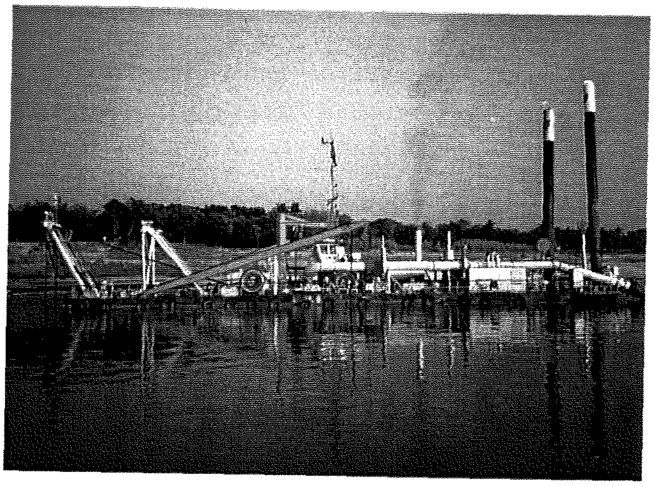
Morphological response to dredging of the Upper Gorai River




Main report

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September 2001

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In February 2001 I visited the project area of the Gorai River Re-excavation Project in Bangladesh. During this period I collected the data for my study and I gained ample insight into the project. This period was very motivating and proved to be fruitful throughout the subsequent study period. Therefore I would like to thank all people I met in Bangladesh, who helped me with my thesis and who gave me such a pleasant stay.
First the Bangladesh Water Development Board, represented by Mr. Hasan Zubair, who gave me the permission for my visit.
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Alice Clijncke
September 2001

ABSTRACT

Introduction

The Gorai River is a tributary of the Ganges River and is the only river in the Southwest region of Bangladesh, which provides fresh water from upstream. In the past decades the flows in the Gorai River have been decreasing. From 1988 on, the flows in the lean season were even reduced to zero, due to heavy sedimentation in the off-take.

In 1996 the government of Bangladesh initiated the Gorai River Restoration Project (GRRP). The main target of the GRRP is to augment the flows in the Gorai River and to ensure flow in the dry season. Until a permanent solution can be realised, a channel is dredged during the falling stage of the water level to keep the Gorai River flowing. With the Pilot Priority Works, an immediate improvement has been realised and valuable insight into the response of the river to dredging is gained.
During the dredging works data has been collected on the Gorai River and the off-take, consisting of measurements of the bed topography, water levels, discharge and sediment transport. In this report the data from April 1999 to April 2001 are used to study the morphological response to dredging. For the analysis, the GIS application ArcView with the Spatial Analyst is used. Besides a qualitative analysis, the effects of dredging are studied based on an analysis of the change in the cross-sections of the river and its effect on the discharge and the sediment transport capacity. Moreover, the sediment balance is extrapolated to include the effect of future maintenance dredging.

Data analysis

The analysis is mainly based on bed level measurements. The study area covers 31 kilometres of the Upper Gorai River from the off-take. From these 31 kilometres, the upstream 17 kilometres have been dredged in the past three dredging seasons. The data sets of the bed levels consist of cross-sections of the river. In this study three data sets have been used:

- Data from November 1997,which relates to the conditions before the dredging intervention.
- Data of the submerged part of the river beds from April 1999 to January 2001, with an interval of two weeks to one month.
- Data covering the full width of the river of April 1999, 2000 and 2001.

For the analysis, the river bed and the deposition and erosion are visualised in ArcView and sediment balances, based on last two data sets mentioned above, have been made. The balance based on the data sets with the submerged river bed resulted in net deposition, while the data set based on the full width of the river resulted in net erosion. This difference is most likely caused by the combination of two different data types and the difference in accuracy of the two types of data. Further study on the cause of this difference is required. The conclusions in this study are mainly based on the results of the combined hydro and topo data sets, since these sets cover the full width of the river and are considered to be the most accurate.

Development of the Gorai River from April 1999 to April 2001

In the analysis several effects of the dredging strategy are studied.

Stability of the alignment
The alignment is changed each dredging season, depending on the experiences gained through the years. The alignment is usually located at the natural location of the low water channel. At two locations important changes in the alignment have taken place: near the Kushtia groynes and upstream the Gorai Railway Bridge. In the latter case the alignment was stable in 2000. The low water channel near the Kushtia groynes still moves towards the outer bend where the groynes are located. In order to protect the river banks and for practical reasons the location of the alignment in both stretches are optimal.

Area below Standard Low Water
Upstream the Gorai Railway Bridge and in the off-take, the river bed returns to the Standard Low Water level or even above this level. Therefore these two locations remain to be the bottlenecks in the Upper Gorai River. Especially in the off-take retarded scour diminishes the height of the bar with falling water levels. The period in which the water levels drop is therefore of major importance for the off-take area. In the past retarded scour was able to lower the bar level to a level below SLW, and therefore the Gorai River remained flowing. The stretch upstream of Gorai Railway Bridge has less self scouring capacity and therefore requires dredging in an early stage.
At Kp 24.0, which is downstream the Kumarkhali groyne, and around Kp 27.0, shallow points are developing. However, these locations are not likely to lead to downstream blockage of the river. Extra attention could be paid to these locations in the future.

Annual sediment balance
From both the annual balance and the balance over the monsoon it can be concluded that the dredging strategy of the third season has a more positive effect on the Gorai River than the second season. For both the second and the third season net erosion is found in the sediment balances, which corresponds to an improvement of the conditions in the Upper Gorai River.

Deposition and erosion patterns
The sediment balances indicate net erosion over the monsoon and over the hydrological year. However, deposition is found in the low water channel when studying the deposition and erosion patterns. This can be explained by lateral diffusion and flow from the higher lying areas towards the low flow channel. Both processes cause more gentle slopes of the low water channel and therefore deposition in the low water channel and erosion on both sides of the low water channel.
Another important observation that is made, from studying the deposition and erosion patterns, is the formation of a bar in the off-take over the full width of the low water channel. The flow velocities in the Ganges River are higher than in the Gorai River. The difference in flow velocities between the Ganges River and the Gorai River causes this deposition in the off-take.

Effects of dredging on the sediment transport

Dredging with deposition within the banks of the river is a means of reducing the width of the river, and therefore augmenting the flow velocities and the sediment transport. A study on this effect of dredging is carried out with data sets for November 1997 and April 1999, 2000 and 2001, which can all be counted to the low water period. The situation at the end of the monsoon, in this case September 1999 and 2000, is also studied, in order to describe the return of the cross-section to the situation without dredging.
In the dredged stretches for all discharges an augmentation of the sediment transport capacity is found compared to the situation of November 1997. For high discharges (> 800 m^3/s) the sediment transport capacity is enlarged over the dredging seasons, while for low discharges the sediment transport capacity has slightly decreased over the dredging seasons. For the part of the Upper Gorai River where no dredging activities have taken place the sediment transport capacity has slightly decreased over some of the dredging seasons. The combination of increased discharges and increase hydraulic slopes may still lead to net erosion in this part of the Upper Gorai River.
In general it can be concluded that the dredging works become more and more effective, also over the monsoon.
In this study a constant hydraulic slope and bed roughness is used for the dredged part and the part of the river where no dredging activities have taken place. In the Upper Gorai River the variation in both parameters in space and time is large. Therefore, in practice, different values for the discharge and the sediment transport can be found for the separate stretches.

Effects of future maintenance dredging

In view of the positive effect that dredging has on the Upper Gorai River, maintenance dredging should be considered as a serious option for the long-term solution. The effect of dredging on augmentation of the sediment transport has not yet reached its maximum.
The dredging activities determine the outgoing sediment in the sediment balance. The incoming sediment is mainly determined by the planform of the Ganges River upstream of the off-take. From a study on the planform of the Ganges River, in combination with the relative sediment intake in the Gorai River, it was found that the maximum sediment intake is occurring at this moment. A trend in sediment intake would predict a decrease or at most an equal sediment intake in the future.

VOLUME 1: MAIN REPORT

VOLUME 2: APPENDICES

Number of pages

SYMBOLS AND ABBREVIATIONS

B	[L]	width
C	$[L^{1/2}T^{-1}]$	Chézy co-efficient
c_b	$[LT^{-1}]$	celerity of disturbance
D_{50}	[L]	average grain diameter
Fr	[-]	Froude number
h	[L]	water depth
i	[-]	hydraulic slope
IP	[-]	Interaction Parameter
Lp	[L]	wave length
m		factor in sediment transport formula, dependent on formula
n	[-]	scale factor
Q	$[L^3/T]$	discharge
s	$[L^2/s]$	sediment transport per unit width
S	$[L^3/s]$	sediment transport
t	[T]	time
T	$[L^3]$	sediment volume
u	[L/T]	flow velocity
u_*	$[LT^{-1}]$	shear flow velocity (x-direction)
w_s	$[LT^{-1}]$	fall velocity
θ	[-]	(approach) angle
θ	[-]	Shields parameter ($u_*^2/\Delta gD$=$hi/\Delta D$)
μ	[-]	ripple factor; correction co-efficient
Δ	[-]	relative density (ρ_s - ρ/ρ)
λ_s	[L]	adaptation length of the sediment transport
λ_w	[L]	adaptation length of the water movement

BWDB	Bangladesh Water Development Board
ADCP	Acoustic Doppler Current Profiler
bl	bed level
DGPS	Differential Global Positioning System
EGIS	Environmental and GIS Support Project for Water Sector Planning
FAP	Flood Action Plan
FAP 4	Southwest Area Water Resources Management Project
FAP 24	River Survey Project
GIS	Geographical Information System
GRB	Gorai Railway Bridge
GRC	Gorai River Contractors
GRRP	Gorai River Restoration Project
Kp	Kilometre point
MSL	Mean Sea Level
PPW	Pilot Priority Works
PWD	Public Works Datum
RIZA	Rijksinstituut voor Integraal Zoetwaterbeheer en Afvalwaterbehandeling
SLW	Standard Low Water
SWMC	Surface Water Modelling Centre
wl	water level
1D	one dimensional
2D	two dimensional
3D	three dimensional

1. INTRODUCTION

1.1. *Scope*

The Gorai river is a tributary of the Ganges. It is the only main river flowing through the Southwest Region of Bangladesh, providing fresh water from upstream, and is therefore an important source of fresh water for that region. For the last 20 years the discharge in the dry season (January-May) in the Gorai River has been decreasing, resulting in increasing salt-water intrusion. The salt-water intrusion has a negative environmental impact. The increase of concentrations of salt in the water is a serious threat to for the Sunderbans, which is the largest mangrove forest in the world.

Another aspect of the decreasing flows is that this will add to the siltation of the off-take of the Gorai channel to an extent that the river may be permanently disconnected from the Ganges. In the years 1988 to 1998 the river even dried up completely during the dry season. The balance between sediment supply in the off-take and transport capacity of the Gorai is disturbed, since the building of Farakka Barrage, which is situated 110 kilometres upstream from the off-take on the Indian side of the border. The sediment supply during the monsoon increased while the flows and therefore the transport capacity in the dry season decreased. This disturbed balance is seen as the major cause of the problems.

In order to improve the socio-economic circumstances and to prevent environmental degradation of the Southwest Region, the Gorai River Restoration Project has been started. The main objective of this project is to prevent salt-water intrusion by ensuring fresh water flows in the wet season, and augmenting these flows in the dry season.
The way this objective will be met is by creating a continuous flow into the Gorai river. Until a long term solution can be realised, a channel is dredged during the falling stage of the water level to keep the Gorai flowing. This is called the Gorai River Re-excavation Project or Pilot Priority Works.

During the dredging works data has been collected on the Gorai River and the off-take, containing bed level measurements of cross-sections, hydraulic slopes of the river sections and discharges. With these data the morphological response to the dredging works can be analysed.
The Gorai River Re-excavation Project, or Pilot Priority Works, is the basis of this thesis study: Study on the morphological response of the Upper Gorai River to dredging. Witteveen+Bos, who supports the employer with technical and contractual matters and has the supervision of the dredging works, proposed the subject and provides the technical support for this study.

1.2. Objective

There is a need for more knowledge on the morphological development of the Upper Gorai River. Mathematical models and a one dimensional analysis with data from the dredging season 1999-2000 have already been made for prediction of the dredging volumes and reaction of the river on dredging. A two dimensional analysis would contribute to the understanding of the morphology of the Gorai River. With the available data that were measured during the survey campaign, this two dimensional analysis can be made with the programme ArcView. The results of the two dimensional analysis can be used for the implementation of a prediction tool for dredging volumes and response of the river to dredging. This leads to the title of this thesis study:

Morphological response to dredging of the Upper Gorai River

In this study the following questions will be answered:
- What are the effects of dredging on the morphology of the Upper Gorai River?
- Does the dredging intervention, which leads to a reduction of the river width, have a positive effect on the annual sediment balance of the Upper Gorai River?
- If the present maintenance dredging would be continued, what would be the effect on the morphology of the Upper Gorai River and the functioning of the off-take in the future?

In this study the effects of the dredging works on the morphology of the Gorai are described and studied. The data resulting from the survey campaign for the years 1999/2000 and 2000/2001 are used for this purpose. As such this study is a continuation of the earlier study by Mamun (2000 [15]). Improvements over this study are that also the data from the dredging season 2000/2001 are used, while as the tool for the analysis here ArcView is used, whereas Mamun did his analysis using spreadsheets.

1.3. Restrictions and assumptions

- This report concentrates on the morphological effect of dredging. The effect on the salt intrusion is not discussed herein.
- The situation that is analysed concerns the Gorai River. The development of the Ganges River is of course of major importance for the development of the Gorai River, but is only taken into account by possible scenarios for the future development of the planform of the Ganges River.
- This study concentrates on the development of the first 30 km of the Gorai River starting from the off-take, as from this part the most data is available.
- The impact of the structures that are proposed for the long term solutions is not taken into account. Insight into the potential contribution of dredging to a long term solution can be part of the results of this thesis study.
- Erosion due to shipping traffic is negligible on the Gorai River;
- Only erosion and siltation due to dredging or sediment transport by the river is studied. Sediment transport due to wind or other human activities than dredging are not taken into account.

1.4. Structure of the report

In this report the development of the Upper Gorai River and the response to dredging is described. Chapter two contains the background of the Gorai River Restoration Project. Chapter three provides a theoretical background and a description of the characteristics of the Gorai River. Chapter four contains the analysis of the response of the Upper Gorai River to dredging, made with ArcView with the data from dredging seasons 1999-2000 and 2000-2001. This resulted in sediment balances and deposition and erosion rates for all stretches of the studied area. The situation is visualised and sedimentation and erosion patterns are explained.

Chapter five discusses the effects of dredging on the bed level and the width of the river, since dredging is a means of reducing the width of the river. This is studied by comparing the width of the river for different stages for the situation with dredging intervention and the situation without dredging intervention (in this case the situation of November 1997). The changes in width and water depth resulted in changes in the relation between the discharge and the sediment transport.
In chapter six this study is extrapolated for future situations with maintenance dredging. Scenarios for the development of the Ganges River give insight in the future situation for the incoming sediment in the Gorai River.

Chapter seven contains a discussion on the used methods and the available data for this study. Chapter eight summarises the conclusions and recommendations and answers the questions posed in section 1.2.

This report consists of two volumes. This volume contains the text part of the report. In the second volume all graphs, pictures and other relevant information are presented.

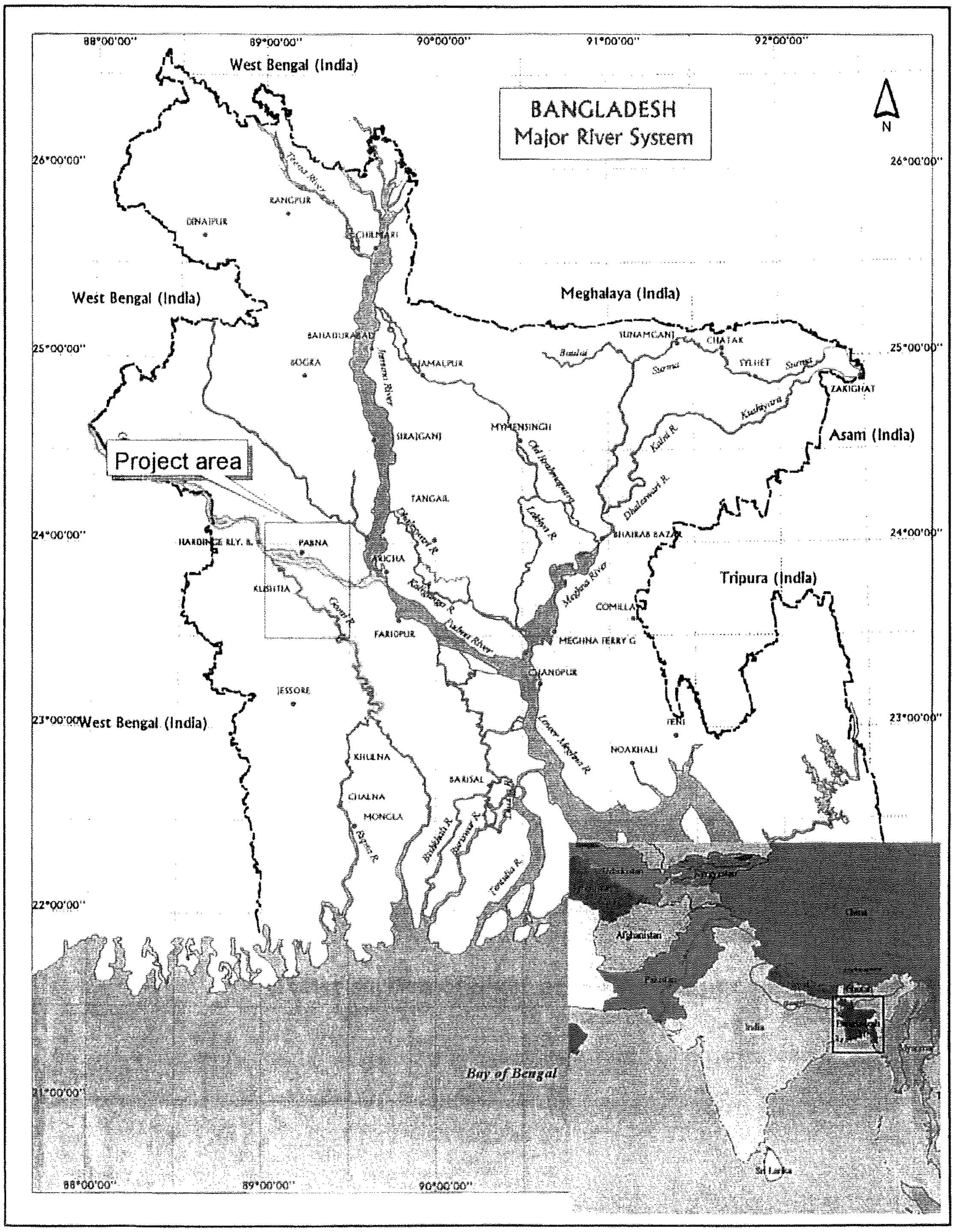


Figure 1.1: Major Rivers in Bangladesh and indication of the project area (GRC, 1999)

2. PROJECT BACKGROUND

2.1. History of the Gorai River

At Talbaria the Gorai River takes of from the Ganges. After about 190 kilometre from the off-take the Gorai flows into the Bay of Bengal. According to DHV-Haskoning (2000) the Gorai River was probably first developed during the 14th and the 15th centuries. Its planform changed due to changes in the planform of the Ganges.

Hardinge Bridge

In the end of the 19th century the Ganges has been constrained and contracted by extensive training work at Hardinge Bridge, which is situated 17 kilometres upstream of Talbaria. The Hardinge Bridge influences the location of the Ganges River.

Planform of the Gorai River in the 20th century

In the 20th century the Gorai off-take developed it characteristic large funnel shape. Flow records indicate that in 1953 the Gorai received practically no water in the dry season. Between 1957 and 1962 the mouth was much narrower and the flow in dry season was about 14% of the flow of the Ganges, which is high compared to the current situation. From 1973 on satellite images are available, see figure 2.1. In 1973 the orientation and position of the Ganges was favourable because the main Ganges flow was entering the Gorai straightforward. In this time the Gorai took a lot of water. After that the planform of the Ganges changed. Not only the natural planform of the Ganges changed in this period, the influence of the Farakka Barrage is also noticeable.

Farakka Barrage and the water sharing treaty

In 1975 the Farakka Barrage was built 110 km upstream of the off-take on the Indian side of the border. From 1988 to 1996 there existed no water sharing treaty between India and Bangladesh, therefore the dry seasons flows of the Ganges decreased. The influence of the Farakka Barrage combined with two heavy monsoons in 1987 and 1988 caused the closing off of the Gorai for a few months per year.
To illustrate the changes in flow the table 2.1 contains the figures of the annual average flow in the periods described above, it can be seen that this annual average flow is highly dependent of the existence of a water sharing treaty:

Table 2.1: Annual average flow of the Ganges (EGIS, 1999)

Period	Water sharing treaty	Annual average flow (m^3/s)	Change from Pre-Farakka
Pre-Farakka (1934-1975)	-	11,690	-
Post-Farakka (1975-1988)	Yes	11,300	-3%
Post-Farakka (1988-1996)	No	9,500	-18%
Post Farakka (1996-1998)	Yes	10,200	-13%

It should be noted that the main changes in flow during the non-treaty period occurred in the dry season, especially from January to April. In this season the change in discharge of the Ganges was more than –18% related to the Pre-Farakka period. These changes could be up to 77%. Besides a decrease in flow in the Ganges, the discharge ratio of Ganges / Gorai also changed.

Not only the total discharge changed in the Post-Farakka period. WL|Delft Hydraulics (1996) identified an important difference in the duration of the flood recession between Pre- and Post- Farakka period. In the Pre-Farakka period the fall of the water from 11 to 7m +PWD took 4.5 months averagely compared with 2.5 in the Post- Farakka period. It was proposed that a quicker recession did not leave sufficient time for the river to scour to the natural profile that used to maintain the perennial flow in the Gorai.

It can be stated that the major cause of the problems around the off-take are caused after the building of the Farakka Barrage.

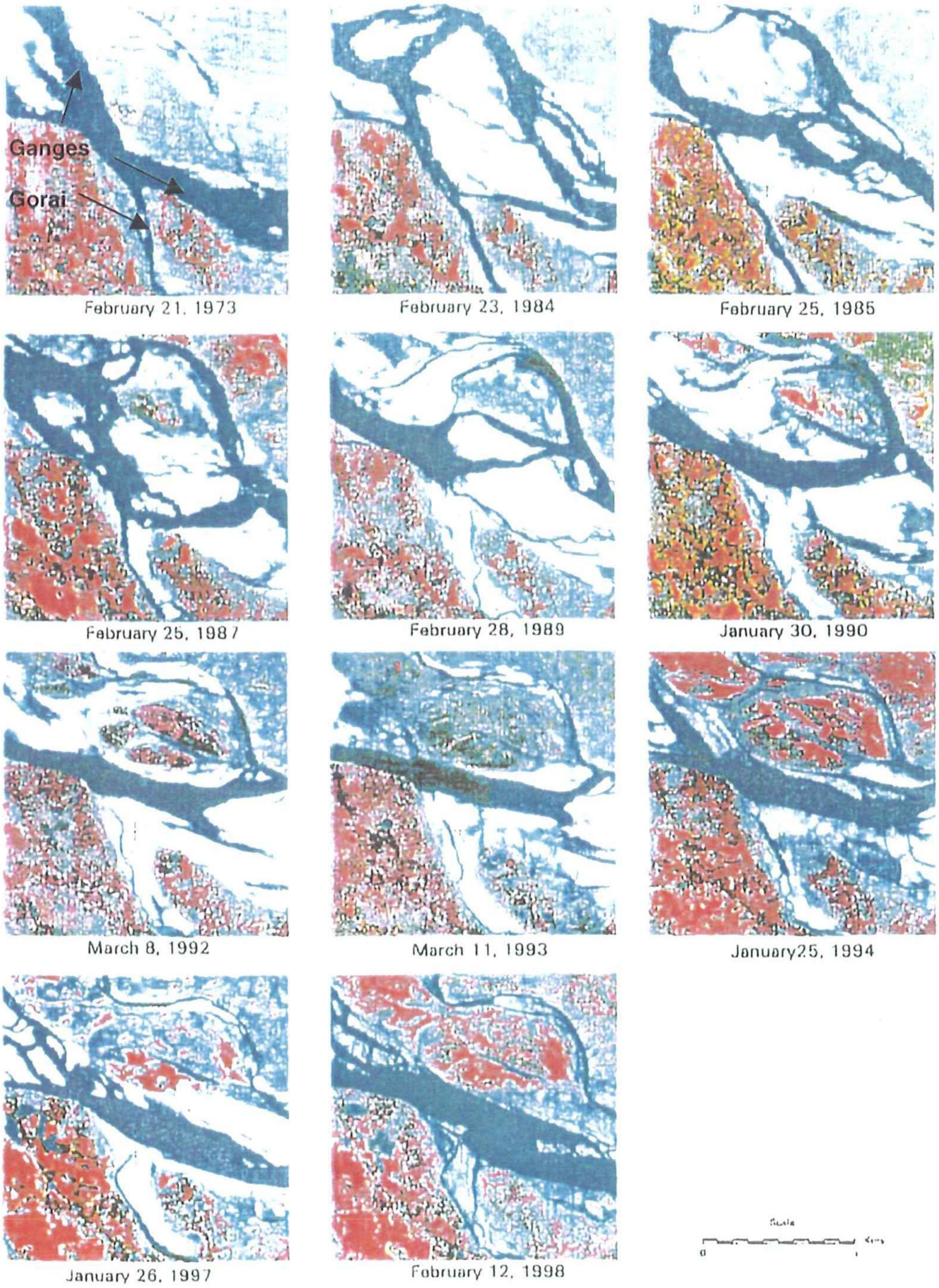


Figure 2.1: Satellite images of the Gorai off-take from 1973 to 1998 (GRC, 1999)

2.2. The Gorai River Restoration Project

2.2.1. General

When the water sharing treaty was signed in 1996, the Government of Bangladesh decided measures should be taken to restore the Gorai River and its surroundings. This resulted in the Gorai River Restoration Project. The overall objective of the project is:

> *To prevent environmental degradation in the South West Region of Bangladesh, especially around Khulna, the coastal belt and in the Sundarbans by undertaking restoration of the Gorai River and hence ensuring fresh water flows in the wet season and augmenting these flows in the dry season.*

Within the Gorai River Restoration Project (GRRP) the Main Study focuses on the long term solution while the Pilot Priority Works (PPW) would ensure a continuous flow of at least 4-8% until the long term solution is reached. The PPW generates data trough an intensive survey campaign and gives insight in the contribution that dredging works can have for the long term solution.

2.2.2. Main Study

In the Main Study, options are being developed for a long term solution. The effects of the long term solutions are modelled in physical and mathematical models. The socio-economical effects are also studied. The studies and design of the long term solution is financed by the Worldbank and the Government of the Netherlands.

2.2.3. The Pilot Priority Works

To achieve a continuous flow in the Gorai River a channel is dredged every year during the recession period. In October 1998 the dredging works began. Until March 1999 the first 19 kilometres of the Gorai River (from the off-take of the Ganges) were dredged to obtain the required depth and width for the flow (capital dredging). The maintenance dredging works took place from September 1999 to late January 2000 and from October 2000 to December 2000. In February and March 2001 some additional dredging works in the off-take area have been implemented.
The total project area of the PPW is the first 30 kilometres from the off-take.

Parties involved in the Pilot Priority Works

The client for the pilot project is the Bangladesh Water Development Board (BWDB) of the Ministry of Water Resources. The dredging works and the design are executed by the Gorai River Contractors (GRC), a joint venture of dredging companies. The following contractors are part of this joint venture:

- Boskalis International B.V. (representing the joint venture);
- Dredging International NV;
- Hollandsche Aanneming Maatschappij BV (HAM);
- Van Oord ACZ B.V.

Witteveen+Bos provides the experts on behalf of the Government of the Netherlands in order to support the employer with the technical and contractual matters. Also the supervision of the works is done by Witteveen+Bos.

2.3. The Pilot Priority Works

2.3.1. Design and planning

Design

Reference level

For the design of dredging works an inclined plane is used as reference level. For dredging works on rivers in the Netherlands this level is the OLR, Overeengekomen Laagste Rivierstand. For the PPW a new reference level, Standard Low Water (SLW), is defined. Compared to a flat reference plane the SLW reference plane is an inclined plane with a slope of 5 centimetres per kilometre. This slope is based on historical slopes of the sixties between Talbaria (Kp 0) and Khoksa (Kp 30). The reference plane starts at Talbaria and goes down into the Gorai. The SLW reference level (SLW + 0m) is based on the 95% exceeding limit of the water levels (in Public Works Datum, PWD) at Talbaria. The corresponding water level of the SLW + 0m reference level is PWD +4.5m. The conversion from a water level in PWD to SLW at a certain location along the Gorai is as follows:

$$wl(SLW) = wl(PWD) - 4.5 + 5*10^{-5}*Kp$$

Kp is the location (in metres) of the water level station on the chainage. Figure 2.2 illustrates the relation between PWD and SLW.

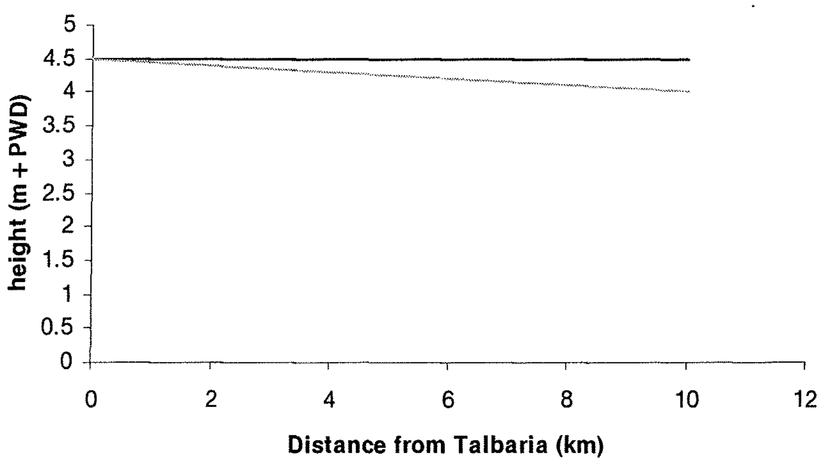


Figure 2.2: Relation between PWD and SLW

For dredging activities the positive direction as seen from the reference level is downwards. This implicates that the largest depth will have a high positive value. In this study the positive direction indicates areas that are situated **above** SLW.

Alignment

The alignment of the dredging works is chosen in such a way that the natural low water channel is followed. Exceptions on this are made for safety and stability of the embankments and for economic and morphological reasons. During the dredging seasons the dredging alignment is adjusted. Appendix XIV shows the dredging alignment of the three seasons. Along the alignment the Kilometre Points (Kp) are indicated. This Kp indication is changed over the years. In 2000 Kp 0 has been moved about one kilometre upstream. As a result Khoksha is now situated at Kp 31.25 instead of Kp 30. The Kp notation will only be used to indicate a position. The Kp indication can also be found in appendix XIV.

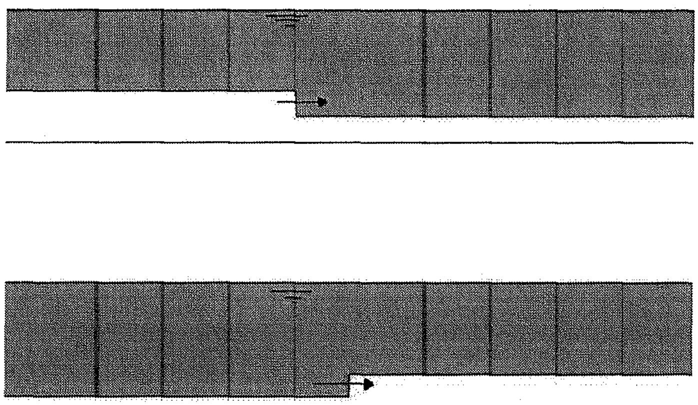


Figure 2.3: *Consequences of dredging in up- and downstream direction*

In the case when dredging takes place in downstream direction, the water depth decreases downstream of the dredged front. Therefore the flow velocities will increase and the front will translate in downstream direction. When dredging in upstream direction the flow velocities decrease downstream of the dredged front and the front moves in downstream direction, into the recently dredged channel. Besides this effect there is the spill which will go into the dredged channel when dredging in upstream direction. Spill is the sediment that is cut loose by the dredged but not removed by suction.
The transport capacity of the river is less with low waters, therefore dredging in upstream direction will only take place with low water levels. From the second season on the dredging took place in two layers in some stretches. In this way the heavy siltation during high water levels is reduced.

Table 2.3 shows the starting times and starting points of the dredging works for the three seasons. It should be noted that due to the late start in the first season the most unstable stretch could not be dredged first. The off-take had to be dredged first to avoid early closure of the Gorai.

Table 2.3: Starting date and point of the dredging works (Witteveen+Bos, 2001)

Season	Starting date	End date	Starting point
First	20th of October 1998	16th of March 1999	Kp 0.0
Second	16^{h} of September 1999	20th of January 2000	Kp 6.0
Third	12th of October 2000	16th of December 2000	Kp 10.0

Progress and weekly dredging volumes

For the second and third season one Cutter Suction Dredger, the Gemini, was available. An average production of 0.28 Mm^3 a week is used as an indication of the progress. The average workable hours per week is 100 hours. The production is dependent of the dredging method, box cutting or profiling, and the type of sediment, clay or sand. In the observed period for this study no dredging in clay took place, only in the off-take area where additional dredging works took place from February to March 2001 clay was encountered. The progress of the Gemini in the second and third dredging seasons is indicated in figure 2.4.

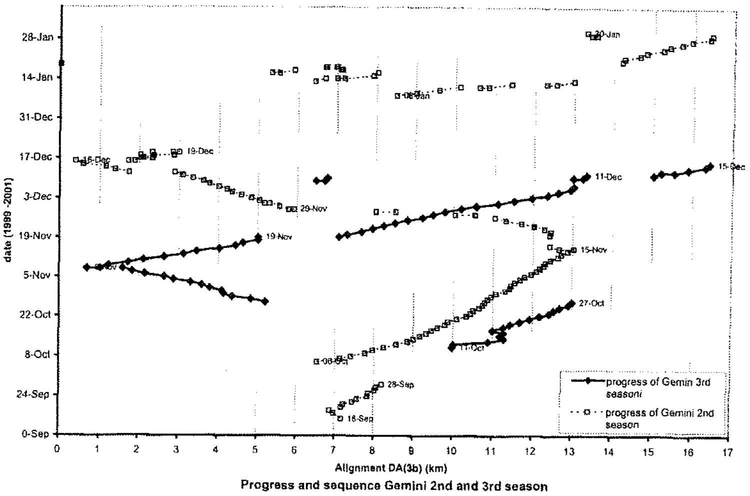


Figure 2.4: Progress of the Gemini in the second and third dredging seasons (GRC, 2001a)

2.3.2. Survey campaign

Monitoring surveys were carried out before, after and during the dredging works. From the second and the third dredging season bed level measurements will be used for this study, together with water levels, discharges, sediments. Downstream of the first 30 km no surveys have taken place frequently. The data consist of:

Table 2.4: Survey programme for different types of data

Type of data	Frequency
Meteorological	Daily (every 6 hours)
Water levels	Daily (every 6 hours)
Hydrographic (monitoring survey)	Fortnightly
Discharge	Fortnightly
(Suspended) sediments	Fortnightly

In the following sections the measuring campaigns are described for all types of data that were used for this study.

Water levels

Water levels are measured at 8 stations along the upper part of the Gorai River (the first 30 kilometres from the off-take). Three times a day, usually at 6:00 h, 12:00 h and 18:00 h, the water levels are read from the 8 gauges. The gauges are related to a fixed reference point in Kushtia, with the PWD as reference level. The accuracy of the water level readings is about 2 to 5 centimetres. From the water levels the hydraulic slope of the stretch between two gauges can be calculated. Figure 2.5 shows the locations of the gauges, in the right upper corner a picture of a gauge is displayed.

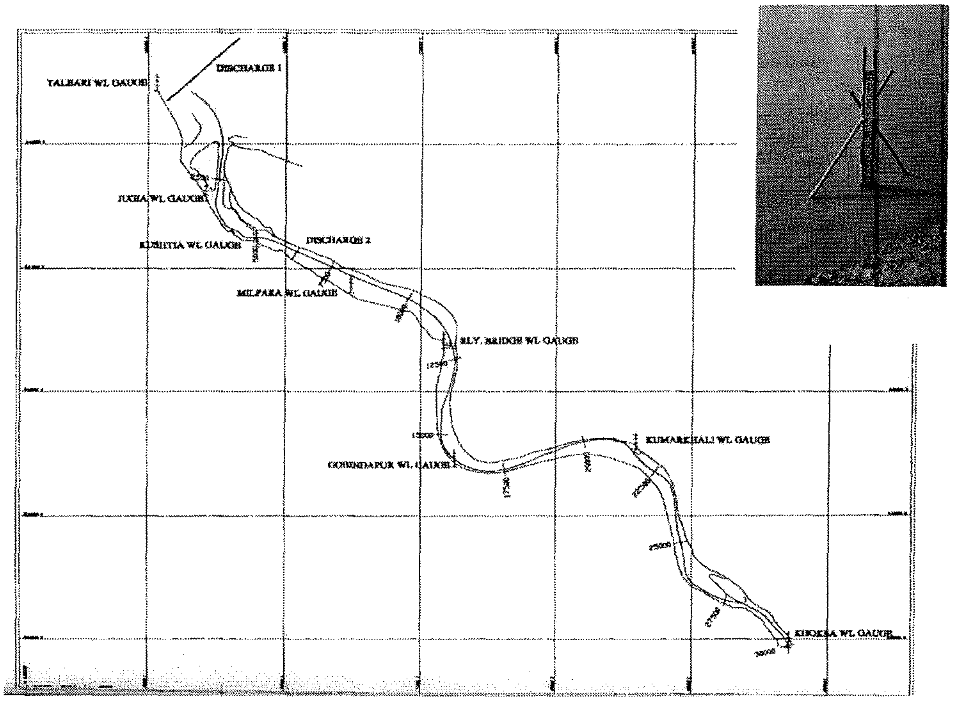


Figure 2.5. Water level measuring stations (GRC, 1999)

Bed topography

There are three different types of surveys for the bed topography. First there are the pre and post surveys, which are carried out to determine the dredged volume. These surveys are made of stretches of 500 metre length, with an interval of 50 metres between the cross-sections.

The second and third type of surveys are the monitoring surveys. The hydro monitoring survey covers the distance from Kp 0.0 to Kp 30.0. During the monsoon these surveys were carried out on a fortnightly basis. During the dredging season the monitoring surveys are carried out every month. After the dredging season a topo survey is carried out. The intervals of the monitoring surveys for the second and the third season are described in the following table. A complete list of the used survey data is added to this appendix.

Table 2.5: intervals of the cross-sections, monitoring survey, second and third season

	Second season u/s GRB	**Second season d/s GRB**	**Third season u/s GRB**	**Third season d/s GRB**
interval (m)	250	500	200	250

The surveys are carried out by the "Redsum", see figure I.2. This vessel is equipped with GPS (Global Positioning System) to determine the position of the vessel (longitude and latitude). A DGPS system on the shore connected by radio with the Redsum gives a correction on the position. The depth is measured by echo sounding. The generator transmits a strong electrical pulse to the transducer, which amplifies the signal and transforms it into an acoustic signal. This acoustic signal is sent to the river bed.

Cross-section profile for the second and third season
The dredged profile is V-shaped with a centre line at 4.5 metre below SLW.
The side slopes of the profile have been adjusted to the natural side slope of the material. In general sand is found in the Gorai, with a side slope of 1:7 (in the monsoon this is 1:15). The side slope of 1:7 is used in the design. This leads to a design dredging area of approximately 140 m^2 below SLW.

Disposal sites
The disposal sites are located at a place where natural sedimentation can be expected, such as an inner bend or in an abandoned channel. For the three dredging seasons the disposal sites were located on the same places. The aim is to locate the disposal sites as close as possible to the banks and with a height just below bank level. In this way the cross-section volume of the river during high water does not change. Appendix XV shows the disposal sites for the three seasons. The planned disposal sites 9 – 11 have not been used. In the third dredging season disposal site no. 2 has been extended to the embankment near Jugia. In this way the second flow channel in the off-take is partly filled up.

Dredged volumes
Table 2.2 shows the dredged volumes for the three seasons. These volumes are the actual dredged volumes, not the payable volumes. The payable volume is the volume that is within the pay lines. These pay lines are determined by the client and the contractor. The volumes of the additional dredging in the off-take in the third season are not taken into account.

Table 2.2: Dedged volumes for the three seasons (Witteveen+Bos, 2001)

	First season	Second season	Third season
Channel length (km)	19.5	15.5	16.0*
Total dredged volume (m^3)	9.20	5.87	3.73

*Note: the Kp is changed before the third season, Kp 13.0 for the third season corresponds to Kp 12.0 for the previous seasons.

Planning

Period
In principle the dredging works take place after the monsoon, during falling water. By dredging a channel during falling water from a deep outer bend to the next outer bend the river can scour more after dredging. This scouring process is called retarded scour. The process of retarded scour is described in chapter four. The dredging works also increase the hydraulic slope upstream of the dredged stretch. Therefore the scouring capacity of the upstream stretch in enlarged.

Starting date
Dredging is possible from water levels below +7 m SLW. From this water level on the flow velocities in the Gorai are such that navigation is possible. From +6.5 m SLW and lower the river becomes more stable, because the dune heights reduce. The optimal starting date depends on the water level, that should be between 6.5 m and 7m above SLW.

Starting point and dredging sequence
Experience gained in the years of the PPW learned that it is favourable to dredge the bottlenecks first. In this case the starting point is the unstable stretch upstream of Gorai Railway Bridge (GRB). In this way the low water channel is defined in this stretch. Preferable the dredging takes place in downstream direction. Only when this is not possible, for instance when the depth is insufficient for the dredger, dredging in upstream direction will take place. The reason for dredging in downstream direction is as follows. When dredging in downstream direction the artificial erosion from the dredging will continue downstream of the dredged part. When dredging in upstream direction the recently dredged profile is filled up again. Figure 2.3 illustrates this process:

From the elapsed time between the sending and the receiving of the signal the depth can be calculated. Because of the high transmission frequency the individual depth measurements form an almost continuous line. After processing the data, depth measurements become bed levels with a distance between the points of about one meter.

Figure 2.6. Survey vessel "Redsum" (GRC, 2000c)

The echo sounder needs at least 0.4 meters of depth. The vessel also needs at least 0.4 meters of depth. Therefore depths smaller than 0.8 meters can not be recorded. The ship movements, such as roll and pitch are taken into account in the recording of the measurements
The accuracy of the measurements is dependent of the frequency of the transmitter and the allowed angle wherein the sound reflection is measured. In this case the accuracy of the measurements is estimated at 10 cm. The relative accuracy is therefore lower with small water depths.
When measuring water depth bedforms have to be taken into account. It is well possible to measure the top of a dune rather than the average bed level. This "inaccuracy" is not dependent of the measuring method but have to be kept in mind when analysing the data.

The processing of the raw data obtained from the measurements takes place in a three steps:

- Reduction: conversion of the water depth to bed levels. The measured depth is the depth from the transducer to the river bed. To find the actual bed level (z) with respect to SLW the water level has to be determined. This is done by calculating the water level at the location of the survey vessel by interpolating the water levels measured at the 8 stations in time and space. This resulted in a water level graph as a function of time. This was used with survey software to find the bed level in SLW.
- Reducing files: reducing density of depth figures. Simultaneously with the conversion from the water depth to bed levels in SLW the density of the measurements is reduced from about five to one sample per meter of cross-section. This is done by averaging the measurements per meter sounding line.
- Editing: validation, removing of spikes. In this final step the data is edited, the presentation of the data is inspected on flaws and gaps in the sailed cross-section (due to shoals). Unreliable data are removed and the data from one cross-section are put together, resulting in an ASCII file with x,y,z values from the cross-sections.

Discharge measurements

The discharge measurements take place on a fortnightly basis. On the Ganges River the discharge is measured near Kp 0.0, on the Gorai River the discharge is measured on Kp 3.25. During the monsoon discharge measurements were not possible due to the high flow velocities on the Ganges. In the first and second season RCM 9 has been used for discharge measurements. In the third season ADCP (Acoustic Current Doppler Profiler) measurements have been taken. The output of the measurements is the total discharge, local velocities and flow direction in small segments of the river. The accuracy of the RCM measurements is about 2 cm/s or ± 5% of the measured velocity.

Sediment measurements

At the same time as the discharge is measured, water samples of about one litre with sediment are taken. These samples are taken at five points in the cross-section of both Gorai and Ganges River. The samples are analysed in the GRC laboratory and give insight in the suspended sediment in both rivers.

3. CHARACTERISTICS OF THE UPPER GORAI RIVER

3.1. Introduction

Before the effects of the dredging works can be analysed, the planform and the natural development of the Gorai River has to be known. Many studies have been carried out that describe the development of the planform of rivers in general and the Gorai River in particular. This chapter gives a brief overview of the relevant theory.

The planform of a river is mainly determined by the following factors:
- Boundary conditions, such as discharge, water levels and hydraulic slopes;
- Sediment and sediment transport, or morphological processes, such as river bends and bedforms.
- Geology of the flow area, such as fixed (clay) points and man made structures;

In the first section a general description of the planform of the Gorai River is given. In this description the location of the structures and clay hard points is also indicated. In Appendix XI some characteristic figures for the Gorai over the years is shown.

3.2. Current planform of the Gorai River

The Gorai River is a meandering river, although at some points it also has characteristics of a braiding river. There is only one low flow channel in the Gorai, except for the off-take area where there are two channels during high water. The width of the low flow channel is about 100m , while the total width of the river varies between 500 and 1500 m. The largest width can be found in the off-take.
Downstream of Kp 31 the planform of the Gorai is more stable. Appendix I contains a figure of the Upper Gorai River, which is the study area, and the stretches that are distinguished in this study. In figure 3.1 this Upper Gorai River is shown on a smaller scale. On the following pages the characteristics of these stretches are described. The Kp indication used here is the Kp indication of the third dredging season.

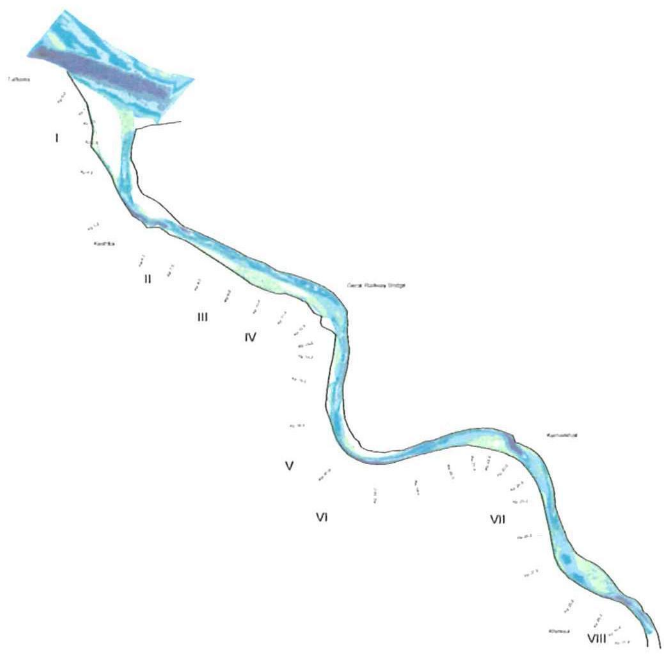
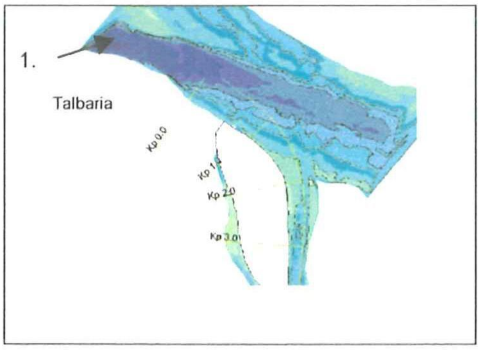


Figure 3.1. Study area and indication of the eight stretches

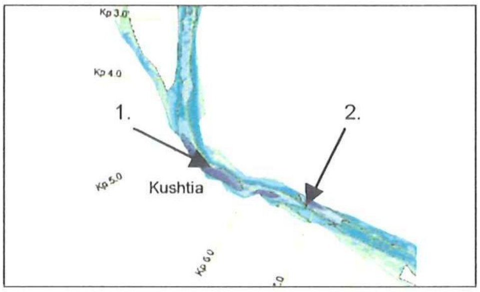
Figure 3.2 a-h. Stretches of the Upper Gorai River

a. Off-take area, Kp 0.0-3.5

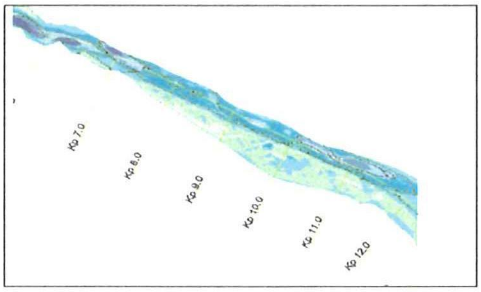
The off-take area is the beginning of project area. Kp 0.0 is near the town of Talbaria. On the right bank of the Ganges River before the off-take there is a large scour hole near the Talbaria clay hard point (1). The off-take curves around a clay hard point at Talbaria. During the monsoon a bar builds up in the off-take between Kp 2.0 and 2.5.
There are two low flow channels during the monsoon. The major low flow channel, near the left bank, is the major low flow channel.



b. Kushtia, Kp 3.5 – 7.0
After Kp 4.0 there is the confluence of the two low flow channels in the off-take area. In the bend to the left there are groynes near the town of Kushtia (1) the influence of the groynes is also noticeable downstream of the groynes. For example near the left bank, where the diverted current from the groynes cause a scour hole (2).

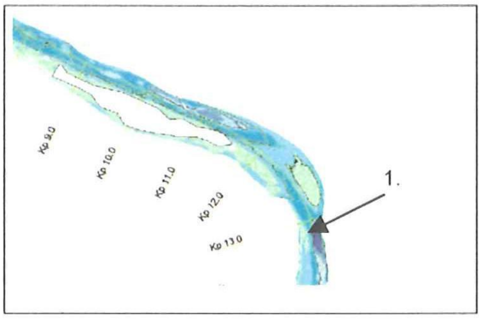


c. Straight stretch, Kp 7.0-9.0
After the Kushtia groynes there is a long straight stretch. In former times Kushtia was situated at the off-take of the Gorai from the Ganges River, so this stretch is the remains of the river bend of the Ganges River. This part of the straight stretch is relatively stable with the characteristics of a crossing. Along the right bank there is a disposal site.

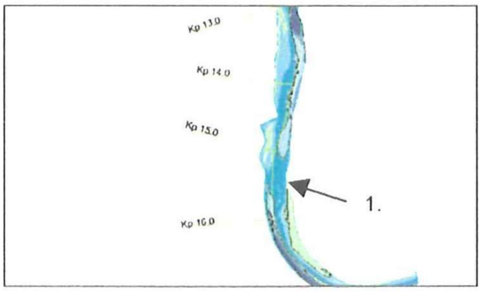


d. Upstream GRB, Kp 9.0 – 13.0

From Kp 9.0 to Kp 11.0 is the lower part of the straight stretch. This part however does not have a stable low water channel. The dredging works aim to fix the location of the low water channel.
In this part of the Upper Gorai River alternating bars might occur. Upstream of the Gorai Railway Bridge, Kp 13.0 (1), there is a bend to the right.



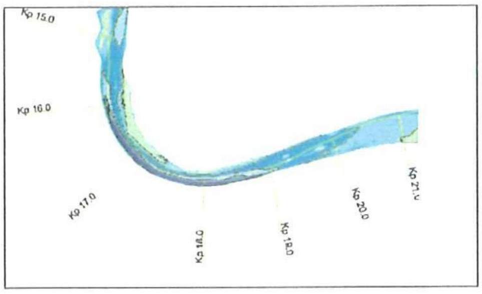
e. Downstream GRB, Kp 13.0 – 17.0
This stretch can best be described as a crossing (1) between two bends. Downstream of the GRB the influence of the piles of the bridge is noticeable. During the first and the second season the shoal between the bend was dredged to improved the flow patterns in this part.
For the second and third dredging seasons this was the last stretch to be dredged.



f. Upstream Kumarkhali, Kp 17.0 – 20.5

This part is characterised by a stable bend to the left followed by a crossing. Open groynes and a revetment are present in the bend.

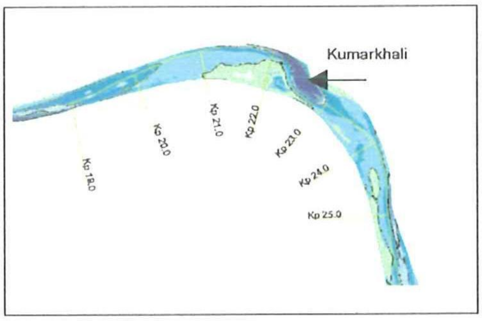
For the first dredging season, this was the last stretch to be dredged.



g. Kumarkhali, Kp 20.5 – 26.0

In this stretch there is a bend to the right with a groyne near the town of Kumarkhali, Kp 22.5, which determines the location of the low water bed. Upstream of the groyne there is a large shoal in the inner bend. This shoal develops in the monsoon. Downstream of the groyne the low water bed does not have a fixed location. Downstream of the Kumarkhali groyne a shoals develops between the right and the left bank during the monsoon.

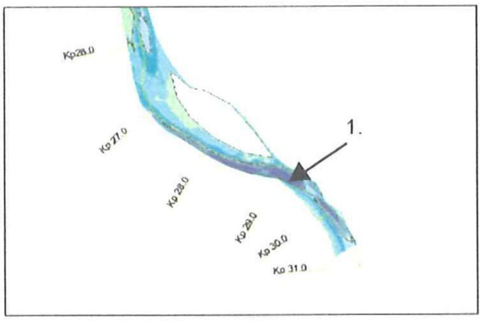
No dredging works have taken place in this section.



h. Downstream Kumarkhali Kp 26.0 – 31.0

The stretch downstream Kumarkhali is the end of the project area. Downstream of Khoksa, Kp 31.0, the Gorai River is thought to be stable.

This stretch can be characterised as a slight bend to the left with a large shoal. On left side of the shoal a second low flow channel is developing. At Kp 29.0 there is probably a clay hard point that directs the flow towards the left bank and causes a scour hole (1).



3.3. Hydraulic parameters

The hydraulic parameters determine the boundary conditions of a river system and have therefore a large influence on the bathymetry. On its turn the bathymetry also influences the hydraulic processes and the hydraulic slopes of a river

3.3.1. Discharge

The discharge ratio between the Gorai and the Ganges River is about 10% during low water. This discharge is usually in phase with the discharge of the Ganges River. Both the Ganges River and the Gorai River have a period of high water and a period of low water. The period of high water is caused by the rainfall during the monsoon in the catchment area of the Ganges River and the inflow from the Himalaya. The period of high water is from July to September. The low water period is from January to April.

The discharge in the Gorai varies between almost 0 m^3/s and 8,000 m^3/s. The average discharge is 1,400 m3/s (source: WL|Delft Hydraulics [28]).The figure below shows the maximum, minimum and mean monthly flow in the Gorai.

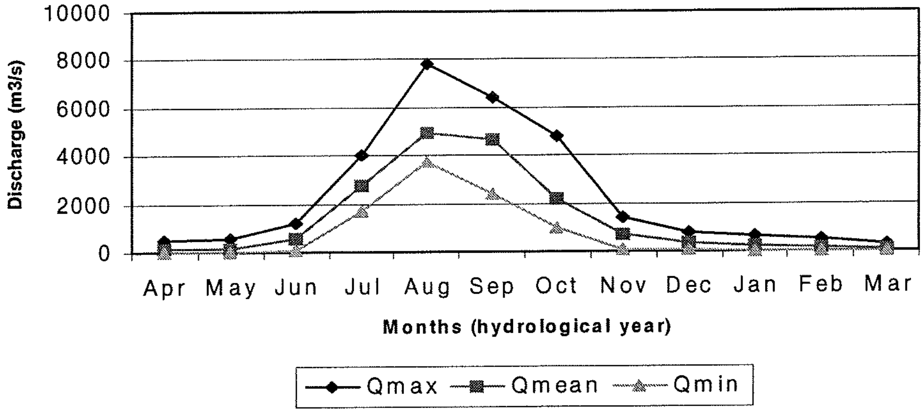


Figure 3.3.Monthly flow of the Gorai based on data from 1965 to 1989 (WL|Delft Hydraulics, 1996).

Another characteristic value, except from maximum and mean discharge, is the dominant discharge. The dominant discharge can be defined as the discharge which determines most of the deposition and erosion processes. Here the dominant discharge is determined as follows (DHV-Haskoning, 2000):

> *The dominant discharge is the median of incremental discharge class responsible for transporting the most sediment in the long run (Biedenharn & Thorne, 1994).*

In this case it was found that the dominant discharge class of the Ganges River is 35,000 m^3/s to 40,000 m^3/s. The dominant discharge class of the Gorai is 4,125 m^3/s to 4,375 m^3/s.

It is expected that the moment with the highest discharge will cause the highest deposition and erosion rates. With low discharges the deposition and erosion rates will be low.

3.3.2. Water levels

The water levels follow the discharge, although some hysteresis can be found. This causes a higher corresponding stage at falling water for a certain discharge than at rising water. Figure 3.4 shows the average yearly water level development and the development for the second and third dredging sea

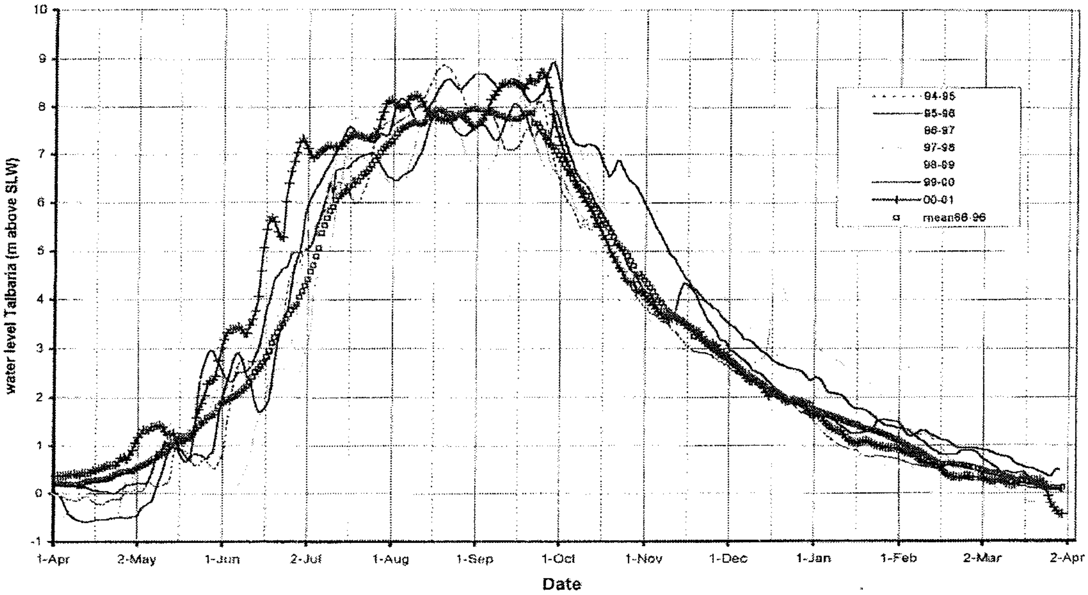


Figure 3.4. Yearly variation of the water level in the Gorai at Talbaria from 1994 to 2001 (GRC, 2001a)

The 1999-2001 Q-h rating curve is shown in figure 3.5:

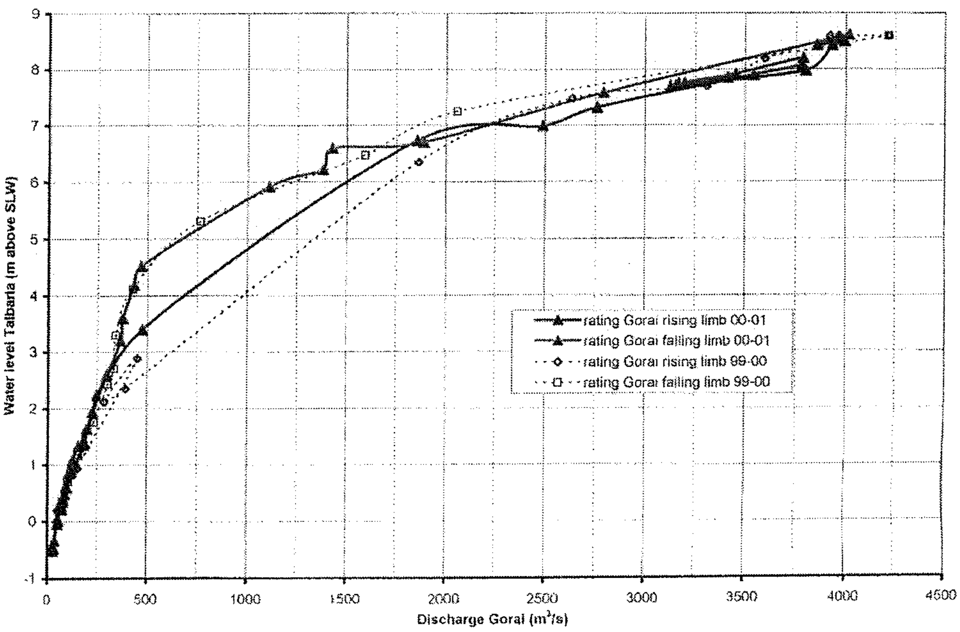


Figure 3.4. Rating curve for the Gorai River at GRB, 1999-2001 (GRC, 2001a)

3.3.3. Hydraulic slope

Usually in low land rivers the hydraulic slope can be considered to vary little in time and space. The most important factor that determines the water levels and therefore the hydraulic slopes are the downstream boundary conditions, such as a downstream water level. Dependent on the 2-D morphology of the river the hydraulic slope has a variation in space. Between two river bends a larger slope can be expected during low flow conditions, because of the shallow wide reach of the crossing in between the bends. The scouring process that results from this locally increased slope during the fall of the hydrograph is called retarded scour. Retarded scour is discussed in more detail in section 3.4, river morphology.

In the Gorai River these differences in slope are larger. The variation in time can be described as follows:

At the beginning of the monsoon (May) the slope for the reach between Talbaria and the Gorai Railway Bridge is 6 cm/km (average from 1987 to 1995). At the peak of the monsoon the hydraulic slope was 6 to 8 cm/km. During the falling stage of the water level the hydraulic slope increases rapidly. In the Gorai case counter clockwise hysteresis occurs; for the same water level at rising water as during falling water the hydraulic slope is not the same. For falling water the hydraulic slope is larger than in the case of rising water.

The dredging works also influence the local hydraulic slope. The stretch upstream of the dredged stretch will have a larger slope than without dredging.

Along the alignment there are variations in slope as well. Figure 3.5 shows the variation of the hydraulic slope in for the water levels. In figure 3.6 and 3.7 the variation of the slope is shown as a function of time.

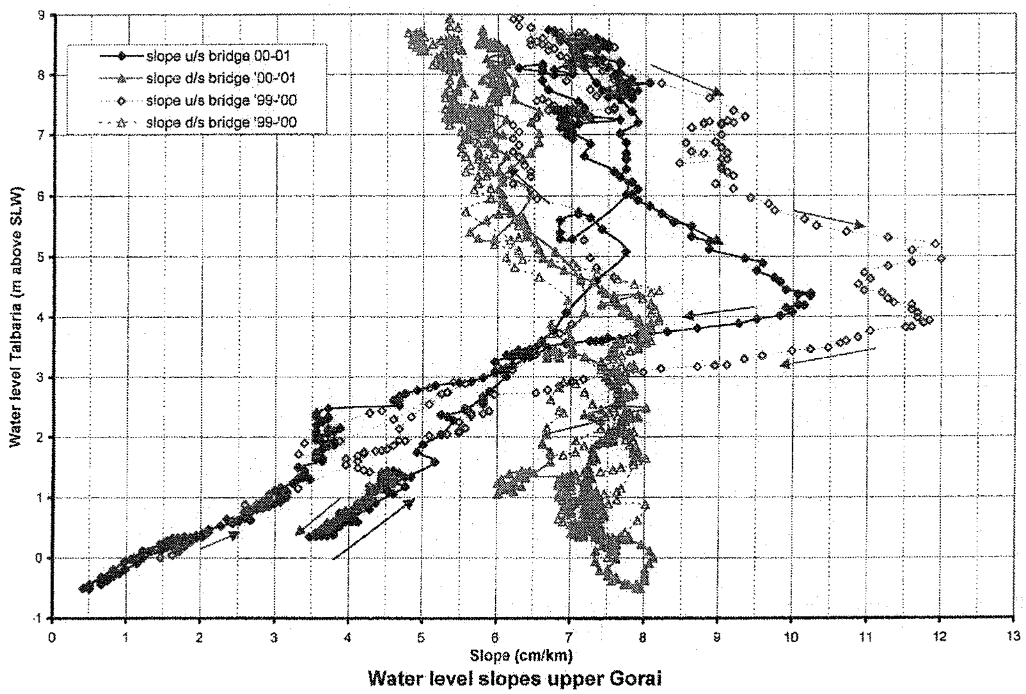


Figure 3.5: Hydraulic slopes on the Gorai River in time (GRC, 2001a)

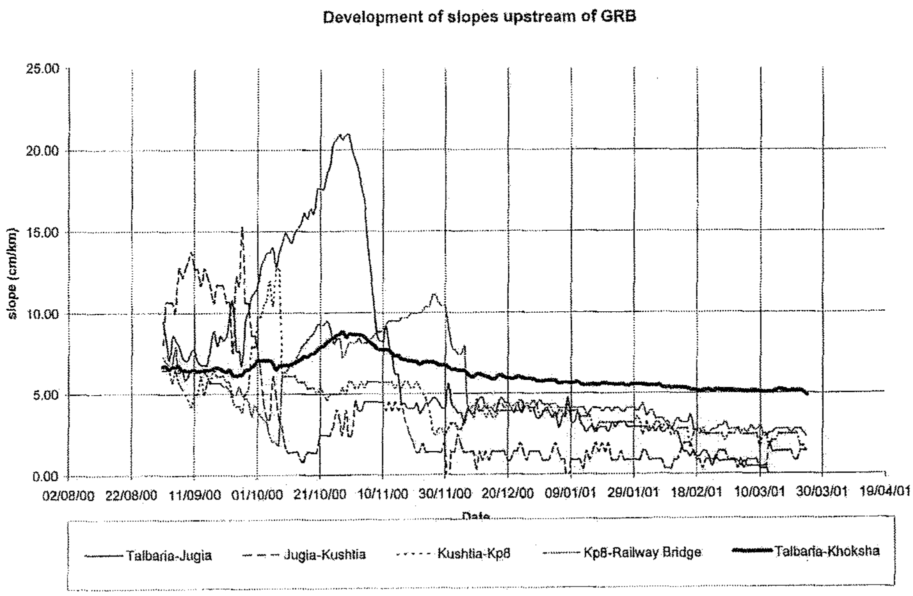


Figure 3.6. Variation of the hydraulic slope along the alignment, upstream Gorai Railway Bridge, 2000-2001 (Witteveen+Bos, 2001)

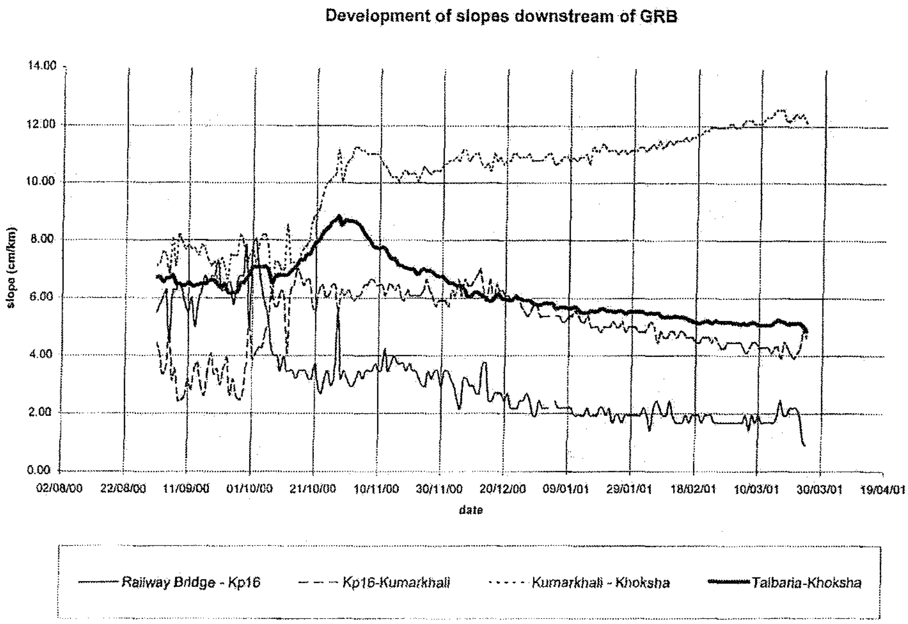


Figure 3.7. Variation of the hydraulic slope along the alignment, downstream Gorai Railway Bridge, 2000-2001 (Witteveen+Bos, 2001)

3.3.4. Backwater effect

In the months May and June backwater effects can occur. The water level in the Jamuna rises faster than the water levels in the Ganges River. In this way the water levels in the Jamuna influence the water levels in the Ganges River. This effect reaches as far as Talbaria, which is 60 km upstream of the confluence of the Jamuna and the Ganges River, so also the water levels and therefore the flow in the Gorai is determined by the Jamuna. This flow is thought to be positive for the off-take, since the backwater effect implies that more discharge is flowing in the off-take but with a lower sediment concentration, as the Ganges River is still carrying hardly any flow and hence the sediment concentrations are low. Therefore erosion is expected in the off-take in May and June.

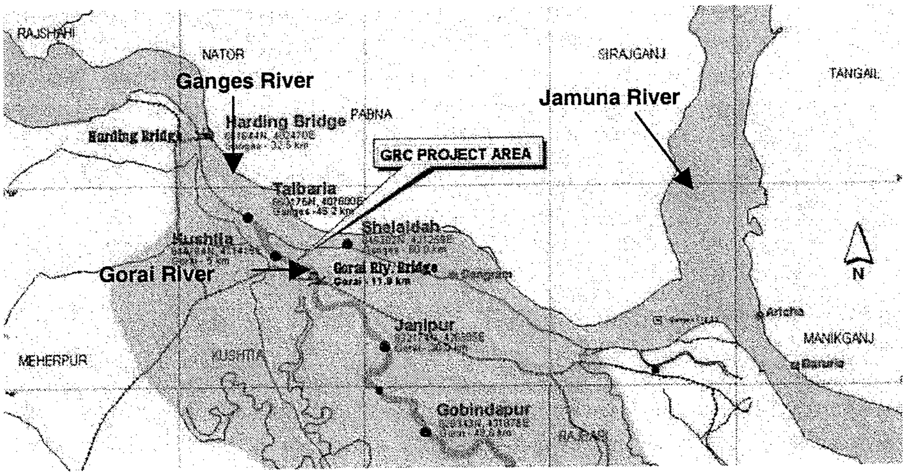


Figure 3.8. Situation of the confluence of the Jamuna and the Ganges River

3.4. River morphology

The main objective of this study is to identify the response of the Gorai River to dredging. These dredging works are not the only cause of changes in the cross-section of a river. The bed of a river is continuously in motion. Therefore the natural development of a river is discussed first.
The bed topography of rivers in general is influenced by the following phenomena:

- Bedforms.
- River bends and crossings.
- Alternating bars.
- Autonomous developments after changes at up- or downstream boundaries.
- Made structures.

During the considered period for this thesis study it is assumed that no changes in boundary conditions did occur.

3.4.1. Sediment and sediment transport in the Gorai River

Type of transport

Sediment transport consists of bed load transport and suspended transport.

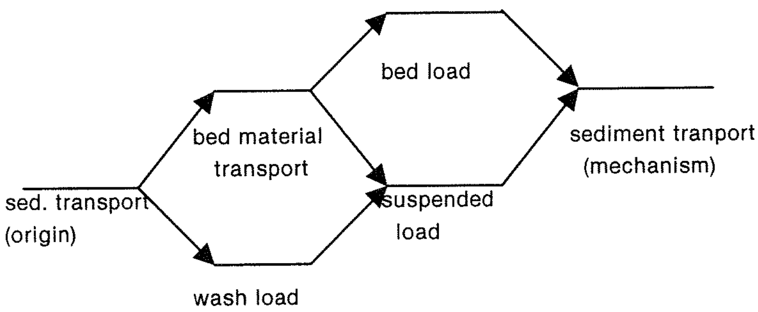


Figure 3.9: Classification of sediment transport (Jansen e.a., 1979)

Since no data is available on bed load transport the following approach is made to determine the importance of bed load transport on the Gorai River:
The fall velocity of sediment (w_s) is an indication for the influence of suspended material, the shear stress velocity (u_*) is an indication of the importance of bed load material. Suspended sediment transport is dominant when:

$$\frac{u_*}{w_s} > 1.5$$

With:

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

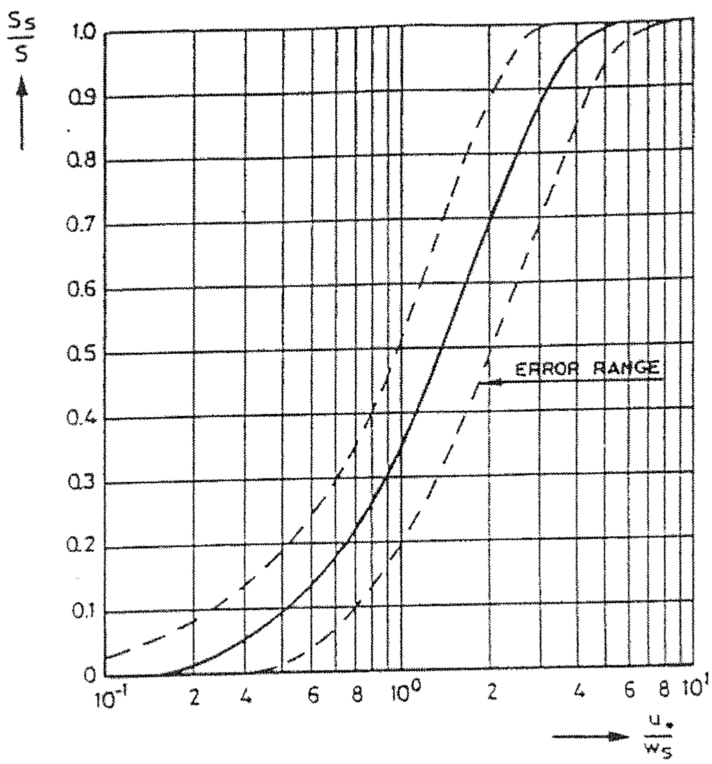
and:

$$w_s = \frac{10\upsilon}{D}\left(\sqrt{1+\frac{0.01\Delta g D^3}{\upsilon^2}}-1\right)$$ if 100 < D < 1000 μm (van Rijn, 1993)

The Gorai River has most of its morphological activity in the monsoon period. For this period the ratio u_*/w_s is determined. The following figures are used:
$D = 150\mu m$
$\Delta = 1.65$
$h = 12$ m
$i = 7 * 10^{-5}$
$\upsilon = 1.0*10^{-6}$ m^2/s
The resulting ratio is:

$$\frac{u_*}{w_s} = 5.6$$

The suspended load transport is therefore dominant in the Gorai River. However, the morphology can still be determined by bed load transport. The following figure by van Rijn, 1986 (Akkerman, 1993) illustrates the rate of suspended sediment transport as part of the total sediment transport: With u_*/w_s= 5.6, about 90% of the sediment transport in the monsoon is suspended sediment transport.



$S_s = f(u_*/w_s)$

Figure 3.10. Part of suspended sediment transport of the total sediment transport (Akkerman, 1993)

Transport formula

There are three types of transport formulas:

- formulas for bed load only;
- formulas for suspended load only;
- formulas for total transport.

In many of the transport formulas the following dimensionless variables are used:

$$\Phi = \frac{s}{\sqrt{g\Delta D^3}}, \qquad \text{transport parameter}$$

$$\Psi = \frac{\mu \tau_b}{\rho g \Delta D} = \mu\theta = \mu \frac{hi}{\Delta D}, \qquad \text{flow parameter}$$

$$\mu = f\left(\frac{C}{C_{90}}\right)$$

with C= Chézy co-efficient, related to D_{90}:

$$C_{90} = 18 \log \frac{12h}{D_{90}}$$

In the Meyer-Peter Muller formula for bed load transport the factor μ is used, via which the influence of the bedforms are introduced. For other formulas other parameters are introduced, such as C^2/g in the Engelund-Hansen formula for total transport.

The most frequently used formulas in river engineering are:

- Meyer-Peter-Mûller, for bed load only.
- Engelund-Hansen, for total transport.
- van Rijn, for bed load and suspended load separately.

In general all sediment transport formulas can be expressed in the following formula (RIZA, 2000):

$$\Phi = A \frac{1}{1-\varepsilon} \beta_u (\mu\theta)^{\gamma_u} (\mu\theta - \theta_{cr})^{\alpha_u}$$

For the main rivers in Bangladesh neither of the above mentioned transport formulas, such as Engelund-Hansen or van Rijn, proved to be applicable for modelling. Therefore the general transport forumula is callibrated with the available measurements from rivers in Bangladesh (WL|Delft Hydraulics, 1996).

$$\frac{s}{\sqrt{g\Delta D^3}} = \frac{0.165}{1-\varepsilon}\left(\frac{hi}{\Delta D}\right)^{3.64} \frac{C^2}{g}$$

3.4.2. Natural processes in a river

Bedforms
Grains start to move when critical flow velocity is reached. Dependent on the flow velocity, the water depth and the sediment characteristics bedforms may develop. These bedforms are of importance for the bed roughness of a river. Roughly stated the following bedforms can occur:
Calm regime, Fr << 1, flat bed, ripples, dunes
Transition regime and upper regime: Fr<1 and Fr >1. antidunes, standing waves and washed out dunes
The flow regime is characterised by to the Froude number :

$$Fr = \frac{u}{\sqrt{gh}}$$

Figure 3.11 illustrates these patterns:

Low Froude numbers: (rivers) **High Froude numbers: (flumes)**

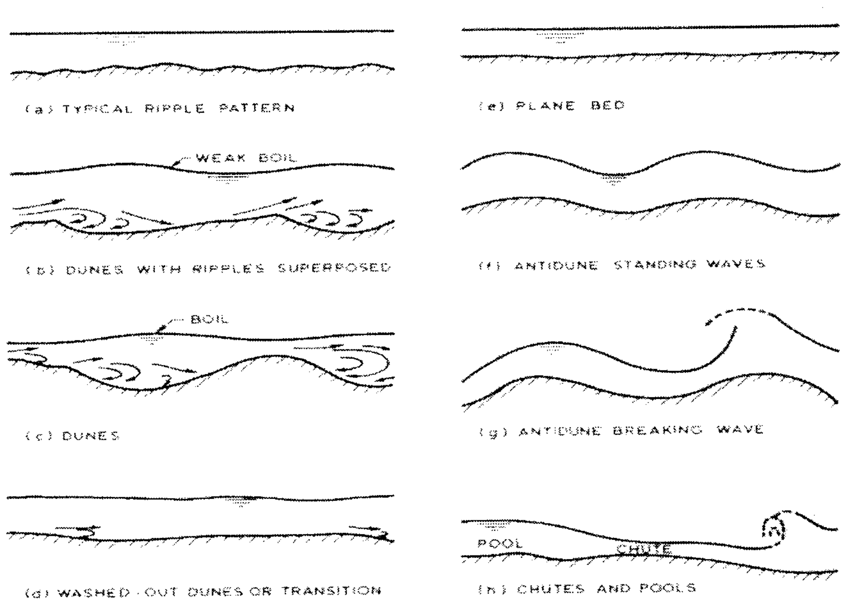


Figure 3.11: Bedforms (Jansen, 1979)

Ripples occur just after the critical flow velocity is reached. With higher velocities dunes develop. Dunes are bedforms with larger height and wave length. With even higher velocities a transit regime with a flat bed occurs. Later, antidunes develop which propagate in opposite direction of the flow. In general only the situations on the left side of the figure can be found in rivers. The situations on the right side occurs rarely in nature.

In the Gorai River ripples and dunes occur. During the monsoons dunes with a length of about 80 metres and a height of about 4 metres were recorded. These dunes could propagate downstream with a celerity of 40 m / day. (GRC, 2000c). At the beginning of the dredging season (around the end of September) the dune height was already reduced to 1.5 m.

Bends and crossings

The morphology in river bends cannot be described as a 1D process. The processes that occur in a river bend can be summarised as follows:
In river bends the water is pushed towards the outer bend due to the centripetal force. This causes a higher water level in the outer bend than in the inner bend. There is a lateral hydraulic slope over the cross-section. Difference in water level causes pressure differences. The sum of the force caused by pressure difference and the force by the velocity results in a force that is not equally distributed over the depth. Therefore there is a current towards the outer bend near the surface and a current towards the inner bend near the bed. This current is called the secondary flow and it is smaller in magnitude than the primary flow. Together these two form the spiral current. In the inner bend the water wants to flow upwards, but is hindered by gravity. Therefore the current upwards is smaller than the current downwards at the outer bend and deposition of sediment will occur in the inner bend while erosion will occur in the outer bend. Figure 3.12 illustrates this process. The shallow part in the inner bend is called a point bar. There is also a segregation of fine and coarse sediment in river bends.

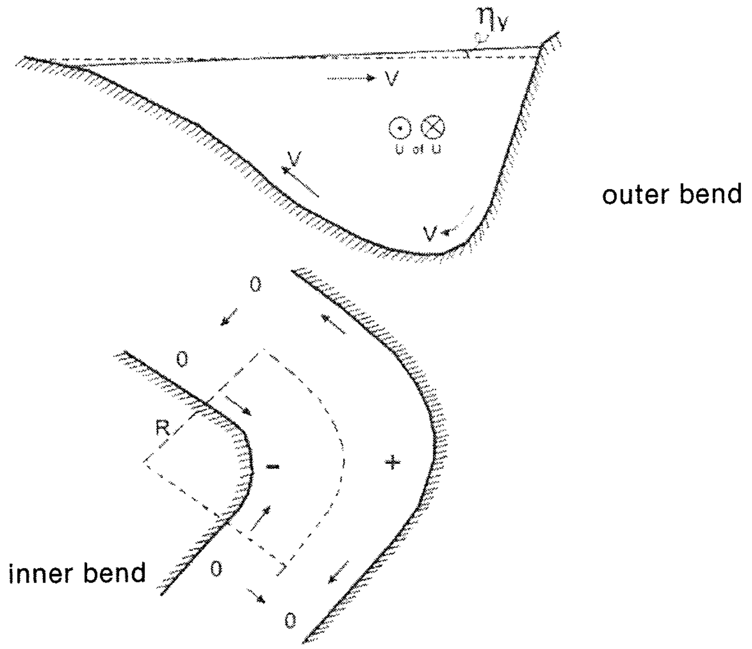


Figure 3.12: Spiral current in a river bend (Stive, 1999)

The spiral current causes that the outer bend will erode with higher stages and discharges and the point bar in the inner bend will build up. Displacement of the outer bend can also occur. In that case the outer bend erodes and will translate more to the outside. In this way sediment is added to the system, which deposits again on the crossing and the next point bar.

Between two bends in opposite direction there is an area where the spiral current changes direction. This area is called a crossing. Crossings show characteristics of both bends and therefore a shallow part can be found in the middle of the cross-section. Characteristic cross-sections of both bends and crossings are indicated in figure 3.13:

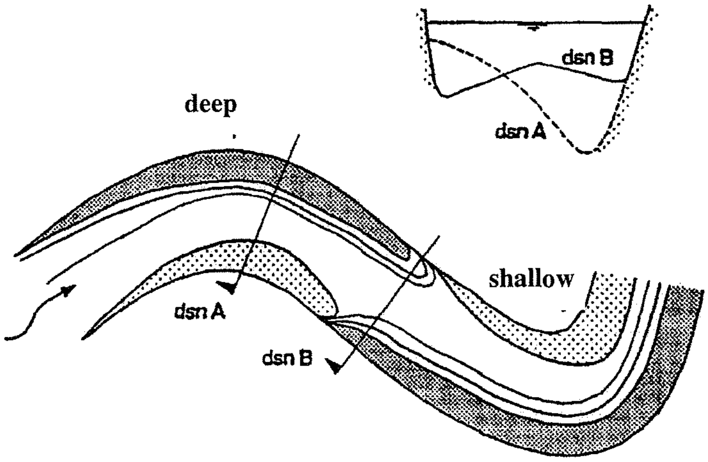


Figure 3.13: Cross-sections of river bends and crossings (Schepman, 2000)

Retarded scour

During falling water the hydraulic slope over shallow parts in a river is larger than the slope over deeper parts. This locally increased slope causes local erosion, which is called retarded scour. The places where retarded scour will occur are crossings and in the case of the Gorai also in the off-take. Dredging can accelerate the retarded scour. Therefore retarded scour is always taken into account in the dredging strategy. The stretch downstream of the shallow part is dredged first. This increases the hydraulic slope over the shallow part and therefore the scour increases as well. In general retarded scour is also accelerated after dredging from one outer bend to the following outer bend.

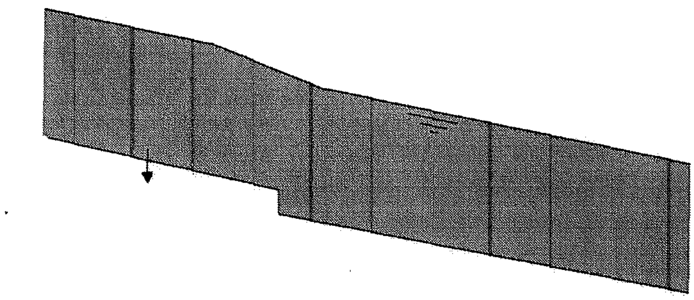


Figure 3.14: retarded scour

Retarded scour is an important process in the Upper Gorai River. Due to retarded scour the bar in the off-take is partly scoured by the river itself. The dredging strategy can enlarge the retarded scour.

Alternating bars

Bars do not only occur in river bends, but also in straight stretches. The bars in straight stretches are called alternating bars. Alternating bars can move from one side of the river to the other and they can also move downstream.
The interaction parameter, IP, is an important parameter for the occurrence of alternating bars and other autonomous morphological developments of a river. The interaction parameter is defined in the following way:

$$IP = \frac{\lambda_s}{\lambda_w}$$

With:

$$\lambda_w = \frac{C^2 h}{2g}$$

$$\lambda_s = \frac{1}{(m\pi)^2} h \left(\frac{B}{h} \right)^2 f(\theta)$$

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

With:
λ_s = adaptation length of the bed development
λ_w = adaptation length of the water movement
θ = Shields parameter
m = factor which describes the shape of the bed in cross direction (m=1 for meandering rivers)

The following figure is derived to determine the occurrence of alternating bars. The stability curve indicates the transition between growth and diminishing of alternating bars. Important factors in the occurrence of alternating bars are the ratio between width and depth of the river, and the bed roughness. For both the monsoon and the low water period the interaction parameter has been calculated. These are indicated in the figure. The figures that have been used for the calculation can be found in table 3.1. Due to the low interaction parameter, caused by the low width-depth ratio, in both cases it is unlikely that alternating bars can be found on the Gorai River. Besides, the right side of the long straight stretch between Kushtia and GRB is used as disposal site during the dredging works. This disposal site stabilises this stretch. This is another reason why alternating bars are not expected to be found in the analysis.

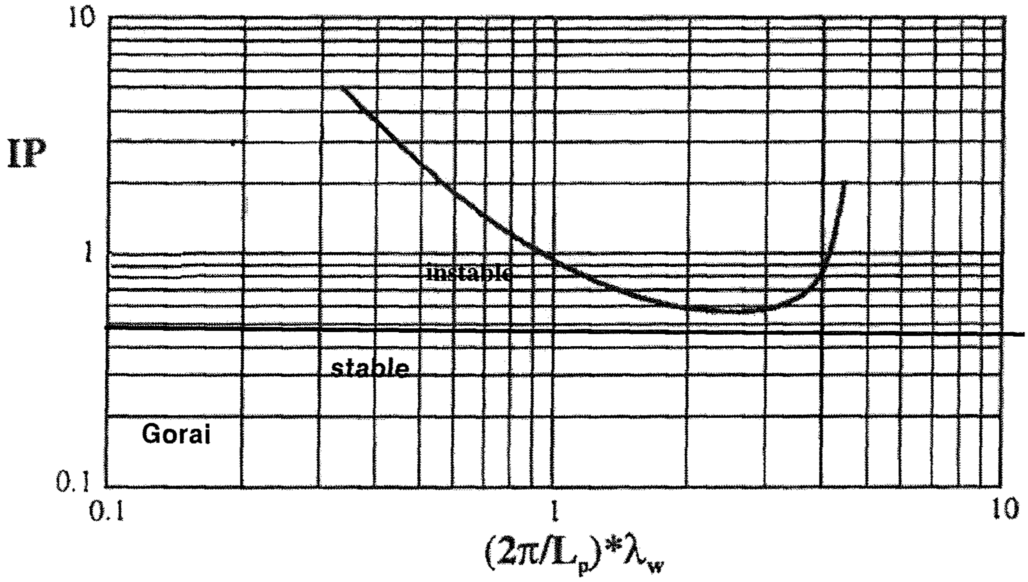


Figure 3.15: Stability curve, indication of occurrence of alternating bars (Struiksma, 1997)

Table 3.1: Characteristics of the Gorai River to determine the interaction parameter

	Monsoon	Dry season (low water)
h (m)	8	5
B (m)	500	100
i (-)	$8*10^{-5}$	$5*10^{-5}$
D (m)	$150*10^{-6}$	$150*10^{-6}$
C ($m^{1/2}/s$)	65	40
Δ (-)	1.65	1.65
λ_s	875	81
λ_w	1724	980
IP	0.50	0.08

3.4.3. Deposition and erosion patterns as a result of 1 and 2D flow

The discharge and especially flow velocities are of major importance to determine whether deposition or erosion will occur. In Mamun (2000), a prediction tool of one dimensional flow situations was developed. Therefore the moments of 1 and 2D flow were determined. This was done on the basis of a typical cross-section of the Gorai River. In this report the determination of the moments of 1 and 2D flow is reconsidered. Figure 3.16 shows the possible different stages that can be found in a river.

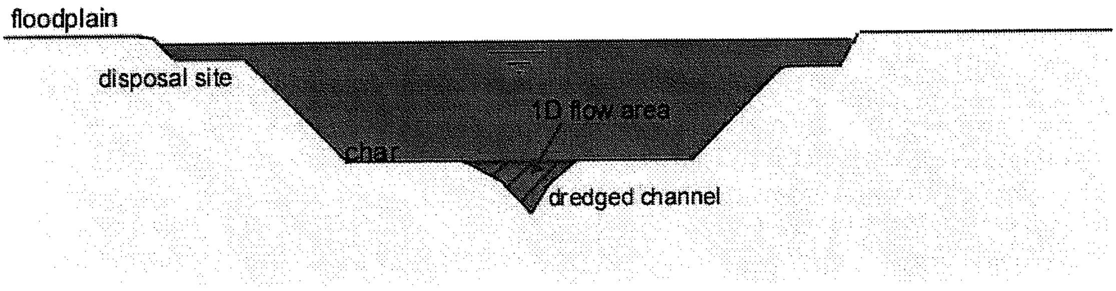


Figure 3.16. Theoretical cross-section of the Gorai River

In the cross-sections of the year 1999 no difference was found between the natural low water bed and the dredged channel. Therefore combination of these two is chosen as the area where 1D flow might occur with low stages. When the stages are above the level of the low water channel, 2D flow conditions become more pronounced.
Note: a distinction is made in 1D flow conditions in the off-take and in the river downstream of the off-take. This is done since there is a major difference in stages characterising 1D flow in the off-take and the river downstream of the off-take. The analysis of the cross-sections resulted in the following characteristic discharges and stages when either 1 or 2D flow is dominant.

For this situation the transition between 1 and 2D flow is determined based on figure of the 1999 situation. It is possible that, due to the change in the disposal sites, these levels are not applicable for the 2000-2001 situation.

Table 3.2. 1 and 2D flow in the Upper Gorai River 1999-2000

Location	Discharge	1999-2000		
		Period	Wl (m ,above SLW)	Q_{Gorai} (m^3/s9
Off-take	$Q<Q_{charfull}$	Apr-mid Jul	<7	<2600
	$Q>Q_{charfull}$	mid Jul-mid Oct	>7	>2600
	$Q<Q_{charfull}$	mid Oct-Apr	<7	<2000
Downstream off-take	$Q<Q_{channellull}$	Apr-May	<2	<300
	$Q>Q_{channelfull}$	Jun-Nov	>2	<300
	$Q<Q_{channelfull}$	Dec-Apr	<2	<600

Table 3.3. 1 and 2D flow in the Upper Gorai River, 2000-2001

Location	Discharge	2000-2001		
		Period	Wl (m ,above SLW)	Q_{Gorai} (m^3/s9
Off-take	$Q<Q_{charfull}$	Apr-Jun	<7	<2600
	$Q>Q_{charfull}$	Jun-Sep	>7	>2600
	$Q<Q_{charfull}$	Sep-Apr	<7	<2000
Downstream off-take	$Q<Q_{channellull}$	Apr-May	<2	<300
	$Q>Q_{channelfull}$	Jun-Oct	>2	<300
	$Q<Q_{channelfull}$	Nov-Apr	<2	<600

The effect of hysteresis causes the different discharges for which there is expected to be 1D flow with falling stages and with rising stages. For falling stages the discharge below which 1D flow is expected to occur is lower than for rising stages.

1D situation

Dredging has an influence on the bed level and hydraulic slope in a river. In a 1D situation the effects are usually schematised as a protruding and reshaping of the scoured stretch. Figure 3.17 illustrates this:

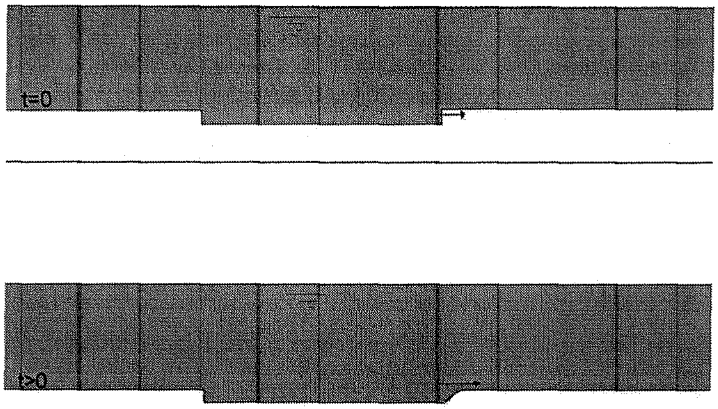


Figure 3.17. Translation and re-shaping of a disturbance in a river section

$$\frac{\Delta z}{\Delta t}+\frac{\Delta s}{\Delta x}=0$$

This protrusion celerity of the front is than:

$$c_b=\frac{b}{1-\varepsilon_p}\frac{s}{h}$$

with:
b = exponent of the sediment transport formula
ε_p = percentage of pores (-)
s = average sediment transport per unit width (m^2/s)

2D situation

The dredged profile is V-shaped. Therefore the channel is fed with sediment from both sides of the channel.

There are several way in which the low flow channel can fill up during the monsoon. These possibilities are discussed below:

Flow parallel to the channel

When the flow is parallel to the channel there is sediment transported into the channel with an equal amount at both sides. This is likely to happen in the straight stretch. In addition lateral diffusion occurs, resulting in more gentle slopes as well.

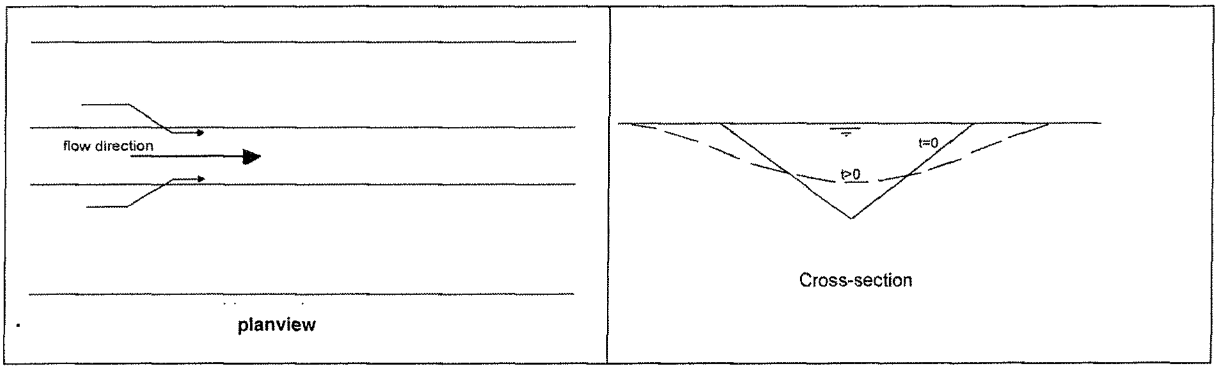


Figure 3.18. Effects of flow parallel to the channel

Flow with an angle with the channel

When the flow has an angle with the channel one side of the channel will erode and the other will grow. This is likely to occur in the off-take, a growth of the right shoal towards the channel will occur.

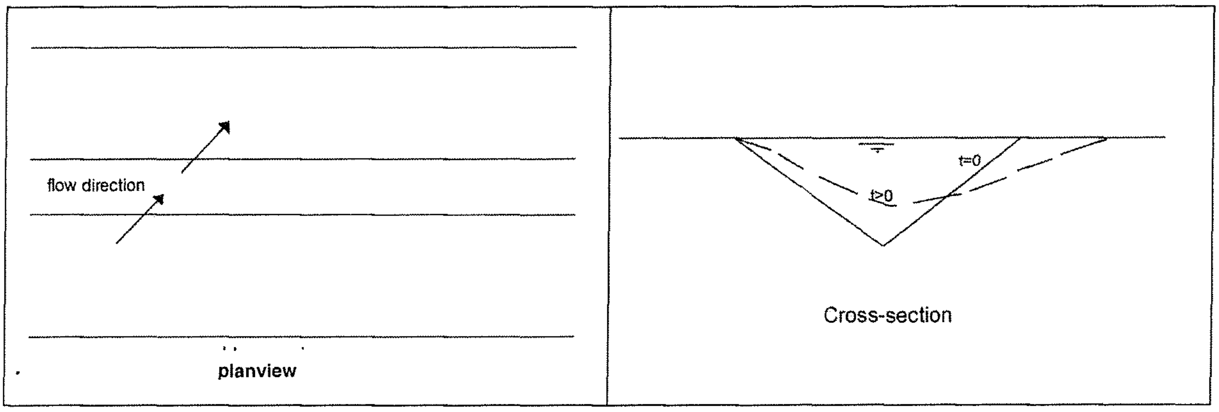


Figure 3.19. Effects of flow with an angle with the low water channel

Bank erosion

Sediment can be added to the system when banks erode. This can happen when the flow lines are contracted or in river bends

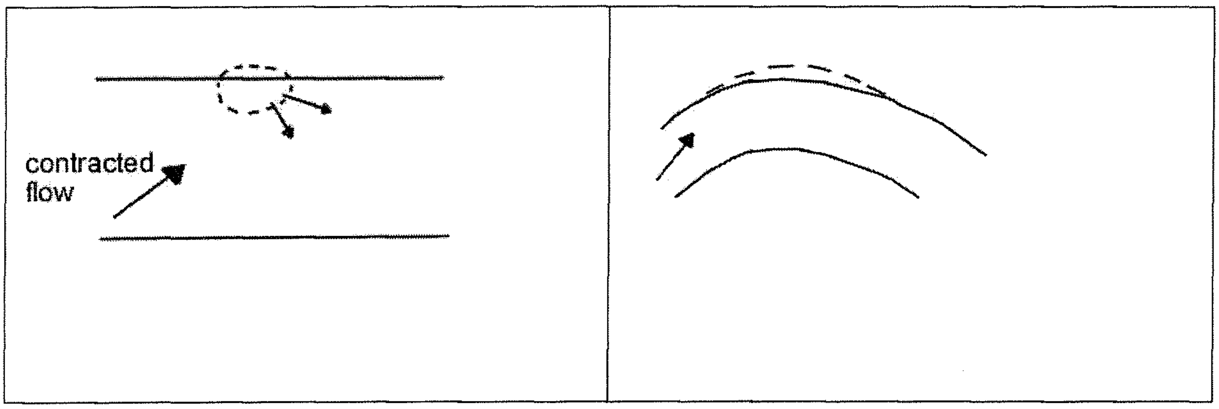


Figure 3.20. Bank erosion, by contracted flow (left) or erosion in outer bends (right)

Influence of bends

In outer bends erosion will occur with high water levels and high discharges. This sediment will settle downstream of the bend, creating a crossing.

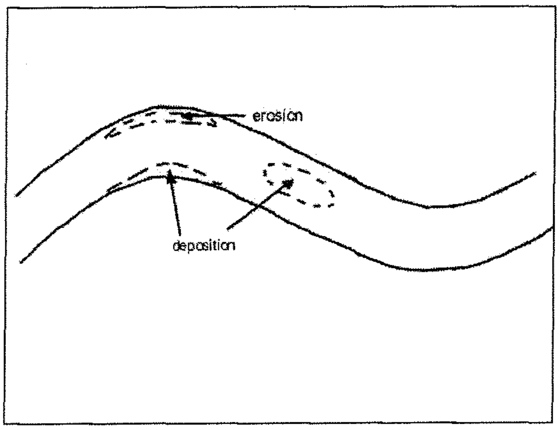


Figure 3.21. Effect of bends

Influence of man made structures

behind man made structures scour holes will develop with high stages. The sediment will settle downstream of the structure.

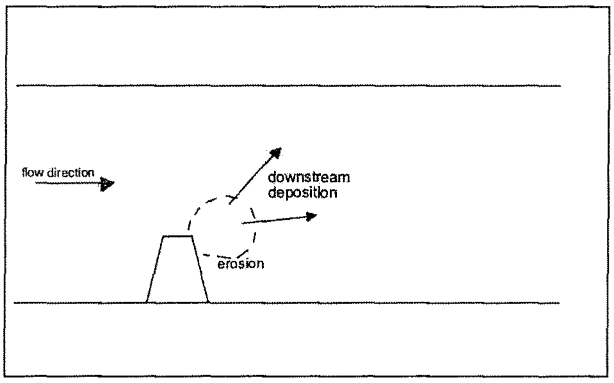


Figure 3.22. Influence of man made structures

Influence of clay hard points

Clay hard point will divert the current. This can cause contraction of the flow lines and therefore erosion on the opposite bank. The scour holes due to these clay hard points can move in downstream direction. This is observed near Talbaria after the monsoon.

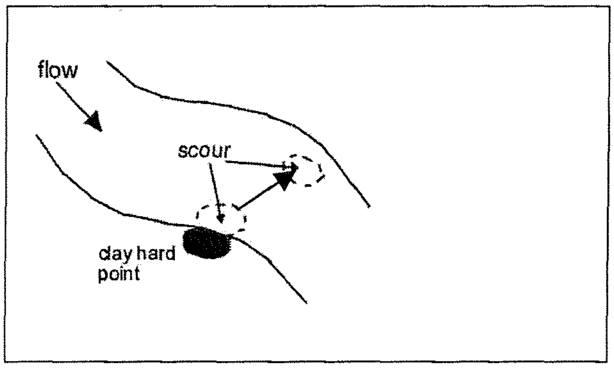


Figure 3.23. Effect of clay hard points

Sliding of slopes of disposal sites

When the slopes of the disposal sites are not stable, sliding may occur. This results in a sudden deposition in the channel near the disposal site.

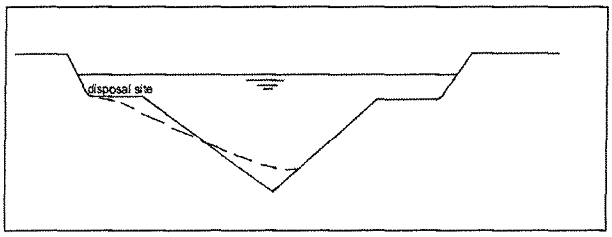


Figure 3.24. Effect of Sliding of slopes on a cross-section

3.5. Morphology of off-takes

Off-takes are bifurcations where the one branch is clearly minor compared to the other. The minor branch is the off-take of the main branch. In this case the Gorai River is the off-take of the Ganges River near Talbaria. In this study the reach from Kp 0.5 to Kp 3.5 is considered to be the off-take area.

3.5.1. Sediment distribution in off-takes

The parameters that influence the sediment distribution over the off-take are:

- The discharge ratio $Q_{Gorai@}/Q_{Ganges\ River}$.
- The importance of bed load transport for the total sediment transport, expressed in w_s/u_*.
- The situation of the off-take, related to the main river.
- The downstream boundary conditions.

Bulle, 1926 (Akkerman, 1993) stated that the off-take of a straight channel collects more sediment relative to the discharge than the ongoing channel because of the spiral current that is developed (see figure 3.25). The bed load transport is then directed towards the off-take

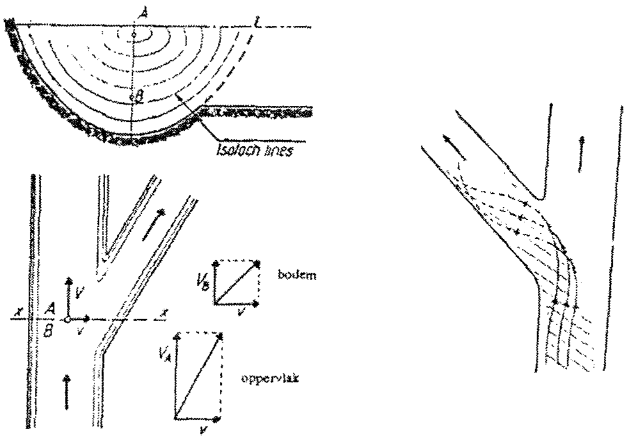
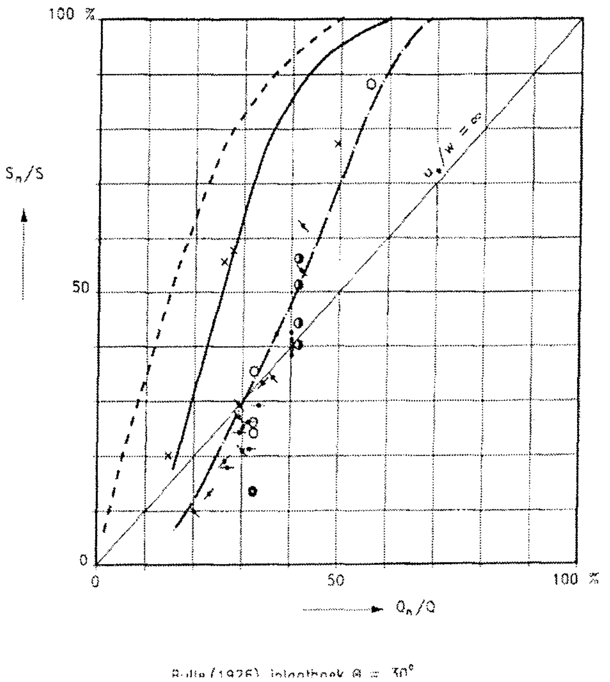


Figure 3.25: Off-take from a straight channel and Bulle effect (Akkerman, 1993)

In a situation where the ongoing channel also has an angle with the main channel, the ongoing channel or off-take with the largest angle will collect relatively the most sediment. The shape and geometry of the off-take also determines the curvature of the flow lines entering the off-take and therefore the occurrence and magnitude of the secondary flow (DHV-Haskoning, 2000).
This effect is stronger when the off-take is situated in an inner bend. When the off-take is situated in an outer bend this is favourable for the sediment intake in the off-take: less sediment will come into the off-take.

Besides angle and shape of the off-take, the discharge ratio of the off-take and main channel is important for the sediment intake. The discharge is distributed over the two channels, dependent on downstream boundary conditions and therefore the slopes in the ongoing branches. When the suspended sediment consists mainly of wash load and will therefore be distributed equally over the vertical, the suspended sediment is equally distributed as the discharge. The ratio of the bed load transport is not equal to the ratio of the discharge of the two channels. In the section on river morphology it is stated that the suspended sediment is dominant for the situation of the Gorai River. Figure 3.26 illustrates the influence of the discharge ratio for the sediment distribution. Small discharge ratios, as for the situation of the Gorai, are favourable for the sediment intake in the off-take.

However, the angle to the main channel, which is about 70° in the Gorai case, is also important for the sediment intake. According to Indlekoffer, with a discharge ratio of 10% and an angle of 90°, this gives a sediment intake of 35% of the bed load of the Ganges River!



Bulle, anlge -= 30°

Indlekoffer, angle = 90°

Indlekoffer, angle = 90°, with groyne

Figure 3.26: Sediment intake, dependent of angle and discharge ratio (Akkerman, 1993)

A difference in approach angle will result in a difference in sediment intake in the Gorai River. A decrease in the angle between the Ganges River and the Gorai River will result in a decrease in sediment intake in the Gorai River.

3.5.2. Development of the Gorai off-take

As stated before the off-take of the Ganges River to the Gorai is funnel shaped. The direction of the flow at a funnel shaped off-take is rapidly changed due to the rapid change in width. The flow velocities in the Ganges River are higher than in the Gorai River. This leads to a loss in velocity and the formation of a large bar at the off-take.
In the Main Study (DHV-Haskoning, 2000), the change in relative sediment distribution over relative flow distribution over the years is indicated. The parameter that is used for this purpose is:

$$\sigma = \frac{S_{Gorai}/S_{Ganges}}{Q_{Gorai}/Q_{Ganges}}$$

Figure 3.27 gives the values of σ for the years 65-66 to 97-98.
The increase in σ indicates the increase in a relatively larger sediment input compared to the discharge input. Since the flows, and therefore the sediment transport capacity, decreased over the years and the sediment intake increased, problems concerning siltation occurred in the off-take. This is confirmed by observations.

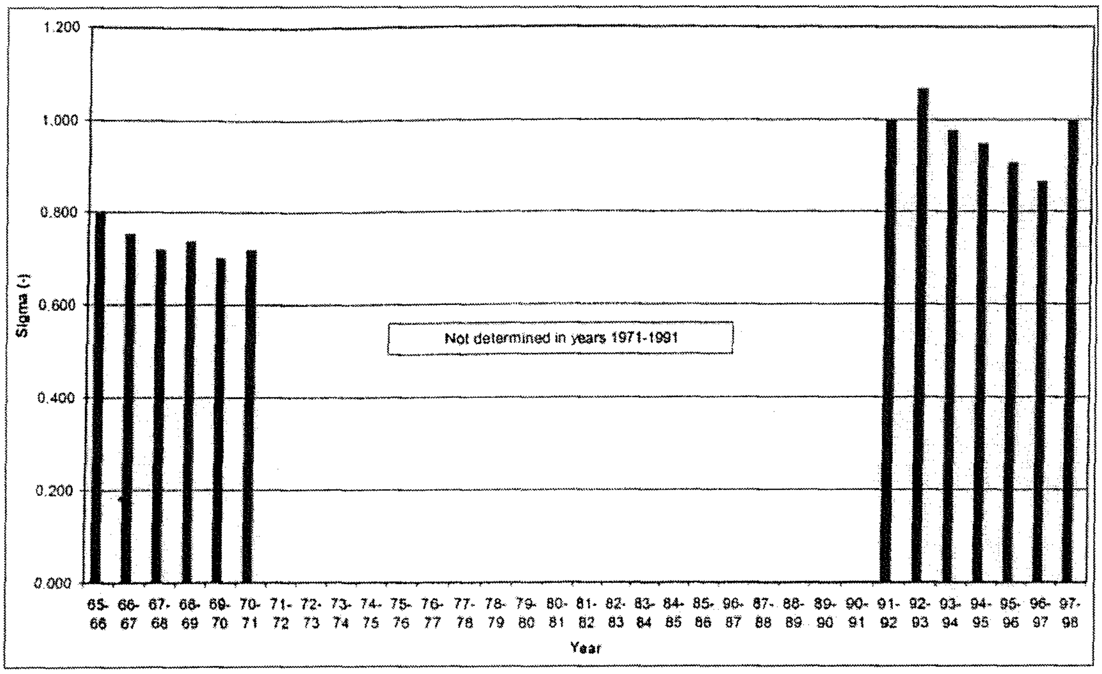


Figure 3.27: Change of σ for the Gorai between 1965 and 1998 (DHV-Haskoning, 2000)

3.5.3.Fate of the Gorai off-take

Two approaches are available to determine the fate of the Gorai off-take. First there is the nodal point relation developed by Wang (1995) for mathematical modelling, secondly there is Lane´s balance, which describes the relation between the sediment inflow and the transport capacity. Lane´s balance was applied to the Gorai situation by DHV-Haskoning (2000).

Stability of river bifurcations in 1D morphodynamic models

In 1995 Wang e.a. developed a nodal point relation for presenting bifurcations in mathematical models. This nodal point relation is also an indication of the stability of the bifurcation and the fate of the ongoing branches.
Physically the sediment distribution is determined by the geometry and the current structure at the bifurcation. An accurate representation is not possible in a 1D model. Therefore a nodal point relation is important for the understanding of the behaviour of the model. Wang e.a made a mathematical analysis of this nodal point relation.
The basis of the nodal point relation is that the sediment distribution over the ongoing channels is dependent on the following dimensionless quantities:

$$\frac{S_1}{S_2} = f\left(\frac{B_1}{B_2}, \frac{Q_1}{Q_2}, \frac{C_1}{C_2}, \frac{h_1}{h_2}, \ldots\right)$$

with:
S= sediment transport
Q= water discharge
h= water depth
B= channel width
C= Chézy coefficient

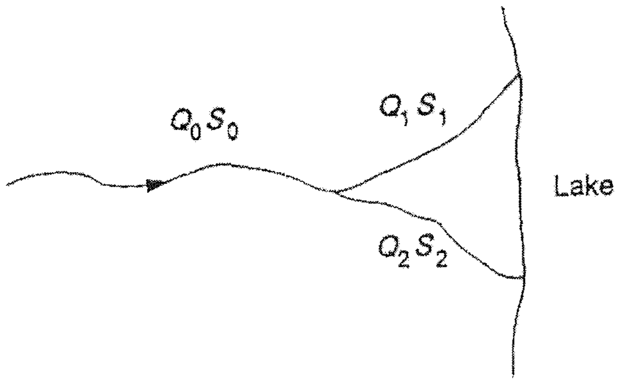


Figure 3.28: Sketch of a bifurcating river (Wang, 1995)

One of the requirements to the nodal point relation is that it is symmetric. The following function satisfies this requirement:

$$\frac{S_1}{S_2} = \left(\frac{B_1}{B_2}\right)^{k_B}\left(\frac{Q_1}{Q_2}\right)^{k_Q}\left(\frac{C_1}{C_2}\right)^{k_C}\left(\frac{h_1}{h_2}\right)^{k_a}$$

in particular the following case will be discussed:

$$\frac{S_1}{S_2} = \left[\frac{Q_1}{Q_2}\right]^k \left[\frac{B_1}{B_2}\right]^{1-k} \qquad (k > 0)$$

An equilibrium state occurs if the flow is uniform in all branches and if the sediment transport capacity of each branch is equal to the sediment supply at the upstream end of the branch. The equilibrium state is determined by the following equations:

mass balance for water

$$Q_1 + Q_2 = Q_0$$

water motion according to Chézy

$$Q_j = B_j C_j h_j^{\frac{3}{2}} i2_j^{\frac{1}{2}} \qquad (j = 1{,}2)$$

geometric relation

$$i_1 L_1 = i_2 L_2$$

mass balance for sediment

$$S_1 + S_2 = S_0$$

sediment transport described by the power law

$$S_j = B_j m \left(\frac{Q_j}{B_j h_j}\right)^n \qquad (j = 1{,}2)$$

These equations can be solved to determine the eight variables Q_j, S_j, a_j, i_j (for j=1, 2)
Solving these equations lead to the following relation between the sediment transport ratio and the depth ratio.

$$\frac{S_1}{S_2} = \frac{B_1}{B_2}\left(\frac{C_1}{C_2}\right)^n \left(\frac{h_1}{h_2}\right)^{\frac{n}{2}} \left(\frac{L_1}{L_2}\right)^{-\frac{1}{2}}$$

with:
n= power used in the sediment transport formula (for example: Engelund-Hansen uses n=5)

There are three equilibrium states:

1. Both branches are open and each branch transports a part of the water and sediment;
2. Branch 2 is closed (Q_2=S_2=a_2=0) and all the water and sediment is transported through branch 1;
3. Branch 1 is closed and all the water and sediment is transported through branch 2.

Wang e.a. found that for k>n/3 the first equilibrium will occur, with two branches with its equilibrium depth and discharge. In case of k<n/3 one of the branches will silt up. The following figure illustrates this: In this figure the depth is indicated by "a_i".

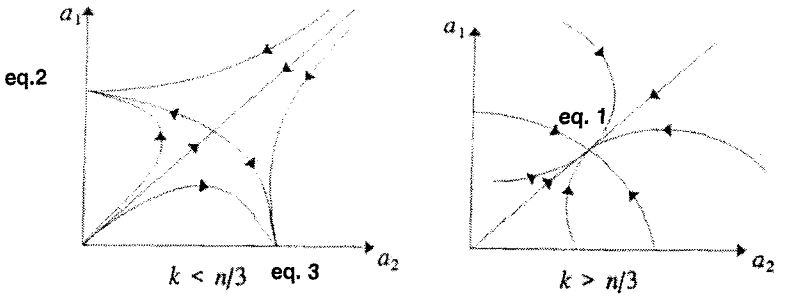


Figure 3.29: Phase diagrams of the differential equations (Wang, 1995)

Lane´s balance

Lane´s balance describes the relation between the sediment inflow and the transport capacity (DHV-Haskoning, 2000):

$$SD \propto Qi$$

with:
S = sediment transport (m^3/s)
D = grain size (mm)
Q = discharge (m^3/s)
i = energy slope of the river (-)

From this relation it follows that in case of increasing sediment intake for a given discharge the river responses with an increase in slope. An increase in slope in the river downstream of the off-take results in increased stages downstream, which results in further deterioration of the off-take.
Klaassen (1995) investigated Lane´s balance further to assess the state of the equilibrium of the main rivers in Bangladesh. He combined the balance with the Chézy equation for flow:

$$u = C\sqrt{hi}$$

and the sediment transport formula

$$s = mu^n$$

With m and n being constant, and assuming the grain size does not change, the modified Lane´s relation for the Gorai/Ganges River ratio can be written as:

$$S_{Gorai} \approx i_{Gorai}^{n/3} Q_{Gorai}^{n/3}$$

Comparing the Gorai River with the Ganges River River gives the following relation:

$$\frac{S_{Gorai}}{S_{Ganges}} = k\left(\frac{i_{Gorai}}{i_{Ganges}}\right)^{n/3}\left(\frac{Q_{Gorai}}{Q_{Ganges}}\right)^{n/3}$$

SWMC model simulations showed that the Chézy number is depth-dependent, instead of being constant. (C::$h^{0.5}$). Therefore the powers of i and Q become different. The changed powers are:

Table 3.4. Modified powers of Lane´s balance (DHV-Haskoning, 2000)

	Q power		i power	
	General	n=5	General	n=5
Constant Chézy number	(n+3)/6	1.33	n/3	1.67
Depth dependent Chézy number (C::$h^{0.5}$)	(n+1)/3	2.00	n/4	1.25

Similarities with Wang´s nodal point relation can be found in the modified Lane´s balance. The discussed case in the nodal point theory is:

$$\frac{S_1}{S_2} = \left[\frac{Q_1}{Q_2}\right]^k \left[\frac{B_1}{B_2}\right]^{k-1}$$

When $k \geq n/3$ the system with two branches is stable. In the modified Lane´s balance the equilibrium is also found for $k \geq n/3$.

Figure 3.30 gives a comparison of the relative sediment and relative flow distribution for the Gorai River for the periods of 1965-1971 and 1991-1998. For the period 1965-1971 there was an equal distribution of sediment and discharge. For the period of 1991-1998 the sediment load has decreased, the flow has decreased even more. The balance was disturbed and according to Lane´s balance this would lead to further deterioration of the off-take channel.

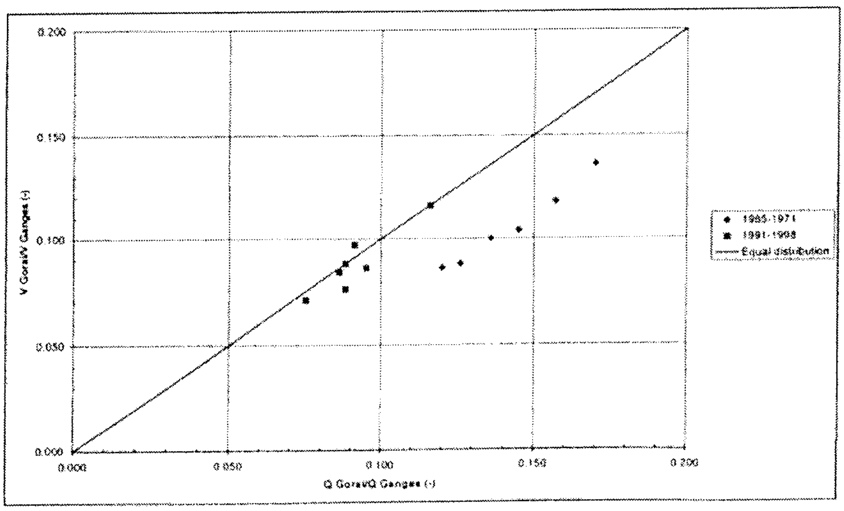


Figure 3.30: Relative sediment and flow distribution for the Gorai (DHV-Haskoning, 2000).

4. MORPHOLOGICAL DEVELOPMENT OF THE UPPER GORAI RIVER, 1999-2001

4.1. Introduction

For the study of the morphological response of the Upper Gorai River to dredging the GIS application ArcView is used. ArcView with Spatial Analyst has the following possibilities that can be used for this study:

- 3D visualisation.
- Simple analysis, such as visualisation and quantification of cells with a defined characteristic and statistics of a grid of cells.
- Identification of cell values.
- Simple calculations, such as difference between two grids.

ArcInfo, the programming language behind ArcView has more options.

The visualisation of the bed levels and the deposition / erosion patterns can be found in Appendix III to VI as a series of maps. In these figures the bed levels have been coloured blue. A darker blue indicates a lower bed level. The deposition and erosion patterns have a colour ranging from blue to purple for erosion and yellow to orange for deposition. These figures give a good impression of the development of the river. When in this section the development of a particular stretch is discussed, the relevant figures are also used in this section.

4.2. Available data

The data that are used for the analysis are water levels, discharges and bed levels. These are measured with the following frequency:

Table 4.1: Available data

Data	frequency	interval / number of stations
water levels	daily	8 stations
discharge	fortnightly	1 (Kp 3.25)
bathymetry, hydro during monsoon	fortnightly	200 / 250 / 500 m
bathymetry, hydro outside monsoon	monthly	200 / 250 / 500 m
bathymetry, combined topo and hydro	yearly (April)	50 m

The data on bathymetry using hydro surveys consist of cross-sections of the submerged area. Due to the draught of the survey vessel not every location is accessible. This results in gaps within the cross-sections on several high lying areas such as disposal sites. Since no accurate data are known on the bed level of these locations, these locations are not taken into account in the sediment balances. When a sediment balance is made with the data on bathymetry, the disposed sediment will only be taken into account when the height of the disposal site is at least 0.7 m below the momentary water level. This results in a balance which indicates too much erosion, since dredging is taken into account in the low water channel, but not the deposition of the sediment within the banks of the river. Therefore these data sets are only used as a basis for the deposition and erosion patterns and an indication of the activity of the river. The following data set is used for the sediment balances:

In April, after the dredging season, a topo survey is carried out, which covers all dry locations within the banks of the river. GRC combined these topo surveys with the hydro survey from the same month that year. This resulted in cross-sections with an interval of 50 m. These data cover the full width of the river, and give therefore also information on the disposal sites.

In this analysis both types of data sets are used. The data sets with an interval of two weeks to one month give an indication of the development in a short time step and the most active periods. The data containing the topo surveys are used to obtain a total sediment balance over the year. The data set with the topo survey and the data set with the hydro survey of September, which is the end of the

monsoon, are used to give an indication of the deposition and erosion over the monsoon and the dredging season.
There is a difference between the sum of the balances with an interval of several weeks and the balance over a larger time period. This is due to the fact that a balance only covers the locations which the two consecutive data sets have in common. With rising water the data set of the first moment will cover a smaller area than the second moment. The difference in width can be up to 300 m for two consecutive recordings.
It is possible that inaccurate measurements were taken, which give an incorrect impression of the deposition and erosion pattern in a period of time. These possible inaccurate measurements are indicated in the sections on the analysis per stretch.
The data on water levels and discharge required little processing before these data could be used. The data on bathymetry did require processing as described below.

4.3. Data processing

Before the river bed could be visualised as a continuous bed, the data of the cross-sections were interpolated to a continuous bed using the programme Surfis. The output of the interpolation is a continuous representation of the river bed with grid cells of 10 * 10 m. The original cross-sections and the analysis of Mamun (2000) and of GRC (2001) were used as a validation check of the interpolation method.

4.3.1. Surfis

The programme Surfis40, which was made available for this study by RIZA, is used for the interpolation. Surfis interpolates linearly along flow lines. The method is described hereafter:

Boundaries

At first the boundaries of the river and the total boundaries of the area are determined, see figure 4.1. Since at most periods only hydro surveys have been carried out the boundaries of the river have been set at the boundaries of the survey data. For this purpose a programme has been written that determines the first and last point of a cross-section. The obtained points on the river boundaries are interpolated linearly by Surfis and form two continuous river boundaries.

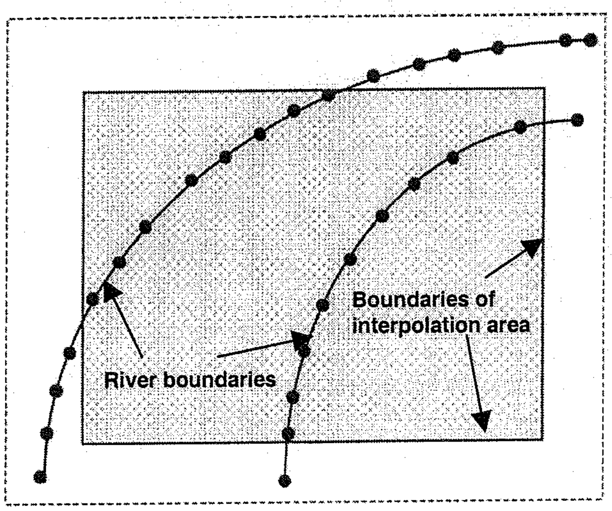


Figure 4.1. Boundaries of the interpolation area and the river (Fioole, 1999)

Since at different stages different boundaries should be used, the river has been divided into periods of high, low and transition stages. For the years 1999-2000 and 2000-2001 the following categories have been made:

Table 4.2. River boundaries for the interpolation

Stage	Months
low	April-May 1999
transition	June 1999
transition	July 1999
high	August-September 1999
transition	October 1999
transition	November – December 1999
low	January – May 2000
transition	June 2000
transition	July 2000
high	August-September 2000
transition	October 2000
transition	November – December 2000
low	January 2001

For the data sets containing topo survey the boundaries of April 1999 are used, these cross-sections have an interval of 50 m.

For the total boundaries the river is divided into two sections, based on the interval of the cross-sections.

Table 4.3. Total boundaries of the interpolation area

	sections 1999	interval (m)	sections 2000	interval (m)
upper part	Kp 0.0 – Kp 13.0	250	Kp 0.0 – Kp 17.0	200
lower part	Kp 13.0 – Kp 31.0	500	Kp 17.0 – Kp 31.0	250

Flow line

Since Surfis interpolates along a flow line, a flow line should be given as input. The co-ordinates of the alignment are used for this. For the two dredging seasons that are studied in this report, different alignments were designed. Therefore a flow line was defined for each dredging season. In the survey campaign the cross-sections are sailed perpendicular to these alignments.

Search distance

Another input parameter in Surfis is the search distance. For the calculation of a point on a flow line, the search area for points that are needed for the calculation has to be defined, see figure 4.2.

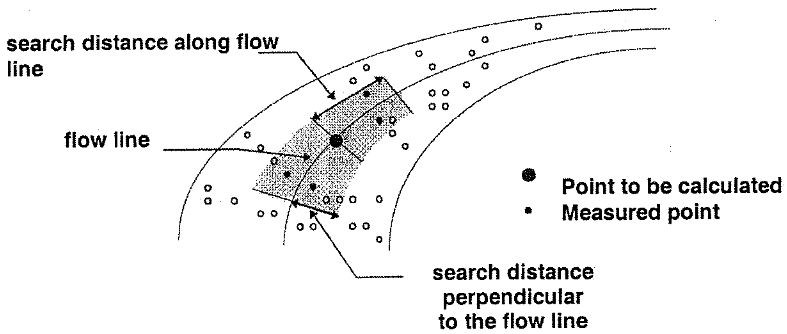


Figure 4.2. Search area for the calculation of a point (Fioole, 1999)

The maximum search distance along the flow line is set at the interval of the cross-sections +100 m, with intervals of 100m. The maximum search distance perpendicular to the flow line is set at 15 meter, with an interval of 5 m.

In this way for large areas with missing data the interpolation can not be made. Therefore at periods with high stages the information of some areas is not available. This is caused by the fact that the area with missing data has a bed level varying between the water level –0.7 m and every possible value above the water level. The table below gives an indication of the areas with no data:

Table 4.4. Areas with no data with high stages

Location	Left bank/ Right bank
Kp 0.5-3.0	Right bank
Kp 8-10	Right bank
Kp 20-21	Right bank
Kp 26-28	Left bank

Calculation

For the calculation of the bed level, or z-value of a point, multiple linear regression is used. The four points nearest to the points that has to be calculated form a quadrant. The area of this quadrant is calculated with multiple linear regression. The z-value of the point is the value on this surface.

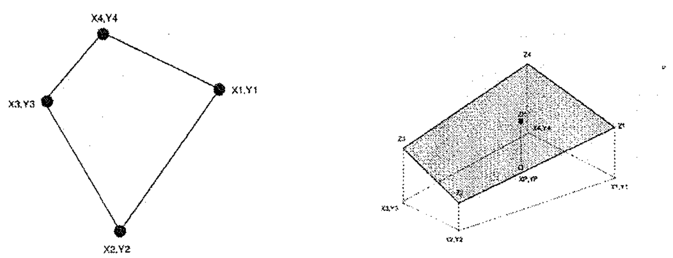


Figure 4.3. Illustration of the multiple linear regression method (Fioole, 1999)

Transformation

The obtained grid from the interpolation contains values for points with an interval of 10 metre. This interval is chosen based on the minimum submerged width of the river. For low stages the width can be as low as 60 m. When using an interval of 10 metres there are about 6 cells in this minimum cross-section. Before this can be used for analysis in ArcView the grid points have to be transformed into cells. This step contains only a transformation of the data, no additional calculations are made. The transformation gives the are around a point on the grid the same value as that point.

4.3.2. Validation of the obtained grids

The validation of the interpolated grid is done in three steps:

- Comparison of the original cross-sections with the grid.
- Comparison of the balances of 1999-2000 with 1D analysis of Mamun (2000).
- Comparison of the balances of 1999-2000 and 2000-2001 of GRC (2001).
- Comparison of the balances with a small time step and the balances with a large time step.

Comparison with the original cross-sections

After a comparison of the value of the grid cells with the original cross-sections it can be concluded that there is little difference in the value of the grids cells and the original cross-section. It has to be stated that the cross-section has data every one metre, while a grid cell covers an area of 10 * 10 m.

Comparison with Mamun (2000)

One of the results of the 1D analysis made by Mamun was a set of balances for every consecutive two survey periods per 500 m of the river for Kp 1.5-13.0. These balances were compared to the balances of every consecutive survey campaign. At most points there was only a small difference between the balances obtained from ArcView and the balances obtained from the 1D analysis. A logical explanation for these differences is:

- For the analysis with ArcView the cross-sections with an interval of 250 m have been used, while for the 1D analysis the cross-sections had an interval of 500m. Especially in river bends and in stretches with scour holes around structures this can cause differences.

A large difference was found in the stretch around the Kushtia groynes, Kp 3.5 – 7.0. This stretch does not only contain a bend, but also two groynes. When an interval of 500 m is used, scour holes are not taken into account that can be seen when using the 250 m interval. The 2D analysis resulted in a larger erosion in this stretch than the 1D analysis.

A second difference is found in the period end July-begin August. The balances for all stretches are different from the balances obtained from the 1D analysis.

Comparison with the analysis of GRC

GRC has also made a 2D analysis of the Upper Gorai River. For this analysis the combined hydro / topo surveys are used and the hydro surveys over the monsoon. The topo survey data was combined with the hydro data for every used data set in the monsoon. In this way every data set covers the full width of the river. The result of this study were balances which covered a period of one month during the monsoon and a total balance over the monsoon for the year 2000-2001 and a total balance over the hydrological years 1999-2000 and 2000-2001.

The balances which cover a larger time period (ie the total balances over 1999-2000 and 2000-2001) showed small differences with the analysis with ArcView. The sum of these differences is however approximately 1 Mm^3, which is about 30% of the balance. The trend in deposition and erosion however was the same in both analyses. The difference can only be explained by the difference in interpolation method, linear interpolation with multiple linear regression on the one hand and triangular interpolation on the other hand. This is discussed further in chapter 6.

Comparison of the balances with a small time step and a large time step

Two data sets have been used for this study, the one includes topo surveys, the other does not. The results of the balances that are derived from these data sets should be comparable for the situation of April to September (monsoon), since for this period no dredging works have taken place.
When the results of the sediment balances for smaller times steps are accumulated and compared to the results of the balance for a large time step enormous differences are found. These differences were not just a large percentage of the volume, but when using the small time steps net deposition was found, while the balances for a large time step resulted in net erosion. When the results for the stretches are studied identical large differences were found.
Table 4.5 shows the results for the two studies:

Table 4.5. Results of the balances for small time steps and for a large time step (April to September) All volumes are in Mm^3

Stretch	Monsoon 1999 small time steps	Monsoon 1999 large time step	Monsoon 2000 small time steps	Monsoon 2000 large time step
Kp 1.5-3.5	0.65	-0.20	0.70	0.01
Kp 3.5-7.0	-0.12	-1.45	-0.82	-1.56
Kp 7.0-9.0	0.74	0.20	0.87	0.20
Kp 9.0-13.0	1.50	-0.46	0.39	-0.38
Kp 13.0-17.0	1.25	-0.02	-0.01	-0.78
Kp 17.0-20.5	0.22	-0.40	0.65	0.46
Kp 20.5-26.0	0.76	-0.78	1.59	-0.01
Kp 26.0-31.0	0.66	-1.41	0.21	-1.69
Kp 1.5-31.0	5.66	-4.50	3.58	-3.77

The same differences can be found when comparing the study of Mamum (2000), who uses the small time steps, and GRC (2001), who uses larger time steps and topo surveys.
The reason for these large differences could be:

- A difference in topo and hydro surveys.
- The processing of the hydro and survey data to obtain the data set with cross-sections with an interval of 50 m.
- The accuracy of both types of surveys is not comparable. For example the hydro surveys are carried out with echo soundings When a sand-water layer is present with high stages and flow velocities near the bed of the river this can cause differences in density of the medium and therefore differences in measurements.
- There are dunes and other irregularities present which cannot be measured by the hydro survey with an interval of 200m but which can be measured with an interval of 50 m.

Concluding it can be said that:

- When hydro survey data is used with a small time step the results are comparable to the results of Mamun (2000).
- When the combined hydro and topo survey data is used the results are comparable to the results of GRC (2001a).
- Therefore ArcView gives results that can be validated by other studies.
- The causes of the differences between the balance based on hydro surveys and combined hydro / topo surveys needs further studying.

4.3.3. Possibilities and restrictions

Restrictions and points of attention when using the results of the analysis:

- Due to the minimum required depth of the survey vessel there were no bed levels recorded on the location of the shoals (which coincide with the disposal sites, upstream of GRB). Therefore the analysis will not consider the development of the disposal sites throughout the monsoon.
- The erosion and deposition patterns and the sediment balances only cover the cells that two grids have in common, this is the river with the lowest water level of the two considered periods. The difference in width between to consecutive surveys can be up to 300m.
- The sediment balances which cover long periods of time are the result of incoming minus outgoing sediment. Bank erosion and sediment trade is included in these balances.
- The sediment balances which cover small periods of time are only an indication of the activity of the river in that period of time. The disposal sites are often not taken into account, since no data is available on these locations, and therefore the sum of these balances is not representative for the sediment balance.
- It is possible that inaccurate measurements are taken, these give a incorrect impression on the deposition and erosion patterns.
- The bedforms that are present can give a incorrect impression of the actual bed level.
- The analysis of the sediment balance considers the Gorai River from Kp 1.5 to Kp 31.25. Kp 0 is in the low water bed of the Ganges River. Kp 1.5 is the about the first point in the Gorai River, in this way the erosion and sedimentation in the Ganges River will not influence the sediment balance of the Gorai River.

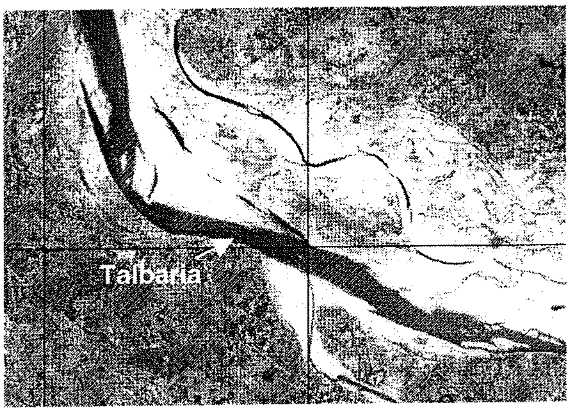
4.4. Analysis per stretch of the morphological development from April 1999 to April 2001

In the analysis the morphological development is discussed. This is done based on of visualised bed levels and deposition and erosion patterns, sediment balances, deposition and erosion rates and detailed studies on local bed level development in cases of specific morphological features. In Appendix III to X the results in the form of figures, tables and graphs can be found. In this section the main conclusions from these studies are described. In the analysis the eight stretches of the Upper Gorai River are considered separately.

4.4.1. Off-take, Kp 0.0-3.5

Situation of the Gorai River in relation to the low flow channel of the Ganges River

The low water channel of the Ganges River is very mobile. The only fixed point near the Gorai off-take of the low water channel is the scour hole near the clay hard point at Talbaria. Since the location of the off-take with respect to the Ganges River is important for the sediment ratio in relation to the discharge ratio the satellite images for April of the years 2000 and 2001 are considered.



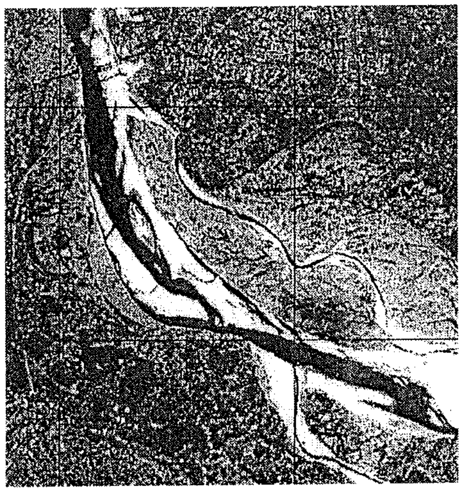


Figure 4.4. Planform of the Ganges River in 2000 (left) and 2001 (right) (GRC, 2001)

From these satellite images it can be seen that the approach angle of the Ganges River changed between 2000 and 2001. This resulted in a smaller angle between the Ganges River and the Gorai River. In 2001 the Gorai off-take is located more in an outer bend. It is expected that this will have a positive effect on the sediment intake in the Gorai River in the following monsoon.

4.4.1.Off-take, Kp 0.0-3.5

From April 2000 the Ganges River was included in the survey campaign. The planform of the Ganges River near the off-take shows a shift of the low water channel between April 2000 and October 2000.

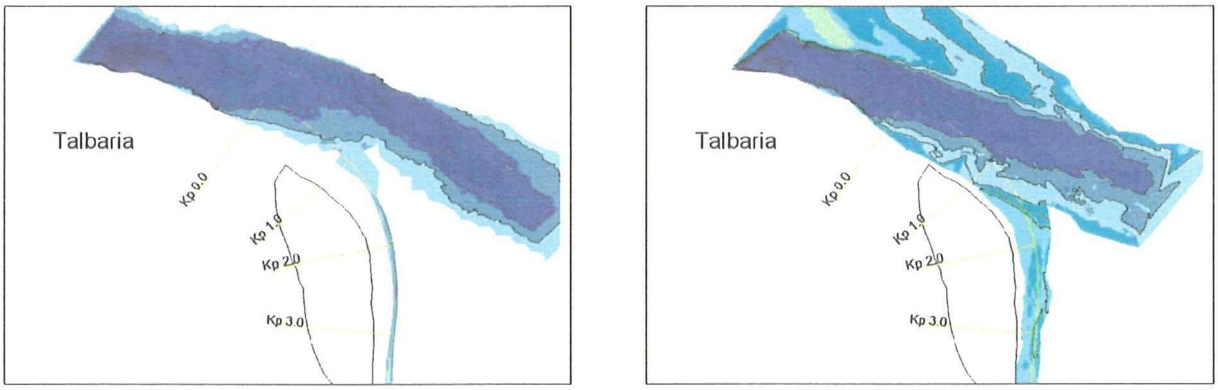


Figure 4.5. Shift of the low water channel of the Ganges River near the Gorai off-take. Left: April 2000, right: October 2000

The low water bed of the Ganges River shifted towards the Gorai River. If is possible that this resulted in a lower deposition over the hydrological year.

Planform of the Gorai River

The low water channel in the off-take does not have the morphological characteristics of a river bend. This can be explained by the fact that the bend in the alignment is a bend that is imposed on the river by dredging. The morphological developments in the Ganges River are stronger and therefore the part from Kp 0.0 to Kp 1.0 acts more as a part of the Ganges River than as part of the Gorai River.

Development of the bar in the off-take and retarded scour

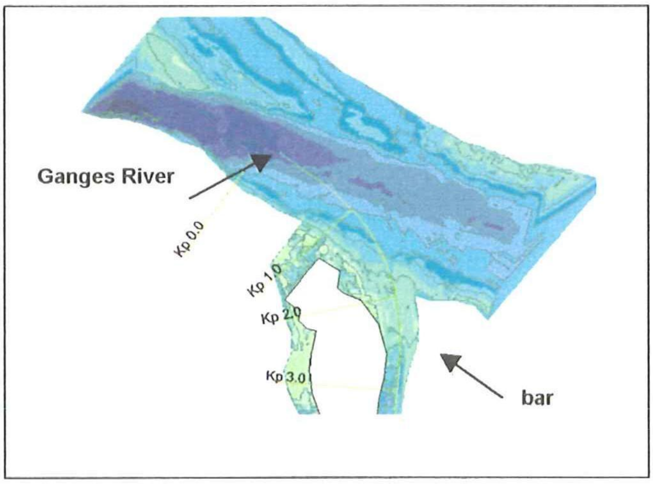


Figure 4.6. Gorai off-take Sep. 25th 2000

The shallow part on both sides of the low flow channel are expanding towards the low flow channel throughout the monsoon. At the end of the monsoon, end of September, the bar in the off-take between Kp 2.0 and 2.5 is completely developed. That the month of September contributes most to the development of the bar can also be found in the sediment balances. Between the beginning of

Directly with falling water the retarded scour starts. Between the end of September and the end of October 2000, 0.45 Mm^3 *of sediment was eroded from the off-take. The results of September to* October 1999 show a different figure. In that period there was a net deposition of 0.47 Mm^3. The sudden rise of the water levels can explain this. The development of the highest point of the bar in time can be seen in figure 4.7:

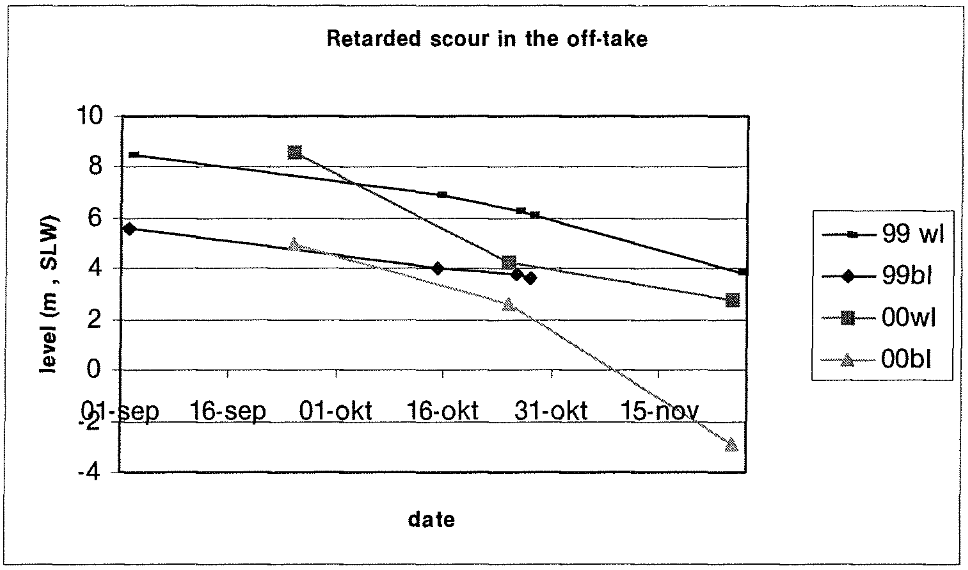


Figure 4.7: *retarded scour in the off-take*

From the figure above the following differences in the building up of the bar for the years 1999 and 2000 can be found:

- The highest level of the bar was higher in 1999 than in 2000, this is due to higher stages during the monsoon.
- The gradually falling of the water level has a positive effect on the self scouring capacity, in this *case retarded scour, in the off-take.*
- In the case of 1999 the bed levels changes can keep up with the changes in water level; the slope of the water level and the slope of the bed level are almost parallel.
- Quick falling of the water level in time cause more erosion.
- When analysing the above figure it should be noted that from the end of October dredging works took place in the off-take, the first layer (to SLW) was dredged.
- The effect of the dredging sequence can not be concluded from this figure, since the water level changes are the dominant factor in process of retarded scour in the off-take.

No conclusions can be made on the effects of the dredging sequence on the retarded scour. It is expected that dredging downstream of the bar will have a positive effect on retarded scour

Development of the secondary flow channel

The development of the secondary flow channel in the off-take is not clearly visible from the figures made with ArcView. It can be seen though that there is erosion at the location of the low flow channel, see figure 4.8. This implies that the secondary channel still attracts flow during the monsoon. Interesting is the development of the low flow channel in the following monsoon, now that the secondary channel upstream of the confluence of the two channels is used as disposal site. It is expected that the remaining low flow channel will attract more flow in the monsoon and will therefore remain open for a longer time.

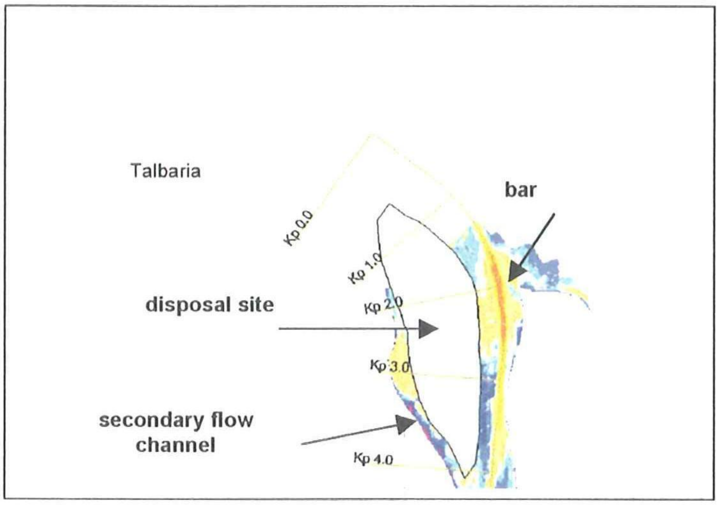


Figure 4.8. Erosion and deposition in the off-take from April to September 2000

Backwater effect

In the months May and June there is a slight erosion in the off-take, while in the dry season there is mainly deposition. This might be due to the backwater effect, which is described in section 3.3.4. However, the rates in this period are still very low and contribute little to the balance over the year. The backwater effect is therefore not considered further.

Deposition and erosion patterns

Only in the monsoon, from July to September, there is a 2D flow pattern in the off-take. In the off-take the sediment is redistributed. The higher areas erode during the monsoon. This is caused by lateral diffusion and flow from the higher areas to the low flow channel. This has also as a result that sediment is deposited in the low flow channel. In September the main part of the deposition takes place, this is also the time that the bar in the off-take builds up.

Behind the bar in the off-take, which is located between Kp 2.0 and 2.5, a deep channel develops. The depth of this channel had a maximum of 9.2 m below SLW in 1999 and 7.1 m below SLW in 2000. This with water levels of resp. 8.52 m above SLW and 7.52 m above SLW.

In figure 4.9 the disposal sites in the off-take area can be seen at the locations where mainly deposition takes place over the hydrological year.

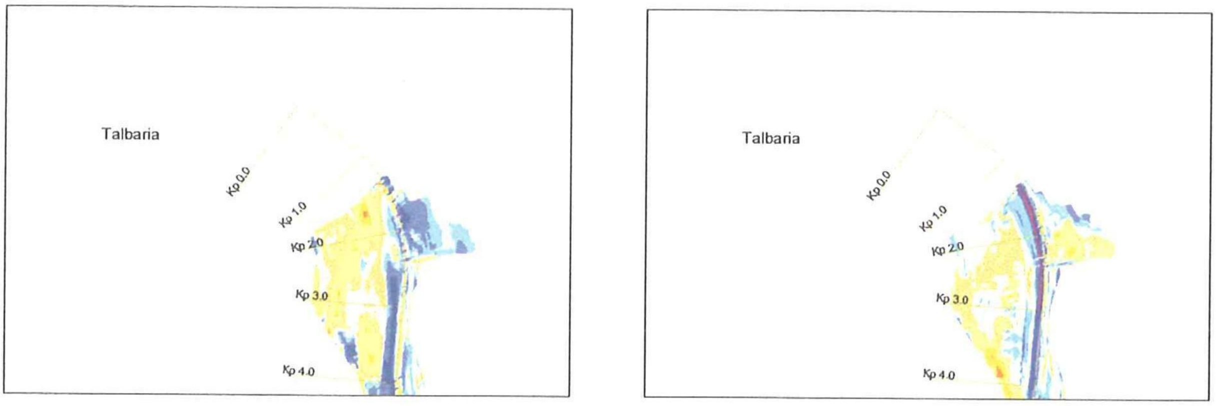


Figure 4.9: total deposition and erosion patterns for 1999-2000 (left) and 2000-2001 (right)

Sediment balance

Table 4.5. Sediment balance off-take area

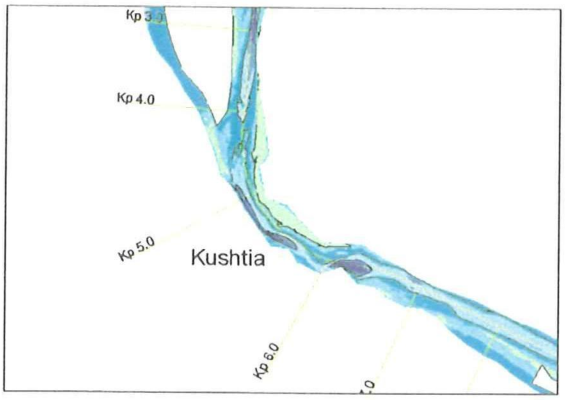
	balance 1999 (Mm^3)	balance 2000 (Mm^3)
monsoon	-0.20	0.01
total Apr-Apr (incl. dredging)	0.53	0.13
dredged volume	-0.62	-0.87 (+1.27 additional)

The following can be concluded from this table:

- The 1999 monsoon indicates erosion in the off-take. This is due to the time of the last survey in the monsoon, which took place on September 2nd. The following survey took place at the end of October. Therefore no clear picture of the deposition and erosion in the monsoon can be given with these figures.
- The total balance of 2000 indicates a lower net deposition than in the year 1999. When studying these figures it should be noted that the additional dredging of 1.27 Mm^3 is deposited in the same stretch, so this will not cause a difference in the balance.
- The self scouring capacity was higher in the third season, this may indicate an improved river system.
- The total balance of 2000-2001 indicates an overall small deposition in the off-take channel.
- Dredging is still necessary in the off-take, without dredging there would be a net deposition over a hydraulic year.

When the balances are studied more in detail it can be found that the most active period in the off-take varies from August in 2000 to September in 1999. In this period net deposition occurs. In 2000 some of the considered periods resulted in a net erosion in the off-take. It is not clear whether this indicates erosion over this period or an incorrect grid.

4.4.2.Kushtia, Kp 3.5-7.0



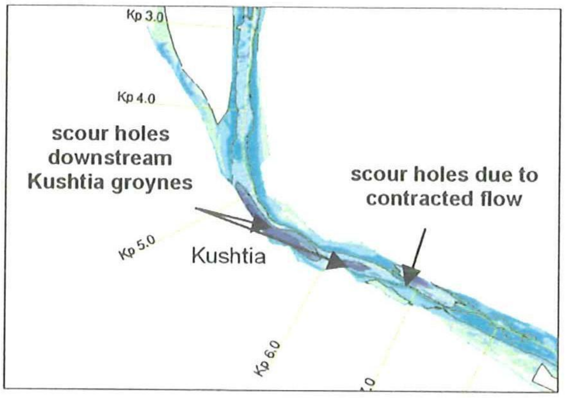


Figure 4.10. Kushtia, kp 3.5-7.0, July 2000 (left) and August 2000 (right)

The Stretch near Kushtia is characterised by the Kushtia groynes. Analysis of the bed levels and erosion and deposition patterns gives the following results:

- The scour holes near the groynes develop late in the monsoon.
- In 2000 the deepest bed level in the scour holes is reached in September, the lowest point is then at –15.5 m below SLW. In October 1999 the same depth was reached. These figures are for the scour hole of the first groyne at Kushtia.
- In 2000 the most shallow point of the scour holes is in April, at that moment the bed level is at 8 m below SLW.
- In 1999 the most shallow point of the scour hole was about 3 m below SLW.
- The scour holes remain deep during falling water, in November the bed level was still at 11 m below SLW.
- Erosion takes place around the groynes, while in the inner bend mainly deposition takes place in the monsoon.
- With lower water levels the scour holes fill up again.
- Near the left bank, downstream of the groynes there is another scour hole. This scour hole is developed because the groynes direct the flow towards the left bank instead of the low water channel. This causes severe erosion of the left bank.
- The scour holes near the left bank develop late in the monsoon.

The bed level of the scour hole near the second groyne and the scour hole near the left bank have been studied more in detail. Figures 4.11 and 4.12 show the results of this study:

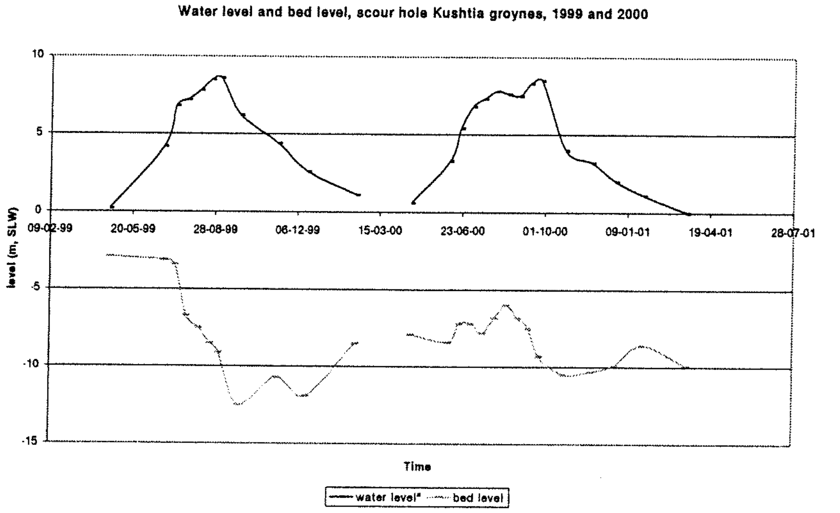


Figure 4.11. Development of the level at the deepest point of the scour hole and the water level in time in 1999 and 2000

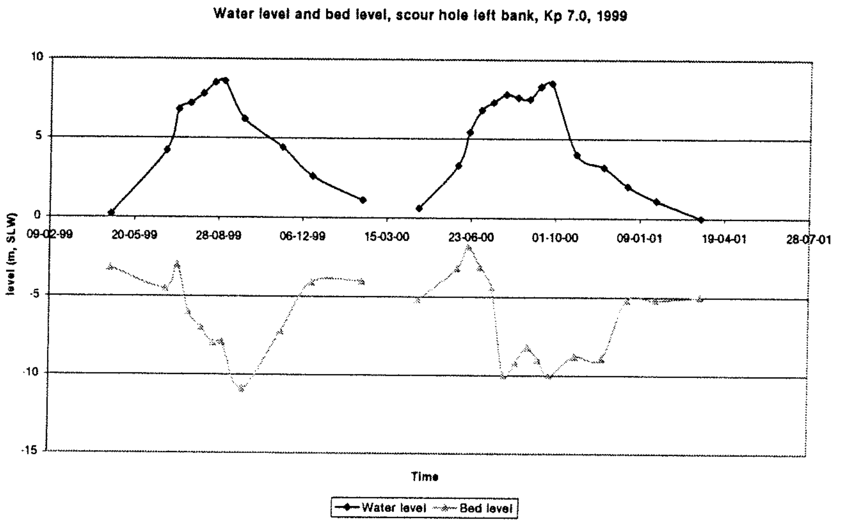


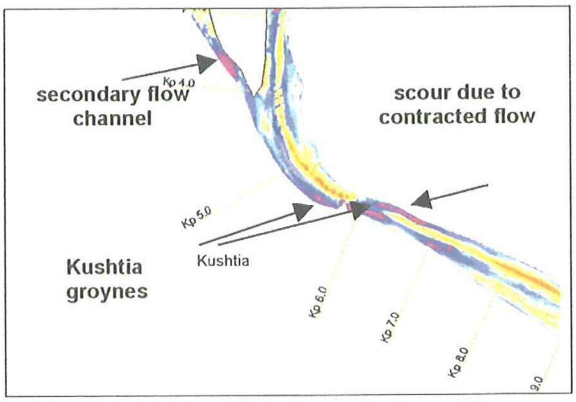
Figure 4.12. Development of the bed level of the deepest point of the scour hole near the left bank, Kp 7.0, in 1999 and 2000

The scour hole downstream of the groyne does not develop with the same trend as the water level. The filling up of the scour hole does not coincide with the falling of the water level. In 2000 the development of the water level is even less recognisable.

The scour hole on the left bank that is caused by contracted flow does follow the water level. A phase lag between the developments can be seen.

Deposition and erosion patterns

The erosion near the groynes is largest in the monsoon. In the third season, 2000-2001, the scour holes did not fill up after the monsoon, in contradiction to the first maintenance season, 1999-2000. The bend near Kushtia erodes in the monsoon. Downstream the bend, on the left side of the centre line erosion occurs. This erosion is due to the contracted flow lines downstream of the groynes. The sediment that is eroded from the scour holes will settle in the stretch Kp 7-9 instead of directly downstream of the groynes. This is also an effect of the contracted flow which has a higher transport capacity.



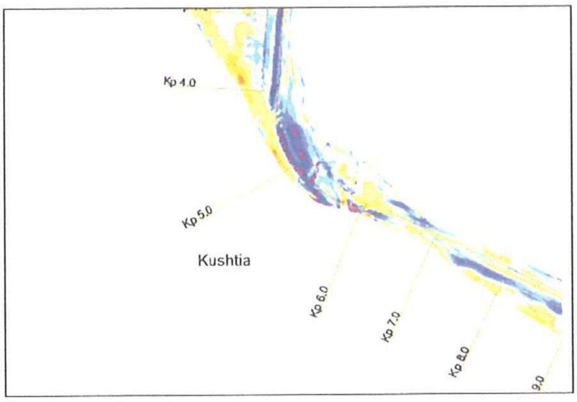


Figure 4.13: Deposition and erosion patterns of the monsoons of 1999 (left) and 2000 (right)

Figure 4.13 shows that there are differences in the deposition and erosion patterns over the monsoons of 1999 and 2000. The alignment of the first season, 1998-1999, was located more to the inner bend than the alignment of 2000. In the 1999 monsoon, which follows on the first dredging season, it can be seen that the dredged channel fills up. In 2000 the low water channel was located at the location of the natural low water bed. Therefore no net deposition was found in the dredged channel in the bend near Kushtia. It can also be concluded that the alignment of the first season was not stable in this stretch. Since the alignment of the third season has the same location as the alignment of the first season it is expected that this alignment will also not be stable during the monsoon.

Sediment balance

Table 4.6. Sediment balance Kp 3.5 – 7.0

	balance 1999 (Mm^3)	balance 2000 (Mm^3)
monsoon	-1.45	-1.56
total	-0.55	-0.62
dredged volume	-0.80	-0.68

- There is little difference between the balances of the two years.
- The net erosion in the monsoon was expected in the stretch around Kushtia, because of the presence of the groynes and therefore the scour holes.
- The erosion mainly takes place around the groynes, in the rest of the low flow channel deposition is dominant in the monsoon.
- The net erosion over the monsoon is larger than over the hydrological year. This is explained by the filling up of the scour holes with falling stages.

This stretch causes the main part of the erosion of the Upper Gorai River.

4.4.3.Straight stretch, Kp 7.0-9.0

This is a relatively stable stretch, were it is expected that mainly deposition will occur in the monsoon. By the dredging works the cross-section is changed. Were it first was a small low water bed with chars on the right side of the right side to a deeper low water bed with high disposal sites. This is expected to have a positive effect on the river.

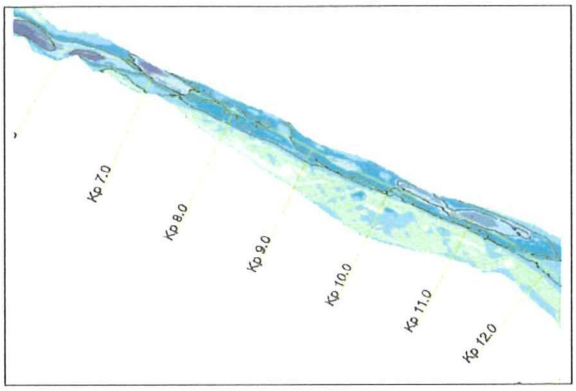
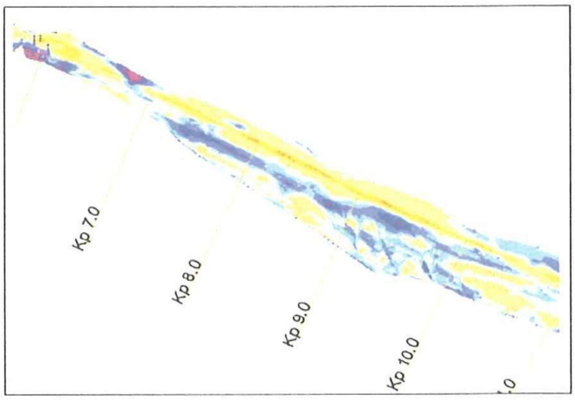


Figure 4.14. Straight stretch, September 2000



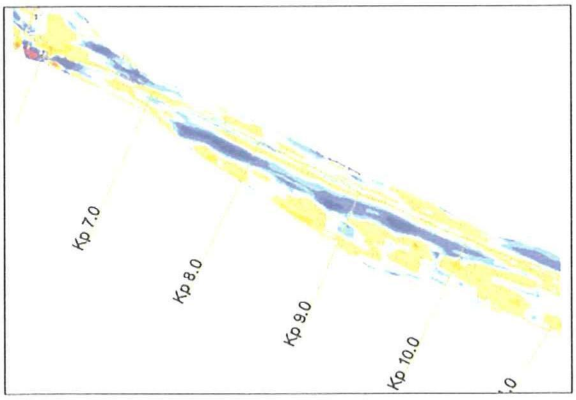


Figure 4.15. Deposition and erosion patterns in the monsoon 2000 (left) and in the hydrological year 2000-2001 (right)

The following observations are made in the analysis:

- In the monsoon there is deposition in the low water channel and erosion on the right side of the low water channel.
- In the middle of the low water channel the most deposition takes place.
- Over the year there is a small deposition in the low water channel.
- The location of the disposal sites can be seen in the figure on the right as a deposition over the hydrological year.
- Over the monsoon there was erosion on the locations of the disposal sites.

Deposition and erosion patterns

In the beginning of the monsoon the deposition and erosion pattern followed the deposition and erosion patterns which occur with flow parallel to the low water channel. Later in the monsoon there is erosion on the right bank and deposition in the main channel, this may indicate instability and therefore sliding of the slopes of the channel. It is also likely that the eroded sediment from the Kushtia stretch is deposited here. Another factor that magnifies the deposition in this stretch is that this stretch shows the characteristics of a crossing. This can be seen in figure 4.14.

Sediment balance

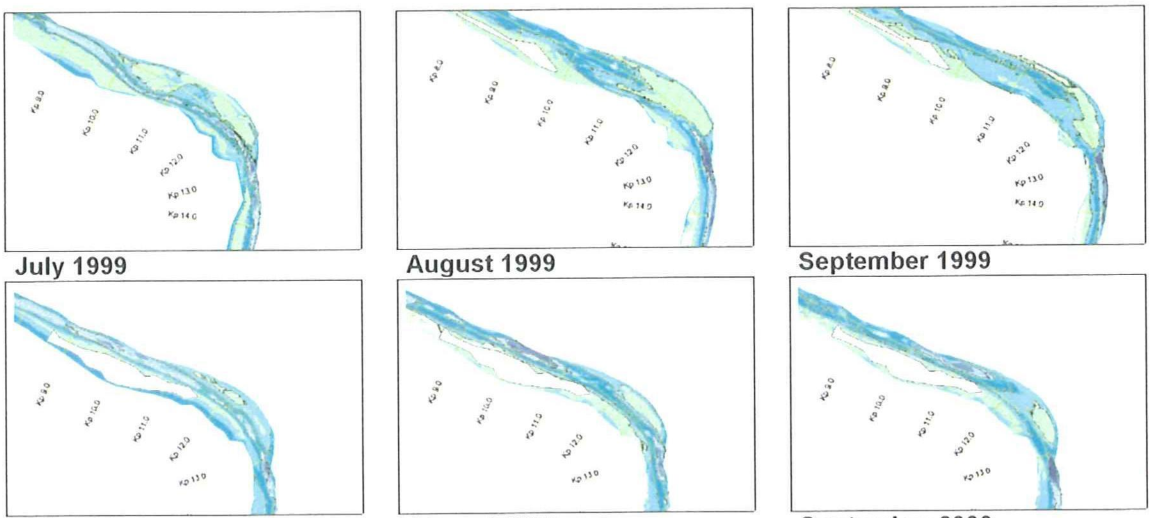
Table 4.7. Sediment balance Kp 7.0 – 9.0

	balance 1999 (Mm^3)	balance 2000 (Mm^3)
monsoon	0.20	0.20
total Apr-Apr (incl. dredging)	-0.09	-0.09
dredged volume	-1.30	-0.43

- The figures from 1999 and 2000 are the same for the monsoon and the total season, only the dredged volume in 2000 is 0.90 Mm^3 smaller than in 1999.
- The smaller dredged volume in 2000 implicates an improved stability of the river stretch.
- The smaller dredged volume may also be due to the dredging strategy. In 1999 this stretch was dredged first. Therefore the river had more opportunity to refill the dredged channel.
- The main part of the deposition took place in the low water channel.

4.4.4. Gorai Railway Bridge, Kp 9.0-13.0

One of the main characteristics of this stretch is the unstable low water channel. The following figures illustrate this:



July 1999 **August 1999** **September 1999**

July 2000 **August 2000** **September 2000**

Figure 4.16. Shifting of the low water channel between Kp 9.0 and Kp 13.0

It can be seen from the figures above that the low water channel has the tendency to follow the outer bend. In this way the hypothesis that the river will show characteristics of bends is confirmed. For economical and logistic reasons the alignment is not located in the outer bend of the river. The alignment of the first season was not stable in this stretch. The alignment of the second season was not completely stable as well, but the imposed location of the low water channel is still visible at the end of the monsoon. In 1999 the deepest point in the outer bend was 0.3 m below SLW and in 2000 this was 4.1 m below SLW. This supports the observation that in 2000 the alignment had a more natural location which the river followed during the monsoon.
Alternating banks have not been observed in the analysis. This may be an effect of dredging. The disposal sites allocate the location of the low water channel.

Deposition and erosion patterns

In the deposition and erosion pattern the shifting of the channel is clearly visible, see figure 4.17. In 2000 the deposition in the channel was partly deposition from the sides and partly the deposition pattern that can be found in the inner bend of rivers, when a point bar is formed.
Upstream of the Gorai Railway Bridge the flow channel fills up during the monsoon. This was not expected, since outer bends of a river usually erode. This can be explained by a shift of the flow channel, which is known to occur in this area and the backwater effect that is caused by the Gorai Railway Bridge, which is in fact too narrow.

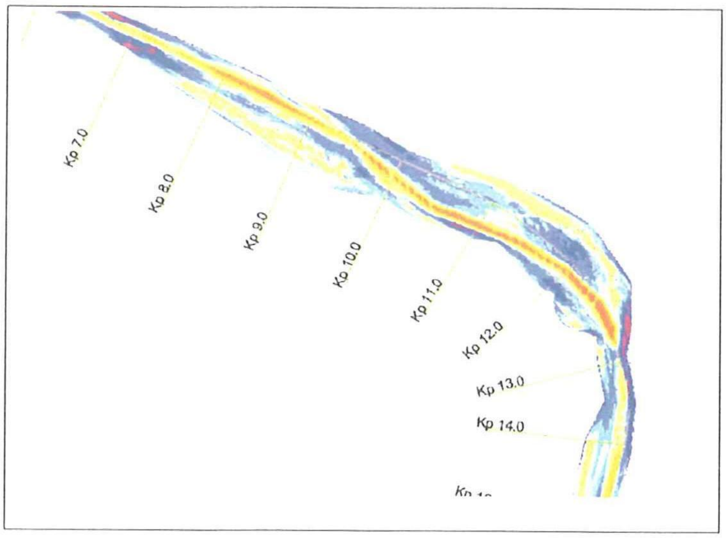


Figure 4.17. Deposition and erosion over the monsoon 1999

This part of the Upper Gorai River is the most shallow part and it is therefore likely that the first problems will occur here when the discharges are low.

Sediment balance

Table 4.8. Sediment balance GRB

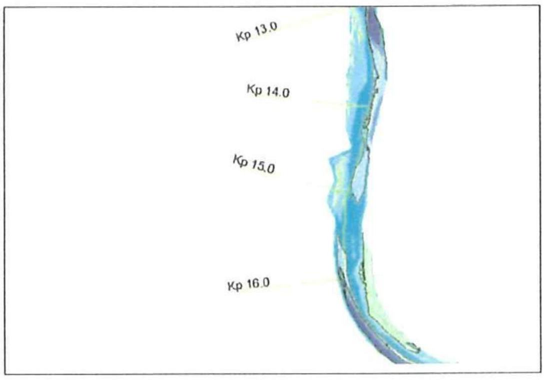
	balance 1999 (Mm^3)	balance 2000 (Mm^3)
monsoon	-0.46	-0.38
total Apr-Apr (incl. dredging)	-0.26	-0.04
dredged volume	-2.69	-1.63

From this balance the following can be concluded:

- The trend in erosion and deposition is similar for the two years.
- The eroded sediment from the river bend is in the 1999 monsoon used to fill up the dredged channel. In 2000 a point bar is formed with this sediment.
- The alignment of the second season is more stable, since a smaller volume had to be dredged to maintain the low water channel. The new dredging strategy, dredging in two layers, may also have contributed to this.
- The stretch suffers from deposition in the monsoon. Overall though there is a net erosion.

The sediment balance shows an improvement of stability of the river. However the large shoal that is formed upstream of the Gorai Railway Bridge maintains to be a bottleneck for the flow in the river.

4.4.5.Downstream Gorai Railway Bridge, Kp 13.0 – 17.0



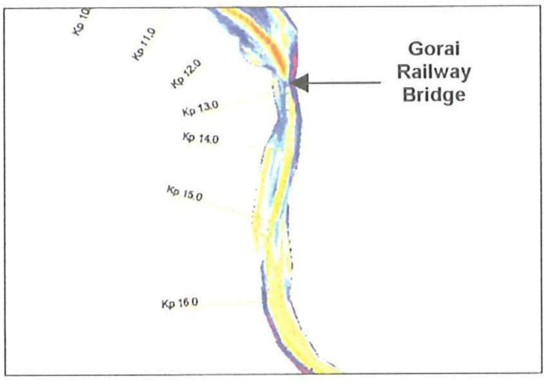


Figure 4.18. Bed level of the stretch 13.0 – 17.0 (September 2000) and deposition and erosion patterns monsoon 1999

The stretch downstream of GRB is the last stretch that was dredged in the second and the third season. In the first season dredging took place until Kp 19.0. The low water channel is located, as expected, in the outer bends and crosses the river from the left to the right bank between Kp 14.0 and Kp 16.0. In this stretch the crossing between Kp 15 and 16 is clearly visible, see figure 4.18. The development of the crossing is also visible in the deposition and erosion patterns over the monsoon. Some time steps indicate erosion on the location of the crossing. This may be an indication of an incorrect grid.

Deposition and erosion patterns

The piers of the Gorai Railway Bridge cause local erosion. Between the two bends a shoal develops during the monsoon. Also near the right bank a shoal develops.
In the bend between Kp 16 and Kp 18 the development of a point bar and the scour in the outer bend are clearly visible. In figure 4.19 the development of the scour hole downstream the piers of the bridge is described.

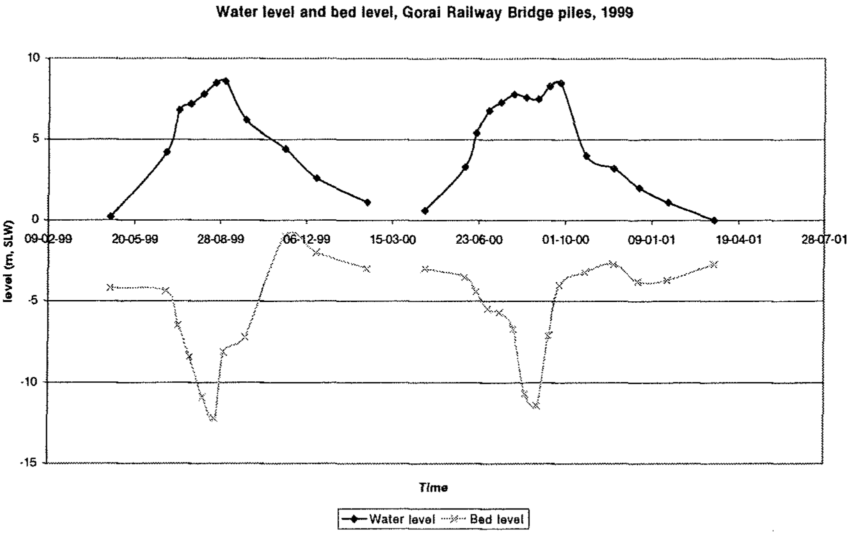


Figure 4.19. Development of the scour hole downstream GRB in 1999 and 2000

The development of the scour hole shows a quick response to the hydrograph. The deepest point was around 11.5 m below SLW for both seasons. In 2000 this bed level was reached with a water level of 7.5 m (on August 30th 2000). At this time the average bed level in the low water channel upstream GRB was around Kp + 2.0 m SLW. A rule of thumb says that the depth of a scour hole is approximately 1.5 times the water depth. In this case the depth of the scour hole would be –5.5 m SLW. This is 6 meters less than measured. This difference can be caused by factor for the shape of the piers that have to be taken into account and the variation in upstream bed level.

Sediment balance

Table 4.9. Sediment balance downstream GRB

	balance 1999 (Mm^3)	balance 2000 (Mm^3)
monsoon	-0.02	-0.78
total Apr-Apr (incl. dredging)	0.29	-0.83
dredged volume	-0.42	-0.32

- In 1999 there is only deposition in this stretch, while in 2000 there erosion.
- *The difference between monsoon and total balance is larger for 1999 than for 2000.*

The stretch Kp 13.0 – 17.0 was an important stretch in contribution to the total balance for the Upper Gorai River. It is likely that no dredging is necessary in this stretch when the balance of 2000 is an indication of the future balances over this stretch.

4.4.6.Upstream of Kumarkhali, Kp 17.0 – 20.5

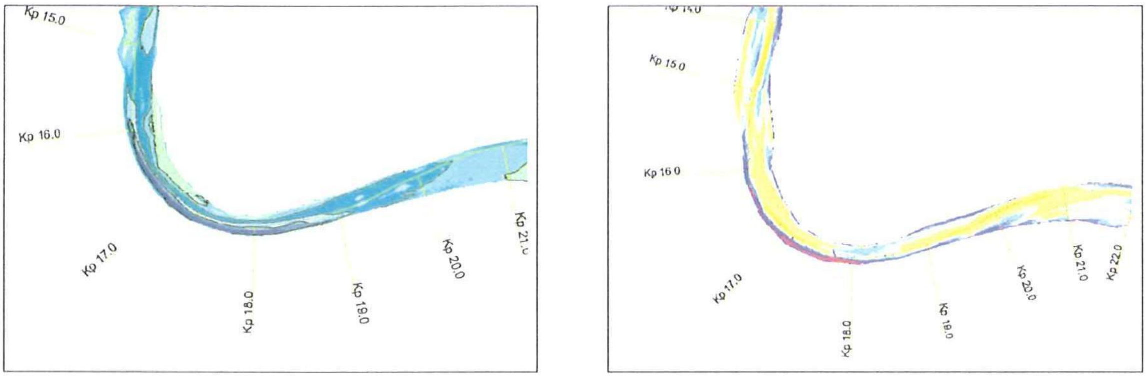


Figure 4.20. Stretch upstream of Kumarkhali, September 2000 (left) and monsoon 1999 (right)

Deposition and erosion patterns

In the second and third season no dredging works took place in this stretch. In the first dredging season dredging took place up to Kp 19.0.

The stretch upstream of Kumarkhali is characterised by a bend to the left and a crossing. Both are clearly visible in figure 4.20. The outer bend erodes in the monsoon and the sediment coming from the outer bend settles in the inner bend and downstream of the bend. The deepest point of the bend was recorded end August to the beginning of September and was around 9.5 m below SLW.

The bed level of the crossing is 0 to 2 m above SLW in the monsoon. In the dredging season this level returns to below SLW.

Sediment balance

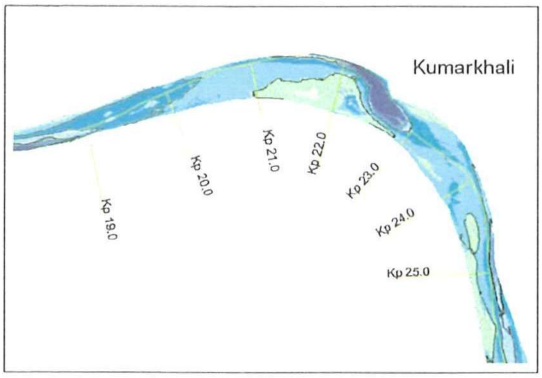
Table 4.10. Sediment balance upstream Kumarkhali

	balance 1999 (Mm^3)	balance 2000 (Mm^3)
monsoon	-0.40	0.46
total Apr-Apr (incl. dredging)	-0.46	0.11
dredged volume	0	0

- Due to dredging in the first season, there is only net erosion in this stretch in 1999, in contrary to 2000 when there is only net deposition.
- In the dredging season there is erosion in this stretch. This is caused by retarded scour over the crossing.
- The small overall net deposition in 2000 and the erosion in 1999 indicate that dredging was not necessary in this stretch. This will probably be the case in the future.

The deposition and erosion rates in this stretch are the lowest of all Upper Gorai River.

4.4.7.Kumarkhali, Kp 20.5 – 26.0



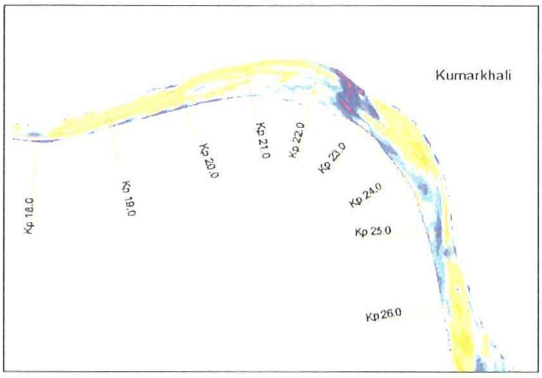


Figure 4.21. Bed level in September (left) and erosion and deposition pattern monsoon 2000.

The Kumarkhali stretch is dominated by the Kumarkhali groyne at Kp 22.5. The scour hole downstream of the groyne erodes with rising water levels and deposition occurs with falling water levels. The largest depth of the scour hole was 13.0 m below SLW on September 2nd 1999. Since this stretch also contains a bend, the characteristics of a bend are expected. These characteristics can only be found upstream of the groyne. The deepest point is 11.8 m below SLW. Downstream of the groyne a shoal develops over the full width of the river. The point bar around Kp 22.0 develops also in downstream direction in the monsoon, a shoal is noticeable along the left bank up to Kp 26. It is likely that there is clay present in this stretch which causes the scour around the right bank at Kp 25.0.
In 2000 the channel downstream of the Kumarkhali groyne shifted a little. At first there was a wide flow channel. Later in the monsoon the channel shifted towards the left bank again. In figure 4.22 the development of the highest point of the shallow part around Kp 24.0 and the lowest point of the scour hole downstream Kumarkhali groyne are described.

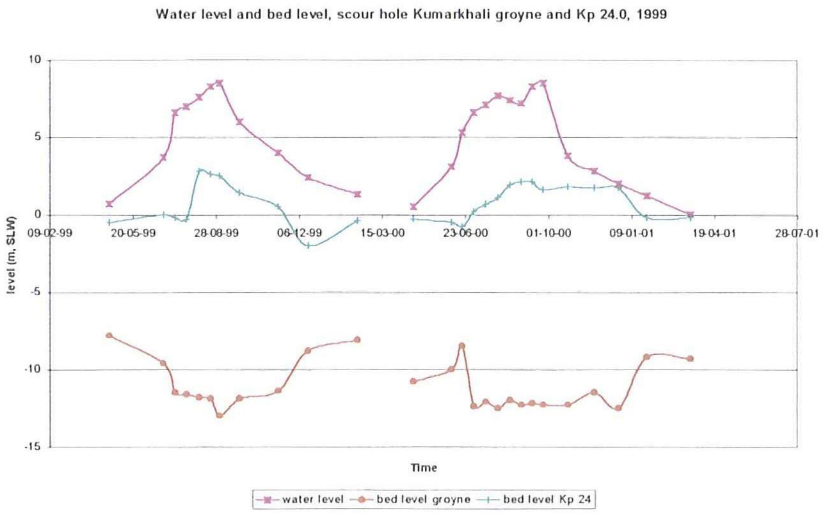


Figure 4.22. Development of the bed level of the scour hole of Kumarkhali groyne and Kp 24.0 in 1999 and 2000

The development of the scour hole and the shallow point around Kp 24.0 do not have a similar development. In 1999 the hydrograph was followed, while in 2000 the development showed more resemblance with the development of the scour hole than the hydrograph.

Deposition and erosion patterns

The presence of the groyne and the clay points determine the erosion and deposition patterns. The presence of the groyne results in a scour hole downstream of the groyne and deposition of the eroded sediment from the scour hole downstream of the groyne, between Kp 23 and 24. On the right bank near Kp 25 a scour hole develops during the monsoon. This can be caused by presence of clay and by the diverted current towards this bank by the Kumarkhali groyne.

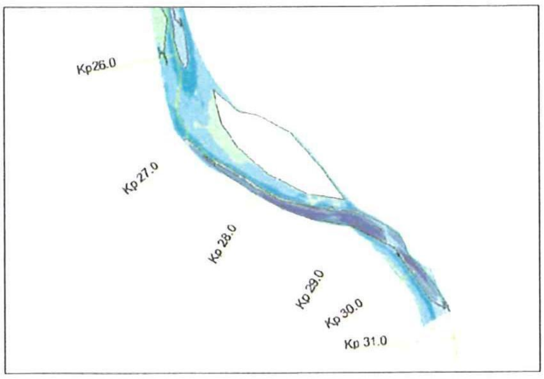
Sediment balance

Table 4.11. Sediment balance Kumarkhali

	balance 1999 (Mm^3)	balance 2000 (Mm^3)
monsoon	-0.52	-0.01
total Apr-Apr (incl. dredging)	-0.78	-0.35
dredged volume	0	0

- There is a net erosion in the monsoon and the total year.
- The erosion in 1999 was larger than the erosion in 2000. This might be caused by higher stages during the monsoon in 1999.
- The erosion in the dredging season was similar for the two seasons. In 1999 0.25 Mm^3 was eroded in the dredging season and 0.34 Mm^3 in 2000.
- This stretch has a large contribution to the sediment balance of the Upper Gorai River.

4.4.8. Khoksa, Kp 26.0 – 31.0



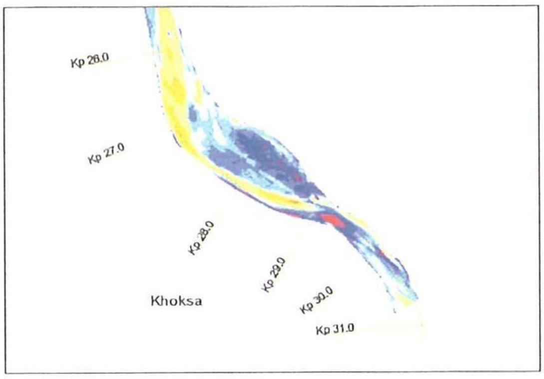


Figure 4.23. Khoksa, bed levels of September 2000 (left) and deposition and erosion patterns monsoon 2000

The last stretch of the study area is characterised by a slight bend to the left and a large shoal in the inner bend. Upstream of the bend there is a crossing, in October the crossing between Kp 26.0 and Kp 27.0 covers the full width. This crossing has a bed level which is 3 to 5 metre above SLW in the monsoon. Between Kp 27.0 and Kp 29.5 the characteristic deep outer bend is recognisable. The deepest point is 10 m below SLW in 2000, while in 1999 not more than –4.2 m SLW was reached.
Around Kp 30.0 a scour hole develops during the monsoon, this is due to a clay hard point on the right bank that diverts the current towards the left bank and the presence of a groyne on the left bank. The deepest level of this scour hole is 15.5 metre below SLW. This was recorded on September 26th 2000. It was expected that the shoals in the Upper Gorai River did not change over a hydrological year. The shoal in this stretch shows erosion over the monsoon and the full hydrological year.

Deposition and erosion patterns

The end of the bend shows the characteristic deposition and erosion pattern of river bends: erosion in the outer bend in the monsoon and deposition in the inner bend. The shoal does not have the characteristics of a point bar. Only erosion occurs on the shoal. This erosion mainly determines the net balance over the stretch. Between Kp 26 and Kp 27 sediment is deposited. It is possible that the bed is fixed at this location because of a fixed layer. Downstream of Kp 29 a scour hole develops as a reaction on a probable clay point. This scour hole was first located near the right bend. Later on this scour hole moved downstream and towards the left bank. In figure 4.24 and 4.25 the development of the scour hole around Kp 29.0 and the shallow point around Kp 27.0 is described.

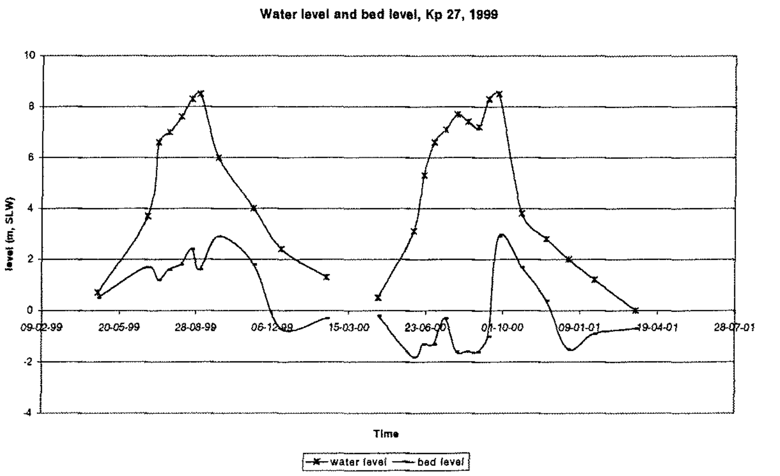


Figure 4.24. Development of the shallow point at Kp 27.0 (left) in 1999 and 2000

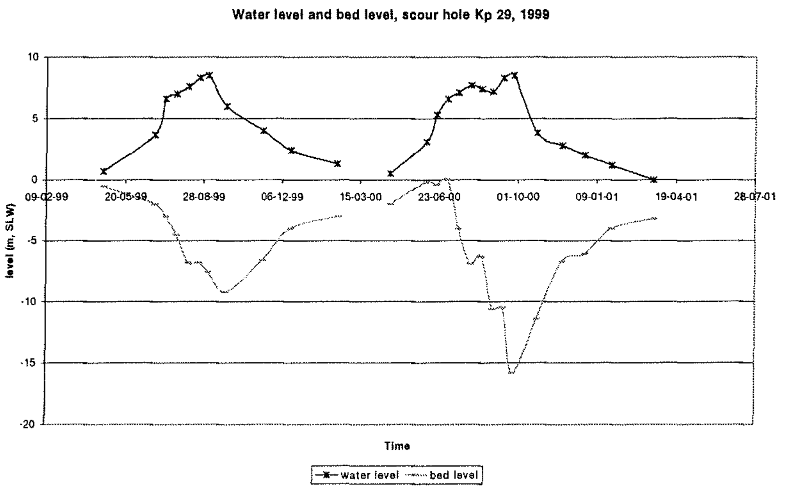


Figure 4.25. Development of the scour hole at Kp 29.0 in 1999 and 2000

The bed level scour hole at Kp 29.0 follows the hydrograph, only in 2000 the maximum bed level is almost twice the bed level of 1999. This can be caused by the smaller interval of the surveys that is used in 2000 (250 m) compared to 1999 (500 m).

The development of the bed level of the shallow point around Kp 27.0 has less resemblance with the hydrograph. Retarded scour can be found over this point with falling water level. In the low water season the bed level is below SLW. It is therefore not expected that this will form a new bottleneck in the Upper Gorai River.

Sediment balance

Table 4.12. sediment balance, Khoksha

	balance 1999	balance 2000
monsoon	-1.41	-1.69
total Apr-Apr (incl. dredging)	-0.18	-0.47
dredged volume	0	0

- During the monsoon erosion takes place in this stretch.
- *In the dredging season there is a net deposition. This deposition is smaller than the erosion in the* monsoon.

Dredging has not been necessary in this stretch for reaching the target flow of 4-8%.

4.5. Analysis of the Upper Gorai River, general

4.5.1. Deposition and erosion patterns

Monsoon

The deposition and erosion patterns in the monsoon are dependent on the local geology of the river. One important pattern that can be distinguished is that in the dredged channel sediment is deposited. This effect can be explained by effects such as lateral diffusion, sliding of slopes of the disposal sites and flow from the higher areas towards the low water channel (see section 3.4.3). These effects cause deposition in the dredged channel and gentler slopes of the dredged channel. Erosion takes place on the higher lying areas on the sides of the dredged channel.
The present man made structures are another important cause of the prevailing deposition and erosion patterns downstream the structures.

Dredging season

In the dredging season there most important deposition and erosion patterns are the erosion caused by retarded scour in the off-take and at crossings and the artificial erosion and deposition caused by dredging.

Low water period

In the low water period, after the dredging intervention, January-May, when no dredging is taking place, it was assumed that mainly deposition would occur in the low water channel. The balances, see Appendix VIII, prove the contrary. In all stretches, except in the off-take, there is erosion. This can be explained by the retarded scour that is still prevailing in this period and the difference in flow velocity between the Ganges River and the Gorai River. The flow velocities in the Gorai River are higher than the flow velocities in the Ganges River. The balance over this period is therefore of minor importance for the total balance over the hydrological year.

4.5.2. Deposition and erosion rates

In this study the following rates are distinguished:

- Erosion rate; which is the eroded volume divided by the stretch length and the number of days between the two surveys.
- Deposition rate; which is the deposited volume divided by the stretch length and the number of days between the two surveys.
- Balance rate; which is the net eroded or deposited volume divided by the stretch length and the number of days between the two surveys.
- Total rate. The total rate is the sum of the absolute values of the erosion rate and the deposition rate. In this way the total rate is an indication of the morphological activity.

All rates are expressed in m^3/m/day.

In Appendix IX the rates are displayed as a function of time and as a function of distance along the alignment. For all stretches the erosion, deposition and balance rates are displayed as a function of time for the two dredging years that are studied (1999-2000 and 2000-2001). In this way a comparison between the two years can easily be made. Per stretch the deposition and erosion rates of one dredging season is also displayed in time. This gives an impression of the periods that mainly cause deposition and the periods that mainly cause erosion. It should be noted that no distinction has been made between artificial (dredging) and natural erosion.
The rates have also been studied as a function of discharge and stage. Since no trend line could be found, these results are not presented in this study.

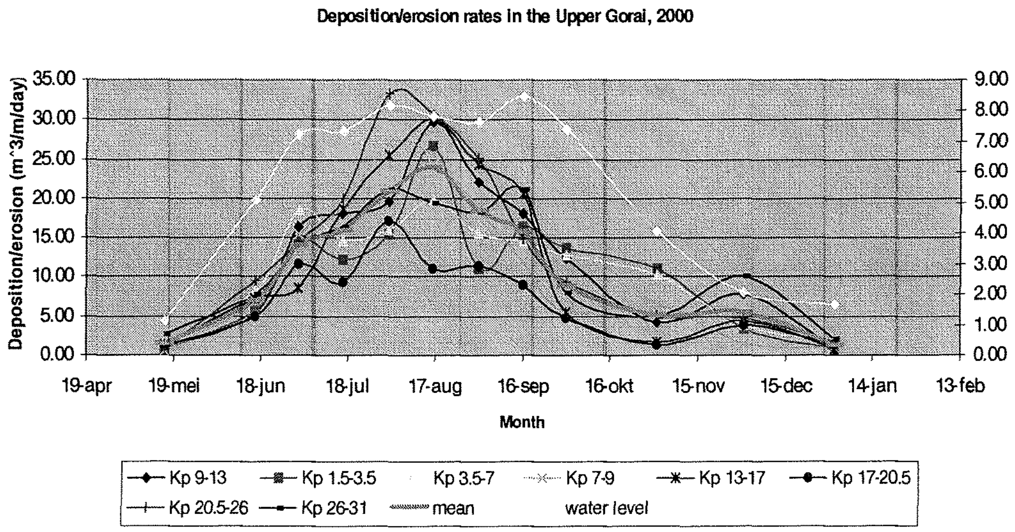


Figure 4.26. Total erosion rates and water level for all eight stretches, 2000

The deposition rates show the following similarities for the two considered dredging seasons:

- The peak was always found mid August. The peak in discharges and water levels is usually found mid or end September. The peak rates are not found together with the dominant discharge as defined in section 3.3. This can be attributed to the dredging intervention. By dredging, the low water channel is defined and therefore, with rising stages, the river finds a low water channel more quickly and is able to respond more quickly to the rising stages.
- Throughout the monsoon there are periods of deposition and erosion. However, no pattern has been discovered in this.
- In stretches where crossings can be found, the erosion rates are high with falling stages. This is explained as retarded scour. The retarded scour starts around mid September.
- The most active stretch in 1999 was Kp 9.0-13.0, this was due to the unstable alignment in the first season.

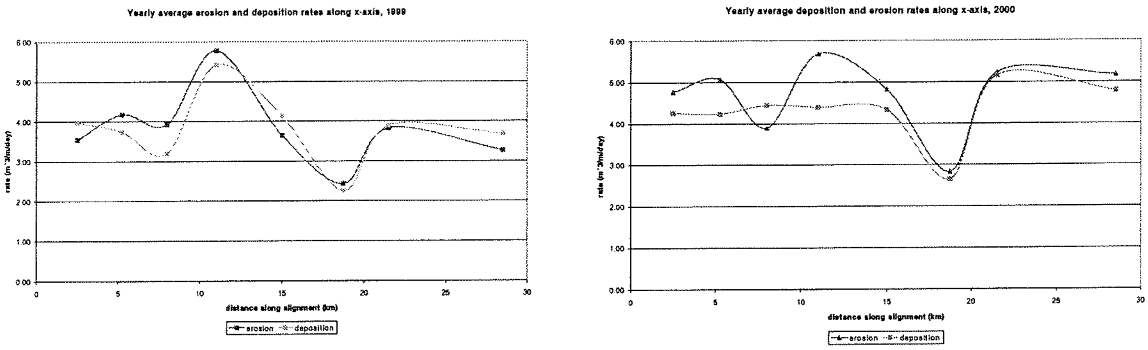


Figure 4.27. Deposition and erosion rates along the alignment, ´99-´00 (left) and ´00-´01 (right)

The analysis of the rates along the alignment give the following results:

- The stretch from Kp 17.0-20.5 showed the lowest morphological activity.
- In both years the stretch from Kp 9.0-13.0 showed the highest activity, only in 2000 this resulted in more erosion than in 1999. The deposition rates in 1999 were higher for this stretch because of the shifting of the low water channel.
- In 1999 there were four stretches with average higher deposition rates than erosion rates, while in 2000 there was only one: Kp 7.0-9.0.
- Stretch Kp 1.5-3.5, Kp 20.5-26.0 and Kp 26.0-31.0 showed more activity in 2000 than in 1999.
- In the figure of 2000-2001 the deposition between Kp 1.5 and 16, this is roughly the dredged part of the river, the deposition rate is almost constant along the alignment. It is an interesting question whether this indicates a stabilizing effect of the dredging activities on the river.
- Downstream Kp 22, the deposition and erosion rates for 2000-2001 where much higher, about 1 m^3/m/day, than in 1999-2000. In this stretch the slopes increased as well. This might explain the higher activity of this stretch.

4.5.3. Sediment balance

Table 4.14. Sediment balance, Kp 1.5-31.0

	balance 1999	balance 2000
monsoon	-4.50	-3.77
total Apr-Apr (incl. dredging)	-1.25	-2.15
dredged volume	-5.81	-3.73

Both figures indicate erosion over the monsoon. The deposition mainly takes place in the low water bed, the erosion outside the low water bed is larger than the deposition in the low water bed.

When analysing the figures for the monsoons it should be noted that the balance for 1999 was set up for the period April to September 2[nd] and for 2000 from April to the end of September. The figure for the 1999 monsoon might be misleading, since in the month of September mainly deposition occurs in the off-take. In September the peak of the water level is reached.

When comparing the figures for the hydrological year it can be said that the balance for 2000 indicates more erosion, with a smaller dredged volume. It can therefore be stated that the morphological situation of the Gorai River has improved. This improvement can be attributed to the dredging activities, and in specific the dredging strategy that has improved over the years.

4.5.4. Effects of the monsoon on the by dredging imposed shape of the river

Dredging works can be seen as reshaping of the cross-section of the river. It is therefore interesting to see what remains of the imposed shape of the river after the monsoon.

Alignment

The alignment is located at the natural low water bed. Near the Kushtia groynes an exception is made, for safety reasons and for the stability of the river banks. There are two locations that need attention when analysing the stability of the alignment.

Kushtia, Kp 3.5-7.0

First there is the alignment near the Kushtia groynes. The alignment of the first dredging season, which was not located in the outer bend, was not stable. In the monsoon the dredged channel filled up quickly and the low water bed moved to the outer bend. In 2000 the alignment was located near the outer bend. This was the natural location of the low water bed. For the third dredging season the alignment is located more to the inner bend. It is therefore expected that the dredged channel will fill up as it did after the first season. For reasons of stability of the banks it can still be preferable to maintain the location of the alignment as chosen for the third season.

Gorai Railway Bridge, Kp 9.0-13.0

The second stretch that needs attention is the stretch from Kp 9.0 to Kp 13.0. The low water bed does not have a fixed location here. It is expected however that, during the monsoon, the low water bed will move towards the outer bend. This is confirmed by the analysis for 1999 and 2000. In both cases the alignment was not located in the outer bend. For the 1999 case the dredged channel filled up quickly in the monsoon and the low water channel was located in the outer bend at the end of the monsoon.
In 2000 the alignment was located more in the centre of the bend (in 1999 it was located near the inner bend). In the monsoon of 2000 the low water channel did again have the tendency to shift towards the outer bend. However, at the end of the monsoon the location of the low water bed was still mostly located at the location of the dredged channel.
The low water channel in this stretch needs guidance. Dredging has this effect on this stretch.

Slopes

In this study no special attention has been given to the slopes of the dredged channel, since previous studies proved that the slopes of the dredged channel remained to be 1:7 during the -dredging season and the dry season and flattened to 1:15 during the monsoon.

Area below SLW

The visualization of the area below SLW is another way in which the development of the low water channel and possible bottlenecks can be analyzed. Appendix X shows the area below the Standard Low Water level (SLW) for four months before and during the monsoon. The figures contain the locations below SLW for November 1997 and April, July, August and September 1999 and 2000.

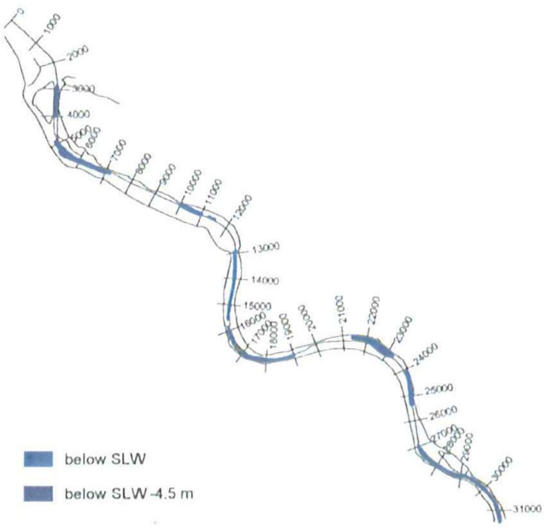


Figure 4.27. Area below SLW in September 2000

Before the dredging intervention there were few locations, upstream Gorai Railway Bridge where the bed level is below SLW. Therefore this part of the Upper Gorai River was considered to be the bottleneck.

Upstream Gorai Railway Bridge
During the 1999 and 2000 monsoon the straight stretch upstream GRB is the first location to become shallow. In 1999 the unstable part of the dredged channel was the first location where the whole width was above SLW. In 2000 the same pattern can be found. Only there are some areas below SLW from Kp 8.0-13.0. the off-take is another location where the bed level is above SLW, since a bar builds up here during the monsoon.
The straight stretch is the major bottleneck, since here little self scouring can be expected, since the retarded scour in this stretch will be less than in the off-take.
Together with the locations below SLW the remaining volume below SLW is studied. These figures indicate no trend in the remaining volume, since at some locations there is erosion and at other locations there is deposition.

Downstream Gorai Railway Bridge
Downstream the Gorai Railway Bridge shallow parts develop not only at crossings but as well downstream of the Kumarkhali groyne. Around these locations the shallow part develop further during the monsoon. The typical crossings erode after the monsoon due to retarded scour and will therefore not be a bottleneck.

Disposal sites

From the analysis with ArcView it can be concluded that a part of the deposited sediment returns to the dredged channel. In some locations, like in the outer bend near Kushtia the deposition of sediment in the outer bend is used as protection for the bend and the river banks. It is therefore accepted that this sediment will wash away during the monsoon.
For the disposal sites near the banks it is accepted that a part of the deposited sediment will wash away during the monsoon. An interesting question is what the remaining volume of the deposited sediment will be. Since not all disposal sites are covered in the hydro surveys this question can not be answered based on the ArcView analysis.
Another interesting question concerning the disposal sites is in what time the equilibrium will be reached and what are the maintenance dredging volume with this equilibrium.

5. MORPHOLOGICAL EFFECTS OF DREDGING

5.1. Introduction

In the previous Chapter it is concluded that the Upper Gorai River has a net sediment export over the year. In order to investigate whether this effect can be attributed to the dredging works, the conditions in the years with dredging are compared to the conditions before the dredging intervention. In order to make this comparison possible, the Surface Water Modelling Centre made upon request the data set with the bed levels of November 1997 available. This data set was entered into ArcView as well.
The hypothesis in this Chapter is that dredging has resulted in narrowing and deepening of the Upper Gorai River, which has resulted in a river which is more efficient in transporting sediment: with the same discharge more sediment can be transported.

5.2. Approach

The identification of the effects of dredging is done in three steps:

- First the topography of the bed of November 1997 is compared with the topography of the bed of April 1999, which is the first bank to bank survey after the capital dredging works in 1998-1999. This resulted in a qualitative description of the changes and an identification of bottlenecks.
- Second, the hypothesis that by dredging an deposition on the disposal sites the width of the river decreases is verified. Therefore the situation of November 1997 is compared with the April surveys of 1999, 2000 and 2001. ArcView is used to determine the average width of the river sections for different stages. In this case data from four low water periods are compared. In order to give a more complete picture of the effects on the width, the situation of September 1999 and 2000, which is at the end of the monsoon, is studied as well.
- The analysis on the changes in width confirmed the hypothesis. Therefore the final step towards the sediment balance is made. This step is the comparison of the discharge-sediment transport capacity for the same periods that are studied in the study on change in width. The hypothesis is that the decreased width and increased water depth cause a higher sediment transport capacity for a certain discharge. This would explain the net export of sediment and the changes in sediment export from the Upper Gorai River.

5.3. Qualitative comparison between the situation before and after dredging

The qualitative comparison between the situation with and without dredging is based on the visualisation of the bed topography for November 1997 and April 1999 and the visualisation of the deposition and erosion patterns between November 1997 and April 1999. Figures for all stretches can be found in Appendix III and Appendix IV respectively, in Appendix X the locations where the bed level is below SLW are identified. Locations which are not below SLW may form bottlenecks.

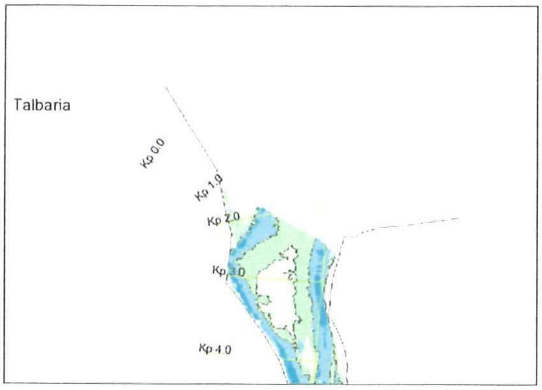


Figure 5.1. Gorai off-take, November 1997

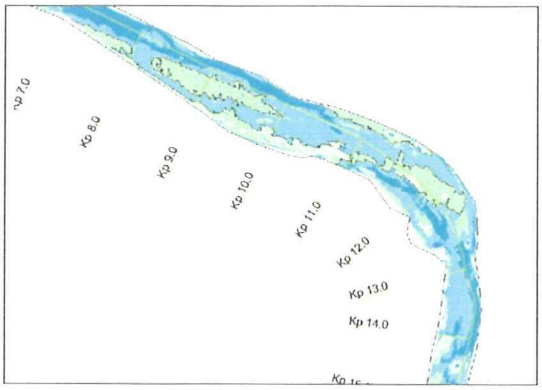


Figure 5.2. Upstream GRB, November 1997

When designing the dredging strategies the following bottlenecks were identified:

- The bar that develops in the off-take.
- The stretch upstream of Gorai Railway Bridge.

Figure 5.1 and 5.2 illustrate this.

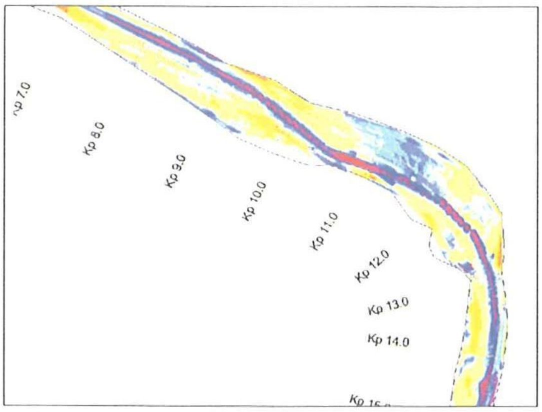


Figure 5.3. Deposition and erosion patterns us GRB, Nov. ´97-Apr. ´99

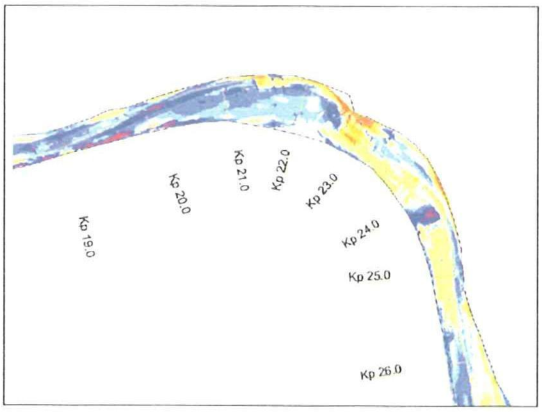


Figure 5.4. Deposition and erosion patterns Kumarkhali, Nov. ´97-Apr. ´99

In the pictures that show the difference in bed level between November 1997 and April 1999 the dredging works are clearly visible. Figure 5.3 is an example of the change in bed topography mainly due to dredging. The dredged channel is clearly visible as erosion and on both sides of the dredged channel the disposal sites can be distinguished. In the first season Kp 19.0 was the end of the dredging works, but the erosion extends towards Kp 21.0 (see figure 5.4). This can be explained by the 1D translation of the front of the dredged channel, as described in Chapter three.

Downstream of Kp 21.0 there is local deposition and local erosion. Mainly around Kp 22.5 much deposition can be observed. This is the filling up of the scour hole downstream of the Kumarkhali groyne. With falling stages the depth of the scour hole diminishes. In this case the situations that are compared are the situation of November, with an average water level of 3.5 m above SLW and April, with an average water level of 0.5 m above SLW. Therefore it can be stated that the observed deposition around Kp 22.5 is not an effect of dredging, but a natural process.

Other changes in topography can be found around Kp 24.0 and Kp 27.0. At these locations possible new bottlenecks are developing. For these locations the bed level at the alignment of November 1997 is compared to the levels of April 1999, 2000 and 2001. A clear trend can not be discovered from these graphs. In can be stated however that the bed level around Kp 24.0 has risen since 1997. Figure 5.5 illustrates this.

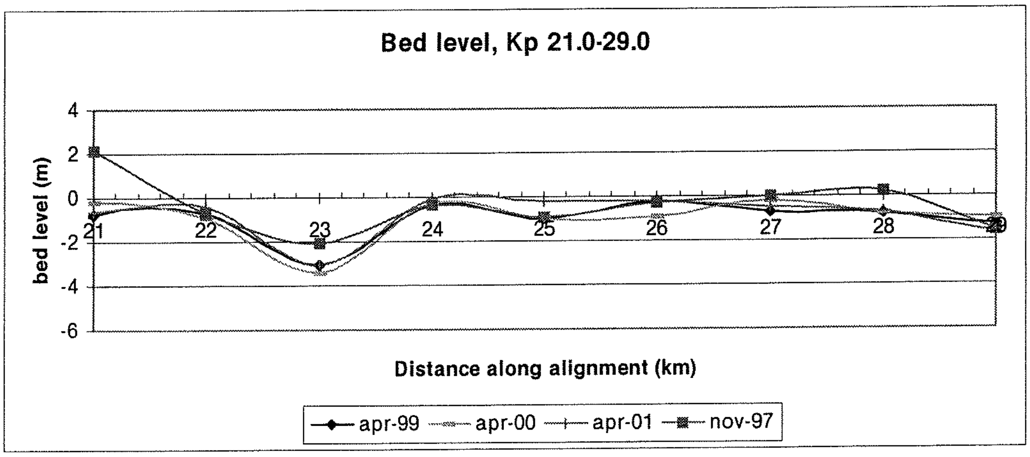


Figure 5.5. Development of the bed level at the alignment

On other locations the bed level of November 1997 is higher than for April 1999, 2000 and 2001. This can be caused by the different periods of recording, November vs. April. Between November and April some retarded scour may be expected at crossings. Therefore it can not be concluded from this figure that dredging has either a positive or negative effect on this part of the Upper Gorai River.

The bottleneck downstream the Kumarkhali groyne can possibly be eliminated by removing the Kumarkhali groyne. In the following section the effect of dredging on the cross-sections and the sediment transport will be studied. With this study other possible bottlenecks and points of attention can be identified.

5.4. Changes in the cross-section after dredging

By dredging, the cross-section of a river changes. For low stages the width increases, since dredging defines the low water channel. For higher stages the width increases, since here the disposal sites results in a reduction in width. The hypothesis is that the width decreases and the average depth is enlarged for high stages and the width increases for low stages. Figure 5.6 illustrates this. On the left the change of the cross-section of the Gorai River is shown. In this study a simplified cross-section is used to explain further details on the approach of the study. This simplified cross-section is shown on the right.

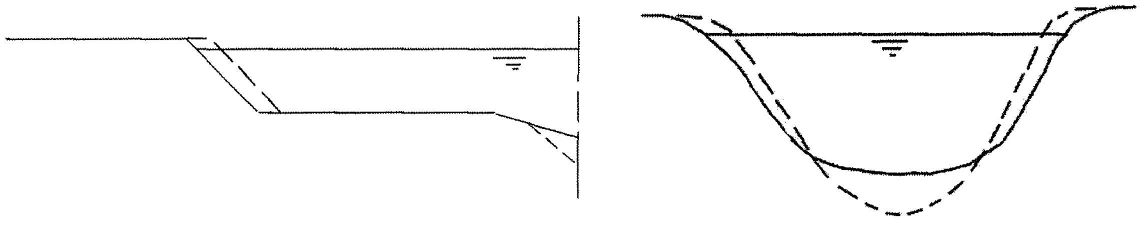


Figure 5.6. Changed cross-section after dredging with disposal within the river banks. Left: Gorai River, Right: theoretical schematisation.

This change in cross-section has an important effect on the discharge and the sediment transport since:
For B>>h:

$$u = C\sqrt{hi}\,,$$

$$\hat{u} = \frac{Q}{A} \approx \frac{Q}{Bh}\,,$$

$$Q = BCh^{\frac{3}{2}}i^{\frac{1}{2}}\,,$$

$$s = mu^{n}\,,$$

$$s = mC^{n}h^{\frac{n}{2}}i^{\frac{n}{2}}$$

with:
u = average flow velocity (m/s)
h = average water depth (m)
C = bed roughness ($m^{1/2}/s$)
i = hydraulic slope (m/m)
Q = discharge (m^3/s)
A = wet area of the cross-section (m^2)
B = average width of the cross-section (m)
s = sediment transport (m^2/s)
n = power as used in the transport formulas (van Rijn: n=4)
m = factor of the sediment transport formula (case dependent)

From the first equation it can be concluded that the flow velocity will increase when the average depth increases. With an equal cross-sectional area and a constant hydraulic slope and bed roughness this implies an increased discharge and an increase in sediment transport. This would explain the observed net sediment export. In this study the full width of the river is assumed to contribute to the sediment transport, hence no distinction is made between the full width of the river, and the width which contributes to the sediment transport. In Chapter 7 the assumption that the hydraulic slope and the bed roughness is constant is discussed.

The hypothesis on the change in width due to dredging can be checked with ArcView. The data used for this analysis are the bed levels for the full width of April 1999, April 2000 and April 2001 and November 1997. Since all these data are recorded after the most active (morphological) period the situation of November 1997 can be compared to the situation of April each year.
The situation of September 1999 and 2000, which is the situation at the end of the monsoon, is studied separately.

In Appendix XI the complete results of the study on width-water level relation can be found for the dredged part of the Upper Gorai River, the part that is not dredged and the eight sections that were distinguished in the previous analyses in this report. Here the most salient results of this analysis are discussed. All water levels are expressed in m, SLW.

5.4.1. Effects on the dredged stretches

For the dredged part of the Upper Gorai River, corresponding to the first 17 kilometre downstream from the off-take, the results for April of the four considered years is shown in figure 5.2.
In this relation the average width from Kp 2.0 to Kp 17.0 is given on the x-axis, the water levels for which the average width is calculated in ArcView is given on the y-axis. The average width is obtained by dividing the number of cells below the given water level, which was the output of ArcView, by the length of the considered stretch. Since each cell covers an area of 100 m^2, the obtained value from this calculation has to be multiplied by 100.

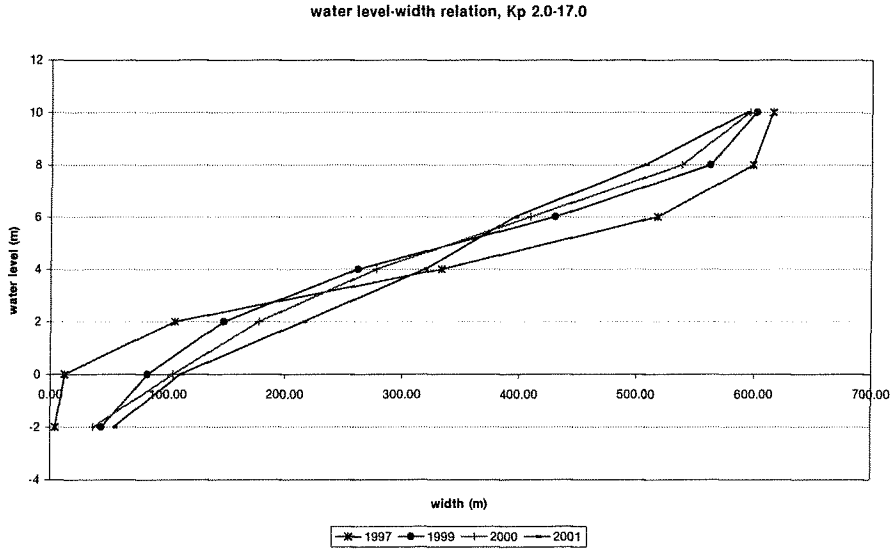


Figure 1.2. Relation between the width and the water level for 1997, 1999, 2000 and 2001

It can be seen that for high stages (>5.5 m, SLW) the width decreased over the years, while for low stages the width increased. The increase in width for low stages can be explained as being the location of the dredged channel. Where before dredging there was hardly a deep low water channel, there now is a more defined low water channel.
For stages of 5.5 m there is a node in the graphs of the years after the dredging started. This level is between the stages below which 1D flow might be expected for the off-take and the downstream river (see Chapter three). It is not the average level below which 1D flow is prevailing. This level is about 2.5 m for the 1999 situation. The intersection of the graph for November 1997 and April 1999 is at approximately this level. The intersections for April 2000 and April 2001 with the graph for November 1997 are at higher levels. This could indicate a higher level up to which 1D flow is prevailing.

When the situation of September is added to the figure the following conclusion can be drawn:

- The same effect as for the situation of April can be observed; increasing width with low stages and a decrease in width for higher stages.
- The effect of the decrease in width is lower in the monsoon compared to the situation after dredging (ie April), but still it is improved compared to the situation of November 1997.
- It is striking that for low stages (<1 m) there is hardly any change in width between April and September from the same year.

The figure below illustrates these observations on the hand of the situation of November 1997, compared with April 2000 and September 2000.

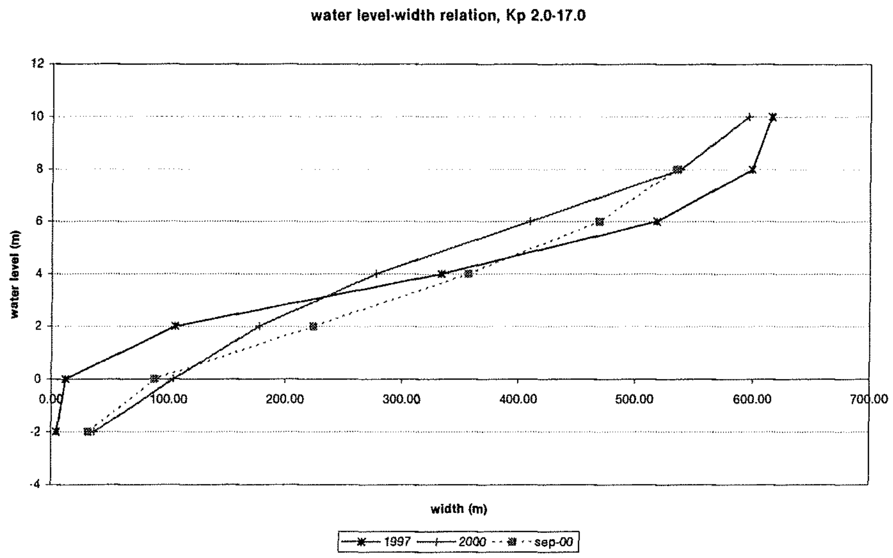


Figure 5.7. Width – water level relation, November 1997, April 2000 and September 2000, Kp 2.0-17.0

All above mentioned observations and conclusions from the study on width – water level relations for the dredged part of the Upper Gorai River confirm the hypothesis on the effect of dredging on the width of the river. An extra conclusion that can be drawn from this analysis is that after the monsoon, the river bed did not return completely to the situation before dredging.

For the stretches separately the width – water level relation is made in the same way as for the total dredged part of the river. The resulting graphs can be found in Appendix XI. Some conclusions and observations from these graphs are listed below:

- The stretches Kp 3.5-7.0, 9.0-13.0 and 13.0-17.0 show the same effects as the overall graphs for the part Kp 2.0-17.0. Only for the stretch Kp 9.0-13.0 the situation after the September 2000 monsoon is far more positive than the situation after the 1999 monsoon. This is due to the improved alignment in the stretch.
- In the off-take, Kp 1.5-3.5, the similar observation for the years 1999 and 2000 can be made as for the average situation in the dredged part of the Upper Gorai River. The situation of April 2001 shows an increase in width for all stages. This is due to the additional dredging activities in the off-take in February and March this year. In this period the width of the low water channel is enlarged by 70 m. The additional dredging activities removed a part of the clay layer and therefore the width of the dredged channel increased. Another difference from the situation for the total dredged channel is the average width decreased in September. This is due to the deep channel that develops downstream of the bar between Kp 2.0 and Kp 2.5 (see Appendix V).
- For the stretch Kp 7.0-9.0 the situation of April 1999 shows a different pattern. A decrease of more than 200 m in width can be observed for some stages. In the monsoon of 1999 the width returned to the situation before dredging. Another striking observation is that the width above SLW +4m is quite similar for the situation of September 2000 and April 2001. This might implicate that the capacity of the disposal sites is almost reached in this stretch and that the most part of the disposed sediment remains on the disposal sites. However, the deposition and erosion patterns do not subscribe this.

5.4.2. Effects on the stretches without dredging

For the part of the dredging where no dredging activities have taken place little change in width is expected. In figure 5.8 the width – water level relations for November 1997, April 1999, April 2000, April 2001, September 1999 and September 2000 are shown. The following observations are made on the hand of this figure:

- For the stretch downstream of Kp 17.0 an increase in width for all stages can be observed. Between April 1999 and April 2000 there was little increase in width, while in April 2001 there was an increase which was larger than in April 2000. When comparing this to the increase in width between September 1999 and September 2000 the same increase can be found. A possible cause for this is the lower stages and discharges during the 2000 monsoon, which caused a lower sediment transport in the Upper Gorai River.
- In the monsoon the width increases, for all theoretical stages. The contrary occurred in the part upstream of Kp 17.0. The graphs for September show a decrease in width of 50 to 100 m. The shape of the graph is similar for September, April and November conditions.

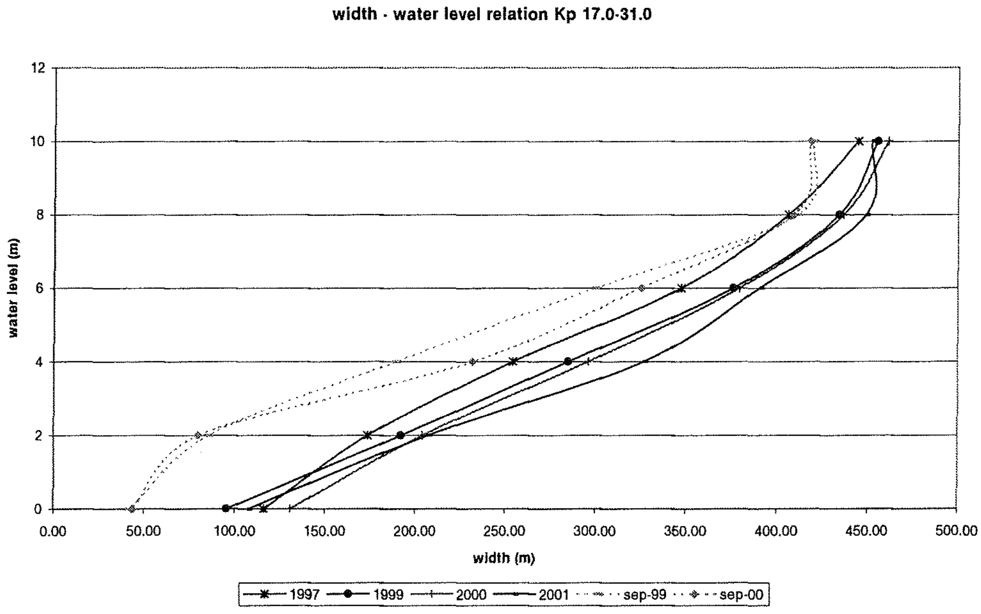


Figure 5.8. Width – water level relation, Kp 17.0-31.0

When considering the stretches separately the following can be concluded:

- For the stretch Kp 17.0-20.5 there is no trend in the increase in width, in contrary to the average picture of Kp 17.0-31.0, where the width increased over the years. For stages higher than 7 m above SLW the width is decreased in the situation of September 1999 and September 2000 compared to the situation of November 1997. Furthermore it is striking that the effects of dredging in 1998-1999 cannot be found in this graph.
- For the stretches Kp 20.5-26.0 and Kp 26.0-31.0 there is little change in the width with low stages. For higher stages an increase in width can be found. For both stretches the September situation show a decrease in width. This explains the sediment export that is found in these stretches in the monsoon. An interesting study would be to compare the situation after this years monsoon with the situation of September 1999 and 2000, since April 2001 showed an increase in width, while there was little difference between the situation of April 1999 and April 2000.

From figure 5.8 it is expected that the sediment transport capacity in this stretch has decreased since the dredging started.

5.5. Changes in sediment transport in the Upper Gorai River

The observed changes in width resulted in the following hypothesis: there will be a higher sediment transport with a certain discharge with decreasing width and an increasing water depth for the dredged part of the Upper Gorai River. For the part of the Upper Gorai River where no dredging activities have taken place the opposite effect or no effect is expected.
To prove the hypothesis, the discharge - sediment transport relation is calculated for the six periods, namely for November 1997, April 1999, 2000 and 2001 and September 1999 and 2000.
The approach is as follows:

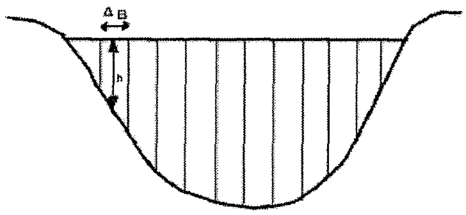


Figure 5.9. 2D approach for the calculation of Q and s

The discharge and sediment transport are both dependent on the flow velocity and therefore on the water depth. In the discharge formula the water depth has a power 1.5 and in the sediment transport formula the water depth has a power of 2. Therefore the discharge and sediment transport per small section of width (ΔB) is calculated instead of using the average depth for the cross-section. The Chézy formula is used to calculate the flow velocity. It should be noted that this formula was originally designed for average cross-sections, instead of small sections of the width. In this case the flow velocity is calculated as:

$$u = Ci^{\frac{1}{2}} \Sigma h^{\frac{1}{2}},$$

and the discharge as:

$$Q = Ci^{\frac{1}{2}} \Sigma \Delta B h^{\frac{3}{2}}$$

Therefore three assumptions are made:
- The bed roughness, C, is constant over the width of the river. This can be doubted, since C is dependent of h.
- The hydraulic slope, i, is constant along the alignment.
- The water depth is used in this formula, while originally the hydraulic radius of the cross-section should be used instead. The water depth can only be used when h<<B. For small sections of ΔB this is not the case.
- There is no interaction between the sections. The flow velocity in one section is independent of the flow velocities in the neighbouring sections.
- The full width of the river is assumed to contribute to the sediment transport.

These assumptions are discussed in Chapter seven, discussion.

The discharges and sediment transport capacities are calculated for six different water levels, from SLW +8m to SLW –2 m. These six water levels cover all possible water levels throughout a hydrological year. The number of sections is dependent on the water level. The criteria for the width of a section is chosen as follows:

- There should be at least 5 recordings of the bed level within each section.
- The maximum number of recordings is 20 per section.

This resulted in sections with a width of 20 meters for high stages to 5 meters for low stages. The corresponding number of sections is then 40 to 10.

Matlab has been used to calculate the average water depth per section and the water depth to the power 1.5 and 2 per section.

For the calculation of the sediment transport capacity, the value of m has to be determined.
In this study the value of m for Engelund-Hansen is used. This is not correct in combination with the sediment transport formula of van Rijn. Therefore the sediment transport capacity has been expressed as a dimensionless variable as well, by dividing the results with the results of November 1997, besides the calculated sediment transport capacity as a result of the discharge.

The hydraulic slope and the bed roughness are the only remaining parameters that have not yet been determined and are necessary to calculate the discharge and the sediment transport capacity. These two parameters are determined from existing studies and graphs. The results is validated by comparing the calculated value for the discharge with the measured discharge. The calculated discharge for the stage at the moment of the survey campaign is used for this. This implies that for April or September different stages are taken for the validation and different variables are used to calculate the discharge and the sediment transport. These two parameters are however by far not uniform over in space and time. And both parameters are in fact affected by dredging. Therefore these two parameters have been determined in the following way:

Bed roughness

The remaining parameters that are needed to determine the discharge are the bed roughness and the slope in the water level. The bed roughness will be expressed in the Chézy value in this study.
In his thesis study, de Groot (1999) has determined the Chézy values for different stretches in the river for the situation of falling water. This resulted in the following values:

Table 5.1. Chézy values for bed roughness (de Groot, 1999)

Month (in 1998)	Kp 1.0-4.5	Kp 4.5-6.3-	Kp 6.3-13.4	Kp 13.4-17.4	Kp 17.4-22.9
September	69	63	76	91	
October	60	61			
November	44	44	48	62	42
December		40	37	98	32

Table 5.1 shows a large variation in the bed roughness. Since the higher stages are of most importance for the morphology of the river, not the average value but a higher value is chosen for this study, since this approaches the situation of high stages more. This resulted in the following values that are used for this study:

Table 5.2. Chézy values (in $m^{1/2}/s$)

Period	Kp 1.5-17.0	Kp 17.0-31.0
April and November	40	40
September	80	40

Hydraulic slope

In Chapter three the slope in the water level is described. From figures 3.6 and 3.7 it can be seen that the hydraulic slope varies in time. For this study a constant value for the hydraulic slope is determined based on this figure. In Chapter 7, discussion, the influence of a variable slope is discussed.
This resulted in the following values for the hydraulic slope:

Table 5.3. Values for the hydraulic slope, i (-)

Period	Kp 1.5-17.0	Kp 17.0-31.0
April and November	$3*10^{-5}$	$6.5*10^{-5}$
September	$8*10^{-5}$	$6.5*10^{-5}$

For all stretches the discharge-sediment transport capacity relation is calculated. The detailed results can be found in Appendix XII. Some of the results are also presented in the following sections.

5.5.1. Calculated discharge – sediment transport relation, Kp 2.0-17.0

For the dredged part of the Upper Gorai River the result of the analysis is shown in figure 5.10:

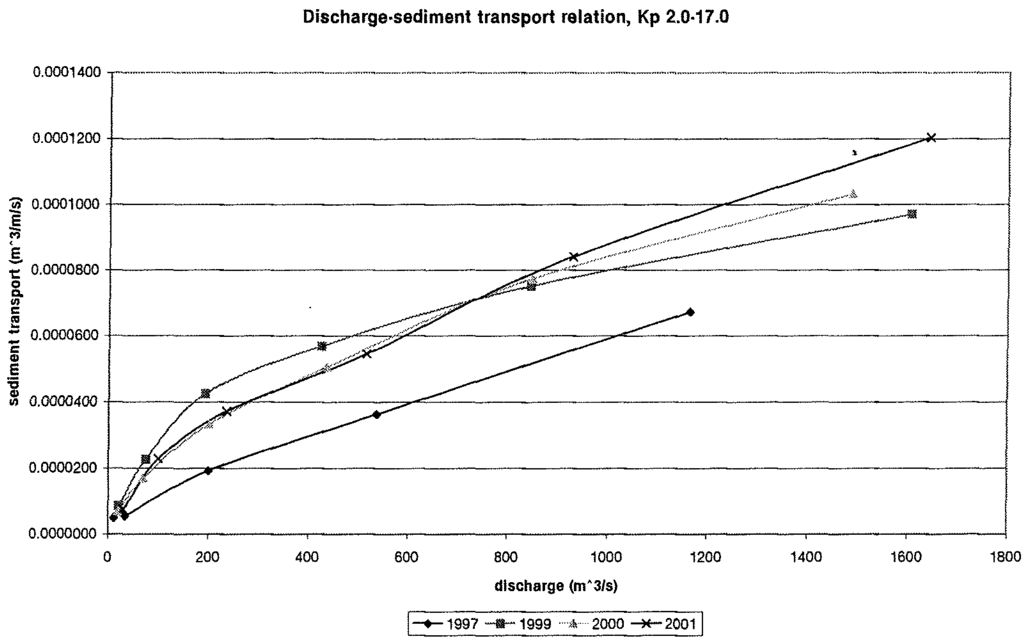


Figure 5.10. Calculated relation between discharge and sediment transport for the years 1997, 1999, 2000 and 2001

For all discharges the sediment transport is enlarged compared to the situation without dredging, this explains the erosion that was found in the analysis. The relation shows the same trend as the width-water level relation, although the intersection of the graphs for the years with dredging have an intersection with the graph for November 1997 at (0,0) instead at a higher discharge. When comparing the years with dredging the following can be found: for low discharges the sediment transport has decreased and for high discharges the sediment transport is increasing. The only difference with the width-water level relation is that the sediment transport in the dredged seasons is always higher than the sediment transport of November 1997. In the width – water level relation the width increased for low stages compared to the situation of November 1997. This difference may be due to the determination of the Chézy value and the hydraulic slope, since the data for November 1997 are far less detailed than the data from September 1998, when the dredging activities and the detailed survey campaigns started. The larger sediment transport in 1999 for low discharge than the situation of later dredging seasons could be caused by the changed design slope for the dredged channel. In 1998-1999 the slopes were 1:5, in later dredging seasons the design slope was set at 1:7. These slopes proved to be unstable

When the situation of September is considered, see figure 5.11, the following can be concluded:

- The sediment transport capacities for high stages, in this case the graphs of September, is extremely higher than for low stages, in this case November and April. This is due to the higher Chézy value and the higher hydraulic slope in September.
- The sediment transport capacity for September 1999 was higher than the sediment transport for September 2000. In the sediment balances for the 1999 and the 2000 monsoon it was found that the in the 1999 the net erosion was higher than in 2000. The sediment transport capacity for these two supports this.

In section 5.5.3. the sediment balance for the 1999 and the 2000 monsoons is calculated.

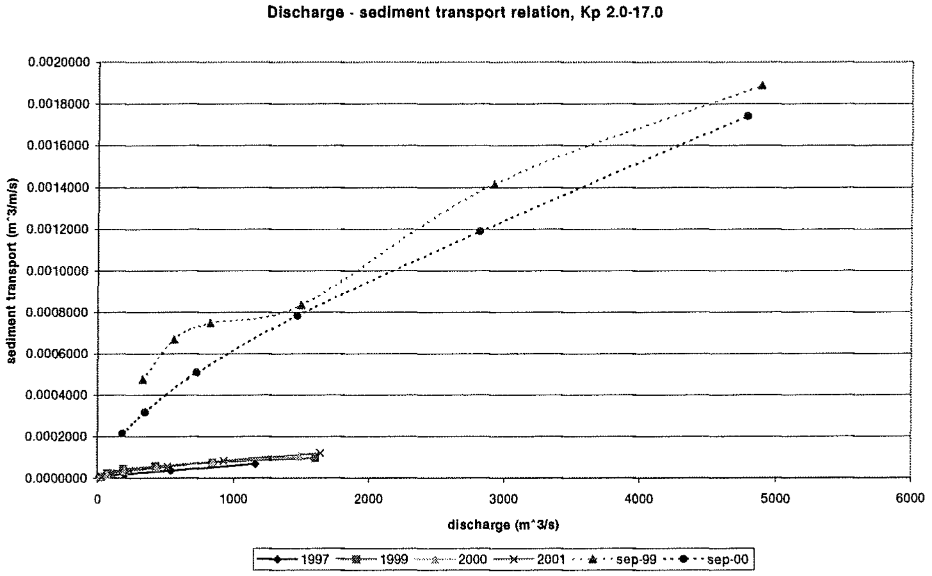


Figure 5.11. Calculated discharge-sediment transport relation, including the months with high stages

This study has also resulted in discharge-sediment transport relations for the 5 stretches where dredging activities have taken place. The results can be found in Appendix XII as well. The study per stretch gives the following results:

- The results for the stretch from Kp 1.5-3.5 clearly show the additional dredging in the off-take. For low discharges the sediment transport has decreased, due to the increased cross-section with low stages and therefore low flow velocities, but for higher discharges the sediment transport shows a large increase.
- The results for Kp 3.5-7.0 and Kp 7.0-9.0show the same trend as the relation for Kp 2.0-17.0.
- For Kp 9.0-13.0 in all cases the sediment transport has increased since the dredging activities started. Only after 1999 the sediment transport decreased, while an increase should be expected and little difference is found between 2000 and 2001. This may implicate that the maximum increase of sediment transport is reached for this stretch. This was quite similar to the width – water level relation of Kp 7.0-9.0. This could indicate a possible mixture in the results.
- For the final stretch in the dredged part of the Upper Gorai River, Kp 13.0-17.0, there is a decrease in sediment transport for low discharges, except for the 2001 situation, and an increase for higher discharges. For the higher discharges there is little increase between the three dredging seasons.

5.5.2. Calculated discharge – sediment transport relation, Kp 17.0-31.0

For the part of the Upper Gorai River where no dredging activities have taken place in the past two dredging seasons the same study is done.

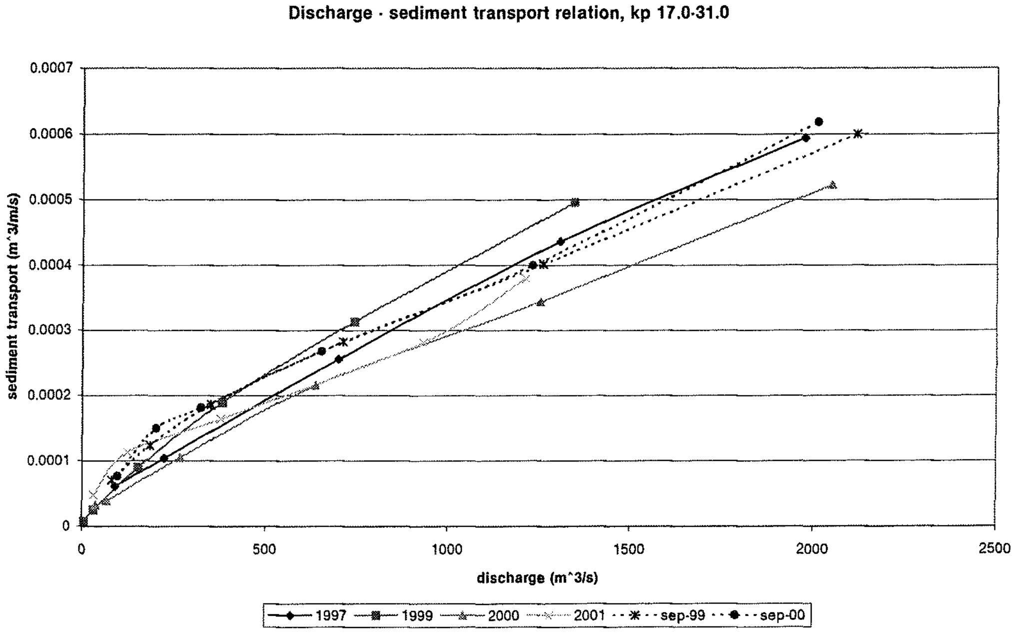


Figure 5.12. *Calculated discharge-sediment transport relation,* Kp 17.0-31.0

In figure 5.12 the same trend as in the width – water level relation for this part of the river can be discovered; a decrease in sediment transport for all dredging years, only April 1999 deviates from the width-water level relation. For low stages there is little difference between April 2000 and April 2001. The situation of September 1999 and 2000 is however close to the situation of November 1997. Between September 1999 and 2000 there was a small increase in sediment transport. It is possible that the increased slopes, which have been observed in this part of the Upper Gorai River, and which have not been taken into account cause higher sediment transport capacities than calculated. It is also likely that the higher discharges result in a higher transport capacity for both high and low stages.

When looking at the results for the three stretches that are not dredged different trends are discovered.

- The stretch upstream of Kumarkhali, Kp 17.0-20.5 show an increase of sediment transport capacity in April 1999 and April 2001, relative to November 1997.The increase in April 1999 might be an effect of the dredging activities that have taken place in the first dredging season, 1998-1999.
- The Kumarkhali stretch show a rather undefined pattern. Little changes in sediment transport capacity have been calculated here.
- In the stretch from Kp 26.0 to Kp 31.0 for April 1999, 2000 and 2001 a lower transport capacity is found compared with November 1997. It is doubted that these results are correct.

5.5.3. Outgoing sediment based on the calculated sediment transport capacities

It is interesting to check these results with the sediment balances that were obtained from the analysis with ArcView.

Since the monsoon is important for the annual sediment balance, this case is used. For both the monsoons of 1999 and 2000 the outgoing sediment is calculated on the hand of the sediment transport capacities that were calculated in this study. The capacities of the dredged stretches and the stretches where no activities have taken place are averaged, in order to obtain an average sediment transport capacity for the Upper Gorai River, which is the study area. In this study, the monsoon is defined from April to end September of the same year. The stages and discharges are by far not constant over this period. Therefore the sediment volume is calculated for rising stages from April to the end of June, with an average water level of 3.0 m above SLW, and high stages from July to the end of September, with an average water level of 7.5 m above SLW. For these stages the corresponding discharges have been derived from the Q-h curve in Chapter three. For rising stages the calculated sediment transport capacity of April is used, for high stages the sediment transport capacity of September is used.

Table 5.4. Calculated outgoing sediment for Kp 1.5-17.0, from the calculated sediment transport capacity and sediment balance from ArcView (volumes in Mm^3)

	1999	2000
rising stages	0.45	0.38
high stages	4.24	3.89
total outgoing sediment	4.69	4.27
total balance from ArcView	-4.50	-3.77

When discussing these figures it should be noted that the balance of the 1999 monsoon did not include September 1999, while the calculated outgoing sediment for the 1999 monsoon does.

The amount of outgoing sediment give realistic values, although they seem to be too low, since with these amounts of outgoing sediment, the incoming sediment should be 0.19 Mm^3 in 1999 and 0.50 Mm^3 in 2000. This would implicate that the Ganges River transported only 1.9 Mm^3 in 1999 in 6 months and 5 Mm^3 in 2000. The calculated outgoing sediment for 2000 indicated a lower value than for 1999. This was also found in the sediment balances made with ArcView.

It is possible that when the outgoing sediment is calculated more in detail, that the sediment balance is approached better. These figures do indicate however that the calculated values for the sediment transport capacity give realistic sediment transports.

5.5.4. Dimensionless sediment transport capacity

The sediment transport capacity can be presented as a dimensionless variable as well. In that case the by calculation obtained sediment transports are divided by the sediment transport that was found for the same stage in November 1997. This figure illustrates the increase or decrease in sediment transport capacity relative to the situation without dredging. By presenting the sediment transports capacities in this way, the values are not sensitive to the used value of m in the sediment transport formula.

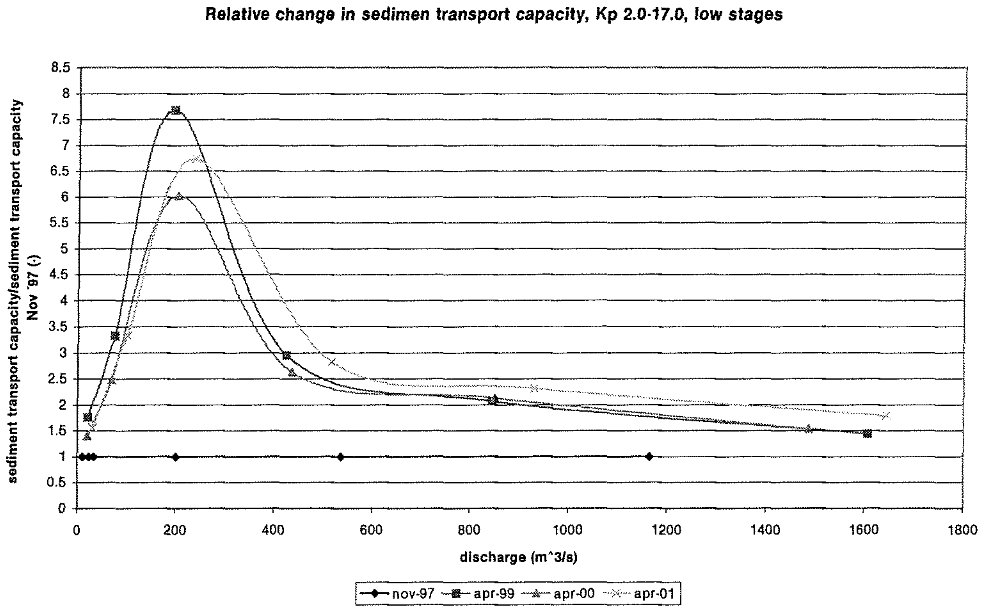


Figure 5.13. Dimensionless sediment transport capacity

In this figure it can be seen that the largest relative increase can be found for low discharge. For low discharges the maximum increase compared with November 1997 is between 600 % and 770 %. In 1999 the relative increase was the largest. This is due to the difference in side slopes of the dredged channel for the first, second and third season. For higher stages the graphs of April of the dredging years show an equal increase in sediment transport capacity in April 1999 and April 2000. In April 2001 this increase was much larger, and was at minimum 80 % increase compared to the conditions of November 1997.

5.5.5. Conclusions from the discharge-sediment relation

For the dredged part of the Upper Gorai River probably an increase in the sediment transport capacity can be found, assuming that the hydraulic slope and the bed roughness are constant. In practise this might explain the net sediment export which was found in the analysis with ArcView. Also in the part that was not dredged a sediment export was found. Since there is a decrease in sediment transport capacity for this part of the river the reason for this result has to be found in an increase in discharge and the increase in slopes in this part of the Upper Gorai River. Since the dredging activities also enlarged the discharge in the Upper Gorai River.

6. SOME REFLECTIONS ON FUTURE DEVELOPMENTS

6.1. Introduction

A highly interesting and relevant question is whether the results of Chapter five, effects of dredging, can be extrapolated for the following years. When answering this question it should be kept in mind that the sediment balance consists roughly of the following components:

$$Balance = S_{in} - S_{out}$$

The study on the effects of dredging through narrowing the river studied one aspect of the sediment balance, the outgoing sediment at Kp 31.0. The incoming sediment, at Kp 1.5, is not yet described. Figure 5.11 illustrates these boundaries. In this way the sediment input by bank erosion within the boundaries of the system and the outgoing sediment, by for example sand mining, are not taken into account. This will however not be of major influence when the trend in sediment balance are studied.

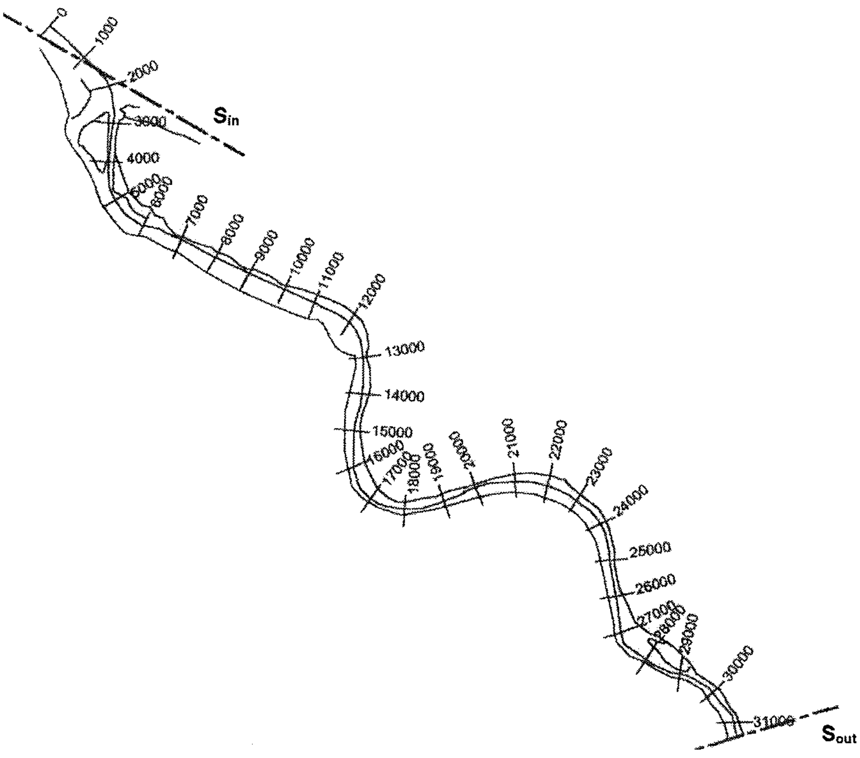


Figure 6.1. Boundaries of the river system for the sediment balance

When the effects of dredging on a longer term are studied the incoming sediment has to be studied as well. Therefore the factors which influence the incoming and outgoing sediment are studied.

Strategies

The sediment transport in the Upper Gorai River determines the outgoing sediment at the downstream border of the system (31 km from the off-take). The changes in the relation between the discharge and the sediment transport can be extrapolated for future situations with dredging. This is difficult to do, since the outgoing sediment is a function of the discharge and the shape of the cross-section. The discharge changes as a function of the changes in bed level in the Upper Gorai River. For the balance another parameter is important, namely the incoming sediment.

Scenarios

The incoming amount of sediment is dependent on the sediment distribution between the Gorai River and the ongoing channel of the Ganges River. This incoming sediment can not directly be influenced by dredging. Therefore scenarios have been developed for the future sediment distribution over the off-take. This is done by studying the parameter σ, which indicates the relation between discharge distribution and sediment distribution. σ is dependent on the approach angle of the Ganges River. Therefore the development of σ together with the approach angle is considered.

The development of the approach angle over the years is studied, based on satellite images of the off-take from 1973 to 1998. For some years of this period DHV-Haskoning (2000) has calculated σ, which describes the relation between the sediment ratio and the discharge ratio for the Ganges and the Gorai.

$$\sigma = \frac{S_{Gorai} / S_{Ganges}}{Q_{Gorai} / Q_{Ganges}}$$

When these figures are combined with the satellite images of the off-take, showing the approach angle of the Ganges River, the range of sigma can be found and a possible trend in sigma in time can be made.

It should be noted that other aspects of the planform of the Ganges River influence the sediment distribution. One of these aspects is whether the off-take of the Gorai River from the Ganges River is in an outer or an inner bend of the Ganges River and if it is located at the beginning or the end of the bend. These aspects are only partly taken into account in this study.

This results in scenarios for the future incoming sediment. Together with the extrapolation of the discharge-sediment transport relation a qualitative prediction of the future effects of dredging in the Upper Gorai River can be made.

There are other means of influencing the incoming and outgoing sediment. These means are not a subject of this study.

6.2. Effect of dredging strategies in future situations

In the relation between the width of the river and the water level a clear trend can be found. For high stages the width of the river is decreasing over the years. For lower stages (below approximately SLW + 5.5 m) an increase in the width is observed. Figure 6.2 shows the change in width for the dredged part of the Upper Gorai River in time for a water level of +6 m SLW.

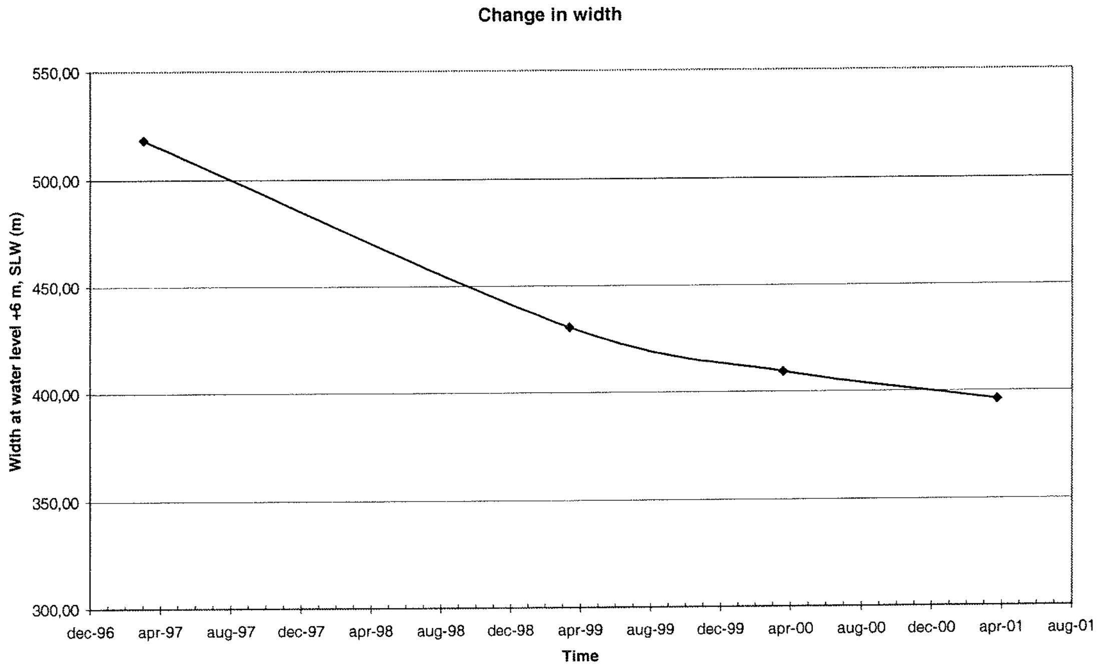


Figure 6.2. Change of width of the dredged part of the Upper Gorai River, water level +6 m SLW

At first the hypothesis was that the effect of the first dredging season would be the largest. The effect of the following seasons would be visible but diminishing over the years. Indeed it can be seen that the first year had the largest effect on the change in width. The effect of the following two dredging seasons was smaller than the effect of the first season.

Another effect of dredging is that the discharges gradually increases. It is therefore not likely that the maximum effect of the decrease in width has already been reached. The impact of the second and third dredging season can therefore used as a prediction for the impact of the fourth season. It is likely that the width for a certain water level will have a minimum. With this minimum the maintenance dredging volume will have a minimum as well. Mathematical modelling can contribute to the understanding of the development of the width of the river towards a minimum and the dredging volume that would be required to maintain the minimum width.

6.2.1.Options for future dredging strategies

Maintenance dredging strategies have a main function of reshaping the river to its state before the monsoon. During the monsoon the slopes of the dredged channel and the low water channel are flattened. This has a negative impact on the transport capacity of the river. After the monsoon the same bottlenecks emerge as before the capital dredging. This implies that maintenance dredging will still be necessary at these locations, although the dredging volumes are diminishing. The dredging volumes have decreased over the years and will increase in the following years. It is interesting to study the following aspects and strategies for future dredging:

- What is the trend in dredging volumes and when will the limit be reached?
- When will the capacity of the disposal sites be reached?
- Is it possible to dredge with a different repetition time (maintenance sequence/interval). For example every two or three years?

This last question can be answered based on a study on the time needed for a cross-section to return to the state before the dredging intervention. From parts of the Upper Gorai Rive, where only in the first year dredging activities have taken place, the return of the width of the river to its state before dredging can be studied. This may result in understanding of the recovery time and speed of the river after dredging. In figure 6.3.the theoretical situation when dredging with a longer return period is applied is shown.

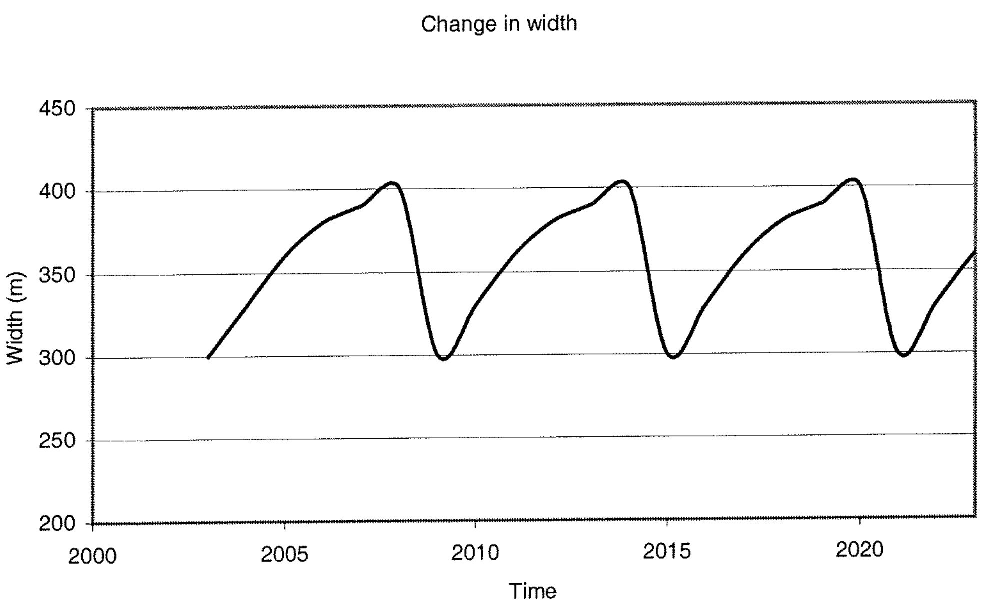


Figure 6.3. Possible effects of maintenance dredging with a larger interval

In the Upper Gorai River there is one stretch where only once dredging activities have taken place, only in the first season, Kp 17.0-20.5. When studying the development of this part of the river insight can be gained into the time needed for the cross-section to return to its state before the dredging intervention. However, a longer observation period is needed to understand the recovery process and indicate the recovery time. The recovery process of the river can also be studied on the hand of physical and mathematical modelling. In both cases the two - and three-dimensional processes have to be taken into account. Since the changes in the cross-sections are not only determined by one-dimensional processes.

6.3. Scenarios for future development of the Ganges River

The main channel of the Ganges River upstream of the off-take has shifted over the years, as can be seen in figure 2.1. There are a few fixed locations of the low water bed. These locations are caused by points that attract flow, such as scour holes near structures and outcrops which function as hard points. In the Ganges River two important fixed locations are the Hardinge Bridge and the associated river guiding works and the scour hole near Talbaria hard point. This hard point at Talbaria and the scour hole that is caused by it are essential for the Gorai River, because connection to the Ganges River is ensured. The Natore bend, upstream the Hardinge Bridge is also important for the planform of the Ganges River. The approach angle does however not have a limited range of possible angles. The approach angle in this study is defined in the following way:

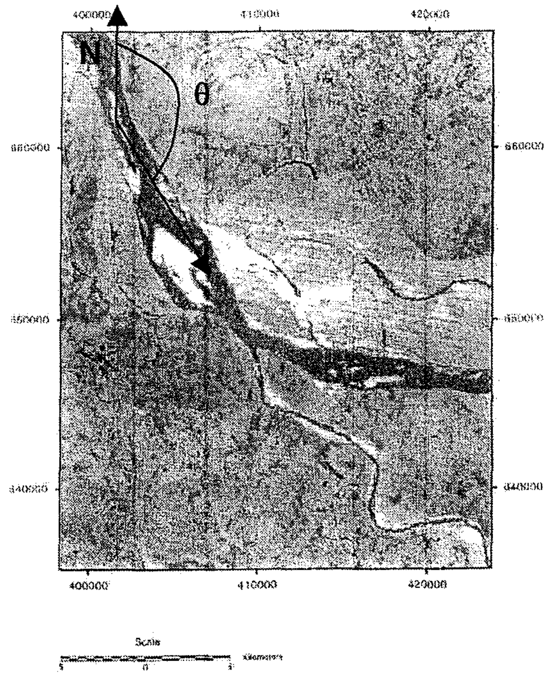


Figure 6.4. Definition of the approach angle of the Ganges River (satellite image: GRC, 1999)

The angle of the approach channel is related to the North. In most cases the Ganges River showed a braiding low water bed. The major channel is usually used to calculate the approach angle. This results in the following values for the available satellite images:

Table 6.1. Approach angle of the Ganges River, 1973-2001.

	'73	'84	'85	'87	'89	'90	'92	'93	'94	'97	'98	'99	'00	'01
θ (°)	159	158	133	136	119	110	105	103	129	112	100	104	102	125

These figures are combined with the calculated sigma by DHV-Haskoning (2000).

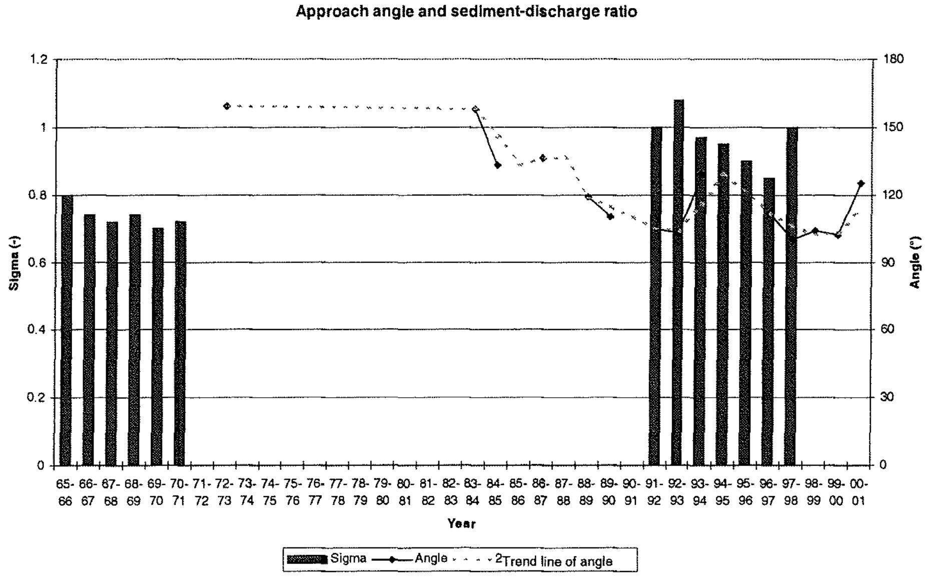


Figure 6.5. Approach angle and sigma for 66-67 to 00-01 (sigma: DHV-Haskoning, 2000)

This figure shows that the approach angle decreased over the years while the sediment-discharge ratio increased. Since only 14 recordings of the approach angle are available it is difficult to discover a trend from this figure, but however it can still be stated that a higher approach angle results in a lower sediment-discharge ratio, which is favourable for the Gorai. In figure 6.4 sigma is presented as a function of the angle. A linear trend line is given as well in this figure, this does not imply that the relation between the two parameters is linear.
Another interesting aspect of this figure is that around 1988 the approach angle decreased substantially. This might have contributed to the closure of the Gorai River.

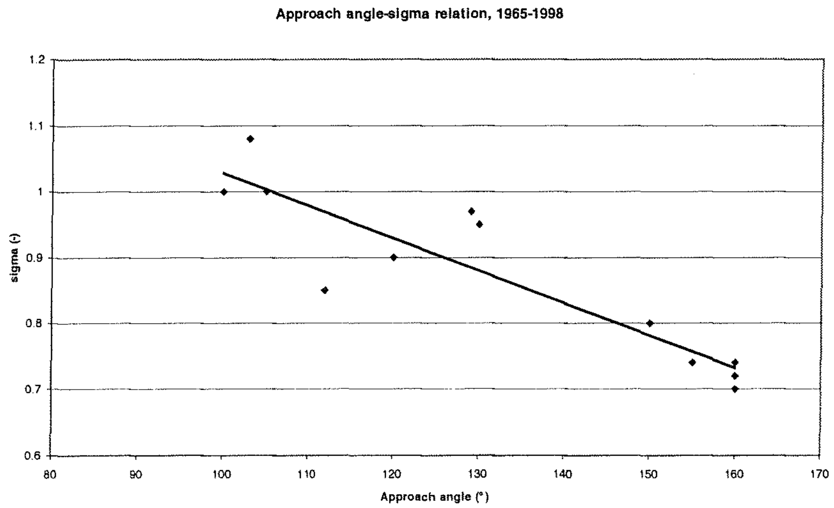


Figure 6.6. Approach angle of the Ganges River versus sigma, 1965-1998 (sigma: DHV-Haskoning, 2000)

Range of the approach angle

The Ganges River has three points that control the approach angle of the Ganges River. These are the Natore bend, Harding Bridge and the Gorai off-take. These locations are indicated in the satellite image of March 2001:

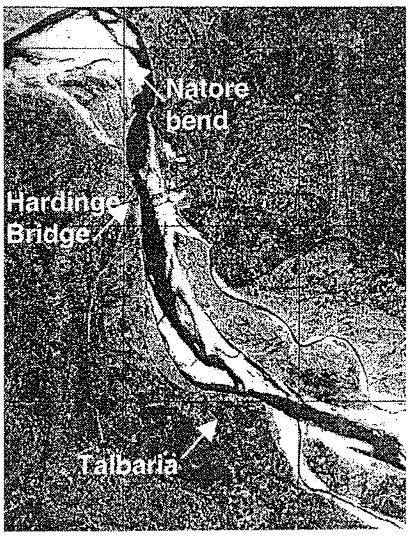


Figure 6.7. Satellite image of March 2001 with two fixed locations of the Ganges River and the Natore bend (satellite image: GRC, 2001)

From this figure, and the approach angles in the recent history, the range of the approach angle of the Ganges River is determined. The highest angle is reached when there would be a straight line between the Hardinge Bridge and Talbaria hard point. This results in an angle of 150°. In 1973 and 1984 higher angles were measured. This is caused by the limited area that is visualised in the satellite images of these years. When the satellite images up to Hardinge Bridge would be given, it is likely that this would resulted in a lower value for the approach angle.

The lower limit of the range for the approach angle can not be determined exactly. It is imaginable that when major low water channel of the Ganges River between Hardinge Bridge and Talbaria hard point shows a bend as the most southern channel of the Ganges in March 2001, the other limit of the ranges is reached. Therefore the lower boundary for the range is set at 100°.

Between 1973 and 2001 both limits of the range were recorded. It is therefore likely that the limit for the sediment-discharge ratio were recorded as well in this period. With this kept in mind the following figure is developed for the possible future values for the sediment-discharge ratio. At this moment (2001) the ratio is at its top. Therefore in the near future only equal or lower values for the ratio, and therefore for the amount of incoming sediment at the upstream boundary of the Upper Gorai River, can be expected.

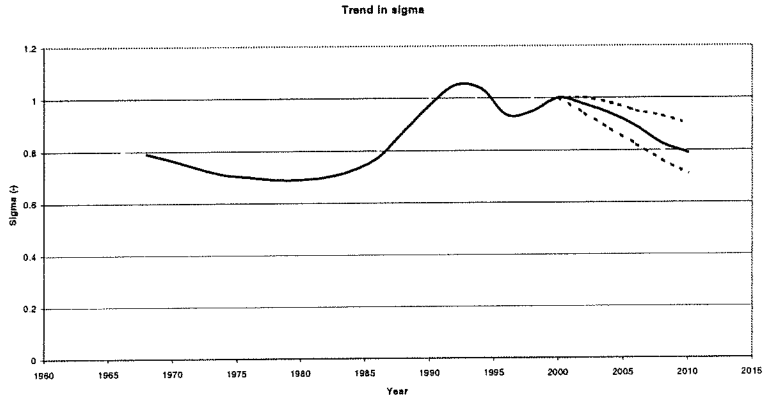


Figure 6.8. Trend line for the sediment-discharge ratio (sigma)

7. DISCUSSION

7.1. Use of ArcView for analyses and predictions

In this study ArcView and the Spatial Analyst have been used for:

- Visualisation of the bed level.
- Visualisation of the deposition and erosion patterns.
- Calculation of the sediment balances.
- Determination of the width- water level relations for 1997, 1999, 2000 and 2001
- Determination of the bed level in time for scour holes near man made structures and of shallow parts of the river.

With ArcView and the Spatial Analyst, grids can be analysed and calculations on these grids can be made. For this study the options of ArcView and the Spatial Analyst were sufficient. However, some extra options would be useful:

- Combination of grids which consist of different gridcells. This option would be useful in order to combine hydro surveys with topo surveys.
- The analyses that are made with ArcView cover an (x, y) surface. Analysis along a user defined line, in order to visualise the bed levels in a cross-section or a long line, is not possible.

ArcInfo has more options than ArcView. For the objective of this study, the possibilities of ArcView and the Spatial Analyst were sufficient. If in future analyses more detail and options would be required, working with ArcInfo is to be considered.

7.2. Used data set

The data sets contain data on water levels, bed topography, sediment and discharge. For the bed topography three different data sets have been used:

- The data set for November 1997, which was measured and made available by SWMC, contains cross-sections with an interval of 100m. Every cross-section was stored in a separate file, which contained the x-, y- and z-co-ordinates of the measured points. Since the Main Study uses PWD as reference level, the bed level values (z-co-ordinates) are converted to the SLW reference level.
- The data sets for the bed level from April 1999 to January 2001 with an interval of two weeks to one month, with the Kp notation and the x-, y- and z-co-ordinates. GRC executed these hydro-surveys and made this data set available. The bed levels are in m, SLW.
- The data sets containing cross-sections of the full width of the river. These data sets consist of combined hydro and topo surveys. The surveys and the combination of the data sets is done by GRC.

From the comparison of the last two data sets a large difference was found in the sediment balances over the monsoon. There are various possible explanations for these of these differences:

- There is a systematic difference between the hydro survey and the topo survey.
- The processing of the hydro and topo surveys cause differences.
- There are dunes or other irregularities present which can not be resolved by the hydro survey with an interval of 200 m but which are resolved with an interval of 50 m. Dune heights of 4 m, with a length of 200 m have been recorded in the monsoon.
- With high currents a sediment-water layer develops, which has a different mass density than water. This causes an inaccurate depth with an echo sounder, since the speed of sound is different in this layer.
- The difference in accuracy between the two types of survey cause differences.
- There are other ways in which erosion or deposition takes place, that are recorded in the topo survey but not in the hydro survey.

Another check for the validity of the measured cross-sections are the deposition and erosion patterns. The deposition and erosion patterns confirm the expectations on the development of the river, and if not, they can be explained based on possible deposition and erosion patterns.

7.3. Interpolation methods

For the data set with the combined hydro and topo data two studies have been made which resulted in sediment balances. The steps that were taken to obtain these balances are the following:

- The cross-sections, of which the data sets consist; are interpolated to obtain a continuous representation of the river bed.
- The grids, for the period of which a balance will be made, are subtracted from each other. ArcView does this by subtracting the value of one cell from the value of the same cell of the other grid.
- The balances are made per stretch. In this study the balances are calculated from histograms, which show the number of cells from which the difference in bed level is within a certain interval. In Excel these figures are processed and result in sediment balances. As a check of this method ArcView also has the possibility to calculate the average erosion or deposition. The comparison of the calculated balances in Excel and the balance in ArcView showed little differences.

Both balances from this study and the study carried out by GRC with the same data set show the same trend in the balances. The difference between the two analyses is however about 30%. The only way this difference can be explained is via the differences in interpolation method.

7.4. Influence of variations in the hydraulic slope and bed roughness on the discharge

In this study the hydraulic slope is considered as a constant for a certain moment. The spatial variations have not been taken into account. The same goes for the bed roughness. The basis for the determination of the hydraulic slopes are figures 3.7 and 3.8 (Witteveen+Bos, 2001) and, bed roughness is determined based on de Groot (1999). The variation of these two parameters can be found in the following tables:

Table 6.1. Variation in hydraulic slope in time and space (in cm/km), Kp 1.5-17.0, 2000-2001

water level (m)	Kp 1.5-3.5	Kp 3.5-6.0	Kp 6.0-8.0	Kp 8.0-13.0	Kp 13.0-16.0
8	7	12	5	6	6
6	15	2	5	6	7
4	20	4	5	9	9
2	4	2	4	4	6
0	2	2	3	3	5
-2	2	2	3	2	5

Table 6.2. Variation in hydraulic slope in time and space (in cm/km), Kp 17.0-31.0, 2000-2001 and 1997

water level (m)	Kp 16.0-22.5	Kp 22.5-31.0	Kp 1.5-31.0 (average)	Kp 1.5-31.0 (1997)
8	4	7.5	7	6
6	3.5	7.5	7	8
4	5	11	8.8	10
2	6	11	5.8	7.5
0	5.5	12	5	7.5
-2	5	12	5	7.5

Table 6.3. Variation of the Chézy value in time and space (in $m^{1/2}/s$) in 1998 (de Groot, 1998)

Date	Kp 1.0-4.5	Kp 4.5-6.5	Kp 6.5-13.5	Kp 13.5-17.5
September	69	63	76	91
October	60	61		
November	44	44	48	62
December		40	37	98

The slopes for 1997 are determined between Talbaria and Gorai Railway Bridge.

Only a small variation of the parameters can cause a large variation in the sediment transport capacity, since the bed roughness has a power 4 in the sediment transport relation and the hydraulic slope has a power 2, according to van Rijn´s formula for sediment transport.

The large variation of both parameters in space has a large influence on the discharge. For the determination of the discharge-sediment transport capacity relation for the dredged part of the Upper Gorai River, the average slope of the stretch upstream GRB has been used. The bed roughness is based on the bed roughness of the five stretches that are studied by De Groot (1999). It is believed that this is a good approximation. For the following situations either a parameter is unknown or an average value has been used, whence the calculated value for the discharge and the sediment transport can deviate from the real values:

- For the situation of November, which is before the dredging intervention, there is no data on the bed roughness. Therefore the same roughness as for the low water situation is used. Since large variations in the bed roughness have been recorded in 1998, it is possible that the original value for November 1997 is different from the value that is used here. For the situation of November 1997 the variation of the hydraulic slope in time is also not known.
- For the relations per stretch the average value for the upstream or downstream part is used. These values can deviate from the real values and therefore cause differences. These differences will be between stretches, not within the relation for one stretch. For example: in stretch Kp 26.0-31.0, $6.5*10^{-5}$ is used for the hydraulic slope, while for low stages the slope is $12*10^{-5}$ in this stretch. When using this figure this results in a discharge which is about 40% higher than when $6.5*10^{-5}$ is used.

From the comparison of the hydraulic slopes it can be said that the hydraulic slopes in 1997 were higher than the slopes of the following years. Since the dredging intervention, the slopes in the dredged part of the river are high for high stages and low for low stages. For the part of the river where no dredging activities have taken place the difference is smaller and the slope is higher for low stages than for high stages.

Dredging does not only have an initial effect on the hydraulic slopes. During the three dredging seasons the hydraulic slope has changed as well. An example of this is given in figure 7.1. In this figure the hydraulic slopes in time is given for the stretch Kumarkhali-Khoksa, Kp 22.5 – KP 31.0. In the third season the slopes were much higher than the slopes of the second season.

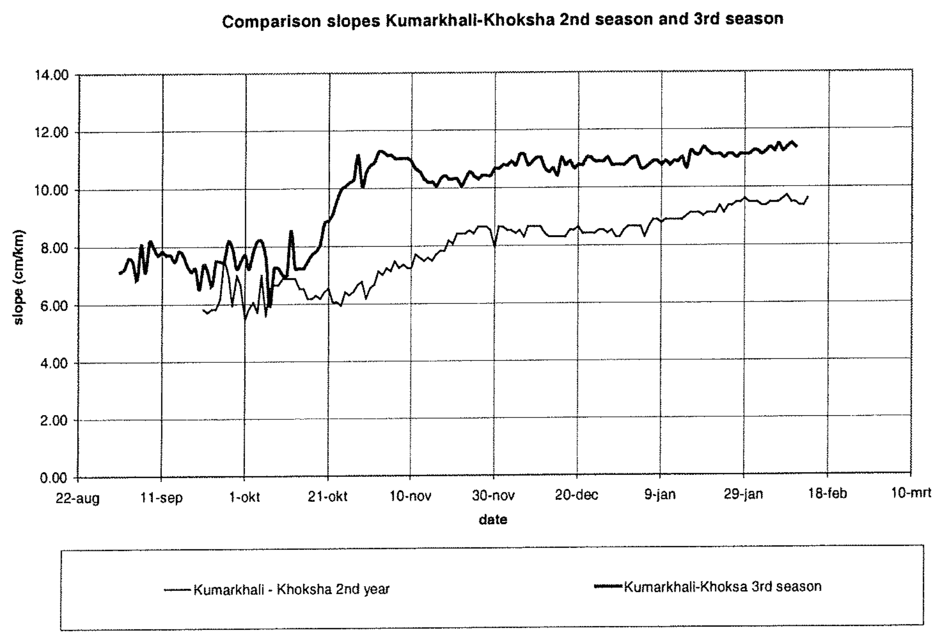


Figure 7.1. Comparison of slopes second and third season, Kumarkhali-Khoksha (Witteveen+Bos, 2001)

Between the second and the third season the slope has increased with 2 cm/km. This could explain the high net erosion that is found in this part of the Upper Gorai River over the hydrological year.

7.5. Influence of further assumptions of the sediment transport capacity

In Chapter five, assumptions have been made on the parameters that influence the sediment transport capacity and the discharge. In section 7.4 the values and developments of two of these parameters have been discussed. The three remaining assumptions are:

- In the Chézy formula for flow velocity the water depth can be used instead of the hydraulic radius, although small sections are used to calculate the powers of the water depth for the discharge formula and the sediment transport capacity.
- There is no interaction between the sections, in which the cross-section is divided. Flow velocities are not influenced by flow velocities in neighbouring sections.
- The full width of the river contributes to the sediment transport.

Apart from calculating the discharge via the smaller sections of the cross-section. The discharge has been calculated as well via the average water depth of the cross-section. This resulted in an average difference of 16.5% between the two methods. The maximum difference was approximately 68%. The highest deviations from the calculated discharge with the method used in this study was found at a water level of 4m + SLW. It is possible that at this water level the 2D flow patterns become more important for the total flow pattern. Furthermore the highest deviations were found mostly in the off-take area, Kp 1.5-3.5, and in the stretch upstream Gorai Railway Bridge, Kp 9.0-13.0.

7.6. Development of the disposal sites

In this study the development of the disposal sites could not be studied, since the hydro surveys did not fully cover the disposal sites. From experience of the present parties in Bangladesh it is expected that about 50% of the deposited volumes remains on the disposal sites after a monsoon. With this approximation and an approximation of the height and the maximum width available, an estimation can be made on the capacity of the disposal sites and the time needed for them to reach their full capacity. This could be a concern for future dredging activities.

7.7. Considered elements of the long term solution

For the long term solution alternatives have been generated. These alternatives consist of elements that guide more flow towards the Gorai River and elements that control the planform of the Gorai River (DHV-Haskoning, 2000).

Ganges training works:

- Ganges guide bund, located on the left bank downstream the Hardinge Bridge. This guide bund diverts the flow towards the right bank of the Ganges River.
- Ganges cross bund, adjacent to the low flow bank of the Ganges River. This will prevent future new channel development and to keep the thalweg at its current position.
- Ganges groynes, upstream of the off-take near the right bank of the Ganges River to stabilise the bank line.

Gorai off-take works:

- A flow divider on the left bank (downstream side) of the off-take. This is a means of augmenting the flow in the Gorai River by enlarging the discharge ratio.
- Bottom vanes in the Ganges River in front of the off-take. These bottom vanes reduce the amount of incoming sediment by catching a part of the bed transport.
- Guide bunds on the right bank of the off-take, which should narrow and stabilise the off-take geometry.

Gorai training works:
The elements that guide the flow in the Gorai River are:

- Bank protection (revetment) on the right bank between Kp 7.0 and 13.0.
- Groynes in the left bank in the bend upstream Gorai Railway Bridge. Together with the previous element, the groynes stabilise the alignment upstream Gorai Railway Bridge.
- Construction of three groynes near the right bank near Kushtia, to protect the bank.
- The removal of the Kumarkhali groyne, Kp 22.5, and replacement by revetments.
- Dredging:
  - Capital dredging in the clay layer of the off-take, in order to create a deeper and wider cross-section in the clay area. In February and March 2001 GRC has carried out additional dredging works in the scope of this element for the long term solution.
  - Maintenance dredging in the off-take area and the Upper Gorai River, with a smaller dredging volume than in the PPW.
  - Maintenance dredging in combination with fairly light structures, with a higher dredging volume than the previous option. In this option dredging is used to narrow and deepen the Gorai River.

Not all elements will be part of the long term solution.

In another study of the development of the Southwest region of Bangladesh a different option to keep the Gorai flowing is presented. This study is made for a longer term than the GRRP, which is made for the next 20 years. In this study the time in which the water levels drop is considered to be a threat for the Gorai River. When a barrage in the Ganges River would be build, downstream of the off-take, the time in which water levels drop can be controlled. In this way the self scouring capacity of the Gorai River can be restored.
Especially when the time in which the water levels drop diminishes in future situations, this alternative will possibly be the only alternative which can keep the Gorai flowing.

7.8. Options for future dredging strategies

The current dredging strategy is based on yearly maintenance dredging. With the current improvements of the Upper Gorai River, due to the dredging intervention, the alternative which is based on maintenance dredging should be considered as a part of the solution on the long term. Studies to the maintenance dredging volume in the following years should be made in order to make a comparison with the other options for the long-term solution possible. The variants for the maintenance dredging strategy could also contain maintenance dredging with a different return period. This variant on the maintenance dredging strategy will most likely imply a larger depth of the dredged channel and therefore higher volumes. It should be kept in mind that the stretch upstream Gorai Railway Bridge needs guidance and at this location yearly dredging or other means of stabilising the alignment will remain to be necessary. With the current flows and period of falling water the off-take area cannot keep itself and the downstream river open by its own self scouring capacity (retarded scour). Therefore, this stretch requires yearly attention as well.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1. Conclusions

This study concentrates on three research questions, which were formulated in Chapter one, section 1.2, and for which this study should provide an answer. These questions are:

- What are the effects of dredging on the morphology of the Upper Gorai River?
- Does the dredging intervention, which leads to a reduction of the river width, have a positive effect on the annual sediment balance of the Upper Gorai River?
- If the present maintenance dredging would be continued, what would be the effect on the morphology of the Upper Gorai River and the off-take in the future?

In this Chapter tentative answers to these questions are given, based on the studies that were made and which are described in the previous Chapters. Only further studies (as proposed in the recommendations) can provide more definitive answers.

Effects of dredging on the morphology of the Upper Gorai River

Alignment and low water channel

Between Kp 9.0 and 13.0 different alignments were implemented. The alignment of the second season was not stable and resulted in major morphological changes during the monsoon. In the third season the alignment was more stable in this stretch, although the low water bed of the river still had the tendency to shift towards the outer bend. For operational reasons the alignment should preferably be located like in the third season.

The alignment near the Kushtia groynes appeared to be unstable, as well, when it was not situated in the outer bend. For safety and stability reasons the alignment can still be selected more towards the inner bend for future situations.

Disposal sites

The development of the disposal sites could not be studied with the available data set. The study on the width-water level relations proved that a progressive decrease in width can be observed over the dredging seasons. This implies that a large part of the deposited sediment at disposal sites does not return to the dredged channel during the next season.

The stability of the slopes of the disposal sites is another interesting aspect. During the analysis with ArcView sliding of slopes is mentioned as a possible cause for the observed deposition and erosion pattern in the stretch from Kp 7.0 to Kp 9.0. In this stretch deposition is observed in the dredged channel and erosion is observed on the right side of this channel, where there is a disposal site. From the analysis it could not be determined which phenomena caused this pattern. Sliding of the slopes of the disposal sites might be proposed as a possible cause.

Bottlenecks

In the Upper Gorai River a number of bottlenecks can be identified that reduce the inflow in the river.

The bottlenecks that were identified before the beginning of the dredging works still form a bottleneck after the monsoon. These locations are:

- The off-take area. Especially between Kp 2.0 and Kp 2.5, where a bar is formed in the monsoon.
- The stretch upstream of Gorai Railway Bridge (GRB), because of the shifting of the low water channel.

The stretch upstream GRB requires the most attention in an early stage, since at the off-take retarded scour will diminish the height of the bar in the off-take during the recession of the flood. In a later stage, though, dredging is required in the off-take as well.

The period in which the water levels drop is of major influence on the retarded scour in the off-take. In 1999 the water levels dropped slowly, therefore the lowering of the bed levels could keep pace with the water levels.

Self maintenance capacity of the stretches
In the bottlenecks which are mentioned above, dredging will remain to be necessary, unless a substantial reduction of the bed levels in the Upper Gorai has established due to the combined dredging and increased sediment transport capacity as a consequence of the narrowing . This goes in particular for the stretches upstream Gorai Railway Bridge. The necessity of dredging of stretch Kp 13.0-17.0 is questionable. In 2000-2001 net erosion is observed in this stretch. Apart from this it is expected that the river will be able to scour the shallow parts in this stretch.

Deposition and erosion patterns
The shape of the river, as imposed on the river via the dredging intervention, is not stable and changes during the subsequent monsoons. The most important of the observed patterns are:

- Sediment is deposited in the dredged channel during the monsoon.
- On the higher areas erosion occurs.
- The development of scour holes downstream of man made structures (groynes, bridge piers) over time is clearly visible; downstream of these structures sediment is deposited.

The most important phenomena which probably cause the deposition in the dredged channel during the monsoon are lateral diffusion in the dredged channel and flow from higher lying areas towards the dredged channel. Sliding of the slopes of the disposal sites is another phenomenon that might cause the deposition in the dredged channel. These effects tend to modify the slopes of the dredged channel, in that they become more gentle.

Deposition and erosion rates
It was expected that the highest morphological activity (and hence the highest deposition and erosion rates) would occur during the highest stages and discharges. For the first part of the monsoon this was indeed the case. The highest rates were found in August though, whereas in September the highest stages and discharge were recorded. Possibly this is explained by filling in of the dredged channel in the first part of the monsoon.
In periods when either retarded scour or dredging takes place, high erosion rates are found.

Sediment balance
The sediment balances for the hydrological years 1999-2000 and 2000-2001 show an increased erosion in the year 2000-2001. As shown in this study, this is the result of the improved dredging strategy and the accumulated effects of dredging of the three dredging seasons on the morphology of the Upper Gorai River.

Effect of dredging strategy on the retarded scour
The effect of dredging on the retarded scour in the off-take cannot be derived from this study. The hydrographs in the two monsoons and especially the time required for the stages to fall over a certain range caused major differences in the development of the retarded scour in the off-take. Probably these effects were stronger than the effects of the change in dredging strategies, and hence no conclusions can be formulated regarding the effect of the change in dredging strategy. A longer observation period is needed.

Effects of dredging on the sediment balance

Effect of dredging on the width of the river
Over the last few years the average width at high stages has decreased in the dredged parts of the Upper Gorai River (Kp 1.5-17.0) This agrees with expected effect of dredging on the cross-sectional shape of the river. At low stages the width has increased. This is caused by a more pronounced low water bed. Before the dredging started, there were hardly any locations upstream of the Gorai Railway Bridge that were below SLW.
In the part of the river where no dredging activities have taken place, an increase in width is observed at all stages. In 2001 the increase in width is larger than in 2000.

Effect of dredging on the sediment transport in the Upper Gorai River
The same pattern as for the relation between the width and the water level can be found when the relation between the discharge and the sediment transport capacity is calculated on the basis of the changed cross-sectional characteristics. For all years with dredging the sediment transport capacity is higher than for the year without dredging. For high discharges (> 800 m^3/s) the sediment transport capacity appears to increase over the years, while for lower discharge the sediment transport capacity decreases apparently when compared with the first dredging season.
The results of the analysis for the part of the Upper Gorai River where no dredging activities have taken place, Kp 17.0-31.0, showed a decrease in sediment transport capacity. The decrease between 2000 and 2001 was higher than between 1999 and 2000.
Since the dredging intervention higher discharge have been recorded in the low water season. When these figures are combined with the higher sediment transport in the dredged part of the river, the erosion over the hydrological year might be explained. In the part where no dredging activities have taken place the increased discharge and the changes in hydraulic slope might explain the observed erosion in this stretch as well.
The calculated sediment transport capacity is used to calculate the outgoing sediment for the 1999 and 2000 monsoons and compared with the results of the ArcView analysis. As a result it can be said that the sediment transport capacity as calculated in this study might give realistic values, although the sediment transport capacity is slightly underestimated.

Future effects of dredging

Considering that the dredging intervention has clearly a positive effect on the Upper Gorai River it is interesting to discuss dredging as a part of the long term solution. Also because in future the quantities of sediment entering the off-take might reduce due to changes in the planform of the Ganges River. Therefore the future development of the two most important components of the sediment balance were studied, *viz.*: the outgoing sediment, via the increased sediment transport capacity, and the incoming sediment, via an evaluation of the possible changes of the planform of the Ganges River.

Future sediment transport with maintenance dredging
In view of the changes in the cross-sectional characteristics of the Upper Gorai River and its impact on the discharge-sediment transport capacity relations, a further increase in sediment transport capacity is expected for the dredged part of the Upper Gorai River, when maintenance dredging would be continued.

Scenarios for the development of the Ganges River
The approach angle of the Ganges River upstream of the Gorai off-take is an important factor that determines the sediment distribution between the off-take and the downstream Ganges River. At this moment the approach angle results in a sediment distribution that is equal to the discharge distribution. In previous decades the discharge distribution has been larger than the sediment distribution. Considering the historical data for both distributions and the possible changes in the approach angles of the Ganges River it is unlikely that the sediment distribution would be much larger than the discharge distribution in the future. It is more probable that there is a trend in the ratio of these distributions with a maximum that is reached during the last decade. Therefore in the near future the sediment distribution will probably be lower than the discharge distribution and therefore less incoming sediment must be expected.

It appears that the dredging over the last years might have triggered a positive development, which is still reinforced by expected planform changes. It is difficult to assess whether in future need for yearly maintenance dredging will decrease and what the equilibrium dredging volume will be.

8.2. Recommendations

Survey campaign

Insight into the development of the disposal sites in the monsoon would contribute to insight into the lasting effect of dredging after a monsoon period. Hence additional hydro and topo surveys, in particular during and immediately after the monsoon period, are a useful addition to the data set. A survey covering the full width of the river, which is carried out at the end of September would be preferable. In general it holds that the surveying should be continued. The interval of the cross-sections and the period of time in between the surveys is sufficient to give a clear representation of the river bed and the development of the river bed in time.

Furthermore the difference between the balances that are obtained from calculations on the basis of the hydro surveys and the combined hydro and topo surveys are confusing. When the cause of these differences would be known, any conclusions on the morphological phenomena and in particular the sediment balance of the Upper Gorai River could be better based.

Studies on the effects of different interpolation methods

The different interpolation methods that were used in this study and the study by GRC (2001) caused small, acceptable, differences for the stretches which were all less than six kilometres in length. When these differences are accumulated a larger difference is found. For the balance of the hydrological year 2000-2001 this accumulated difference is about 1 Mm^3 over approximately 30 kilometres. For this study these differences are acceptable, since the effect of dredging of the two years that are studied can be derived from these figures. For studies that require more detail it could be useful to study the effect of both interpolation methods.

Study on the possibilities for dredging on a longer term

The current maintenance dredging works are carried out each year and each year the dredging volumes are diminishing. From the past three dredging seasons, it is however not possible to discover a trend in the dredging volumes or to forecast a minimum dredging volume with the current return period for dredging. Imperative appears to be a better understanding of the deposition and erosion patterns in the Upper Gorai River as a function of the discharge and the filling in of the channel and the erosion of the disposal areas.

Another interesting subject for future studies would be whether the return period for dredging could be increased to a number of years, but with most likely higher dredging volumes in that year. This study should be based on a good insight into the typical period over which the effects of dredging (in particular on the width of the river) are still noticeable.

In order to provide answers to these questions mathematical and physical modelling studies should be carried out.

Study on the effect of dredging strategies on retarded scour in the off-take

By making full use of the retarded scour in the off-take the dredging volumes can be reduced. Probably the dredging strategy can influence the retarded scour. In this study it was not possible to derive any conclusions on the effect of the dredging strategy on retarded scour since the hydrograph of the two considered seasons were too different.
It is likely that when using data of more monsoons and subsequent dredging seasons with different strategies, more can be said about the influence of the dredging strategy on retarded scour. An alternative way in which the influence of dredging strategies on retarded scour can be studied is by a (one dimensional) mathematical model of the river.

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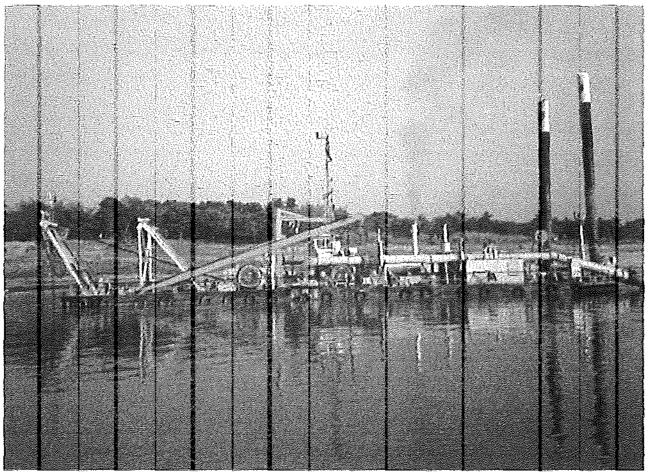
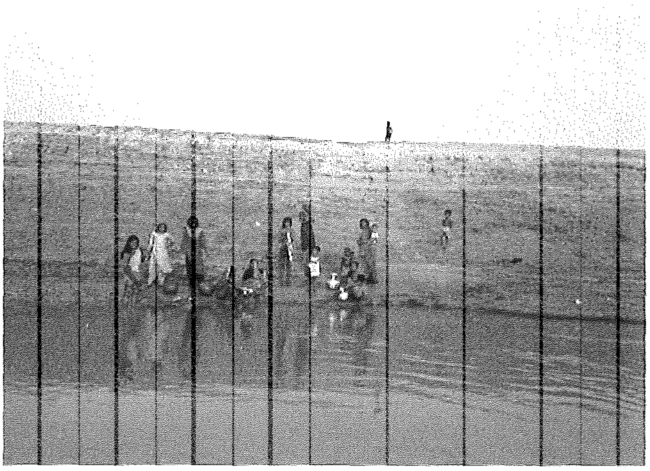
Morphological response to dredging of the
Upper Gorai River

Appendices

A. Clijncke
September 2001

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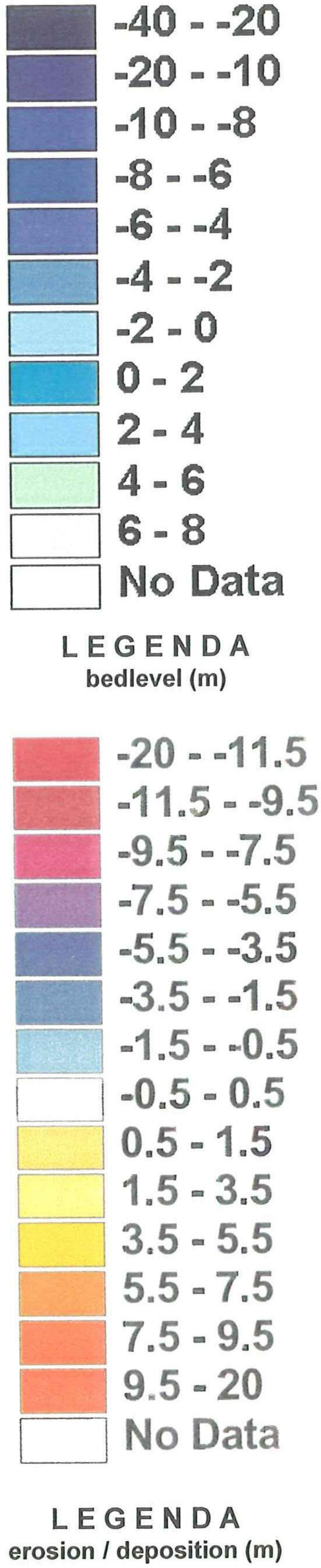
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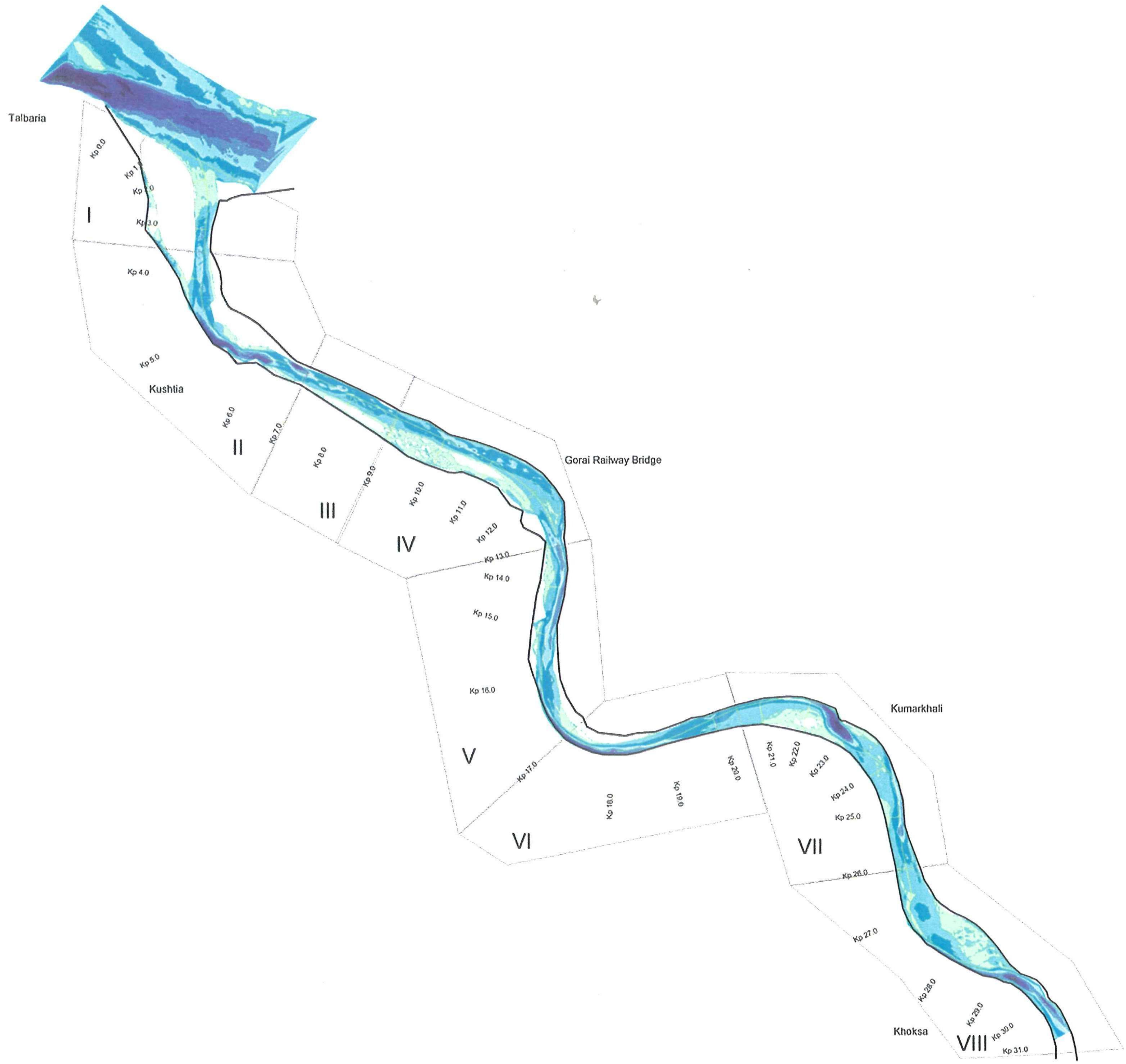
-20 - -10
-10 - -8
-8 - -6
-6 - -4
-4 - -2
-2 - 0
0 - 2
2 - 4
4 - 6
6 - 8
No Data
LEGENDA
bedlevel (m)
-20 - -11.5
-11.5 - -9.5
-9.5 - -7.5
-7.5 - -5.5
-5.5 - -3.5
-3.5 - -1.5
-1.5 - -0.5
-0.5 - 0.5
0.5 - 1.5
1.5 - 3.5
3.5 - 5.5
5.5 - 7.5
7.5 - 9.5
9.5 - 20
No Data
LEGENDA
erosion / deposition (m)

Appendix I:

Overview of the Upper Gorai River

Overview of the Upper Gorai River

September 2000



Appendix II:

Survey data

Table II.1. Data of November 1997

SWMC number	Date	Stretch	Interval (m)
02 to 305	14-11-97 to 25-12-97	Kp 2.5-31.0	100 m

Table II.2: Data of the hydrological year 1999-2000

GRC number	Date	Stretch	Interval (m)
717	13-04-99	0.0-2.5, 2.5-14.0	250,500
736	22-04-99	14.5-30.0	500
779	29-05-99	0.0-12.0,.12.5-17.0	250, 500
781	30-05-99	17.5-28.0, 28.25-30.0	500, 250 +CL
796	26-06-99	-0.50-12.0	250
797	27-06-99	12.5-16.0	500
798	29-06-99	16.5-30.0	500+CL
804	10-07-99	0.25-12.0	250
805	11-07-99	12.5-30.0	500
808	17-07-99	CL	
812	24-07-99	-0.5-12.0	250
814	25-07-99	12.5-30.0	500
817	31-07-99	CL	
823	07-08-99	-0.5-5.25	250
825	08-08-99	18.0-30.0	500
826	09-08-99	5.5-12.0, 12.5-17.5	250, 500
829	14-08-99	CL	
833	21-08-99	-0.5-12.0	250
834	22-08-99	12.5-30.0	500
840	28-08-99	CL	
846	02-09-99	-0.5-12.0	250
847	03-09-99	12.5-30.0	500+CL
925	13-10-99	8.5-11.75	250
926	13-10-99	2.5-5.5	100
929	14-10-99	12.0-30.0	500
931	15-10-99	-0.375-2.5	175
932	26-10-99	-0.5-2.5	250
966	27-10-99	2.75-11.75	250
969	28-10-99	12.0-30.0	500+CL
983	28-10-99	-0.5-2.5	250
1008	10-11-99	12.0-20.0, 20.5-30.0	250+CL
1013	11-11-99	2.75-12.0	250
1083	02-12-99	16.0-30.0	500
1092	04-12-99	5.5-12.0	100+CL
1118	11-12-99	3.0-12.0	100
1135	16-12-99	12.0-16.0	250
1138	17-12-99	16.5-30.0	500+CL
1151	31-12-99	12.0-16.0, 16.0-30.0	500+CL
1152	01-01-00	-0.6-4.0	100
1156	03-01-00	4.1-8.0	100
1157	04-01-00	8.1-12.0	100
1181	15-01-00	12.125-16.0	125
1185	16-01-00	16.5-30.0	500
1253	13-02-00	16.0-30.0	250+CL
1258	15-02-00	8.2-16.0	200

GRC number	Date	Stretch	Interval (m)
1260	16-02-00	-0.6-8.0	200
1282	27-02-00	16.0-30.0	250
1287	29-02-00	8.2-16.0	200
1290	01-03-00	-0.6-8.0	200
1305	11-03-00	16.0-30.0	250
1306	11-03-00	8.2-16.0	200
1310	13-03-00	-0.6-8.0	200
1330	08-04-00	48000-53000	100 (Ganges)
1331	09-040-00		CL
1332	09-04-00	16.0-30.0	250
1336	11-04-00	6.0-16.0	200
1337	12-04-00	-0.6-6.0	200
1338	12-04-00		CL
1343	25-04-00		CL
1344	25-04-00	16.25-30.0	250
1345	29-04-00	8.0-16.0	200
1346	30-04-00	-0.6-7.8	200
1347	06-05-00	48000-53000	200, Ganges
1351	09-05-00	16.25-30.0	250
1352	09-05-00		CL
1353	10-05-00	8.0-16.0	200
1354	11-05-00	-0.6-7.8	200
1360	23-05-00	8.0-16.0	200
1361	24-05-00	-0.6-7.8	200
1362	25-05-00	16.25-30.0	250
1363	25-05-00		CL
1366	06-06-00	-0.6-7.8	200
1368	07-06-00	8.0-16.0	200
1369	08-06-00		CL
1370	08-06-00	16.25-30.0	250
1372	17-06-00	48000-53000	200, Ganges
1374	19-06-00	-0.6-7.8	200
1378	21-06-00	8.0-16.0	200
1380	21-06-00		CL
1381	22-06-00	16.25-30.0	250
1387	02-07-00	-0.6-7.8	200
1388	02-07-00		CL
	04-07-00		CL
1390	04-07-00	8.0-16.0	200
1391	05-07-00		CL
1392	05-07-00	16.25-30.0	250
1394	08-07-00	48000-53000	200, Ganges
1398	16-07-00	-0.6-7.8	200
1399	16-07-00		CL
1401	19-07-00		CL
1402	19-07-00	16.25-30.0	250
1403	20-07-00	8.0-16.0	200
1404	20-07-00		CL
1407	30-07-00	-0.6-7.8	200

GRC number	Date	Stretch	Interval (m)
1408	31-07-00	8.0-16.0	200

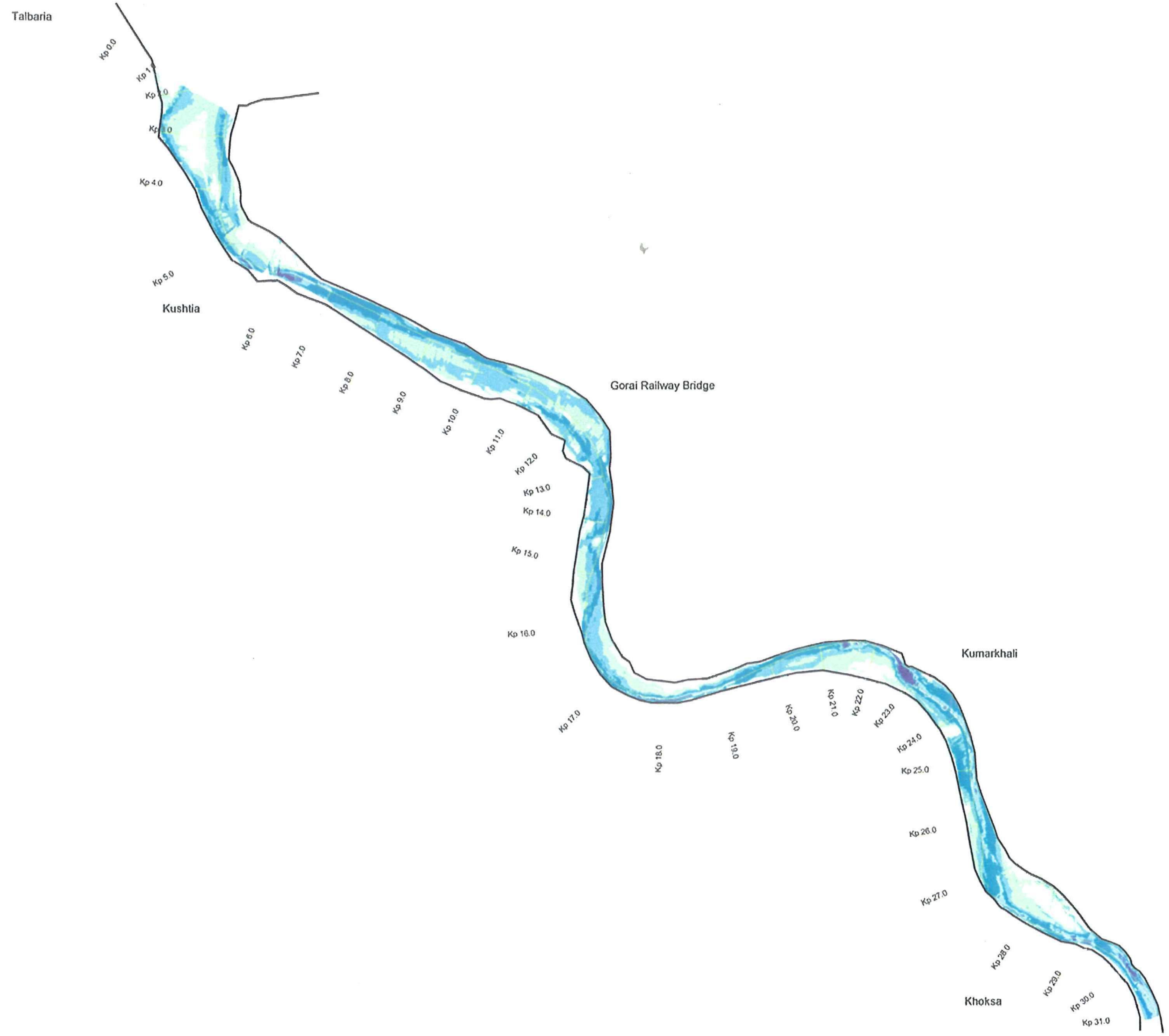
1409	03-08-00		CL
1410	03-08-00	16.25-30.0	250
1416	14-08-00	-0.6-7.8	200
1417	14-08-00		CL
1418	15-08-00	8.0-16.0	200
1419	16-08-00		CL
1420	16-08-00	16.25-30.0	250
1426	28-08-00	-0.6-7.8	200
1427	30-08-00		CL
1428	30-08-00	16.25-30.0	250
1429	31-08-00		CL
1430	31-08-00	8.0-16.0	200
1433	10-09-00	-0.6-7.8	200
1435	12-09-00		CL
1436	12-09-00	16.25-30.0	250
1437	13-09-00		CL
1438	13-09-00	8.0-16.0	200
1444	25-09-00	0.0-8.8	200
1445	26-09-00	9.0-17.0, 10.1-13.0	200, 100
1446	27-09-00		CL
1447	27-09-00	17.25-31.25	250
1462	10-10-00	48000-53000	200, Ganges
1499	22-10-00	1.0-4.0	125
1510	25-10-00	1.0-8.8	200
1516	26-10-00	9.0-17.0	200
1521	28-10-00		CL
1522	28-10-00	17.25-31.25	250
1567	12-11-00	48000-53000	200, Ganges
1607	25-11-00	0.0-8.8	200
1610	26-11-00		CL
1611	26-11-00	17.25-31.25	250
1615	27-11-00	9.0-17.0	200
1619	28-11-00		CL
1653	09-12-00	48000-53000	200, Ganges
1685	24-12-00	9.0-17.0	200
1686	25-12-00	0.0-8.8, 0.0-0.4	200, 100
1690	26-12-00		CL
1691	26-12-00	17.25-31.25	250
1698	04-01-01	48000-53000	200, Ganges
1703	26-01-01	0.0-8.8, 0.0-4.2	200, 100
1704	27-01-01	9.0-15.6	200
1705	28-01-01	15.8-17.0, 17.25-31.25	200, 250
1706	28-01-01		CL

Appendix III:

Bed levels of November 1997, April 1999, 2000 and 2001 and September 1999 and 2000

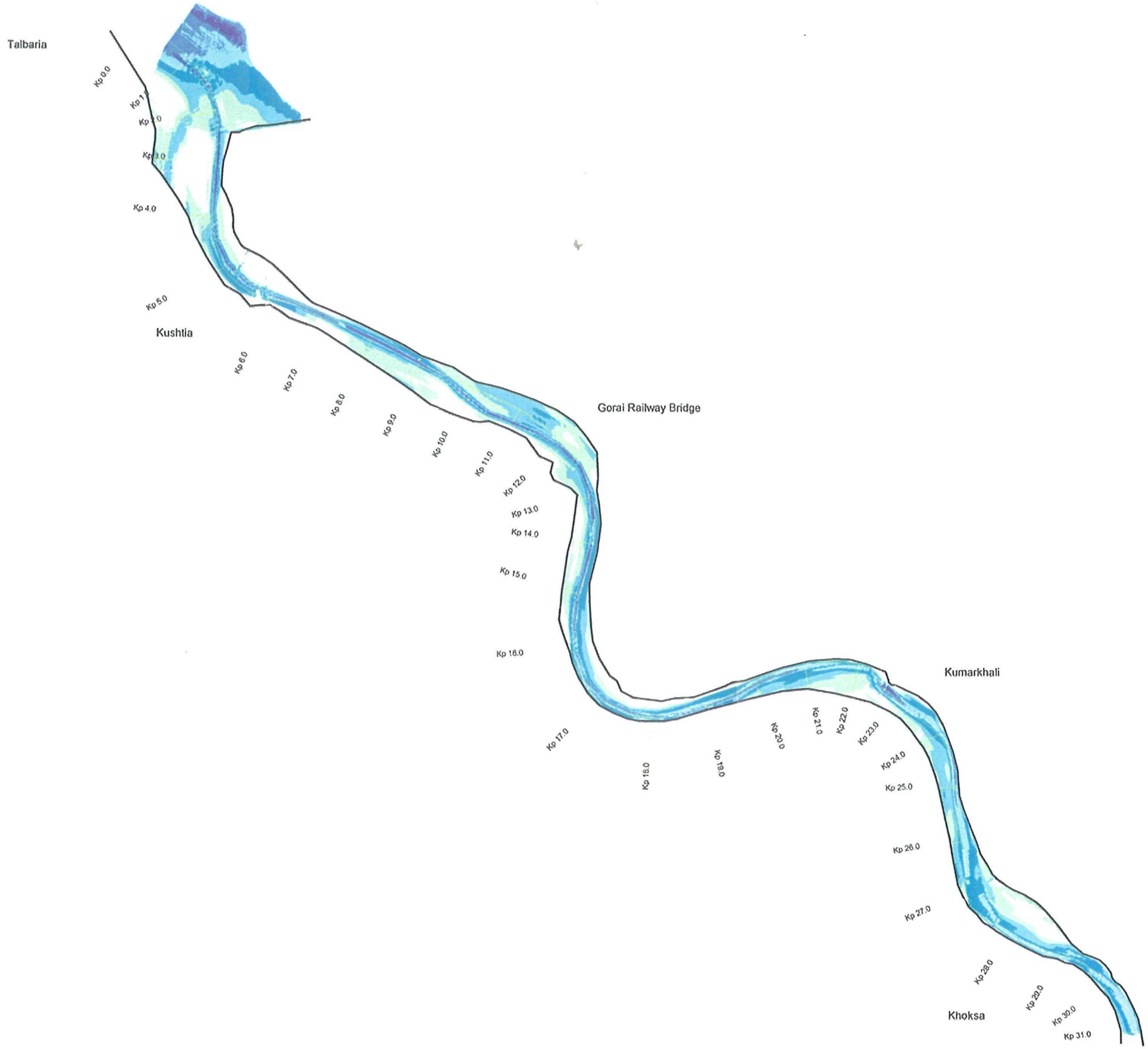
Bed levels

November 1997



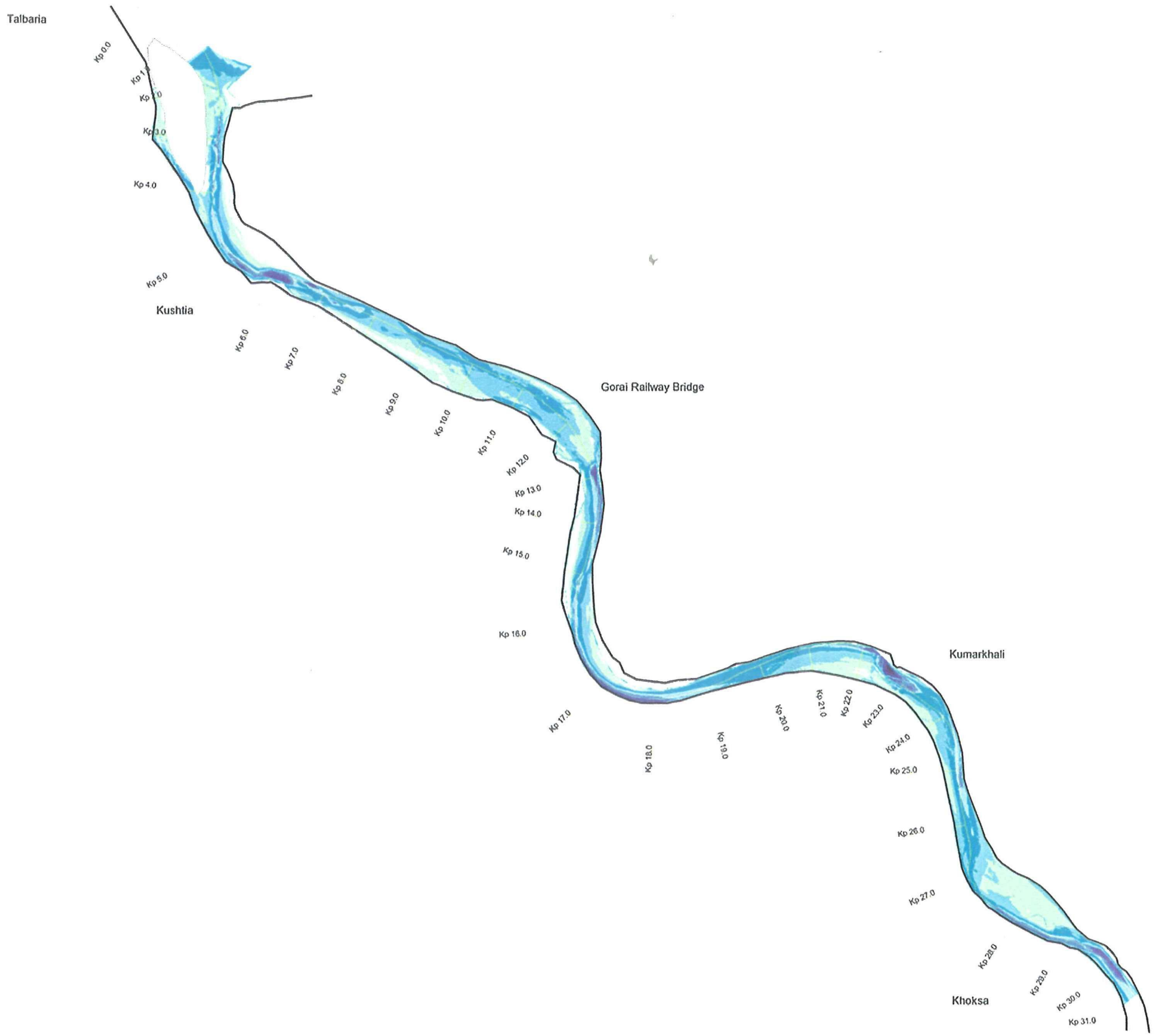
Bed levels

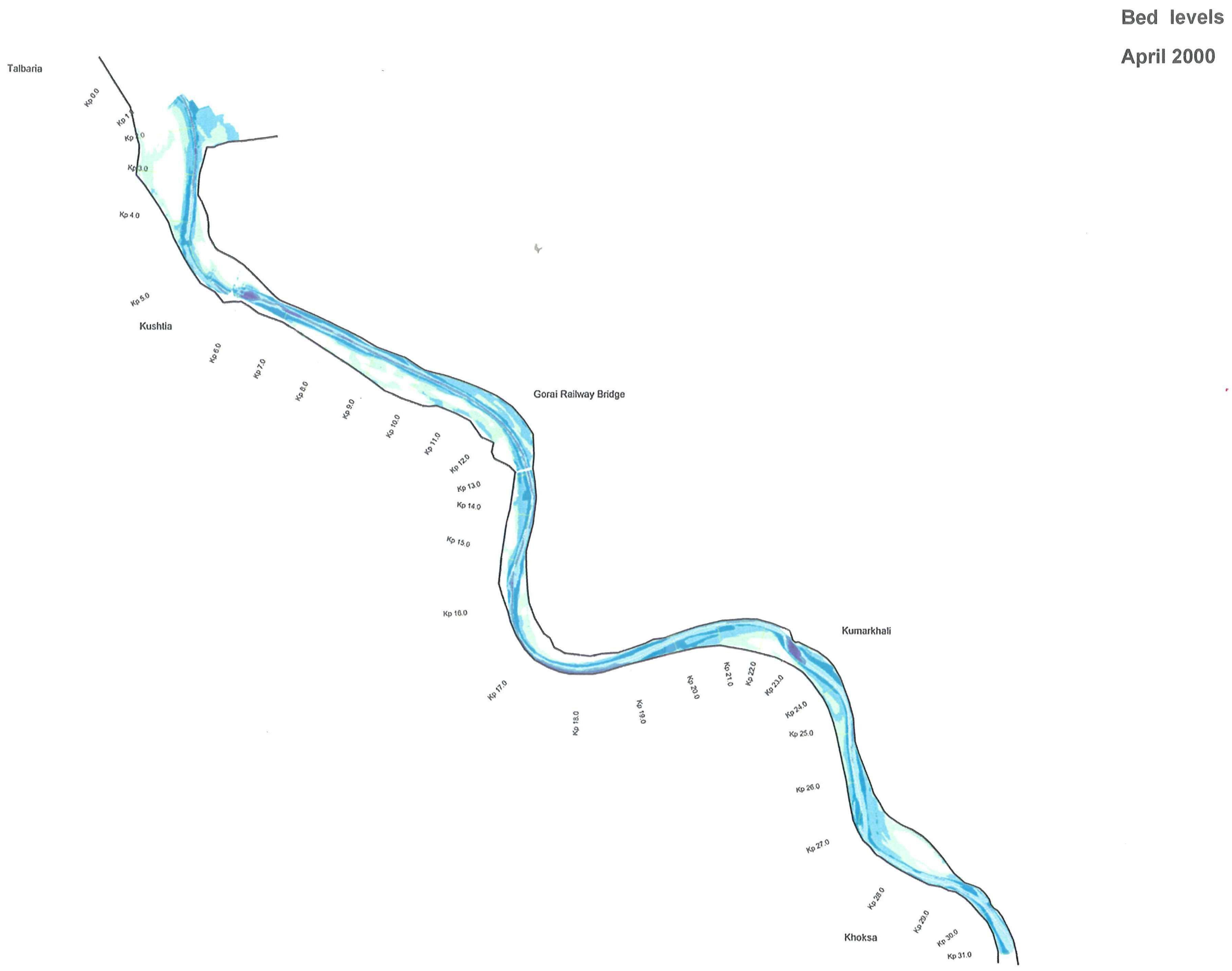
April 1999



Bed levels

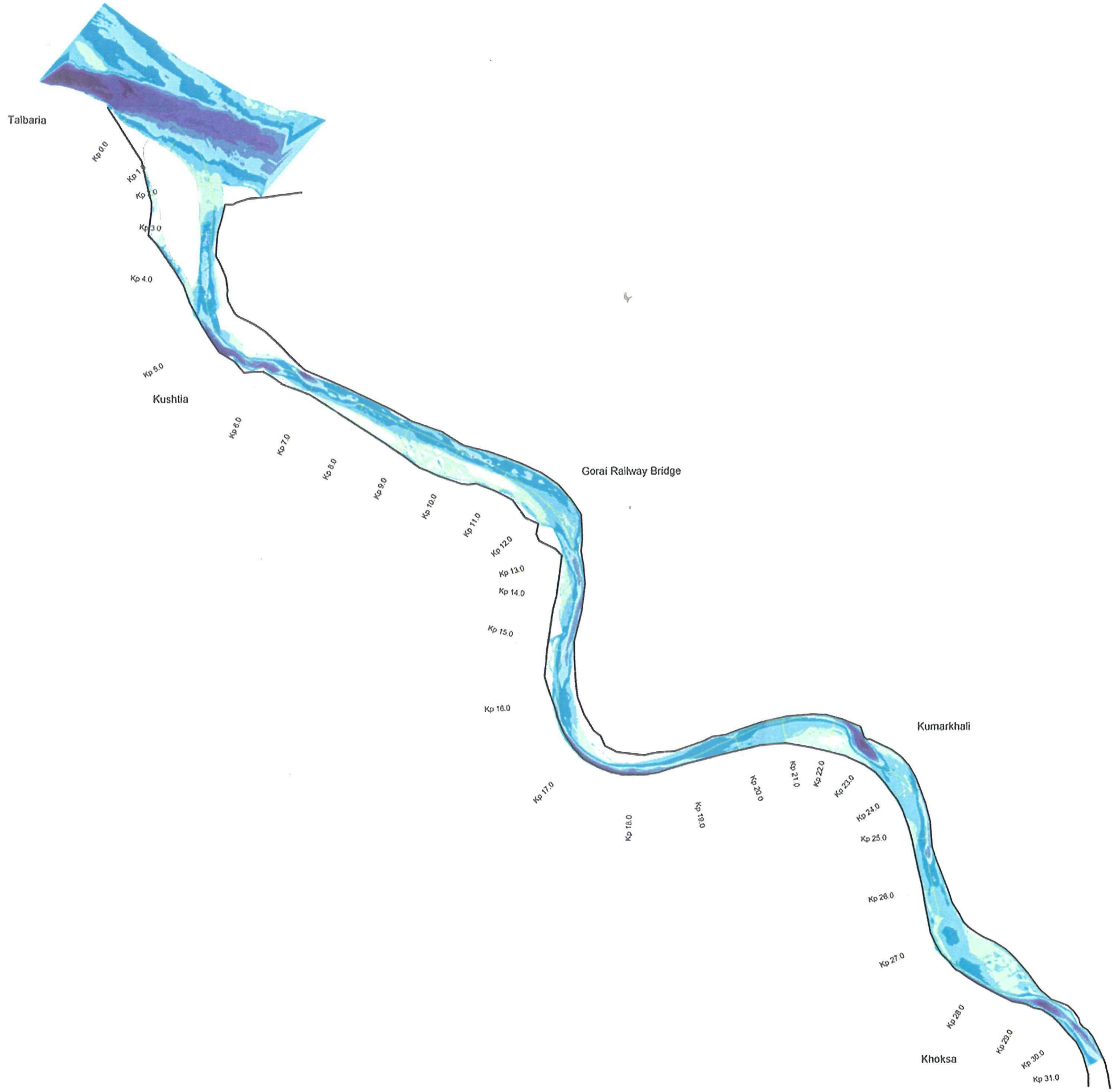
September 1999




Bed levels
April 2000
Talbaria
Kushtia
Gorai Railway Bridge
Kumarkhali
Khoksa
Kp 0.0
Kp 4.0
Kp 5.0
Kp 6.0
Kp 7.0
Kp 8.0
Kp 9.0
Kp 10.0
Kp 11.0
Kp 12.0
Kp 13.0
Kp 14.0
Kp 15.0
Kp 16.0
Kp 17.0
Kp 18.0
Kp 19.0
Kp 20.0
Kp 21.0
Kp 22.0
Kp 23.0
Kp 24.0
Kp 25.0
Kp 26.0
Kp 27.0
Kp 28.0
Kp 29.0
Kp 30.0
Kp 31.0

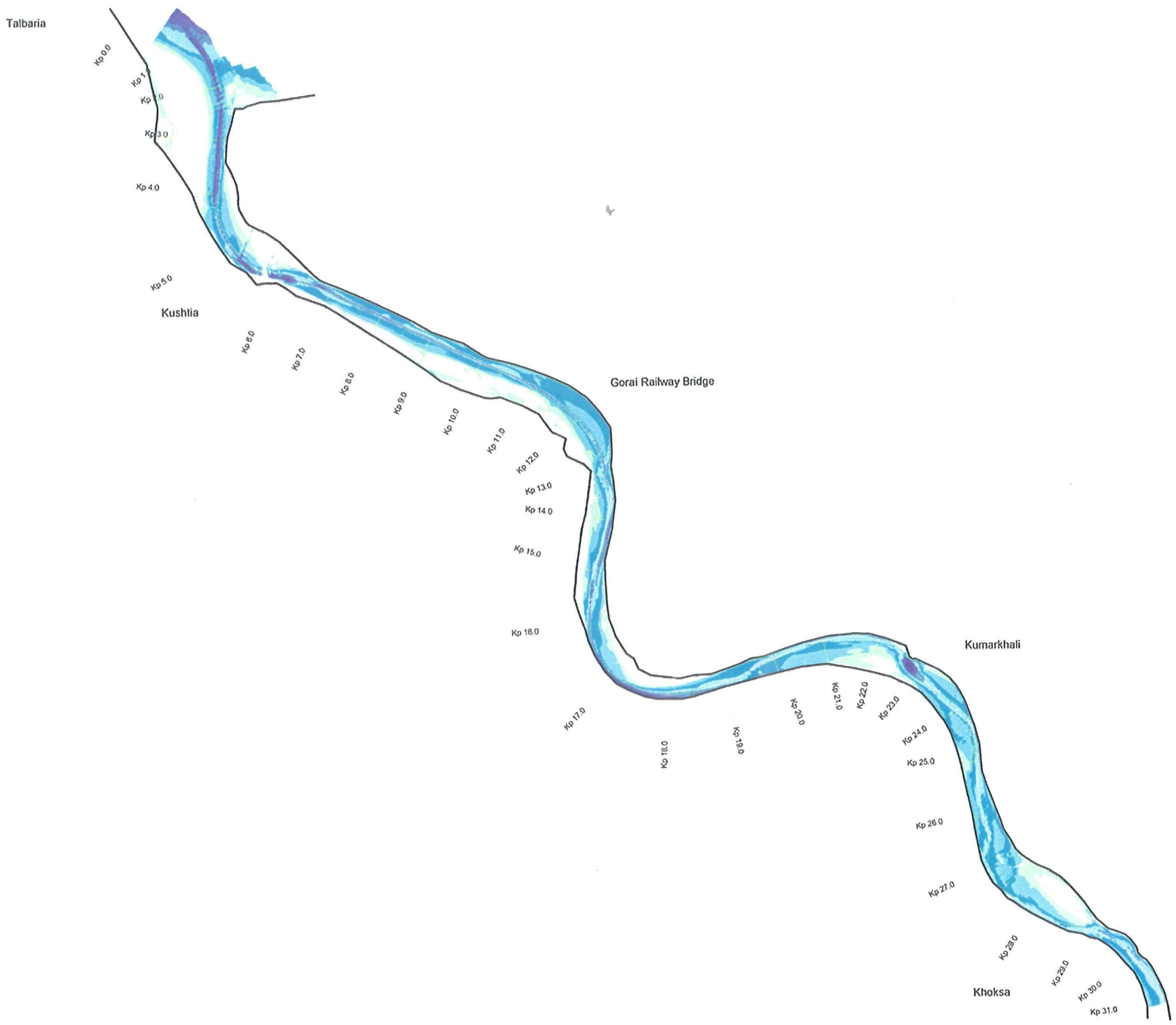
Bed levels

September 2000



Bed levels

April 2001

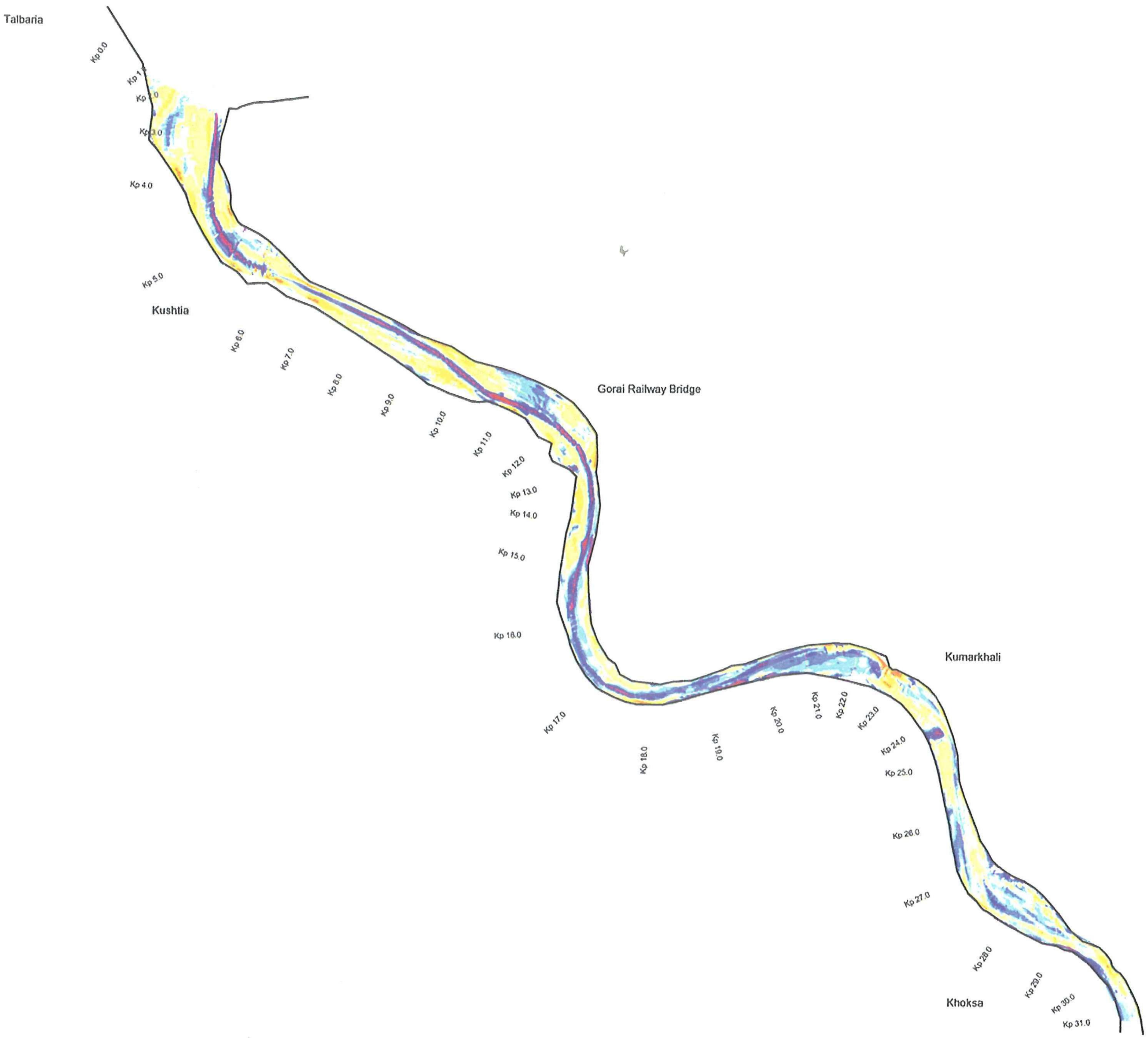


Appendix IV:

Erosion and deposition patterns hydrological year, dredging season and monsoon

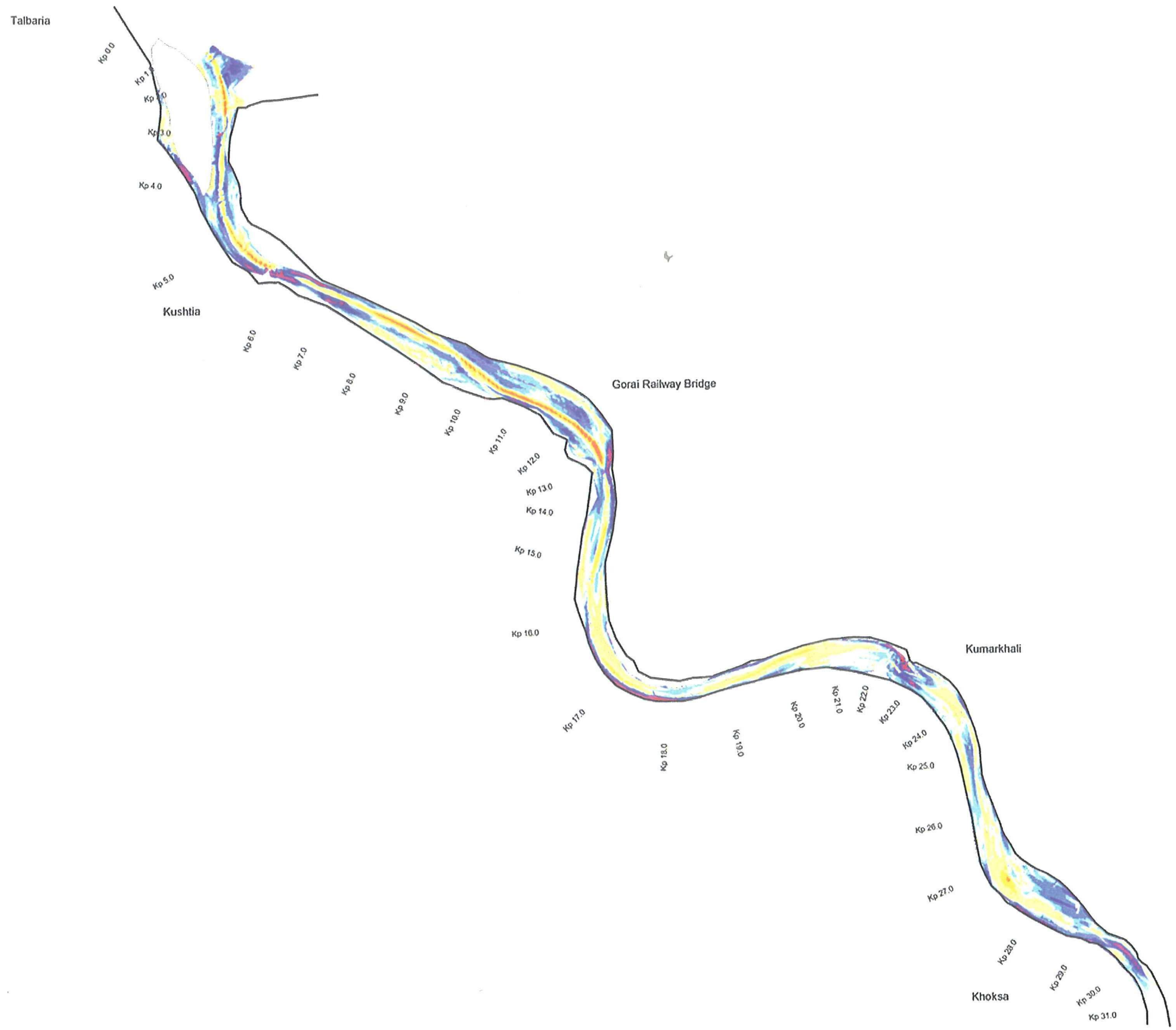
Deposition and erosion patterns

November 1997 - April 1999



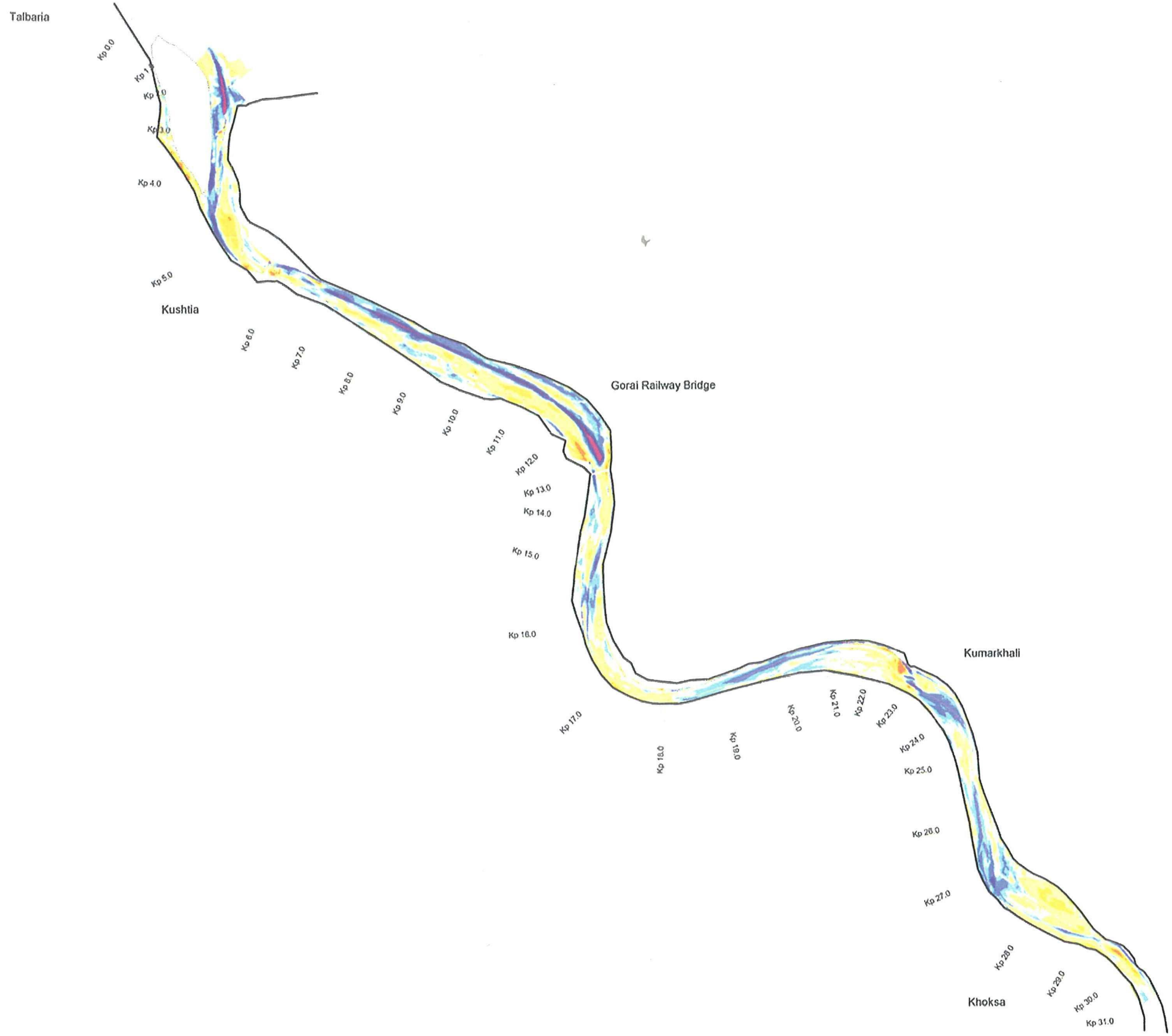
Deposition and erosion patterns

April 1999 - September 1999



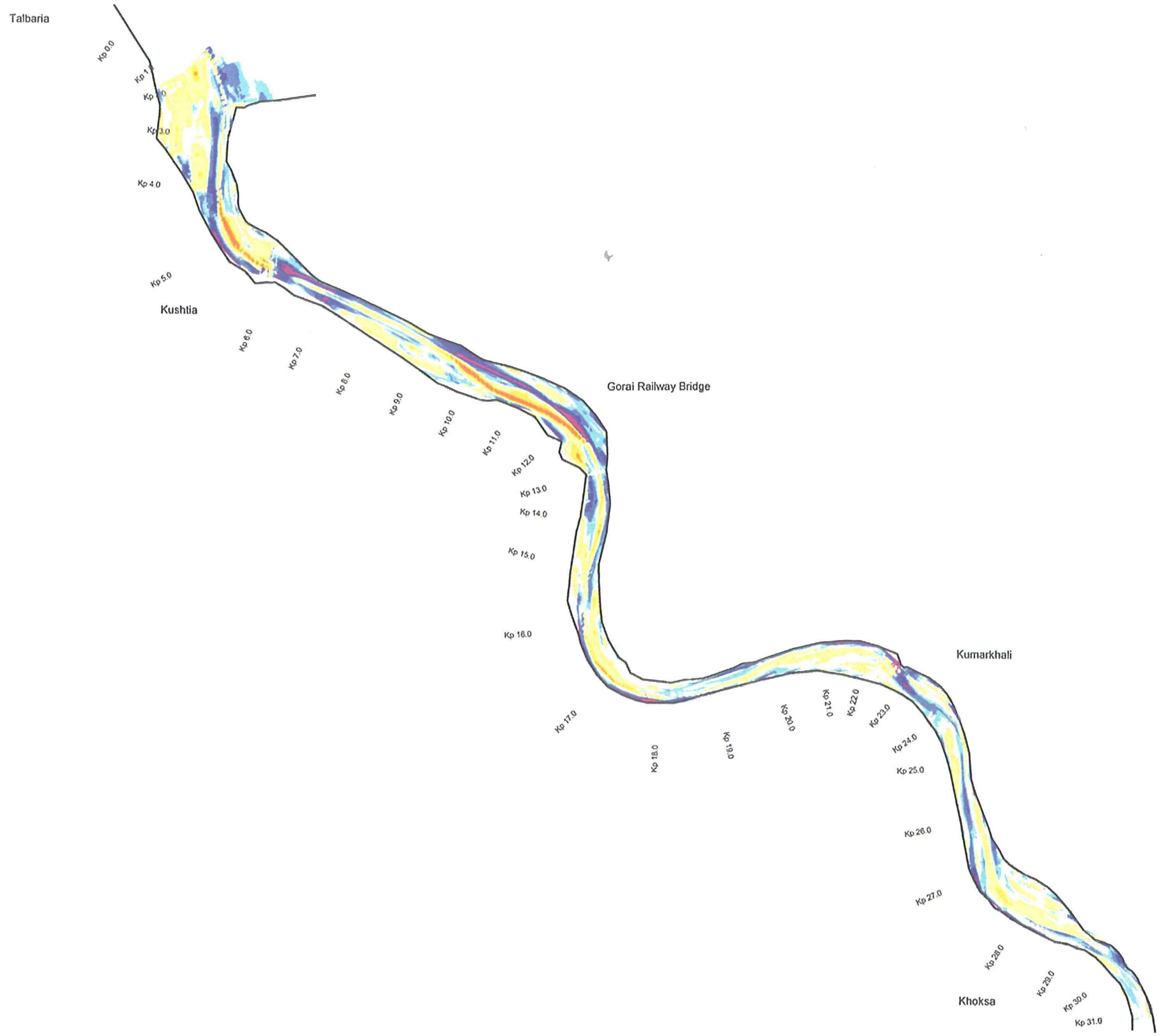
Deposition and erosion patterns

September 1999 - April 2000



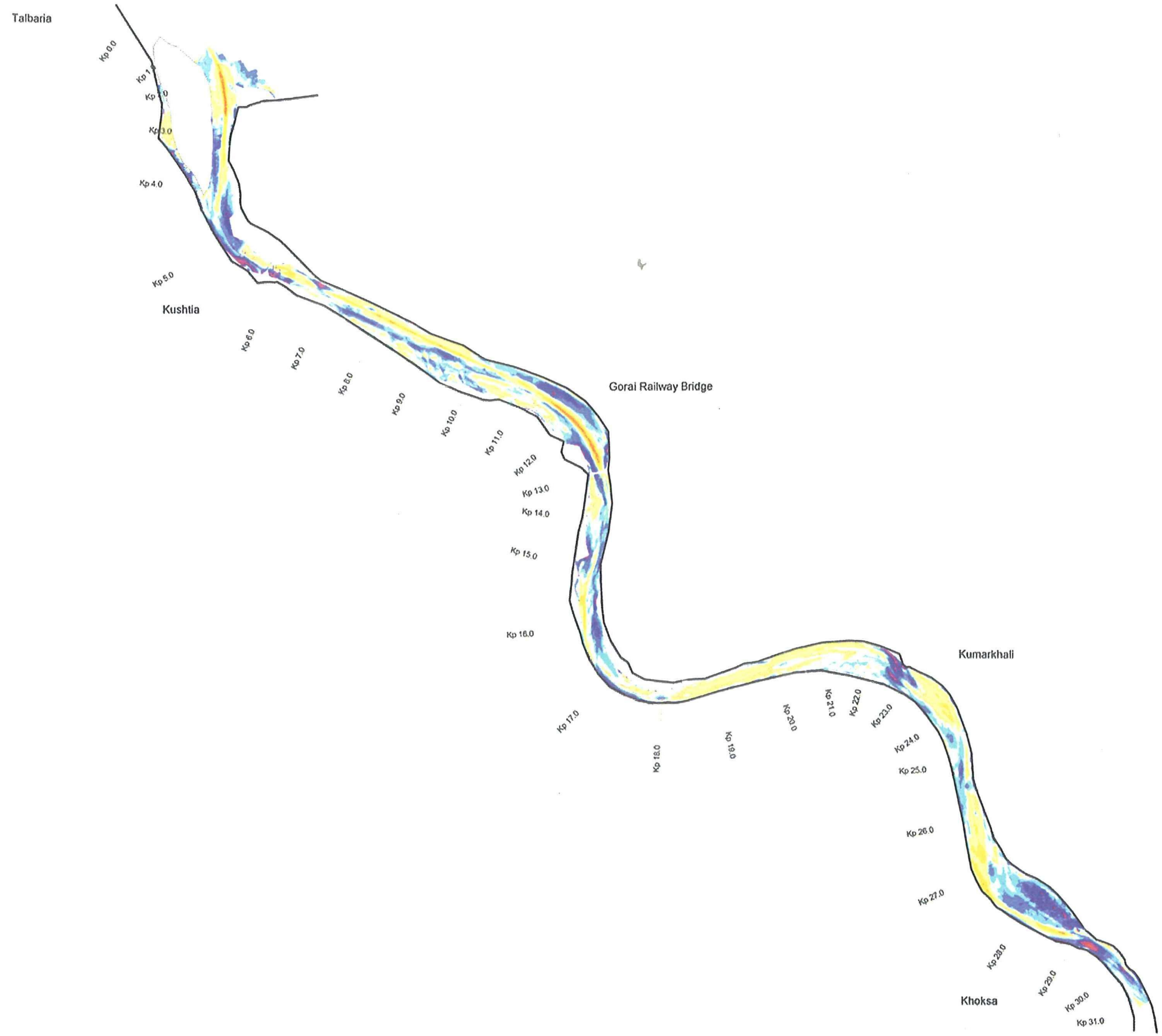
Deposition and erosion patterns

April 1999 - April 2000



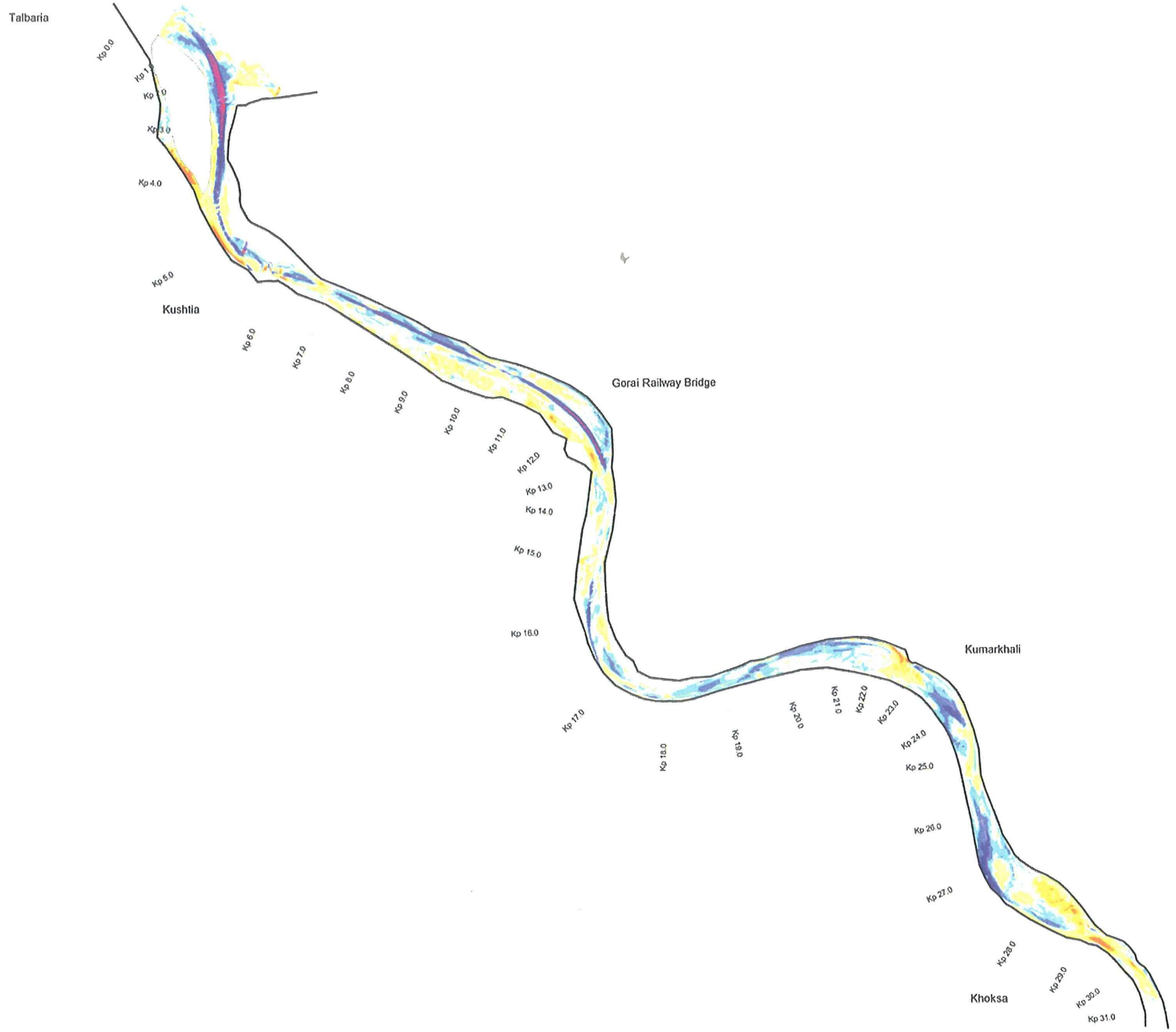
Deposition and erosion patterns

April 2000 - September 2000



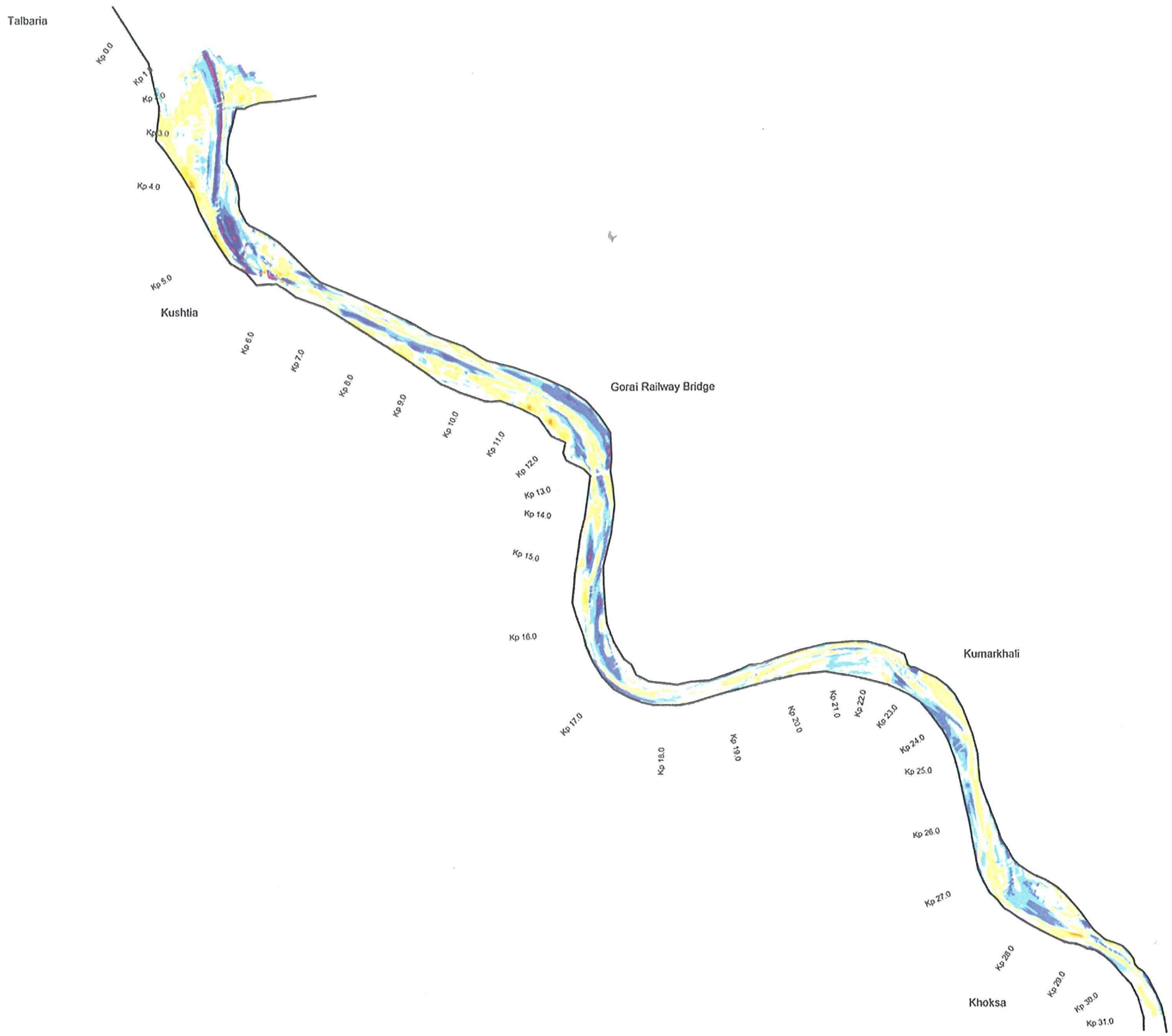
Deposition and erosion patterns

September 2000 - April 2001



Deposition and erosion patterns

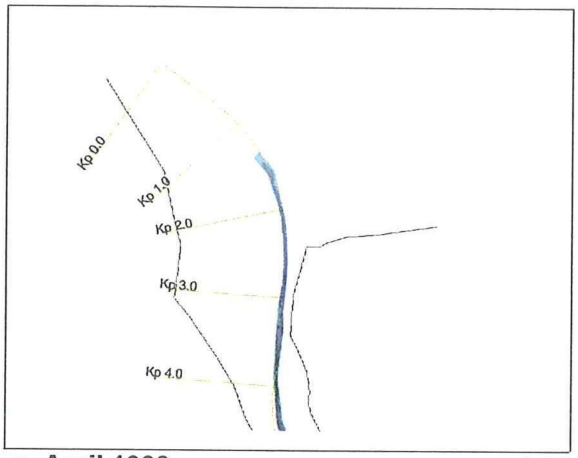
April 2000 - April 2001



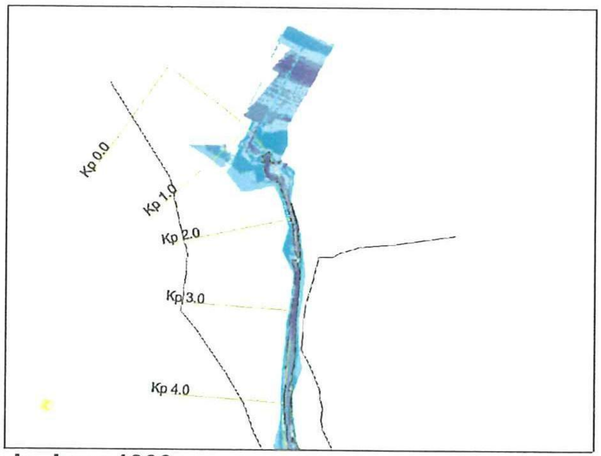
Appendix V:

Detailed Bed levels per stretch
April 1999 – January 2001

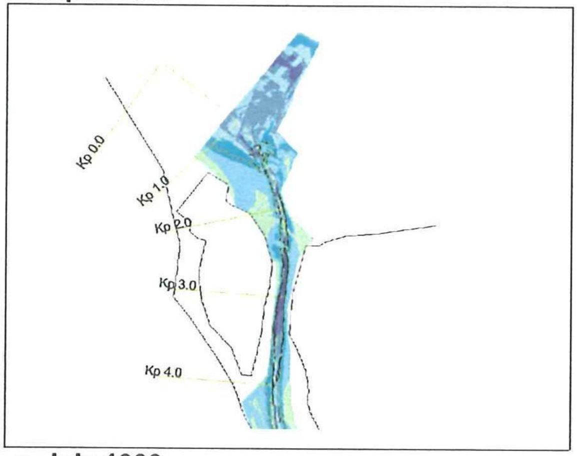
Figures V.1 a-p, off-take area, Kp 0.0-3.5, April 1999 to January 2001



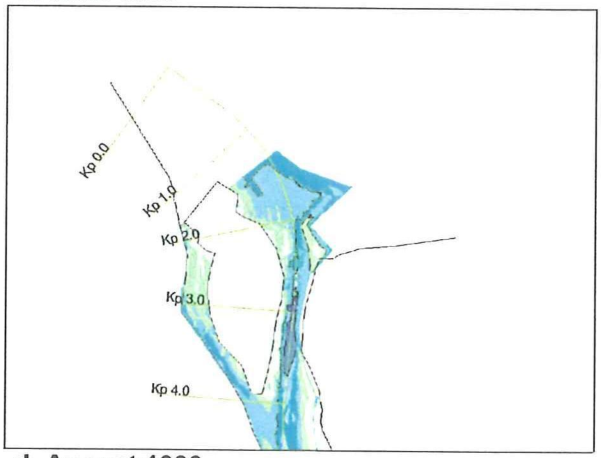
a. April 1999



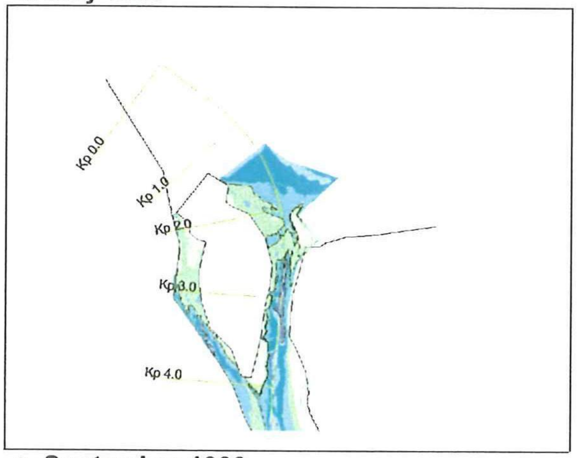
b. June 1999



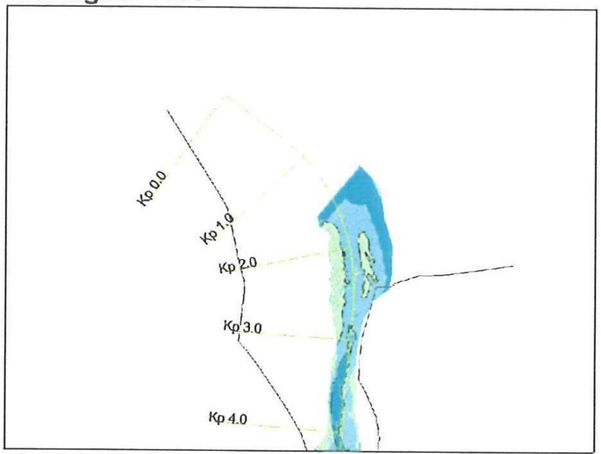
c. July 1999



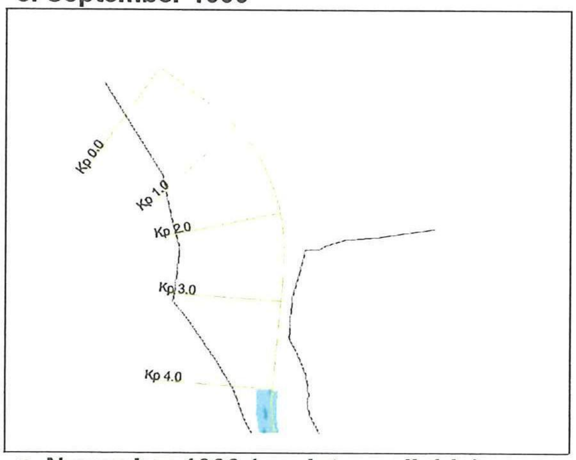
d. August 1999



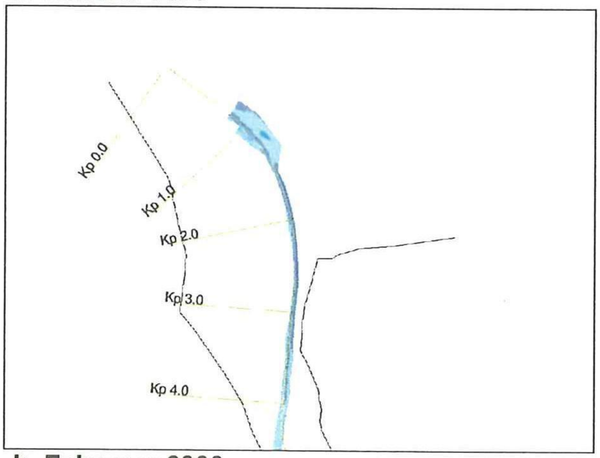
e. September 1999



f. October 1999

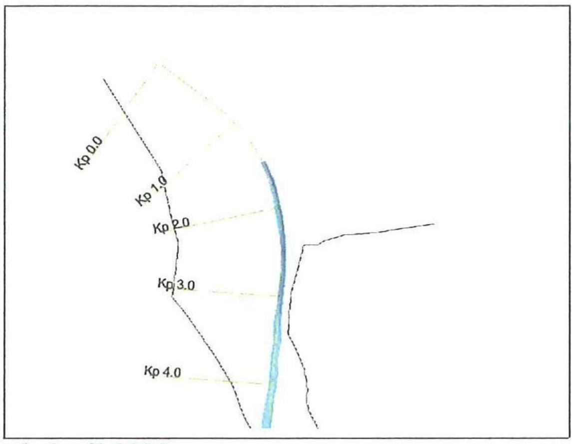


g. November 1999 (no data available)

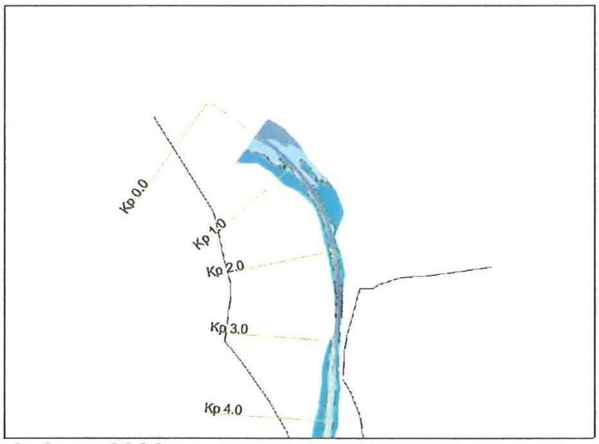


h. February 2000

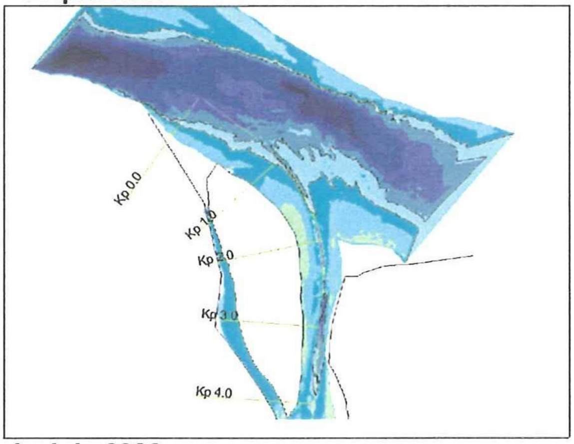
Figures V.1 a-p, off-take area, Kp 0.0-3.5 April 1999 to January 2001



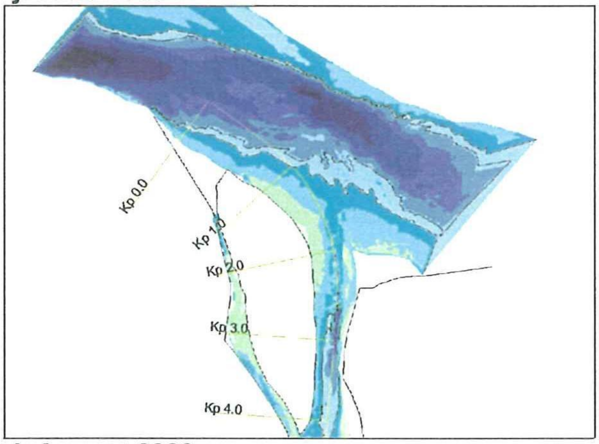
i. April 2000



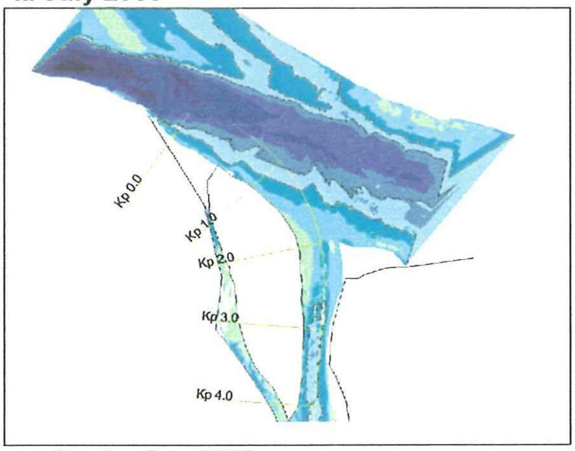
j. June 2000



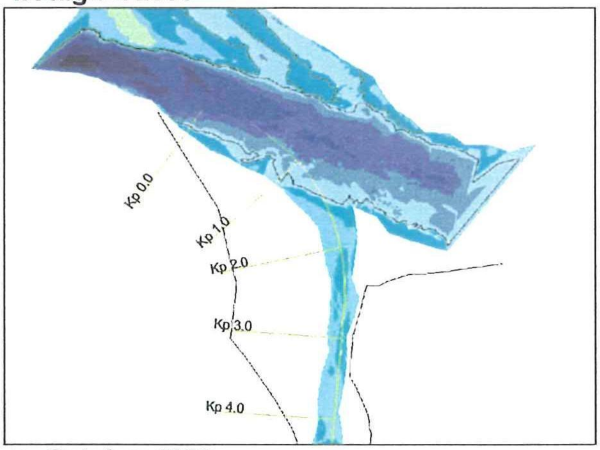
k. July 2000



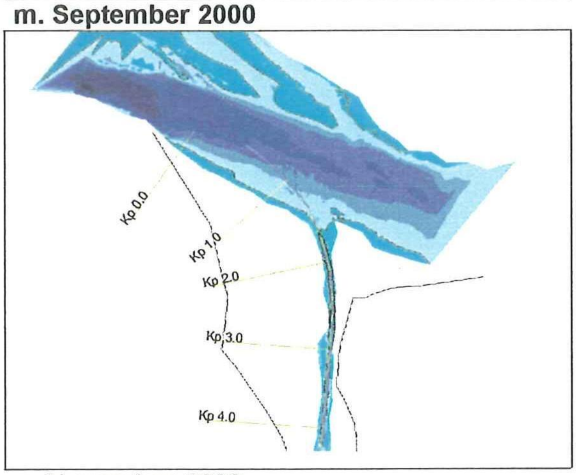
l. August 2000



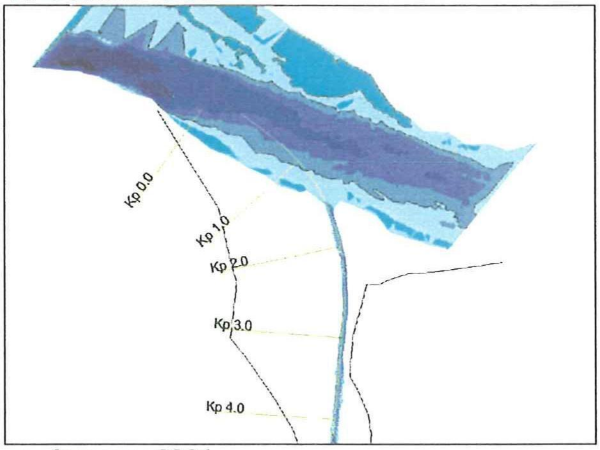
m. September 2000



n. October 2000

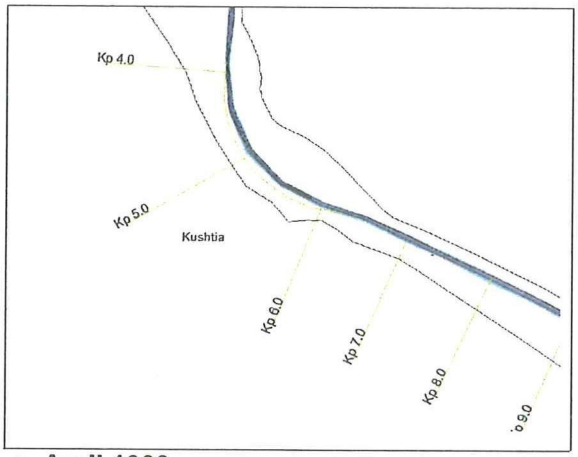


o. November 2000

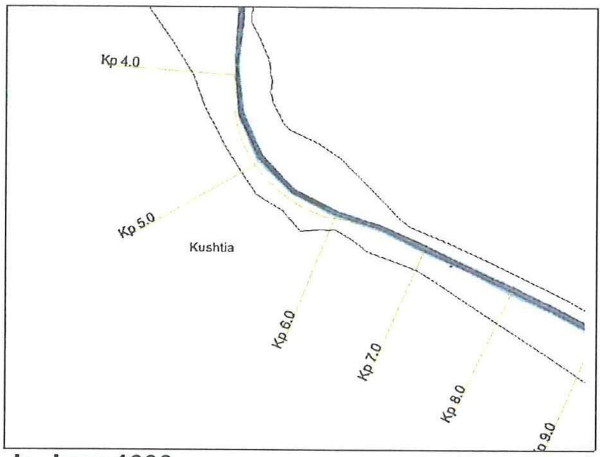


p. January 2001

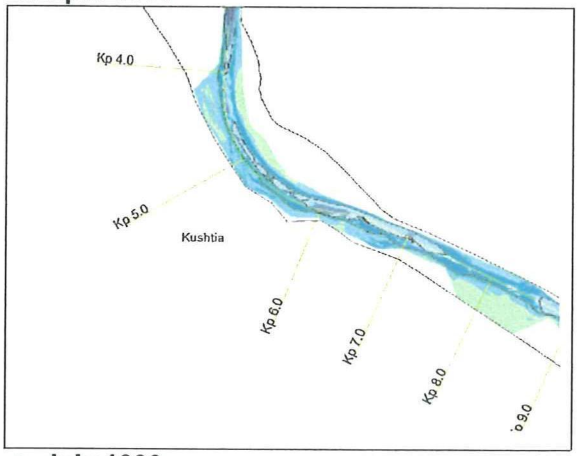
Figures V.2 a-p, Kushtia, Kp 3.5-7.0, April 1999 to January 2001



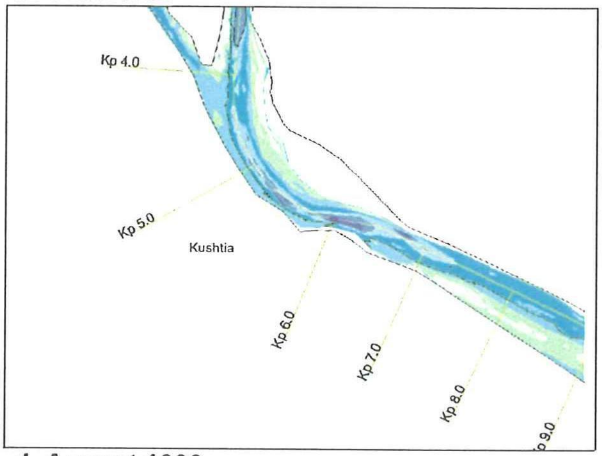
a. April 1999



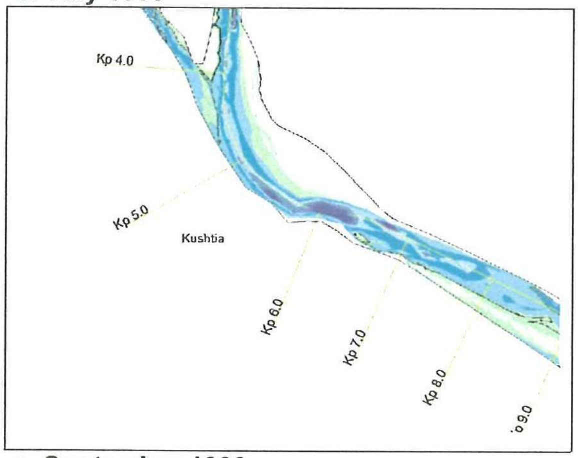
b. June 1999



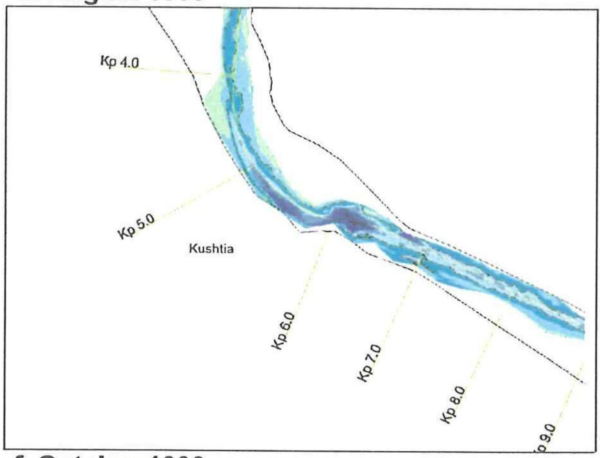
c. July 1999



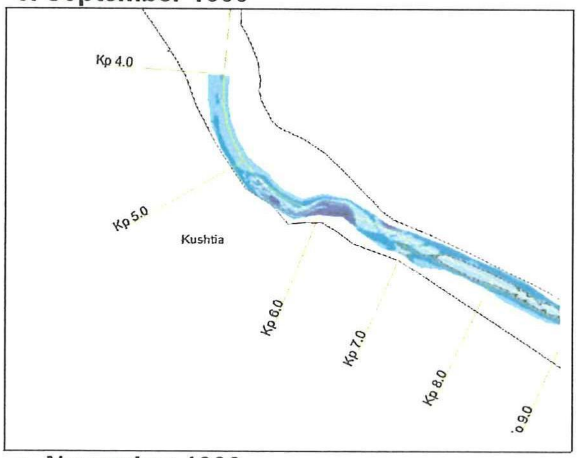
d. August 1999



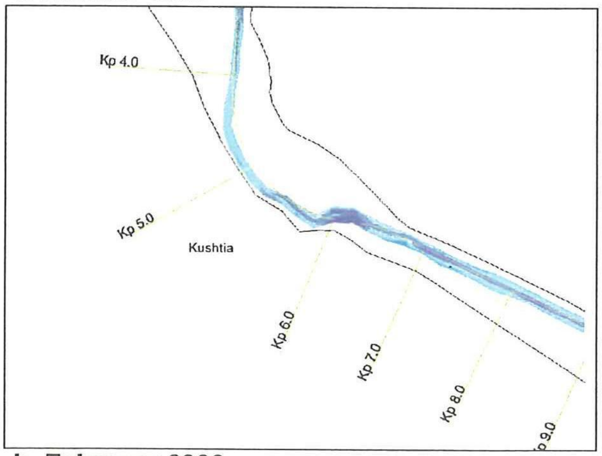
e. September 1999



f. October 1999

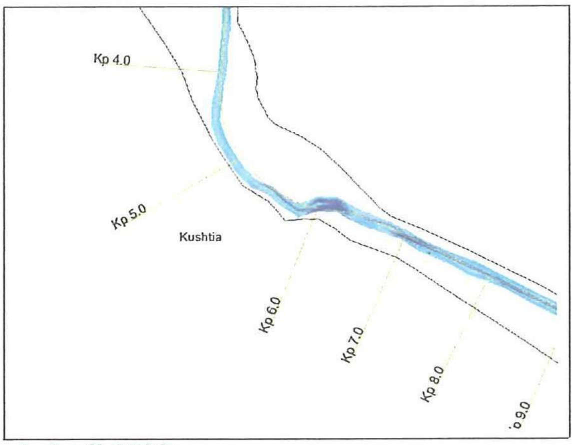


g. November 1999

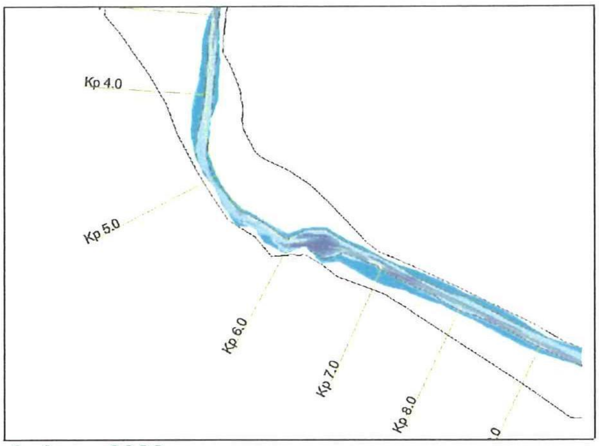


h. February 2000

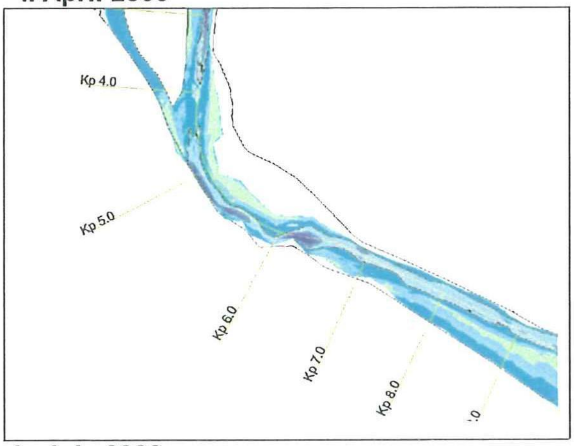
Figures V.2 a-p, Kushtia, Kp 3.5-7.0, April 1999 to January 2001



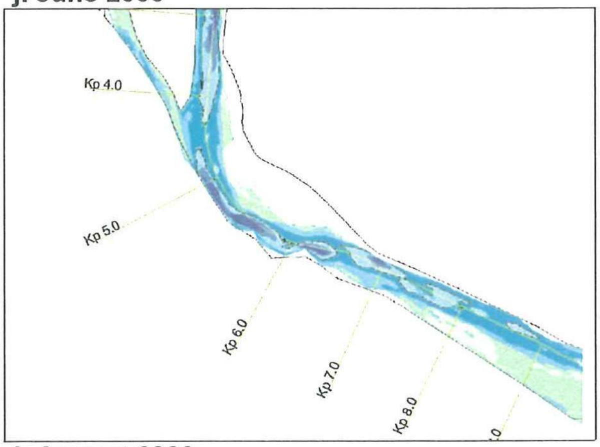
i. April 2000



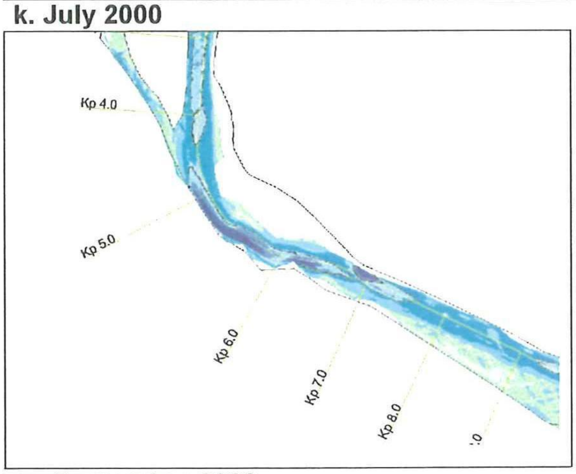
j. June 2000



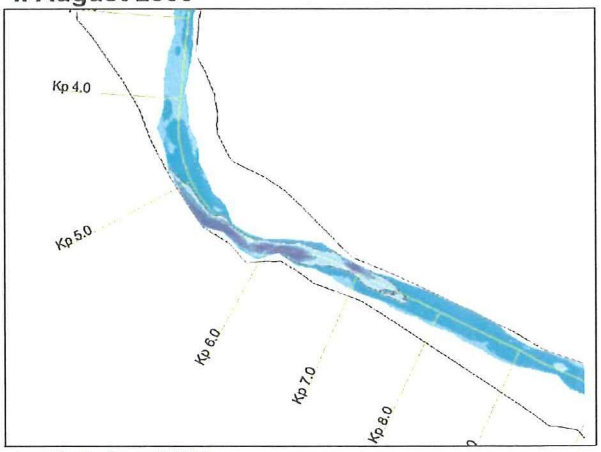
k. July 2000



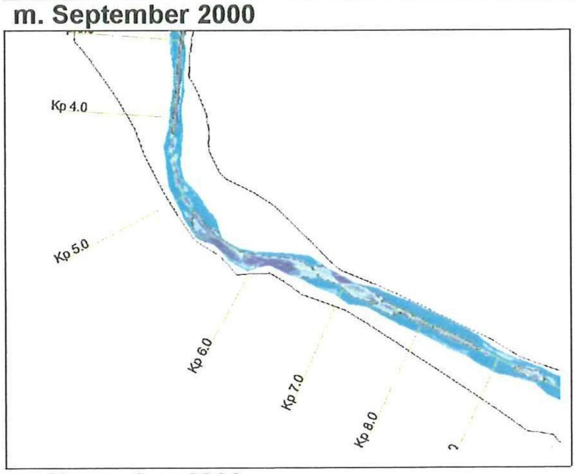
l. August 2000



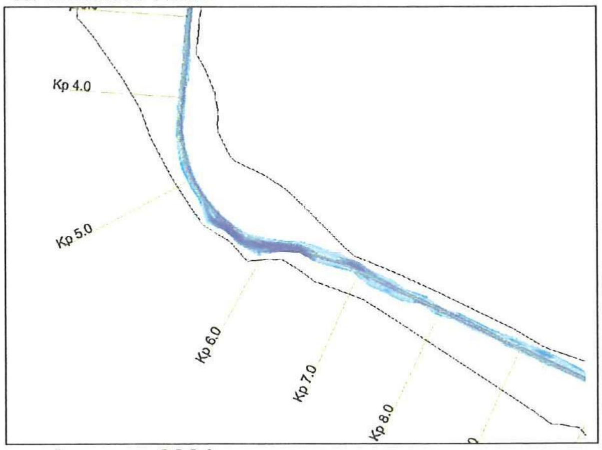
m. September 2000



n. October 2000

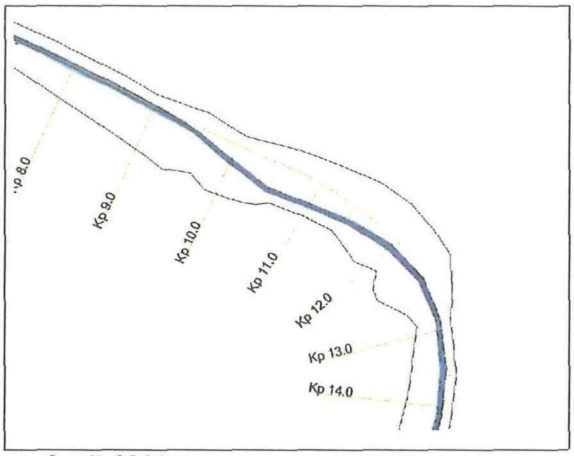


o. November 2000

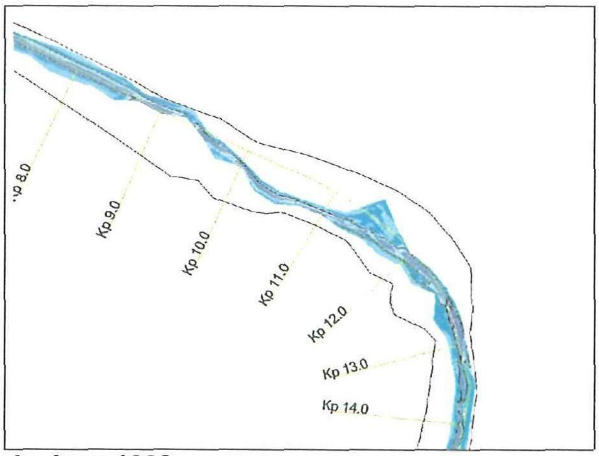


p. January 2001

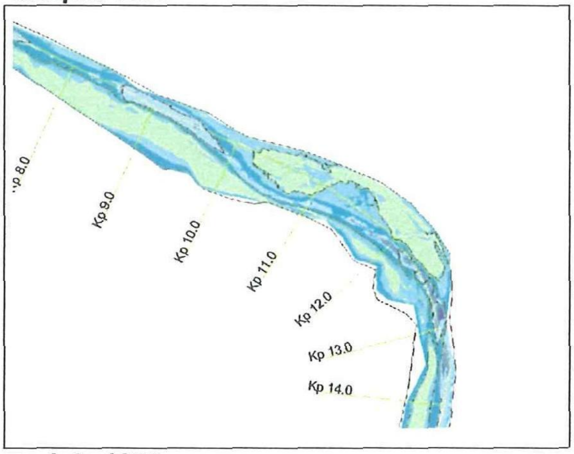
Figures V.3 a-p, Straight stretch and upstream GRB, Kp 7.0-13.0, April 1999 to January 2001



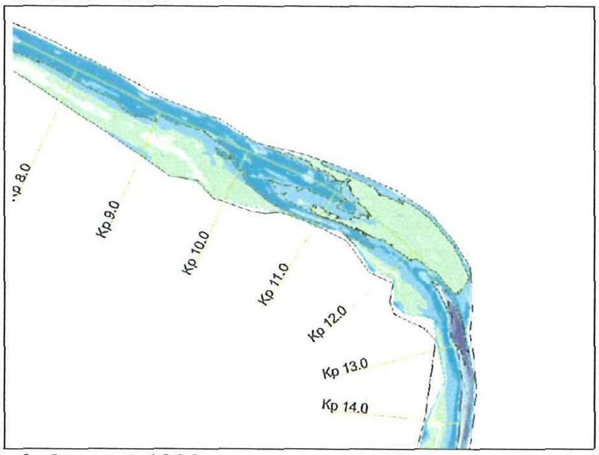
a. April 1999



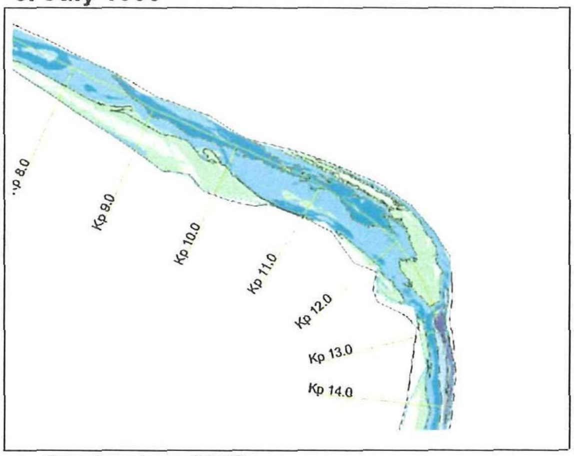
b. June 1999



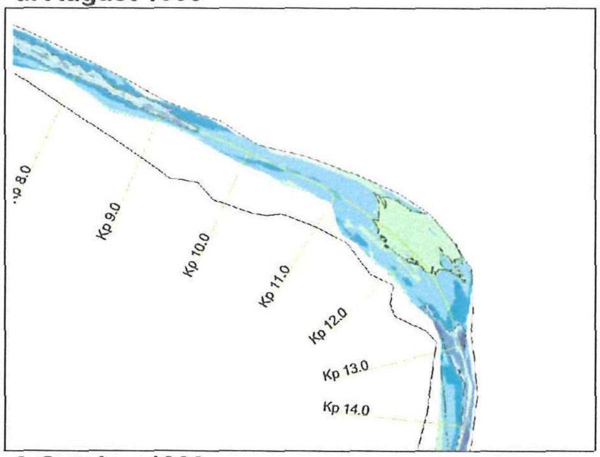
c. July 1999



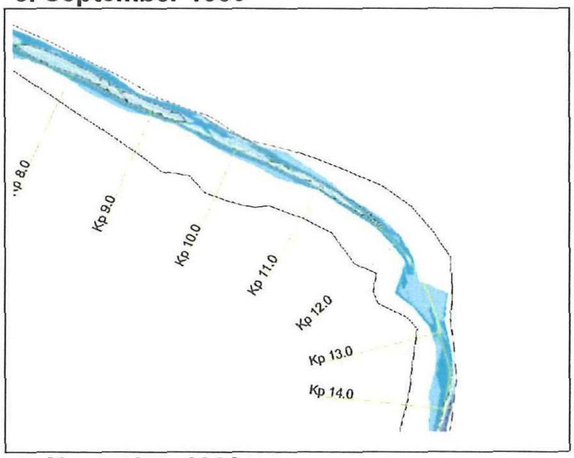
d. August 1999



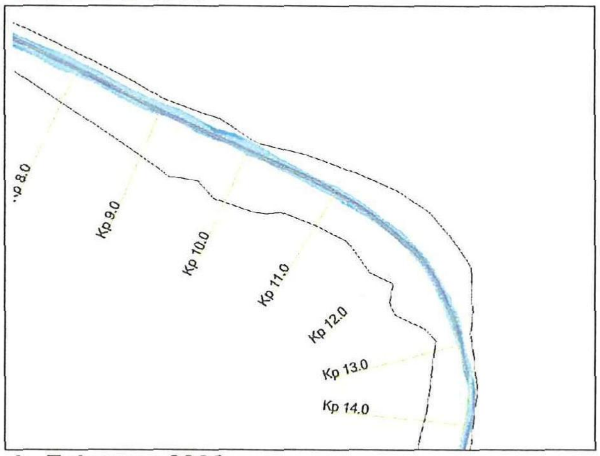
e. September 1999



f. October 1999

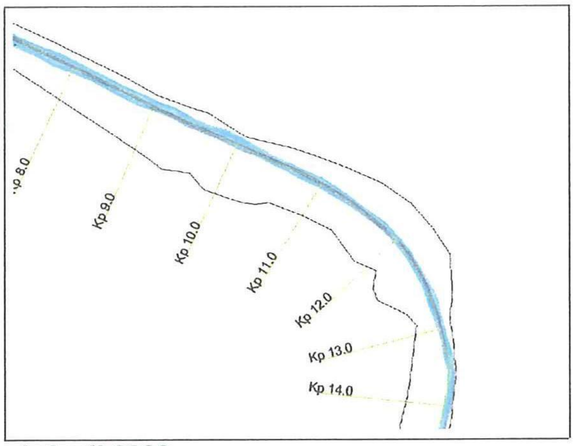


g. November 1999

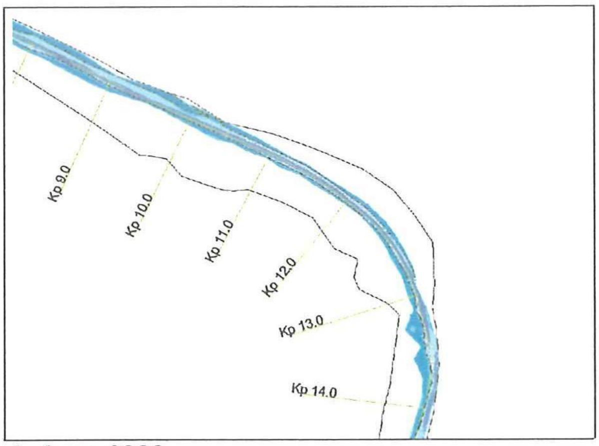


h. February 2000

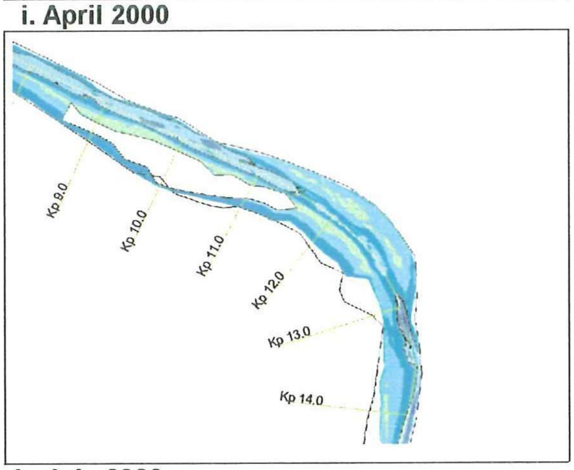
Figures V.3 a-p, Straight stretch and upstream GRB, 7.0-13.0, April 1999 to January 2001



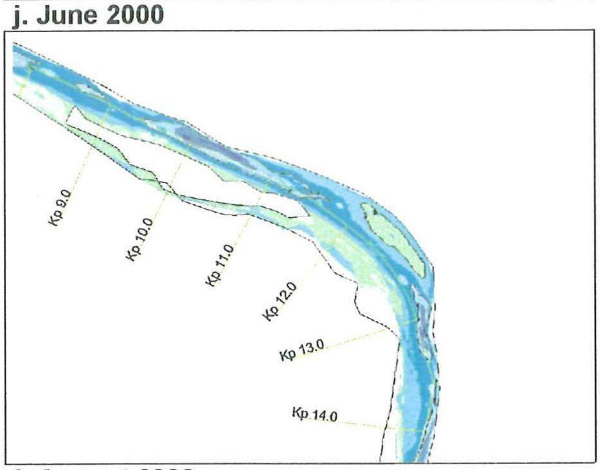
i. April 2000



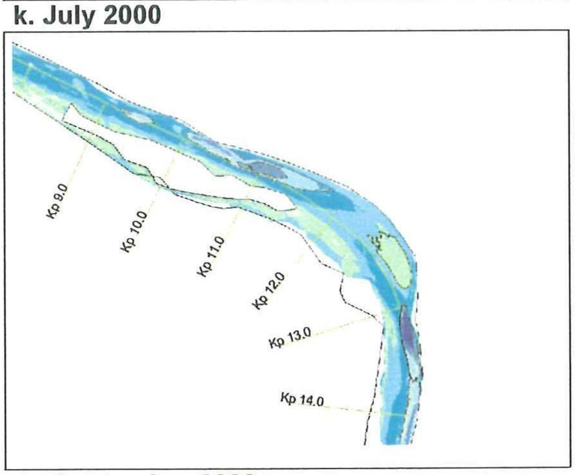
j. June 2000



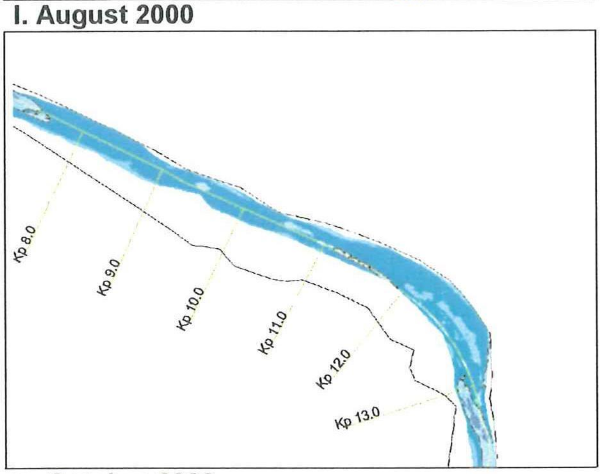
k. July 2000



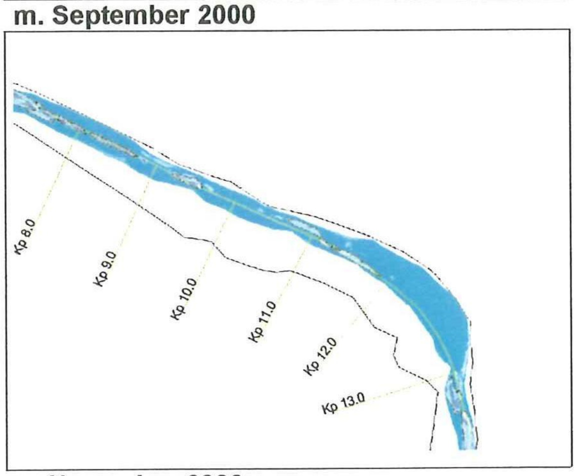
l. August 2000



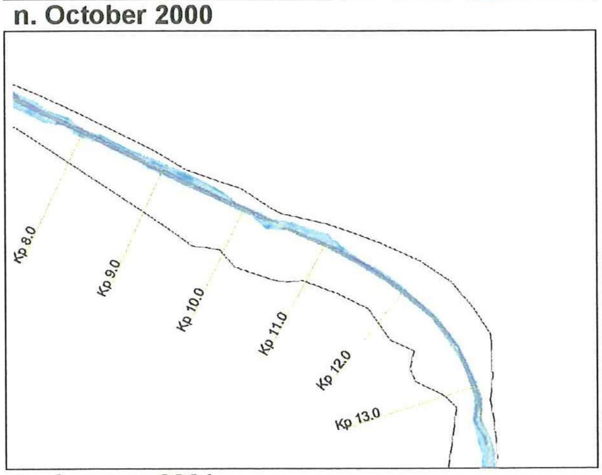
m. September 2000



n. October 2000

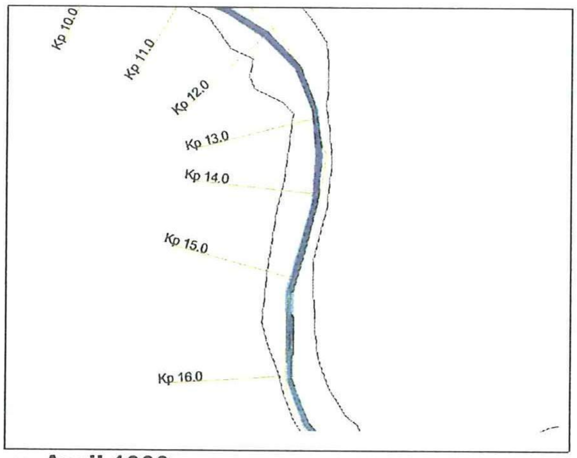


o. November 2000

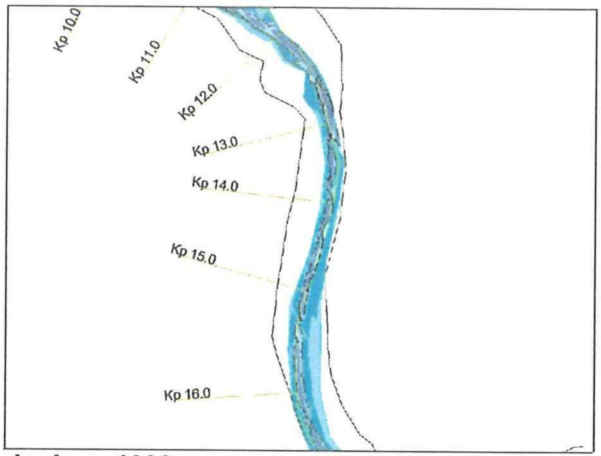


p. January 2001

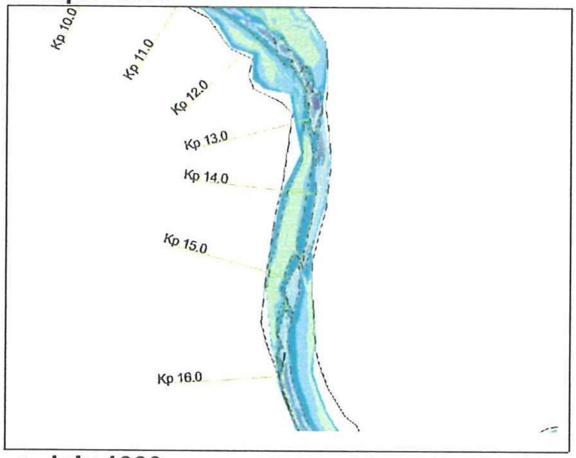
Figures V.4 a-p, Downstream GRB, Kp 13.0-17.0, April 1999 to January 2001



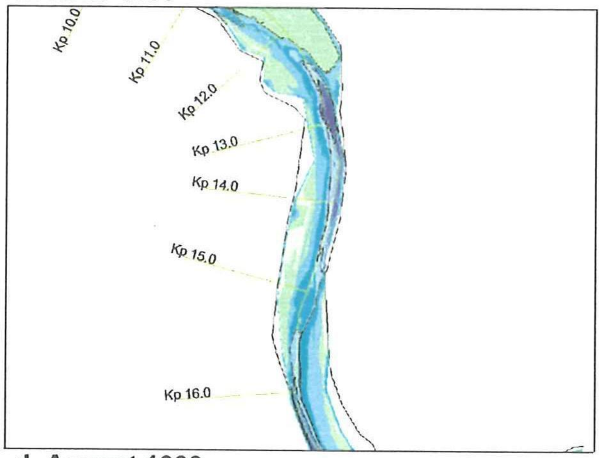
a. April 1999



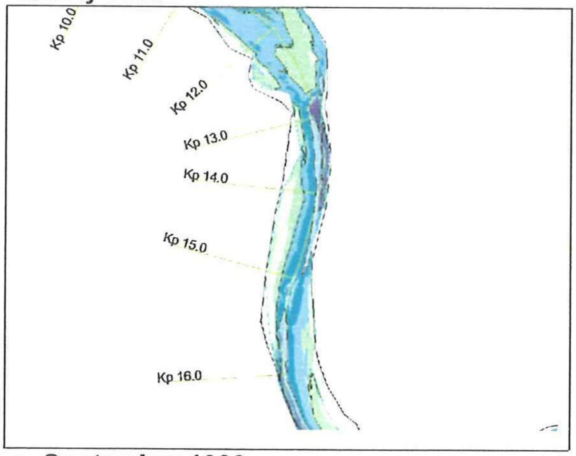
b. June 1999



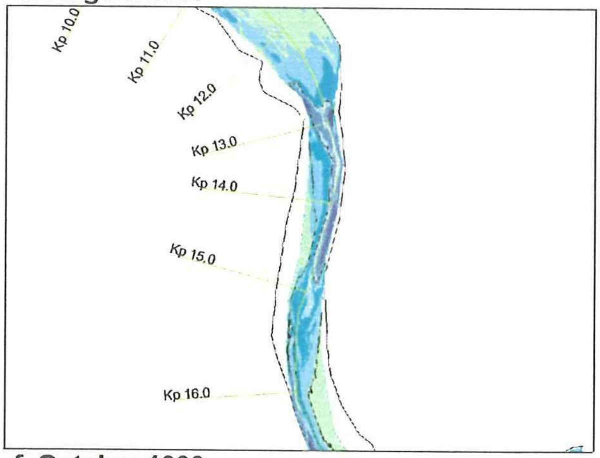
c. July 1999



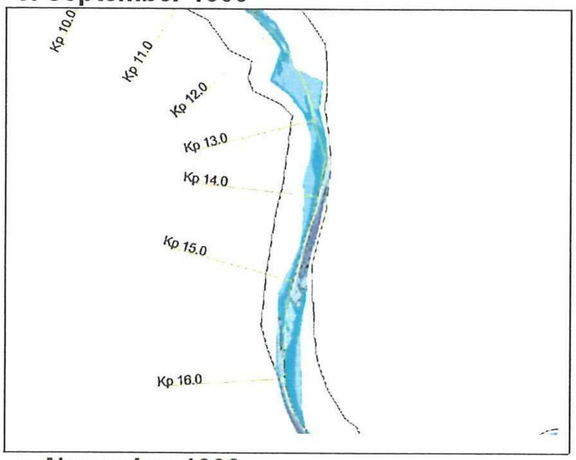
d. August 1999



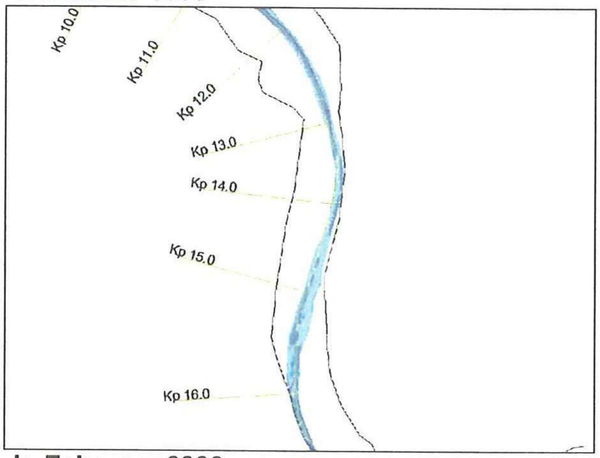
e. September 1999



f. October 1999

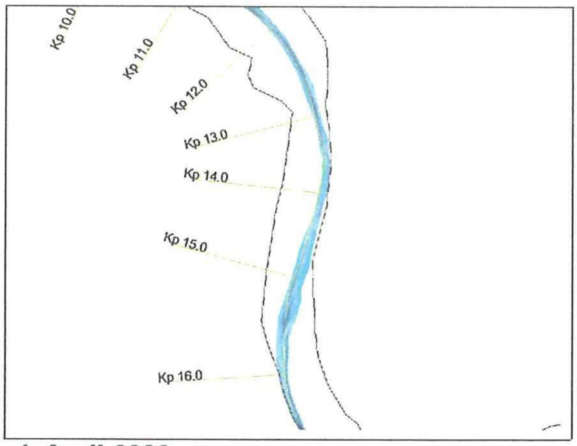


g. November 1999

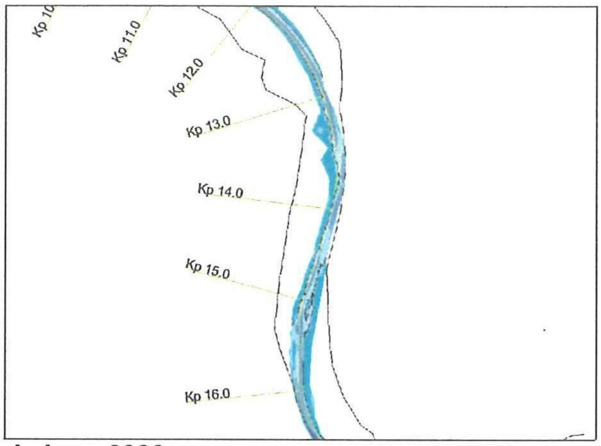


h. February 2000

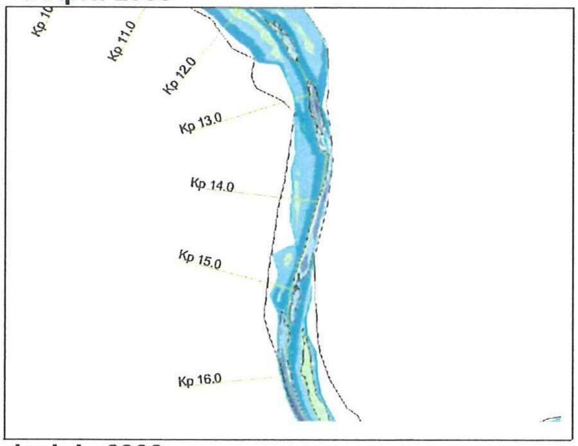
Figures V.4 a-p, Downstream GRB, 13.0-17.0, April 1999 to January 2001



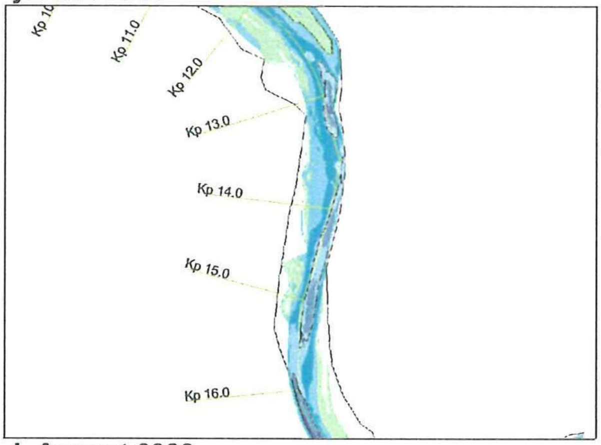
i. April 2000



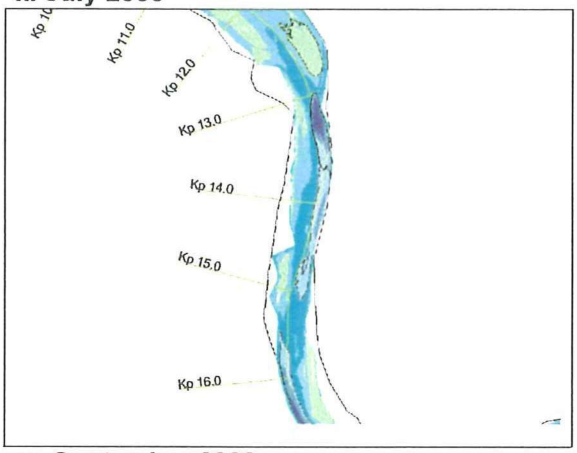
j. June 2000



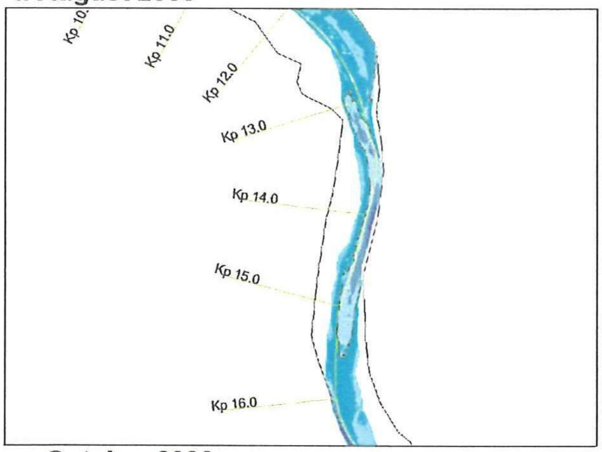
k. July 2000



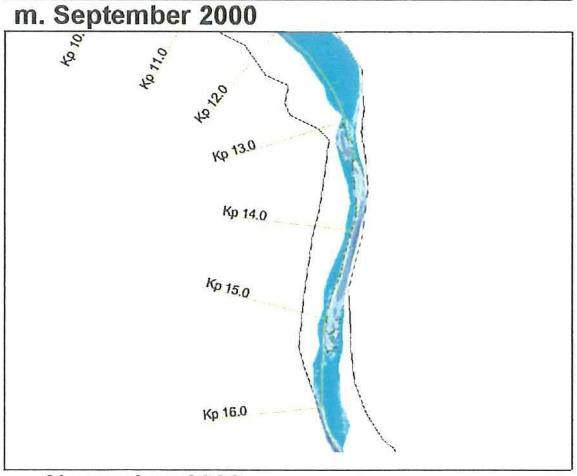
l. August 2000



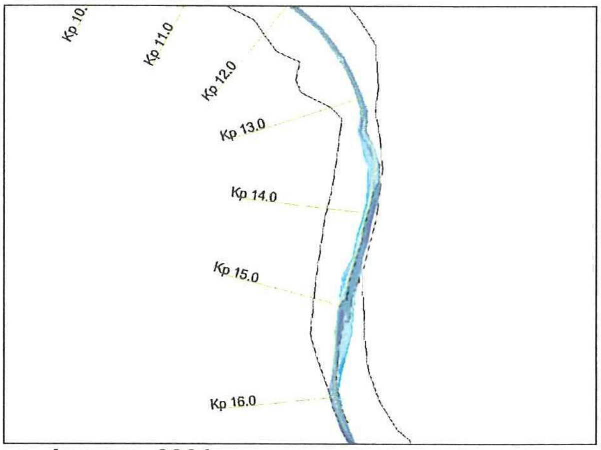
m. September 2000



n. October 2000

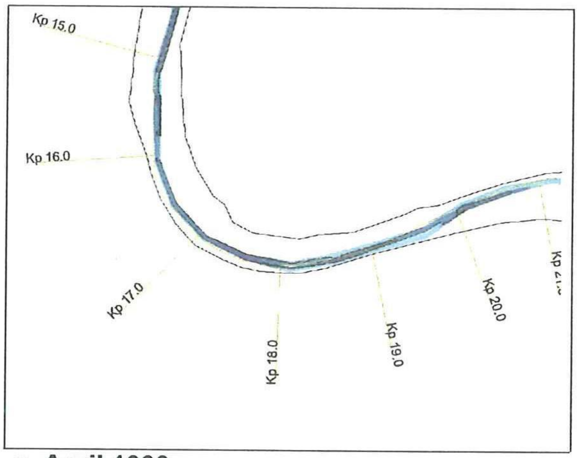


o. November 2000

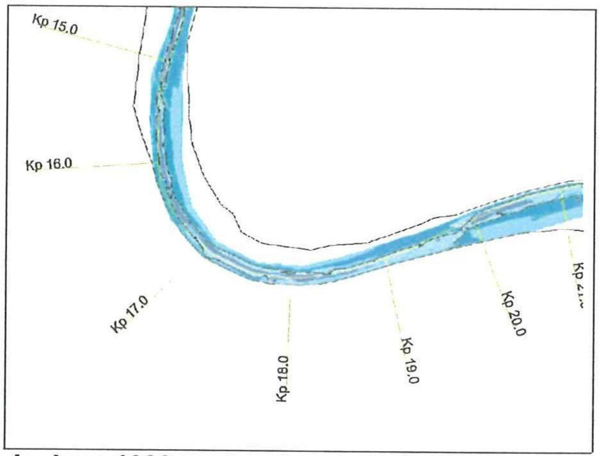


p. January 2001

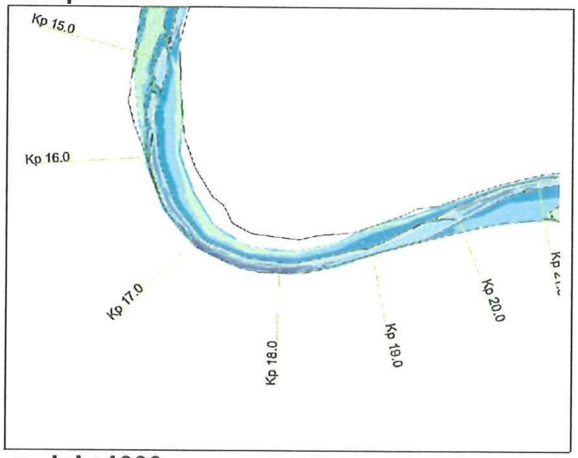
Figures V.5 a-p, Downstream Kumarkhali, Kp 17.0-20.5, April 1999 to January 2001



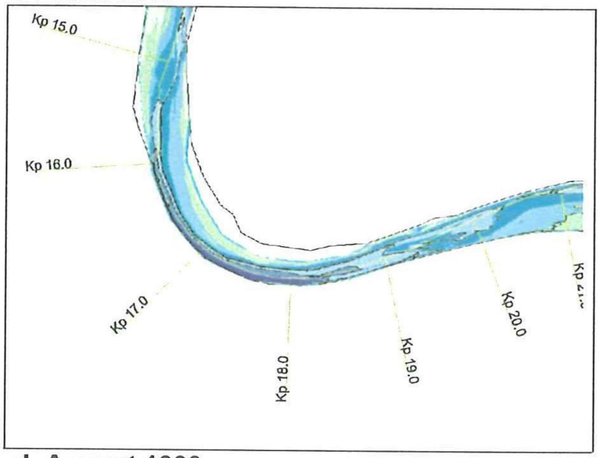
a. April 1999



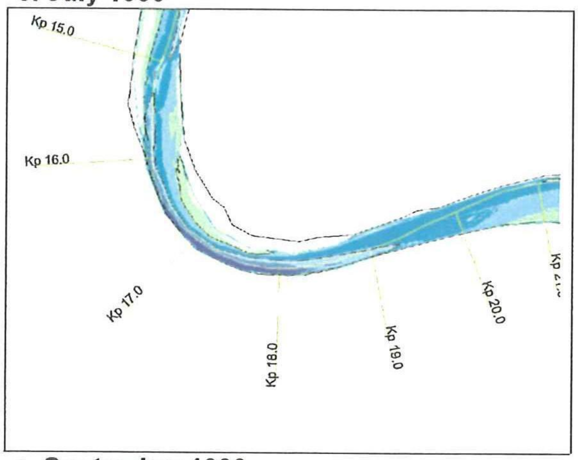
b. June 1999



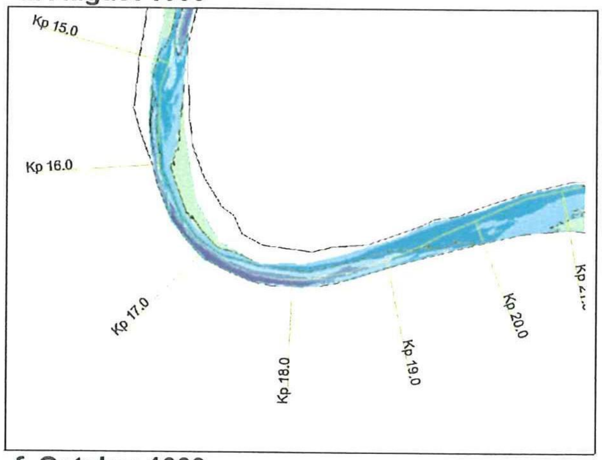
c. July 1999



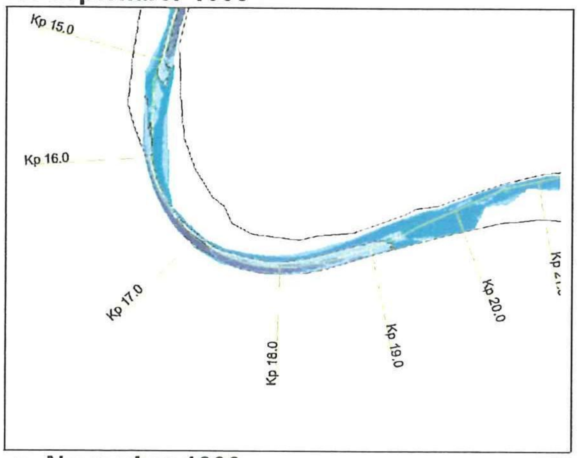
d. August 1999



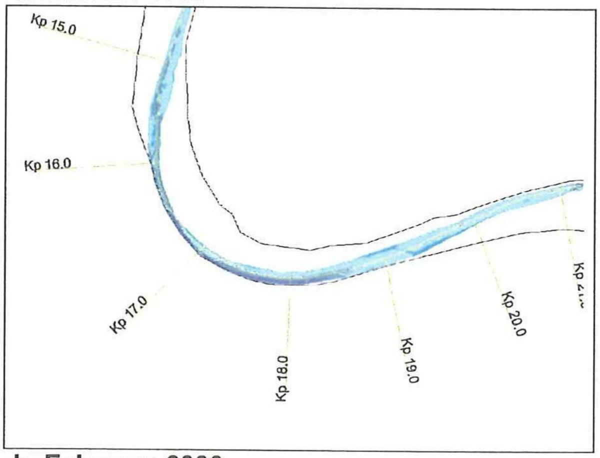
e. September 1999



f. October 1999

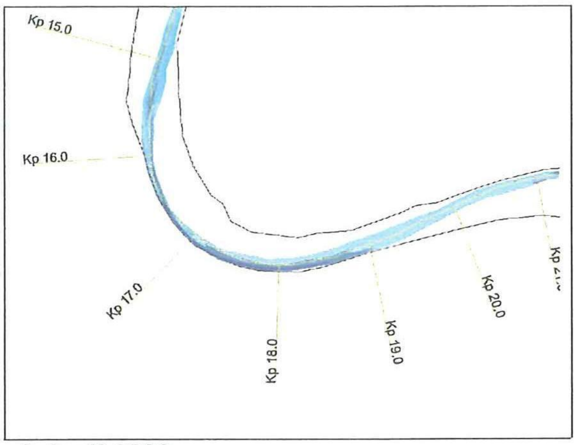


g. November 1999

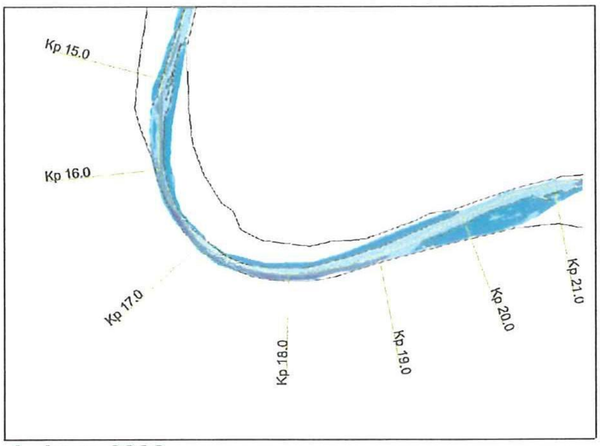


h. February 2000

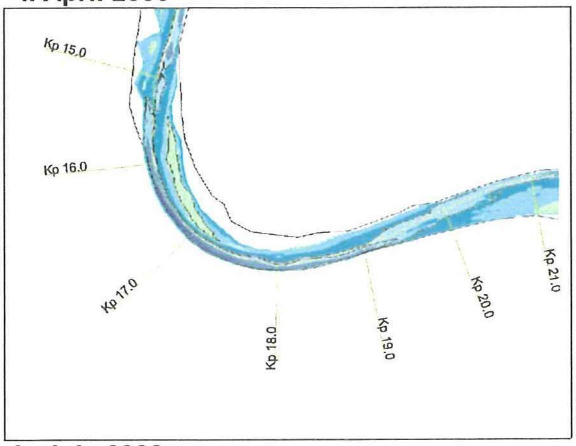
Figures V.5 a-p, Downstream Kumarkhali, 17.0-20.5, April 1999 to January 2001



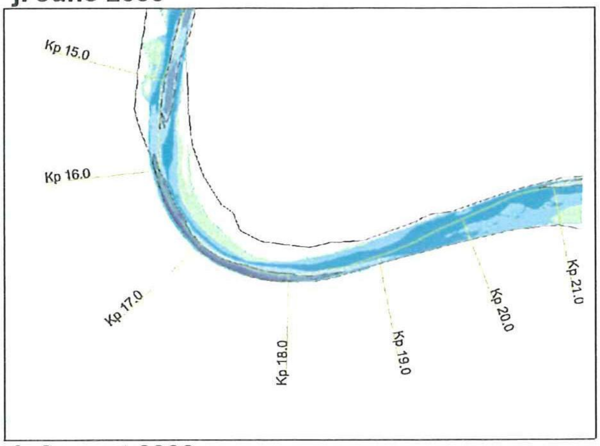
i. April 2000



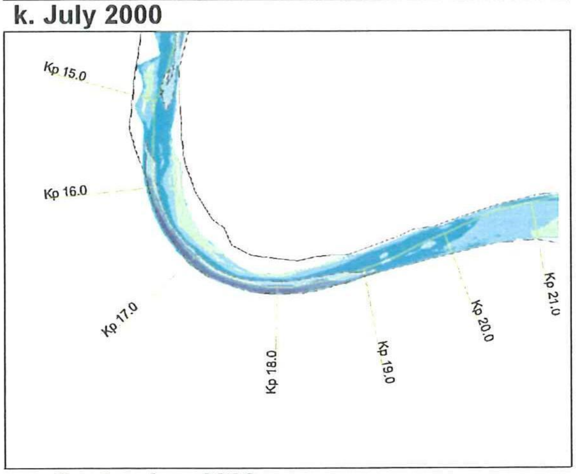
j. June 2000



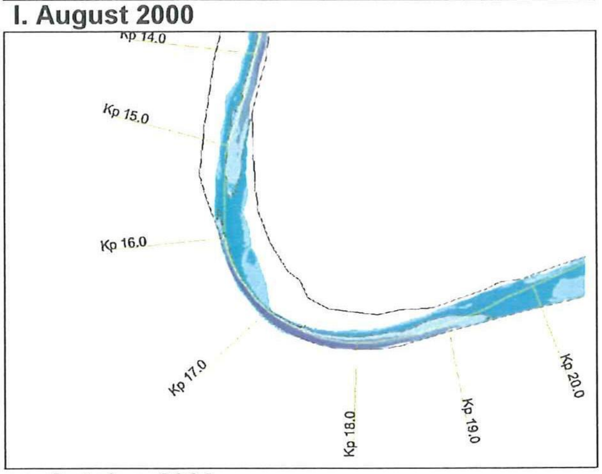
k. July 2000



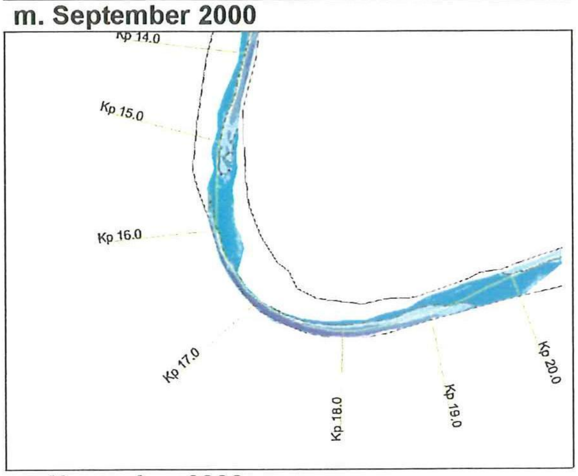
l. August 2000



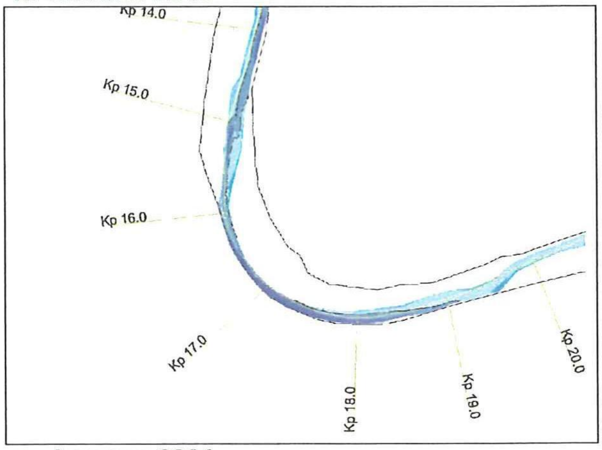
m. September 2000



n. October 2000

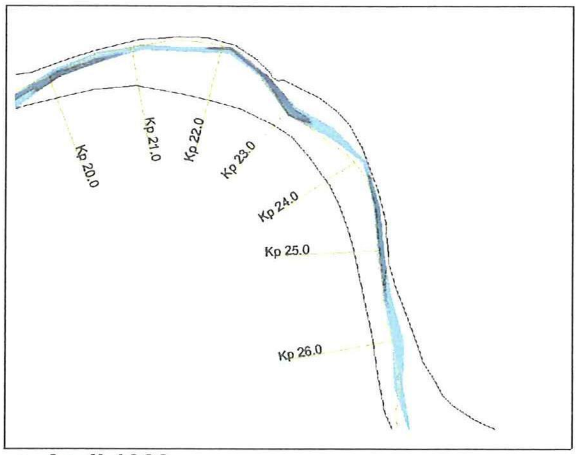


o. November 2000

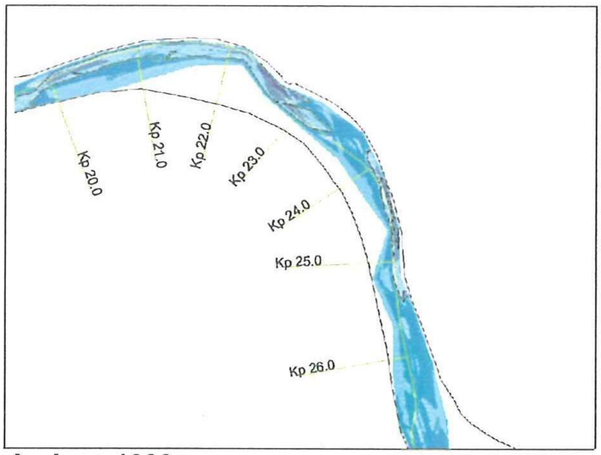


p. January 2001

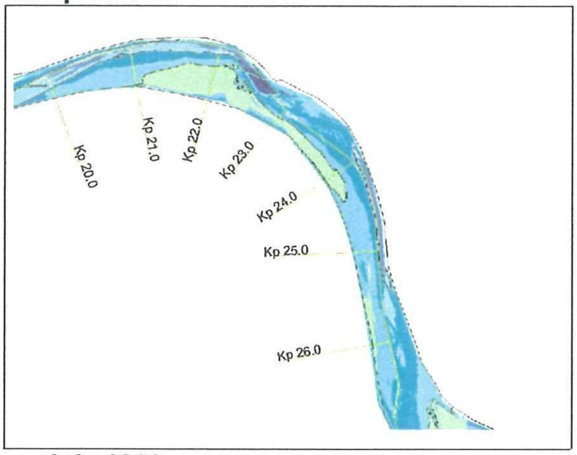
Figures V.6 a-p, Kumarkhali, Kp 20.5-26.0, April 1999 to January 2001



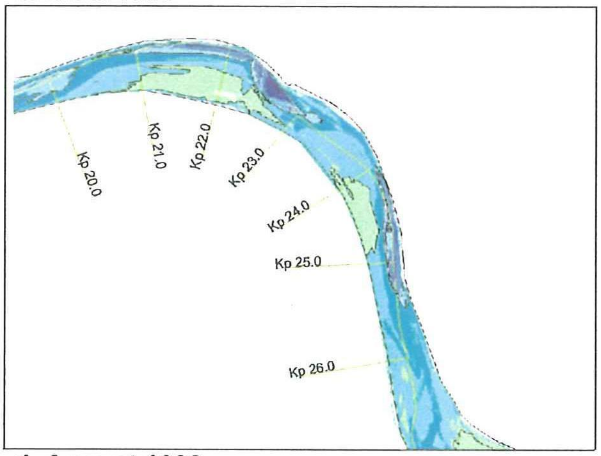
a. April 1999



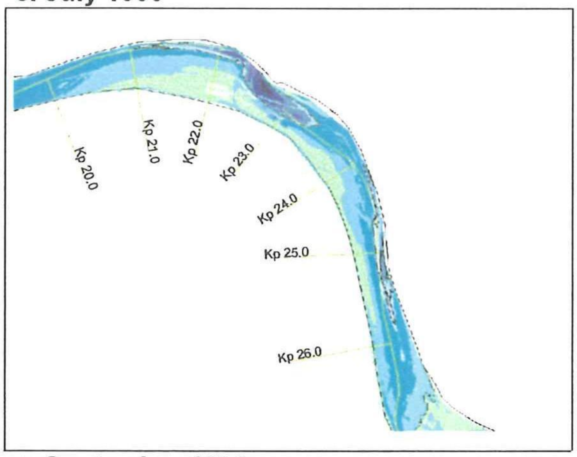
b. June 1999



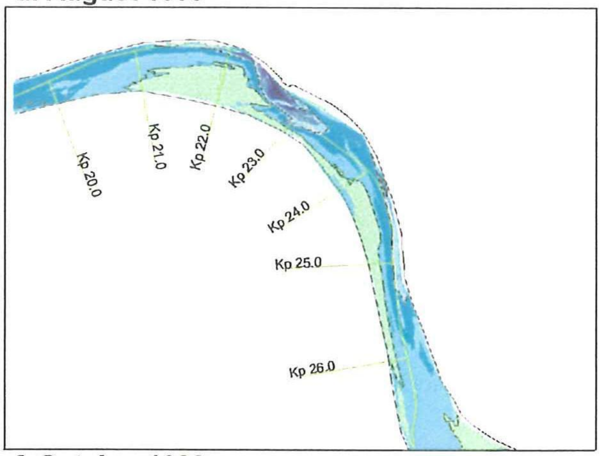
c. July 1999



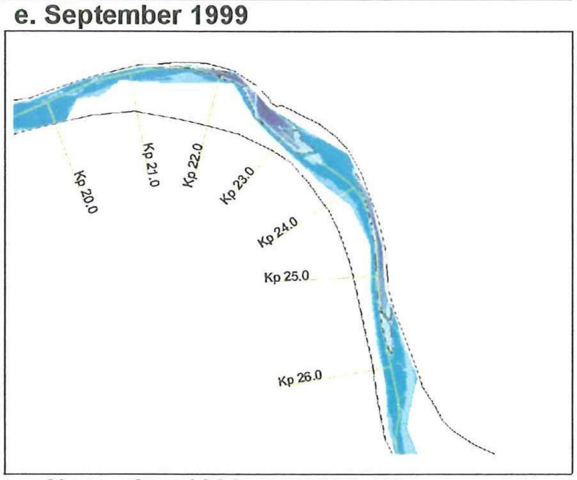
d. August 1999



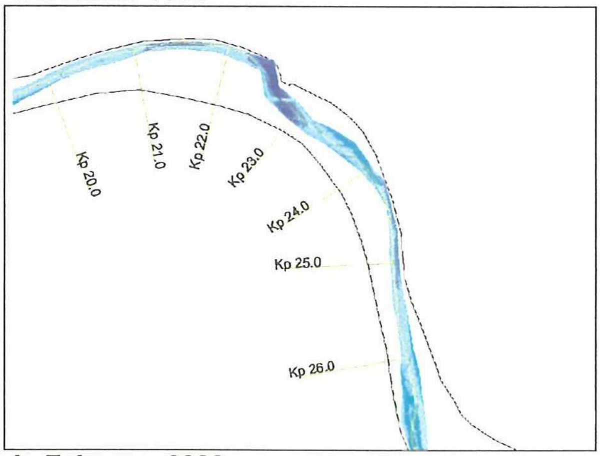
e. September 1999



f. October 1999

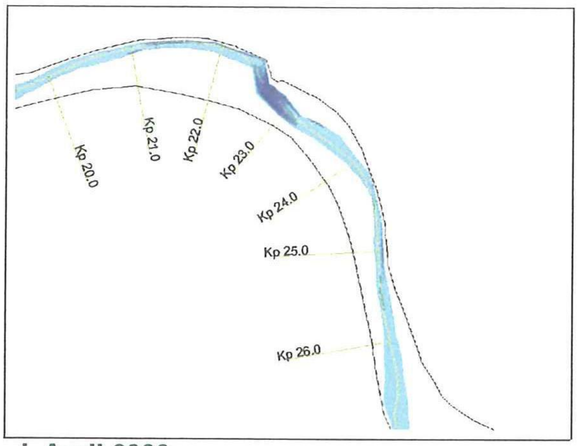


g. November 1999

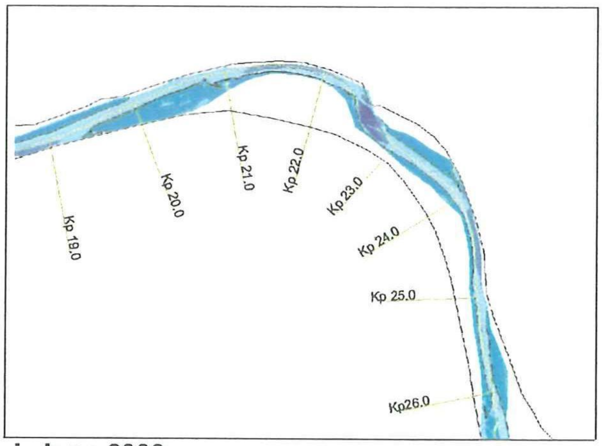


h. February 2000

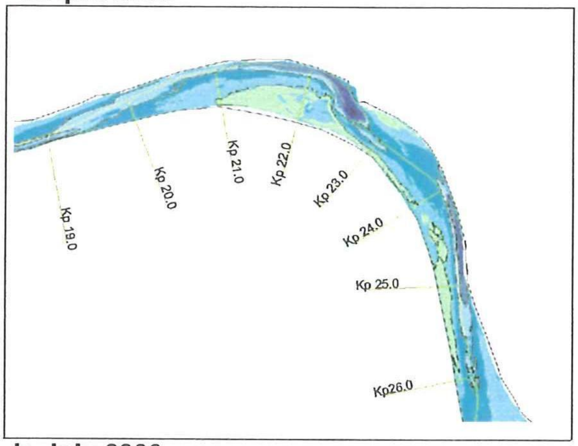
Figures V.6 a-p, Kumarkhali, 20.5-26.0, April 1999 to January 2001



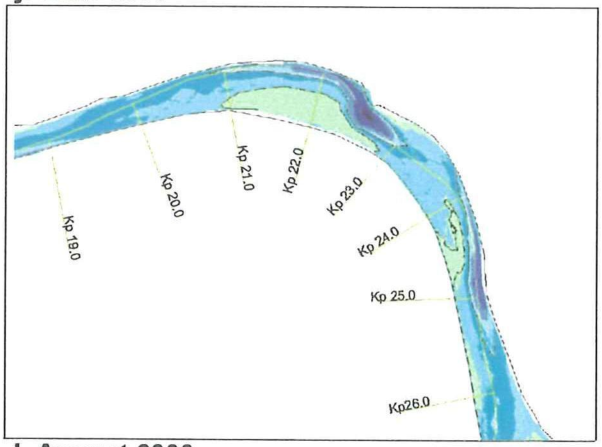
i. April 2000



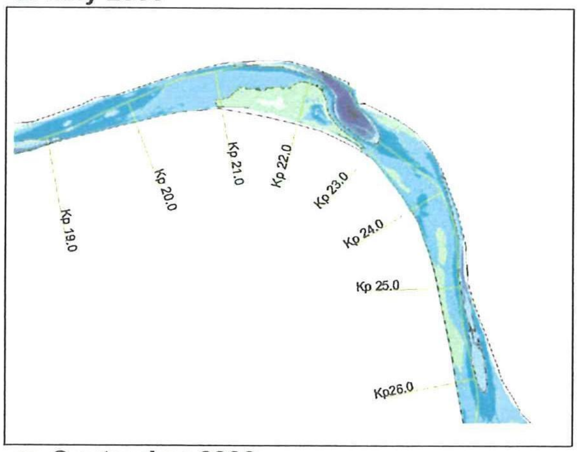
j. June 2000



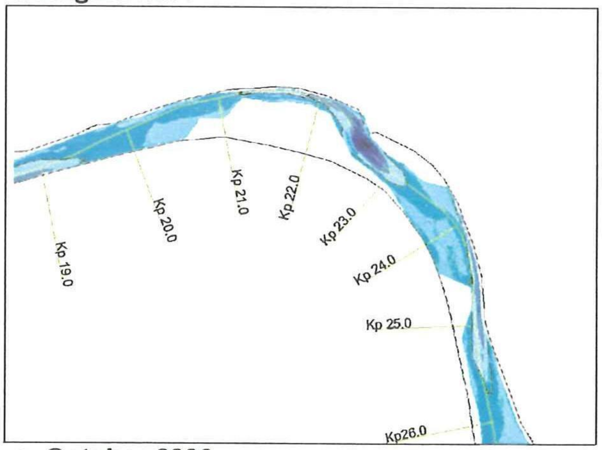
k. July 2000



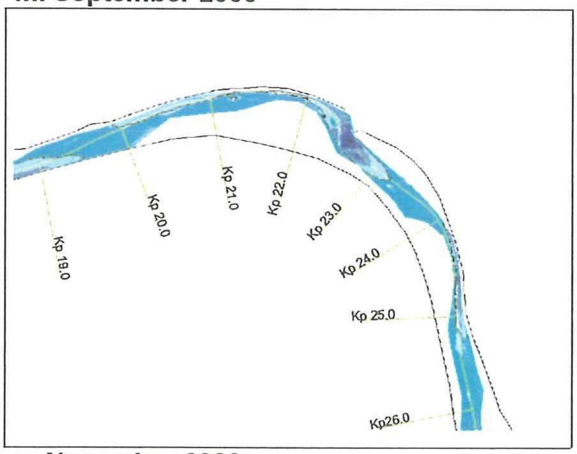
l. August 2000



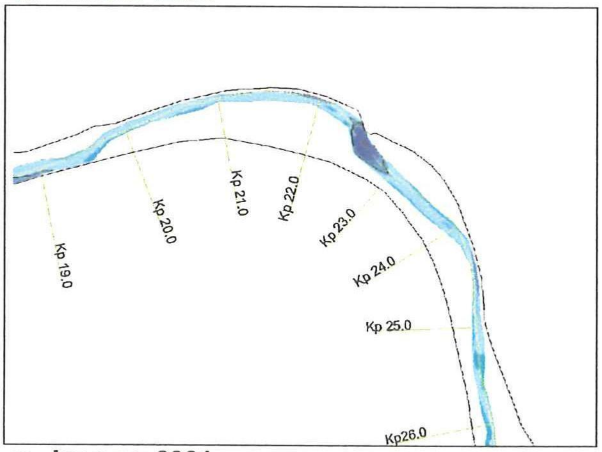
m. September 2000



n. October 2000

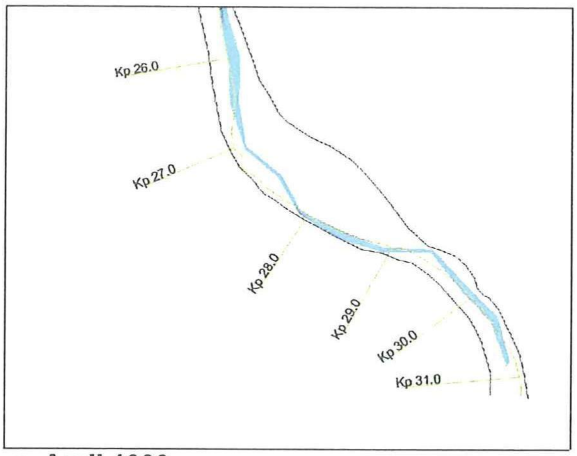


o. November 2000

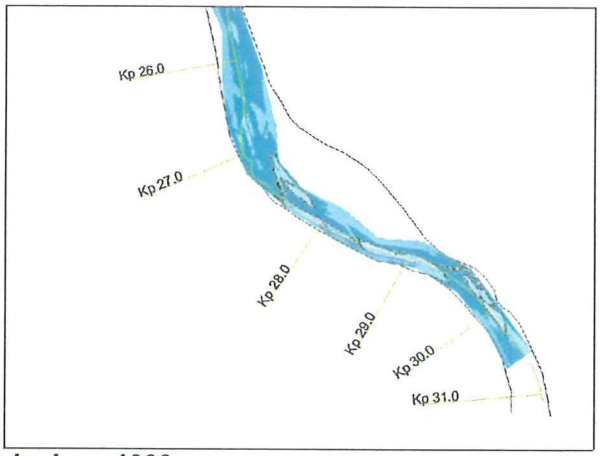


p. January 2001

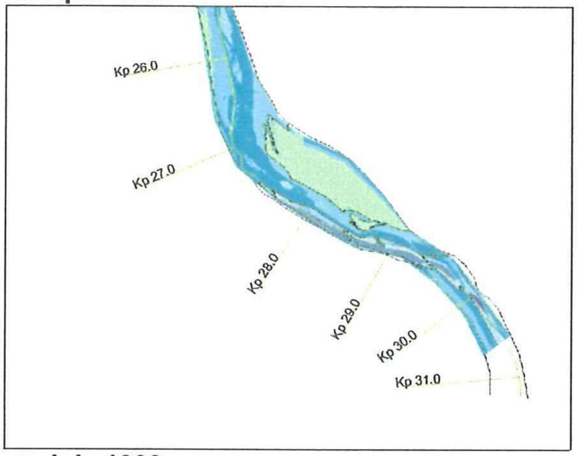
Figures V.7 a-p, Khoksa, Kp 26.0-31.0, April 1999 to January 2001



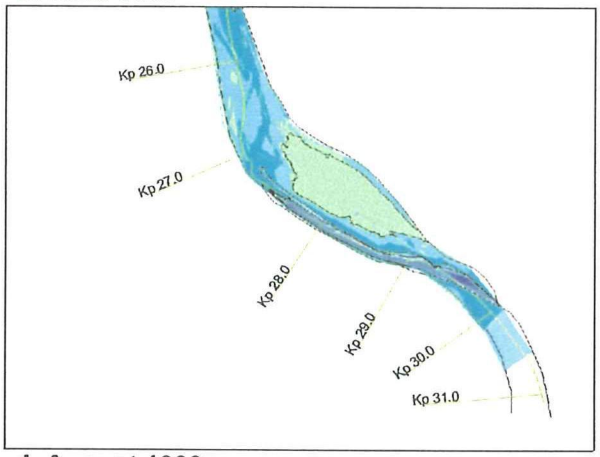
a. April 1999



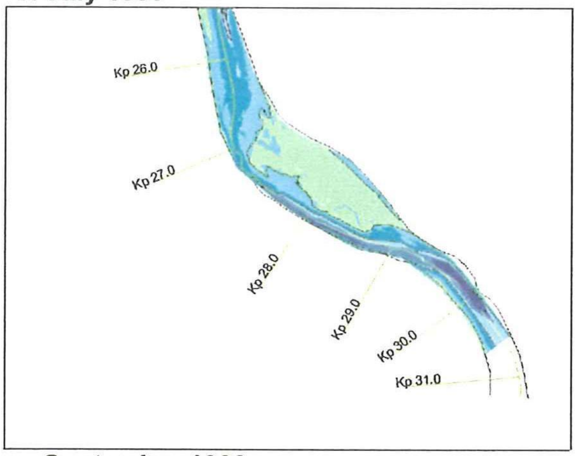
b. June 1999



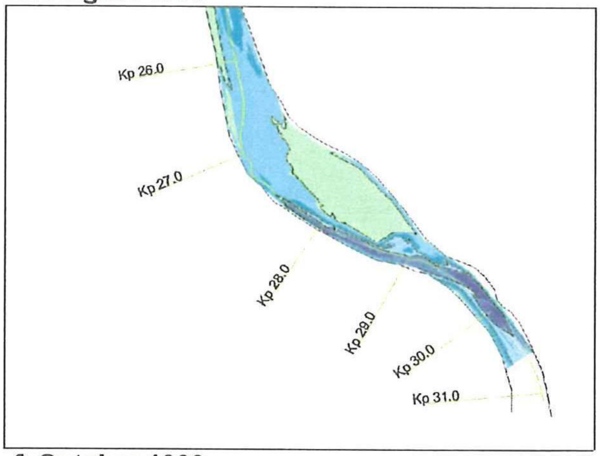
c. July 1999



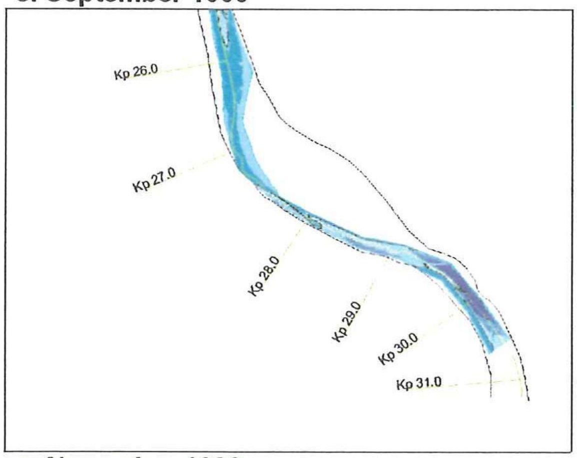
d. August 1999



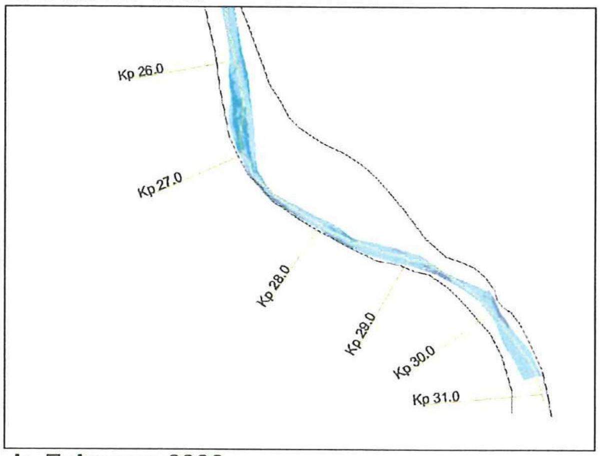
e. September 1999



f. October 1999

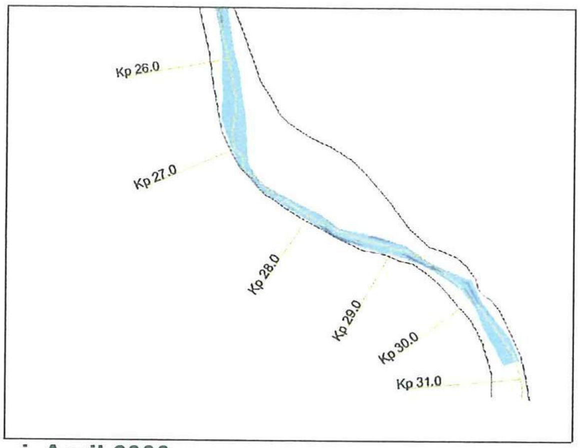


g. November 1999

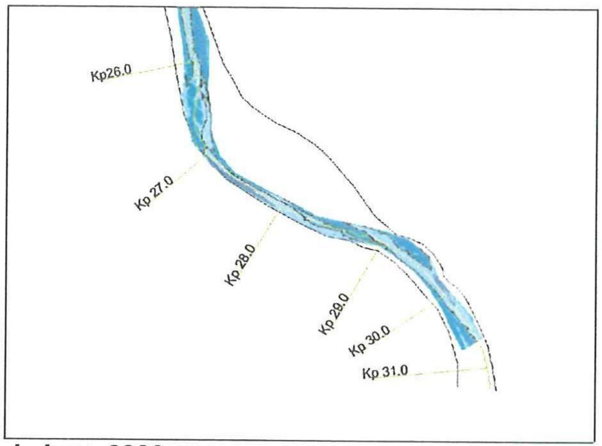


h. February 2000

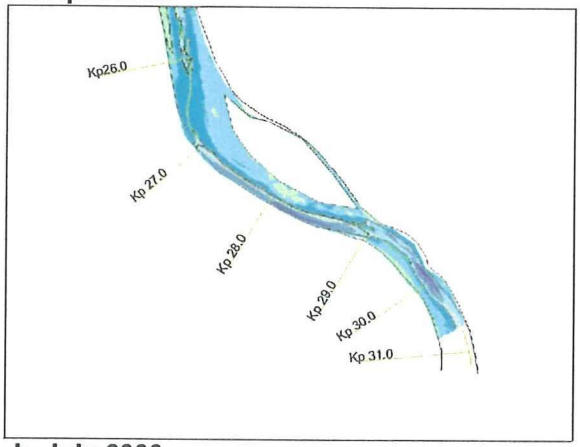
Figures V.7 a-p, Khoksa, 26.0-31.0, April 1999 to January 2001



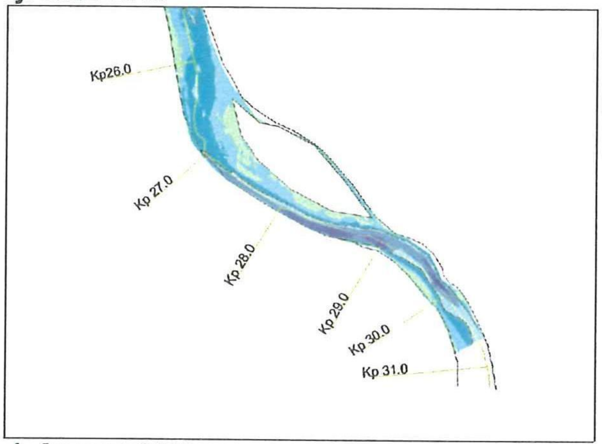
i. April 2000



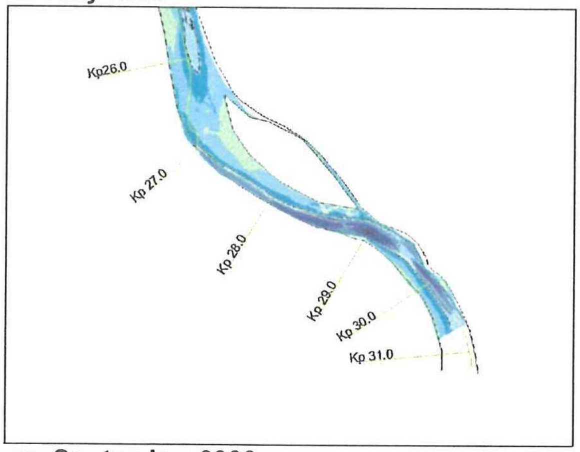
j. June 2000



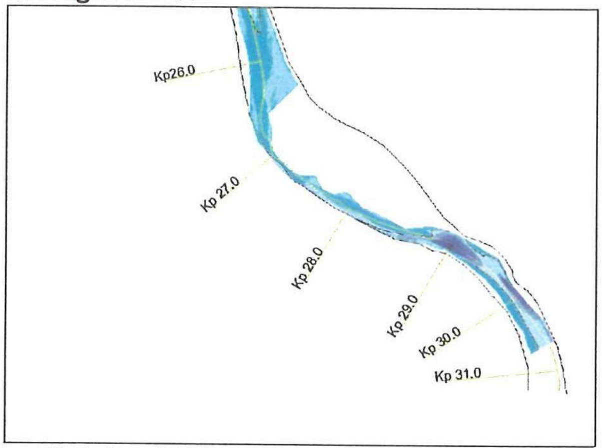
k. July 2000



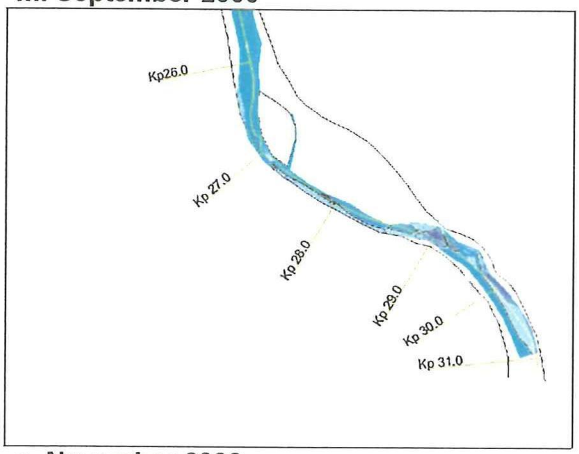
l. August 2000



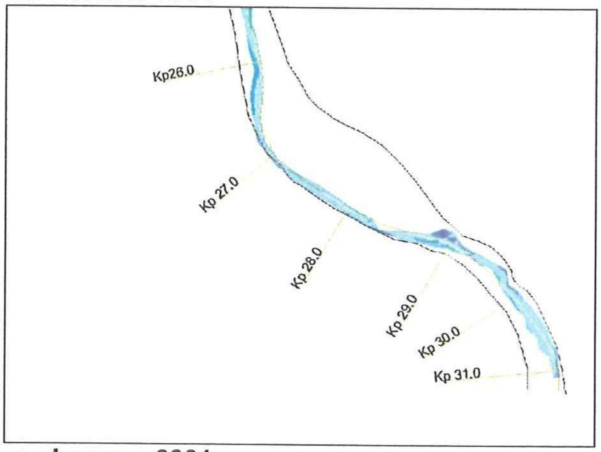
m. September 2000



n. October 2000



o. November 2000

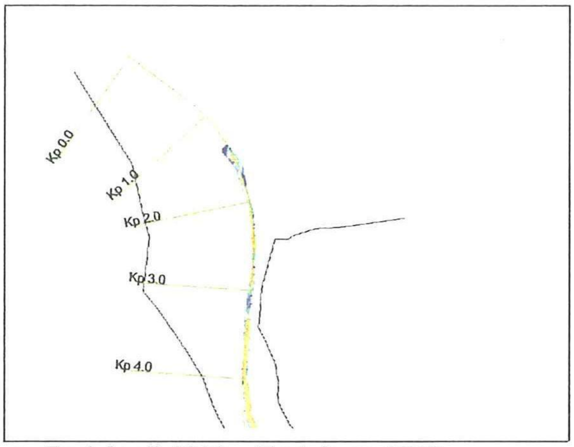


p. January 2001

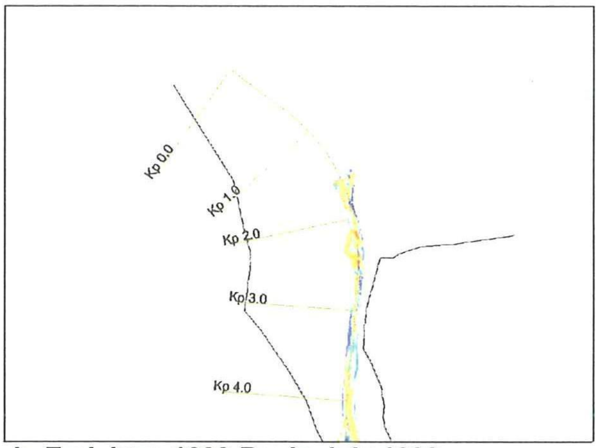
Appendix VI:

Detailed deposition and erosion patterns per stretch
April 1999 – January 2001

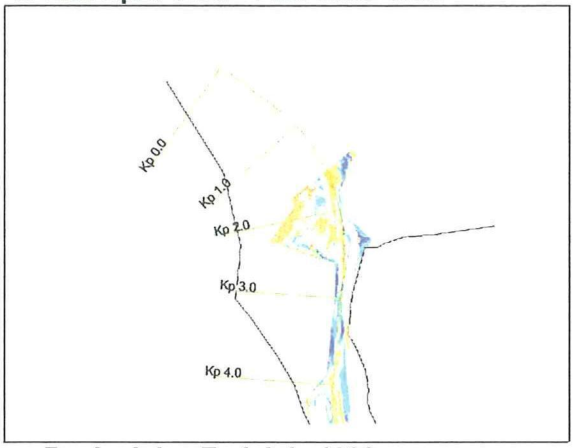
Figures VI.1 a-w, off-take area, Kp 0.0-3.5, April 1999 to January 2001



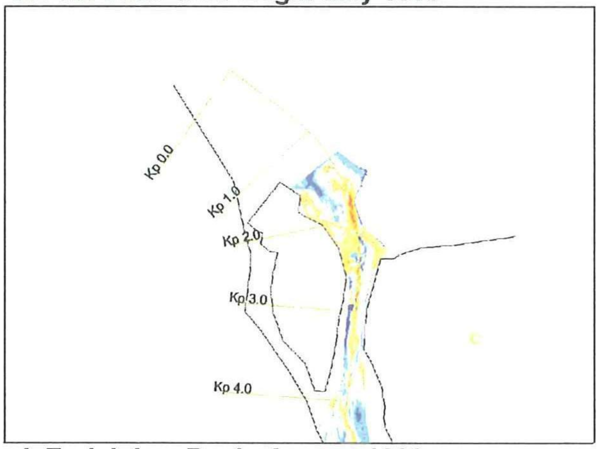
a. End April 1999 – End June 1999



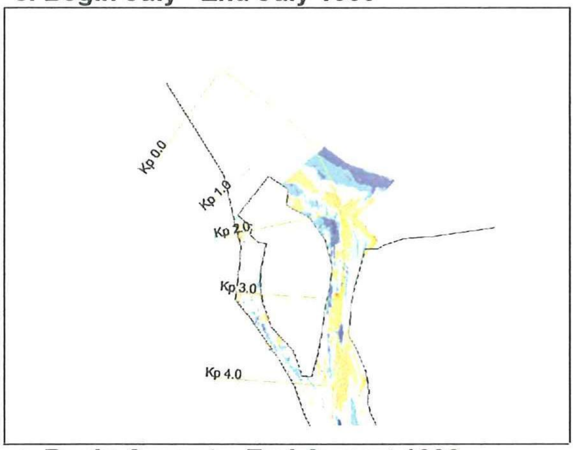
b. End June 1999-Begin July 1999



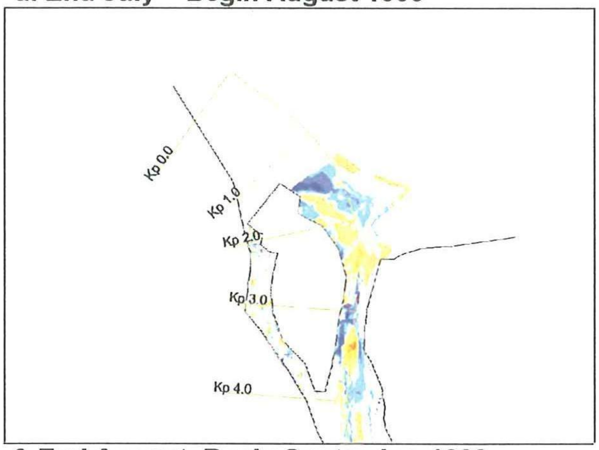
c. Begin July –End July 1999



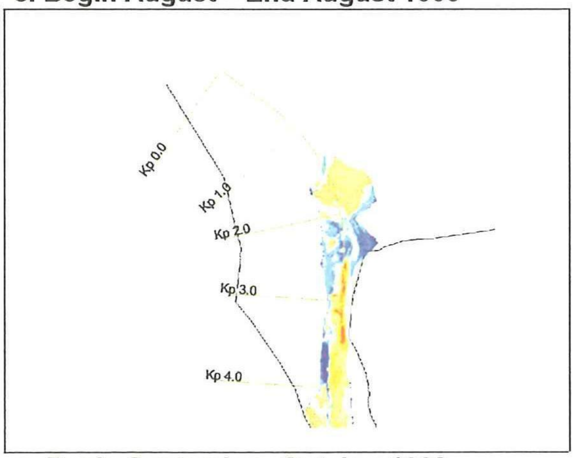
d. End July – Begin August 1999



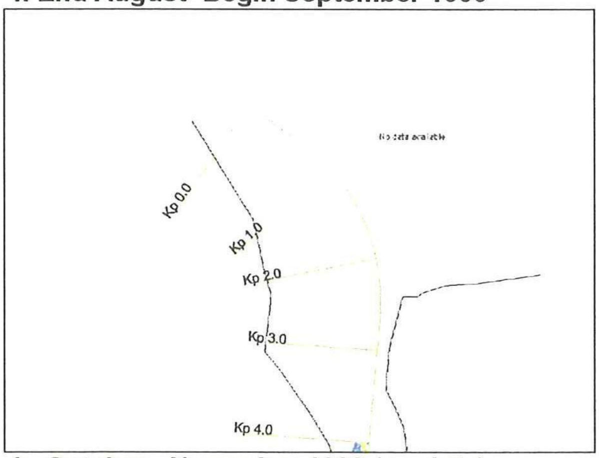
e. Begin August – End August 1999



f. End August- Begin September 1999

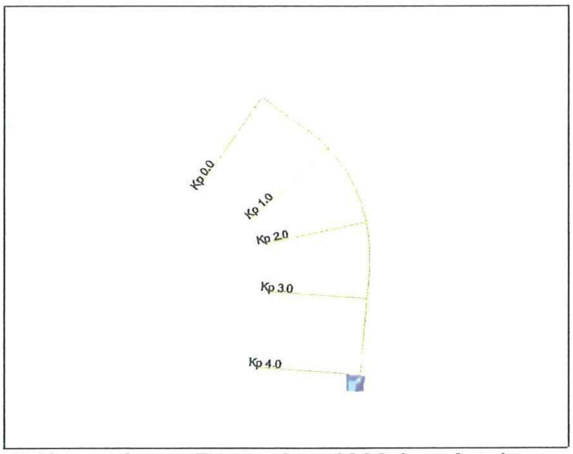


g. Begin September -October 1999

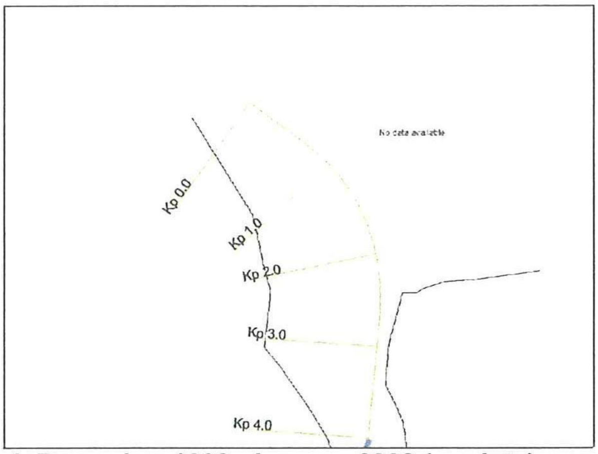


h. October –November 1999 (no data)

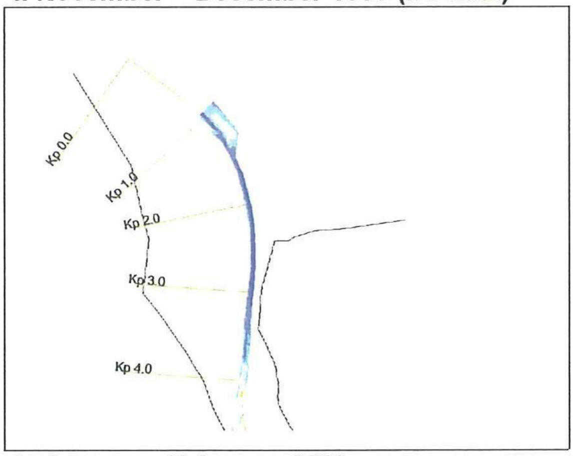
Figures VI.1 a-w, off-take area, Kp 0.0-3.5, April 1999 to January 2001



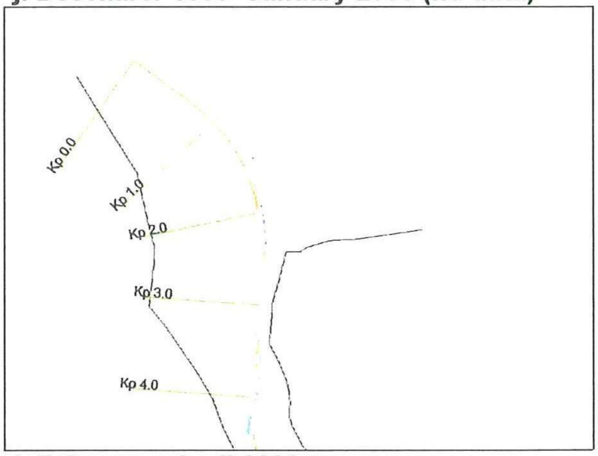
i. November – December 1999 (no data)



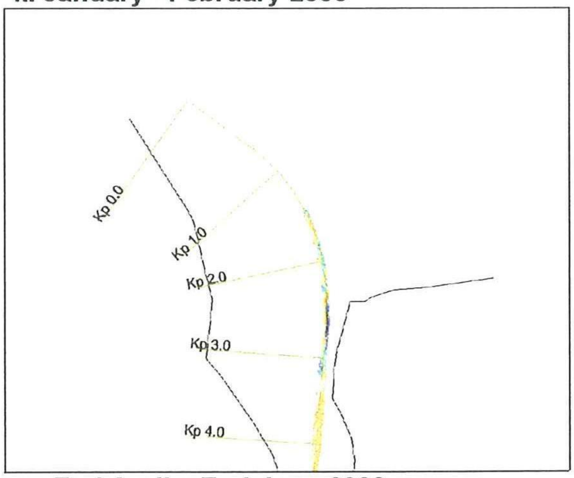
j. December 1999- January 2000 (no data)



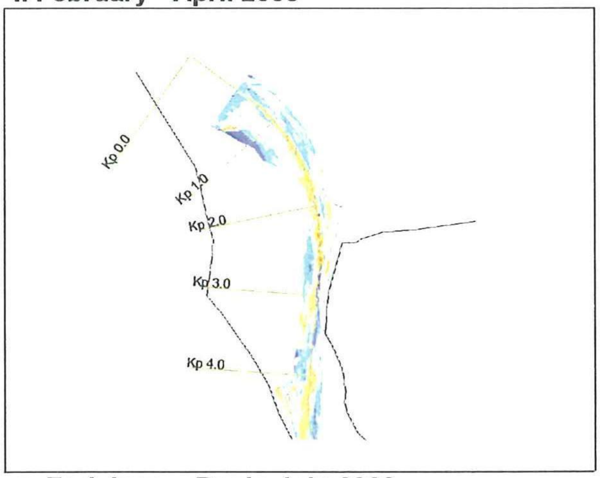
k. January - February 2000



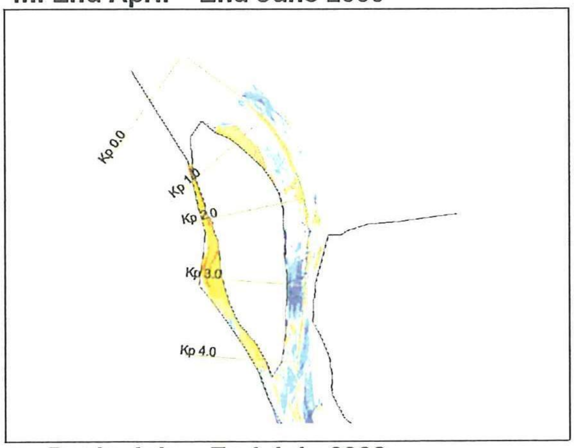
l. February - April 2000



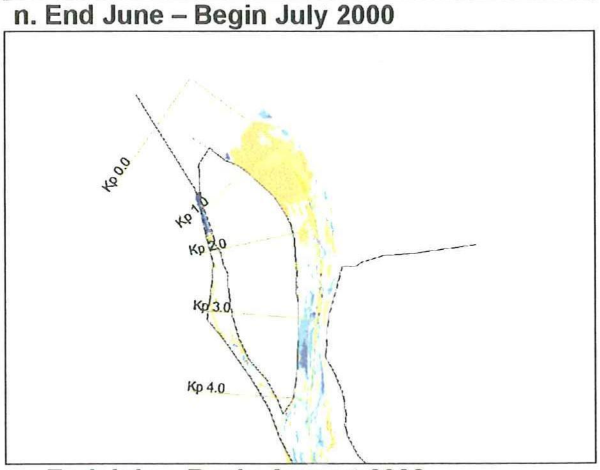
m. End April – End June 2000



n. End June – Begin July 2000

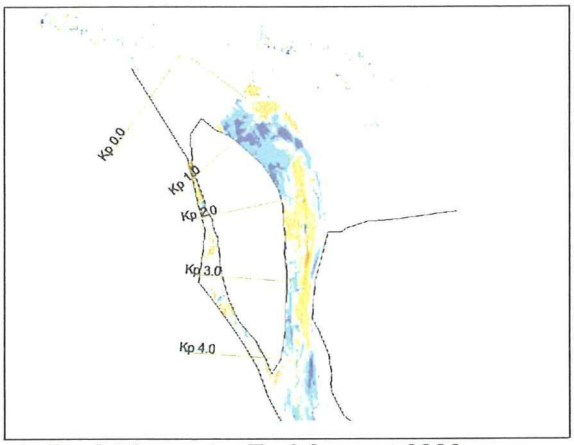


o. Begin July – End July 2000

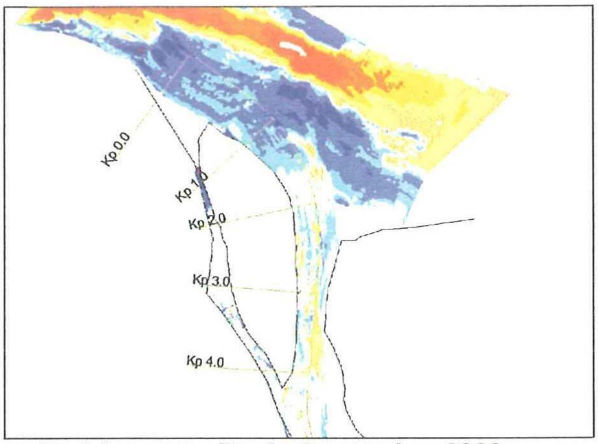


p. End July – Begin August 2000

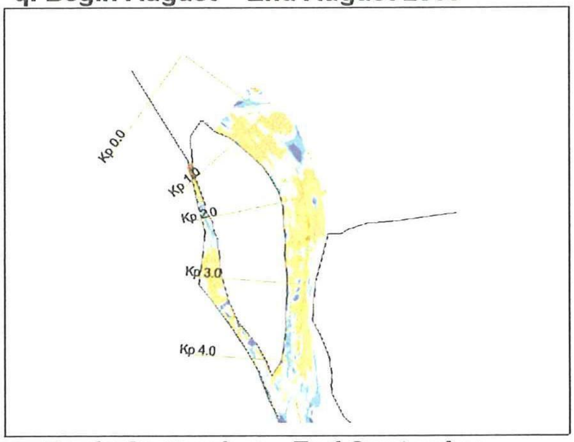
Figures VI.2 a-w, off-take area, Kp 0.0-3.5, April 1999 to January 2001



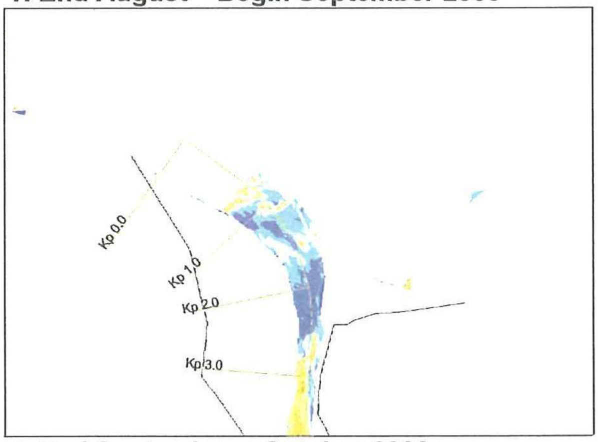
q. Begin August – End August 2000



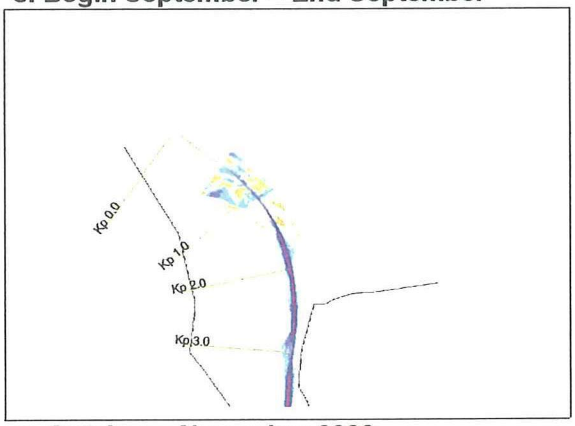
r. End August – Begin September 2000



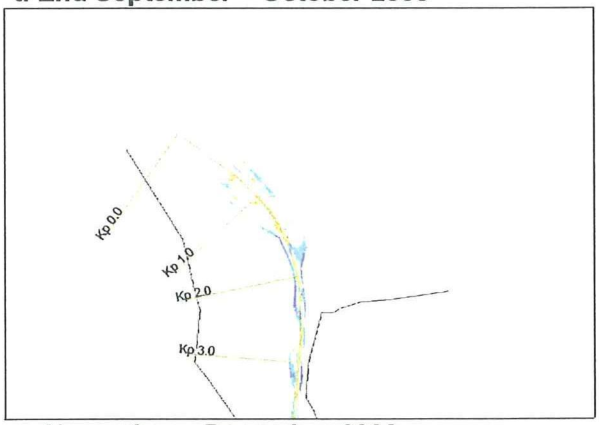
s. Begin September – End September



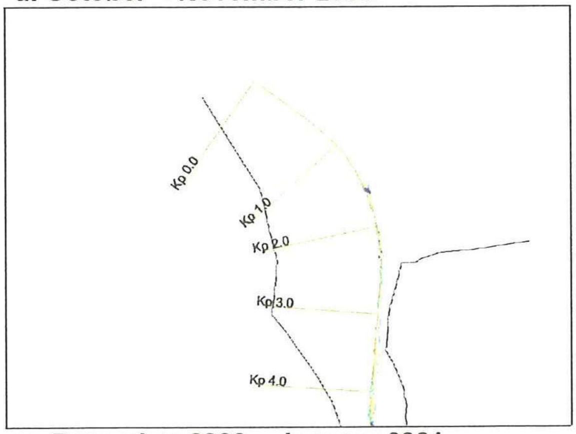
t. End September – October 2000



u. October - November 2000

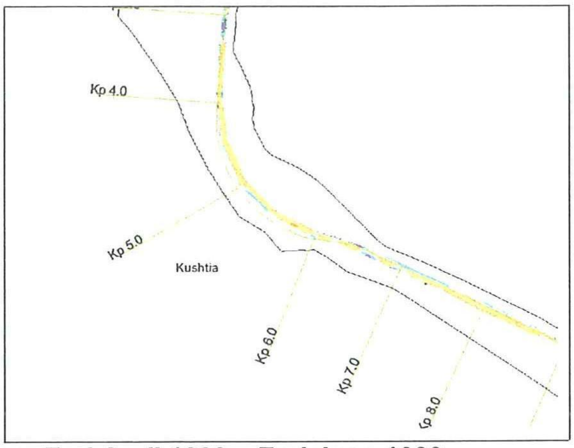


v. November – December 2000

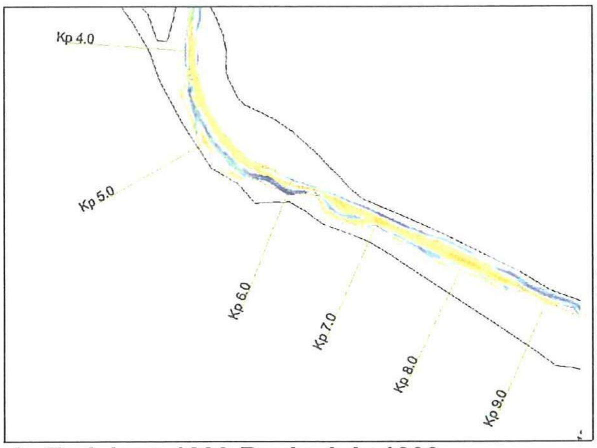


w. December 2000 – January 2001.

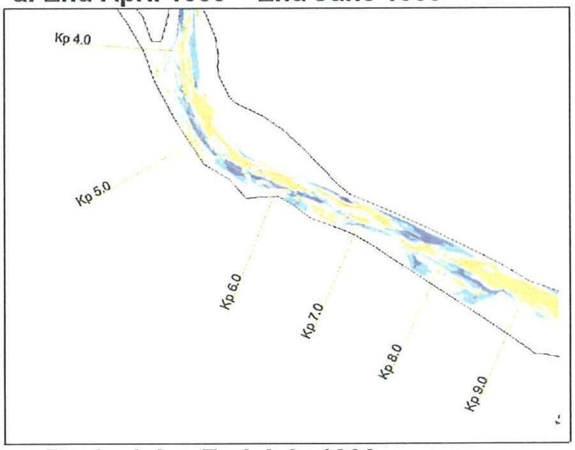
Figures VI.2 a-w, Kushtia, Kp 3.5-7.0, April 1999 to January 2001



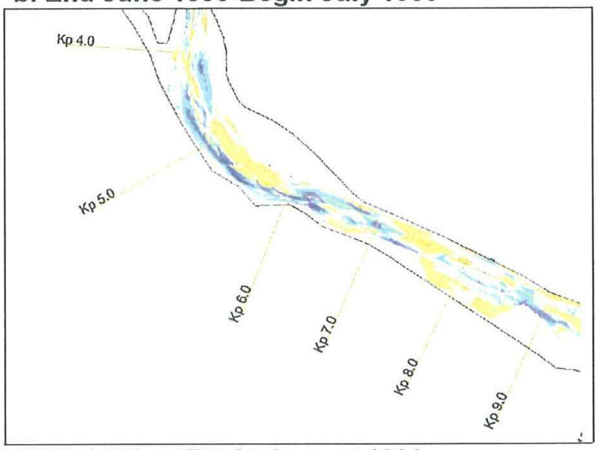
a. End April 1999 – End June 1999



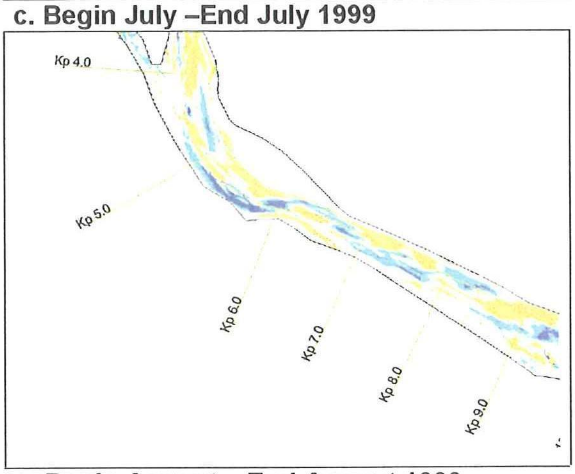
b. End June 1999-Begin July 1999



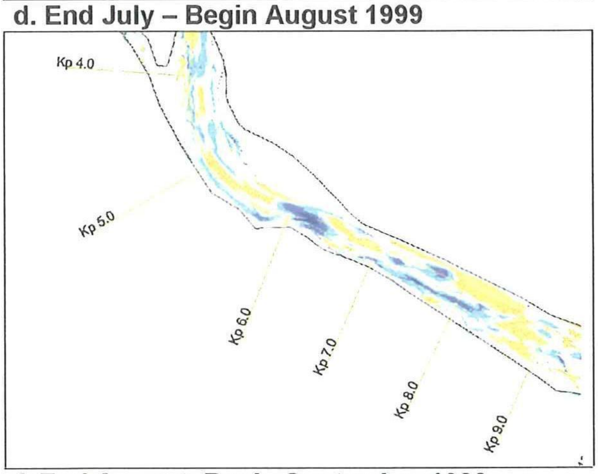
c. Begin July –End July 1999



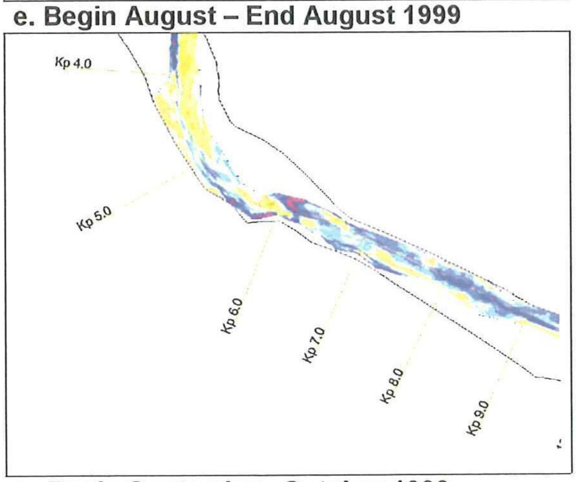
d. End July – Begin August 1999



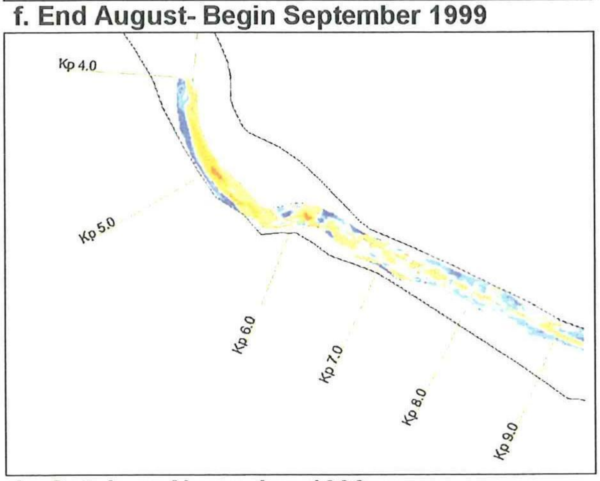
e. Begin August – End August 1999



f. End August- Begin September 1999

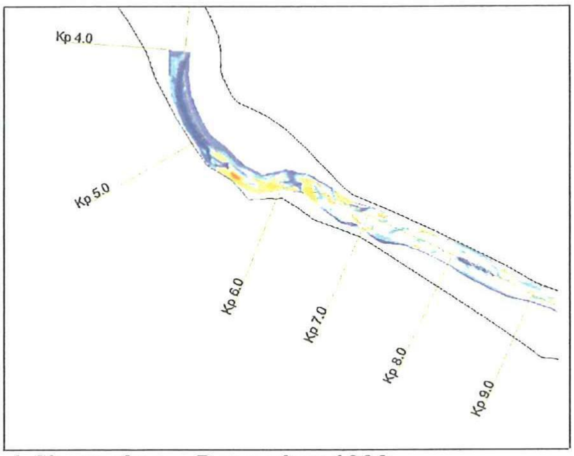


g. Begin September -October 1999

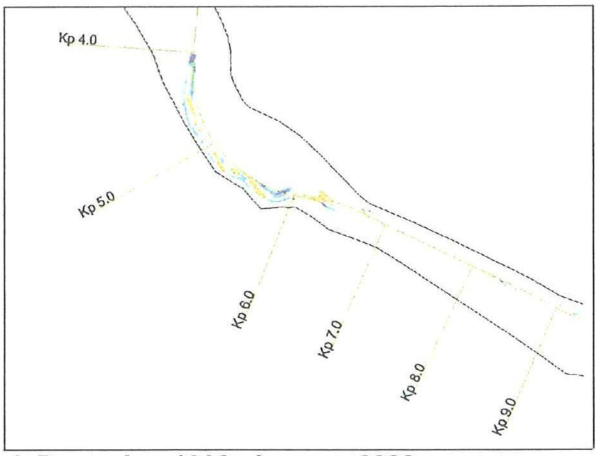


h. October –November 1999

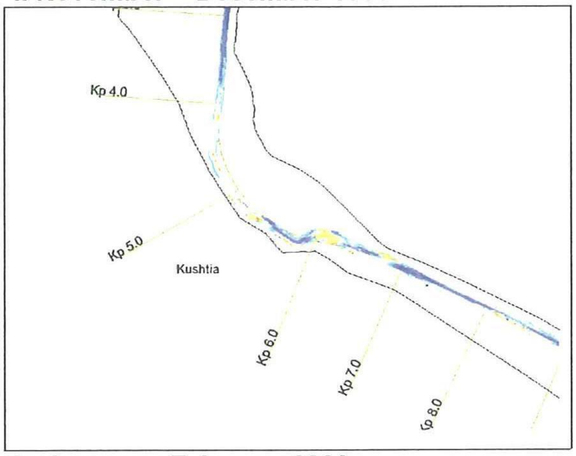
Figures VI.2 a-w, Kushtia, Kp 3.5-7.0, April 1999 to January 2001



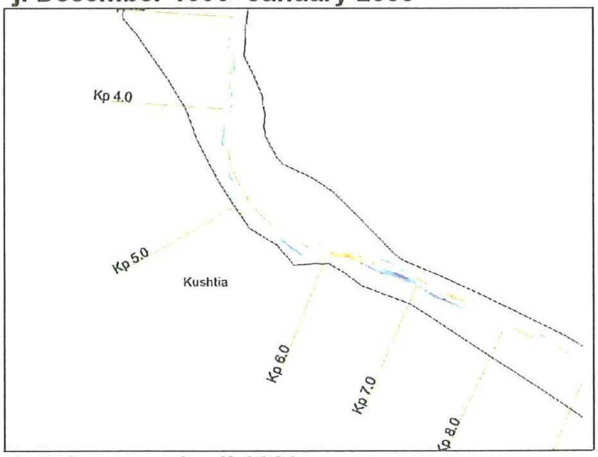
i. November – December 1999



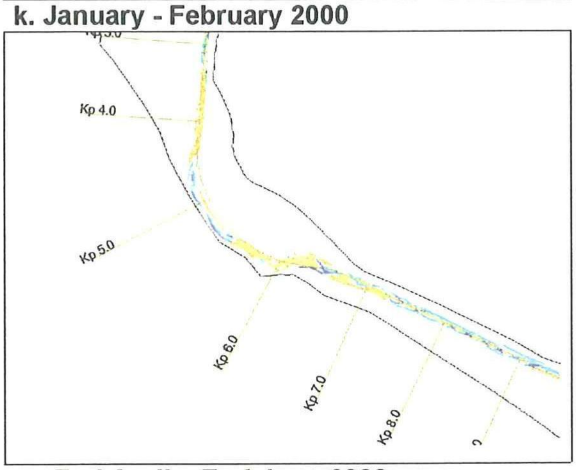
j. December 1999- January 2000



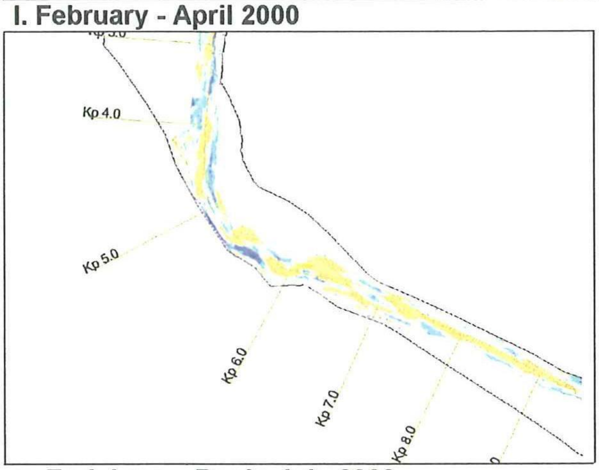
k. January - February 2000



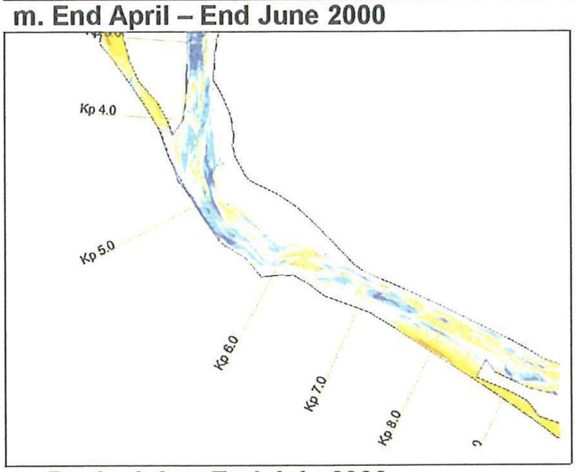
l. February - April 2000



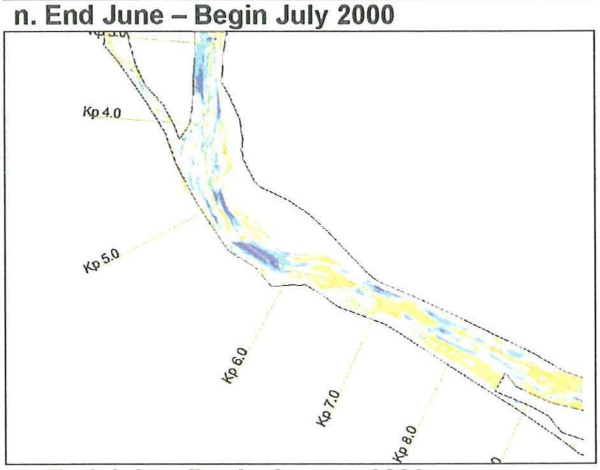
m. End April – End June 2000



n. End June – Begin July 2000

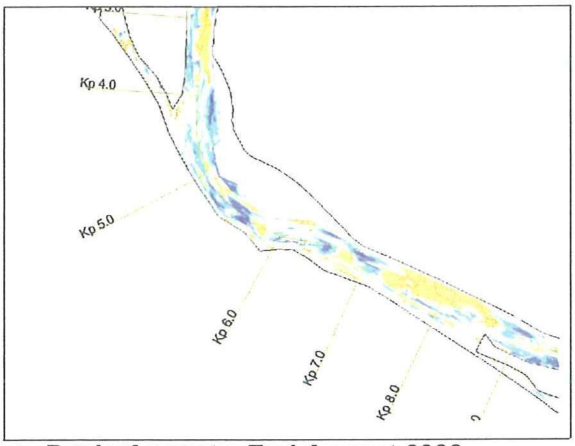


o. Begin July – End July 2000

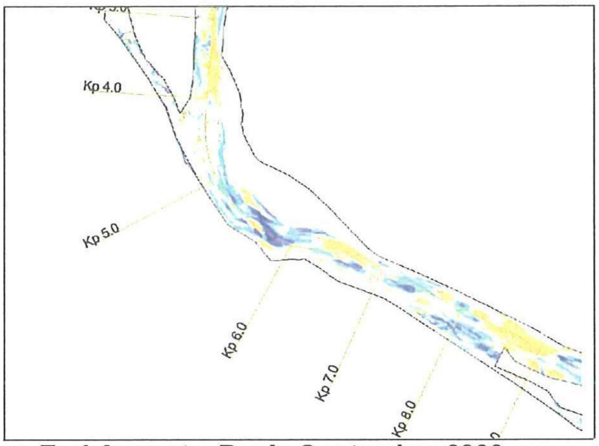


p. End July – Begin August 2000

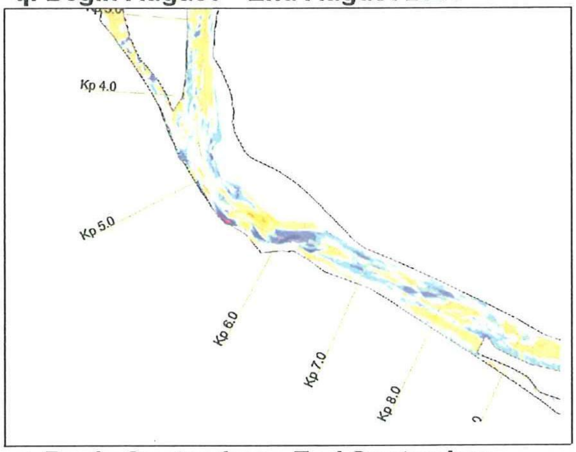
Figures VI.2 a-w, Kushtia, Kp 3.5-7.0, April 1999 to January 2001



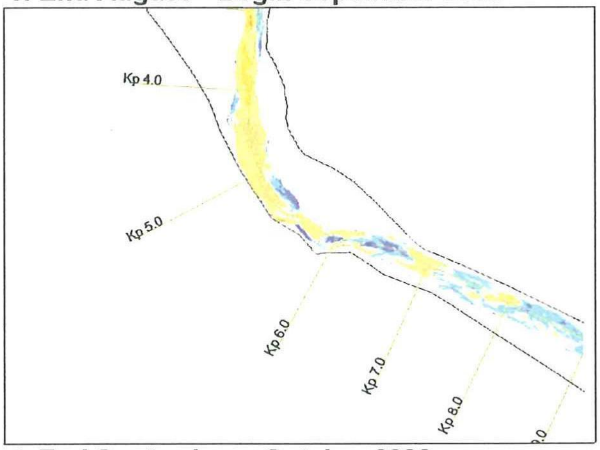
q. Begin August – End August 2000



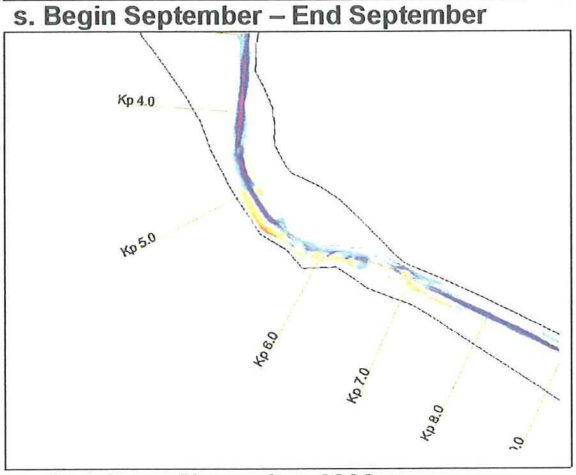
r. End August – Begin September 2000



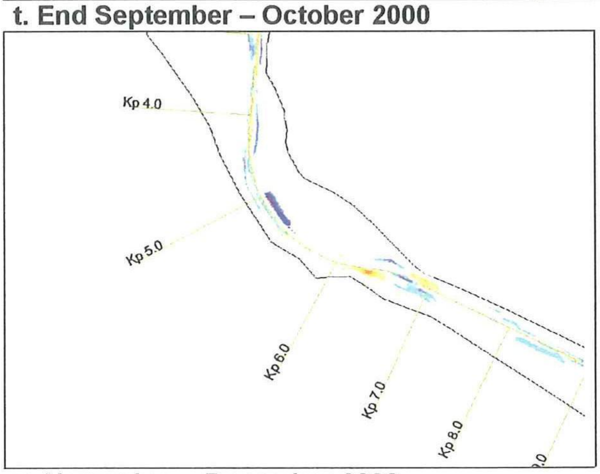
s. Begin September – End September



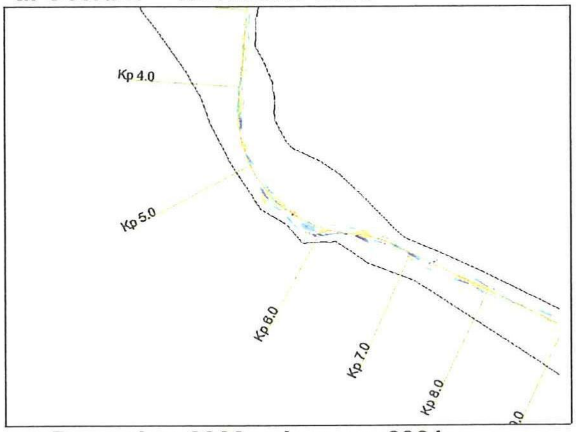
t. End September – October 2000



u. October - November 2000

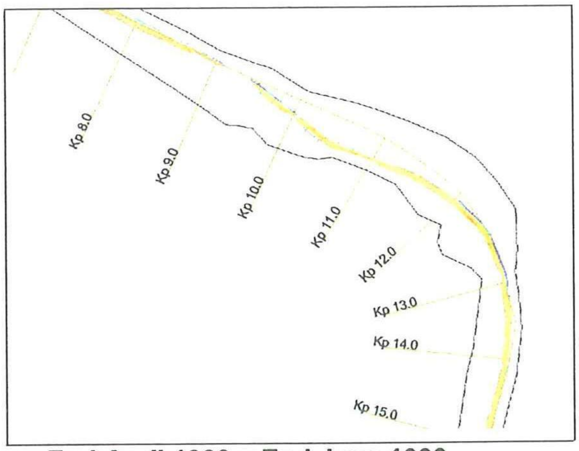


v. November – December 2000

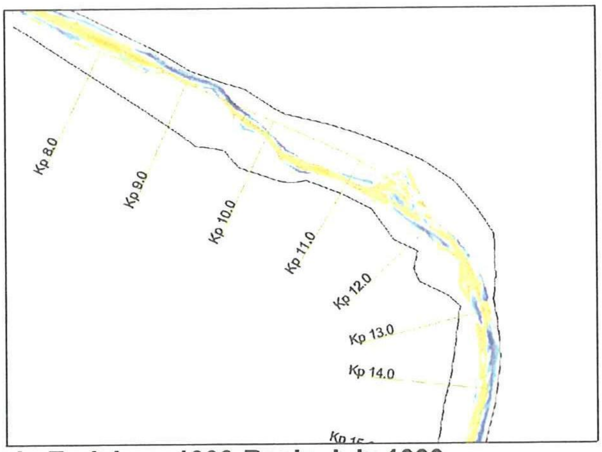


w. December 2000 – January 2001.

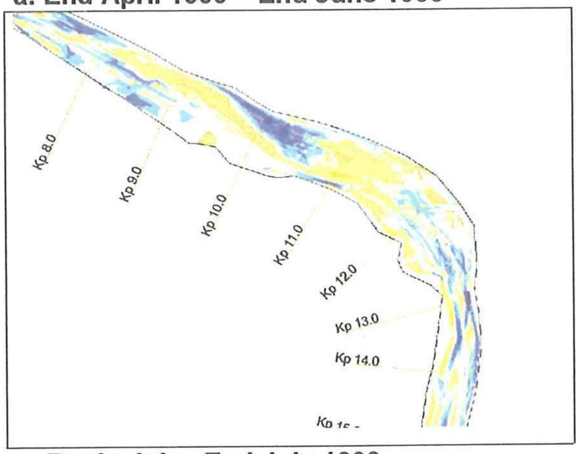
Figures VI.3 a-w, Straight stretch and upstream GRB, Kp 7.0-13.0, April 1999 to January 2001



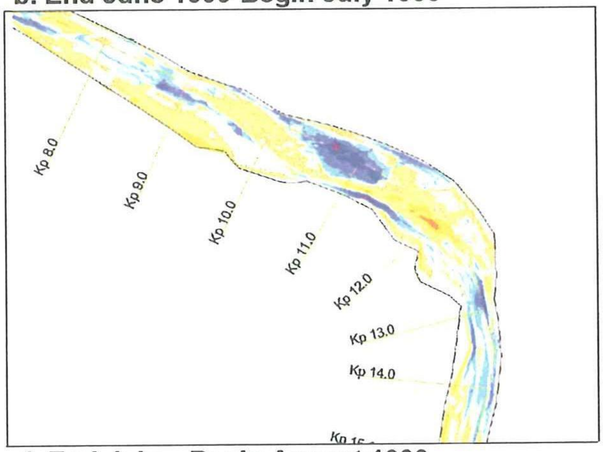
a. End April 1999 – End June 1999



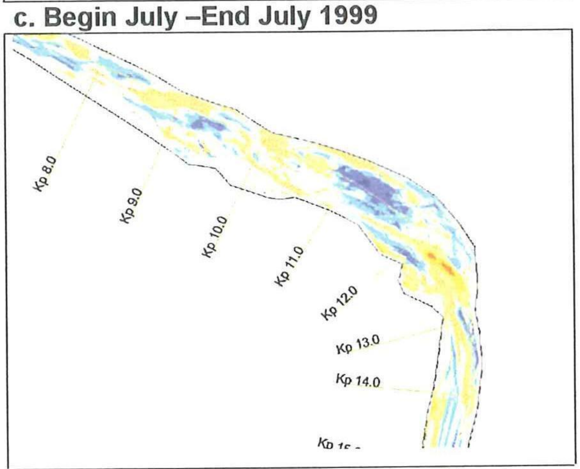
b. End June 1999-Begin July 1999



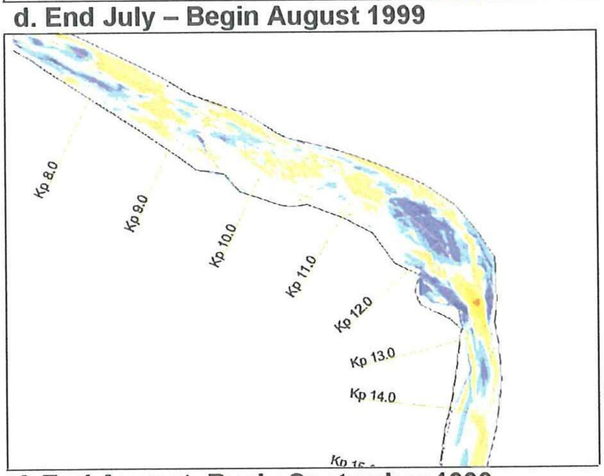
c. Begin July –End July 1999



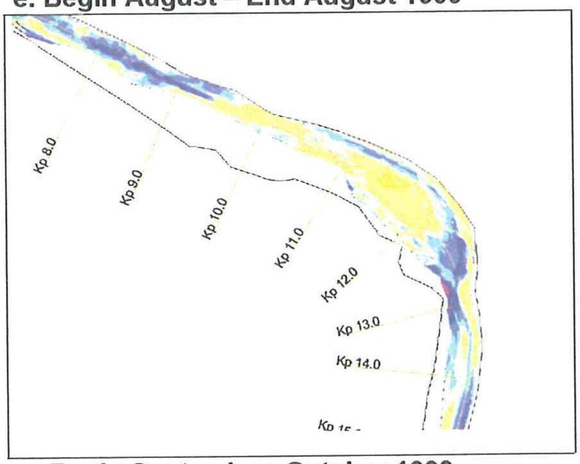
d. End July – Begin August 1999



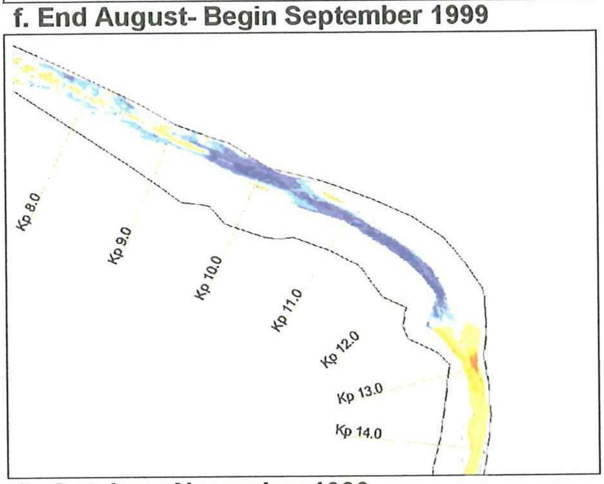
e. Begin August – End August 1999



f. End August- Begin September 1999

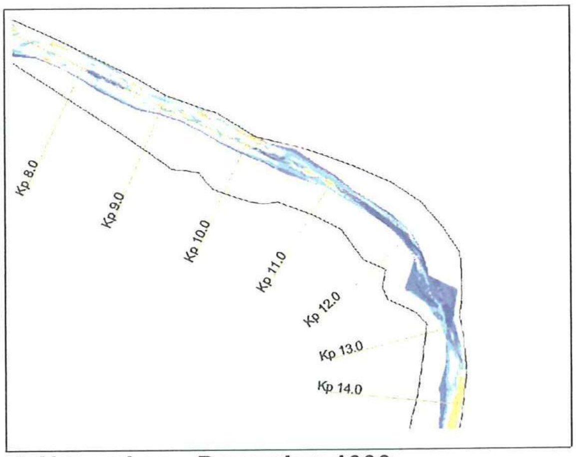


g. Begin September -October 1999

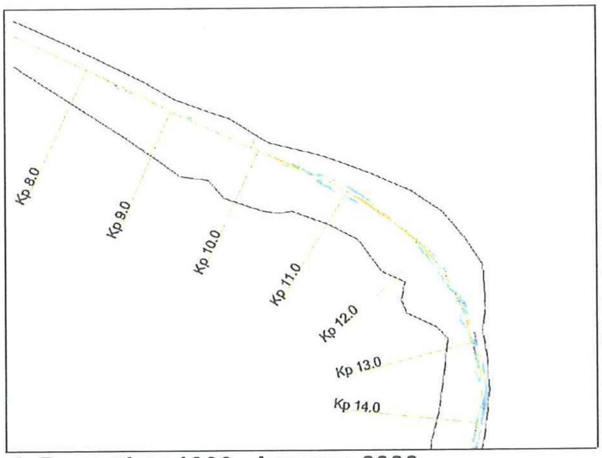


h. October –November 1999

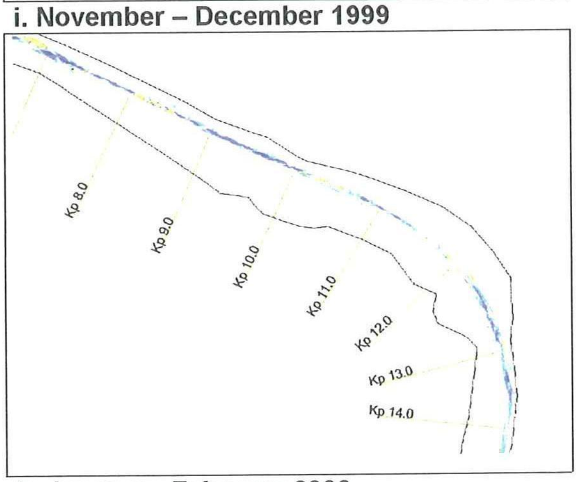
Figures VI.3 a-w, Straight stretcha and upstream GRB, Kp 7.0-13.0, April 1999 to January 2001



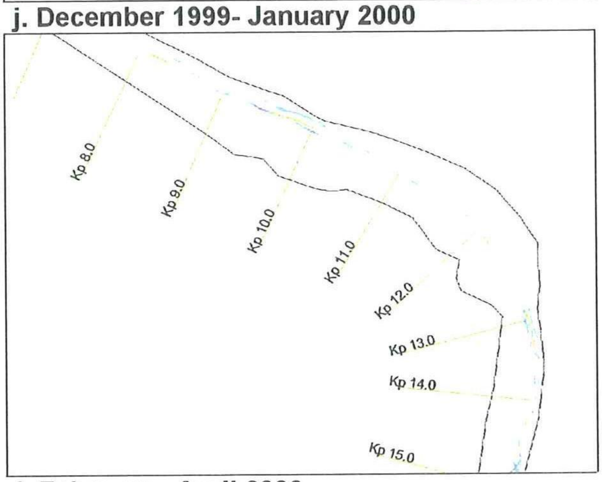
i. November – December 1999



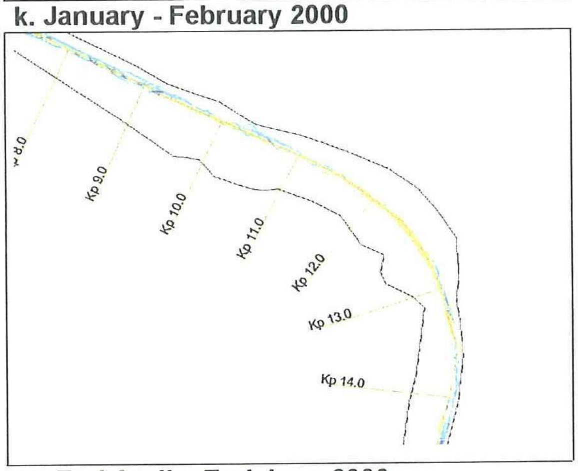
j. December 1999- January 2000



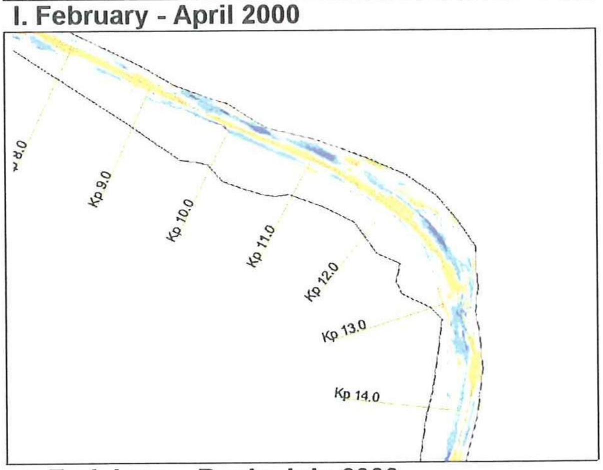
k. January - February 2000



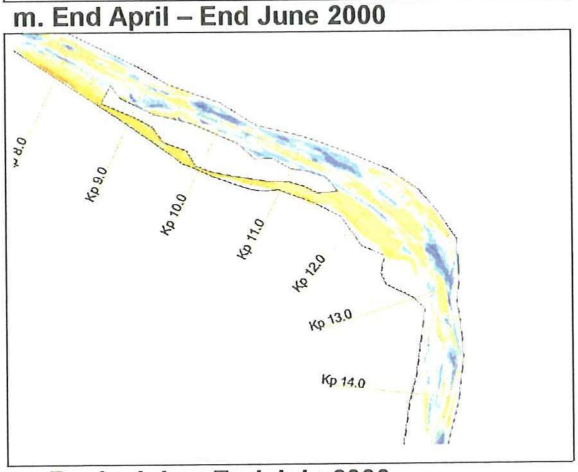
l. February - April 2000



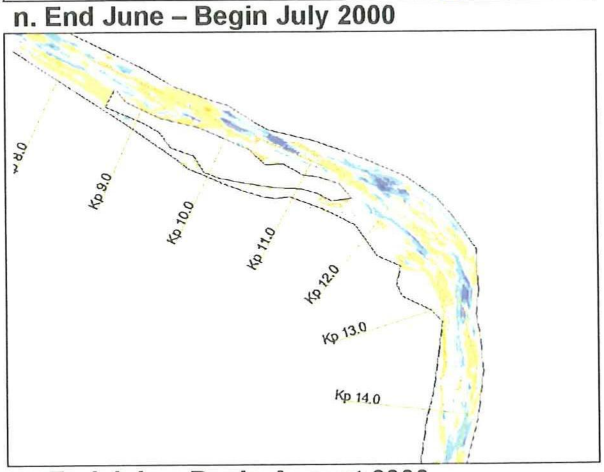
m. End April – End June 2000



n. End June – Begin July 2000

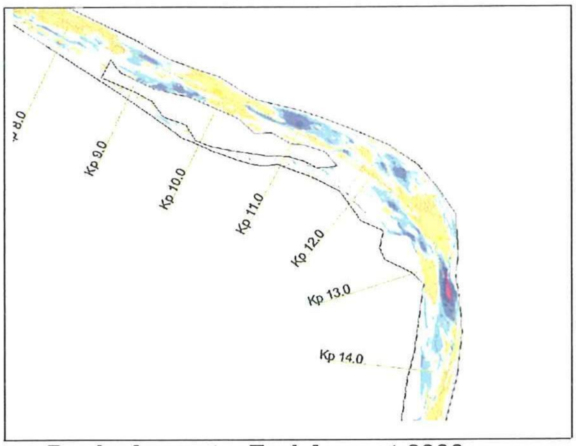


o. Begin July – End July 2000

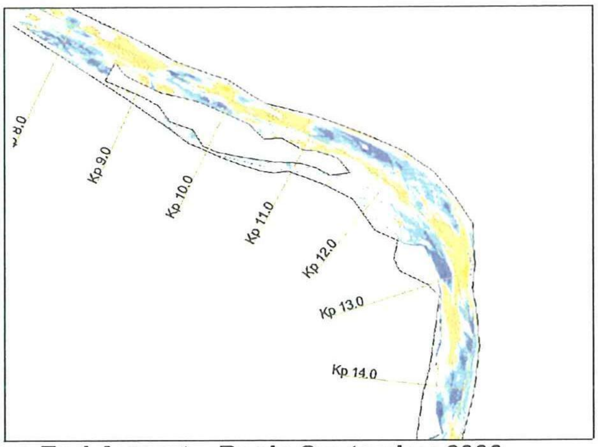


p. End July – Begin August 2000

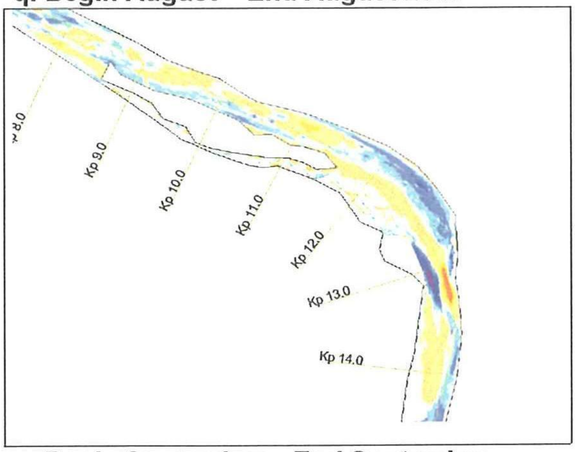
Figures VI.3 a-w, Straight stretch and upstream GRB, Kp 7.0-13.0, April 1999 to January 2001



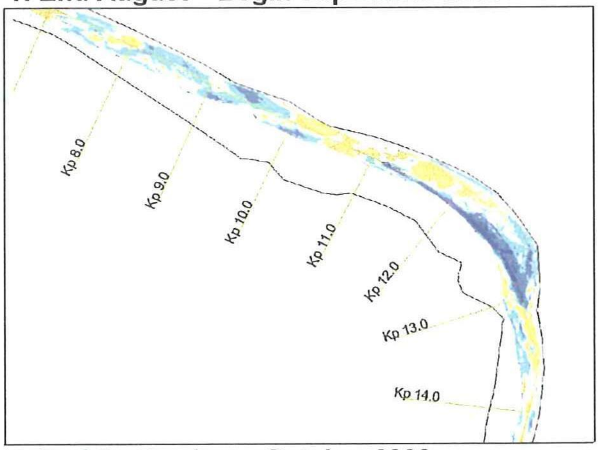
q. Begin August – End August 2000



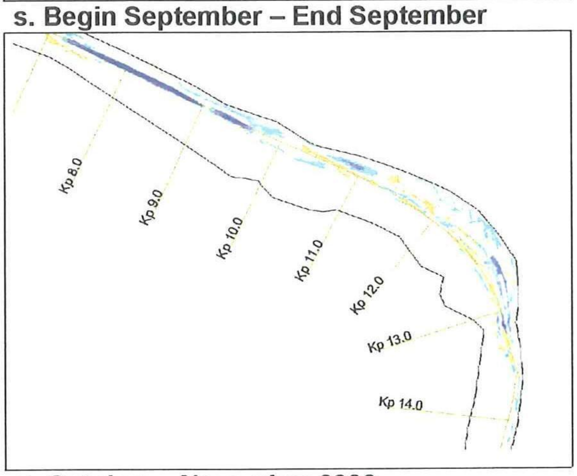
r. End August – Begin September 2000



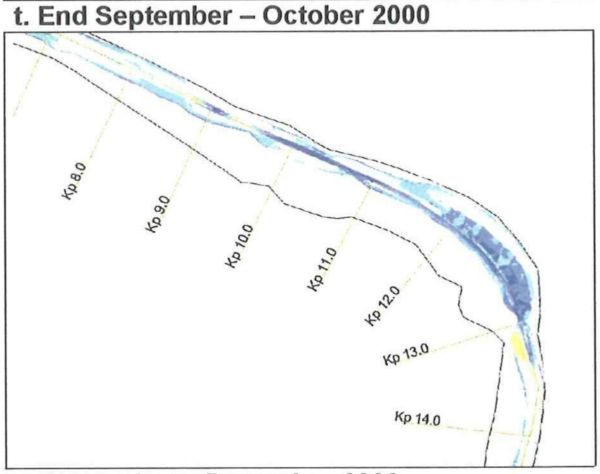
s. Begin September – End September



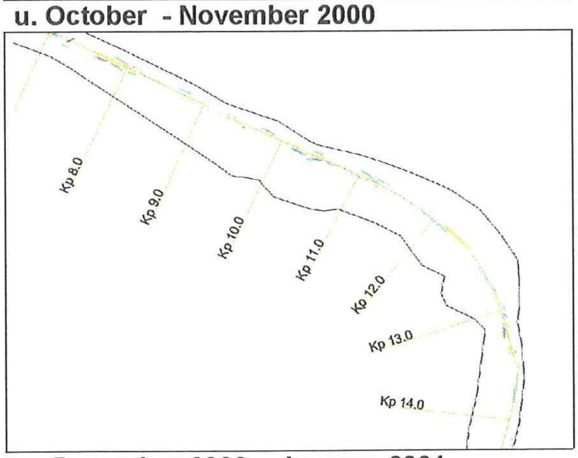
t. End September – October 2000



u. October - November 2000

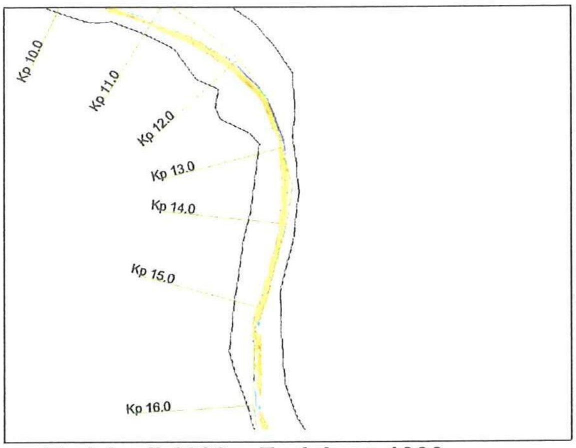


v. November – December 2000

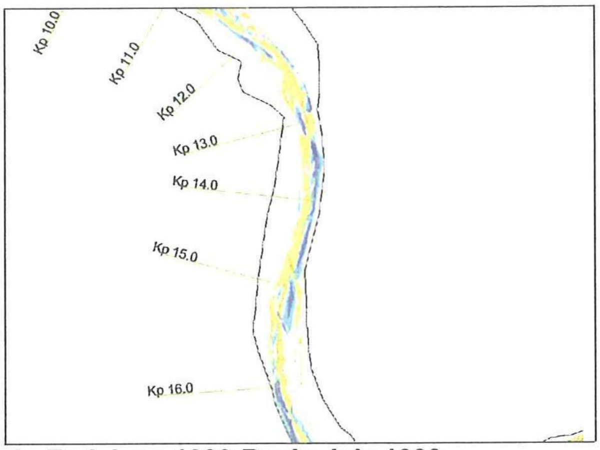


w. December 2000 – January 2001.

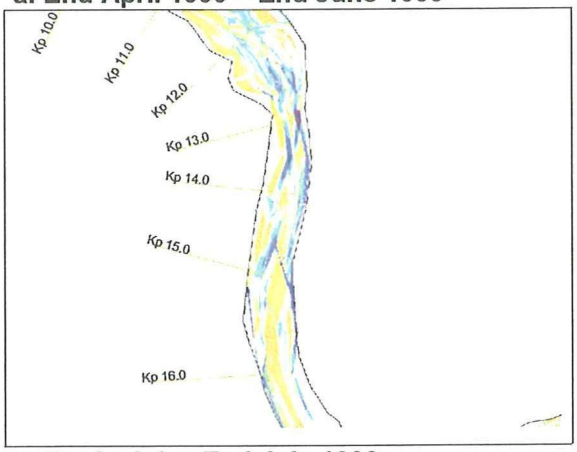
Figures VI.4 a-w, Downstream GRB, Kp 13.0-17.0, April 1999 to January 2001



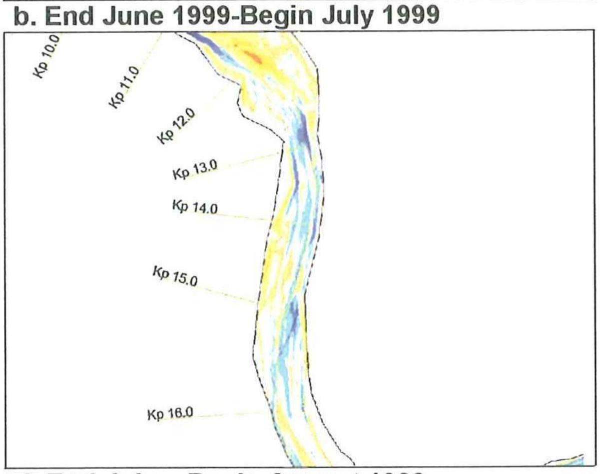
a. End April 1999 – End June 1999



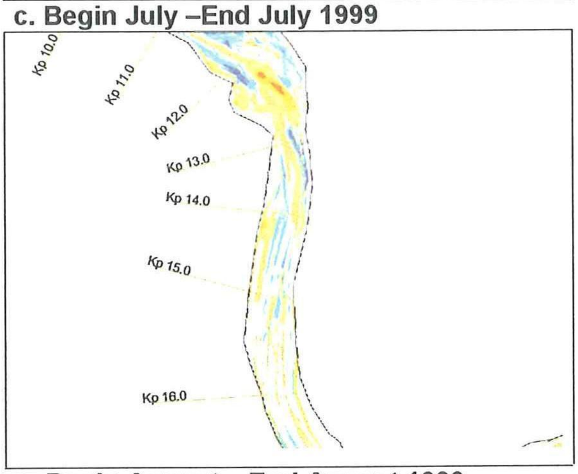
b. End June 1999-Begin July 1999



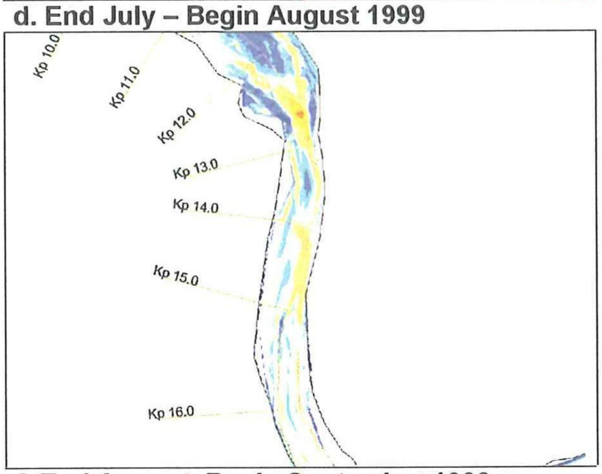
c. Begin July –End July 1999



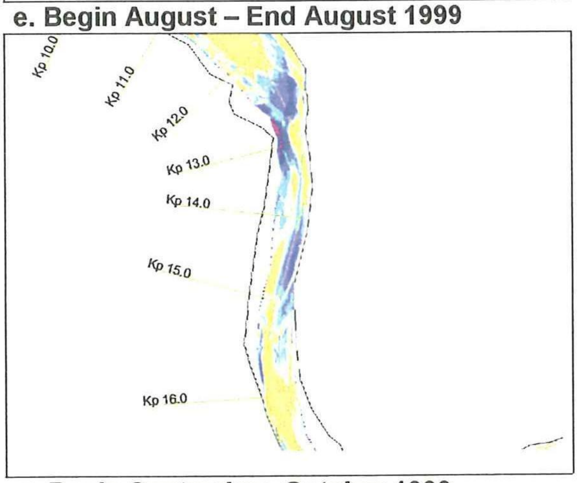
d. End July – Begin August 1999



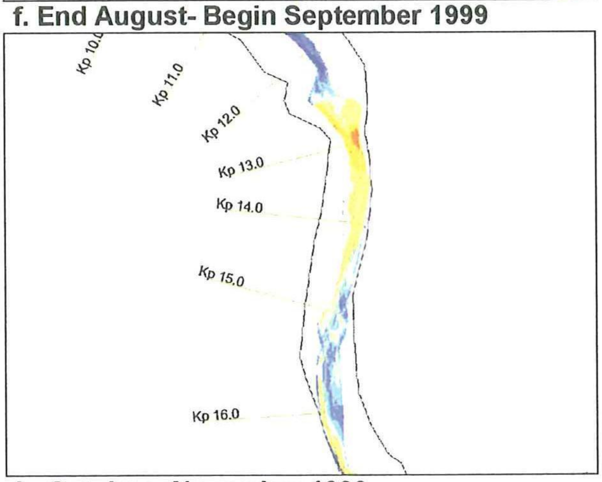
e. Begin August – End August 1999



f. End August- Begin September 1999

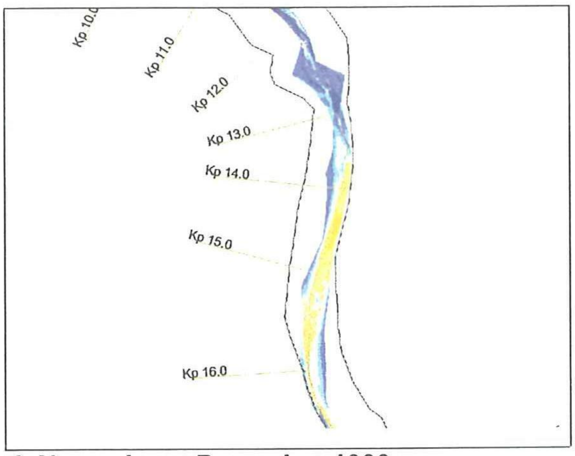


g. Begin September -October 1999

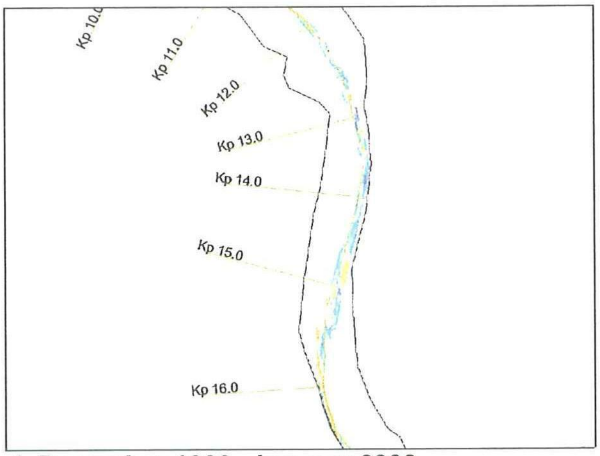


h. October –November 1999

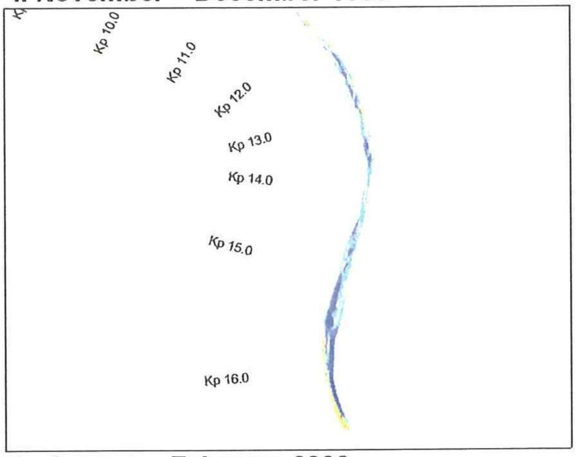
Figures VI.4 a-w, Downstream GRB, Kp 13.0-17.0, April 1999 to January 2001



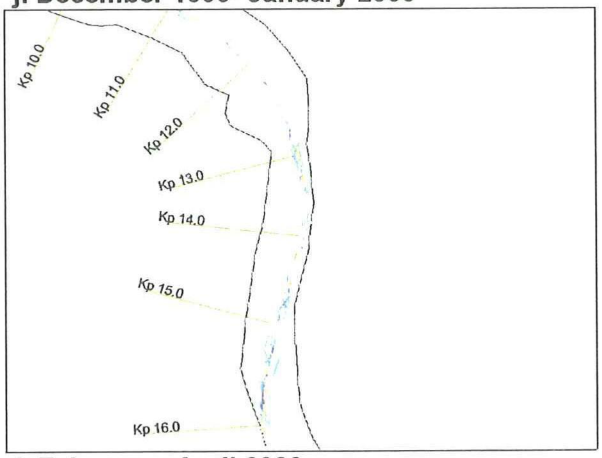
i. November – December 1999



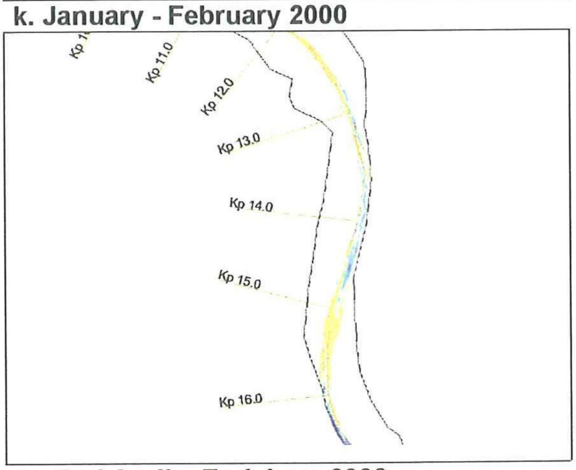
j. December 1999- January 2000



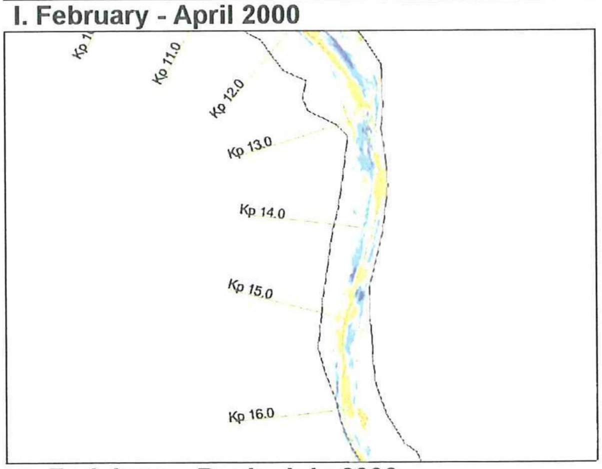
k. January - February 2000



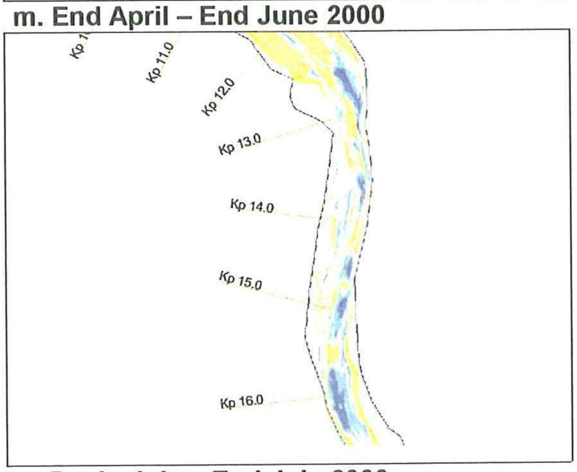
l. February - April 2000



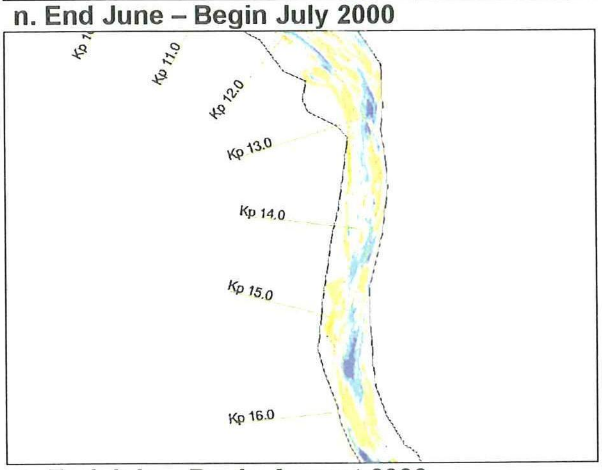
m. End April – End June 2000



n. End June – Begin July 2000

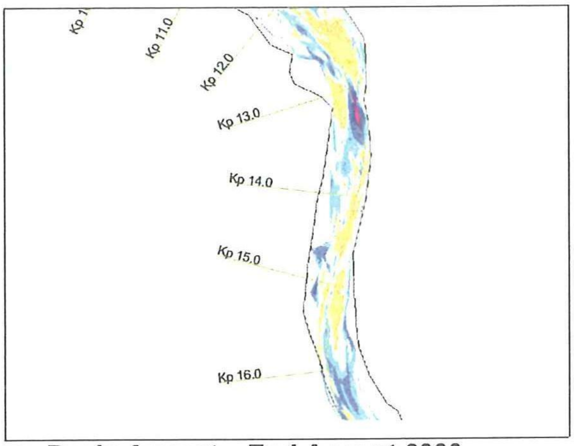


o. Begin July – End July 2000

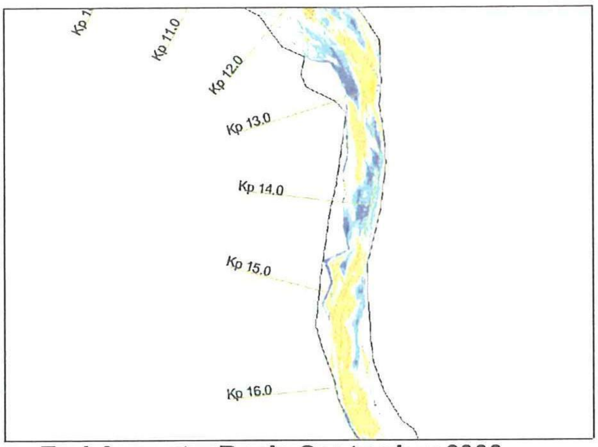


p. End July – Begin August 2000

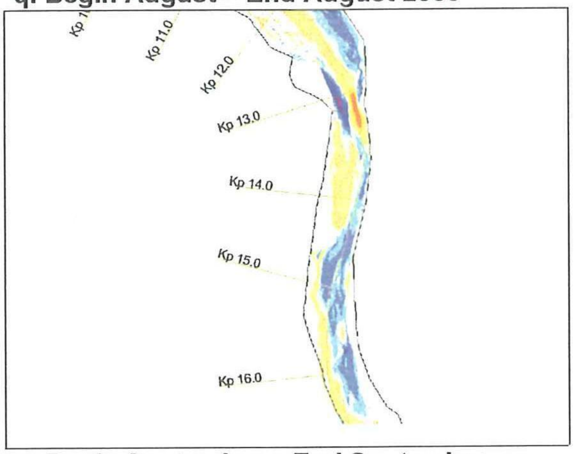
Figures VI.4 a-w, Downstream GRB, Kp 13.0-17.0, April 1999 to January 2001



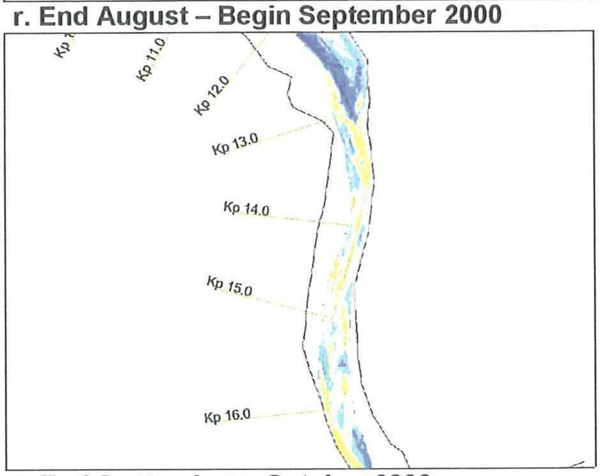
q. Begin August – End August 2000



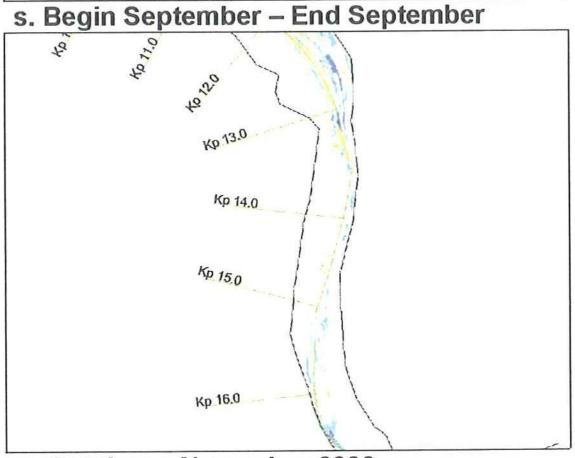
r. End August – Begin September 2000



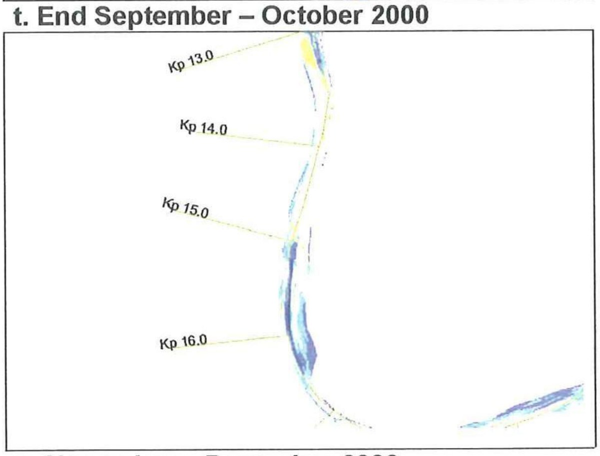
s. Begin September – End September



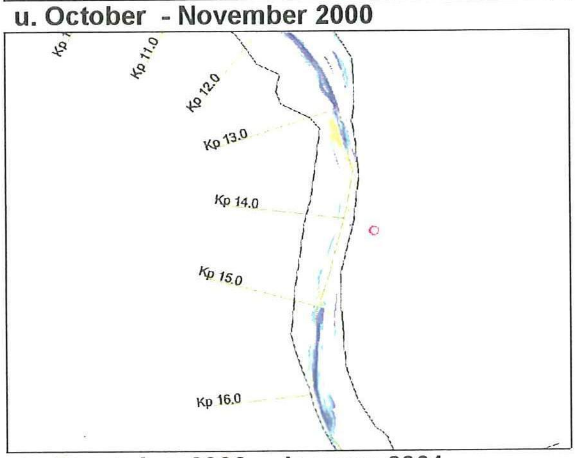
t. End September – October 2000



u. October - November 2000

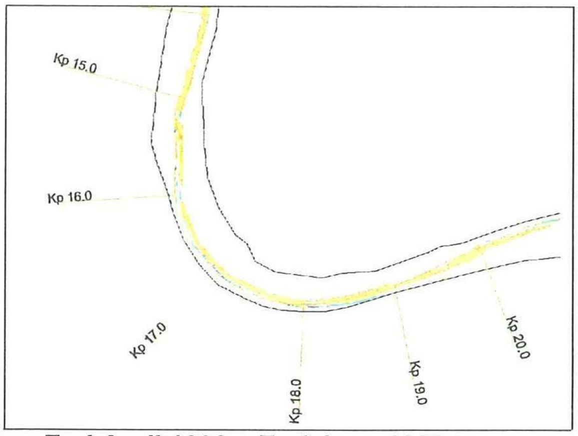


v. November – December 2000

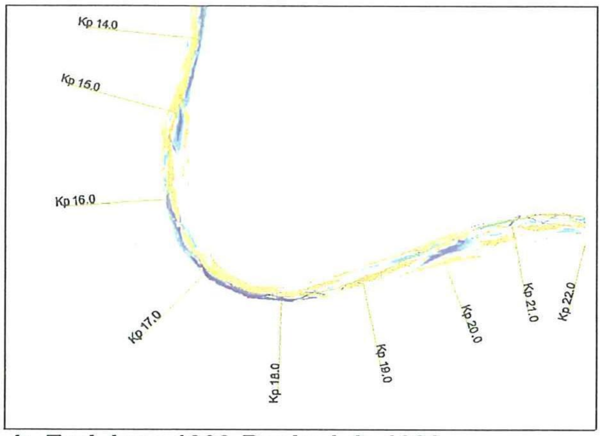


w. December 2000 – January 2001.

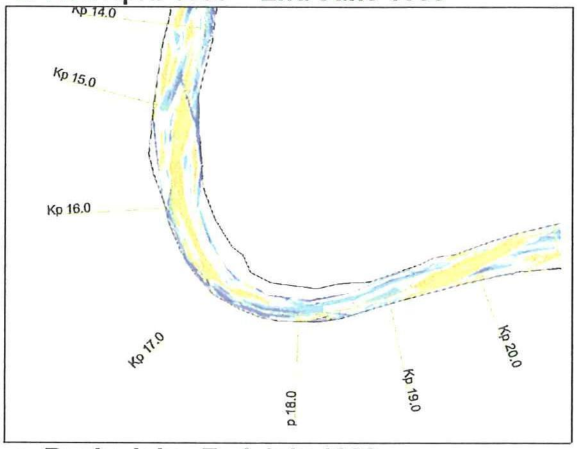
Figures VI.5 a-w, Downstream Kumarkhali, Kp 17.0-20.5, April 1999 to January 2001



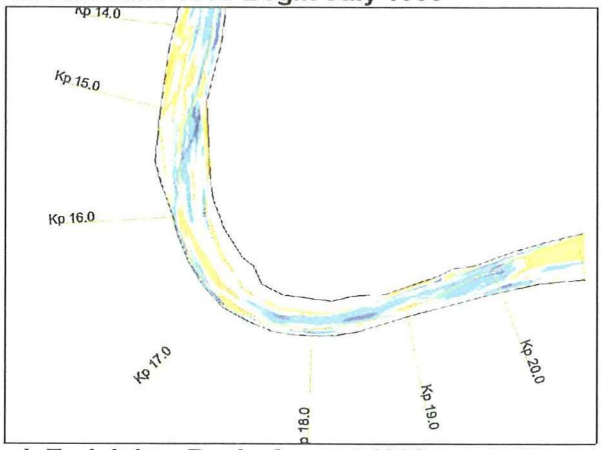
a. End April 1999 – End June 1999



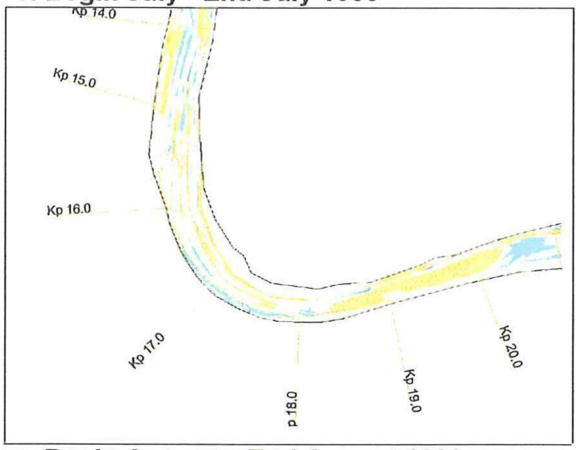
b. End June 1999-Begin July 1999



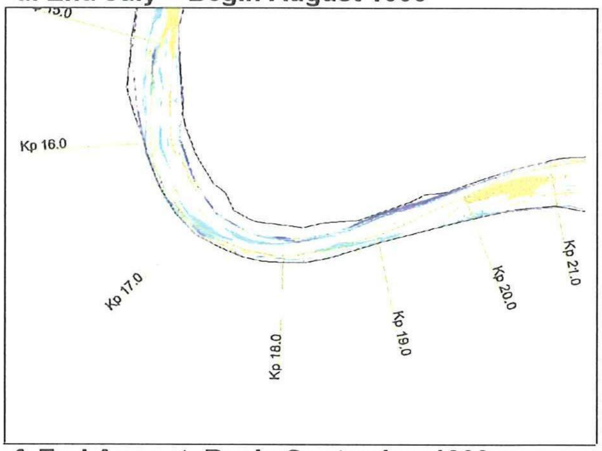
c. Begin July –End July 1999



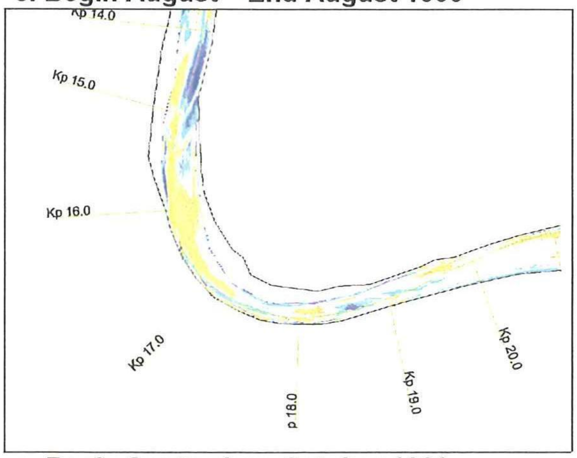
d. End July – Begin August 1999



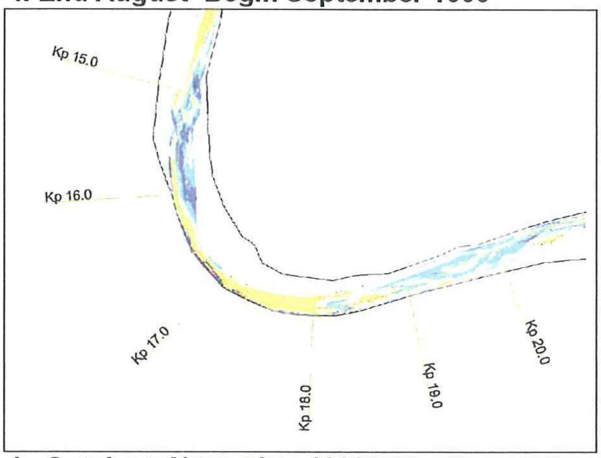
e. Begin August – End August 1999



f. End August- Begin September 1999

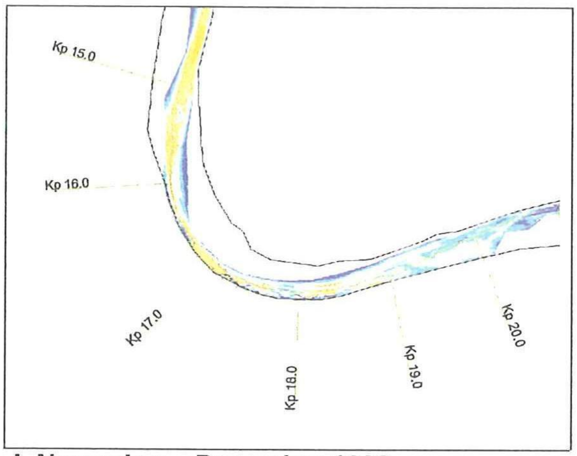


g. Begin September -October 1999

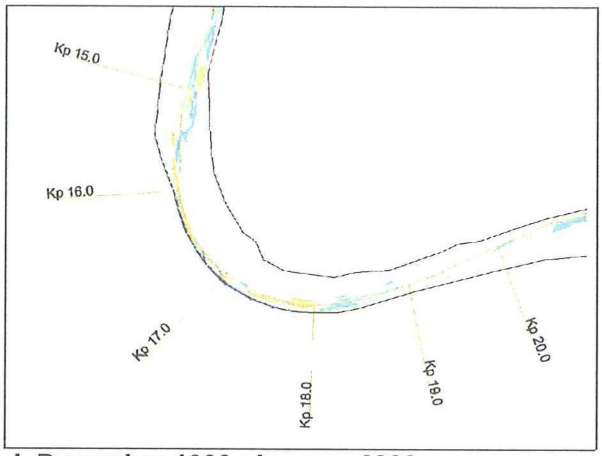


h. October –November 1999

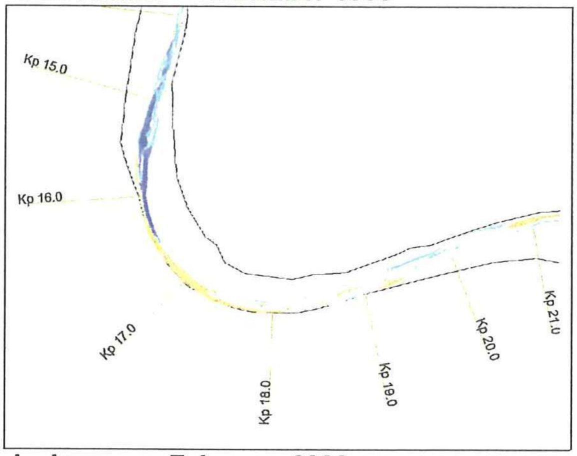
Figures VI.5 a-w, Downstream Kumarkhali, Kp 17.0-20.5, April 1999 to January 2001



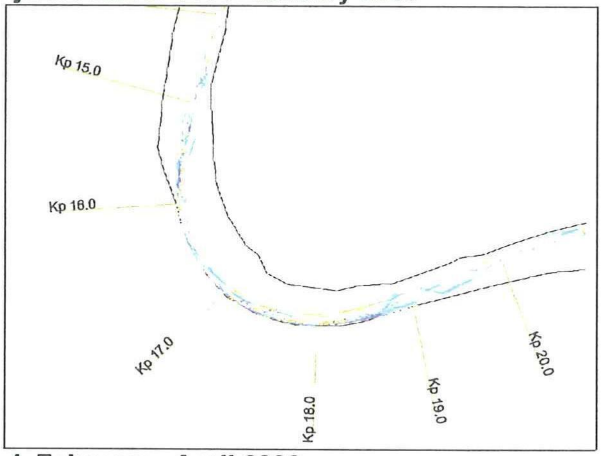
i. November – December 1999



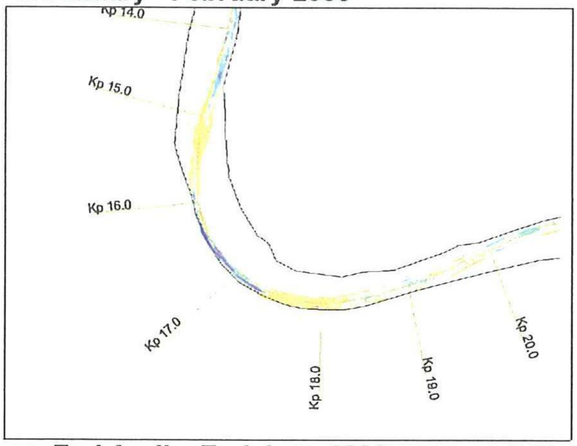
j. December 1999- January 2000



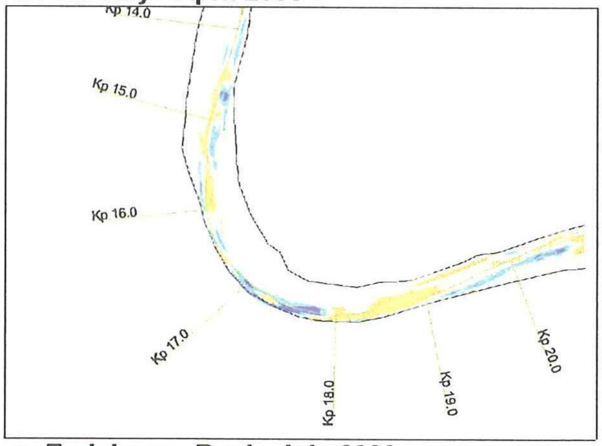
k. January - February 2000



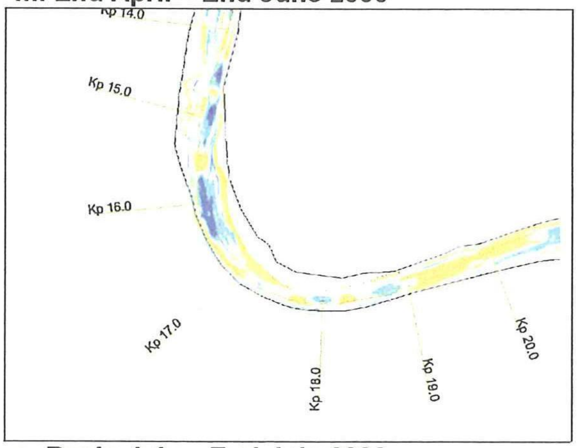
l. February - April 2000



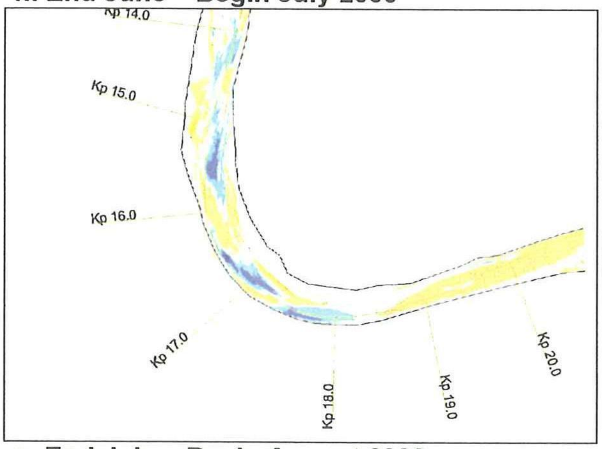
m. End April – End June 2000



n. End June – Begin July 2000

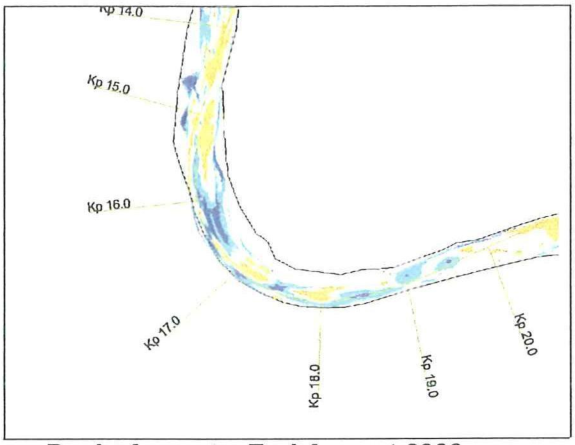


o. Begin July – End July 2000

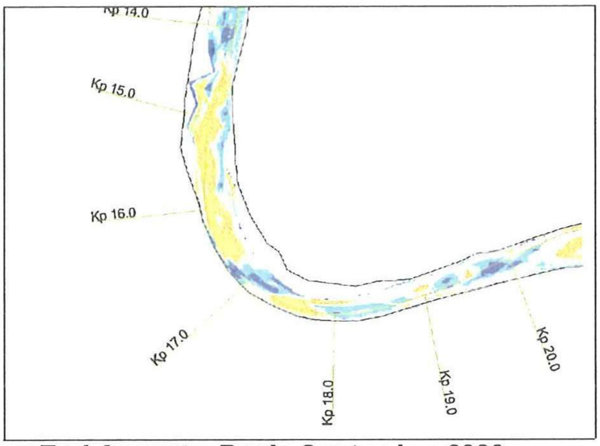


p. End July – Begin August 2000

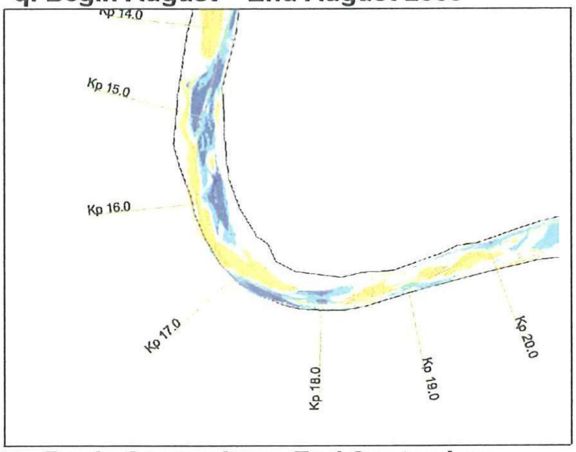
Figures VI.5 a-w, Downstream Kumarkhali, Kp 17.0-20.5, April 1999 to January 2001



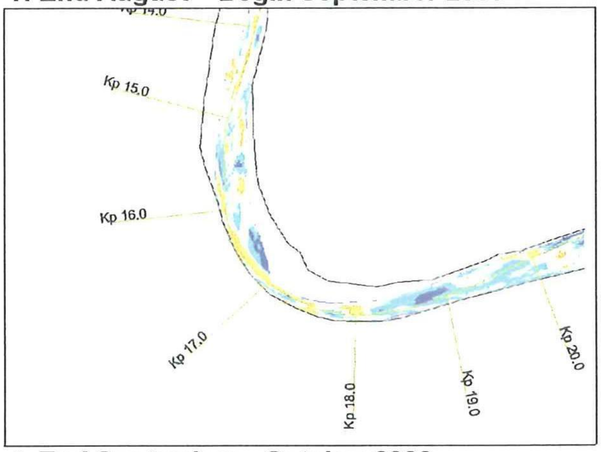
q. Begin August – End August 2000



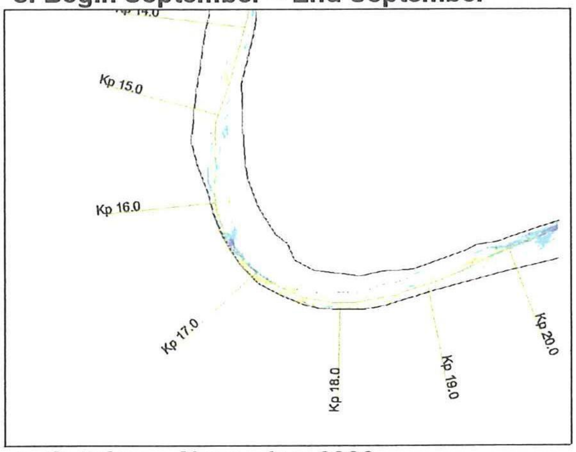
r. End August – Begin September 2000



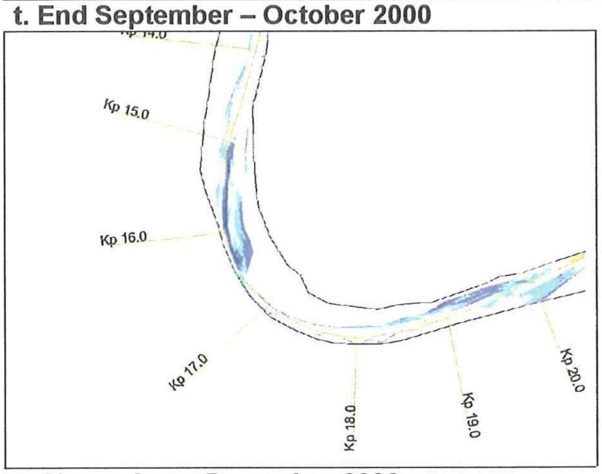
s. Begin September – End September



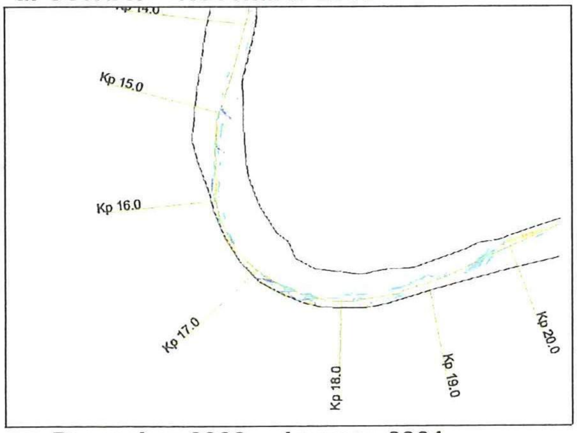
t. End September – October 2000



u. October - November 2000

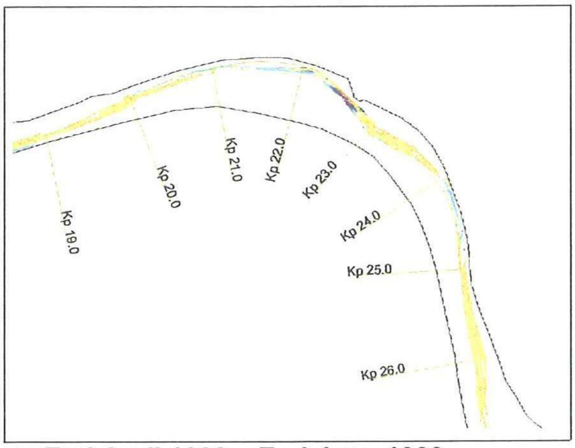


v. November – December 2000

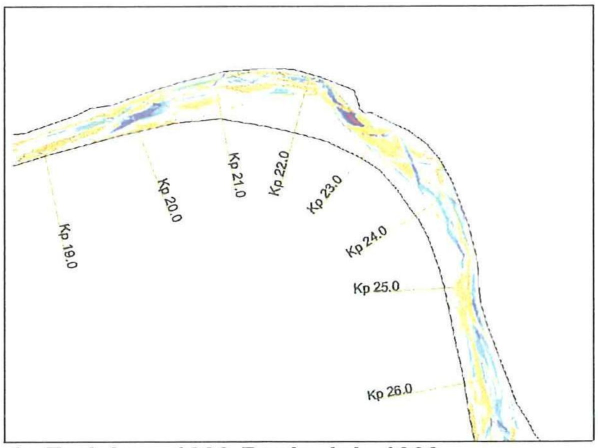


w. December 2000 – January 2001.

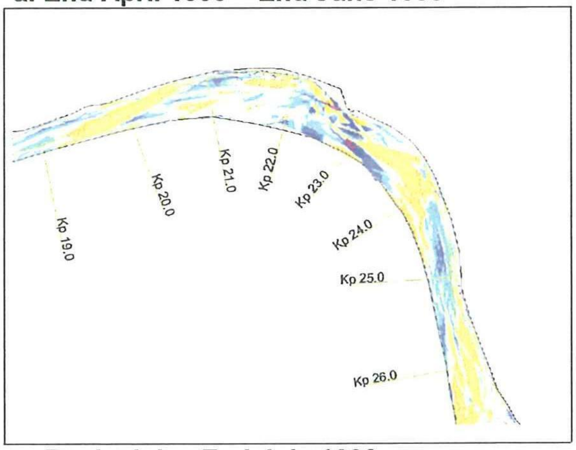
Figures VI.6 a-w, Kumarkhali, Kp 20.5-26.0, April 1999 to January 2001



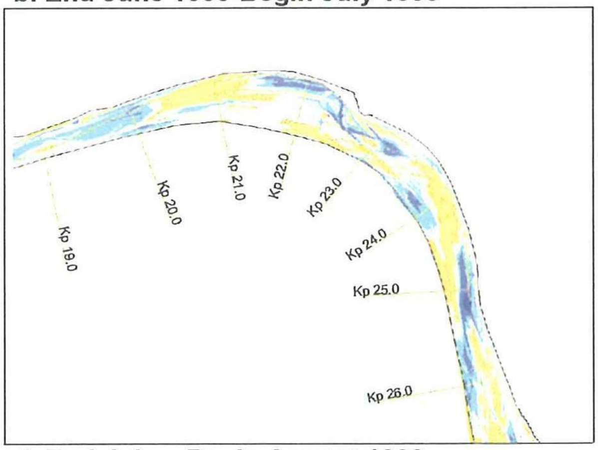
a. End April 1999 – End June 1999



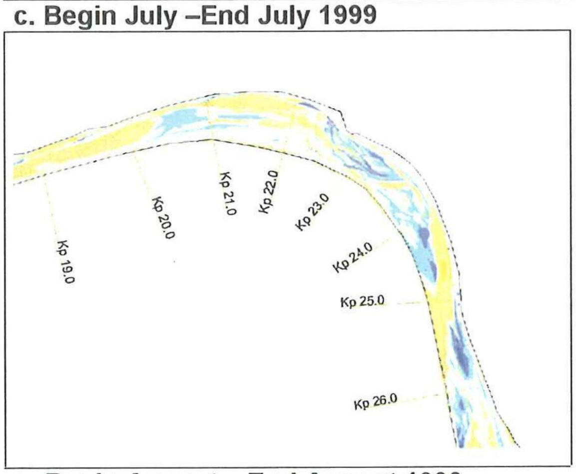
b. End June 1999-Begin July 1999



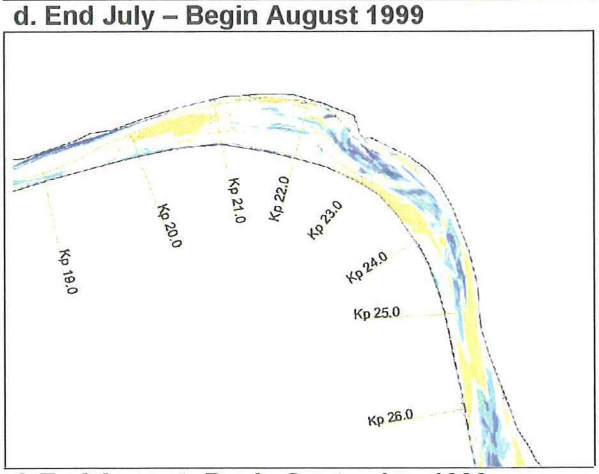
c. Begin July –End July 1999



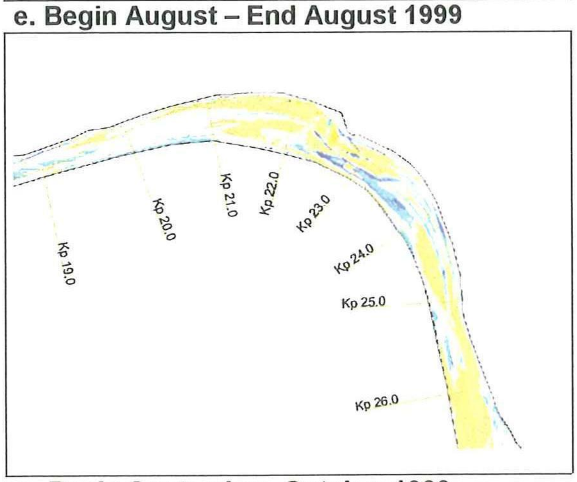
d. End July – Begin August 1999



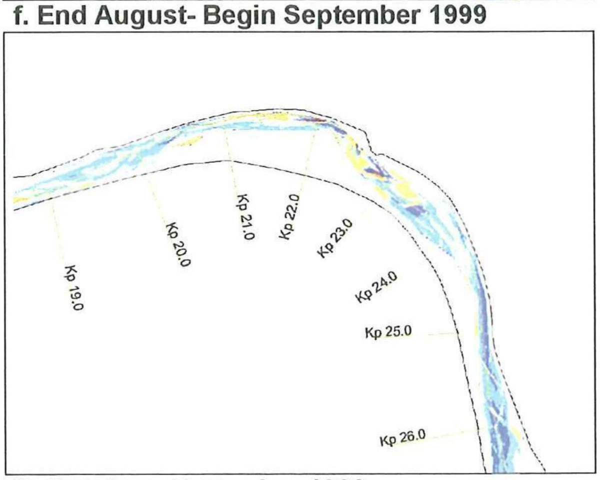
e. Begin August – End August 1999



f. End August- Begin September 1999

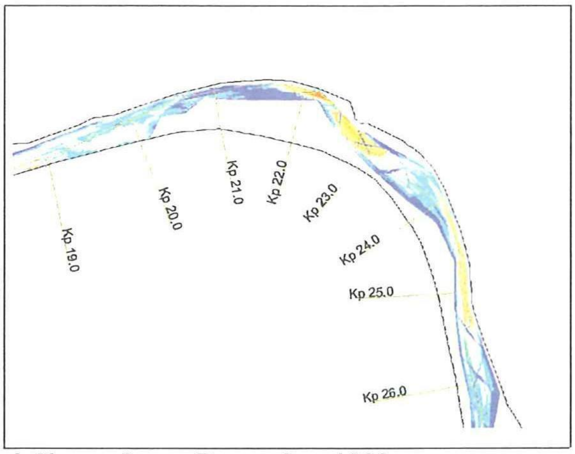


g. Begin September -October 1999

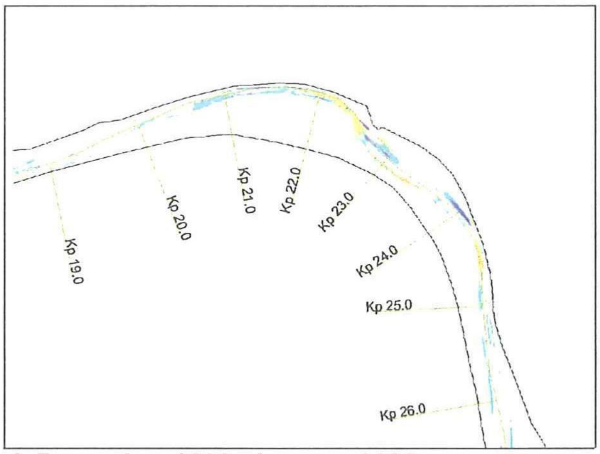


h. October –November 1999

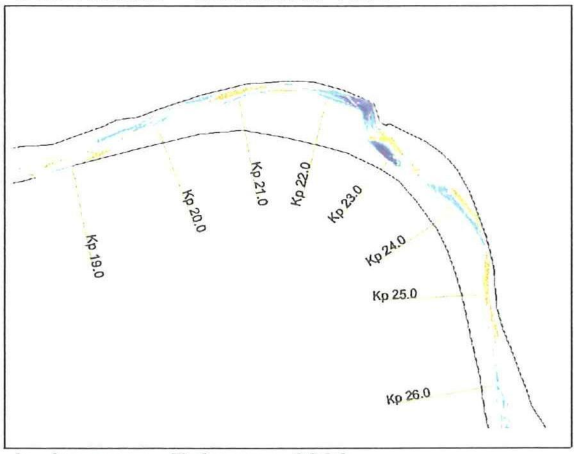
Figures VI.6 a-w, Kumarkhali, Kp 20.5-26.0, April 1999 to January 2001



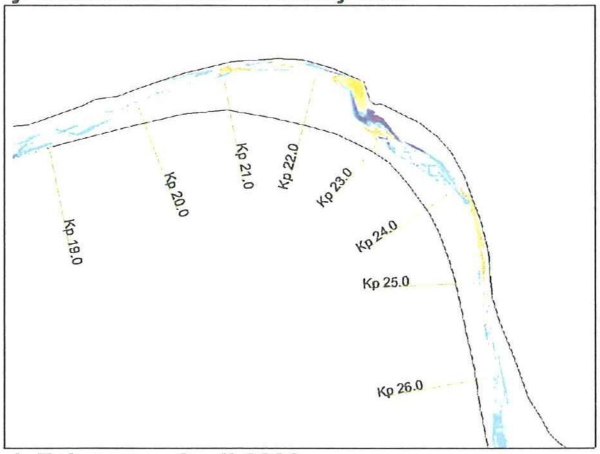
i. November – December 1999



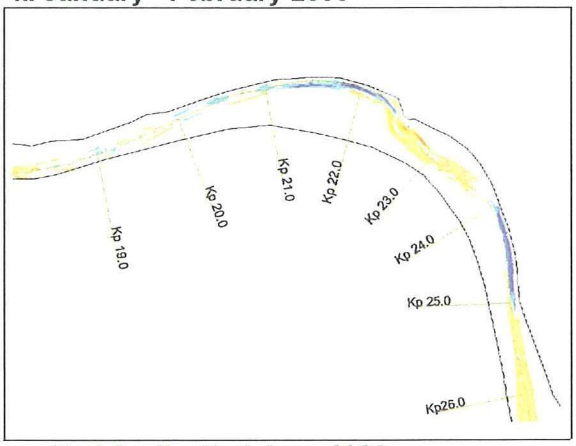
j. December 1999- January 2000



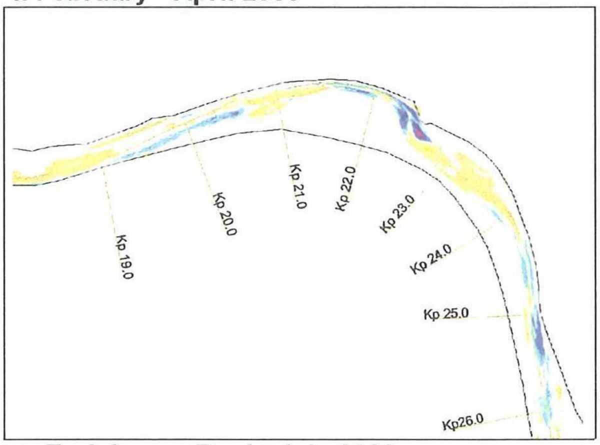
k. January - February 2000



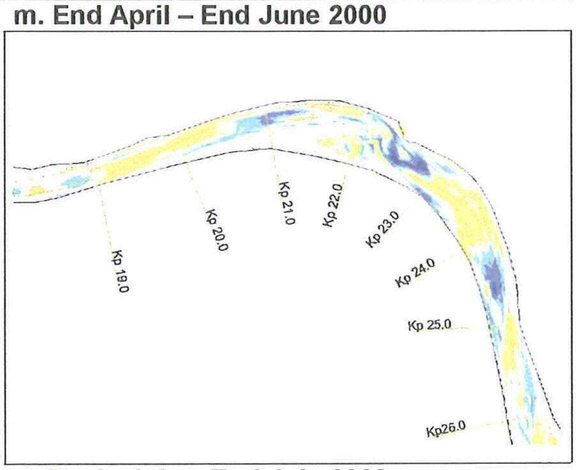
l. February - April 2000



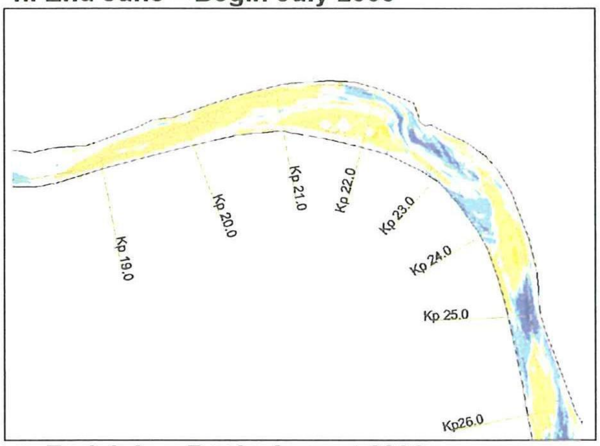
m. End April – End June 2000



n. End June – Begin July 2000

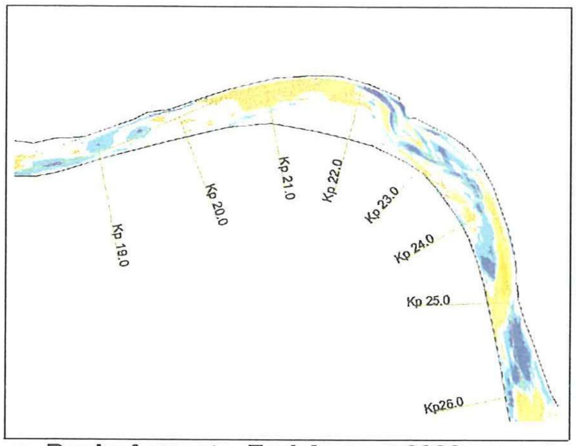


o. Begin July – End July 2000

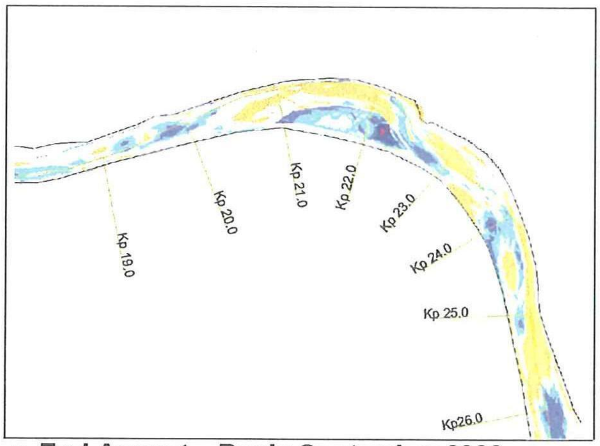


p. End July – Begin August 2000

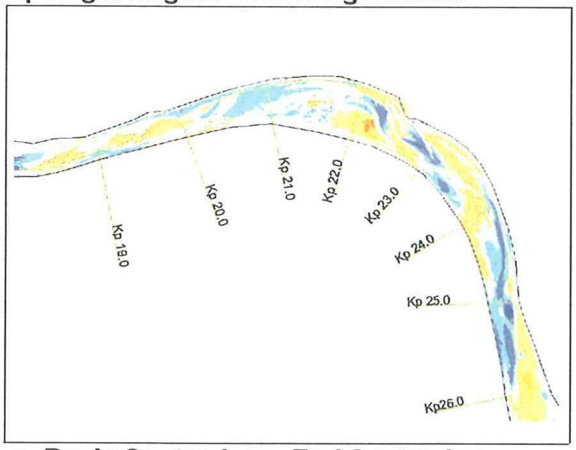
Figures VI.6 a-w, Kumarkhali, Kp 20.5-26.0, April 1999 to January 2001



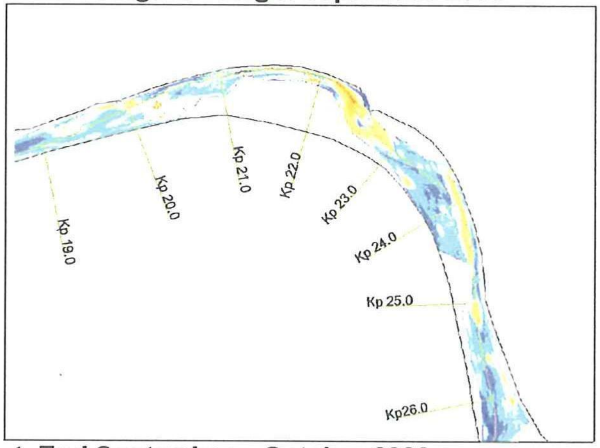
q. Begin August – End August 2000



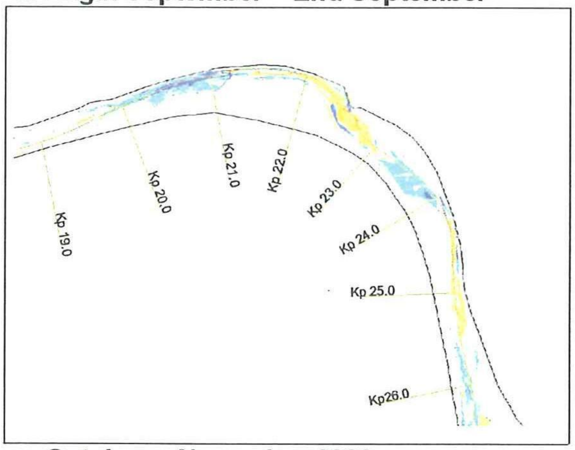
r. End August – Begin September 2000



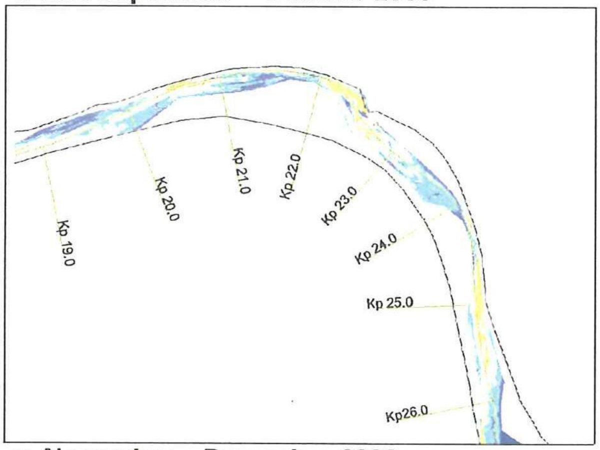
s. Begin September – End September



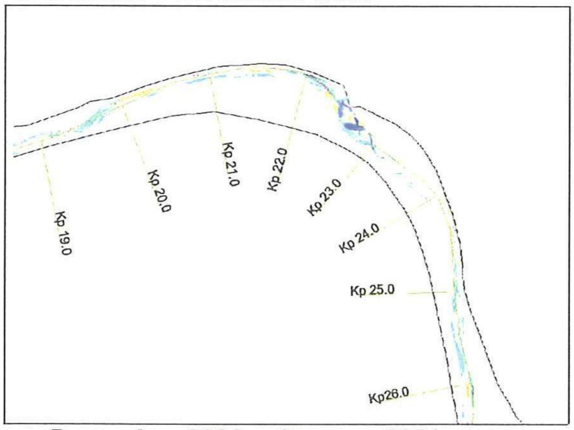
t. End September – October 2000



u. October - November 2000

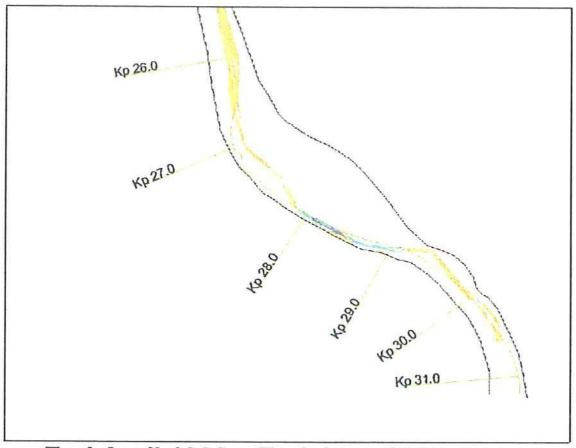


v. November – December 2000

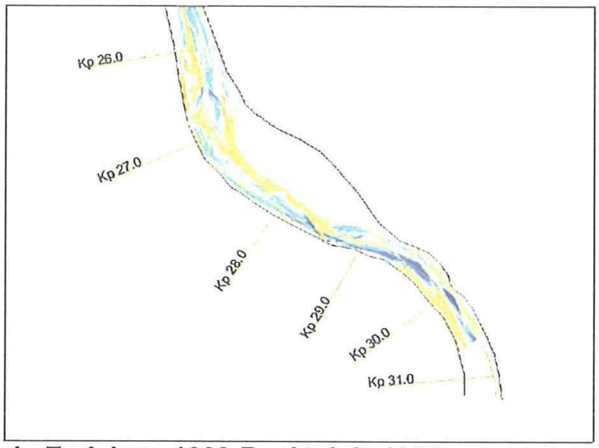


w. December 2000 – January 2001.

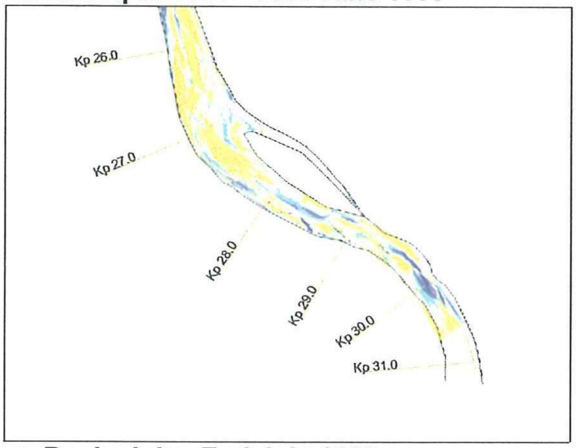
Figures VI.7 a-w, Khoksa, Kp 26.0-31.0, April 1999 to January 2001



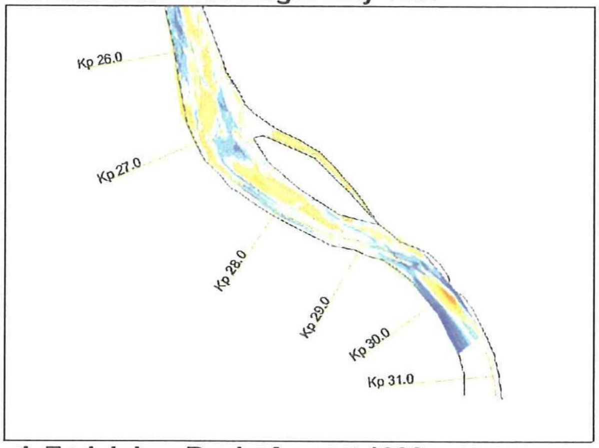
a. End April 1999 – End June 1999



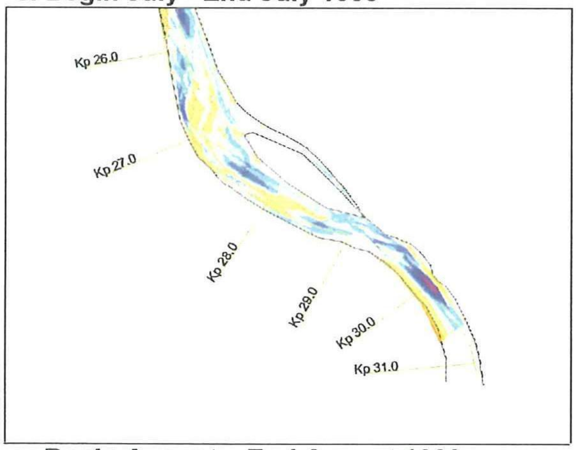
b. End June 1999-Begin July 1999



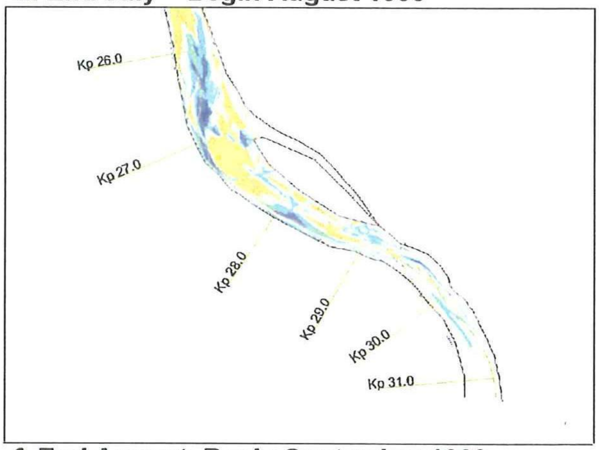
c. Begin July –End July 1999



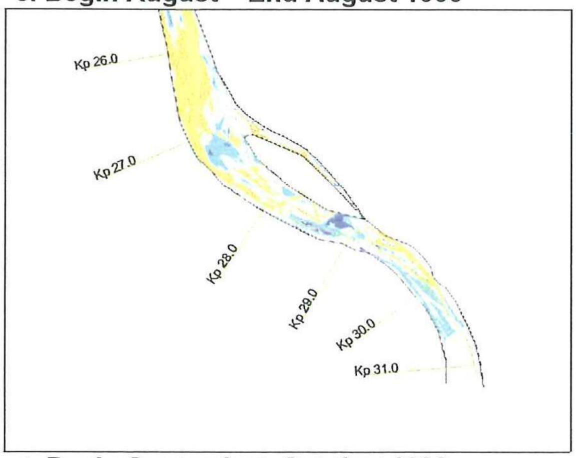
d. End July – Begin August 1999



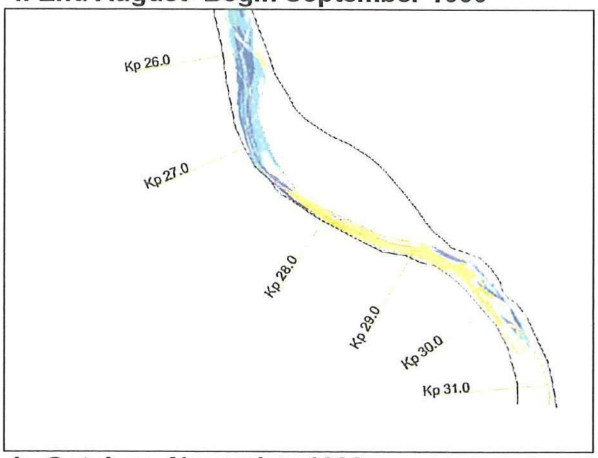
e. Begin August – End August 1999



f. End August- Begin September 1999

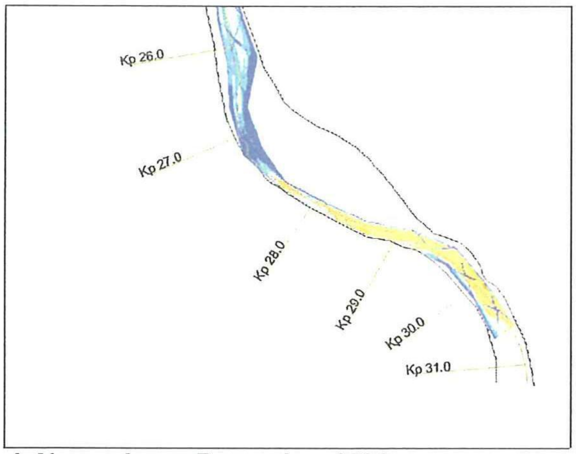


g. Begin September -October 1999

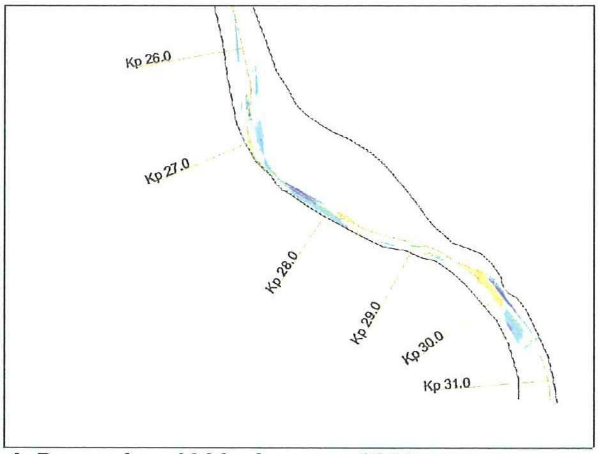


h. October –November 1999

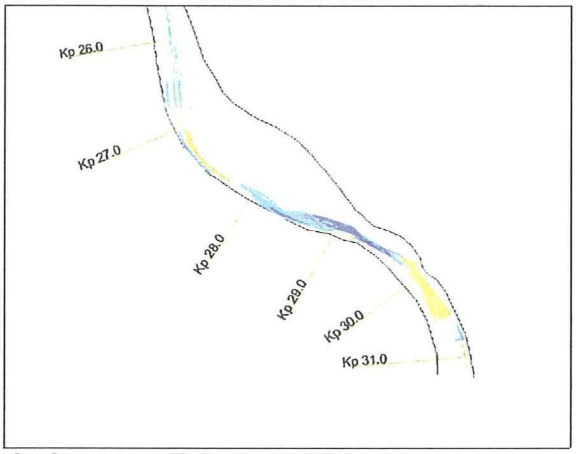
Figures VI.7 a-w, Khoksa, Kp 26.0-31.0, April 1999 to January 2001



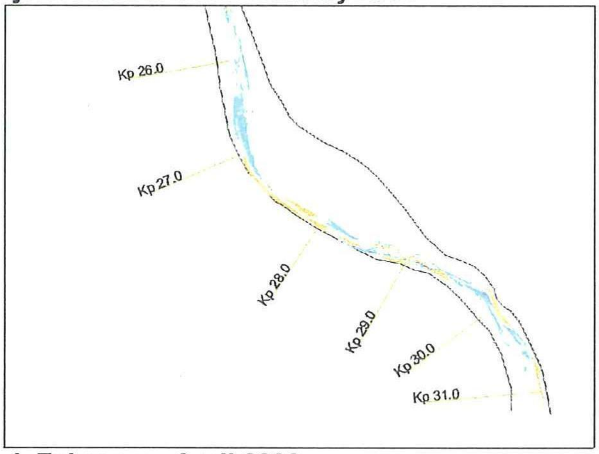
i. November – December 1999



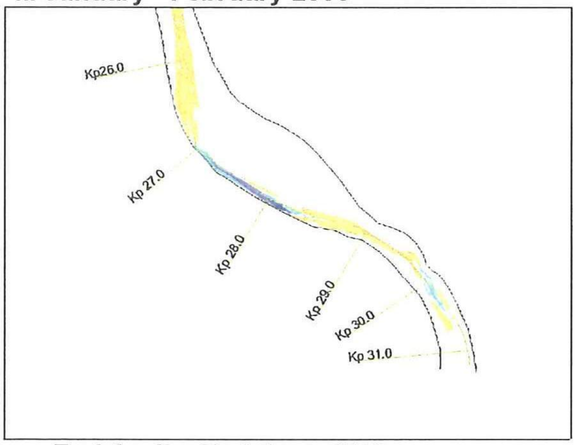
j. December 1999- January 2000



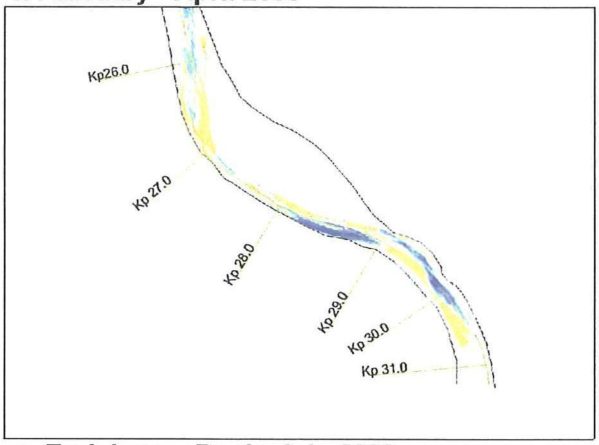
k. January - February 2000



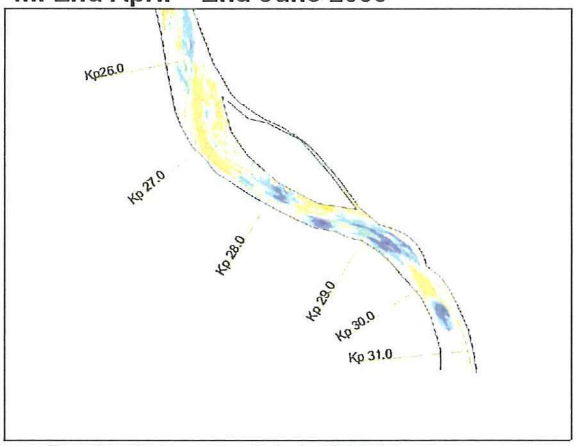
l. February - April 2000



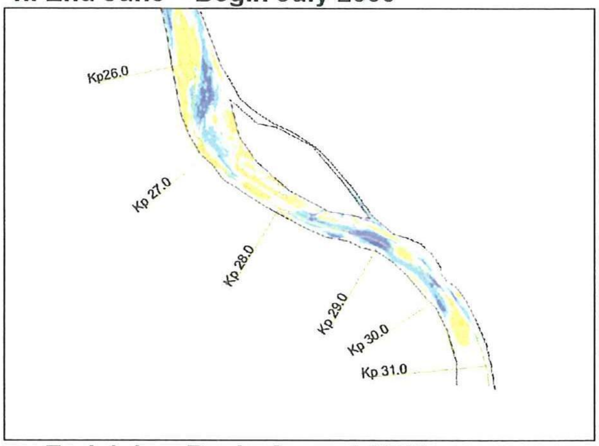
m. End April – End June 2000



n. End June – Begin July 2000

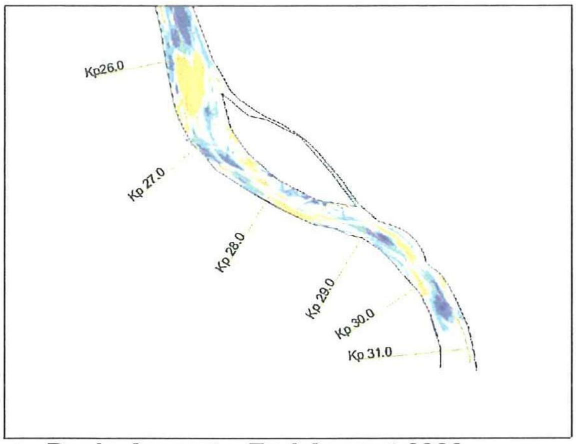


o. Begin July – End July 2000

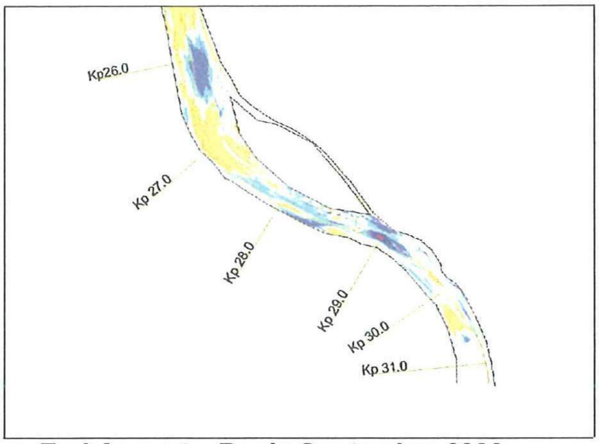


p. End July – Begin August 2000

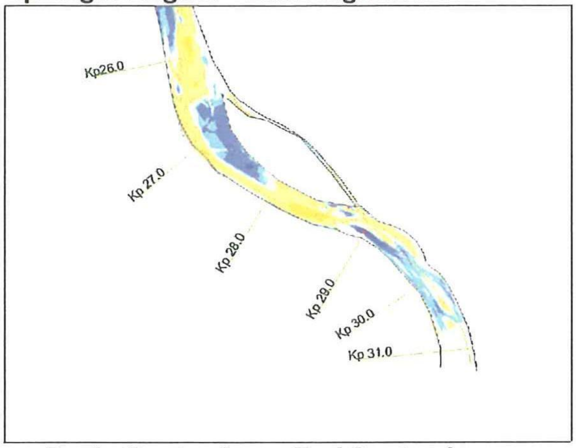
Figures VI.7 a-w, Khoksa, Kp 26.0-31.0, April 1999 to January 2001



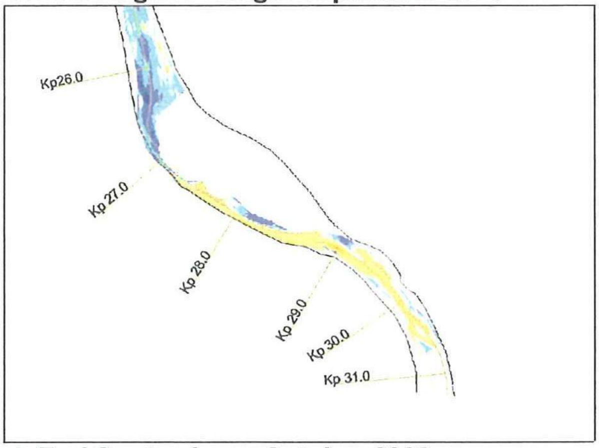
q. Begin August – End August 2000



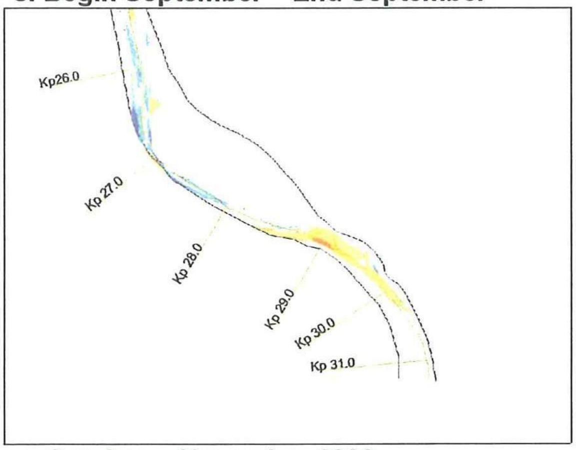
r. End August – Begin September 2000



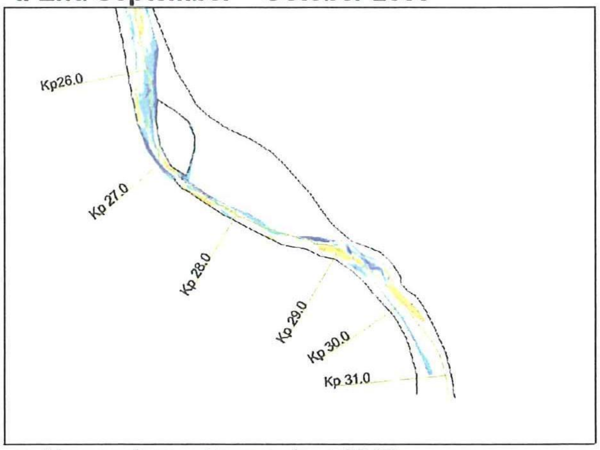
s. Begin September – End September



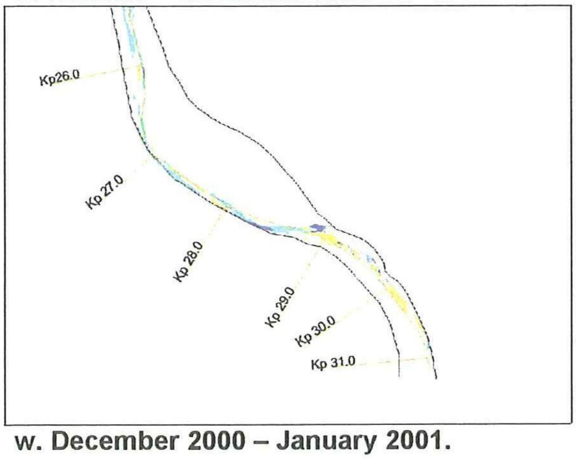
t. End September – October 2000



u. October - November 2000



v. November – December 2000

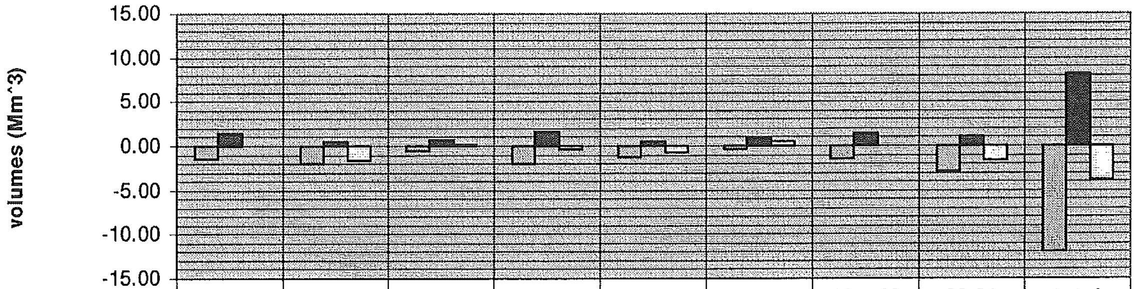


w. December 2000 – January 2001.

Appendix VII:

Sediment balances hydrological year, dredging season and monsoon

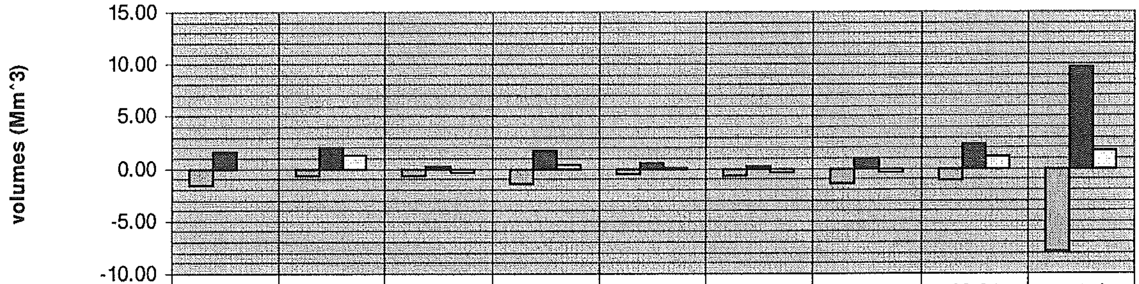
Apr 2000-Sep 2000



	0-3.5	3.5-7	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31	total
erosion	-1.48	-2.05	-0.51	-2.02	-1.27	-0.36	-1.37	-2.83	-11.88
deposition	1.49	0.48	0.71	1.64	0.48	0.82	1.36	1.13	8.12
balance	0.01	-1.56	0.20	-0.38	-0.78	0.46	-0.01	-1.69	-3.77

erosion deposition balance

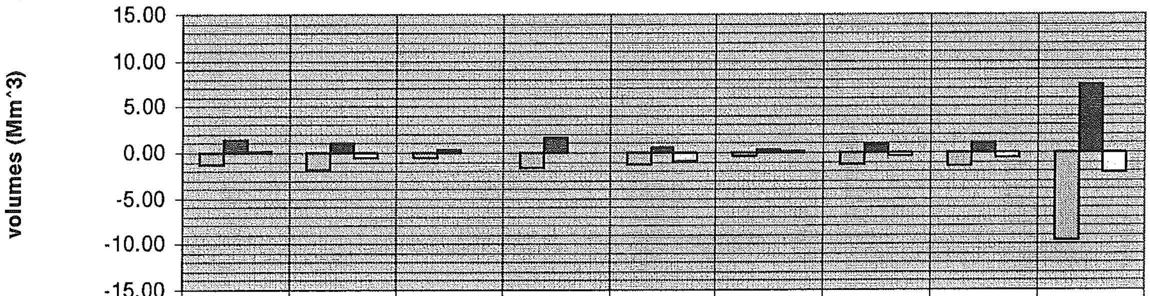
Sep 2000-Apr 2001



	0-3.5	3.5-7	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31	total
erosion	-1.63	-0.70	-0.60	-1.37	-0.49	-0.64	-1.38	-1.09	-7.89
deposition	1.54	1.97	0.29	1.71	0.59	0.27	1.03	2.30	9.71
balance	-0.09	1.28	-0.31	0.34	0.10	-0.37	-0.35	1.21	1.81

erosion deposition balance

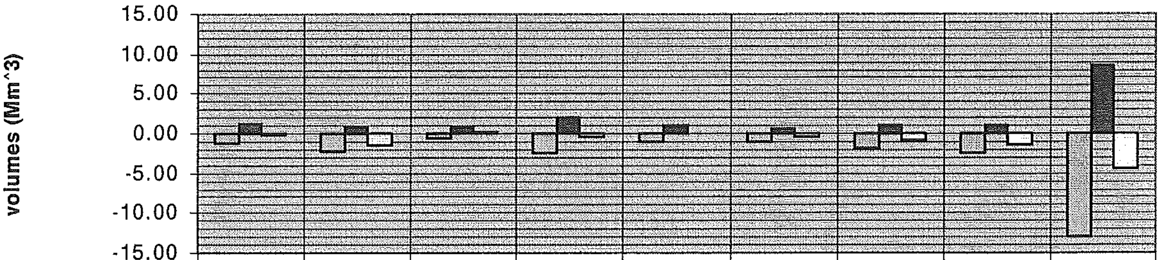
Apr 2000-Apr 2001



	0-3.5	3.5-7	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31	total
erosion	-1.25	-1.74	-0.53	-1.64	-1.35	-0.33	-1.29	-1.46	-9.58
deposition	1.38	1.12	0.45	1.59	0.52	0.44	0.94	1.00	7.43
balance	0.13	-0.62	-0.09	-0.04	-0.83	0.11	-0.35	-0.47	-2.15

erosion deposition balance

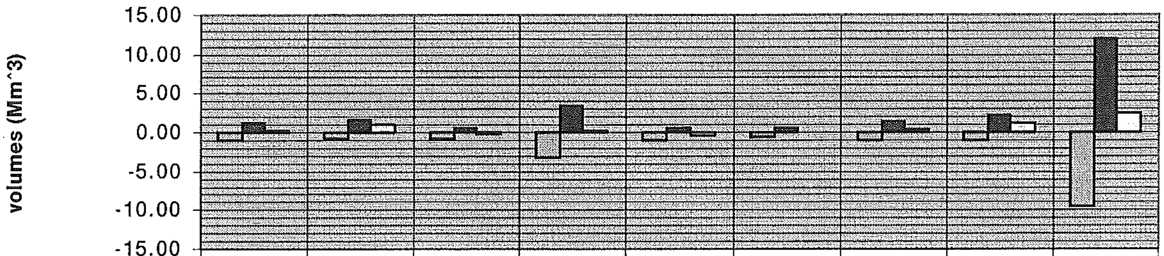
Apr 1999- Sep 1999



	0-3.5	3.5-7	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31	total
erosion	-1.32	-2.29	-0.67	-2.48	-1.05	-1.04	-1.75	-2.48	-13.05
deposition	1.12	0.84	0.87	2.02	1.03	0.64	0.98	1.06	8.55
balance	-0.20	-1.45	0.20	-0.46	-0.02	-0.40	-0.78	-1.41	-4.50

erosion deposition balance

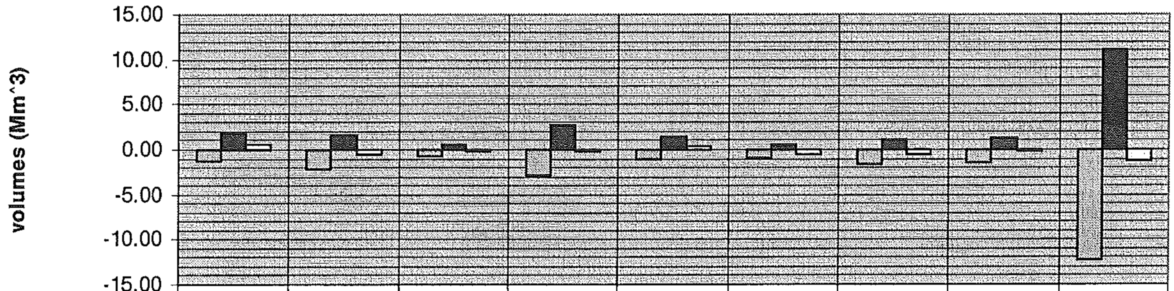
Sep 1999-Apr 2000



	0-3.5	3.5-7	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31	total
erosion	-1.01	-0.72	-0.87	-3.17	-1.07	-0.57	-1.11	-1.01	-9.53
deposition	1.21	1.68	0.58	3.45	0.67	0.63	1.47	2.20	11.90
balance	0.21	0.97	-0.30	0.28	-0.39	0.06	0.36	1.18	2.37

erosion deposition balance

Apr 1999-Apr 2000



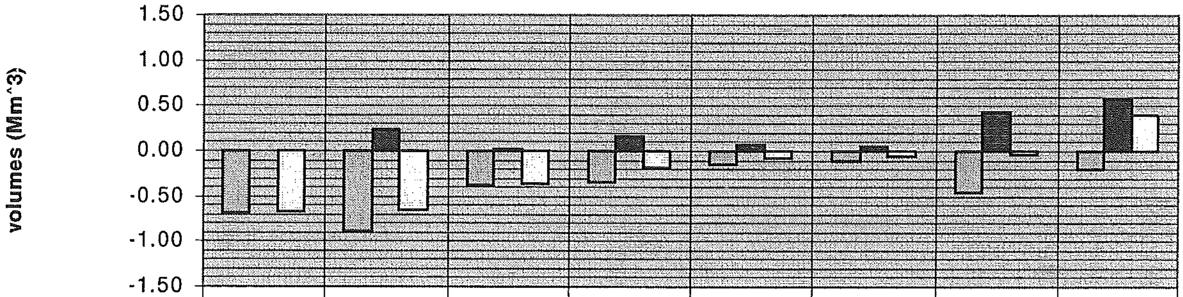
	0-3.5	3.5-7	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31	total
erosion	-1.36	-2.21	-0.69	-2.88	-1.09	-0.97	-1.55	-1.48	-12.21
deposition	1.88	1.66	0.60	2.62	1.38	0.51	1.03	1.29	10.97
balance	0.53	-0.55	-0.09	-0.26	0.29	-0.46	-0.52	-0.18	-1.25

erosion deposition balance

Appendix VIII:

Detailed sediment balances April 1999 – January 2001

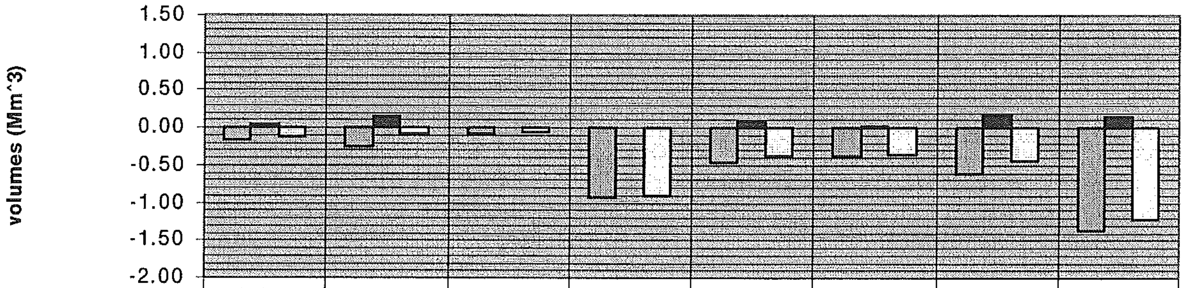
Oct-Nov 2000



	0-3.5	3.5-7	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	-0.68	-0.88	-0.38	-0.35	-0.14	-0.10	-0.46	-0.19
deposition	0.00	0.23	0.02	0.17	0.07	0.05	0.43	0.59
balance	-0.67	-0.64	-0.35	-0.18	-0.07	-0.06	-0.03	0.39

erosion deposition balance

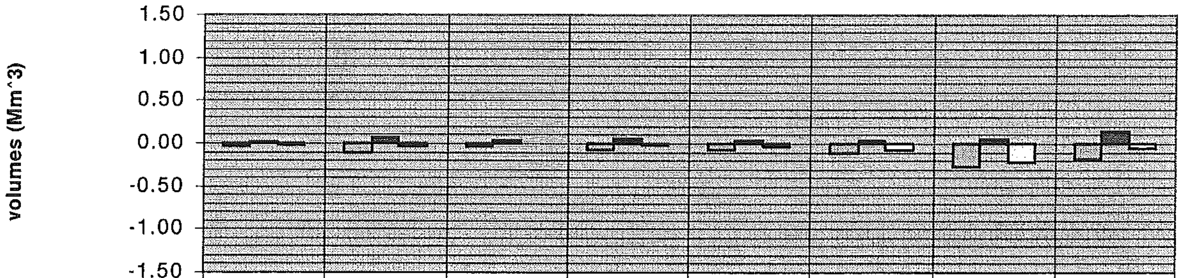
Nov-Dec 2000



	0-3.5	3.5-7	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	-0.17	-0.24	-0.08	-0.92	-0.45	-0.37	-0.61	-1.37
deposition	0.04	0.16	0.01	0.01	0.08	0.02	0.18	0.15
balance	-0.13	-0.09	-0.07	-0.91	-0.37	-0.35	-0.43	-1.22

erosion deposition balance

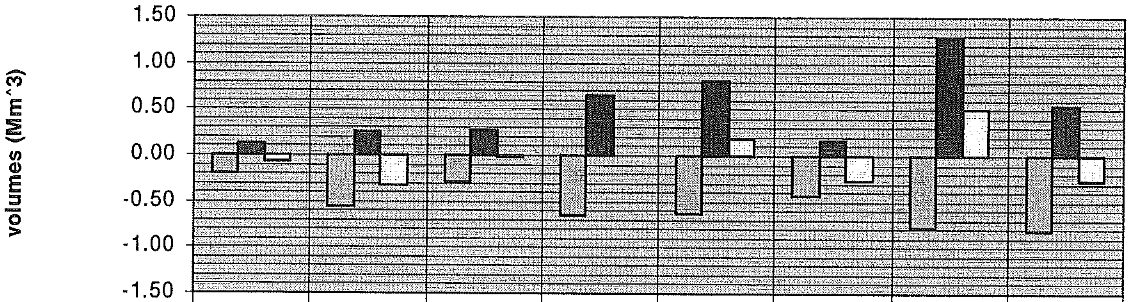
Dec 2000-Jan 2001



	0-3.5	3.5-7	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	-0.03	-0.11	-0.03	-0.06	-0.08	-0.11	-0.26	-0.19
deposition	0.02	0.08	0.03	0.05	0.03	0.04	0.05	0.14
balance	-0.01	-0.03	0.00	-0.02	-0.04	-0.07	-0.21	-0.05

erosion deposition balance

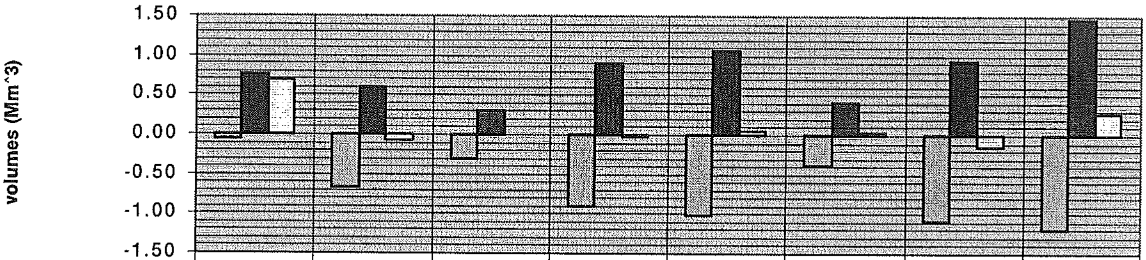
end Aug-begin Sep 2000



	0-3.5	3.5-7	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	-0.20	-0.57	-0.29	-0.66	-0.64	-0.44	-0.78	-0.82
deposition	0.13	0.25	0.27	0.66	0.82	0.16	1.29	0.55
balance	-0.07	-0.32	-0.02	0.00	0.18	-0.28	0.51	-0.27

erosion deposition balance

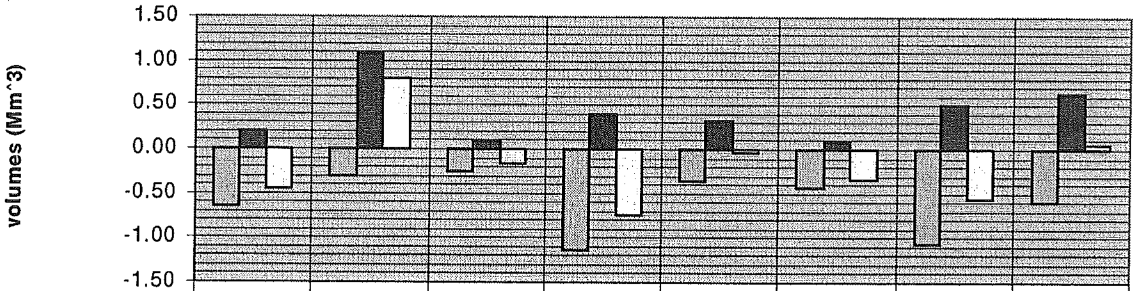
begin Sep-end Sep 2000



	0-3.5	3.5-7	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	-0.06	-0.67	-0.30	-0.91	-1.00	-0.37	-1.09	-1.19
deposition	0.76	0.59	0.30	0.90	1.06	0.41	0.94	1.46
balance	0.70	-0.07	-0.01	-0.01	0.05	0.03	-0.15	0.27

erosion deposition balance

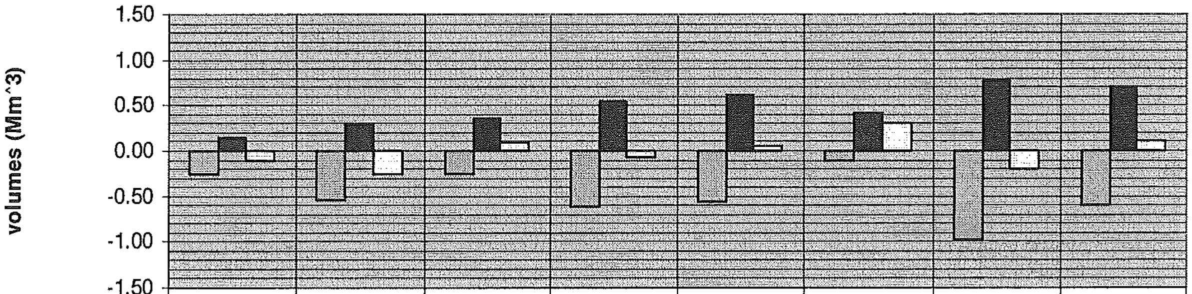
end Sep- Oct 2000



	0-3.5	3.5-7	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	-0.65	-0.30	-0.25	-1.14	-0.36	-0.43	-1.07	-0.59
deposition	0.20	1.09	0.09	0.40	0.32	0.09	0.51	0.64
balance	-0.45	0.79	-0.17	-0.74	-0.04	-0.34	-0.56	0.05

erosion deposition balance

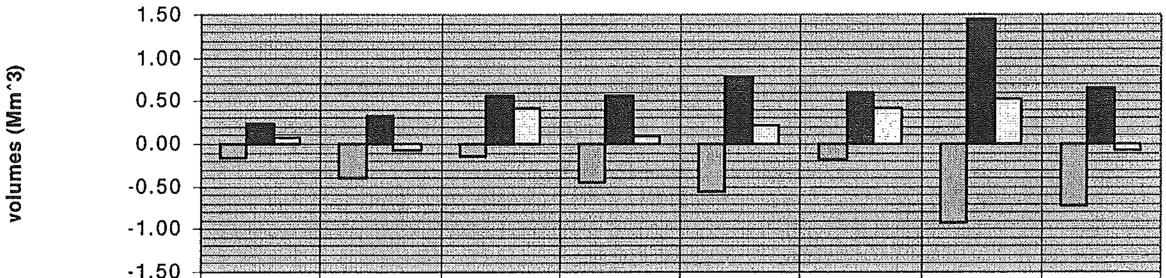
begin Jul-end Jul 2000



	0-3.5	3.5-7	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	-0.25	-0.54	-0.25	-0.61	-0.57	-0.11	-0.98	-0.60
deposition	0.14	0.28	0.35	0.55	0.62	0.41	0.78	0.71
balance	-0.12	-0.25	0.10	-0.07	0.05	0.31	-0.20	0.11

erosion deposition balance

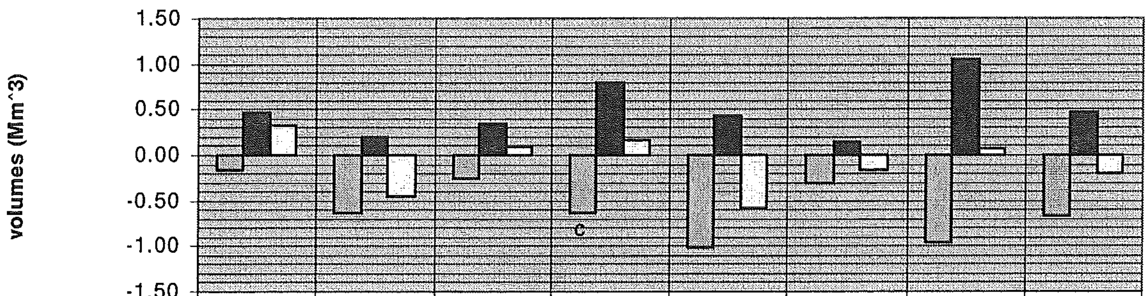
end Jul-begin Aug 2000



	0-3.5	3.5-7	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-31	total
erosion	-0.16	-0.40	-0.14	-0.46	-0.56	-0.18	-0.93	-0.72
deposition	0.24	0.33	0.56	0.56	0.77	0.60	1.45	0.65
balance	0.08	-0.08	0.42	0.10	0.22	0.42	0.52	-0.07

erosion deposition balance

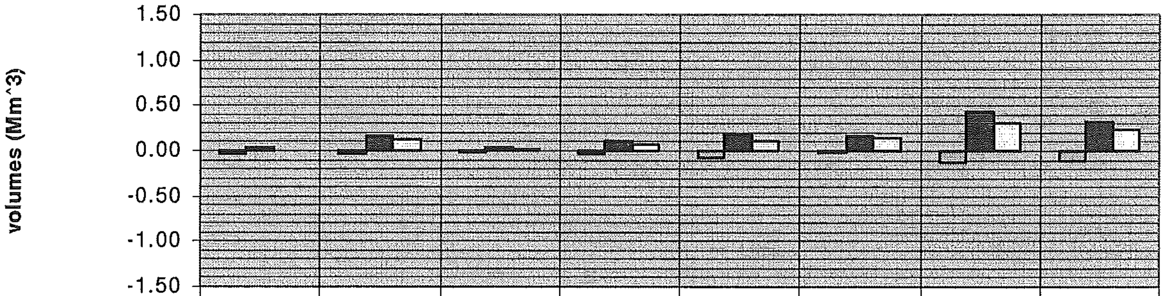
begin Aug-end Aug 2000



	0-3.5	3.5-7	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	-0.16	-0.64	-0.26	-0.63	-1.01	-0.31	-0.97	-0.68
deposition	0.48	0.19	0.35	0.79	0.43	0.15	1.05	0.48
balance	0.32	-0.44	0.09	0.16	-0.58	-0.16	0.08	-0.20

erosion deposition balance

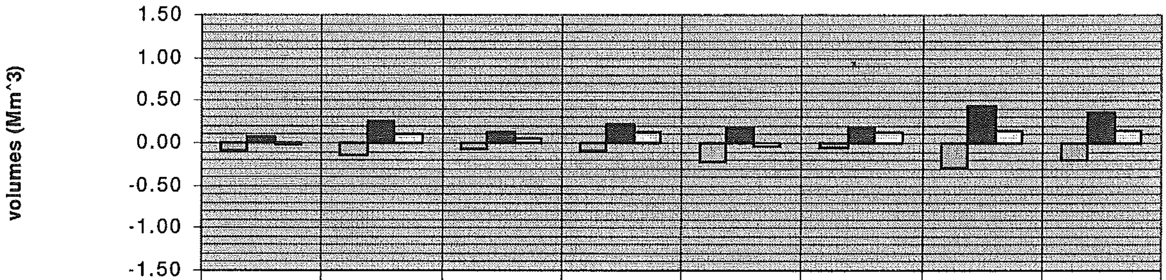
end Apr-begin Jun 2000



	0-3.5	3.5-7	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-31	total
erosion	-0.04	-0.04	-0.01	-0.04	-0.07	-0.02	-0.13	-0.10
deposition	0.03	0.16	0.04	0.11	0.17	0.15	0.44	0.33
balance	-0.01	0.12	0.02	0.07	0.10	0.14	0.30	0.23

erosion deposition balance

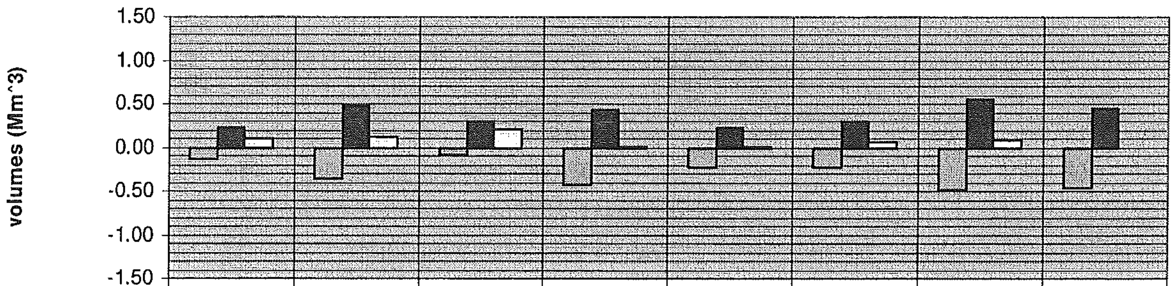
begin Jun-end Jun 2000



	0-3.5	3.5-7	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-31	20.5-31
erosion	-0.09	-0.15	-0.07	-0.08	-0.22	-0.06	-0.29	-0.20
deposition	0.07	0.25	0.12	0.22	0.18	0.18	0.44	0.35
balance	-0.02	0.10	0.05	0.13	-0.04	0.12	0.15	0.15

erosion deposition balance

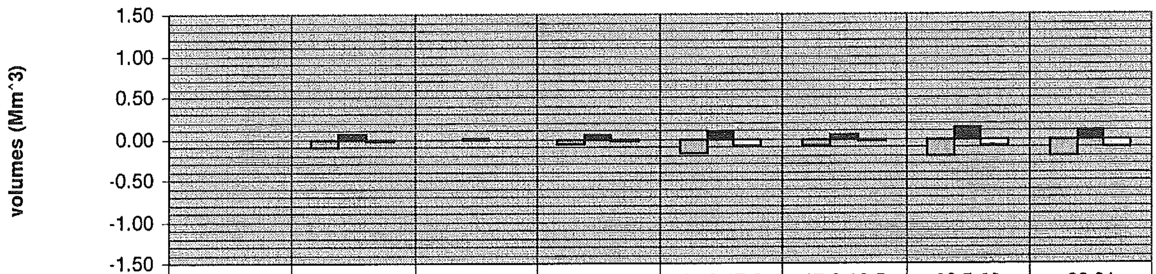
end Jun-begin Jul 2000



	0-3.5	3.5-7	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-31	total
erosion	-0.14	-0.36	-0.09	-0.42	-0.22	-0.23	-0.48	-0.46
deposition	0.24	0.48	0.31	0.43	0.23	0.30	0.56	0.45
balance	0.10	0.12	0.22	0.01	0.01	0.07	0.08	-0.01

erosion deposition balance

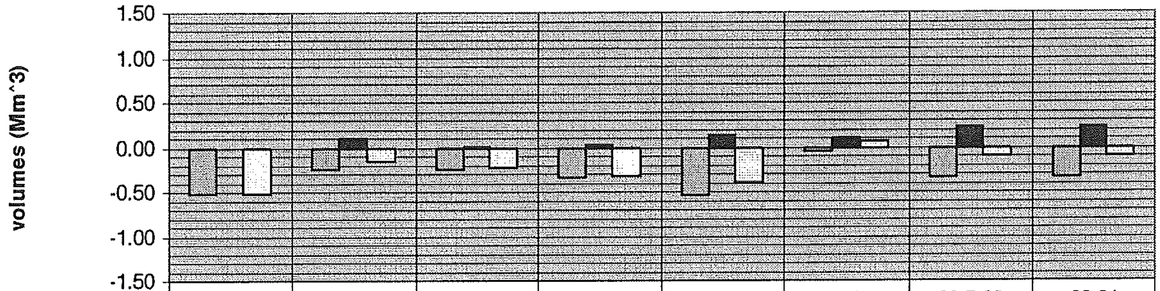
Dec 1999-Jan 2000



	0.0-3.5	3.5-7.0	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	0.00	-0.09	0.00	-0.07	-0.18	-0.07	-0.21	-0.21
deposition	0.00	0.07	0.00	0.04	0.09	0.05	0.13	0.11
balance	0.00	-0.02	0.00	-0.02	-0.09	-0.03	-0.08	-0.11

erosion deposition balance

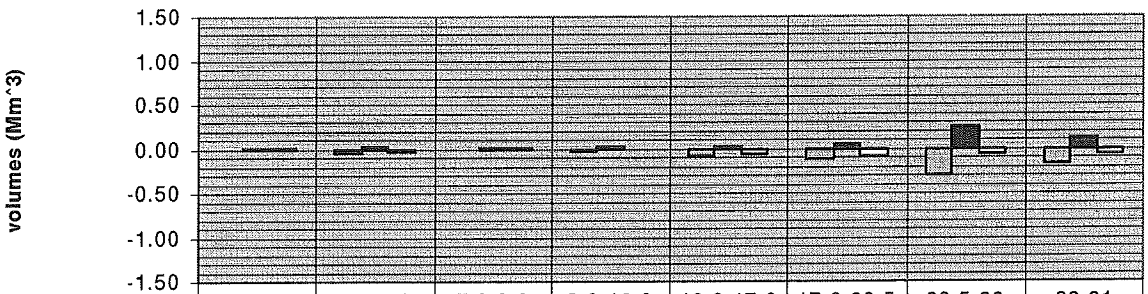
Jan-begin Feb 2000



	0.0-3.5	3.5-7.0	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	-0.52	-0.25	-0.24	-0.34	-0.53	-0.04	-0.33	-0.33
deposition	0.00	0.10	0.01	0.03	0.13	0.11	0.23	0.23
balance	-0.52	-0.15	-0.22	-0.32	-0.40	0.07	-0.10	-0.10

erosion deposition balance

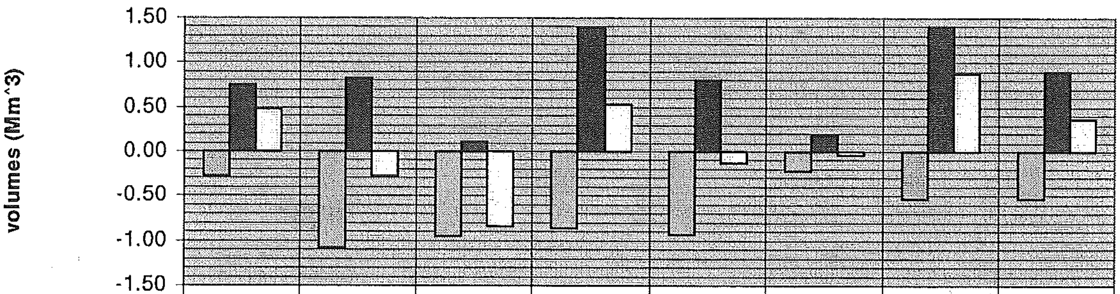
begin Feb- end Apr 2000



	0.0-3.5	3.5-7.0	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	-0.01	-0.04	-0.01	-0.02	-0.08	-0.12	-0.30	-0.18
deposition	0.01	0.02	0.01	0.02	0.02	0.05	0.24	0.11
balance	0.01	-0.02	0.00	0.00	-0.06	-0.07	-0.06	-0.07

erosion deposition balance

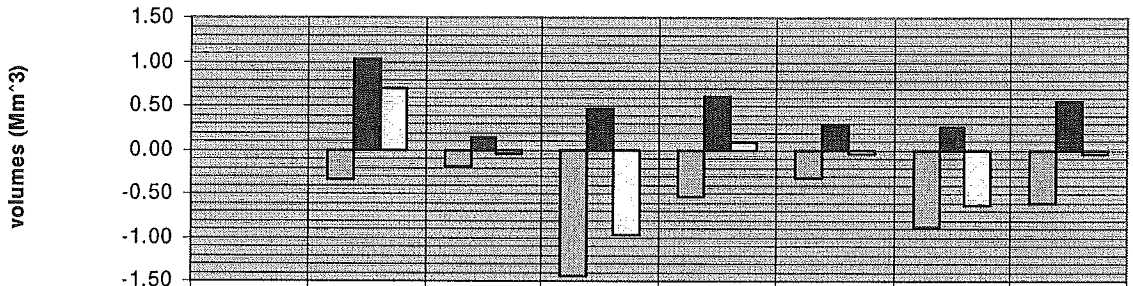
begin Sep-end Okt 1999



	0.0-3.5	3.5-7.0	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	-0.28	-1.08	-0.96	-0.86	-0.94	-0.23	-0.52	-0.53
deposition	0.75	0.82	0.12	1.39	0.81	0.19	1.41	0.89
balance	0.47	-0.27	-0.84	0.52	-0.13	-0.04	0.89	0.36

erosion deposition balance

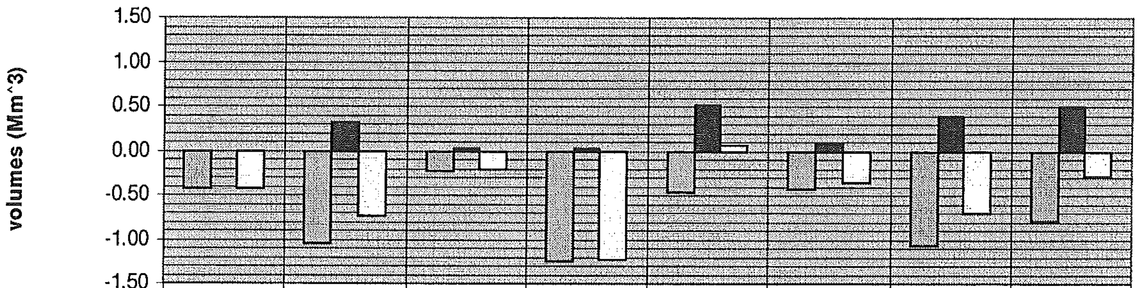
end Okt-Nov 1999



	0.0-3.5	3.5-7.0	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	0.00	-0.33	-0.18	-1.45	-0.53	-0.32	-0.88	-0.60
deposition	0.00	1.03	0.14	0.47	0.62	0.28	0.26	0.56
balance	0.00	0.69	-0.05	-0.98	0.08	-0.05	-0.62	-0.04

erosion deposition balance

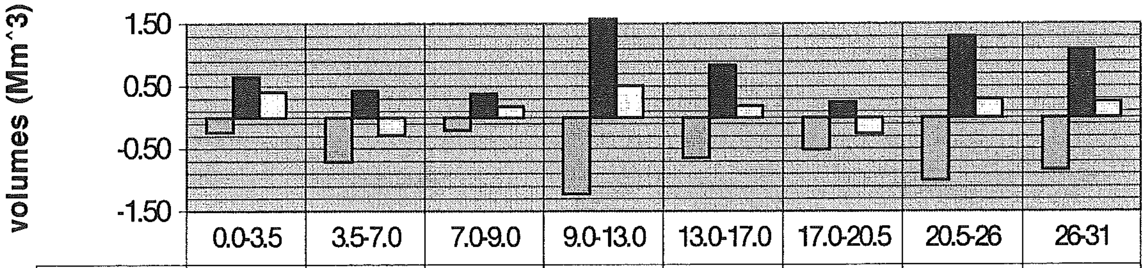
Nov-Dec 1999



	0.0-3.5	3.5-7.0	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	-0.43	-1.05	-0.23	-1.25	-0.46	-0.43	-1.06	-0.78
deposition	0.00	0.32	0.02	0.03	0.53	0.08	0.39	0.51
balance	-0.43	-0.73	-0.21	-1.23	0.07	-0.35	-0.71	-0.28

erosion deposition balance

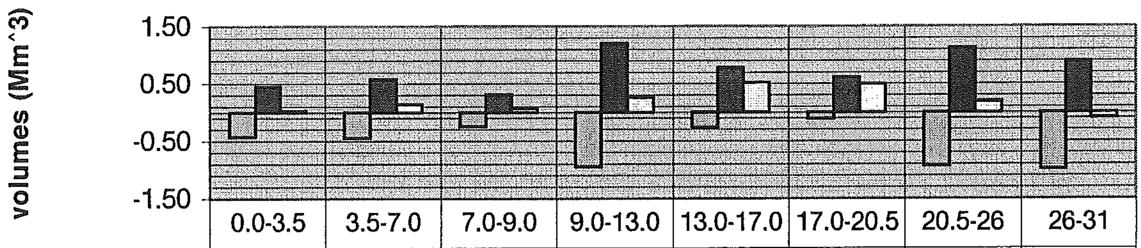
end Jul-begin Aug 1999



	0.0-3.5	3.5-7.0	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	-0.24	-0.71	-0.20	-1.22	-0.65	-0.51	-1.00	-0.84
deposition	0.65	0.43	0.38	1.73	0.83	0.25	1.30	1.09
balance	0.41	-0.28	0.18	0.51	0.18	-0.26	0.29	0.25

erosion deposition balance

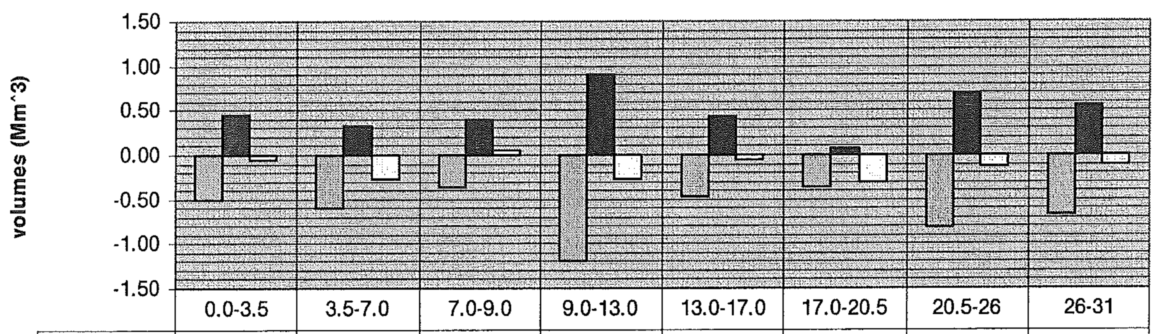
begin Aug-end Aug 1999



	0.0-3.5	3.5-7.0	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	-0.43	-0.45	-0.25	-0.95	-0.26	-0.11	-0.94	-0.99
deposition	0.46	0.58	0.31	1.21	0.78	0.61	1.13	0.89
balance	0.03	0.14	0.07	0.26	0.52	0.50	0.19	-0.10

erosion deposition balance

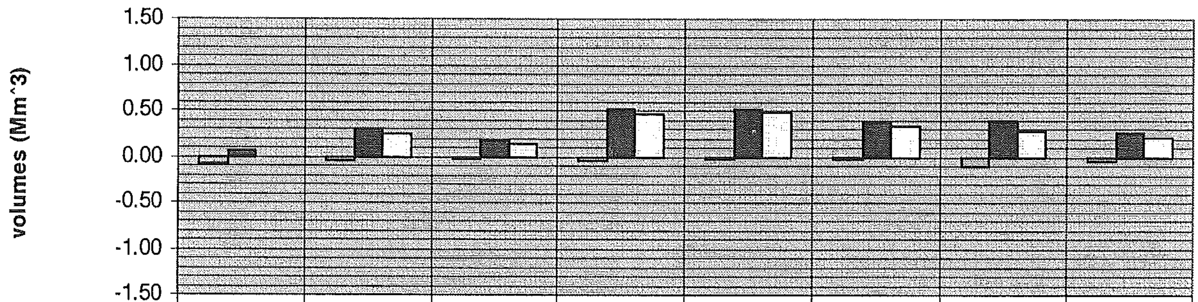
end Aug-begin Sep 1999



	0.0-3.5	3.5-7.0	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	-0.51	-0.59	-0.36	-1.18	-0.48	-0.37	-0.81	-0.68
deposition	0.45	0.32	0.40	0.91	0.43	0.07	0.68	0.56
balance	-0.06	-0.27	0.05	-0.28	-0.05	-0.30	-0.13	-0.12

erosion deposition balance

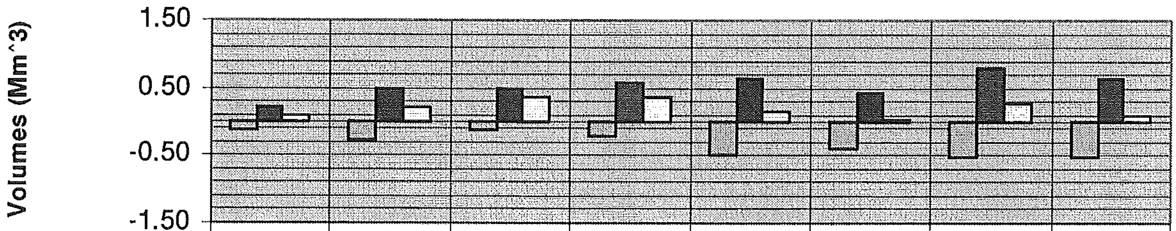
begin Apr- end Jun 1999



	0.0-3.5	3.5-7.0	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26.0	26-31
erosion	-0.08	-0.04	-0.02	-0.05	-0.02	-0.03	-0.10	-0.05
deposition	0.06	0.30	0.16	0.51	0.51	0.37	0.39	0.27
balance	-0.01	0.25	0.14	0.46	0.49	0.34	0.29	0.22

erosion ■ deposition □ balance

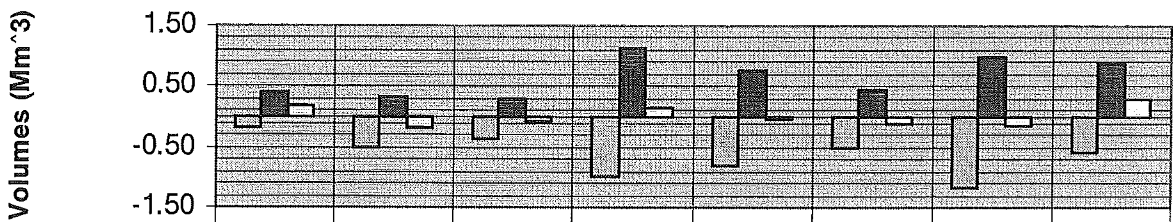
end Jun-begin Jul 1999



	0.0-3.5	3.5-7.0	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	-0.11	-0.29	-0.11	-0.22	-0.48	-0.40	-0.51	-0.53
deposition	0.20	0.50	0.48	0.57	0.64	0.44	0.79	0.64
balance	0.09	0.21	0.36	0.35	0.16	0.04	0.28	0.11

erosion ■ deposition □ balance

begin Jul-end Jul 1999



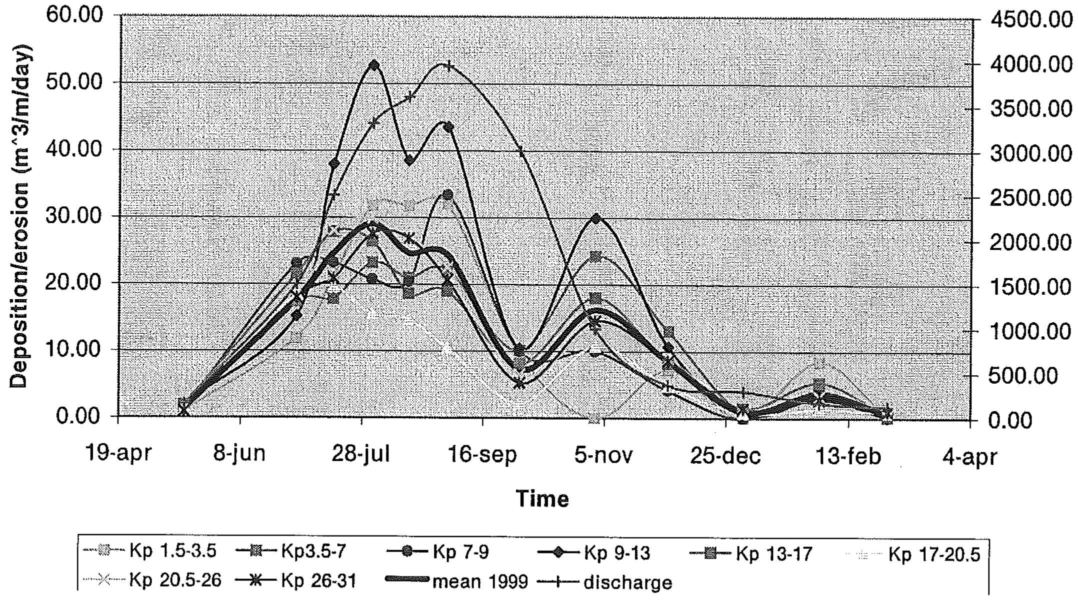
	0.0-3.5	3.5-7.0	7.0-9.0	9.0-13.0	13.0-17.0	17.0-20.5	20.5-26	26-31
erosion	-0.20	-0.52	-0.36	-0.98	-0.81	-0.53	-1.16	-0.58
deposition	0.39	0.35	0.29	1.15	0.75	0.43	1.00	0.88
balance	0.19	-0.17	-0.06	0.16	-0.05	-0.10	-0.16	0.30

erosion ■ deposition □ balance

Appendix IX:

Deposition and erosion rates

Deposition/erosion rates in the Upper Gorai River, 1999



Deposition/erosion rates in the Upper Gorai, 2000

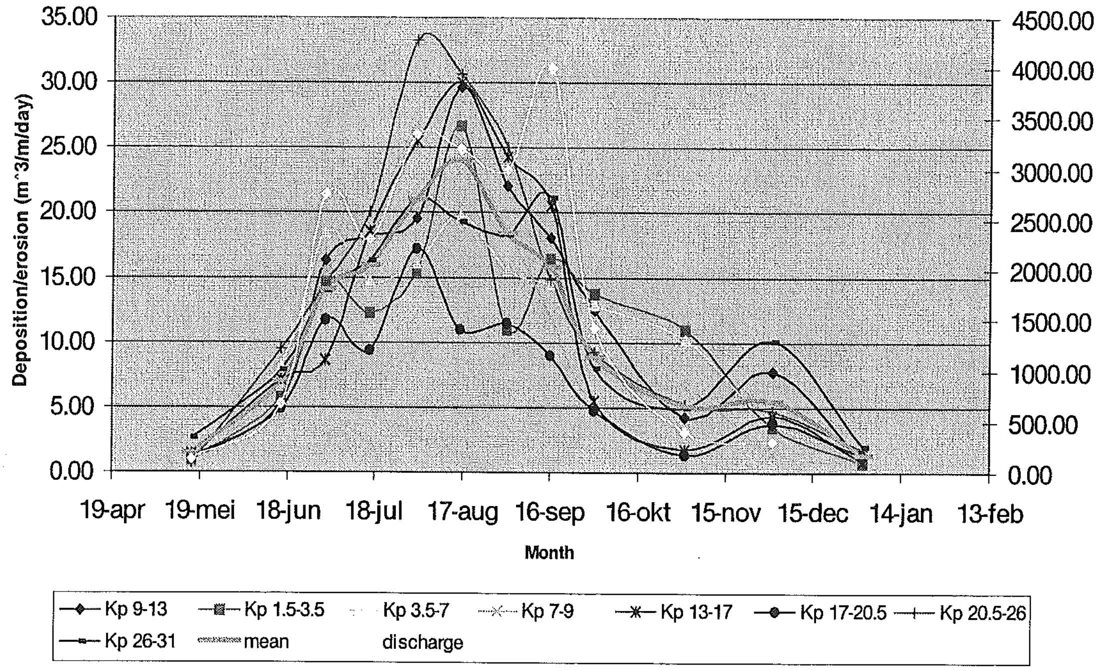
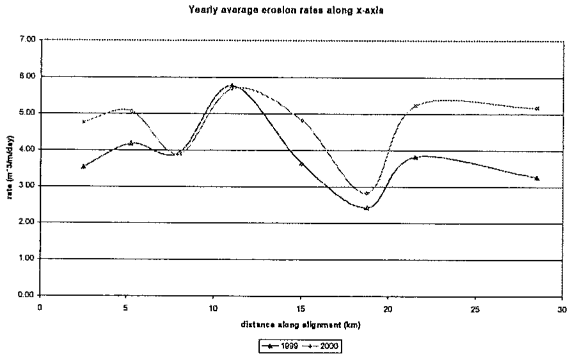
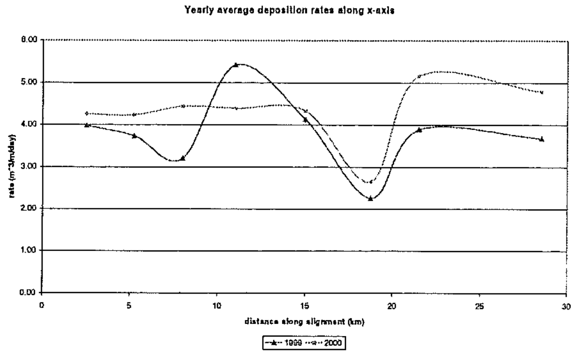
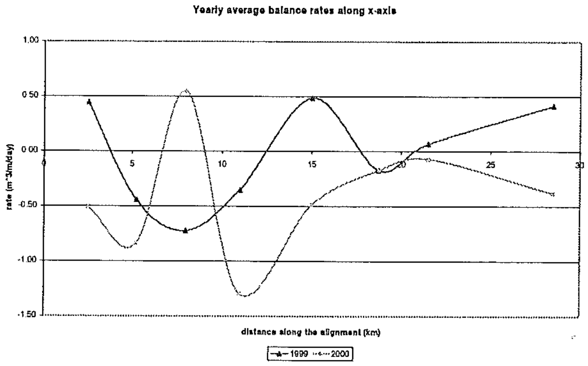
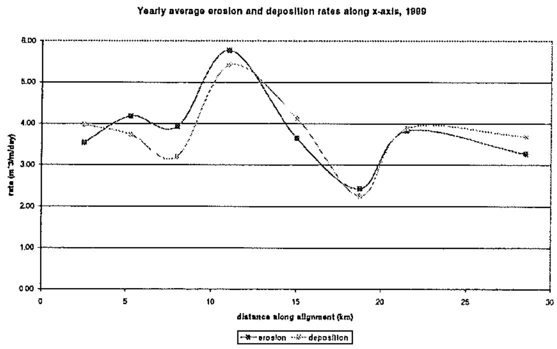


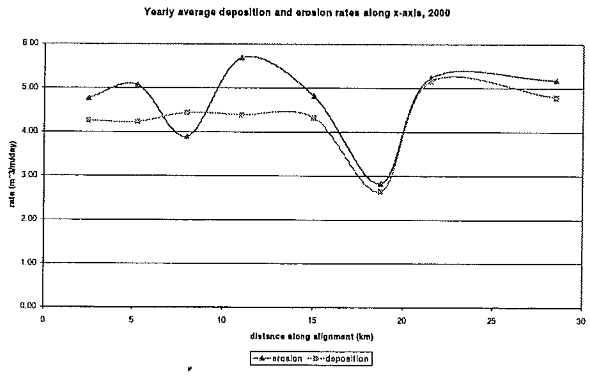
Figure IX.10. Total deposition and erosion rates (abs (erosion rates)+deposition rates)



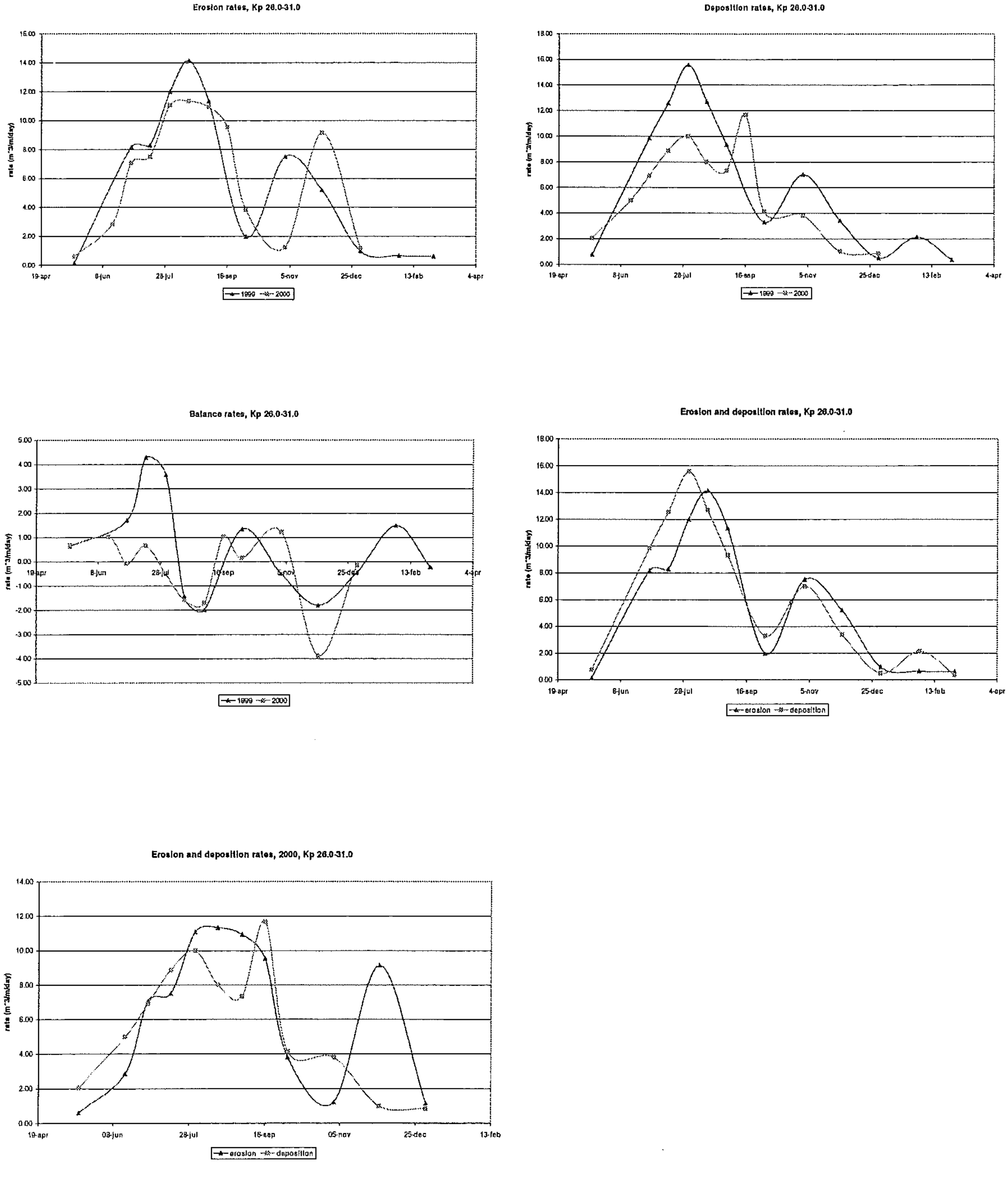




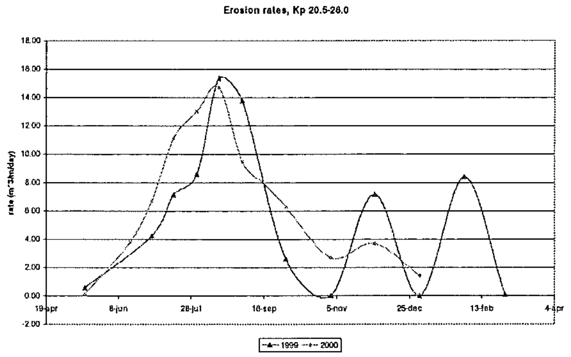


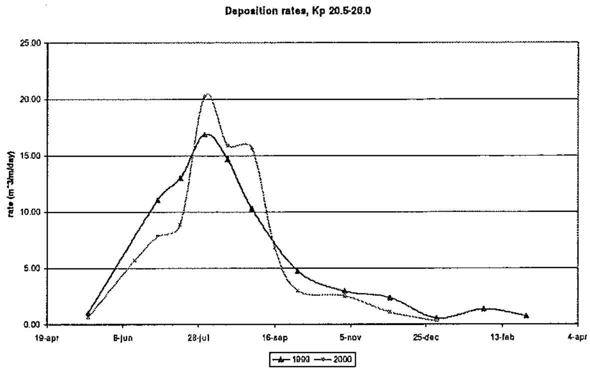


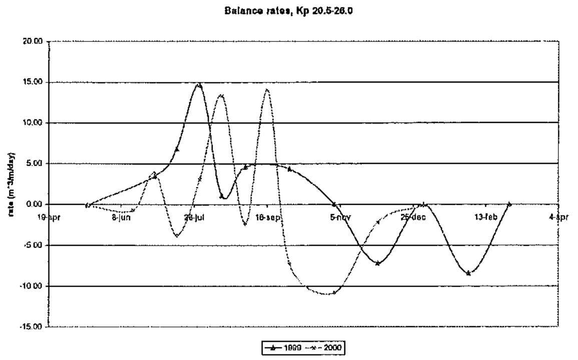
Figures IX.9. Deposition and erosion rates along the alignment

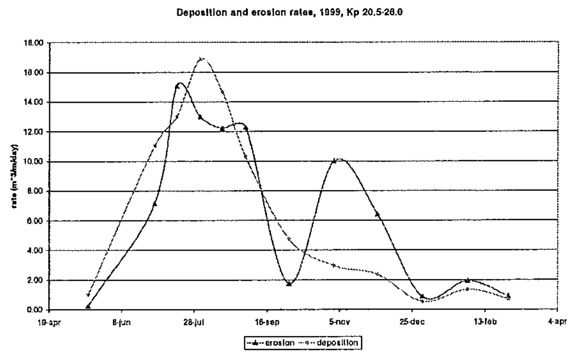


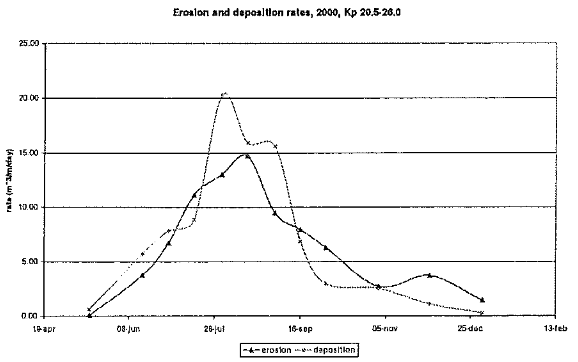
Figures IX.8. Deposition and erosion rates Khoksa, Kp 26.0-31.0



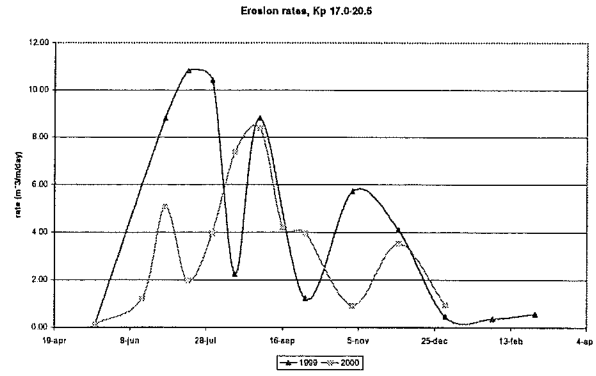


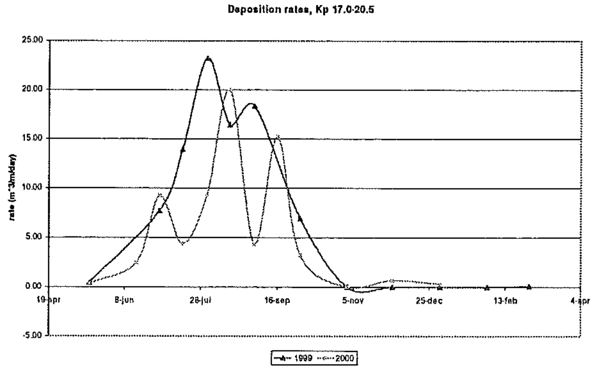


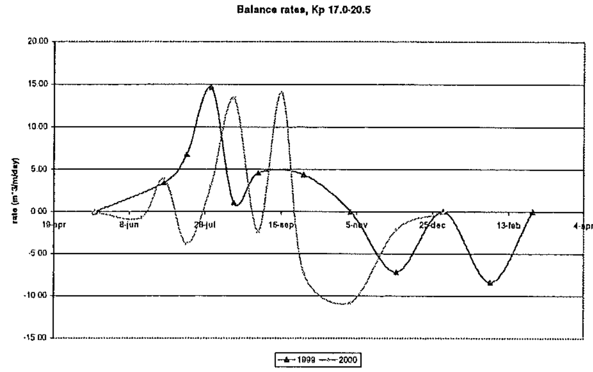


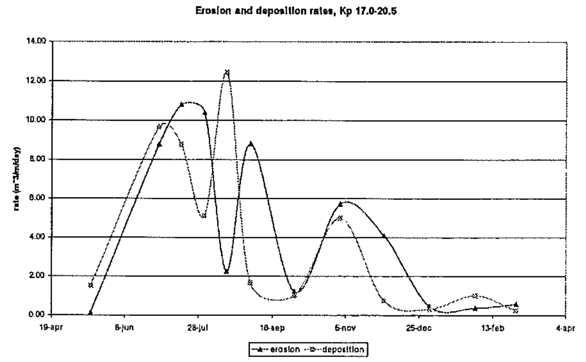


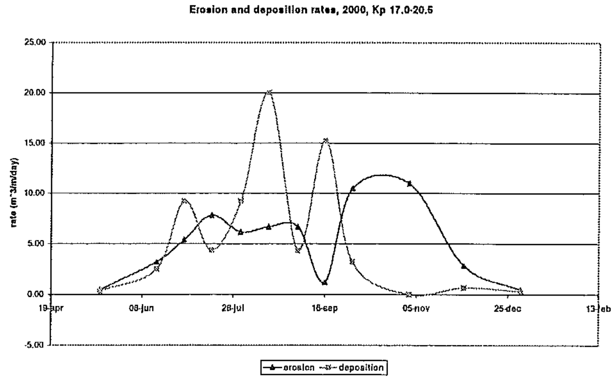
Figures IX.7. Deposition and erosion rates Kumarkhali, Kp 20.5-26.0



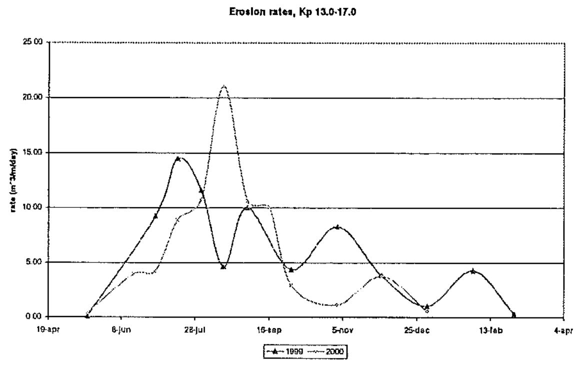


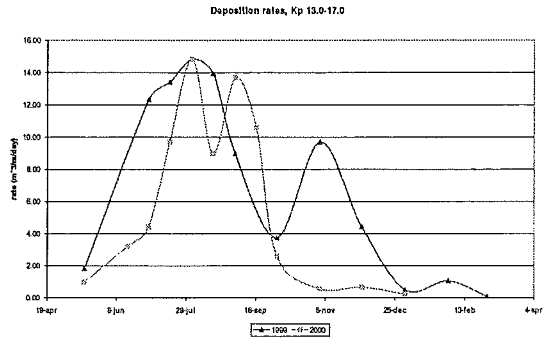


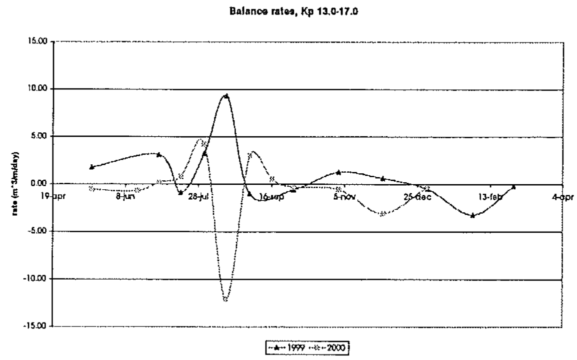


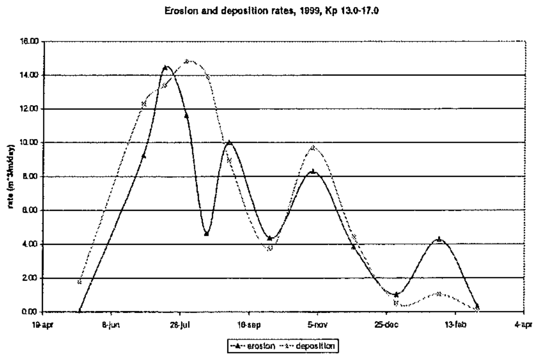


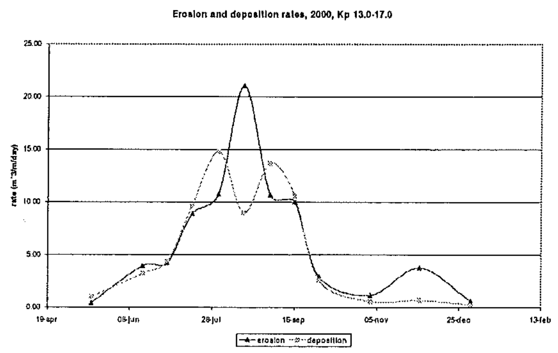
Figures IX.6. Deposition and erosion rates upstream Kumarkhali, Kp 17.0-20.5



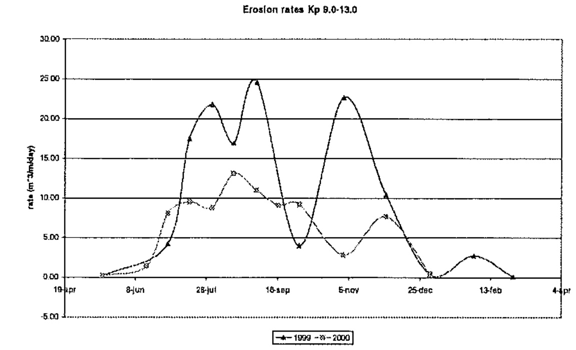


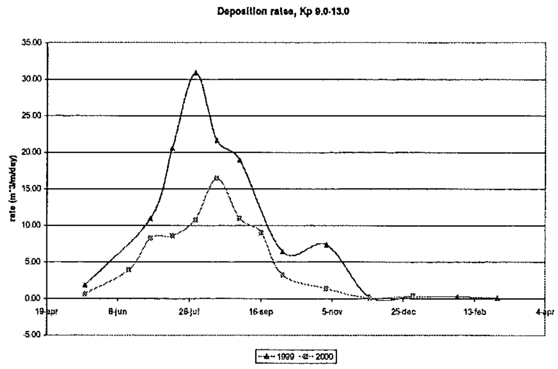


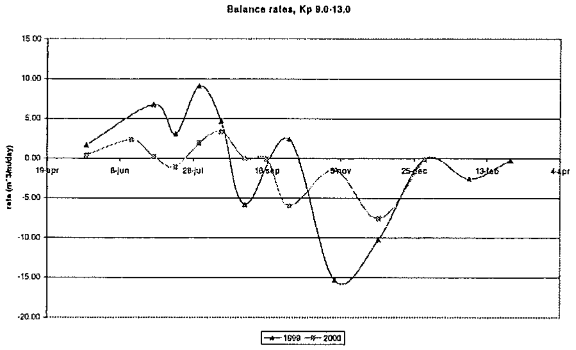


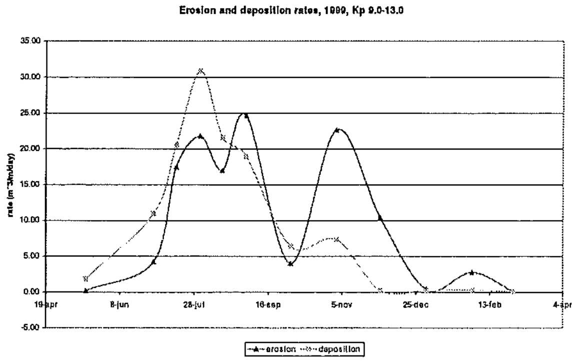


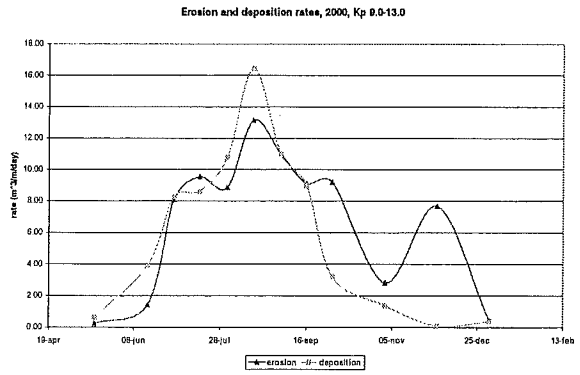
Figures IX.5. Deposition and erosion rates downstream Gorai Railway Bridge, Kp 13.0-17.0



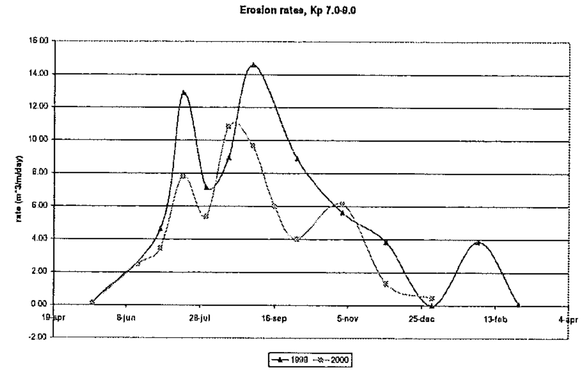


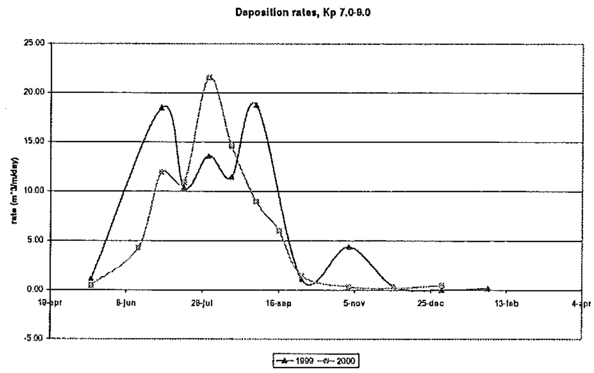


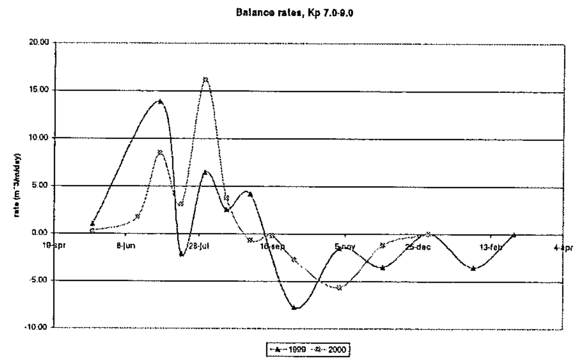


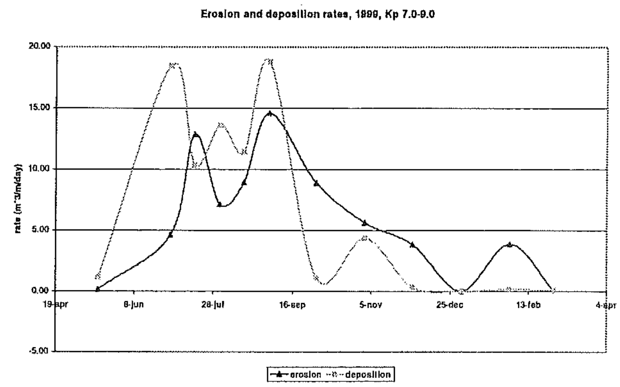


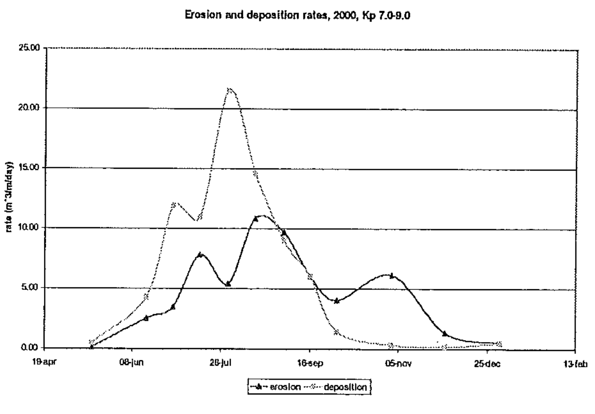
Figures IX.4. Deposition and erosion rates upstream Gorai Railway Bridge, Kp 9.0-13.0



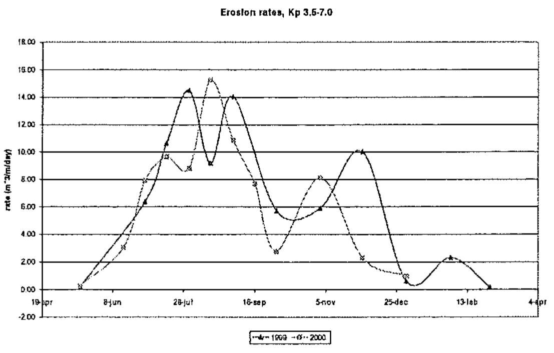


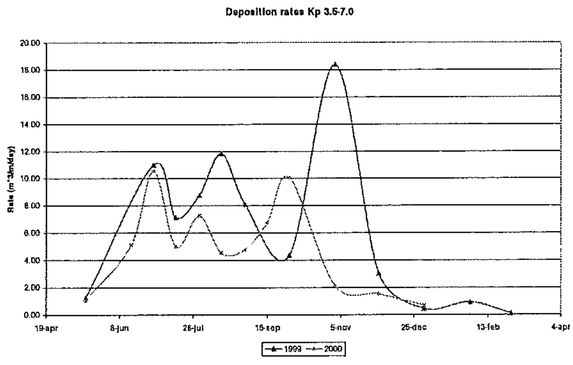


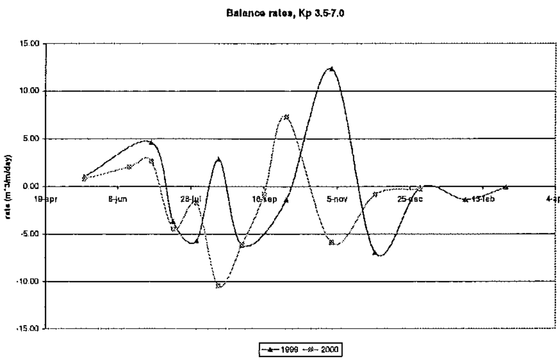


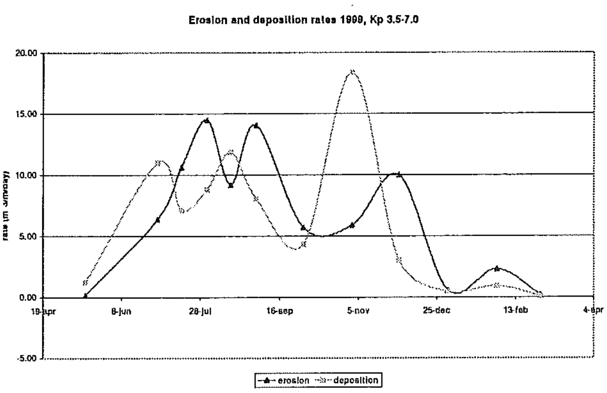


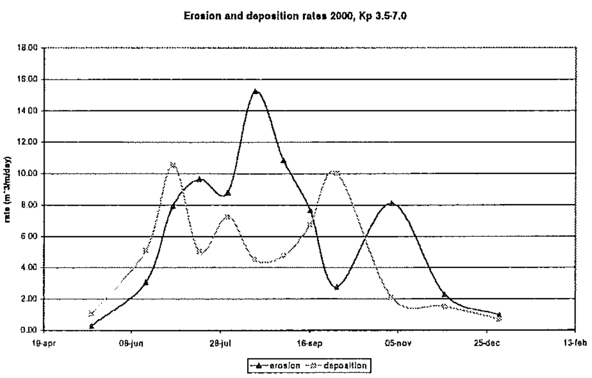
Figures IX.3. Deposition and erosion rates straight stretch , Kp 7.0-9.0



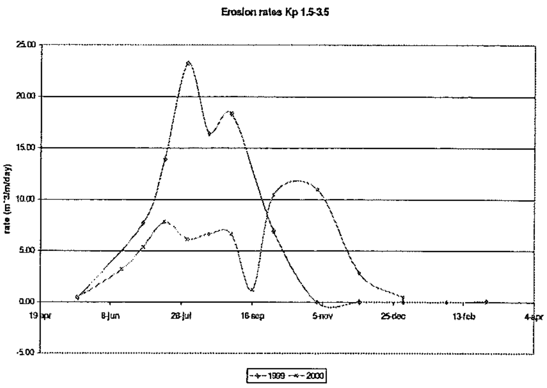


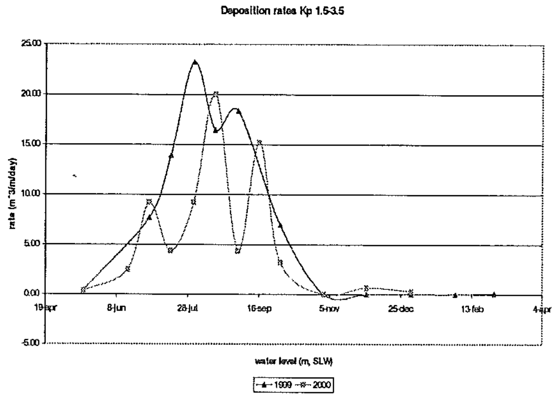


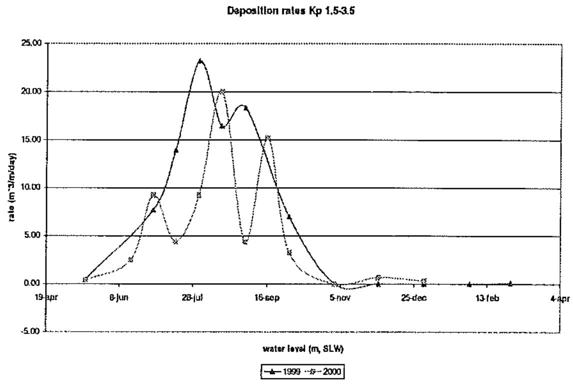


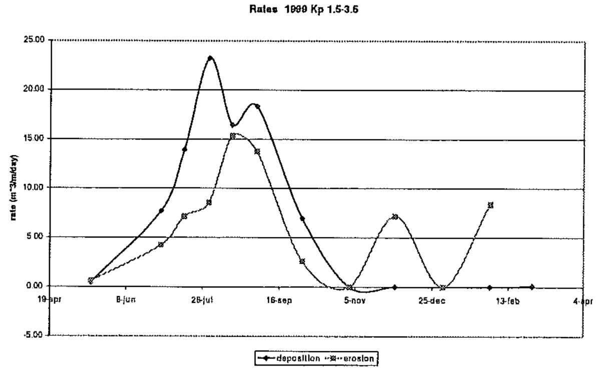


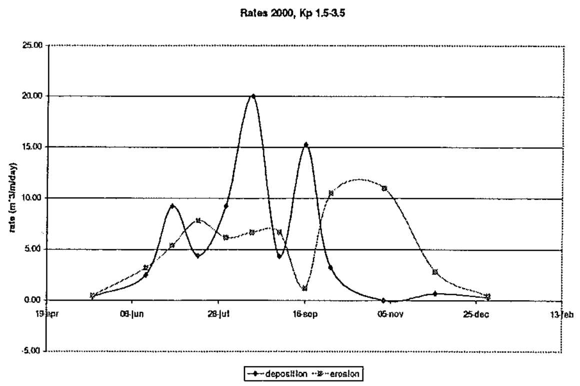
Figures IX.2. Deposition and erosion rates Kushtia, Kp 3.5-7.0











Figures IX.1. Deposition and erosion rates off-take area, Kp 1.5-3.5

Appendix X:

Area below SLW

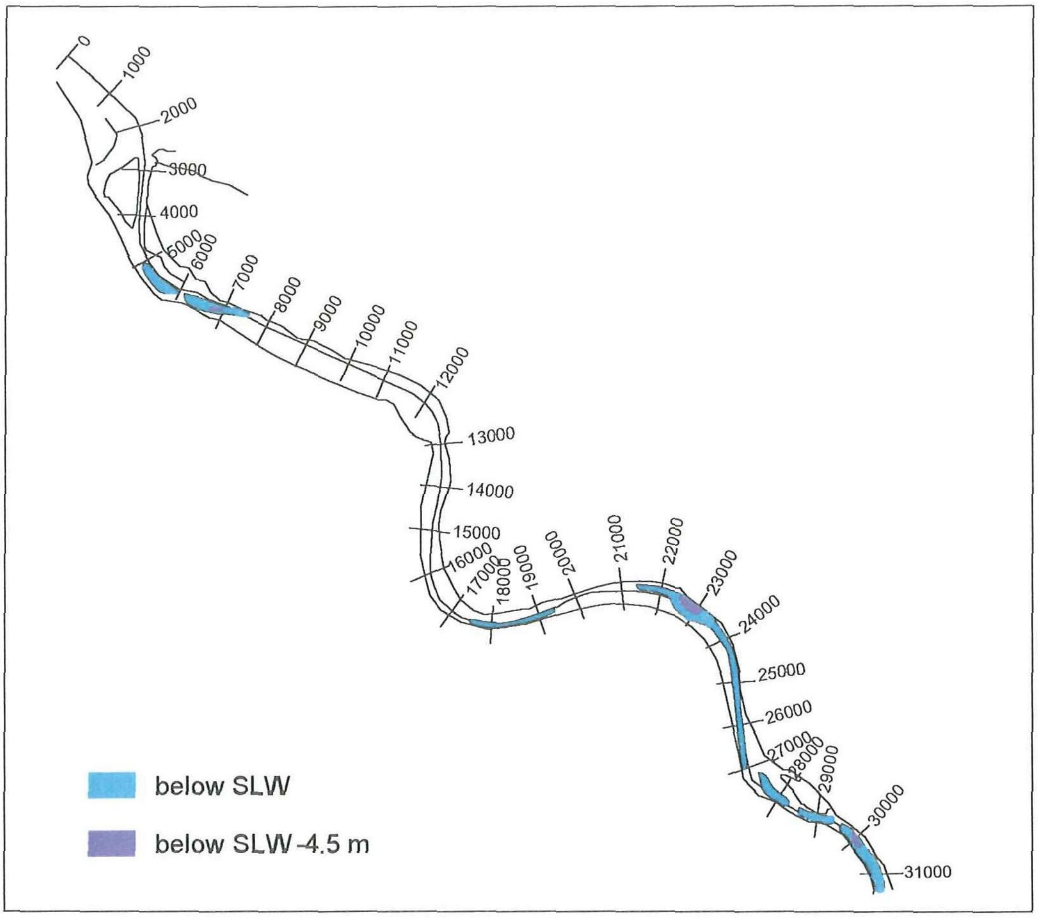


Figure X.1. Sketch of area below SLW and below SLW -4.5 m, November 1997

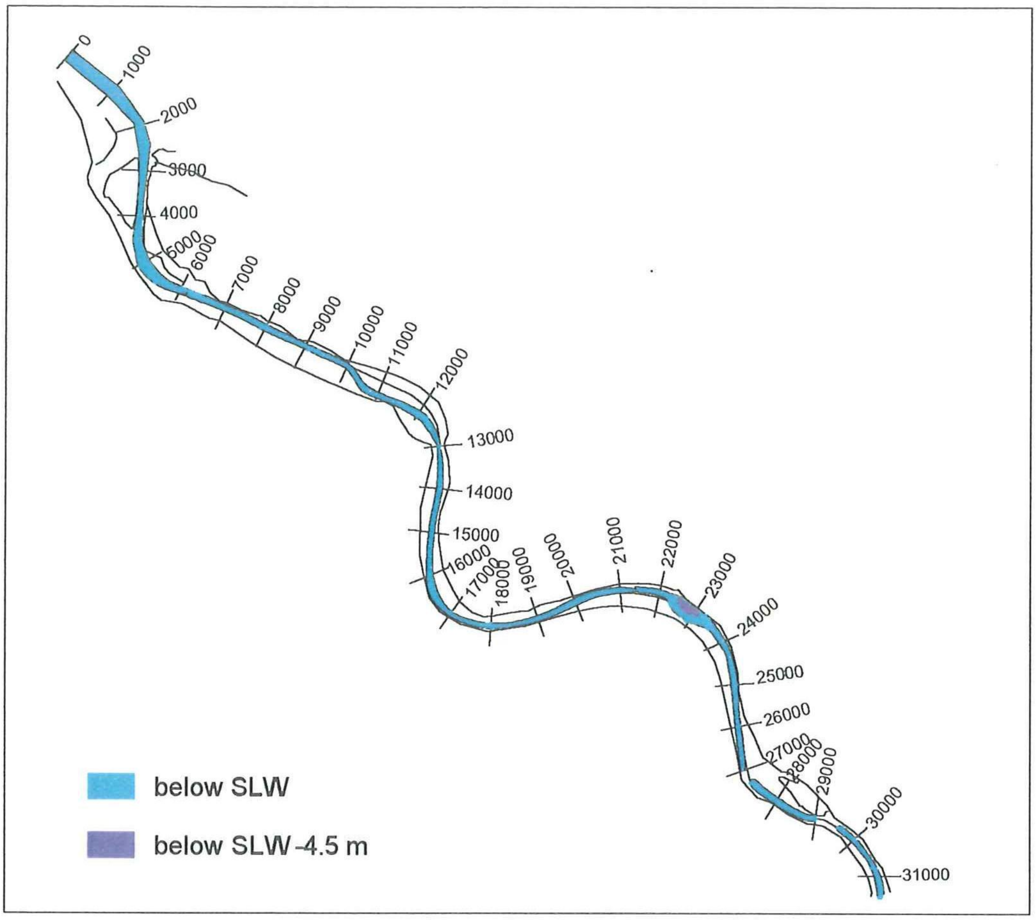


Figure X.2. Sketch of area below SLW and below SLW -4.5 m, April 1999

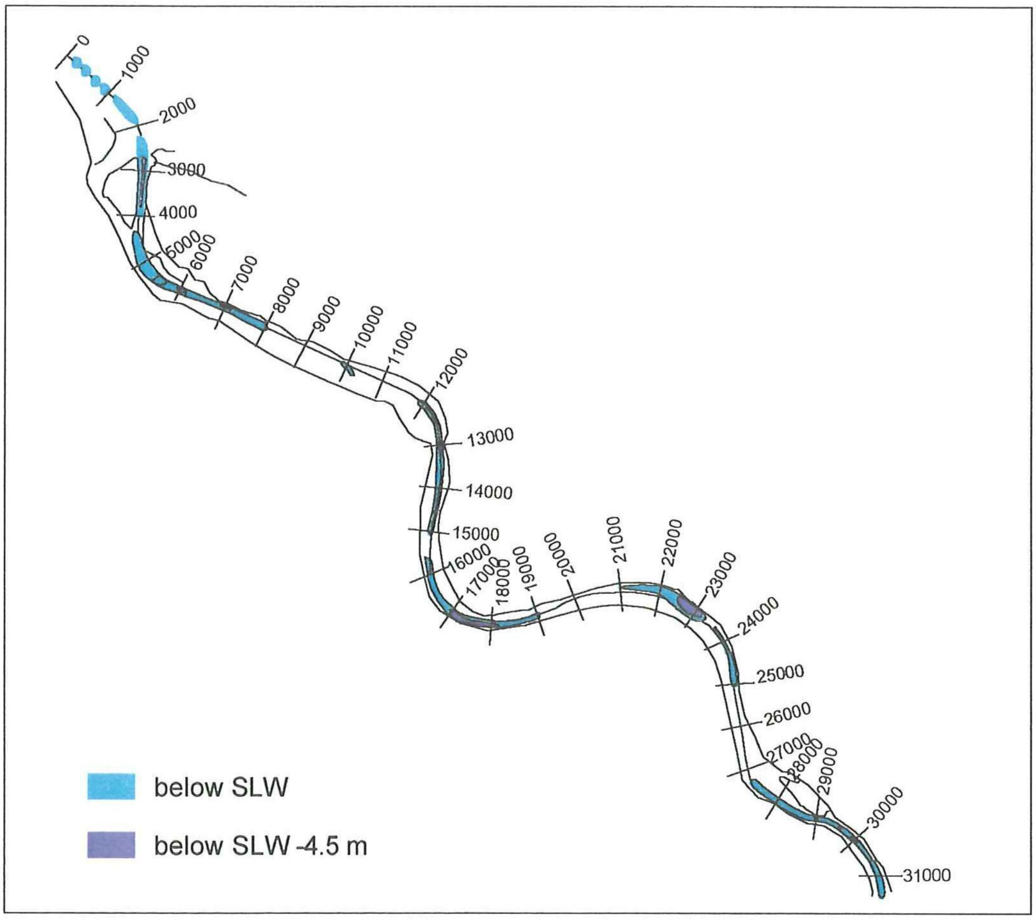


Figure X.3. Sketch of area below SLW and below SLW -4.5 m, July 1999

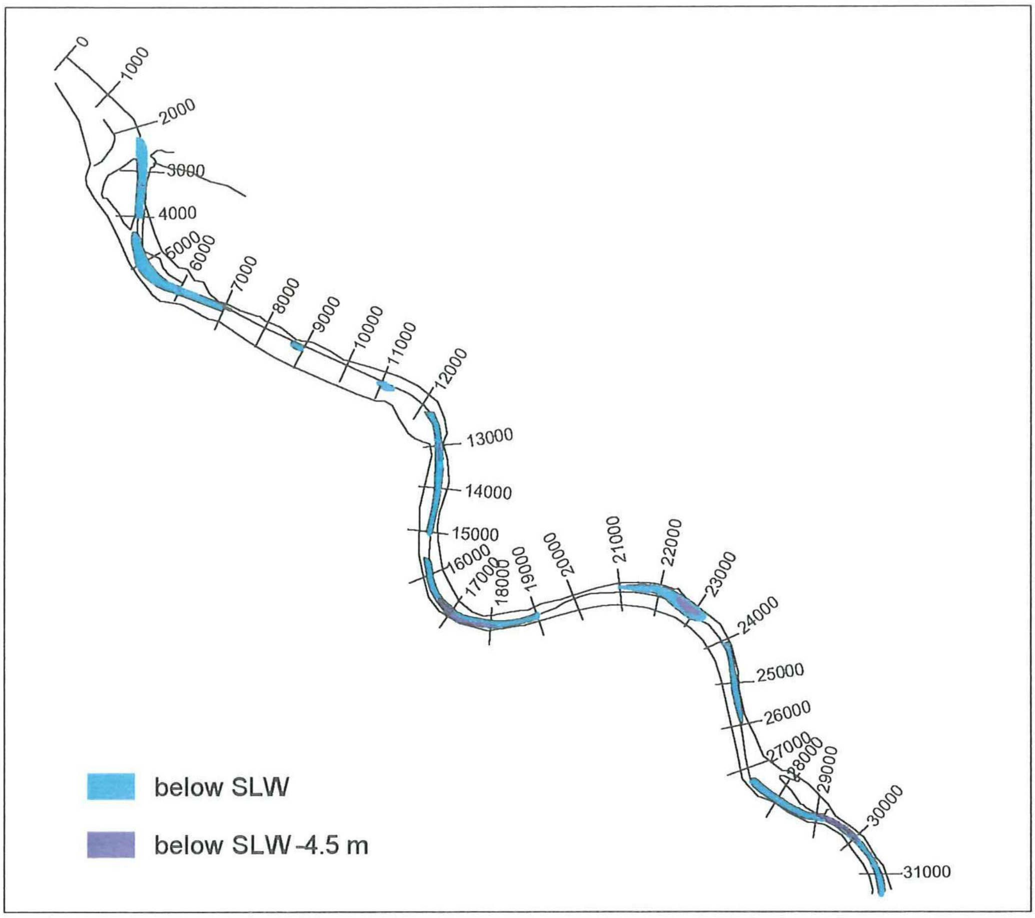


Figure X.4. Sketch of area below SLW and below SLW -4.5 m, August 1999

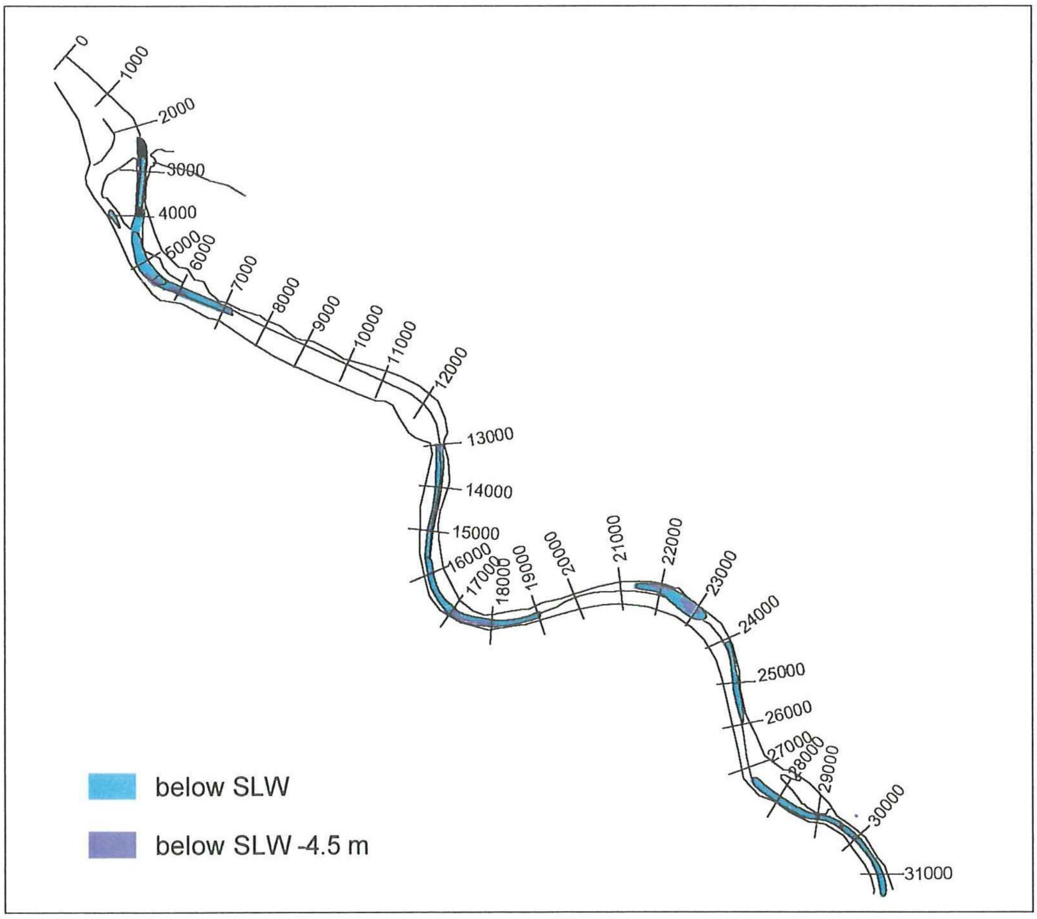


Figure X.5. Sketch of area below SLW and below SLW -4.5 m, September 1999

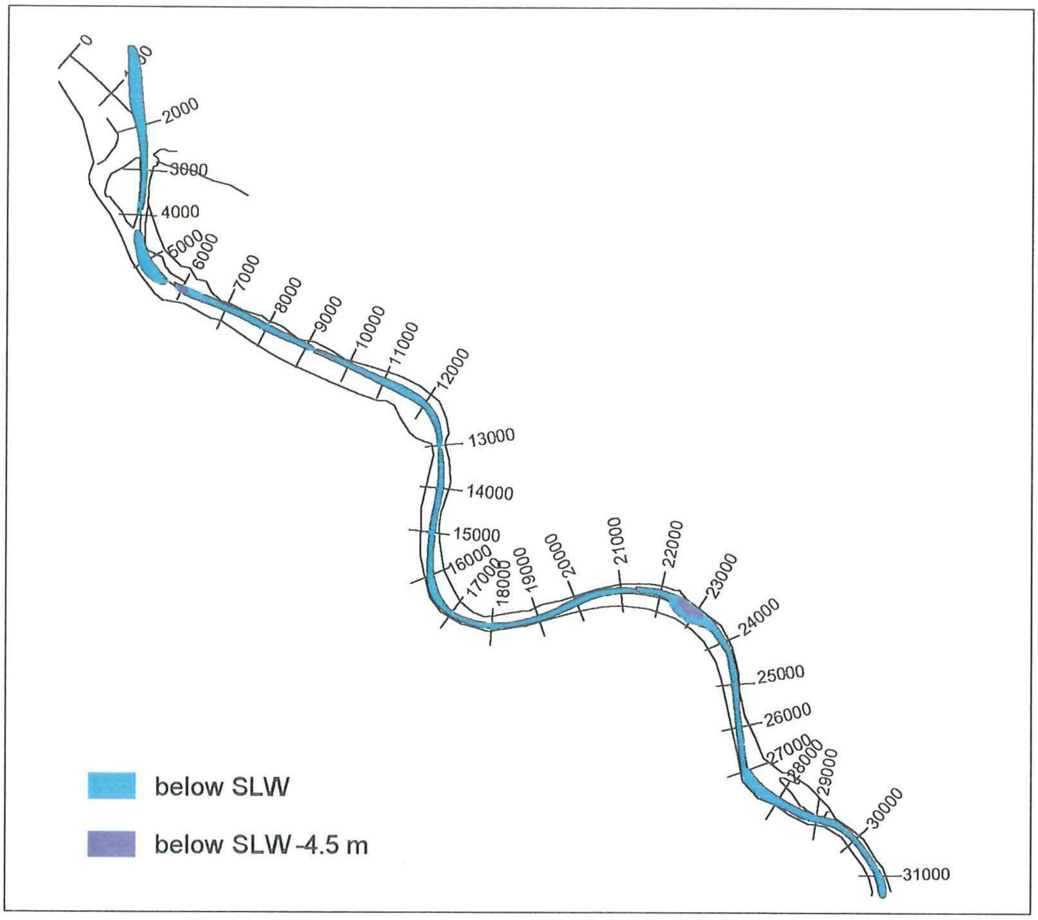


Figure X.6. Sketch of area below SLW and below SLW -4.5 m, April 2000

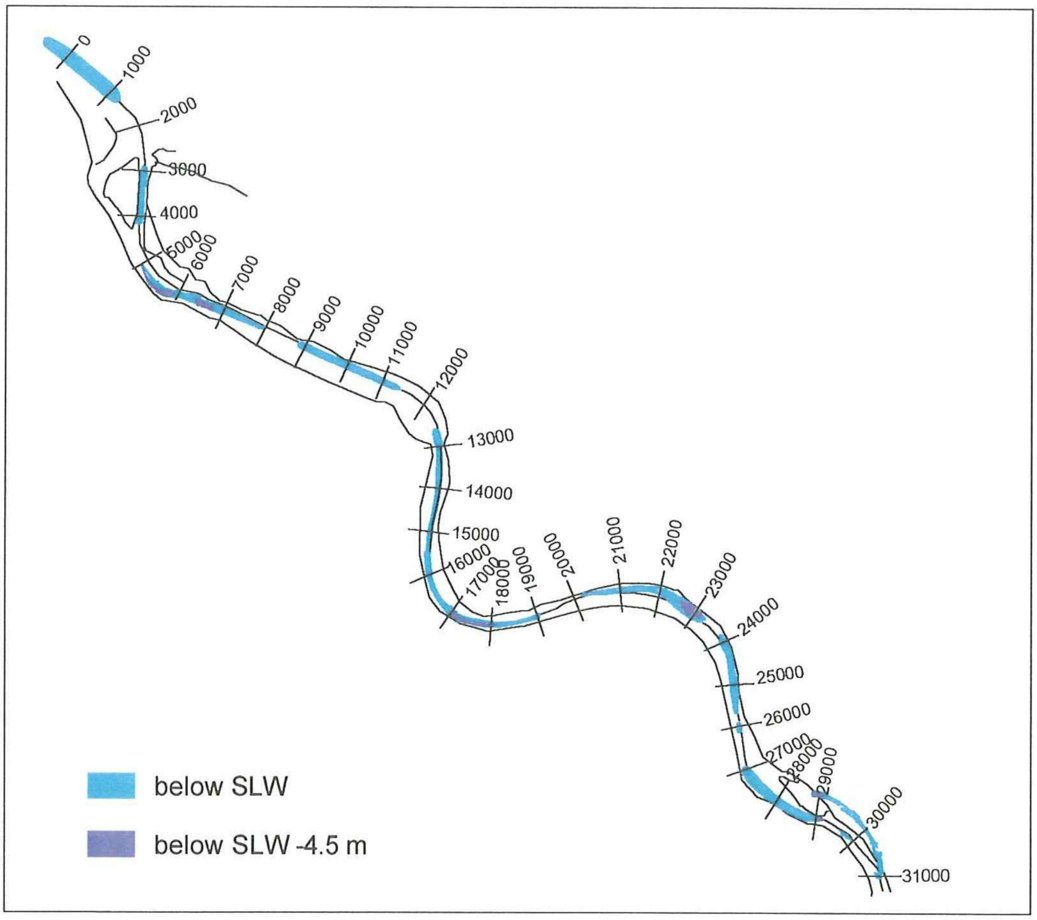


Figure X.7. Sketch of area below SLW and below SLW -4.5 m, July 2000

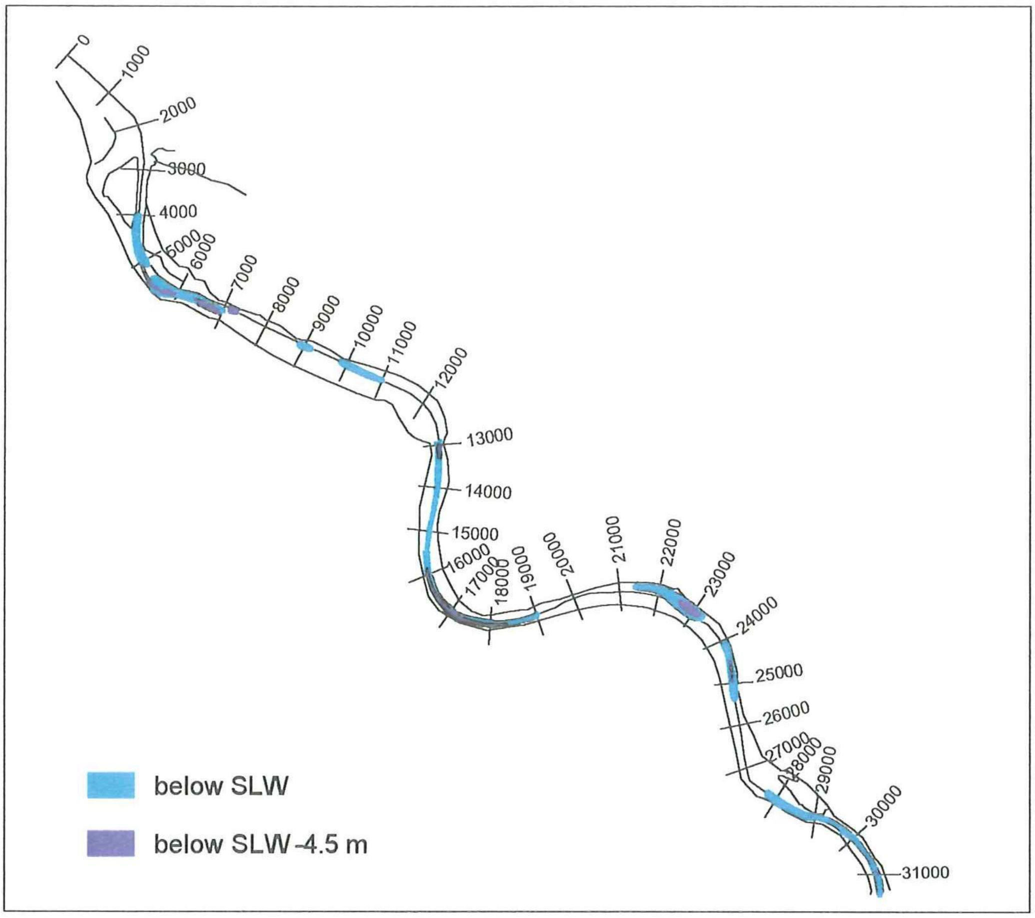


Figure X.8. Sketch of area below SLW and below SLW -4.5 m, August 2000

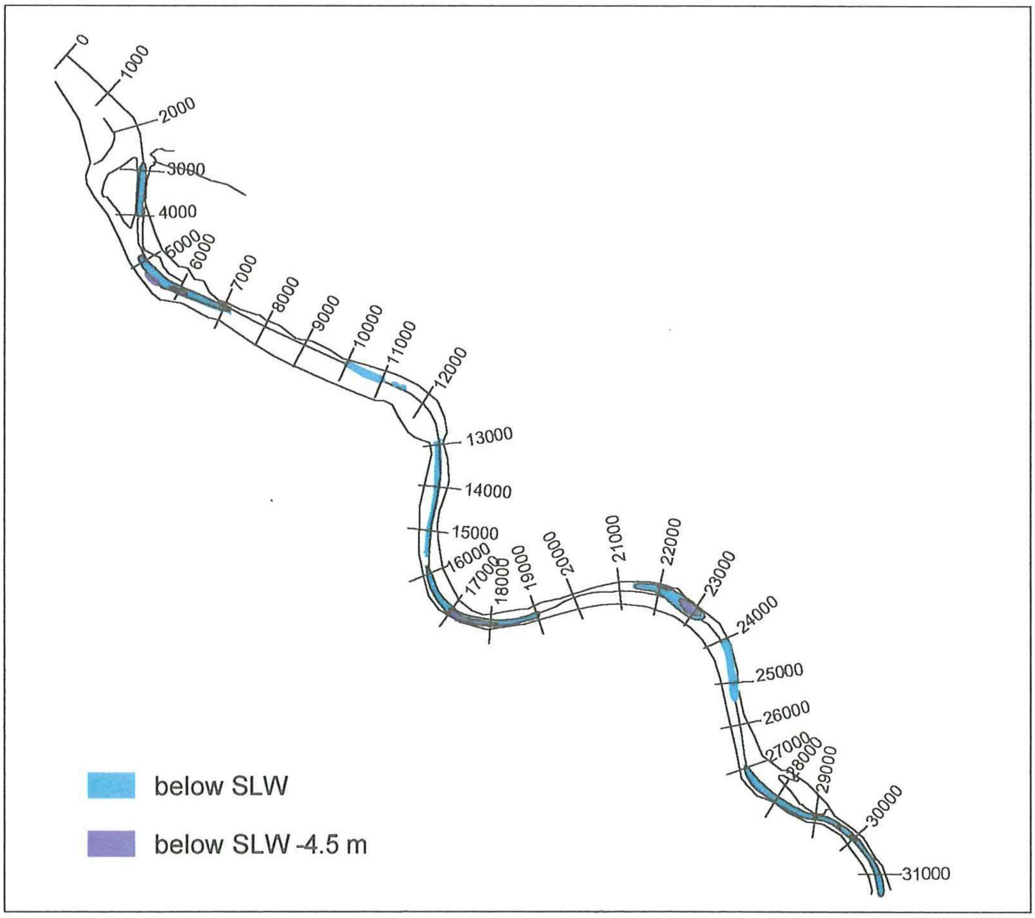


Figure X.9. Sketch of area below SLW and below SLW -4.5 m, September 2000

Appendix XI:

Width – water level relations

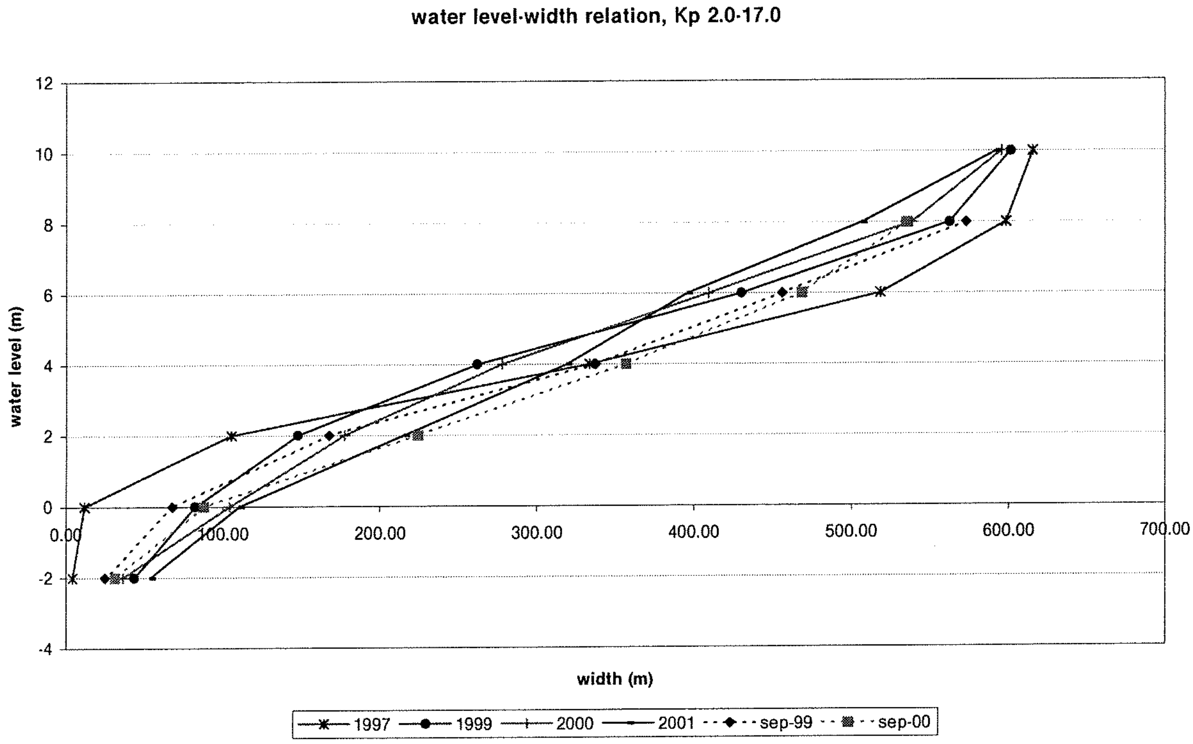


Figure XI.1. Width-water level relation, dredged part of the Upper Gorai River, Kp 2.0-17.0

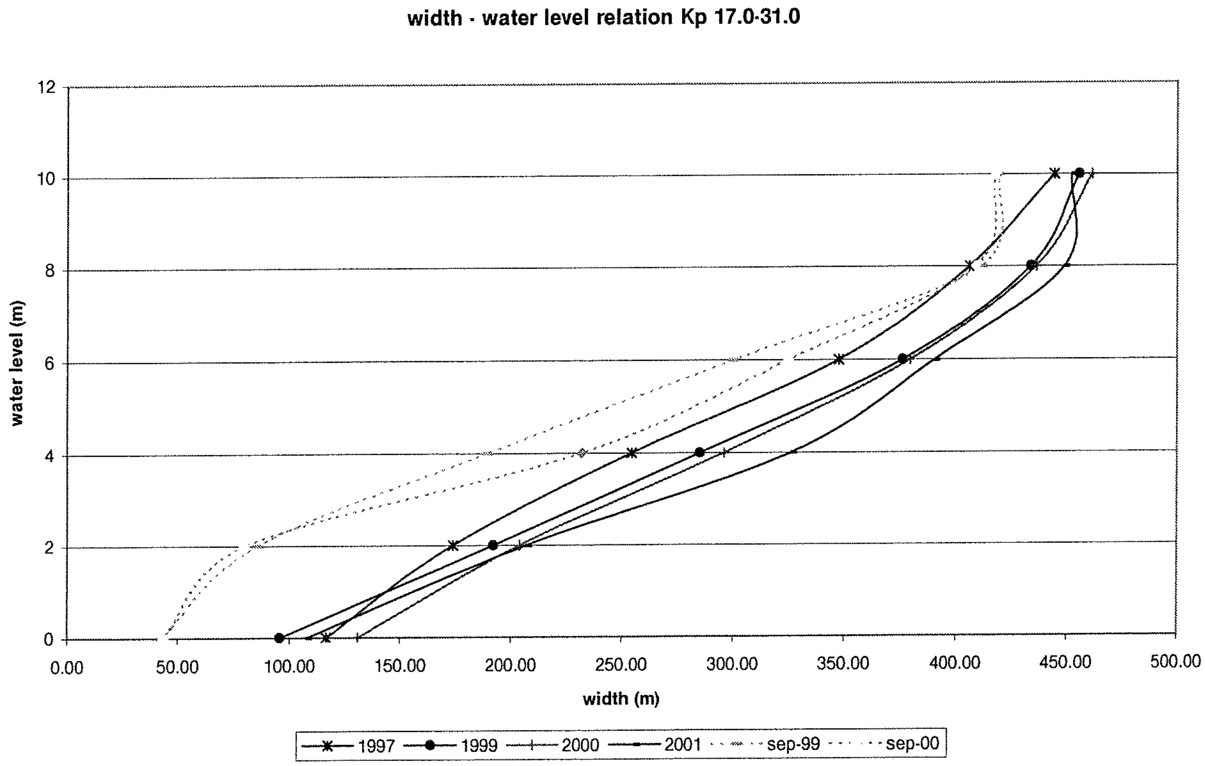


Figure XI.2. Width-water level relation, part of the Upper Gorai River without dredging, Kp 17.0-31.0

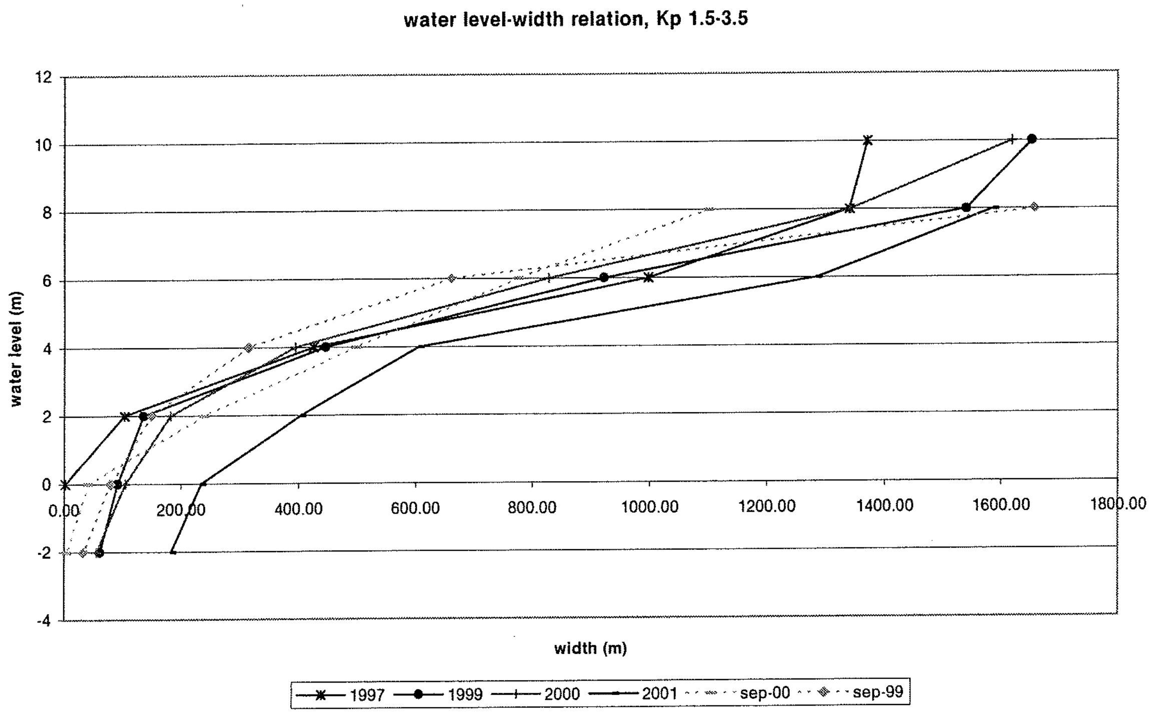


Figure XI.3. Width-water level relation, off-take, Kp 1.5-3.5

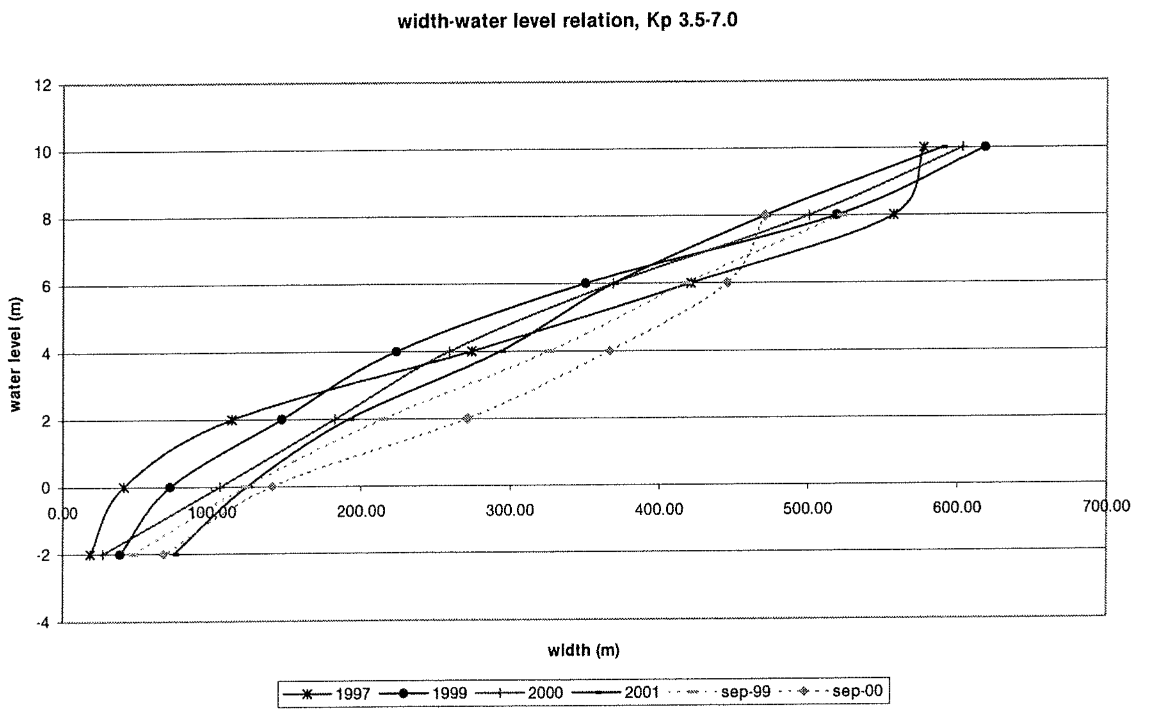


Figure XI.4. Width-water level relation, Kushtia, Kp 3.5-7.0

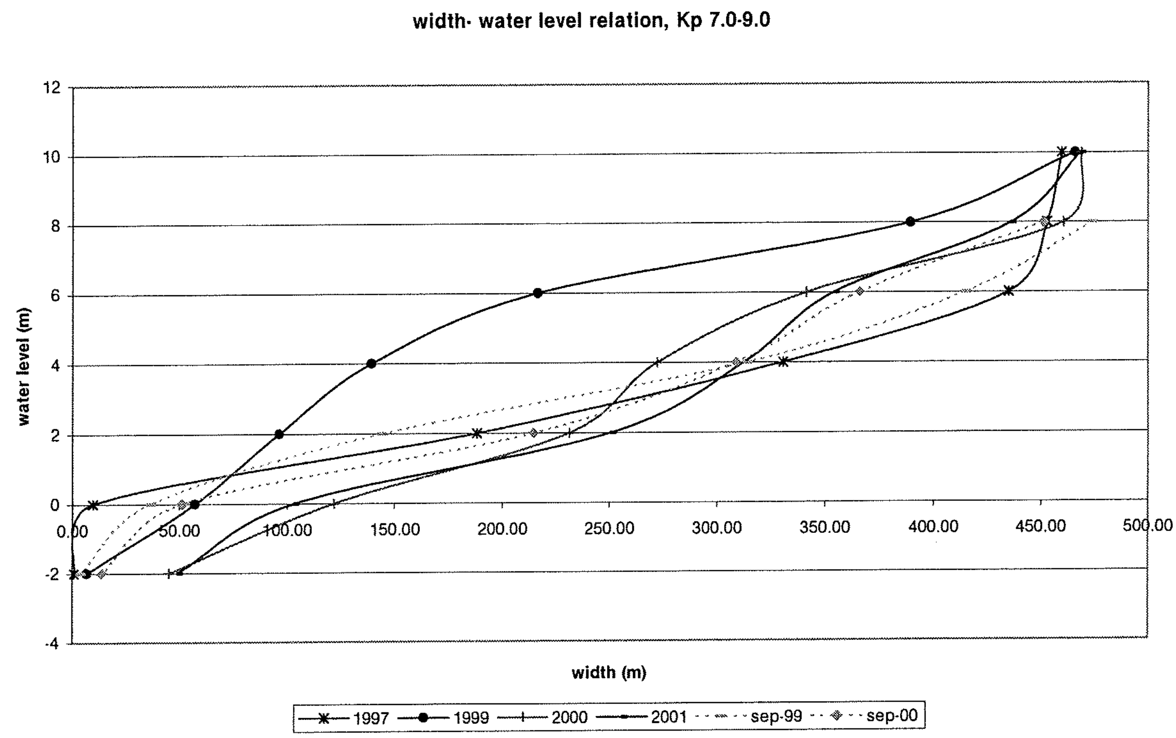


Figure XI.5. Width-water level relation, Straight stretch, Kp 7.0-9.0

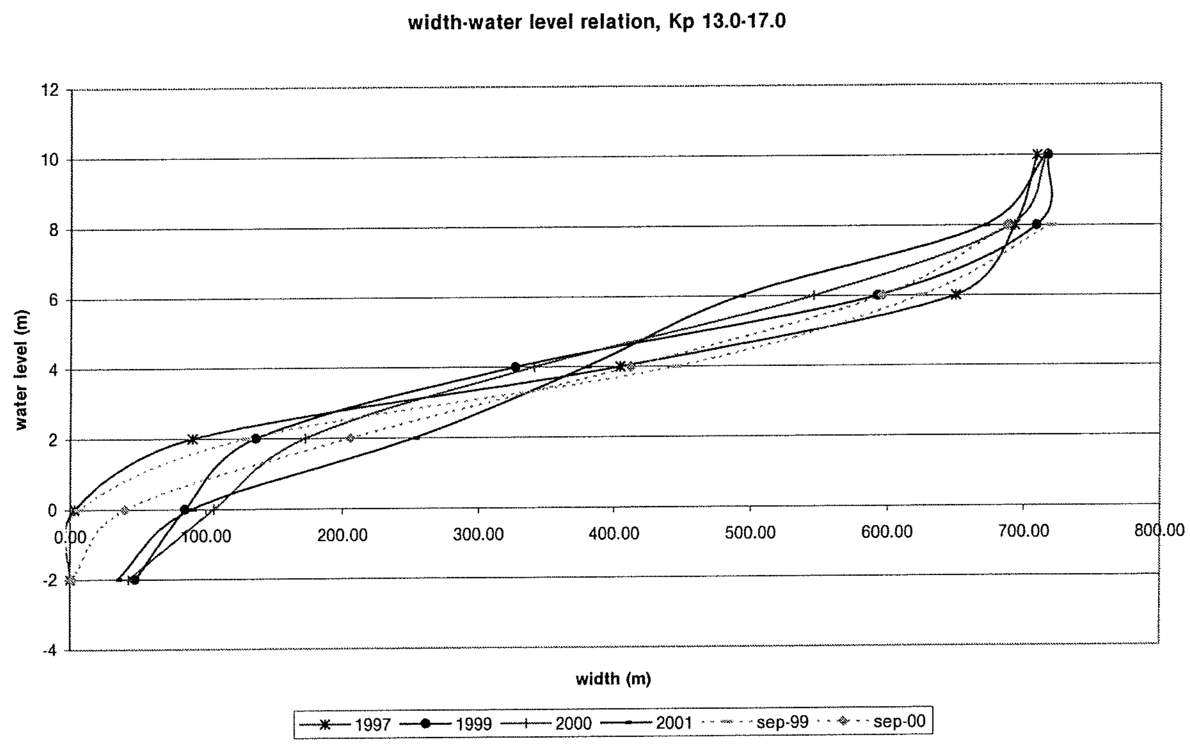


Figure XI.6. Width-water level relation, upstream GRB, Kp 9.0-13.0

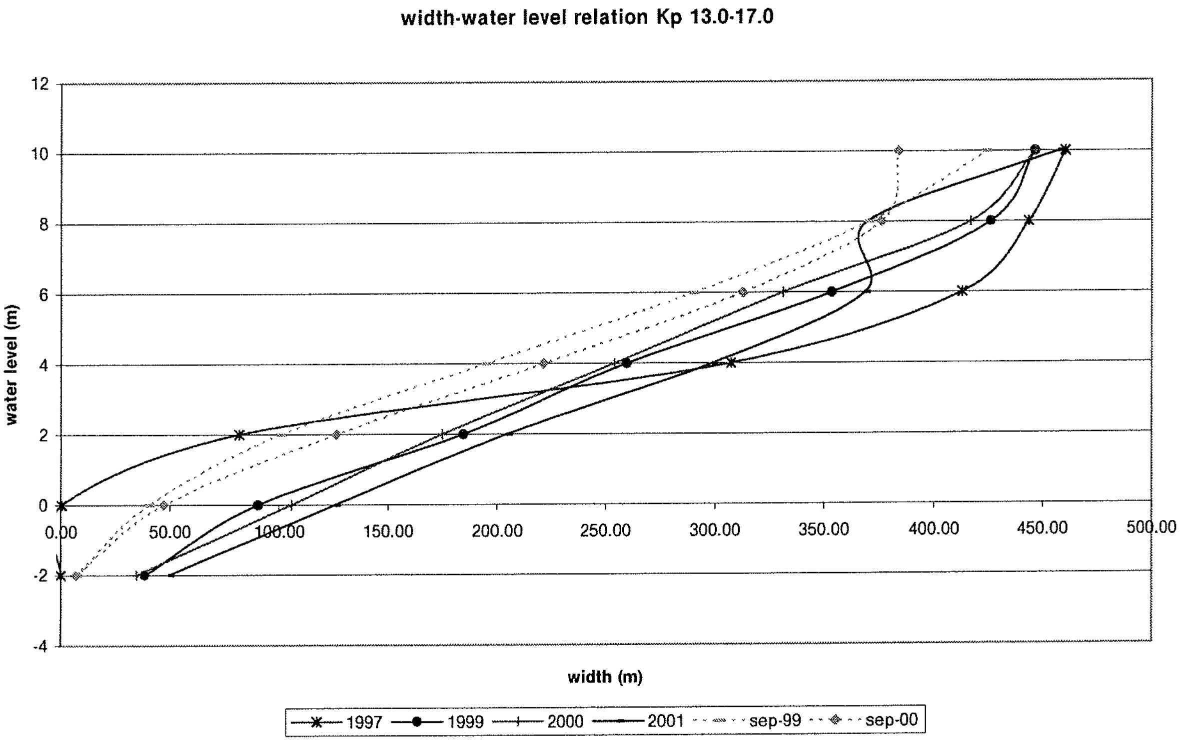


Figure XI.7. Width-water level relation, downstream GRB, Kp 13.0-17.0

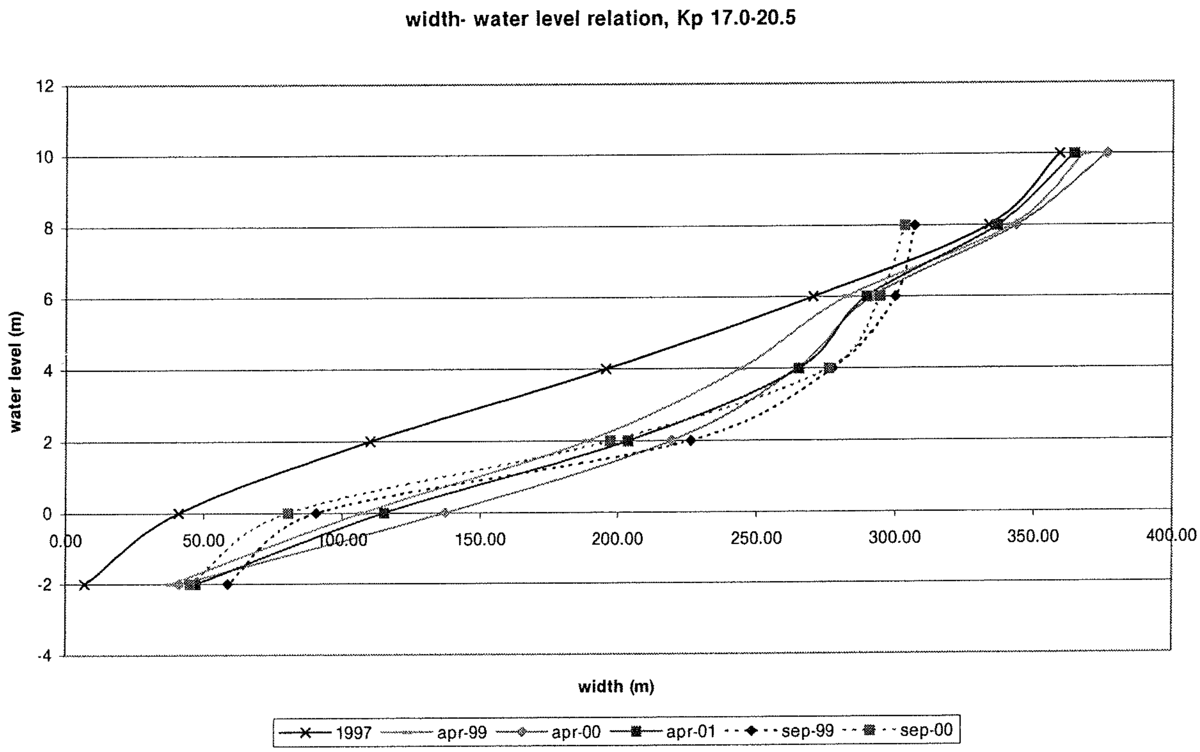


Figure XI.8. Width-water level relation, upstream, Kumarkhali, Kp 17.0-20.5

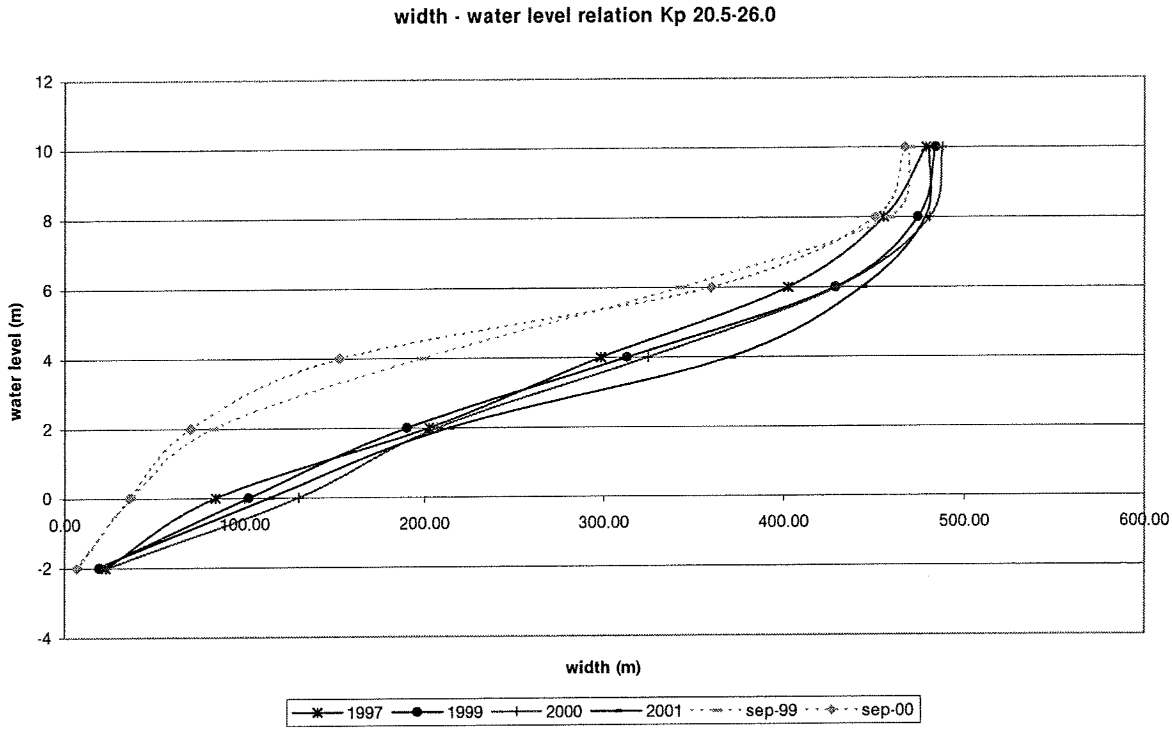


Figure XI.9. Width-water level relation, Kumarkhali, Kp 20.5-26.0

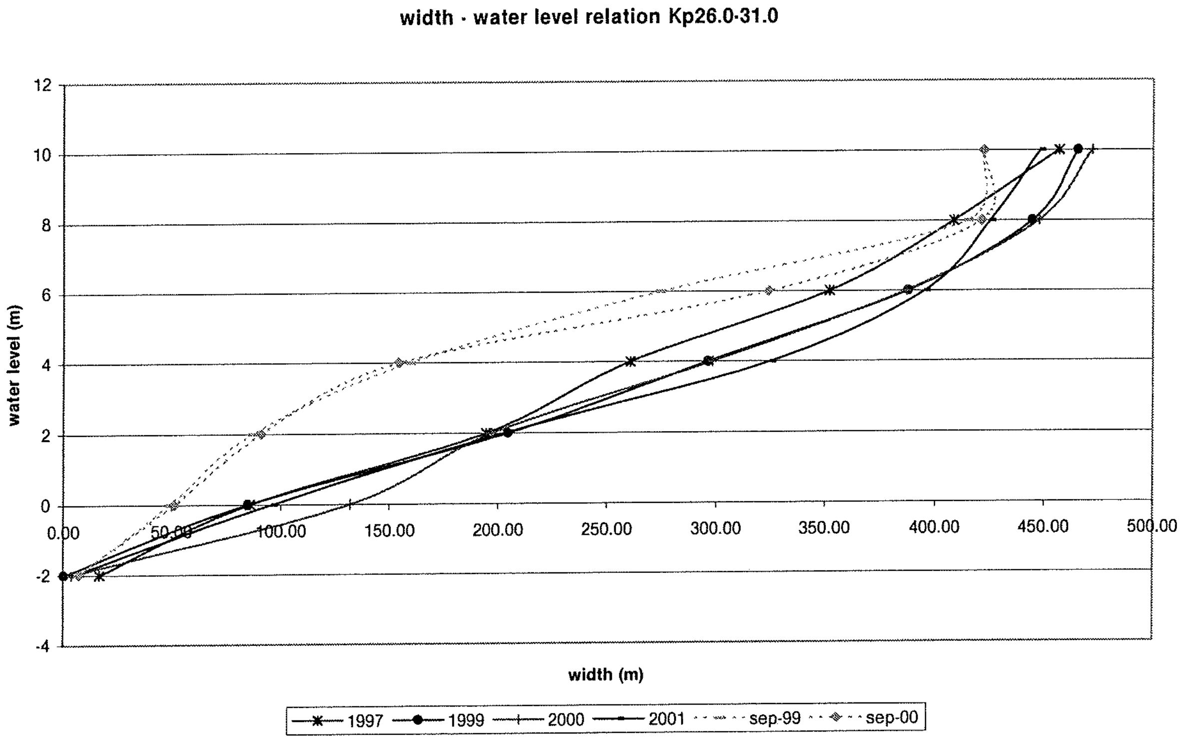


Figure XI.10. Width-water level relation, Khoksa, Kp 26.0-31.0

Appendix XII:

Discharge – sediment transport relations

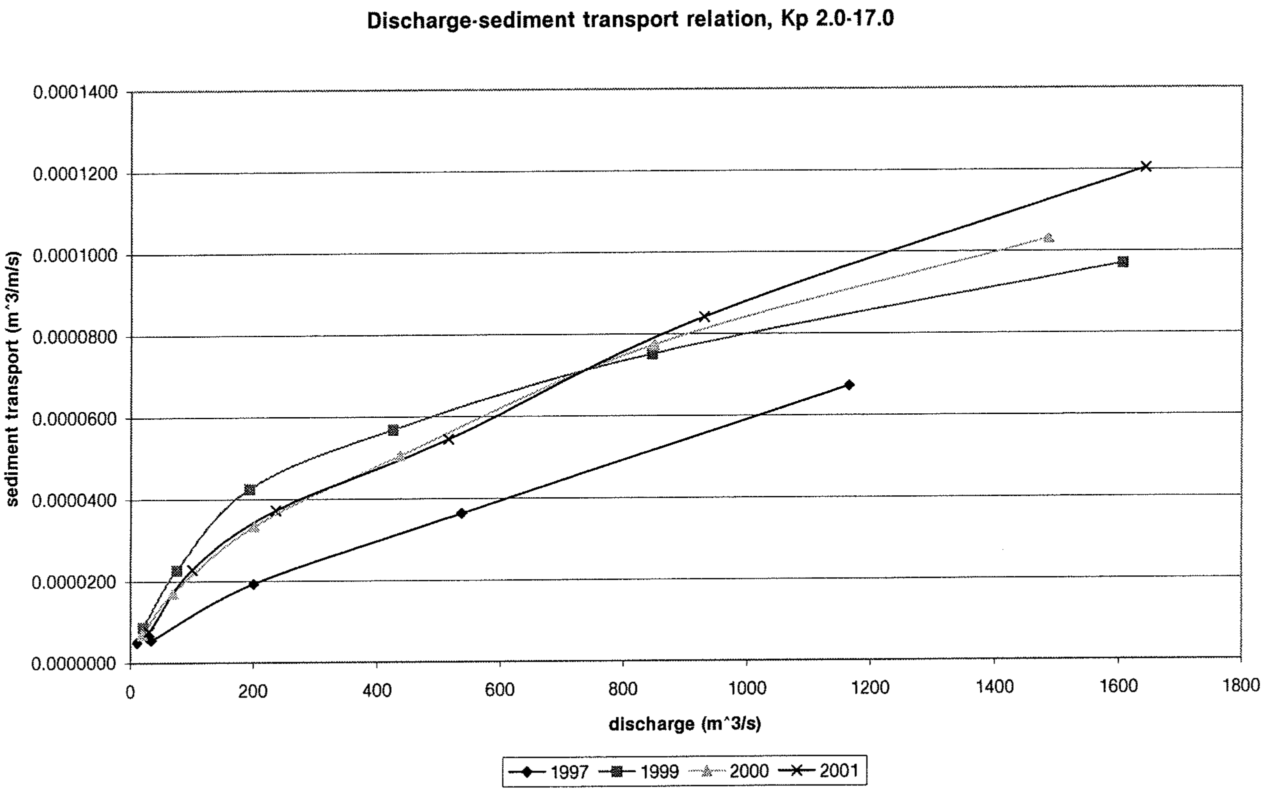


Figure XII.1. Calculated discharge – sediment transport capacity, Kp 1.5-17.0 (dredged) without September situation

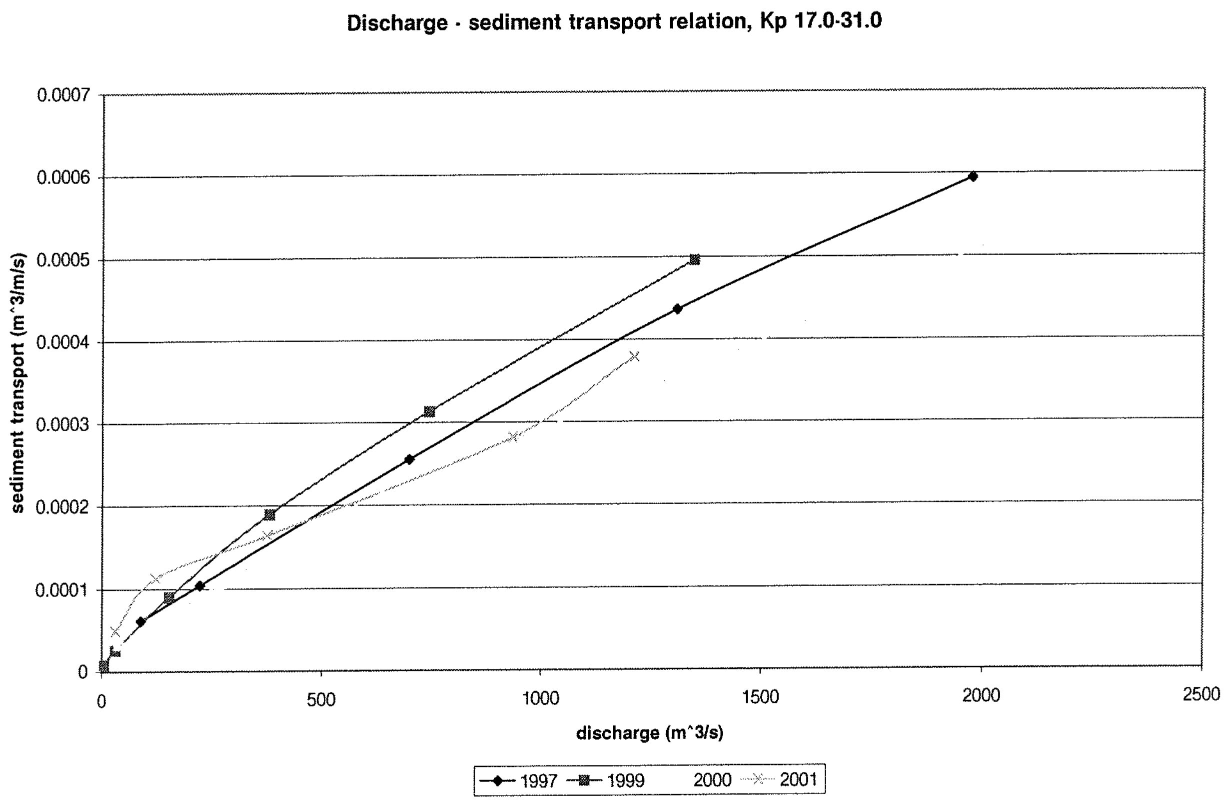


Figure XII.2. Calculated discharge – sediment transport capacity, Kp 17.0-31.0 (not-dredged) without September situation

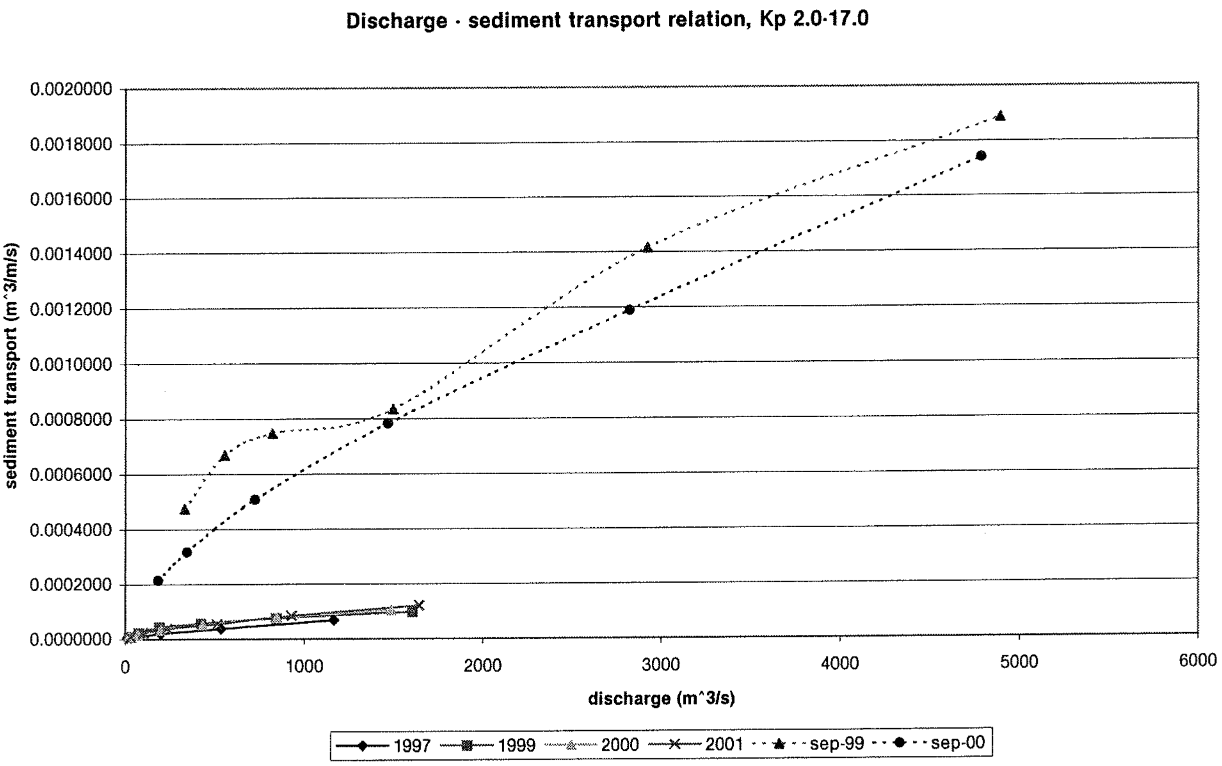


Figure XII.3. Calculated discharge – sediment transport capacity, Kp 1.5-17.0 (dredged) with September situation

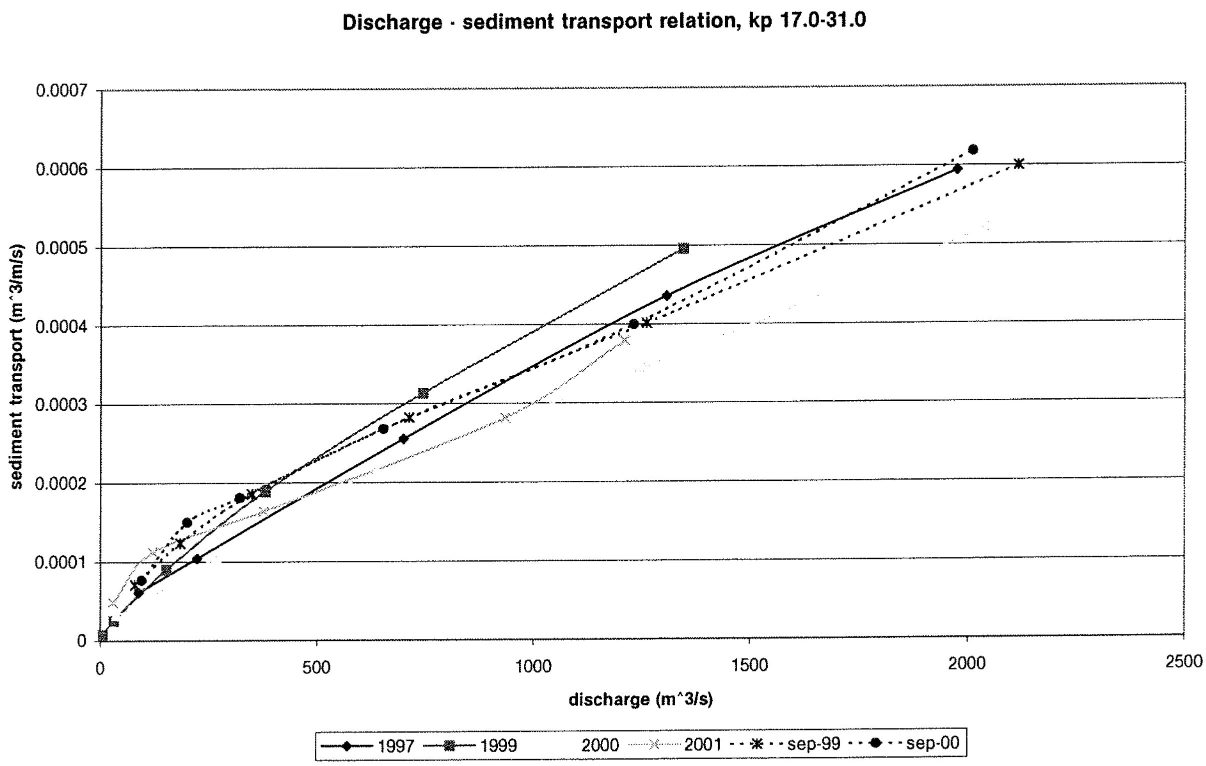


Figure XII.4. Calculated discharge – sediment transport capacity, Kp 17.0-31.0 (not-dredged)4 with September situation

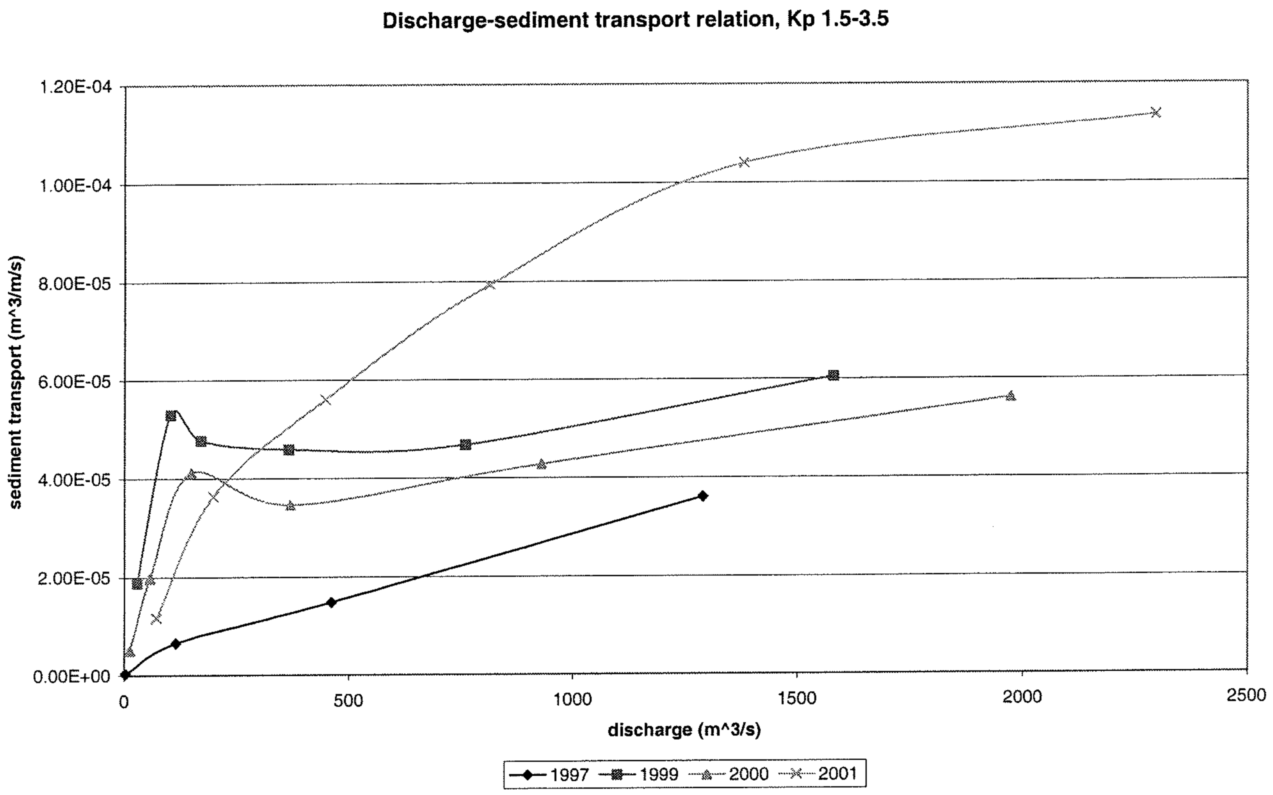


Figure XII.5. Calculated discharge-sediment transport capacity, Kp 1.5-3.5, without September

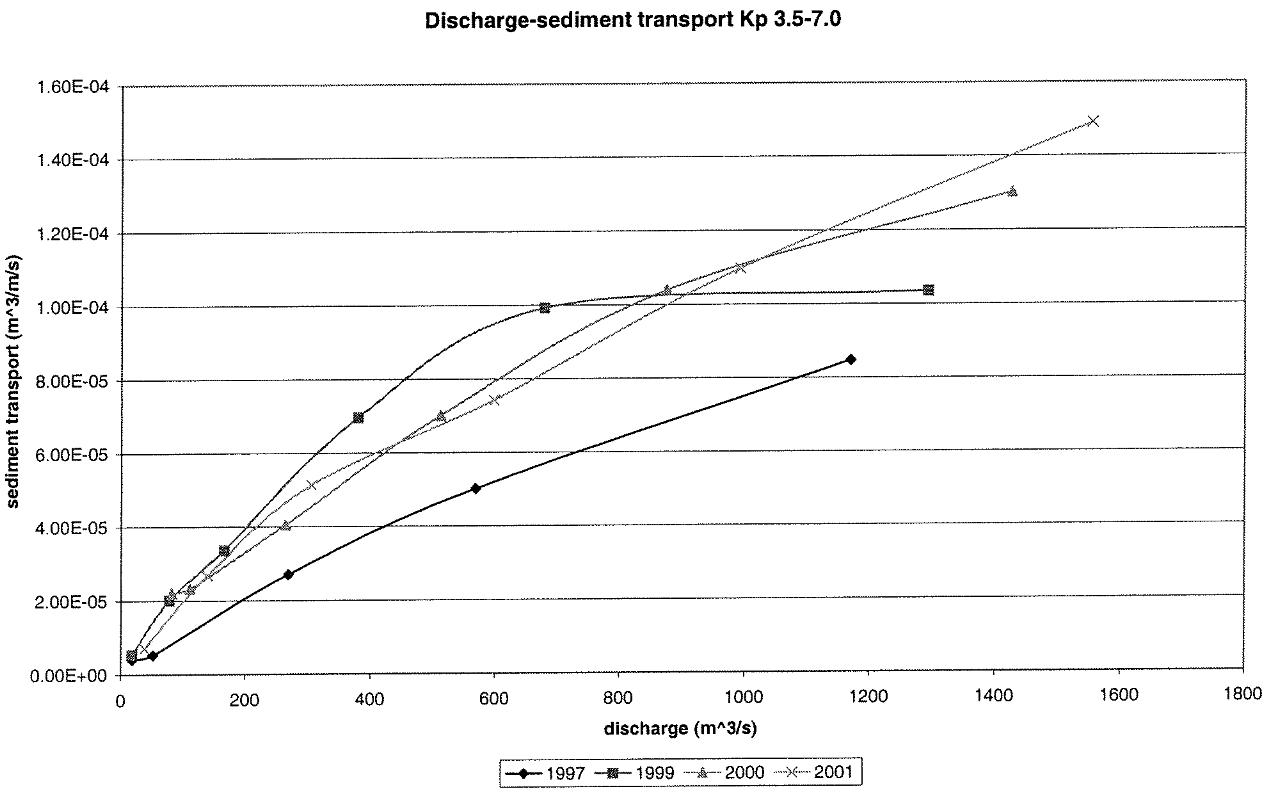


Figure XII.6. Calculated discharge-sediment transport capacity, Kp 3.5-7.0, without September

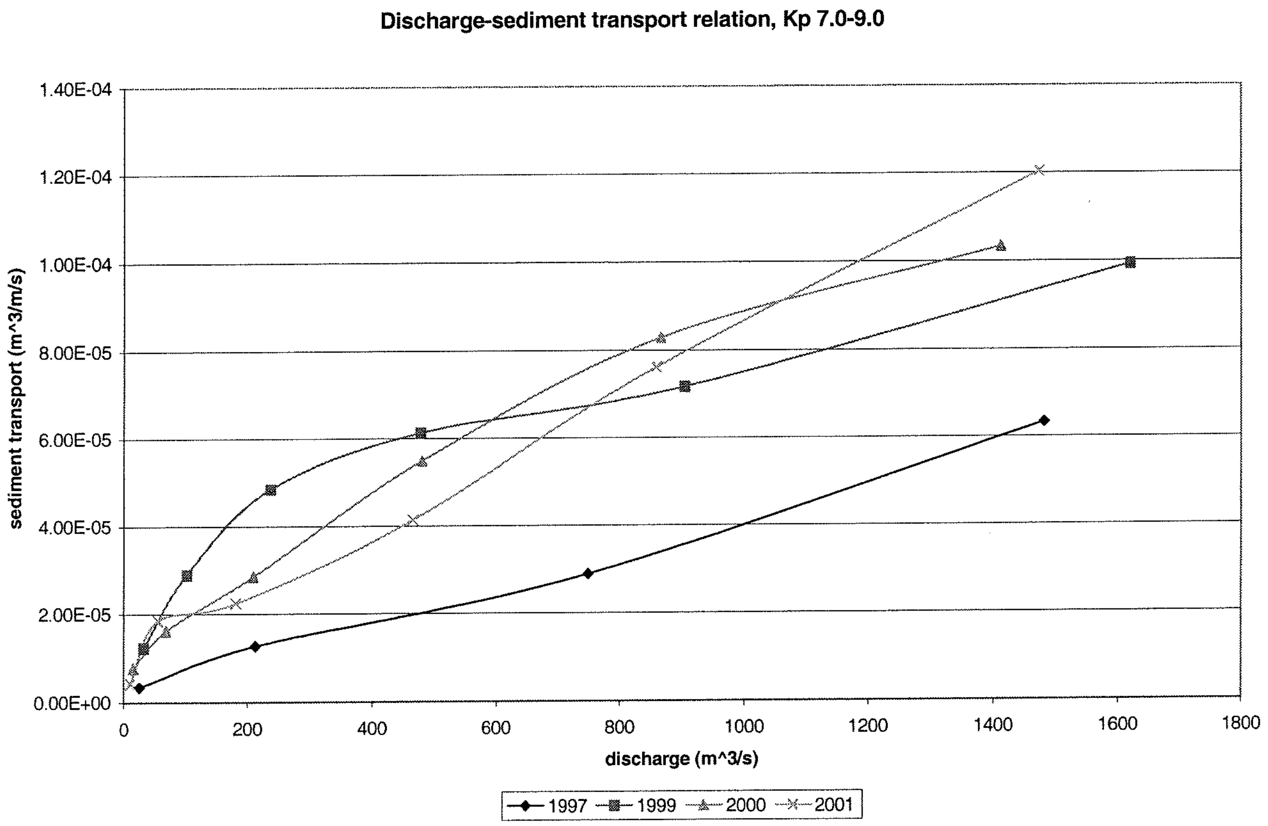


Figure XII.7. Calculated discharge-sediment transport capacity, Kp 7.0-9.0, without September

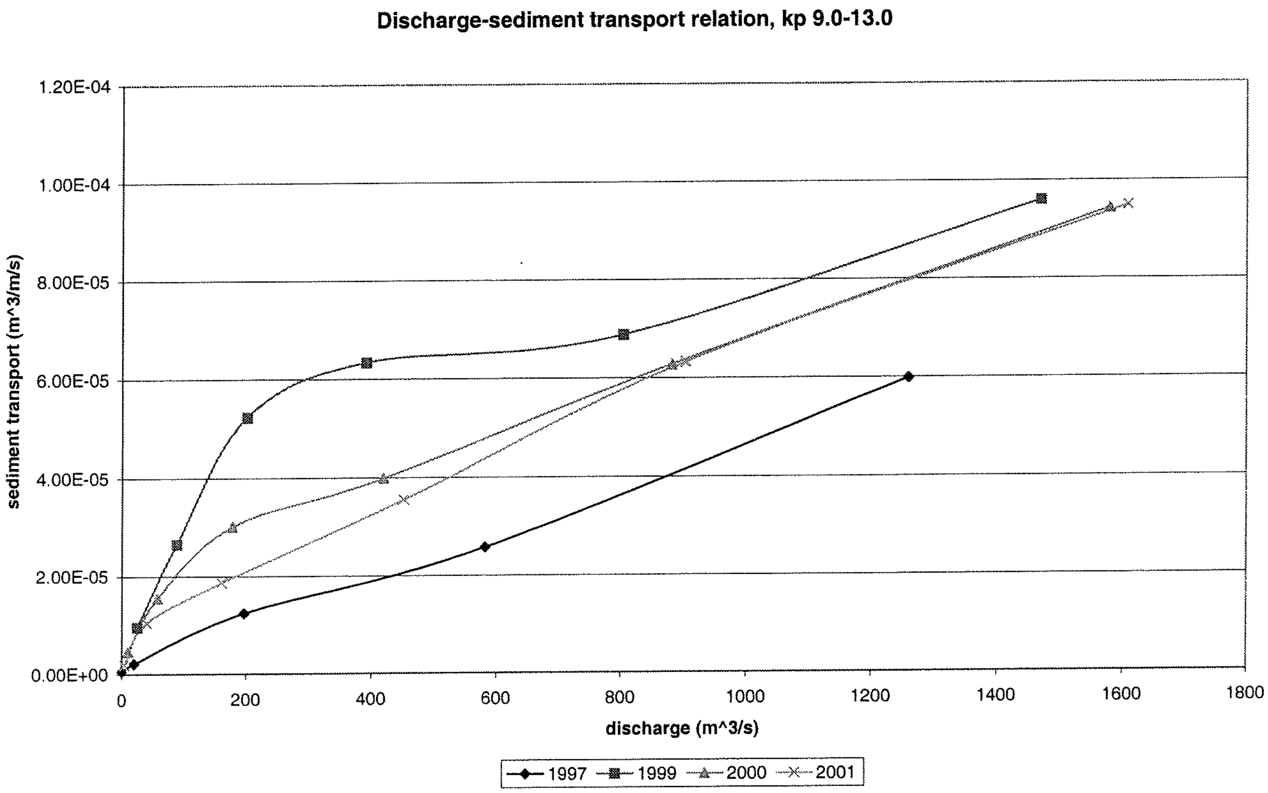


Figure XII.8. Calculated discharge-sediment transport capacity, Kp 9.0-13.0, without September

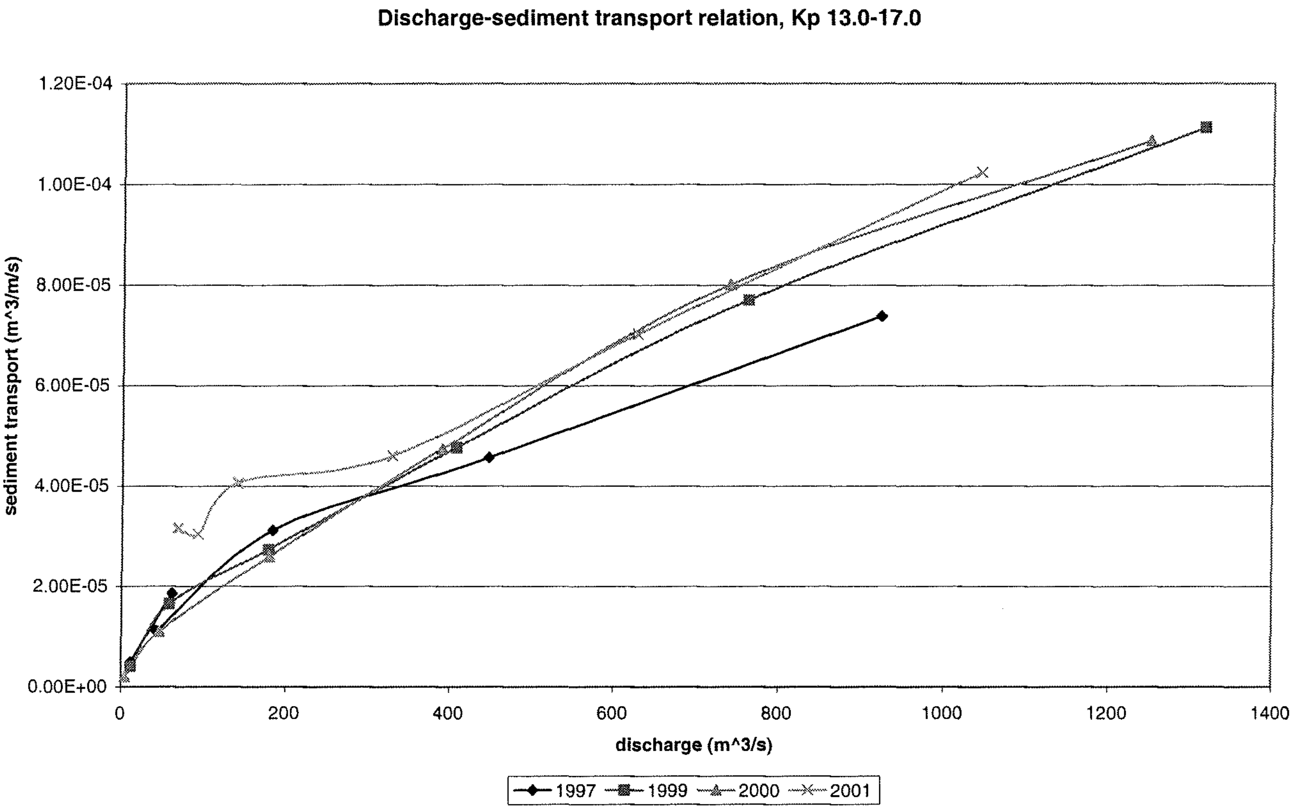


Figure XII.9. ***Calculated discharge-sediment transport capacity,*** **Kp 13.0-17.0, without September**

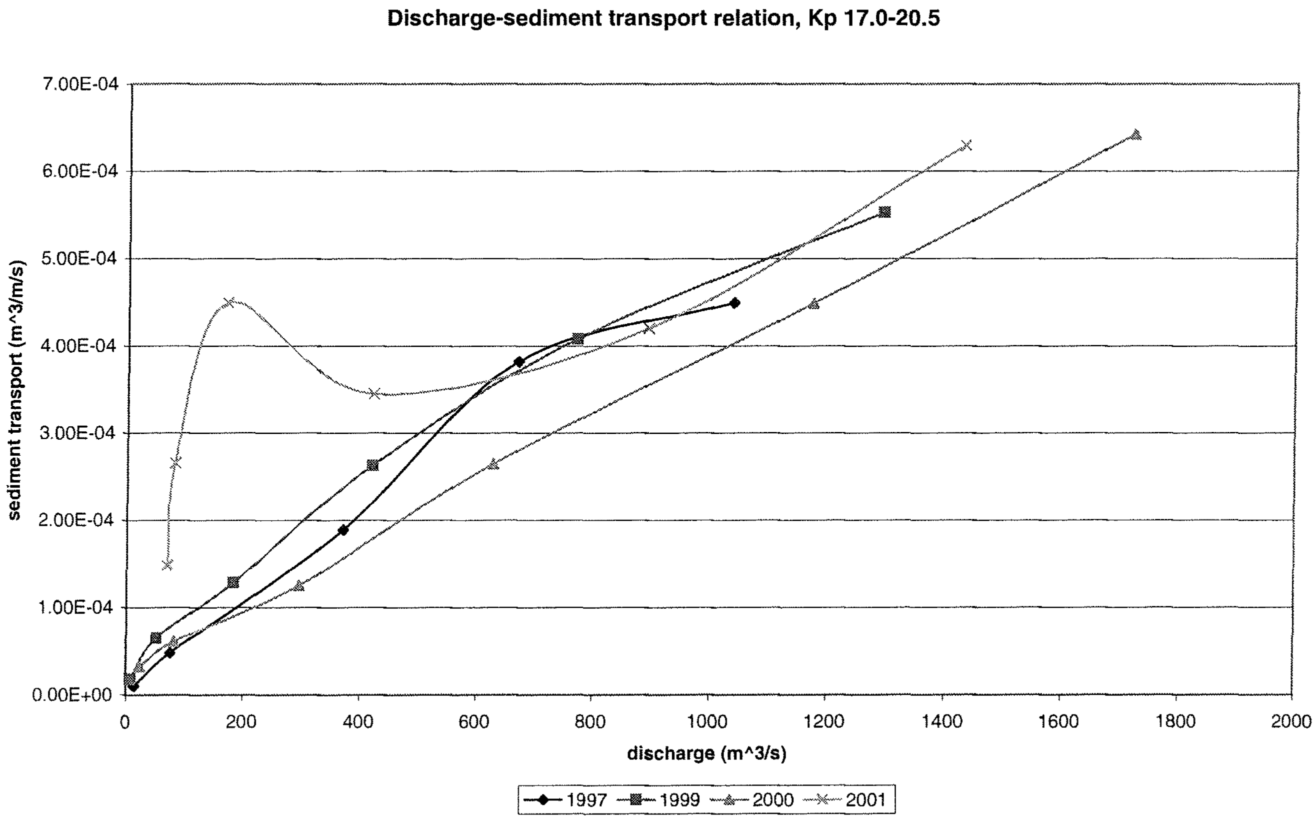


Figure XII.10. Calculated discharge-sediment transport capacity, Kp 17.0-20.5, without September

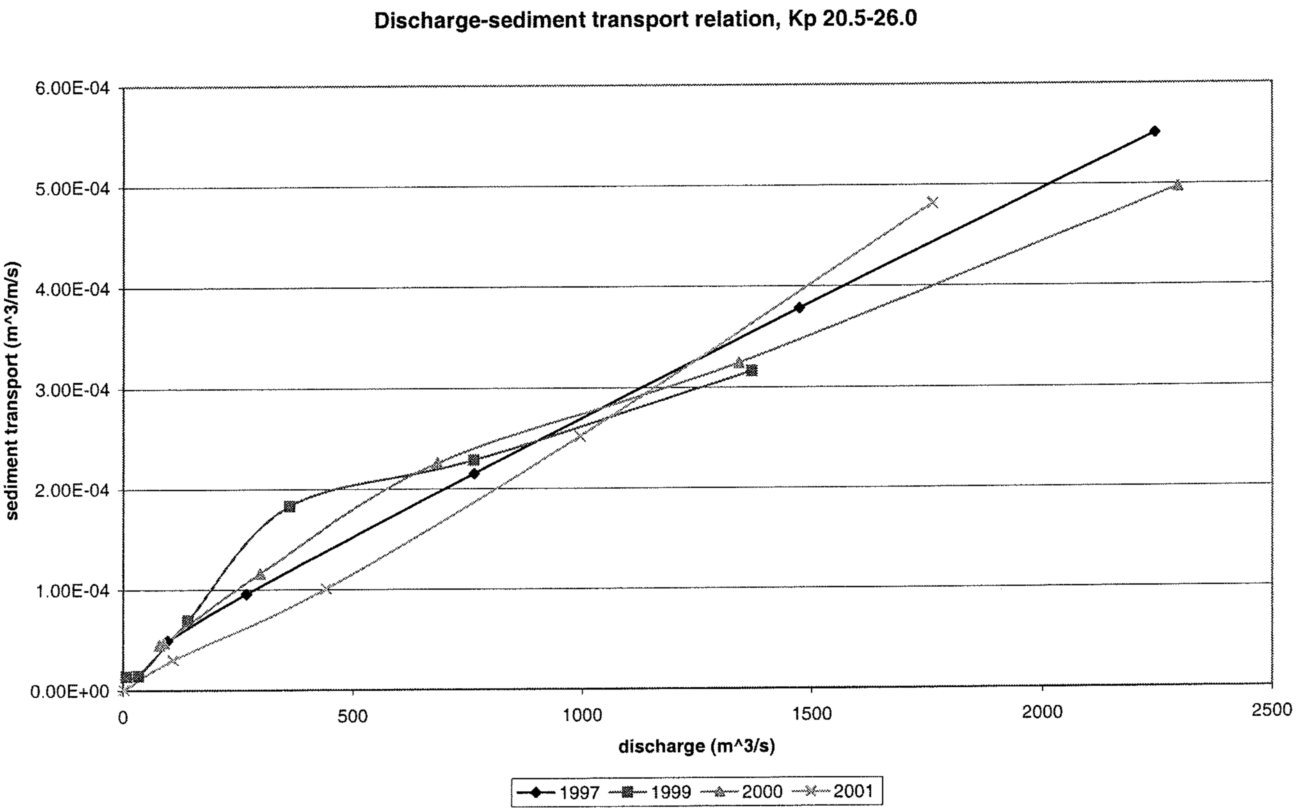


Figure XII.11. Calculated discharge-sediment transport capacity, Kp 20.5-26.0, without September

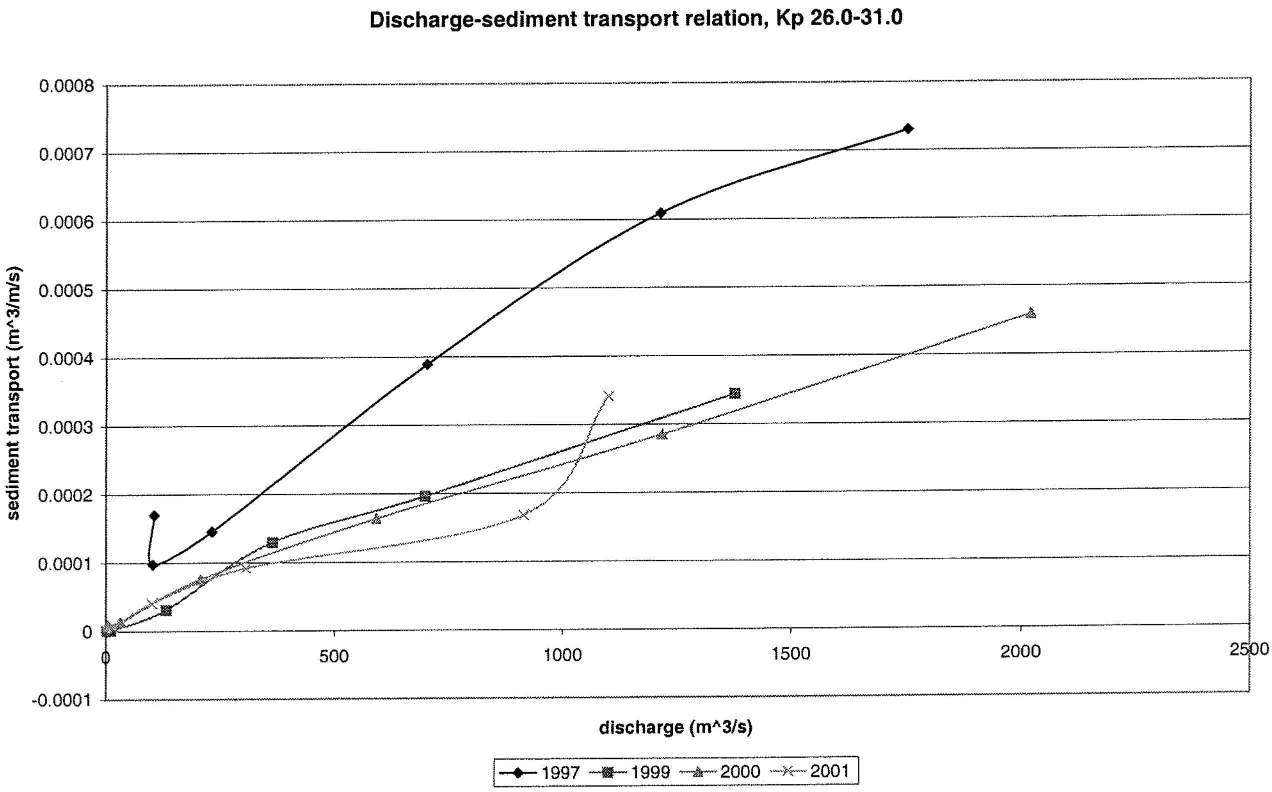


Figure XII.12. Calculated discharge-sediment transport capacity, Kp 26.0-31.0, without September

Appendix XIII:

Satellite images
1998, 1999, 2000 and 2001

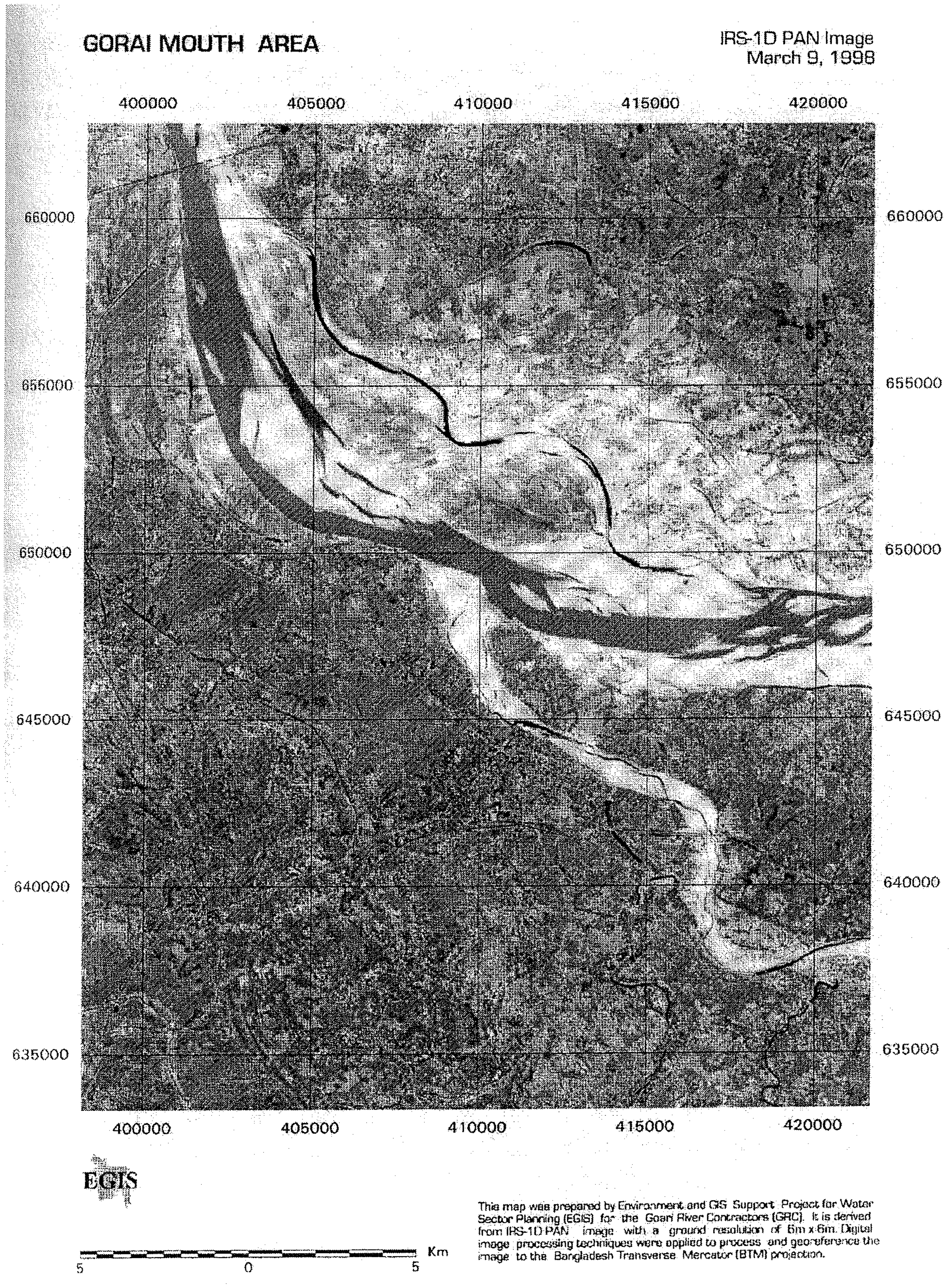


Figure XIII.1. Satellite image March 1998 (GRC, 2001)

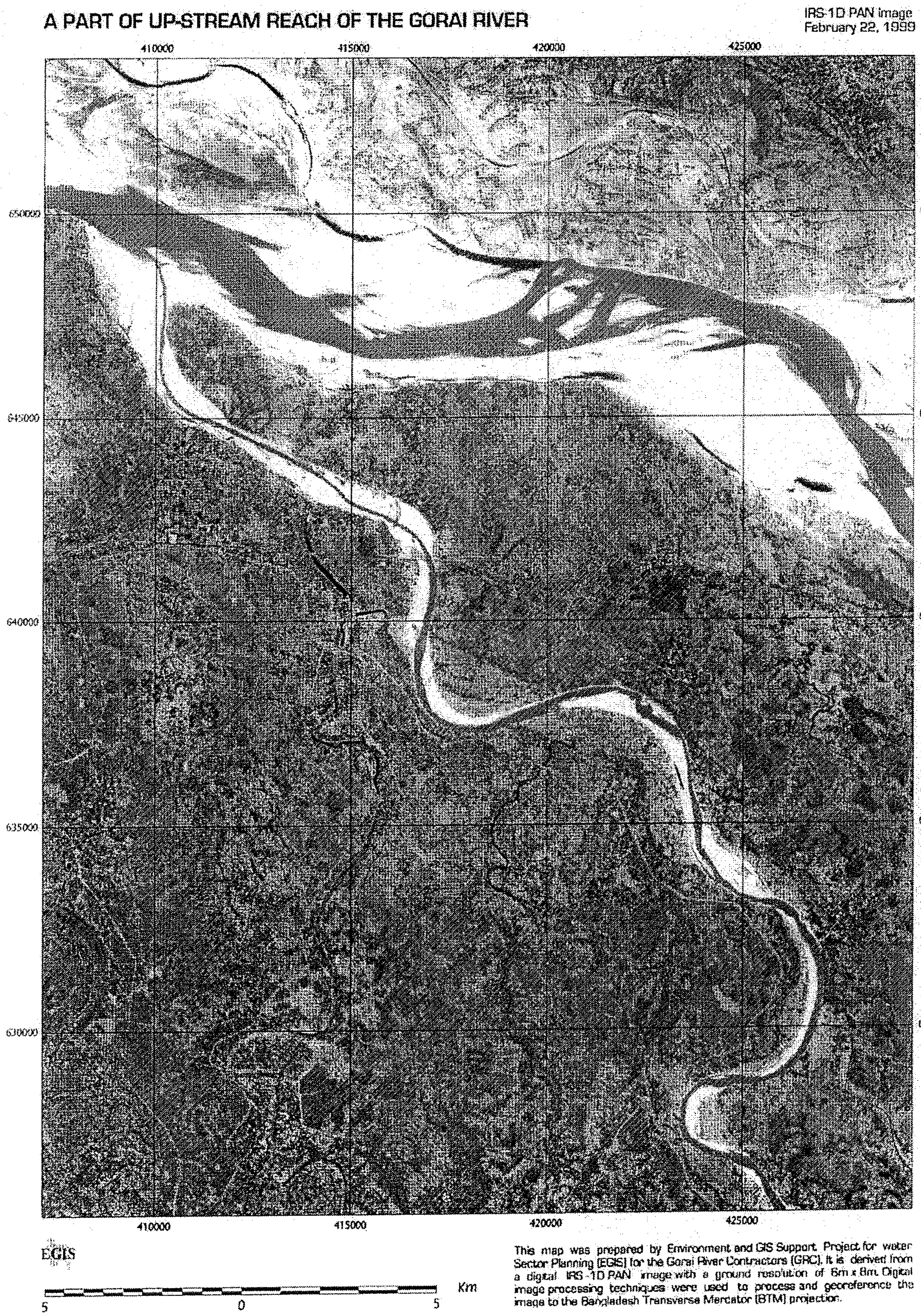


Figure XIII.2. Satellite image February 1999 (GRC, 2001)

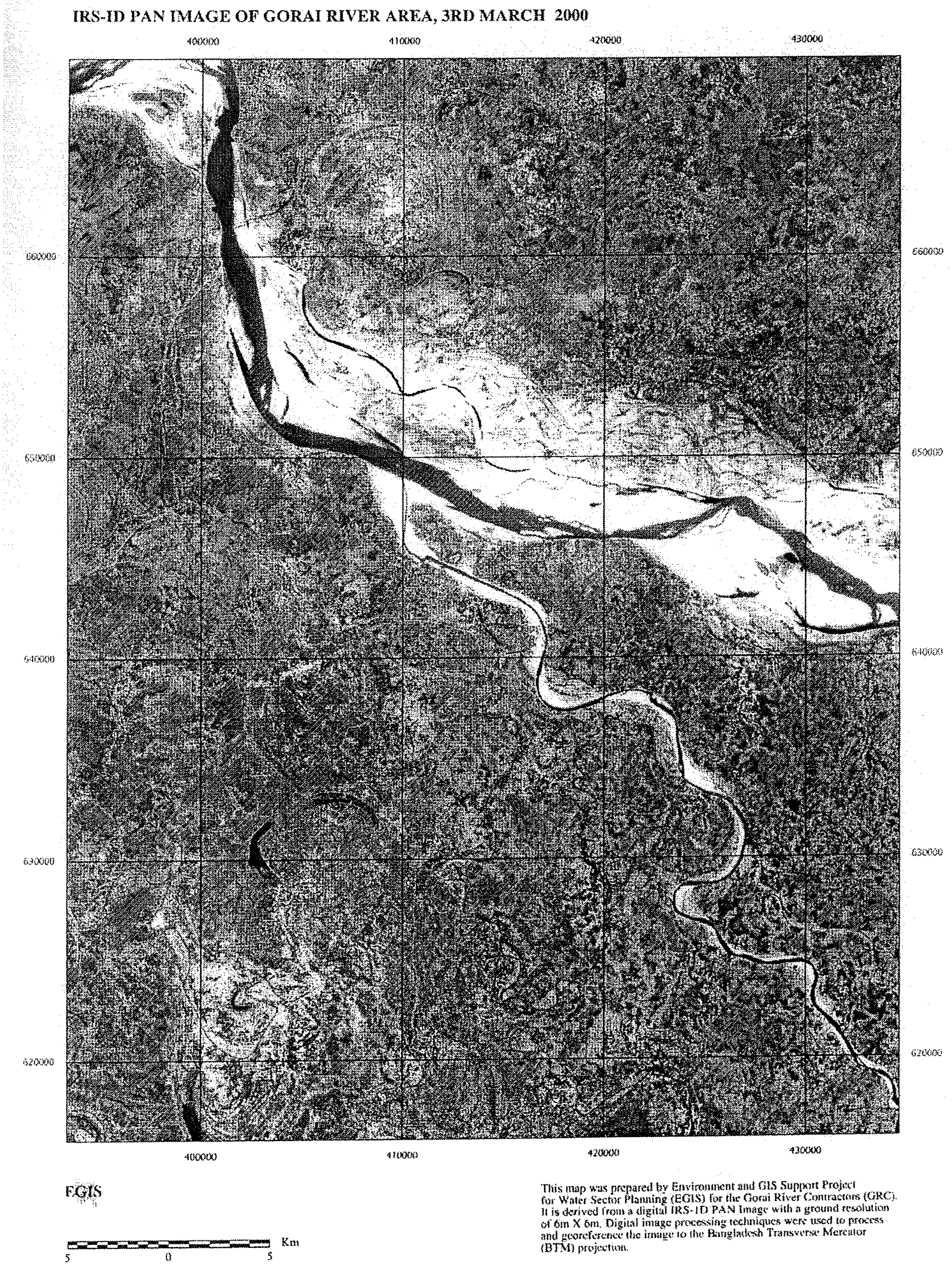


Figure XIII.3. Satellite image March 2000 (GRC, 2001)

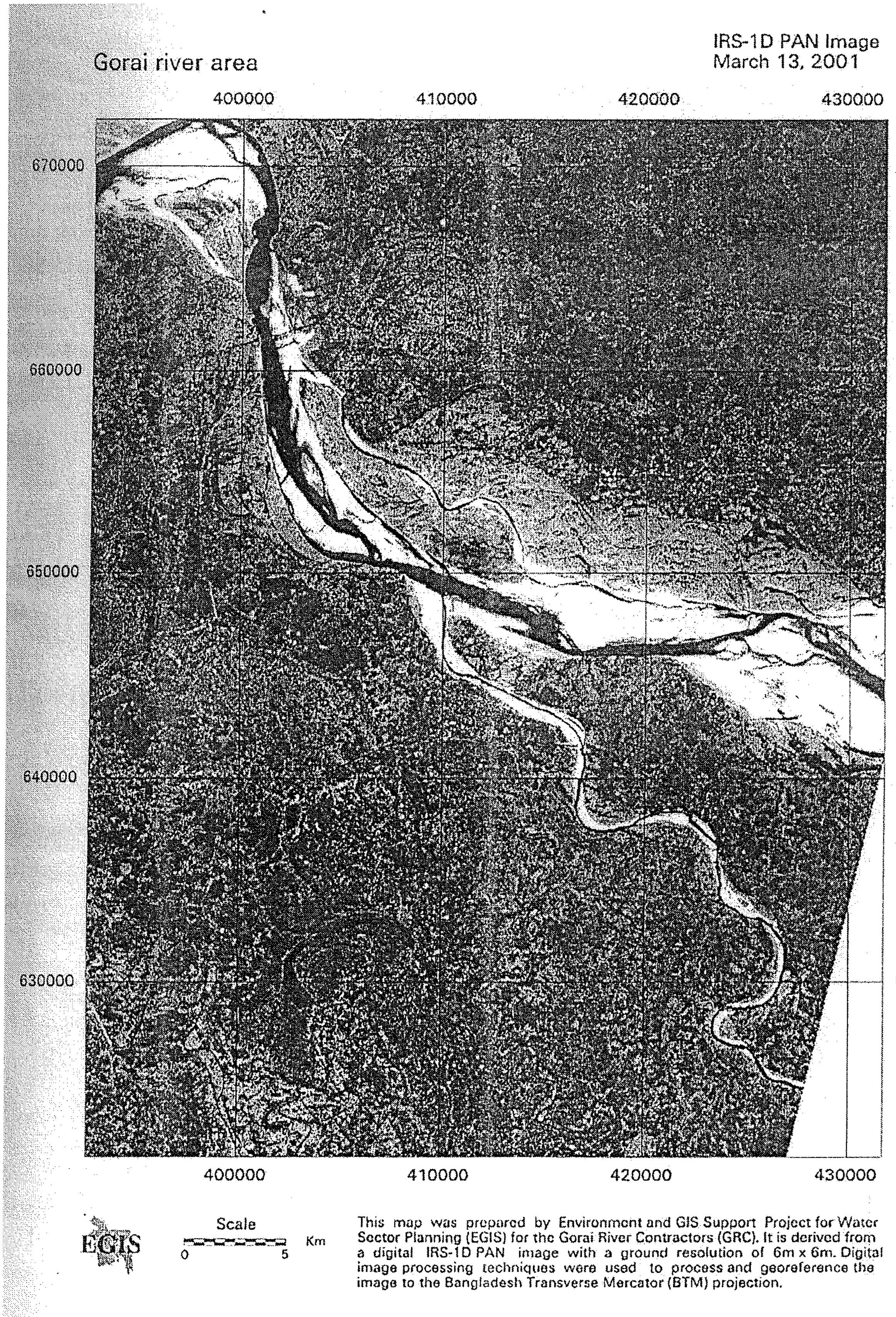


Figure XIII.4. Satellite image March 2001 (GRC, 2001)

Appendix XIV:

Dredging alignment
first second and third season

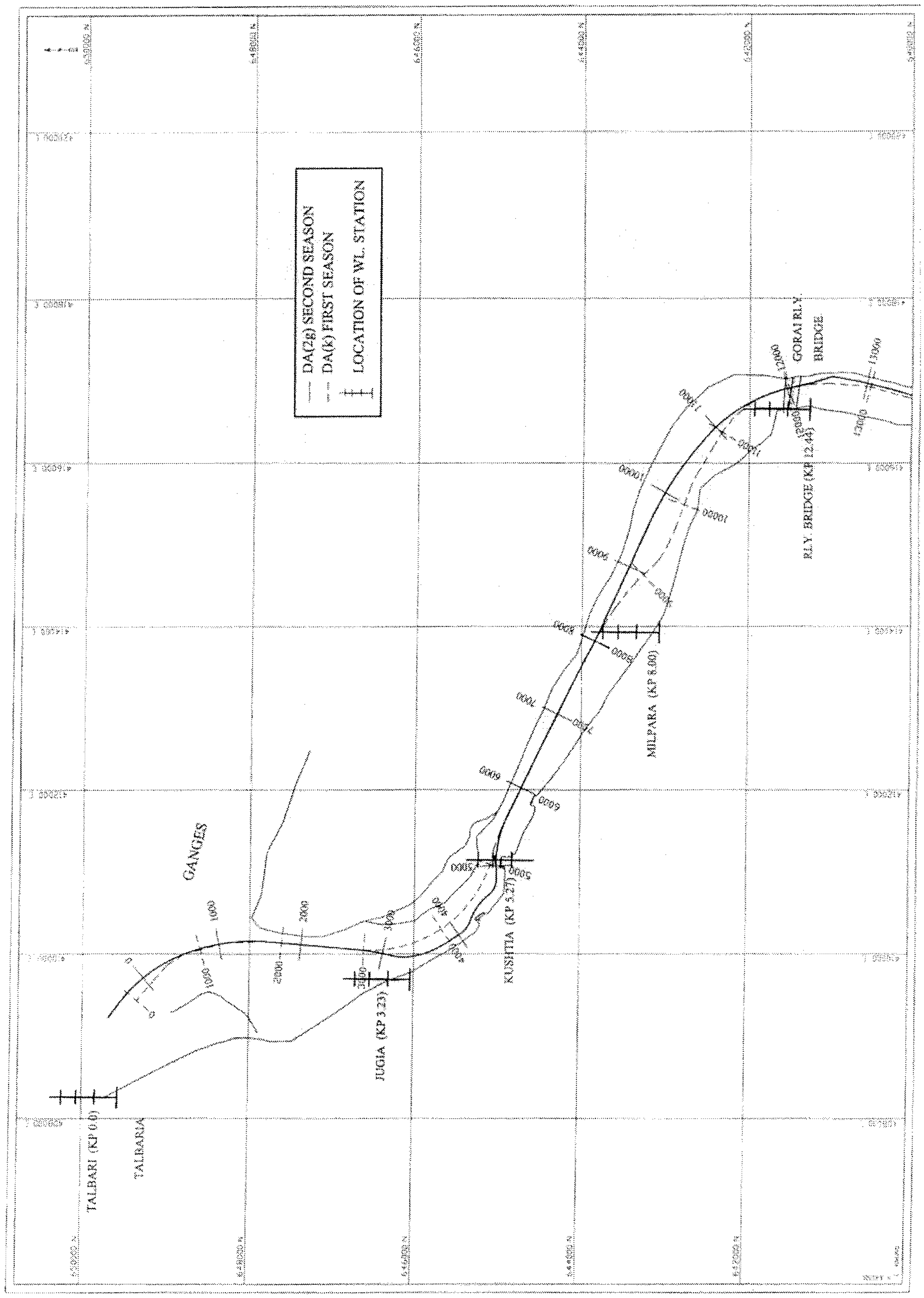


Figure XIV.1 Dredging alignment, first and second season, us Gorai Railway Bridge (GRC, 2000)

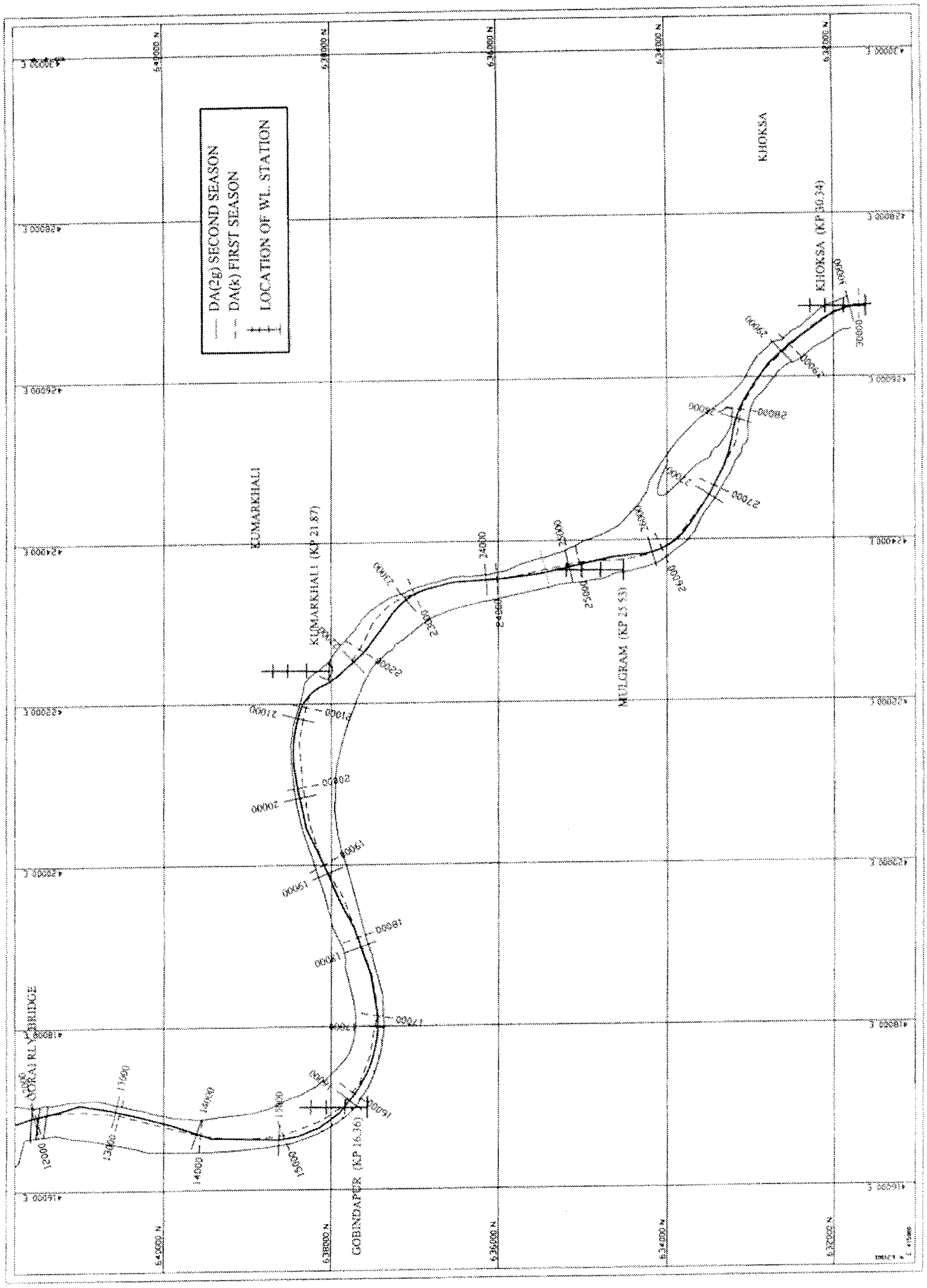
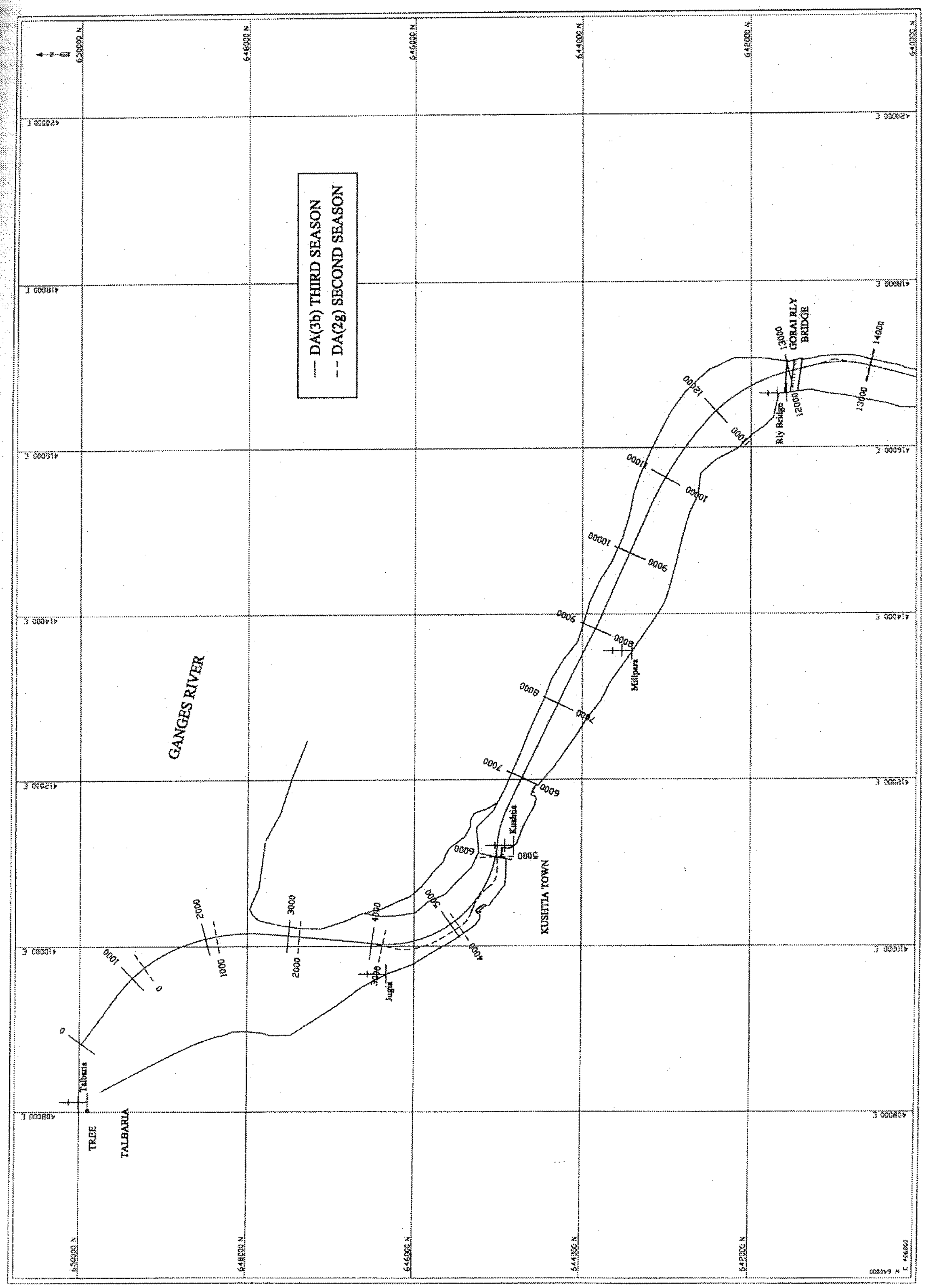


Figure XIV.2. Dredging alignment first and second season, ds Gorai Railway Bridge (GRC, 2000)



Figue XIV.3: Dredging alignment second and third season, us Gorai Railway Bridge (GRC, 2001)

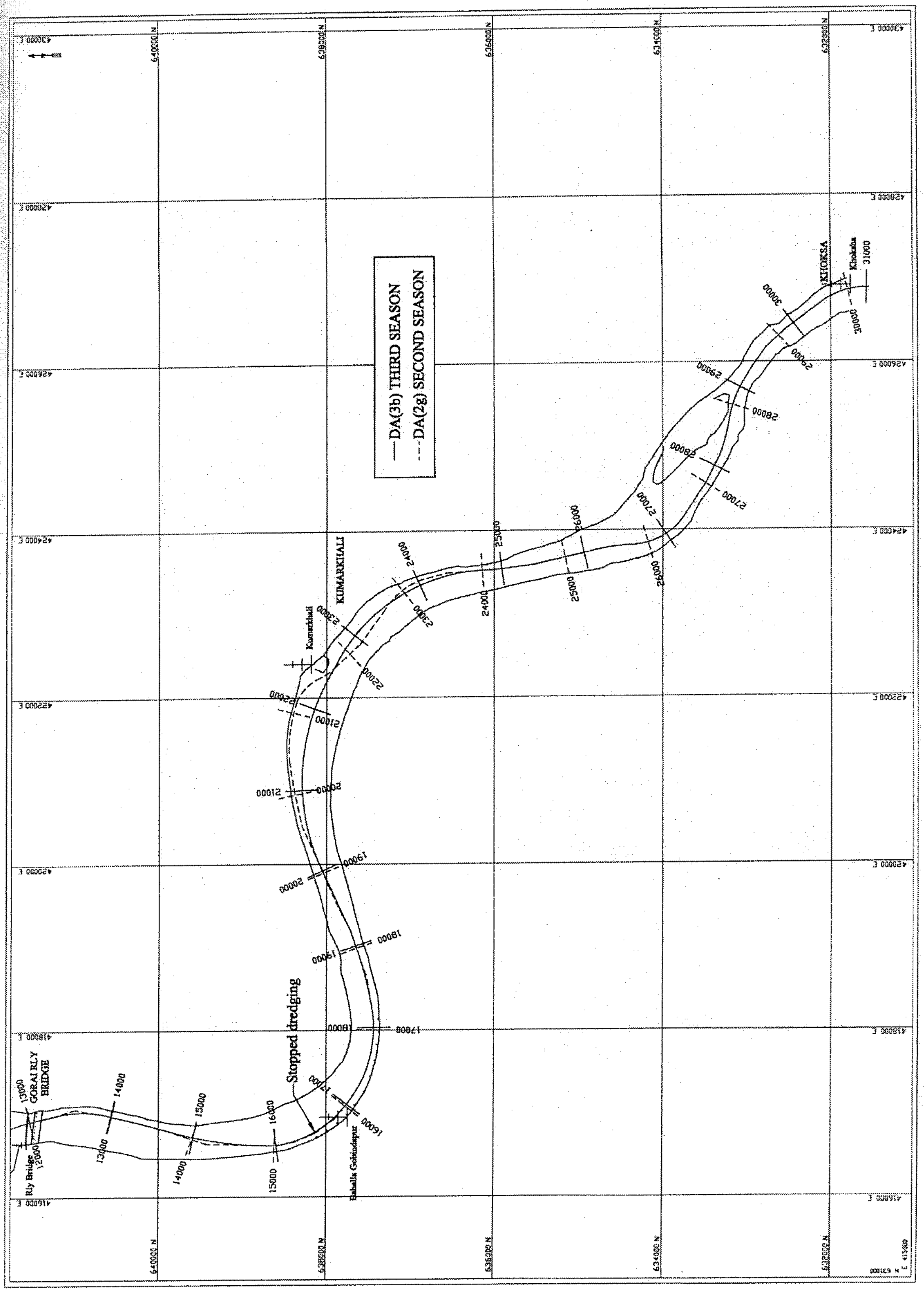


Figure XIV.4: Dredging alignment second and third season, ds Gorai Railway Bridge (GRC, 2001)

Appendix XV:

Disposal sites
first second and third season

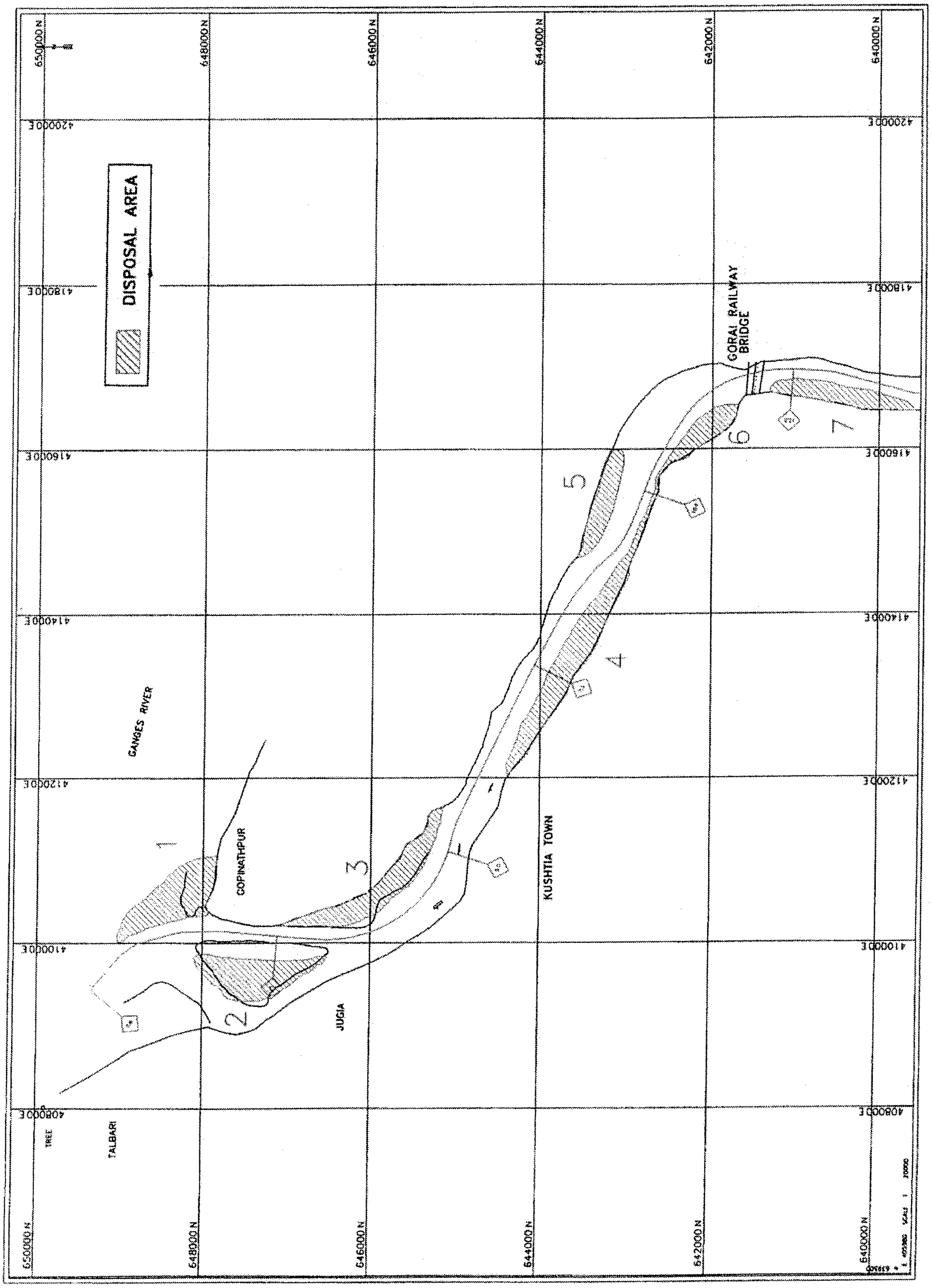


Figure XV.1. Disposal sites first season, us Gorai Railway Bridge (GRC, 1999)

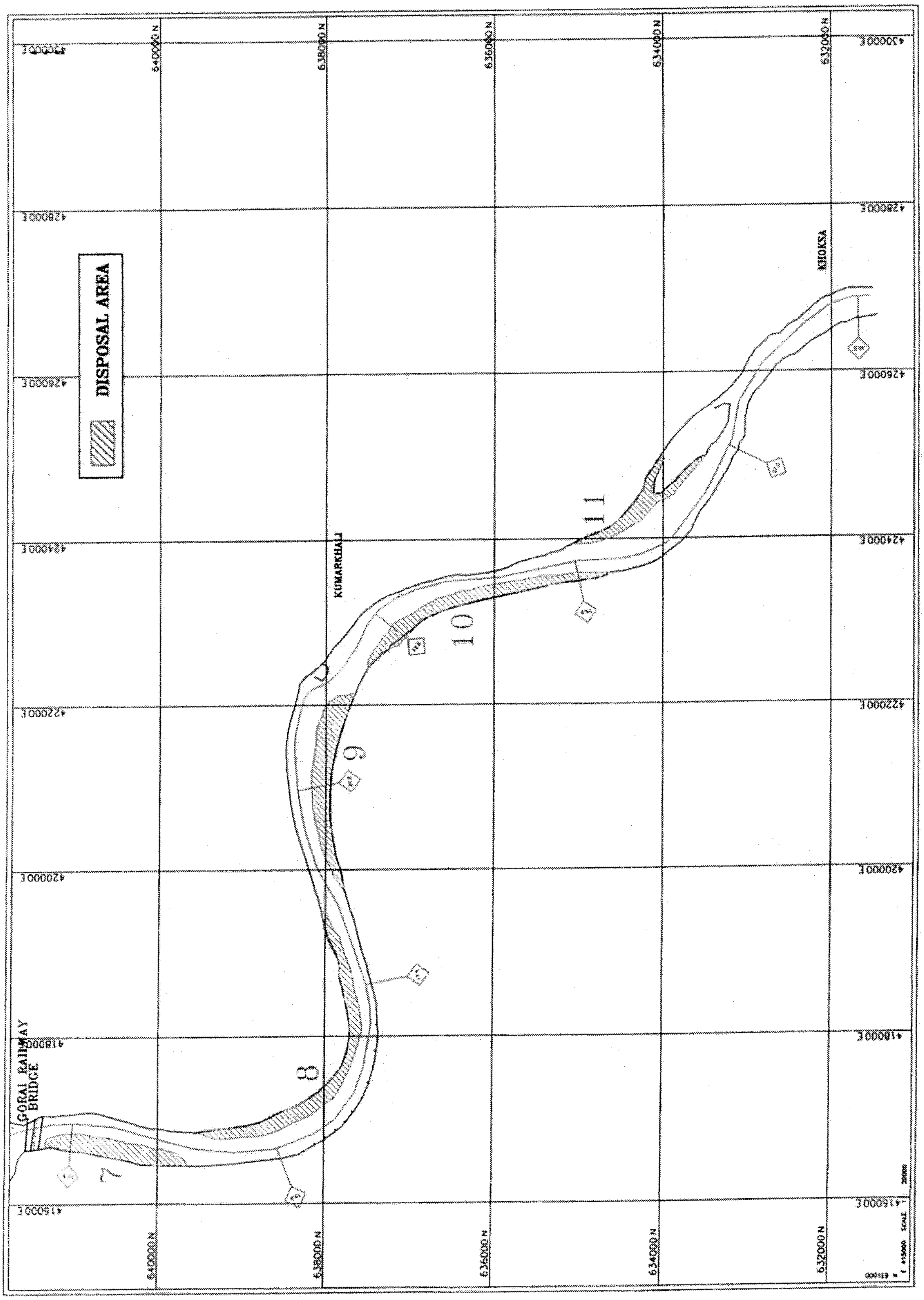


Figure XV.2: Disposal sites first season, ds Gorai Railway Bridge (GRC, 1999)

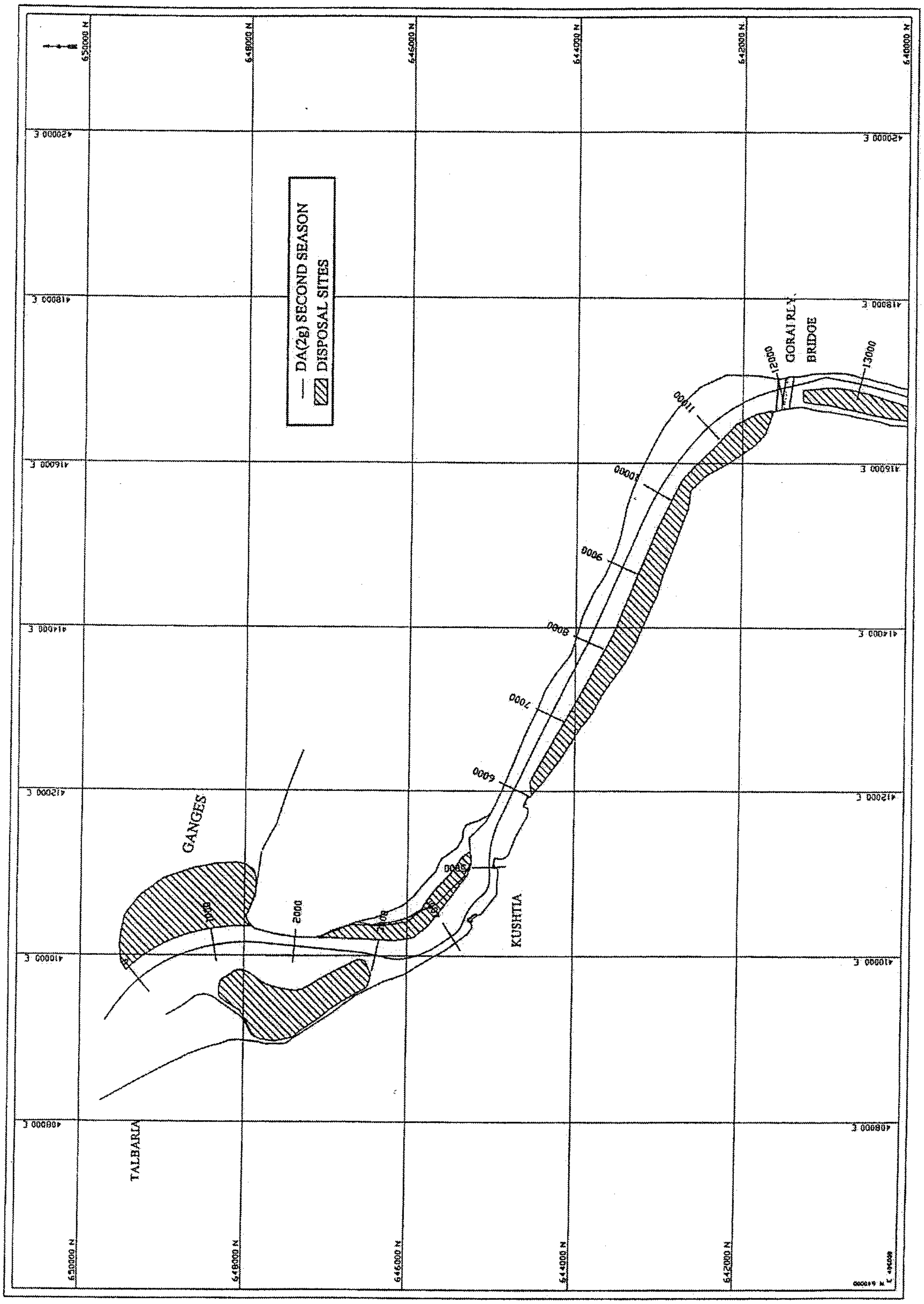


Figure XV.3. Disposal sites second season, us Gorai Railway Bridge (GRC, 2000)

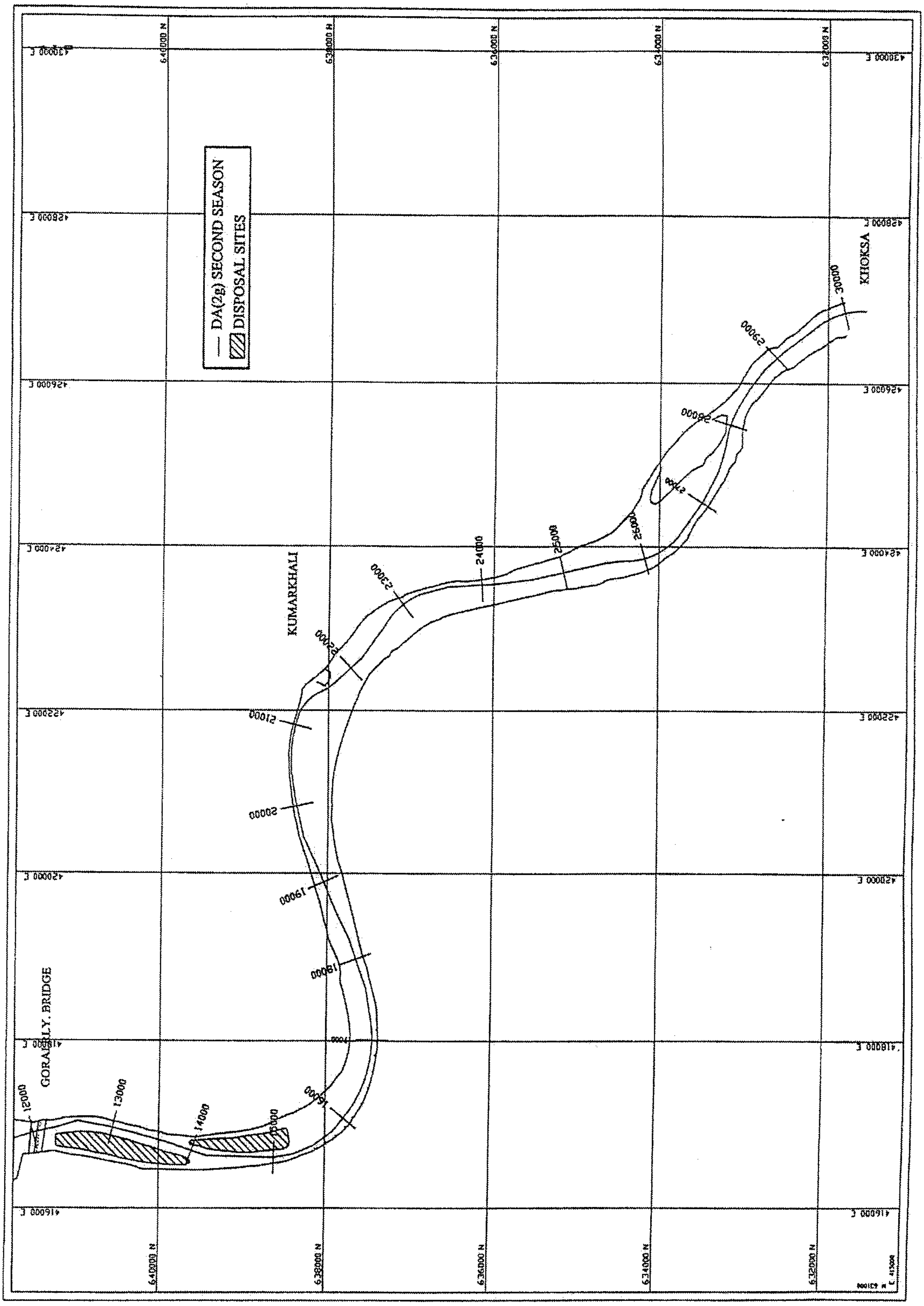


Figure XV.4. Disposal sites second season, ds Gorai Railway Bridge (GRC, 2000)

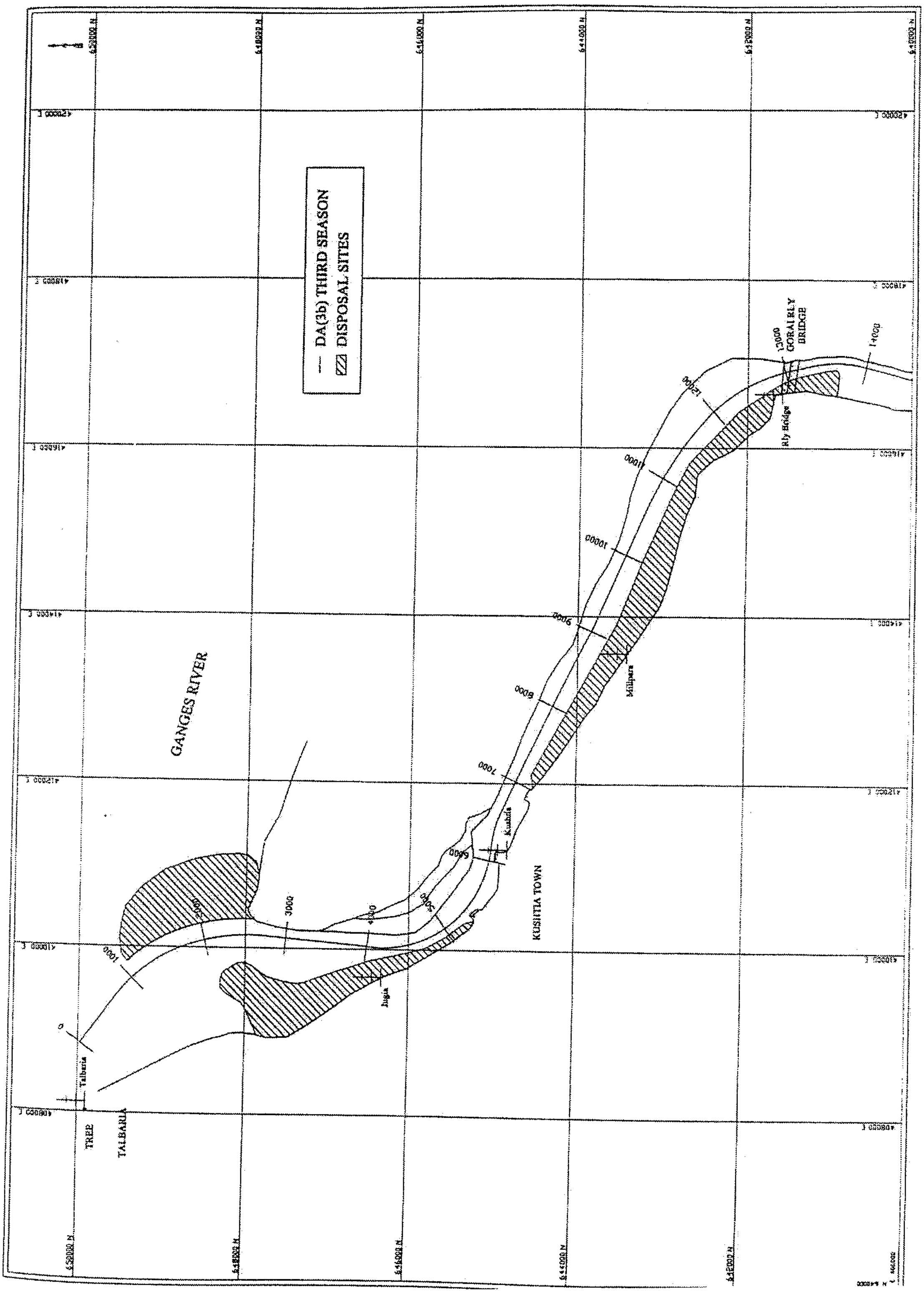


Figure XV.5. Disposal sites third season, us Gorai Railway Bridge (GRC, 2001)

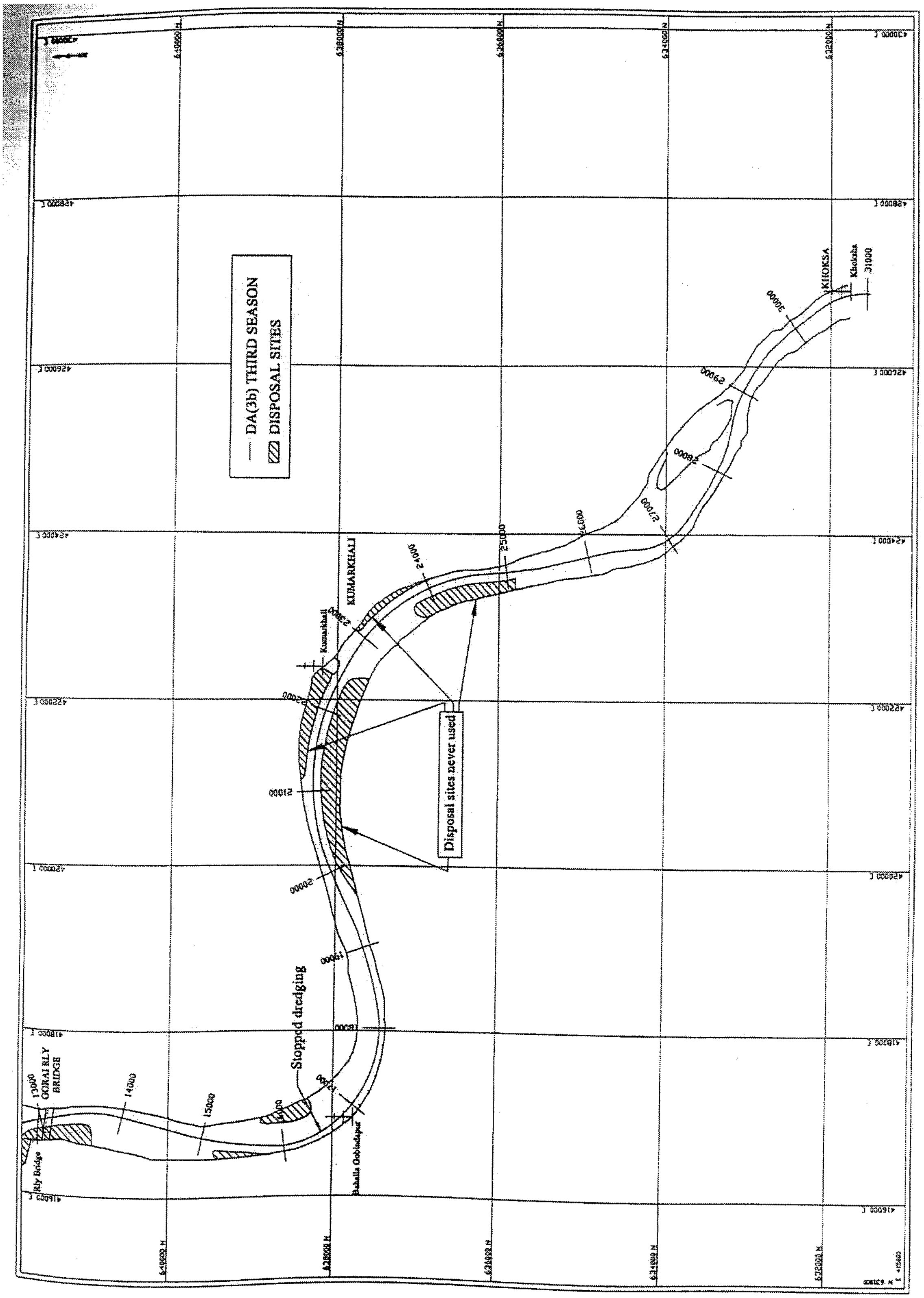


Figure XV.6. Disposal sites third season, ds Gorai Railway Bridge (GRC, 2001)