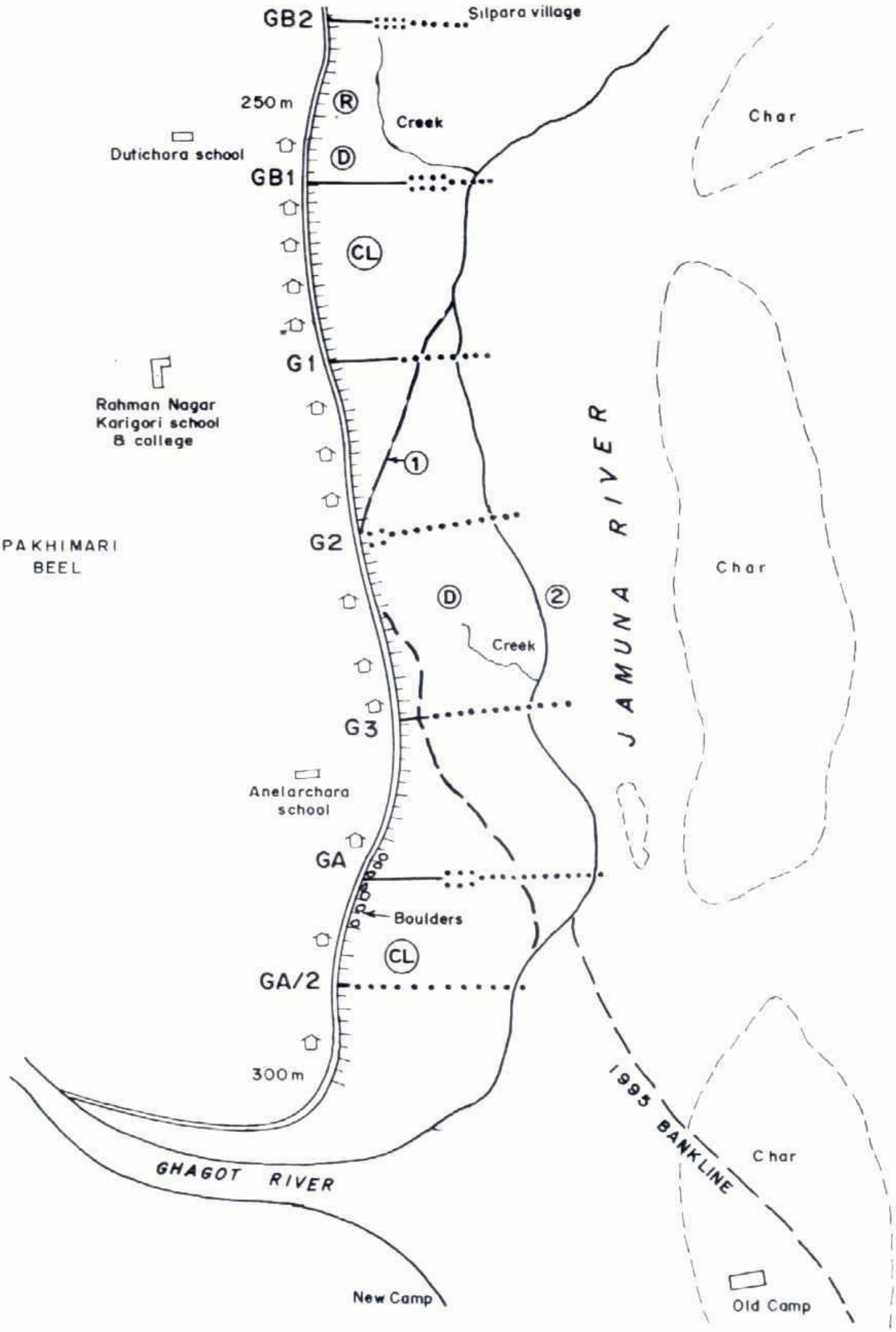

Fig. 8.1-1: Sketch of Kamarjani Site of October 1999

G-B/2 and area between G-B/2 and G-B/1	G-B/1 and area between G-B/1 and G-1	G-1 and area between G-1 and G-2	G-2 and area between G-2 and G-3	G-3 and area between G-3 and G-A	G-A and area between G-A and G-A/2	G-A/2 and downstream from G-A/2
Both impermeable and permeable groynes far away from the river. No damage to the groyne was observed. Sand deposition continued between G-B/2 and G-B/1. Rice cultivation in localized areas. Two-Third of the slope of the embankment between G-B/2 and G-B/1 protected by bricks Debris deposition near G-B/1.	Two-third of the impermeable part covered with cubes on both slopes of the groyne Slope of the embankment between G-B/1 and G-1 protected by bricks. Trees noted in 1995 were washed away. Negligible sand deposition . Capsicum, Bringal and Redish cultivation going on. Three trees were noted.	Impermeable part to the riverine site was covered with boulders to prevent erosion. The slope of the embankment between G-1 and G-2 protected by bricks and wires. Bankline highly irregular.	Since impermeable part washed away, the whole groyne permeable now. Damage of embankment (noted in 1995) had been repaired. Approximately 30 % of the land covered with sand (1 mm thick). Debris deposit-ion very high.	Impermeable part now only 10 m The slope of the whole embankment protected by bricks and wires. Approximately 15 m slope attached to GA is covered with boulders. Big stones and boulders on the top of the groyne removed	Top of the groyne is covered with boulders and bricks. Approximately 15 m of the slope of embankment attached to G-A protected by boulders. The remaining portion up to G-A/2 covered with bricks and wires. Wheat cultivation in progress.	No Damage was noted Slope of the embankment up to approx. 50 m after G-A/2 covered with bricks and wires. Embankment up to the Ghagot river mouth in good condition.

Table 8.1-1: Description and conditions of the groynes and the areas between the groynes

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8.1.2 Flood and Erosion after the Groynes Construction

Only during the first monsoon season after completion of the Groyne Test Structure in 1995, a localized temporary breach of the embankment contributed to an inundation of the hinterland of the structure. After repair and adaptation works in the following dry season, the villages and the agricultural land behind the structure were well protected. The more or less strong flow of the Jamuna river was interrupted by the groynes and diverted downwards where the old camp sites and the village Chirakuthi were completely washed away. In the following years the erosion downstream from the groyne field continued in the area from Syedpur to Balashi Ghat, but no erosion occurred at the test site.

8.1.3 Charlands

A number of Charlands were formed both upstream and downstream from the project site. A Char formed in the old Camp site (Chirakuthi village) is now used for raising rice seedling.

8.1.4 Water Chemistry

Near the groynes water is highly turbid and back current is creating scour and making the water more turbid. Away from the groyne, the water is more clear than in the groyne area. However, water samples were collected both from the groyne areas and further away in the middle of the river. The water was analysed for pH, chloride, conductivity, total dissolved solids (TDS), and total suspended solids (TSS). In addition, plankton study was also done to see the differences in population in the turbid water (groyne areas) and in comparatively clean water away from the groynes. The results of water chemistry are given in Table 8.1-2.

Measurements	Water Samples		Ghagot River
	Groyne Area	Free Channel	
pH	5.9 to 6.1	6.3 to 6.8	5.8
Chloride mg/l	49 to 64	41.5 to 59.9	52 – 59
Conductivity micro mhos/cm	110 to 180	100 to 150	120 - 150
Total Solids (TS)			
Total dissolved solids (TDS)			
Total Suspended Solids (TSS)			
Total hardness (mg/l)			
Permanent hardness (mg/l)			
Temporary hardness (mg/l)			
Alkalinity (mg/l)			

Table 8.1-2: Water analysis of the Brahmaputra-Jamuna at Kamarjani

The water chemistry shows differences in suspended particles. The particles are bigger and the concentration is higher in the groyne areas than away from the groynes.

Plankton Population was extremely low in water samples collected from the groyne areas. This is because of higher turbidity and because light cannot penetrate. Plankton species are given in Plates 8.1-1 to 8.1-9.

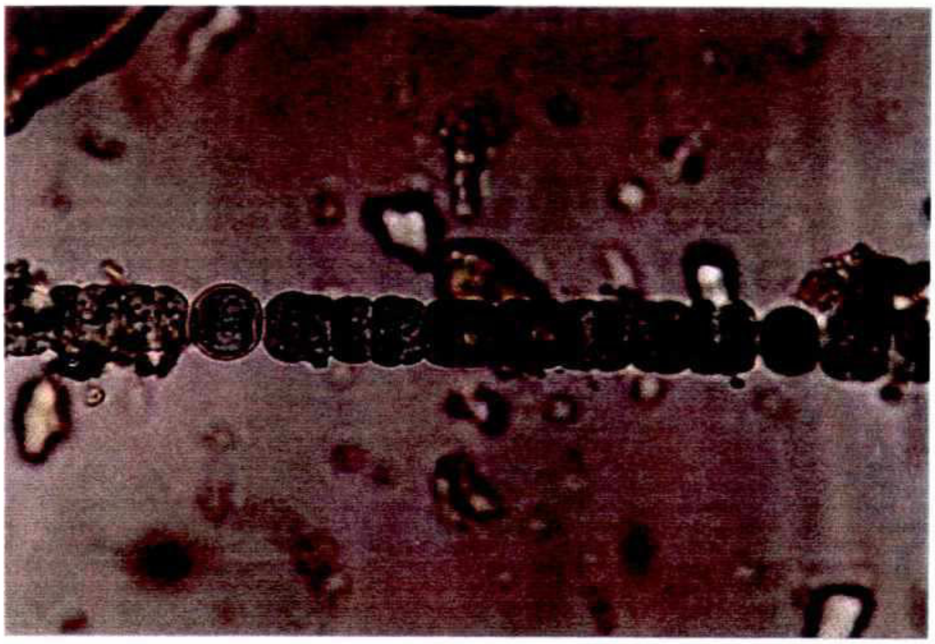

Plate 8.1-1: *Anabaena sp.* **(x 40)**

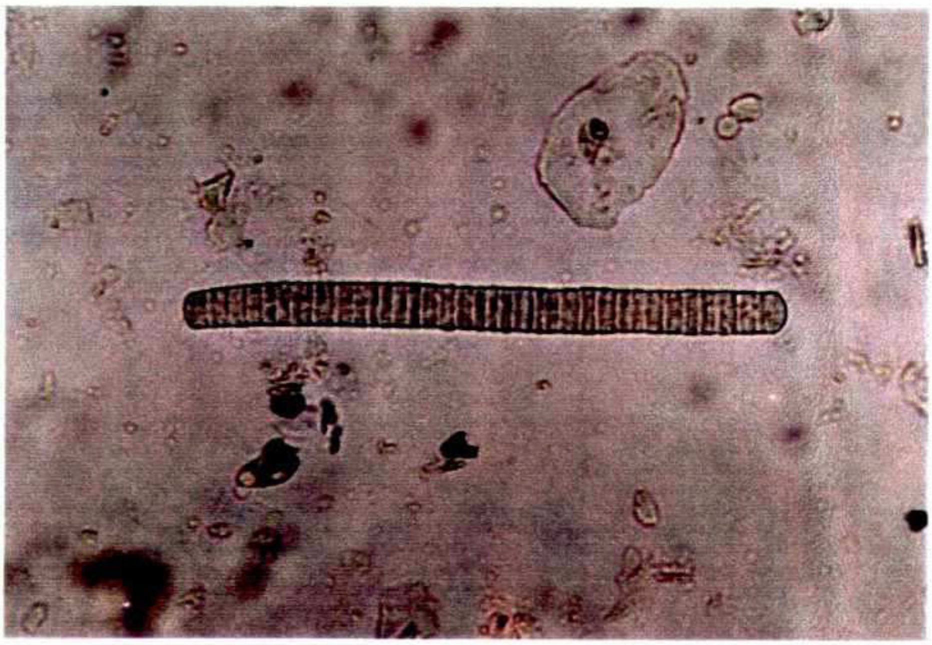

Plate 8.1-2: ***Oscillatoria sp.*** **(x 40)**

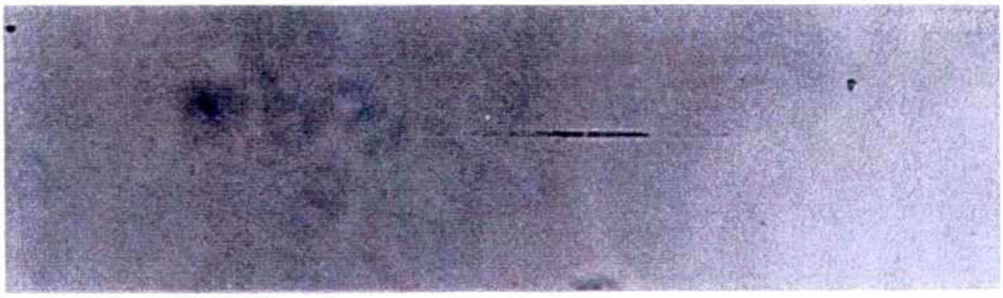

Plate 8.1-3: ***Ankistrodesmus sp.*** **(x 40)**

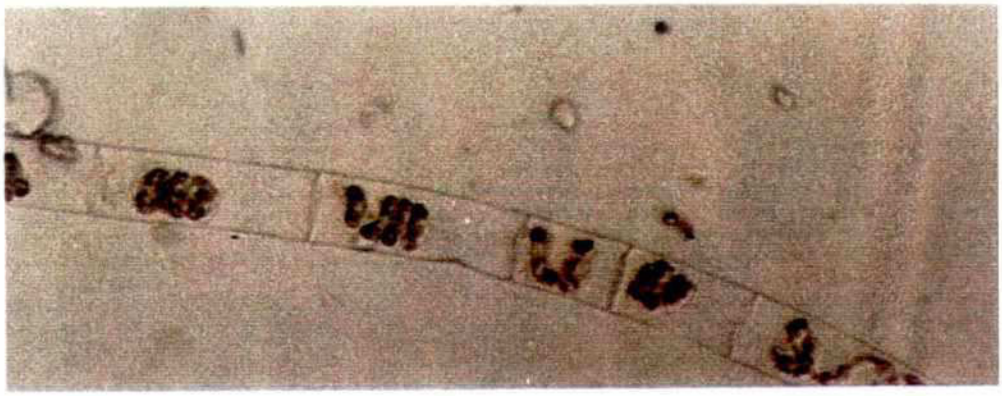

Plate 8.1-4: ***Mougeotia sp.*** **(x 40)**

Plate 8.1-5: ***Spirogyra sp.*** **(x 40)**

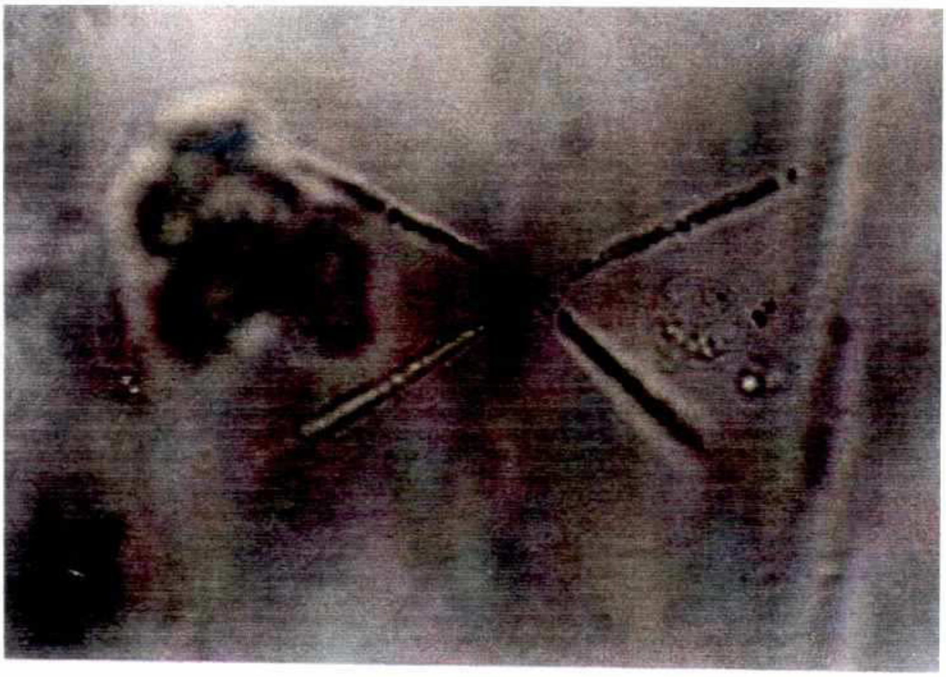

Plate 8.1-6: *Actinastrums sp.* **(x 40)**

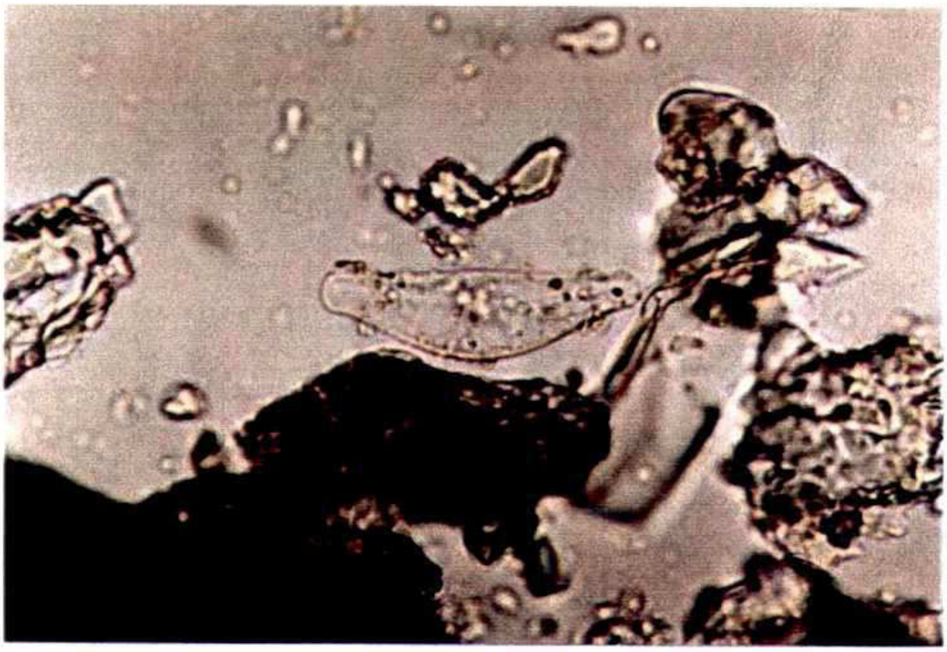

Plate 8.1-7: *Cymbella sp.* **(x 40)**

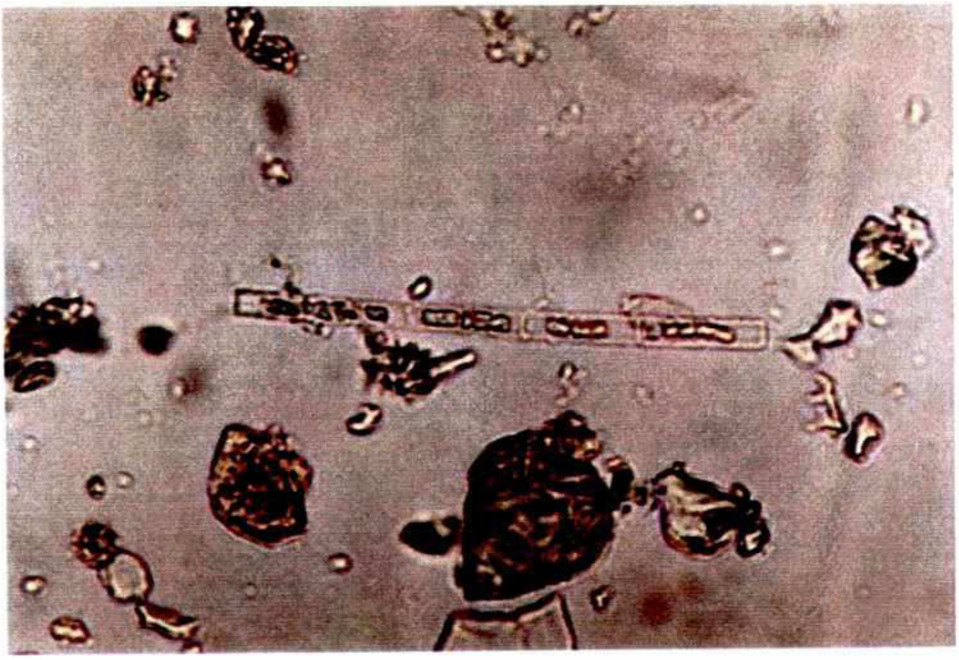

Plate 8.1-8: ***Melosira sp.*** **(x 40)**

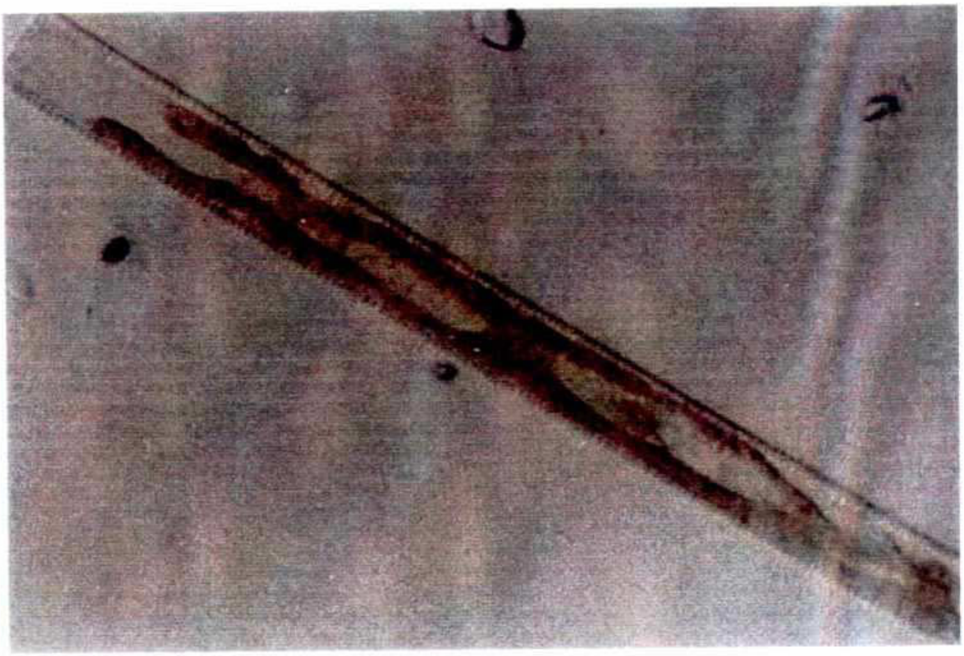

Plate 8.1-9: ***Pinnularia sp.*** **(x 40)**

8.1.5 Terrestrial Flora

A list of flora growing on the embankment and its slope, on the impermeable part of the groyne and on flood plain including its spreading is given in Table 8.1-3. Aquatic flora of the borrow pits, which were created in the course of the construction works, are also given.

It is important to mention that *Trewia polycarpa* are showing healthy growth both on the slope and also on the top of the embankment. *Ipomoea crassicaulis* are growing both in terrestrial and aquatic conditions.

The following trees (singleton) were noted between G-B/1 and G-1. Debris accumulation near G-B/1 and G-3 was very high. The debris (plant biomass) are collected by village people and used as fuel.

Flood plain vegetation (both on sand deposition and on soils) include *Lippia nodiflora* and *Datura fastusa.* Gramineae and Cyperaceae plant species of artificial banks and on sandy beaches, and natural eroded bank are given in Table 8.1-3.

8.1.6 Aquatic Ecology

The aquatic ecology depends on the frequency of inundation, the water depth, the flow velocity and the turbulence. Borrow pits and Pakhimari beel during monsoon show considerable growth of aquatic plants. Euhalophyts which flourish in the monsoon, die and decompose when the water level recedes. Hence, substantial amount of organic matter is added in the soil environment of low lying areas.

8.1.7 Terrestrial Fauna

The area lacks dense vegetation where mammals take their residence. Hence, fauna composition is not rich and is the same as found in 1995. However, the charland which is very dense with *Saccarum* sp. (Kash) is the only breeding ground of local ducks and some birds.

Common Name	Scientific Name and Status	
(A) <u>TERRESTRIAL</u>		
(i) Trees (cultivated)		
Am	*Mangifera indica*	(C)
Jam	*Syzizium grandis*	(C)
Babla	*Acacia nilotica*	(C)
Ata	*Anona muriatica*	(R)
Bel	*Aegle marmelos*	(R)
Neem	*Azadirechta indica*	(R)
Kadam	*Anthocephalus chinensis*	(R)
Koroi	*Albizia procera*	(C)
Kathal	*Artocarpus heterophyllus*	(C)
Kul	*Zizyphus muritiana*	(C)
Shimul	*Bombax ceiba*	(R)
Khejvr	*Phoenix sylvestries*	(R)
Jiga	*Lannea coromandelica*	(Fc)
Varenda	*Ricinus communis*	(C)
Sisso	*Dalbergia sisso*	(C)
Coconut	*Cocos nucifera*	(C)
Shajna	*Moringa oleifera*	(R)
-------	*Sesbania cannabina*	(R)
Papya	*Carica papya*	(Fc)
Banana	*Musa paradisica*	(Fc)
(ii) Lianas		
Kadu	*Lageneria vulgari's*	(Fc)
Jhinga	*Lufaa acutangula*	(Fc)
Sim	*Vicia faba*	(Fc)
(iii) Herbs (Weed)		
	Solanum melongena	
	Croton bonplandiana	
(B) <u>AQUATIC</u>		
Kalmi		
Khudipana	*Ipomoea aquatica*	(C)
Water Hyacinth	*Lemna perpusila*	(C)
Halencha	*Elchhornia crassipes*	(R)
----------	*Enhydra fluctuans*	(C)
	Potamogeton sp	(R)
	Nymphoids indica	(C)

Fc = Fairly common; C = common ; R = Rare

Table 8.1-3: Plant species of homestead and wetland of the project area, recorded during the field survey of November 1999

Scientific Names	Embankment		Flood plain
	Top	Slope	
Alternanthera sessius		+	
Amaranthus spinosus	+		
Amaranthus viridis	+		
Croton bonplandiana	+		
Cassia tora	+		
Centella asiatica		+	
Cyperus iria		+	
Datura fistusa	+		
Desmodium sp	+		
Euphorbia hirta		+	
Eclipta prostrata	+		
Ludwigia octavalvis			+
Leucas aspera	+	+	
Lippia nodiflora			+
Murdania nodiflora			+
Polygonum hydropiper			+
Polygonum plebejum	+		
Rorippa indica	+		
Rumex maritimus	+		
Solanum nigrum		+	
Trewia polycarpa	+	+	
Xanlhium mdicum		+	

Table 8.1-4 : List of plants noted form the embankment, groynes and flood plain

8.2 TEST SITE II AT BAHADURABAD

8.2.1 Brief Description of Bahadurabad Site

On the left bank of the Brahmaputra-Jamuna river near Bahadurabad, a Revetment Test Structure was built to protect the bank against erosion. The structure had different combinations of various materials. To the east of the revetment structure there is the densely populated village Kulkandi. About 1 km further downstream from the revetment there are Chora khal and Balu khal, which were both silted up in November 1999and winter vegetables are cultivated. About 2 km upstream from the revetment the village Harindhara is situated where bank erosion had increased considerably. After completion of the revetment, the bank erosion had stopped in the project site area. The security and safety of the population have become stronger than before. The project site area, the infrastructure and the living conditions were investigated during the field visit on October 22 to 23, 1999.

8.2.2 Erosion after the Revetment Construction

The revetment structure has fully stopped the bank erosion in the project site area. However, about two kilometres upstream near Harindhara village and about four kilometres downstream from the test site at Ghutail Bazar, bank erosion has increased considerably.

8.2.3 Water Chemistry

Water samples were collected upstream and downstream from the structure. They were analysed for pH, Chloride, conductivity, total dissolved solids (TDS) and total suspended solids (TSS). Furthermore, plankton identification was also done. Water Chemistry did not show any significant differences to samples collected from Test Site I at Kamarjani (see Table 8.1-2).

The plankton species were somewhat different from that at Kamarjani site.

8.2.4 Terrestrial Flora

In the northern part, the density of the plants was higher than in other areas. In addition, through the openings of the cc-slabs grasses and other species are coming out. The floodplain vegetation was found to be basically nil. Cultivation of rice may be done during the winter season when the floodplain is not flooded.

The following flora species were found growing in various sections of the Revetment Test Structure:

- *Amaranthus spinosus;*
- *Solanum xanthocarpum;*
- *Polygonum hydropiper;*
- *Selaginella sp;*
- **Cassia tora;**
- *Cassia occidentalis;*
- *Pauzalzia indica;*
- *Ludwigia octavalvis;*
- *Euphorbia hirta;*
- *Pilea microphylla;*
- *Blumea lacera;*
- *Fern;*
- *Polygonum plebejum;*
- *Eclipta prostrata;*
- *Leucas aspera,* and
- *Murdania nodiflora*

8.2.5 Aquatic Ecology

Near the test site there were some big ditches, which were very poor in aquatic plant community.

8.2.6 Terrestrial Fauna

The area is very rich in homestead and dense plant community. Bamboo bushes and various fruit trees were found in every homestead. Rice and sugarcane cultivation are common and provide good habitat for wildlife.

2+2

9 ENVIRONMENTAL IMPACTS

9.1 TEST SITE I AT KAMARJANI

9.1.1 Physical Impacts (Water)

(a) River Flow

Apart from the Brahmaputra-Jamuna there are two other rivers in the project area, which contribute to the environmental impact. This is the Tista about 8 km upstream from the Groyne Test Structure and the Ghagot river, which is highly active during the monsoon season, just a few hundred metres downstream from the groyne field. Furthermore, there are other Flood Control and Drainage Projects (FCD) in the region and hence a cumulative impact was highly significant.

Compared with the dimensions of the Brahmaputra-Jamuna river, especially during the monsoon season, the size of the Groyne Test Structure is small only. However, its impact on the river flow is very strong, not only just at the test site, but also upstream and downstream from it. The main parameters are the discharge, the flow velocity, the water levels, the rate of rise and fall of the latter as well as the duration of the different water levels.

The groyne field divert the flow and has hence **positive impacts** within the test site area. People of Dhutichara and adjacent villages, which are protected by the structure, have expressed their satisfaction at this Project. They are of the opinion that if the groyne field was not built, another unfavourable river channel diversion would have taken place and would have washed away their homesteads and agricultural lands. This actually happened downstream from the structure from Rasulpur village to Balashi ghat.

(b) River Quality

Key parameters for the quality of a river are the sewage, the content of agro-chemicals, the sediment load and the salinity. The scale of the Project relative to the dimension of the river precludes any significant impact. There has been some increase in the use of agro-chemicals as HYV cultivation has increased. Maybe, the population growth would also have occurred without the project, but the structure has increased the stability of the entire area and hence the number of homesteads, because the population feel safer after construction of the groynes. Sanitation standards do not seem to be better than in other stretches along the river. Salinity is not an important factor in this high rainfall area.

(c) River Morphology

The high flow velocity of the river, especially during the monsoon, has a strong influence. The river morphology is strongly affected such as bank erosion upstream and downstream from the Project, siltation and scouring. Morphology of the Ghagot river is also controlled by the Jamuna, particularly in the monsoon season when the water level in Jamuna remains high. This does not only hinder the discharge of the Ghagot river, but creates also back flow .

As the Jamuna is a braided river; char formation is a common feature. The groyne field itself has no effect on char formation, but only on the location of chars.

(d) Flooding and Drainage

The objective of the Project was to protect the right bank of the Brahmaputra-Jamuna in the Kamarjani area against erosion, but not to provide any flood control for the villages and adjacent areas in the hinterland. Since the erosion had been stopped in 1995 by the structure, the entire area has benefited from the Project in this regard. Hence, this is a **major positive impact** on the environment.

(e) Groundwater Levels/Recharge

The groundwater level and the recharge of groundwater does not only depend on the Brahmaputra-Jamuna river, but also on the Ghagot river and the Manos river. Early flooding by the Brahmaputra-Jamuna is prevented by the groyne structure, but on the other hand the duration of flooding has possibly increased by the construction of the new Manos regulator, which allows generally a controlled drainage of the hinterland, if properly operated. Since apparently the duration of standing water has not changed, there is no positive or negative impact on the groundwater by the test structure.

(f) Groundwater Quality

The groundwater quality is not affected by the new structure. Actually, the use of the agricultural land could be intensified, because it is well protected by the groyne structure, but it is unlikely that the increased use of agro-chemicals is enough to pose a threat to the groundwater quality, especially with regard to the slow percolation through the upper cohesive soil layers.

(g) Wetland and Water Bodies Extent/Recharge

Wetland areas of the attached villages behind the structure and Pakhimari beel are unaffected, as they are flooded as previously. The extent and recharge of the feed in these areas is decreased slightly, but they still accumulate rainfall runoff, hence **no significant impact** arises.

The borrow pits attached to the embankment of the test structure has possibly increased wetland areas. This is due to drainage congestion caused by the embankment and also by the new Manos regulator Thus, a **minor positive impact** on wetland is registered. But this has negative implications for the farmers concerned.

(h) Wetlands and Water Bodies Quality

Most of the increased use of agro-chemicals drains in the borrow pits and beel areas. Other pollution caused by the dense population might also accumulate. The main problem for an assessment is the fact that no reliable data exist. Therefore, it is assumed that the use of agro-chemicals has increased to such an extent to cause a significant impact. Sewage and other human pollution also seem to be a problem in the this area.

9.1.2 Physical Impacts (Land)

(a) Soil Fertility

In Bangladesh natural soil fertility is primarily related to aquatic vegetation and blue green algae and other organisms. The death and decay of aquatic plants provide organic matter (detritus) and blue green algae (Nostoc, Scytonema) provide nitrogen. In addition, annual sediments by river floods are also considered as a source soil fertility (FAO 1988). The farmers of Bangladesh believe that river silt is vital in this respect.

Assuming the above to be correct, it is the extent of inundation and resulting aquatic vegetation that is very important. The extent of flood duration of the hinterland does not seem to have changed significantly. Hence, no impacts in general on natural fertility are assessed. However, in borrow pits water stagnation remains 6 to10 weeks more where aquatic vegetation flourishes and impact of soil fertility in borrow pits is minor positive. The annual artificial increase in soil fertility by applied fertilizations is ignored, since it is largely consumed by crops or leached/washed away each year.

(b) Soil Physical Characteristics

Significant changes were noted only on the riverine areas. Strong deposition of sand in and around the project side was noted. Hence, moderate negative impact was given in riverine areas and partly on the floodplain.. **No significant impacts** have occurred in the hinterland and thus in cultivated areas.

(c) Soil Moisture Status

In this respect flood timing is an important parameter. The decreased flooding of the hinterland has improved the soil moisture status with improved drying off without any danger of doughtiness due to the poorly permeable soils. Early over wetting of soils is now avoided as the bank is protected by the groyne structure and soil moisture can be maintained into the dry season much longer. In addition, it increases the opportunities also for increased irrigation in many parts. **Moderate positive impacts** are noted.

(d) Soil Erosion

The erosion of the river bank has been stopped by the groyne structure. The villages Anelachara and Dhutichara are well protected against erosion, which is acknowledged by the local population. Hence a major positive impact is given.

The fact that the old project-camp and Rasulpur village were washed away, cannot be connected with the construction of the groyne field.

(e) Land Capability

Although the embankment causes some drainage congestion in the surrounding cultivated lands, a moderate positive impact is to be stated. The cultivated land behind the structure is now well protected. Thus, the land capability is higher than before, also due to the improved status of soil moisture. Moreover, water for irrigation is also available from the borrow pits.

Only in the external riverine areas and the floodplain between the groynes a minor negative impact results from sand deposition.

(f) Land Availability

No permanent loss or gain of land in the riverine areas of the Project has been observed. The char formation is normal. Thus, **no significant impact** is noted.

9.1.3 Assessment of Physical Impacts

The assessment of physical impacts on the environment is summarised in the following table:

Physical Issues	Environmental Impacts		
	Project Area	Downstream	Upstream
River Flow	+ 1	- 1	- 2
River Quality	- 1	0	0
River Morphology	0	0	0
Flooding and Drainage	0	0	0
Ground Water Levels	0	0	0
Wet Land and Water Bodies	0	0	0

Table 9.1-1: Summary of physical impact assessment

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Physical Issues	Environmental Impacts		
	Project Area	Downstream	Upstream
Soil Fertility	+ 1	0	0
Soil Physical Characteristics	0	- 2	0
Soil Moisture Status	+ 2	0	0
Soil Erosion	+ 1	- 1	- 1
Land Capability	+ 2	- 1	- 1
Land Availability	0	0	0

Table 9.1-1 (continued): Summary of physical impact assessment

As to the scaling in Table 9.1-1 reference is made to Chapter 6.

9.2 TEST SITE II AT BAHADURABAD

9.2.1 Physical Impacts (Water)

(a) River Flow

The size of the Revetment Test Structure in comparison with the dimensions of the Brahmaputra-Jamuna river is small only, but has a significant effect on the diversion of the water flow during the monsoon. The diversion of river flow has strong positive impacts within the project area. The erosion has been stopped and the village Kulkandi is well protected by the structure, whereas the erosion process continued upstream and downstream from the new revetment.

(b) River Quality

Sewage, agro-chemicals and sediment have no significant impacts. Since the revetment has shown the stability in the area, the number of homestead has increased and the population accordingly. Salinity is not a factor in this area at present.

(c) River Morphology

The river morphology is strongly affected by the revetment structure. Bank erosion in the project area has been stopped, but is still going in upstream and downstream areas just as the permanently changing siltation and scouring process.. However, the structure itself does not influence the char formation, but of course the location of developing chars.

(d) Flooding and Drainage

The objective of the Project was to protect the left bank of the Brahmaputra-Jamuna in the area of Kulkandi against erosion, but not to provide flood control for the village and adjacent areas in the hinterland. Since the erosion has been stopped by the structure, the entire area has benefited from the Project This is a **major positive impact** on the environment.

(e) Groundwater Levels/Recharge

The extent and duration of flood water/standing water level have not influenced by the new structure. Hence, there is no impact on the groundwater level and its recharge.

(f) Groundwater Quality

Although the use of agricultural land could be intensified, because the area is well protected by the revetment structure, fertilizers and other chemicals are not a threat to groundwater quality.

(g) Wetland and Water Bodies Extent

No significant impacts were observed. The borrow pits which were noted in 1995 were washed by the river before the revetment has been built. However, there are still some ponds/wetland areas in the village attached to the project, but they lack dense aquatic vegetation.

9.2.2 Physical Impacts (Land)

(a) Soil Fertility

As already mentioned earlier in this Annex the revetment structure is small in size and has only a negligible impact on land inundation, which is again related to the growth of aquatic plants. Especially, blue green algae (nitrogen fixation) and aquatic plants (organic matter) increase soil fertility. Hence, no impacts on natural fertility of soil can be taken into account.

(b) Soil Physical Characteristics

There are changes only in the riverine areas. Since waves break after hitting the revetment, deposition of sands and silts in the riverine sites were noted. Both positive impacts (silt deposition) and negative impacts (sand deposition) were observed.

(c) Soil Moisture Status

No significant impact was observed, since there is no difference in flooding of the hinterland before and after construction of the revetment.

(d) Soil Erosion

The erosion of the river bank has been stopped by the revetment structure. The village Kulkandi is well protected against erosion, which is acknowledged by the local population. Hence, a major positive impact is given.

The fact that the erosion process continues in upstream and downstream areas, cannot be connected with the construction of the revetment test structure.

(e) Land Capability

The cultivated lands and homesteads are definitely protected by the new structure. The safety of the entire area is improved. Hence, a **moderate positive impact** is given.

(f) Land Availability

There has been no loss of land by bank erosion in the project area after completion of the structure.

9.2.3 Assessment of Physical Impacts

The assessment of physical impacts on the environment is summarized in Table 9.2-1. As to the scaling reference is made to Chapter 6.

Physical Issues	Environmental Impacts		
	Project Area	Downstream	Upstream
River Flow	+3	-1	-2
River Quality	0	0	0
River Morphology	0	0	0
Flooding and Drainage	0	0	0
Ground Water Levels	0	0	0
Wet Land and Water Bodies	0	0	0
Soil Fertility	0	0	0
Soil Physical Characteristics	0	-2	0
Soil Moisture Status	0	0	0
Soil Erosion	+1	-1	-1
Land Capability	+2	-1	-1
Land Availability	0	0	0

Table 9.2-1: Summary of physical environmental impact assessment

10 BIOLOGICAL ENVIRONMENTAL IMPACTS

10.1 TEST SITE I AT KAMARJANI

10.1.1 Preliminary Remark

Any attempt to assess the biological impacts of this Project has to take into account parallel trends, which started to develop long before the planning and implementation of the Project. Essentially, there are trends associated with the accelerated increase of the population which causes pressure both on physical resources which provide biotic habitats and on the biotic communities themselves. Cultivation, land settlement, vegetation clearance, hunting and fishing have all increased as population density has soared up over the last few decades.

Realistic assessments of the relatively recent project impacts are therefore unlikely to reveal the excessive ecological damage claimed by many detractors of the development planning process. The uncontrolled development and population growth in the past has already wreaked ecological havoc in most parts of Bangladesh.

10.1.2 Biological Impacts (Flora)

(a) Trees

The tree population in the project area has not been significantly affected except possibly in the riverine area where a substantial amount of trees has been washed away. It is not sure what would have happened without the groyne project. Local people are of the opinion that without the groynes the erosion and devastation would have continued as before. The embankment of the new structure has provided scope to plant trees. However, no attempt has yet been made to take advantage of the embankment for afforestation.

(b) Other Terrestrial Vegetation

The widespread planting of *Ipomoea crassicaulis* (Dulkalmi) has been noted. It seems that the plant is propagating itself naturally on some stretches of the embankment resulting in minor negative impacts.

(c) Aquatic Vegetation

Before the Project the communities and habitats concentrated in the Pakhimari Beels. After completion of the structure a number of borrow pits provided the opportunity to form dense vegetation of aquatic plants (*Ipomoea* sp, *Eichhornia* sp. and *Nymphaea* sp. etc.). Hence, there is minor positive impact within the project side in this regard. Upstream and downstream from the project area, the virtually unchanged extents of seasonal wetlands cause no significant impacts.

10.1.3 Biological Impacts (Fauna)

The main problem in evaluating impacts of either population growth or the Project on all fauna considered in this subsection is the lack of data from the past. Old aged people mentioned that birds, fish and other wild animals particularly in the Pakhimari Beel and also in the Jamuna river flourished in large numbers. But no quantified baseline data are available. Thus, all assessments in this subsection are based on assumptions and interference regarding past biotic baselines.

(a) Bird Communities

In the past in the wetlands of Pakhimari Beel must have provided a heaven for both local and migrant water birds. Only sporadic bird life can be observed nowadays, even in late November when the international waterbird migration is well underway.

No significant impact can be ascribed to the Project. The wetland habitats had been completely disturbed before the project activities were started by fishing, grazing and cultivation practices.

(b) Fish Communities

Both fish communities and habitats were subject to long term trends out of which with human activities were the dominant factor in fish ecology. In the absence of adequate data, the assessment given here, is that overfishing has in recent years led to a critical reproductive threshold being passed. The number of fishermen has increased and is using every conceivable method of catching every fish, irrespective of size and stage of growth. It seems that fish population can not longer maintain themselves against such pressure.

Before the construction of the Brahmaputra-Jamuna right embankment, Pakhimari Beel provided large amount of fish to the local market. As a result of the construction, fish resource remained only in some pockets of the wetland of Pakhimari Beel, which in turn, however, are dry out between the monsoon seasons.

On the positive side, it is observed that the increased number of borrow pits caused by the Project encouraged local people to stock the area with fingerlings to harvest after six months and so obtaining a substantial catch and profit.

The Project area and its limited pre-project fishing activities are too small to affect significantly the river fisheries. Again, the fish population is reported to be down but probably due to overfishing and disease.

Local people reported that during the monsoon, fish catches in the groyne area are more than before. It is assumed that the fishes probably visit the groynes for shelter and the proportion of catch is high.

In general, a minor positive impact is assumed.

(c) Other Macro-fauna Communities/Habitats

As a result of the population pressure most terrestrial fauna decreased to negligible or low levels. Embankments provide an excellent habitat for rodents and rat population. Snakes also take advantage of using rat holes, but no increase in the snake population was reported.

10.1.4 Assessment of Biological Impacts

The assessment of biological impacts on the environment is summarized in Table 10.1-1. Regarding the scaling reference is made to Chapter 6.

Biological Issues	Environmental Impacts		
	Project Area	Downstream	Upstream
FLORA			
Trees	0	0	0
Other Terrestrial Vegetation	- 1	0	0
Aquatic Vegetation	+ 1	0	0
FAUNA			
Fish Communities	0	0	
Bird Communities/Habitats	0	0	0
Other Macro Fauna Communities	0	0	0
Micro Fauna Communities	0	0	0

Table 10.1-1: Summary of biological impact assessment

10.2 TEST SITE II AT BAHADURABAD

10.2.1 Preliminary Remark

Although the high population density creates complication to assess any impact occurred due to the Project, some impacts are discussed in the following subsections.

10.2.2 Biological Impacts (Flora)

(a) Trees

The tree population in the project area has shown an increasing tendency. In the past, each year during the monsoon homesteads and trees were washed any. After the revetment construction the erosion has stopped. Therefore, the revetment has provided the opportunity to plant more trees. Hence, a moderate positive impact is assessed.

(b) Aquatic vegetation

Aquatic vegetation is poor. The Project did not show any impact.

10.2.3 Biological Impacts (Fauna)

Already in the past the area had dense vegetation in every homestead. After the erosion has stopped, there is an opportunity to plant even more trees in the homesteads, which will facilitate the conditions for birds and wild animals.

(a) Bird Communities

Due to the presence of homestead plants the Bahadurabad site is rich in bird fauna. Further 5 to 6 km to the east, a number of wetlands were noted, which are used for *Trapa* cultivation. These wetlands provide good habitat for bird communities. The project gave an impetus for bird life and a minor positive impact is assessed.

(b) Fish Communities

The area behind the structure is flood free. Fish cultivation is safe. After the revetment construction, fish culture in the ponds increased. Riverine fishery did not hamper due to the project.

10.2.4 Assessment of Biological Impacts

The assessment of biological impacts on the environment is summarized in Table 10.2-1. Regarding the scaling reference is made to Chapter 6.

Biological Issues	**Environmental Impacts**		
	Project Area	**Downstream**	**Upstream**
FLORA			
Trees	+1	0	0
Other Terrestrial Vegetation	+1	0	0
Aquatic Vegetation	0	0	0
FAUNA			
Fish Communities	0	0	
Bird Communities/Habitats	0	0	0
Other Macro Fauna Communities	0	0	0
Micro Fauna Communities	0	0	0

Table 10.2-1: Summary of biological impact assessment

11 HUMAN ENVIRONMENTAL IMPACTS

11.1 TEST SITE I AT KAMARJANI

11.1.1 Preliminary Remark

Some of the most important impacts of the Groyne Test Structure are those affecting the human environment. This is inevitable in one of the most densely populated areas in the world, where the pre project environment was already essentially an anthropogenic one.

Most of the human issues are covered in detail in other chapters of this report. They can be grouped into five categories:

- human use;
- social;
- economic;
- institutional, and
- cultural issues.

Most of them are discussed briefly only and summarised below in Table 1.1-1at the end of this section.

11.1.2 Human Use Impacts

(a) Crop Cultivation

The following positive impacts of the structure within the test site area can be established:.

- the villages Dhutichara and Anelarchara as well as their hinterland are fully protected by the groyne field and crop cultivation is safe, in particular during the pre-monsoon and the monsoon season. In addition, there has been an increase in irrigation from borrow pits. Hence, a moderate positive impact on crop cultivation is given.

- downstream from the groyne structure the erosion continues resulting in destruction of crop lands. This fact, however, can not be attributed to the new structure. On the other hand, vast areas of char lands in the riverine area provide an opportunity to produce rice seedlings and also to some extent rice.

(b) Livestock

The increased rice cultivation has of course reduced the area of pasture for livestock. Pakhimari beel provided in the past considerable growth of *Eichhornia crassipes*, which was used as livestock feed. At present, however, it is dried up and rice cultivation is done. Increased rice production generally has increased supplies of straw and the capacity to purchase supplementary feed. In general, there seems to be a slight negative impact on animal numbers and health.

(c) Fisheries

This issue has to a large extent been covered in the discussion on fish communities and habitats. The same findings, albeit tentative, apply to fisheries. No significant impact can be attributed to the Project, taking into account the trends of over fishing and in recent years and fish disease.

(d) Fish Culture

Slight increase in fish culture in the borrow pits within the project site area is noted. Some fishes are also dried for future consumption and indicates that fish supply is surplus. This can be considered as positive impact.

(e) Afforestation

Some increased tree planting has been seen after completion of the groyne structure, but this is unlikely to be significant..

(f) Transport Communications

Complaints of the local population about the disturbance of boat communications are not be attributable to the new structure, since the Brahmaputra-Jamuna right embankment had to be built in any case. The latter even allows an improved access by foot or even by vehicle. Only during the monsoon season i.e. for a period of 8 to 12 weeks the operation of country boats within the groyne field might be dangerous to a certain extent.

(g) Infra structure

The project has definitely provided some protection to housing and schools, e.g. a technical school cum college (Rahman Nagar Technical School and College) has been built. This may have resulted from an exaggerated sense of security having led to building in areas that seem not to be at risk. A minor positive impact is assessed.

(h) Sanitation

The main problem in this regard is the cessation of flushing out during the flood season. No data, however, are available to identify any negative impact. The general awareness of the problem and the widespread use of latrines in areas and where settlement is concentrated suggests that no significant impact occur.

(i) Recreation

People believe that without the groynes their houses and assets were washed away. They are mentally happy and passing life in safety. No other activities are noted.

11.1.3 Social Impacts

(a) Human Carrying Capacity

The increased land capability and the resulting increase in crop production have raised the human carrying capacity, basically due to the better land erosion control with negative impact in the riverine areas. Upstream and downstream from the project area, however, the impacts are not positive.

(b) Demography

Since the groyne structure has stopped the encroachment of land by the mighty Jamuna river, the immigration of people has shown a tendency to increase. Hence, demographic structures and trends are perhaps slightly affected in the project area. as. This is only a minor positive impact.

(c) Age

No discernible impact arises, unless the increased agricultural activity offers more employment of the old or takes children out of school too early. Such impacts are unlikely to be significant.

(d) Health and Nutrition

Since the erosion has been stopped in the project area, the cultivation could be increased in the following years and hence also the food supply. This is of course a benefit, which is to be attributed to the Project.

Moreover, the increased food protein due to increase of fishes in the borrow pit areas for a short period in late winter has increased definitely the fish protein supply to the population. No new health problems were reported due to the Project.

(e) Disturbance, Safety and Survival

The threat to safety and survival seem to have been particularly great in the project area. There must have been some seasonal disturbance during project activities. This disturbance would have been greater than the present one without groynes.

(f) Equity

The number and size of relatively large holdings are low. The Project has clearly benefited the poor people in the project area. Only the problem lies with the boatmen and fishermen who have suffered (4 to 8 weeks). However, in general a slight positive impact is recorded.

(g) Social Attitude

A good deal of overall approval within the Project was found. Specific enhancement notably fisheries, crop cultivation and safety of homesteads were attributed to the Project. People feel that they have benefited substantially. Moderate positive impacts were assessed.

11.1.4 Economic Impacts

The three main potential economic impacts on the people are on incomes, employment and land owners. These all have received slight positive impacts in the project area, generally in proportion to the impacts on crop production. This is not a significant one for long term analysis.

11.1.5 Institutional Impacts

In defining institutional impacts by the Project, positive impacts are recognised where performance exceeds the planned levels and achievements and negative impacts where these fall short. Institutional impacts arise, therefore due to the success or otherwise of project management. On this basis institutional activities and effectiveness have suffered a slight negative impact. Operation and maintenance cause problems especially with regard to the impermeable part of the groyne.

11.1.6 Cultural Impacts

The project did not affect scenic qualities or other aesthetic consideration. Cultural continuity seems unaffected.

11.1.7 Assessment of Human Environmental Impacts

The assessment of human environmental impacts is summarised in Table 11.1-1. As to the scaling reference is made to Chapter 6.

Human	Environmental Impacts		
	Project Area	Downstream	Upstream
Human Use			
Crop Cultivation	+2	-1	-1
Livestock	-1	-1	-1
Fisheries	+1	0	0
Fish Culture	+1	0	0
Afforestation	0	0	0
Transport Communications	-1	0	0
Infra structure	+1	0	0
Sanitation	0	0	0
Social			
Human Carrying Capacity	0	0	0
Demography	+1	0	0
Age	0	0	0
Health and Nutrition	+1	0	0
Disturbance, Safety and Survival	0	0	0
Equity	0	0	0
Social Attitude	+1	0	0
Economic Impacts	0	0	0
Institutional	-1	0	0
Cultural	0	0	0

Table 11.1-1: Summary of human environmental impact assessment

11.2 TEST SITE II AT BAHADURABAD

11.2.1 Preliminary Remark

The comments made in Subsection 11.1.1 for Kamarjani Test Site are also true for the second test site at Bahadurabad.

11.2.2 Human Use Impacts

(a) Crop Cultivation

The positive impacts of the revetment structure are noteworthy. The village Kulkandi is fully protected from erosion. Sugar cane, rice and vegetable cultivation have increased.

(b) Livestock

The increased crop cultivation has decreased the area of pasture lands. Only rice straw is dried and stocked for cattle's food.

(c) Fisheries

Riverine fishery does not show any impact. There are too many fishermen in the riverine area. Over fishing is definitely going on. It was noted during the field visit that fishermen are using all kinds of instruments to catch fish for their livelihood.

(d) Fish Culture

No significant impact was observed. As bank erosion has stopped, no more loss of ponds will occur. Before the Project there was a big pond in the project area, which was washed away in 1996 by the strong river flow.

(e) Afforestation

After completion of the new revetment, the Project has planted new trees behind the structure and the local people did the same in their homesteads.

(f) Transport Communications

No complains about boat communication was found. Inside the project areas un-metalled roads are safe as erosion has stopped.

(g) Infrastructure

The Project has given some protection to housing, schools and cultivated lands. This has minor positive impact.

(h) Sanitation

No data are available to assess any negative impact. It is assumed that no significant impacts occurred.

(i) Recreation

People of Kulkandi village are happy and passing there life safely. No other activities are noted.

11.2.3 Social Impacts

(a) Human Carrying Capacity

Within the Project area the land capability has increased and also crop production is safe.

(b) Demography

The immigration of people has shown an increasing tendency as bank erosion has stopped.

(c) Disturbance, Safety and Survival

Both threat and safety have become stronger than before. Some lands and houses were lost due to the project.

11.2.4 Economic Impacts

Incomes, employment and landowner have received slight positive impact.

11.2.5 Assessment of Human Environmental Impacts

The assessment of human environmental impacts is summarised in Table 11.2-1. Regarding the scaling reference is made to Chapter 6.

Human	Environmental Impacts		
	Project Area	Downstream	Upstream
Human Use			
Crop Cultivation	+2	-1	-1
Livestock	-1	-1	-1
Fisheries	+1	0	0
Fish Culture	+1	0	0
Afforestation	+1	0	0
Transport Communications	0	0	0
Infra structure	+1	0	0
Sanitation	0	0	0
Social			
Human Carrying Capacity	0	0	0
Demography	+1	0	0
Age	0	0	0
Health and Nutrition	+1	0	0
Disturbance, Safety and Survival	0	0	0
Equity	0	0	0
Social Attitude	+1	0	0
Economic Impacts	0	0	0
Institutional	-1	0	0
Cultural	0	0	0

Table 11.2-1: Summary of human environmental impact assessment

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