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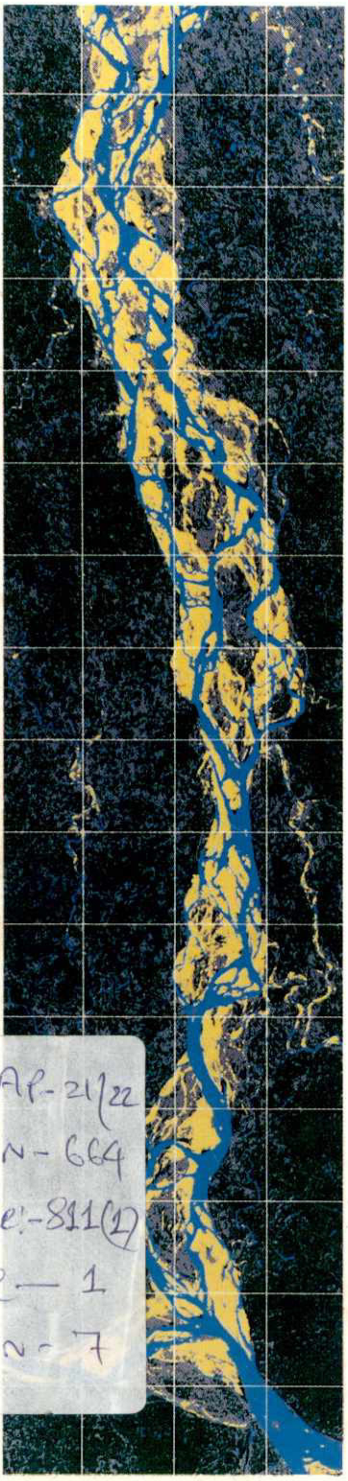
MINISTRY OF IRRIGATION, WATER DEVELOPMENT AND FLOOD CONTROL
FLOOD PLAN COORDINATION ORGANIZATION

KREDITANSTALT FÜR WIEDERAUFBAU (KfW)

CAISSE FRANCAISE DE DEVELOPPEMENT (CFD)



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

TEST AND IMPLEMENTATION PHASE FAP 21

MORPHOLOGICAL PREDICTIONS FOR TEST SITES

JULY 1996

CONSULTING CONSORTIUM FAP 21/22

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

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(AFPM) PILOT PROJECT
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EXECUTIVE SUMMARY

The morphological behaviour of the Brahmaputra-Jamuna River at Kamarjani and Bahadurabad is analyzed on the basis of satellite images and survey data. The results are used to assess the probability of attack of Test Site I at Kamarjani and Test Site II at Bahadurabad.

The probabilities of attack in the **Kamarjani** area in 1996 are 70% for the groynes at Test Site I, 20% for the FAP 21 camp and 90% for Kamarjani-Rasulpur. This means that the certainty of attack of the groynes is decreasing compared to previous years, whereas erosion is threatening the FAP 21 camp more and more. The above values for the probabilities of attack have been strongly influenced by the expectation of a strong attraction of the flow by the scour hole in front of the groynes. Previously this effect was underestimated. If it now turns out to be overestimated, however, the actual probability of attack of the groynes will be lower and the actual probability of attack of the FAP 21 camp will be higher.

The probability of attack of Test Site II at **Bahadurabad** in 1996 is 90%. Attack in 1997 and 1998 is substantially less certain because the absence of a clear bend makes that capricious planform changes easily occur.

The predictions made in September 1995 for Kamarjani turn out to have been quite good, but the predictions for Bahadurabad have been less successful, due to the complexity of the area.

An important element of this report is the outline of a manual for morphological predictions in Appendix B. This manual aims at an integration of the methods developed by FAP 21/22, FAP 24, FAP 1 and EGIS (formerly FAP 19) and is meant to become a part of the future bank protection and river training standards most appropriate for the prevailing conditions at the Brahmaputra-Jamuna River and other rivers of Bangladesh.

1 INTRODUCTION

1.1 General

Two distinct projects are being undertaken by Consulting Consortium FAP 21/22. The first one is the Bank Protection Pilot Project FAP 21. The second one is the River Training / Active Flood Plain Management (AFPM) Pilot Project FAP 22. The objectives of the two projects are explained in Sections 1.2 and 1.3 respectively. Both projects require predictions of the morphological development of the river, but this report deals only with predictions for FAP 21. The sources of information for the predictions are listed in Section 1.4 and the predictions themselves are elaborated in Chapters 2 and 3. The next mission for morphological analyses is scheduled to be carried out in September 1996. The data required for this mission are listed in Chapter 4. The conclusions are given in the Executive Summary at the beginning of this report.

An important element of this report is the outline of a manual for morphological predictions in Appendix B. This manual aims at an integration of the methods developed by FAP 21/22, FAP 24, FAP 1 and EGIS (formerly FAP 19).

1.2 Objectives of Bank Protection Pilot Project FAP 21

The objectives of the Bank Protection Pilot Project FAP 21 are to find improved solutions for protection against bank erosion by constructing different types of groynes and revetments at two selected locations on the Brahmaputra-Jamuna River. The performance of these structures shall be monitored for a period of several years with the aim to develop and to optimize design criteria and cost-effective construction and maintenance methods which will serve as future standards most appropriate for the prevailing conditions at the Brahmaputra-Jamuna River and other rivers of Bangladesh.

An obvious requirement for the testing of these structures is that they will be attacked by the river during the five years the project will last. Yet this condition is by no means trivial since the attack is difficult to predict. The banks of the Brahmaputra-Jamuna River are easily eroded so that the river experiences substantial changes in planform during individual floods. Accordingly, the locations of bank attack shift rapidly over the years, so that morphological predictions are needed to find locations where continued bank erosion can be expected. The development of methods for these morphological predictions and the description of these methods in a manual are an integral part of the project.

There are two locations for the test structures. Groynes have been constructed at Test Site I at Kamarjani-Dhutichara in the lean season 1994-1995. This structure was damaged during the flood of 1995, which led to adaptation and repair works in the lean season 1995-1996. The construction of revetments has been started at Test Site II at Bahadurabad-Kulkandi in the lean season 1995-1996.

1.3 Objectives of River Training / Active Flood Plain Management Pilot Project FAP 22

The objectives of the River Training / Active Flood Plain Management (AFPM) Project FAP 22 are to develop recurrent measures for river training and to assess their technical and economical feasibility through prototype tests in the Brahmaputra-Jamuna River. The performance of these structures shall be monitored with the aim to develop and to optimize design criteria and cost-effective construction and maintenance methods which will serve as future standards most appropriate for the prevailing conditions at the Brahmaputra-Jamuna River and other rivers of

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Bangladesh. The development of prediction methods for morphological changes and the description of these methods in a manual are an integral part of the development of the recurrent measures.

For the time being, the execution of FAP 22 has been suspended.

1.4 Sources of Information

The following information has been used for the morphological analyses in this report:

- Bathymetry maps and bathymetry change maps prepared by EGIS (formerly FAP 19) from river surveys carried out by FAP 24. An overview is given in Table 1.1;
- MOS-MESSR and Landsat satellite images. An overview of all MOS-MESSR and Landsat satellite images acquired by FAP 21/22 is given in Table 1.2. They have been processed by NLR (National Aerospace Laboratory, The Netherlands), DELFT HYDRAULICS (Consulting Consortium FAP 21/22) and EGIS (formerly FAP 19);
- Field visit on 29 February and 1 March 1996. A brief description of this field visit is given in Appendix A.

Area	Month	
	Bathymetry map	Bathymetry change map
Kamarjani (Test Site I)	September 1994 November 1994 March 1995 August 1995 November-December 1995	November 1994 - March 1995 March 1995 - August 1995
Bahadurabad (Test Site II)	November 1994 February 1995 July 1995 November 1995	November 1994 - February 1995 February 1995 - July 1995 July 1995 - November 1995

Table 1.1: Bathymetric survey maps

Year of preceding flood	Date	Image	Water level at Bahadurabad [m+PWD]	Year of preceding flood	Date	Image	Water level at Bahaduraba d [m+PWD]
1971	-	none	-	1986	07-02-87 07-02-87	MSS 138-42 MSS 138-43	13.30 13.30
1972	21-02-73 21-02-73	MSS 138-42 MSS 138-43	13.09 13.09	1987	-	none	-
1973	-	none	-	1988	03-03-89 03-03-89 20-03-89 20-03-89	MOS 51.84W MOS 51.85W MOS 51.85E MOS 51.86E	13.94 13.94 13.77 13.77
1974	-	none	-	1989	06-02-90 06-02-90 30-01-90	MOS 51.84W MOS 51.85W TM 148-43	13.75 13.75 13.69
1975	10-01-76 10-01-76	MSS 138-42 MSS 138-43	13.54 13.54	1990	24-04-91 21-03-91	MOS 51.85W TM 148-43	15.07 13.70
1976	09-02-77 09-02-77	MSS 138-42 MSS 138-43	13.09 13.09	1991	08-03-92 08-03-92	TM 148-42 TM 148.43	13.76 13.76
1977	22-02-78 22-02-78	MSS 138-42 MSS 138-43	13.07 13.07	1992	21-01-93 21-01-93 01-12-92 01-12-92	MOS 51.84W MOS 51.85W MOS 51.85E MOS 51.86E	14.10 14.10 14.55 14.55
1978	26-02-79 25-12-78	MSS 138-42 MSS 138-43	13.11 13.99	1993	25-01-94 25-01-94	TM 148-42 TM 148-43	13.61 13.61
1979	16-01-80 16-01-80	MSS 138-42 MSS 138-43	13.78 13.78	1994	28-01-95 28-01-95	TM 148-42 TM 148-43	13.04 13.04
1980	-	none	-	1995	28-11-95 28-11-95 31-01-96 31-01-96	TM 148-42 TM 148-43 TM 148-42 TM 148-43	14.92 14.92 13.53 13.53
1981	-	none	-				
1982	05-02-83 05-02-83	MSS 138-42 MSS 138-43	13.23 13.23				
1983	23-02-84 23-02-84	MSS 138-42 MSS 138-43	13.12 13.12				
1984	25-02-85 25-02-85	MSS 138-42 MSS 138-43	13.49 13.49				
1985	20-02-86 20-02-86	MSS 138-42 MSS 138-43	13.38 13.38				
MSS = Landsat MSS, TM = Landsat TM, MOS = MOS-MESSR							

Table 1.2: Satellite images 1973-1996

2 KAMARJANI

2.1 Purposes

The morphological analysis of the area of Kamarjani has the following purposes:

- To contribute to the evaluation and the analysis of the damages of the groynes at Kamarjani-Dhutichara;
- To assess the effect of the groynes at Kamarjani-Dhutichara on bank retreat in 1995;
- To predict whether attack of the groynes at Kamarjani-Dhutichara will continue;
- To assess the risk that the present FAP 21 camp at Kamarjani-Dakatia will be washed away during the flood of 1996;

The evaluation and the analysis of the damages of the groynes as well as the assessment of the effect of the groynes on bank retreat are reported elsewhere. The other two purposes are dealt with in the present report.

2.2 Evaluation of Previous Predictions

Morphological predictions made in 1992 (Consulting Consortium FAP 21/22, 1993) resulted in selecting the area of Kamarjani for Test Site I. The suitability of this area was reviewed after the 1993, 1994 and 1995 floods (Consulting Consortium FAP 21/22, 1994a, 1994b, 1995a, 1995b), which led to the conclusion that Kamarjani remained a good area for Test Site I. The banks at Kamarjani continued to be eroded in the period from 1992 to 1995. Groynes were built at Kamarjani-Dhutichara in the lean season 1994-1995. Indeed the structure came under attack and was even damaged during the flood of 1995.

The predictions made by Consulting Consortium FAP 21/22 (1995b) are evaluated in Table 2.1. These predictions are indicated in Figure 2.2 and had been based on Figures 2.1 and 2.5 to 2.8. The evaluation is carried out by comparing the predicted development with the actual development which is shown in Figures 2.3, 2.4 and 2.9.

It turns out that the attraction of the flow and the channel by the scour hole in front of the groynes has been underestimated. This means that the probability of continued attack of the groynes during the flood of 1996 has been underestimated as well. This probability can now be assessed to be considerably higher than 50%.

Worth noting in particular is the correct prediction of the drastic changes according to Development K-9, which was not based on any of the model concepts described in previous reports but the result of experience gained in a later stage of the FAP 21/22 project.

2.3 Analysis in March 1996

Ongoing and predicted morphological developments are presented in Table 2.2 and Figure 2.12. The increased importance of the western channels makes abandonment of the Kamarjani Branch very unlikely, so that the probability of erosion in the area of Kamarjani remains high. To what extent this erosion will occur near the groynes, at the FAP 21 camp or at Kamarjani-Rasulpur depends on the attraction of the flow and the channel by the scour hole in front of the groynes. This attraction was underestimated by Consulting Consortium FAP 21/22 (1995b) and remains difficult to quantify, due to a lack of experience with structures resisting severe attack in the Brahmaputra-Jamuna River. One speculative possibility, for instance, is that the approach channel migrates downstream during the dry season when the attraction by the scour hole is not strong, and is then re-formed further upstream during the next flood. Some lessons might be learned from the morphological history around the Sirajganj Town Protection, but this has not been studied in detail. More will be known when the morphological development around the test structure at Kamarjani has been monitored for a few years.

Continued attack of the groynes during the flood of 1996 is likely, with a probability of, roughly, 70%. This value is higher than estimated previously because the attraction by the scour hole in front of the groynes is now given more importance. Three developments might end the attack:

- abandonment of Kamarjani Branch (Development K-15);
- downstream migration of upper Kamarjani Branch (Development K-16);
- cut-off through inlet along left bank of Kamarjani Branch (Development K-17).

Of these, the downstream migration of the upper Kamarjani Branch has the highest probability.

The probability that the FAP 21 camp will be washed away by the Brahmaputra-Jamuna River is estimated to be 20%. Maybe, however, the threat from the Manos River is more important, but that has not been analyzed in detail.

Morphological development identified and predicted in September 1995	Information used in September 1995	Evaluation in March 1996
K-1: western channels more dominant	Field visit 13 September 1995	Yes: e.g. comparison of Landsat TM images of January 1995 (Fig. 2.1) and January 1996 (Fig. 2.3)
K-2: channels dissecting the charland north of the upper Kamarjani Branch more important	Bathymetries of November 1994 and August 1995, and relation with K-1	Yes: e.g. comparison of Landsat TM images of January 1995 (Fig. 2.1) and January 1996 (Fig. 2.3)
K-3: eastern anabrach along mouth of Sonabari River more important	Landsat TM image January 1995	Yes: as far as the bifurcation immediately upstream concerns, e.g. Landsat TM image of January 1996 (Fig. 2.3)
K-4: eastern branch of 'Central Node' bifurcation more important	Bathymetry of August 1995	Yes: less obstruction by char and more favourable bifurcation angle of eastern branch, e.g. comparison of Landsat TM images of January 1995 (Fig. 2.1) and January 1996 (Fig. 2.3)
K-5: possibility of chute cut-offs through inlets along left bank of Kamarjani Branch	SPOT images of previous years	No: e.g. Landsat TM image of January 1996 (Fig. 2.3), though it should be noted that Consulting Consortium FAP 21/22 (1995b, p.11) mentions the chute cut-offs only as possible 'additional developments' without explicit quantification of the probability
K-6: flow around shoal with dominant southern channel	Bathymetry of August 1995	Yes: see bathymetry of November-December 1995 (Fig. 2.9)
K-7: erosion of left bank of upper Kamarjani Branch	Bathymetry of August 1995	Yes: but much more than indicated in Fig. 2.2, see planform change map (Fig. 2.4)
K-8: decreasing bank erosion at Kamarjani-Rasulpur	Bank-line surveys up to August 1995	Yes: see planform change map (Fig. 2.4)
K-9: Formation of new major channel in eastern anabranch	Landsat TM image January 1995	Yes: e.g. comparison of Landsat TM images of January 1995 (Fig. 2.1) and January 1996 (Fig. 2.3)
Detailed probability of attack during 1996 flood: Test Site I 50%, FAP 21 camp 18%, Kamarjani-Rasulpur 90%	Developments K-1 to K-9	Cannot be judged because 1996 flood did not occur yet. However, it has become clear from the bathymetry of November-December 1995 (Fig. 2.9) that the probability of continued attack of the groynes has been underestimated. The attraction of the flow by the deep scour hole in front of the groynes increases the probability

Table 2.1: Evaluation of September 1995 predictions for Kamarjani

Morphological development identified and predicted in March 1996	Information used in March 1996	Substantiation in March 1996
K-10: Increase in importance of central channel at latitude of Teesta Confluence	Landsat TM image of January 1996	Finger channels immediately upstream indicate channel growth. Relevant bifurcation angles further upstream are negligible
K-11: Probability of abandonment of western channel which joins Kamarjani Branch upstream of test site is 22%	Landsat TM image of January 1996	Bifurcation angle in vicinity of Teesta Confluence equals 50°, hence probability = 0.75 × (50-20) = 22%. Angle is increasing due to growth of confluence bar at mouth of Teesta River, but finger channels in area of bifurcation indicate that angle may decrease by erosion of bar immediately downstream of offtake point. Therefore no need to correct value of 50°.
K-12: Excavation of downstream part of western channel which joins Kamarjani Branch upstream of test site, provided that channel is not abandoned	Landsat TM image of January 1996	Finger channels in downstream part of channel
K-13: Increase in importance of central channel towards Central Node	Landsat TM image of January 1996	Finger channels upstream indicate channel growth. Direction of approach flow at latitude of Teesta Confluence favours growth
K-14: Probability of abandonment of channel from Central Node to Kamarjani Branch is 30%	Landsat TM image of January 1996, bathymetry of November-December 1995	Bifurcation angle equals 60°, hence probability 0.75 × (60-20) = 30%. Western bifurcated channel towards Kamarjani Branch is still the deepest, but eastern bifurcated channel is aligned better at its entrance
K-15: Probability of abandonment of Kamarjani Branch is 7%	Landsat TM image of January 1996, Developments K-11 and K-14	Probability that both western channel (K-11) and channel from Central Node (K-14) are abandoned is equal to 22% × 30% = 7%
K-16: Erosion of left bank of upper Kamarjani Branch	Landsat TM image of January 1996	Western channel and channel from Central Node impinge on left bank
K-17: Possibility of cut-off through inlet along left bank of Kamarjani Branch remains	SPOT images of previous years	Identification of a possibility
K-18: Northern channel of flow around shoal gains importance	Field visit 1 March 1996	Char bank erosion upstream of groynes
K-19: Further advance of new major channel in eastern anabranch	Landsat TM image of January 1996	Development K-10 favours growth of eastern anabranch
K-20: Possibility that FAP 21 camp will be washed away by Brahmaputra-Jamuna River, but threat from Manos River might be more important	Bathymetry of November-December 1995, discussion site staff about Manos River	Downstream migration of upper Kamarjani Branch (K-16) or alignment of channel along G-3 and G-A due to attraction of flow by scour hole in front of groynes
K-21: Growth of scour hole at confluence of western channel and Kamarjani Branch, provided that that channel is not abandoned	Landsat TM image of January 1996, bathymetry of November-December 1995	Development K-12 produces an important confluence
K-22: Downstream migration of bend at test site is slowed down or prevented by the groynes	Bathymetry of November-December 1995	Sharp turn of flow into scour hole along groynes demonstrates attraction of flow by the scour hole
K-23: Detailed probability of attack during 1996 flood: Test Site I 70%, FAP 21 camp 20%, Kamarjani-Rasulpur 90%	Table 2.1, Landsat TM images of January 1995 and January 1996	Maximum probability for each attack is 93% because of 7% probability of abandonment (K-15). For Test Site I higher probability than in Table 2.1 because of expected flow attraction by scour hole: 70%. For FAP 21 camp and Kamarjani-Rasulpur roughly the same probabilities as in Table 2.1.

Table 2.2: March 1996 predictions for Kamarjani

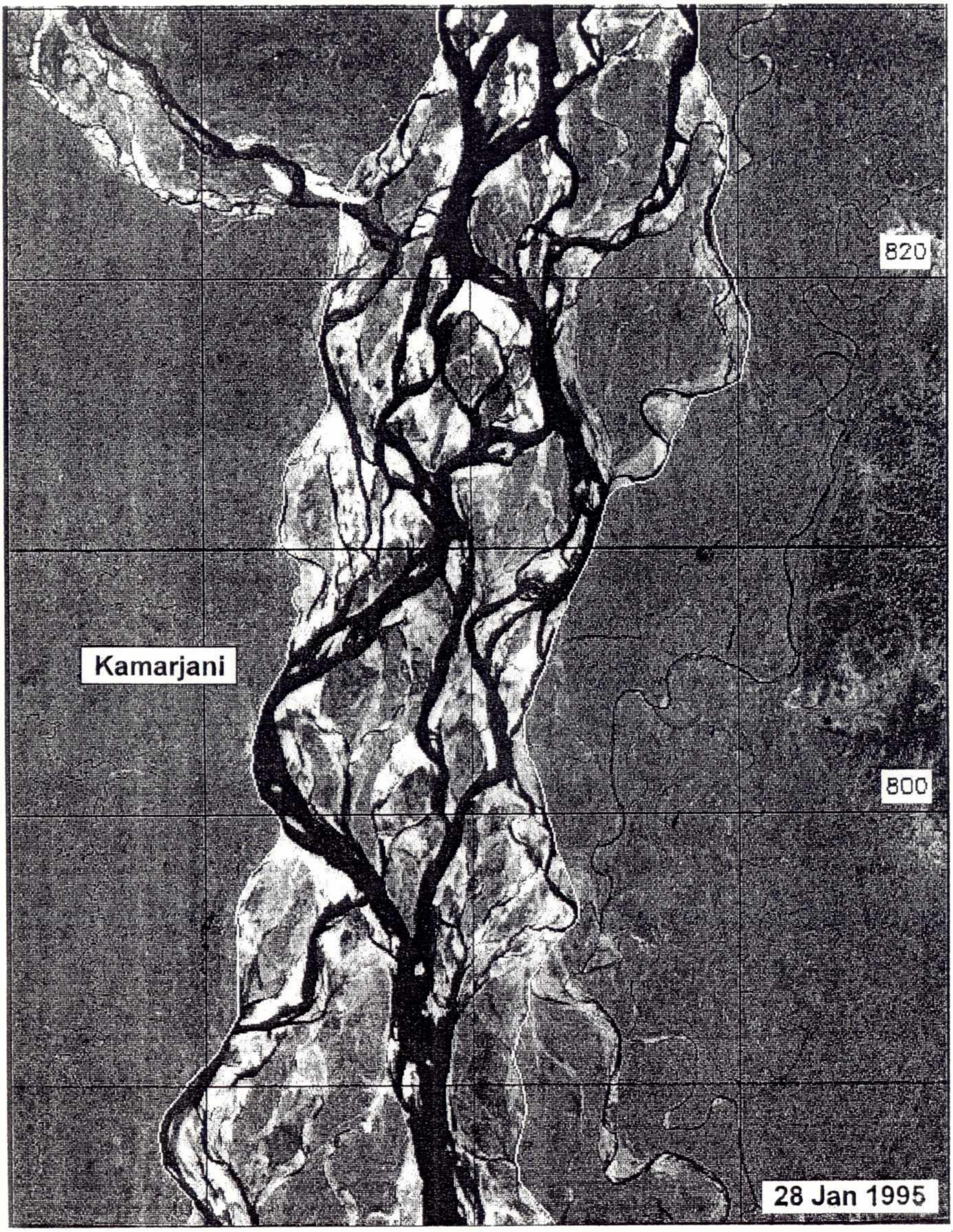

Fig. 2.1: Area of Kamarjani on Landsat TM image of January 1995

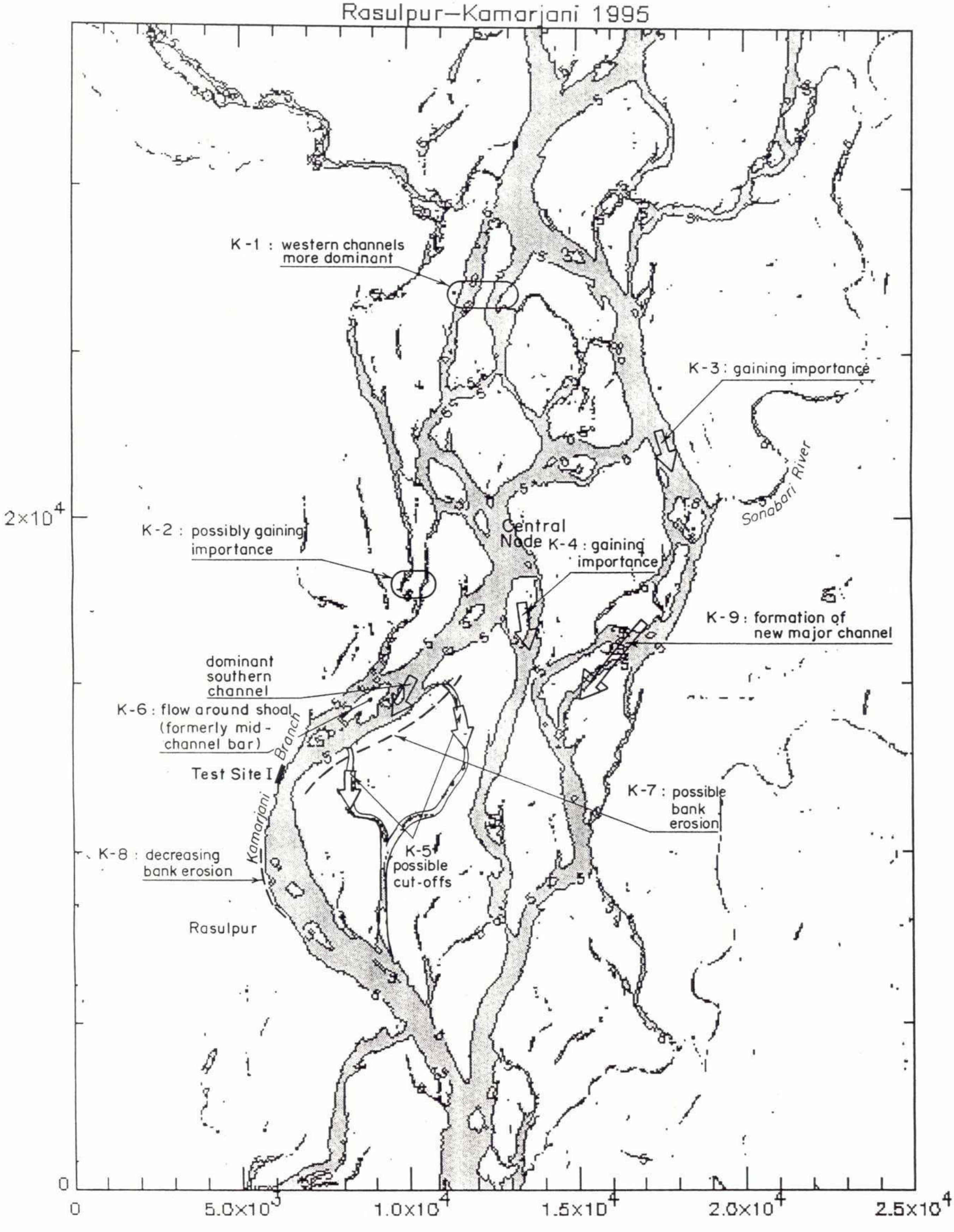

Fig. 2.2: Area of Kamarjani in January 1995 with morphological developments identified and predicted in September 1995

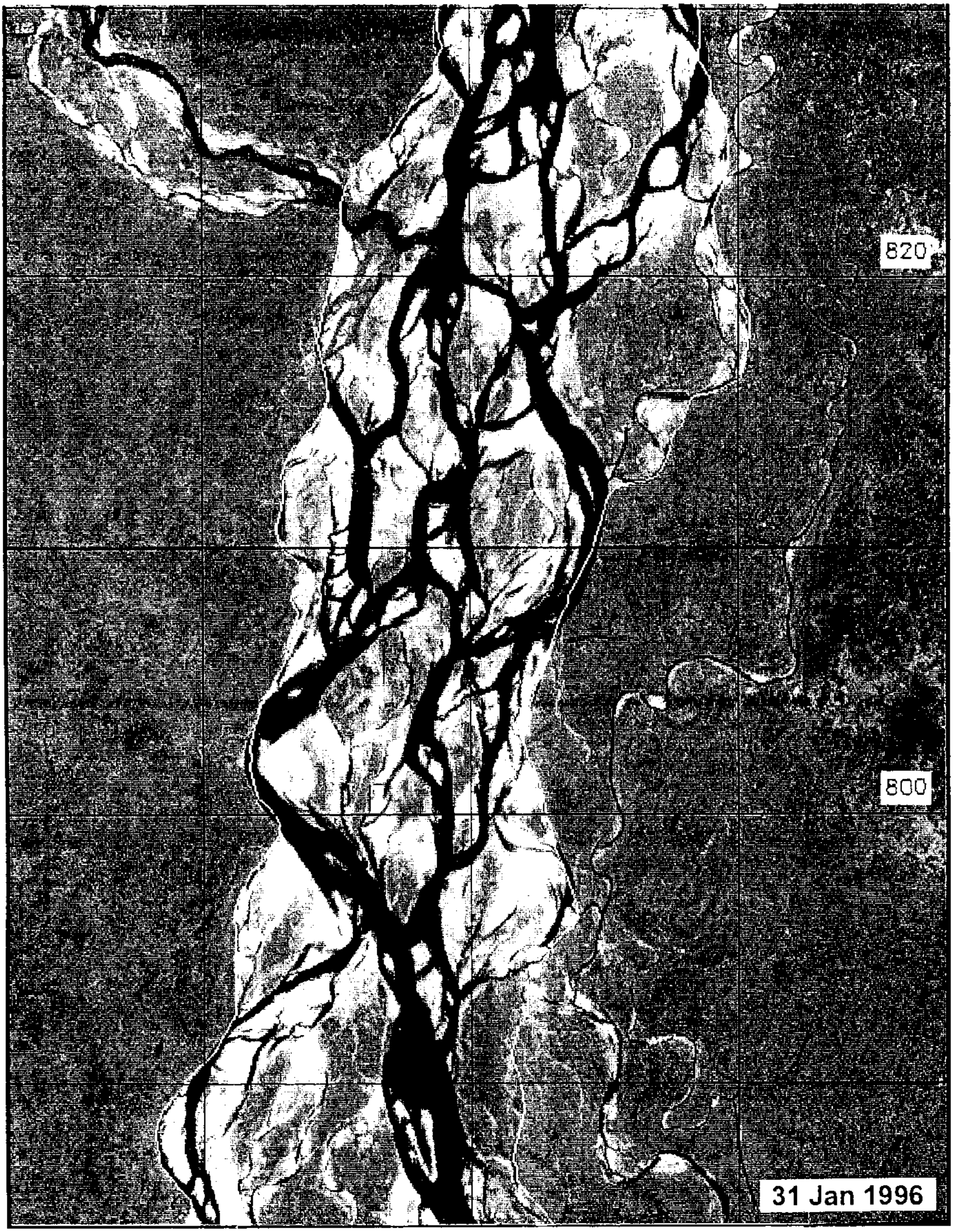

Fig. 2.3: Area of Kamarjani on Landsat TM image of January 1996

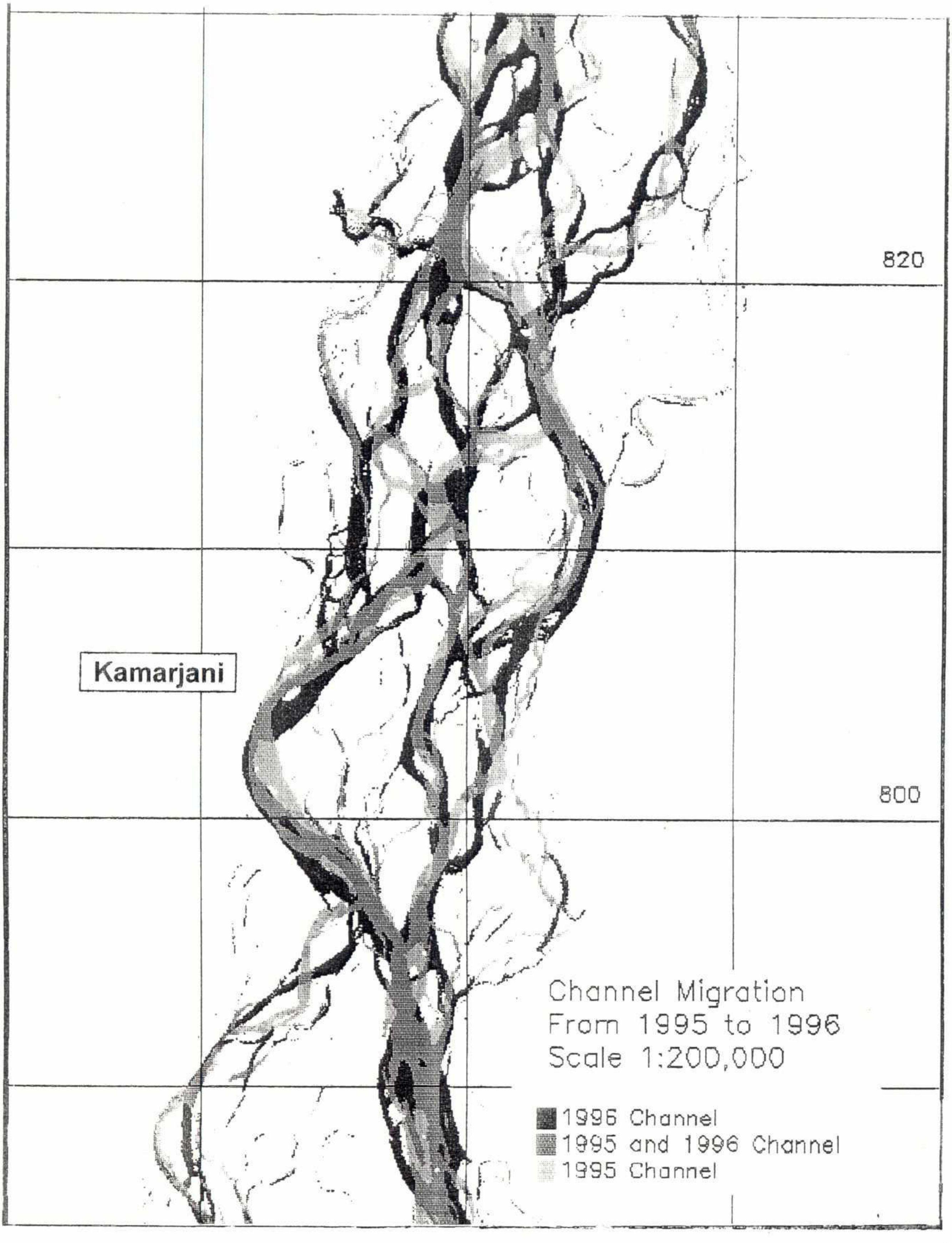

Fig. 2.4: Planform changes at Kamarjani from January 1995 to January 1996 (processed by EGIS)

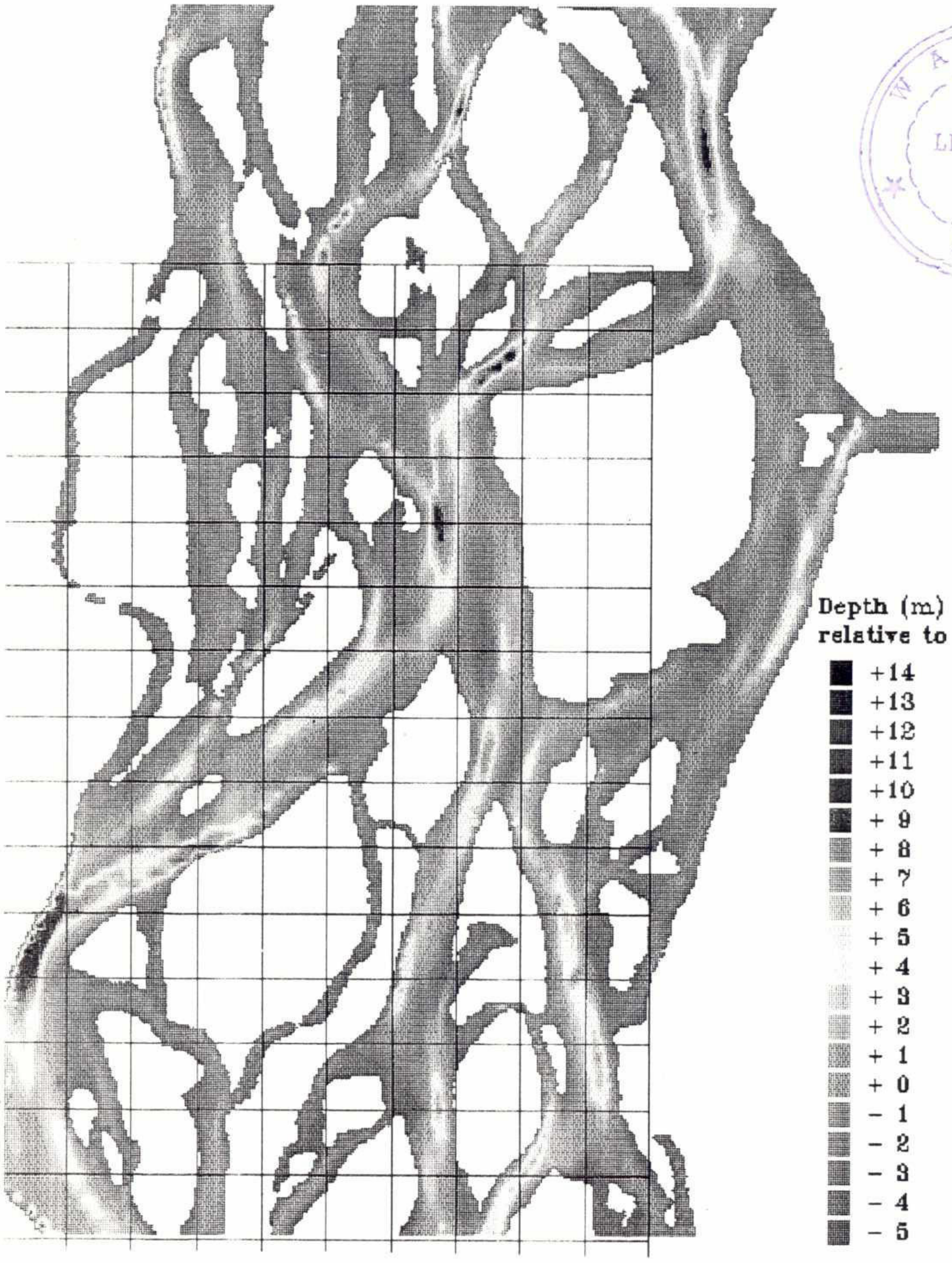

Fig. 2.5: Bathymetry at Kamarjani in September 1994
(surveyed by FAP 24 and processed by EGIS)

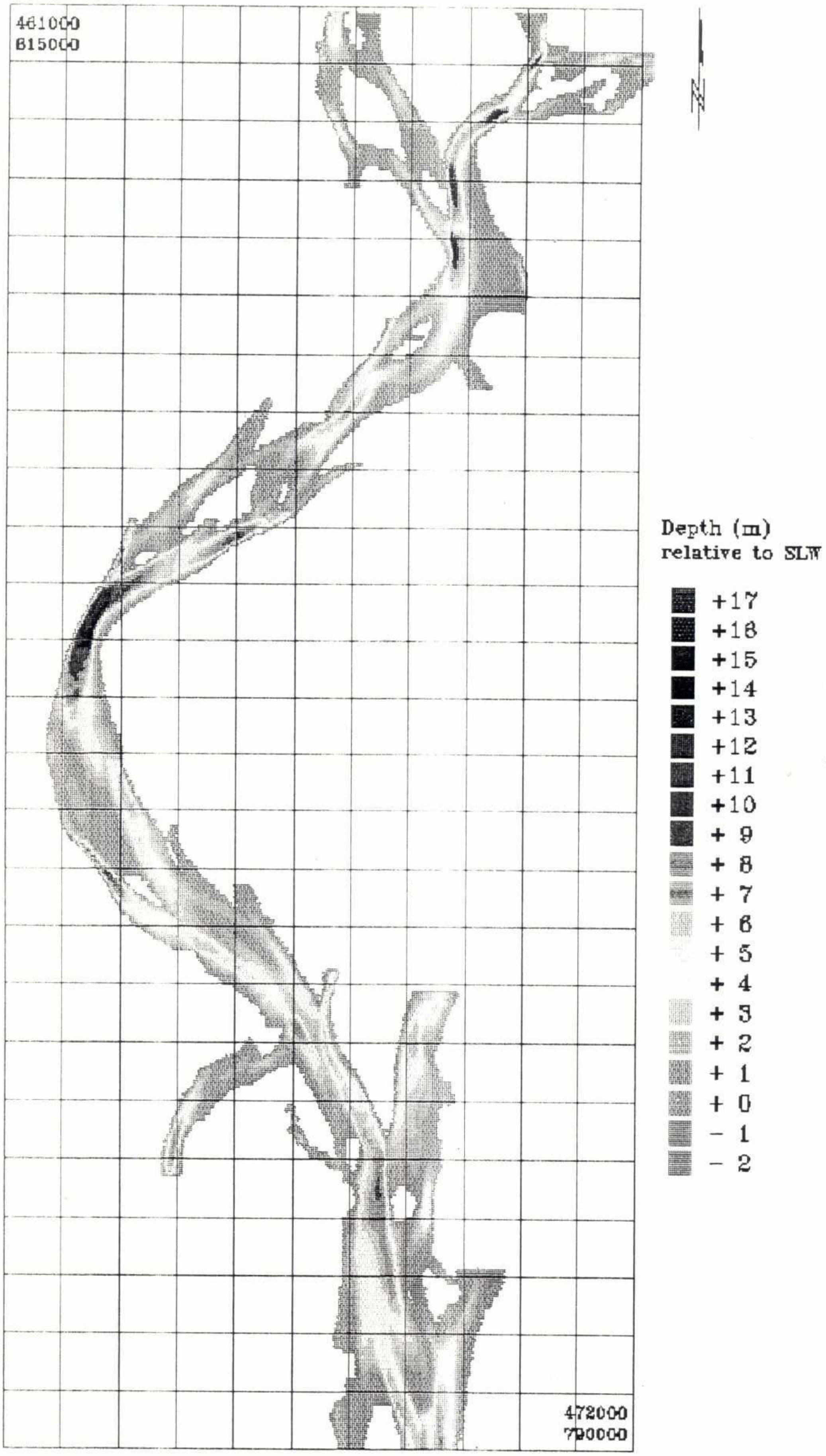

Fig. 2.6: Bathymetry at Kamarjani in November 1994 (surveyed by FAP 24 and processed by EGIS)

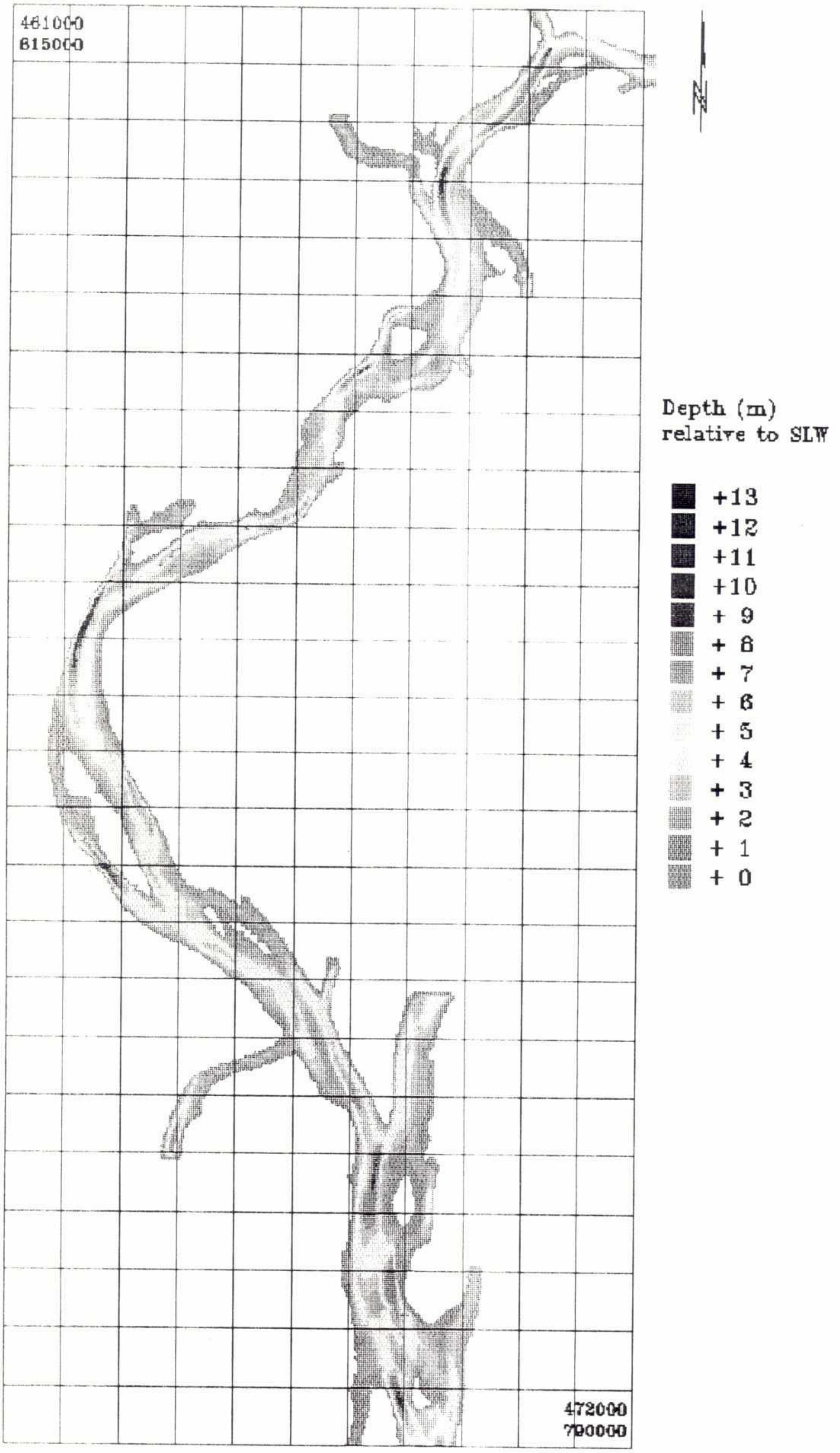

Fig. 2.7: Bathymetry at Kamarjani in March 1995 (surveyed by FAP 24 and processed by EGIS)

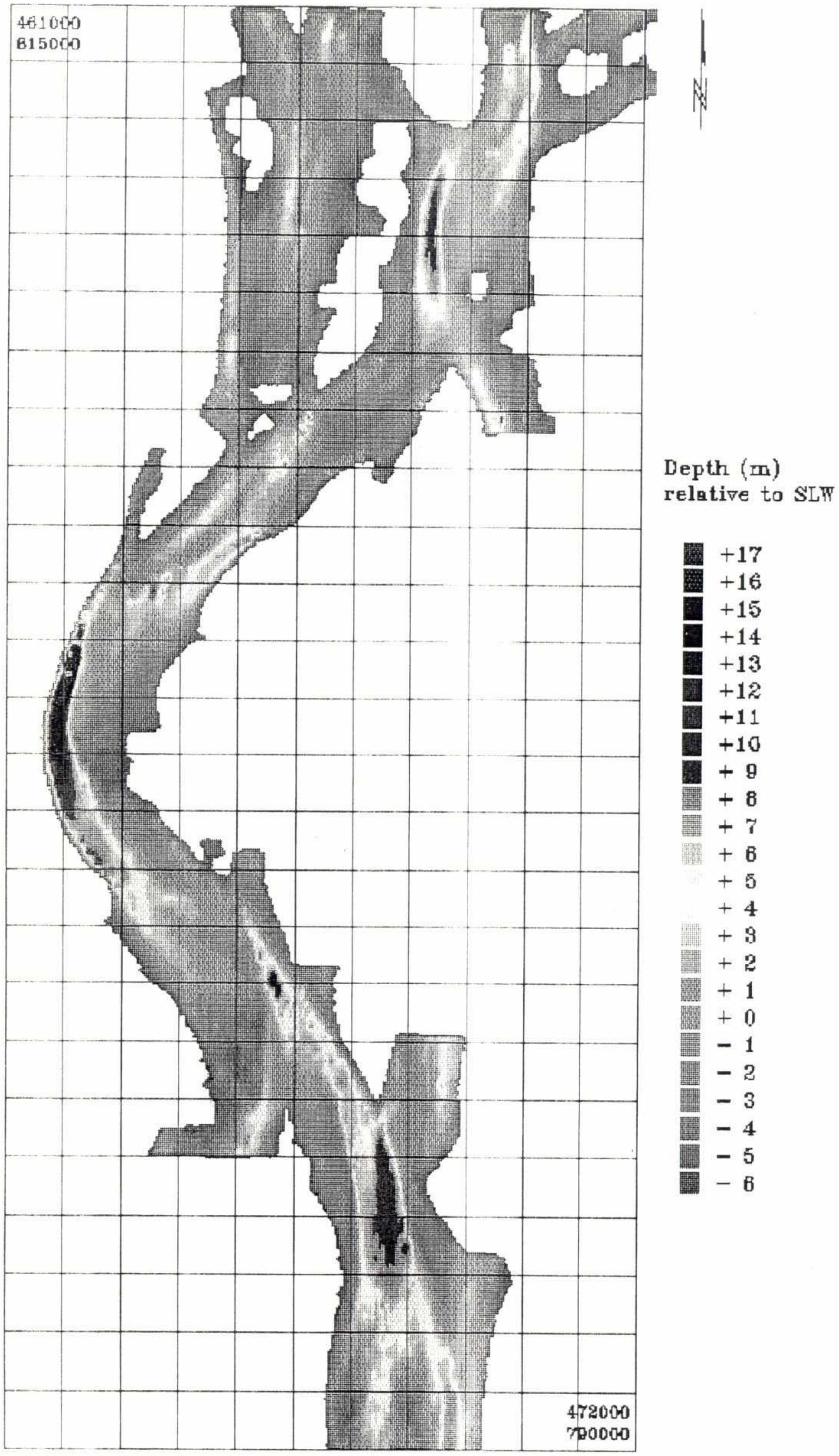

Fig. 2.8: Bathymetry at Kamarjani in August 1995
(surveyed by FAP 24 and processed by EGIS)

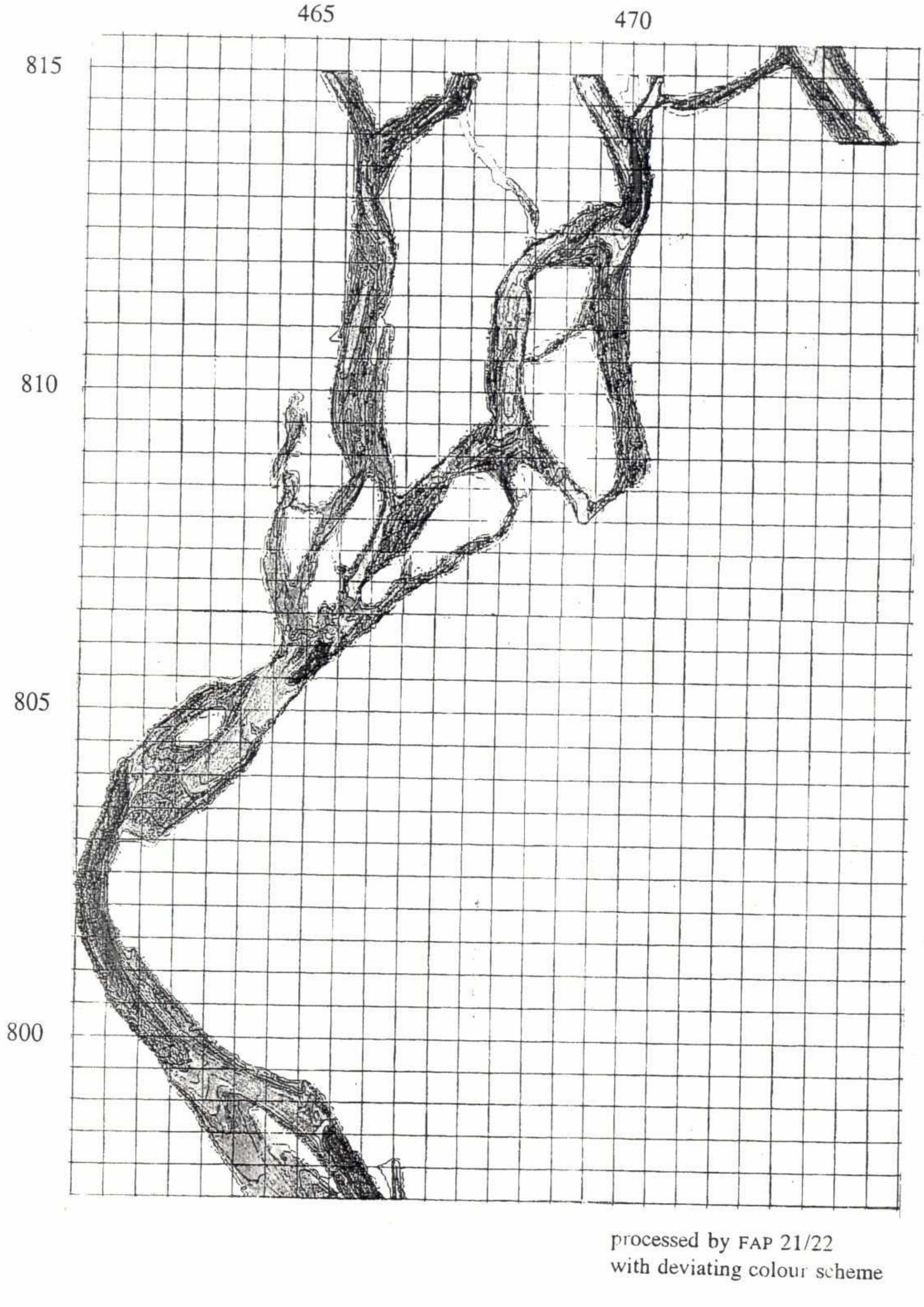

Fig. 2.9: Bathymetry at Kamarjani in November-December 1995 (surveyed by FAP 24)

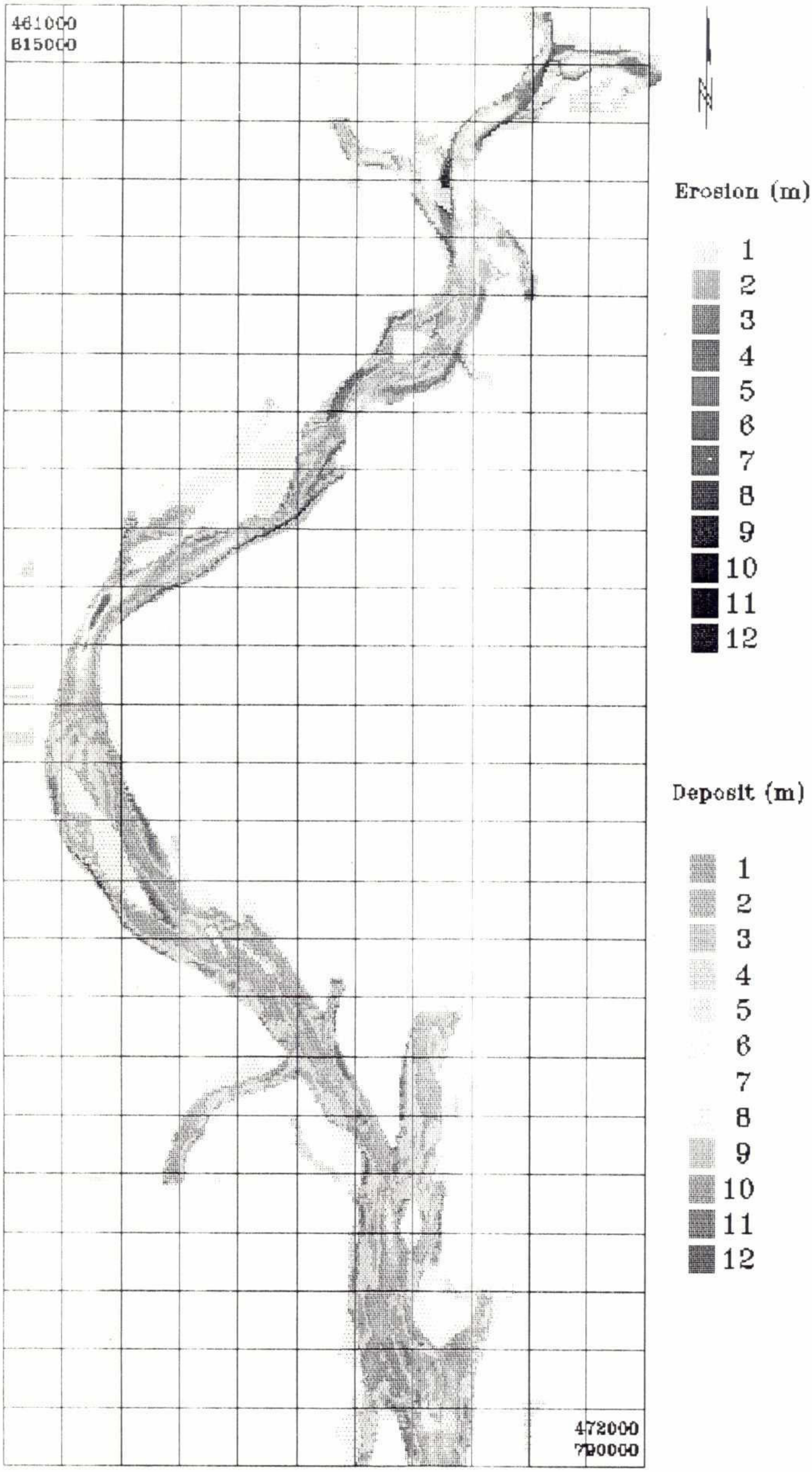

Fig. 2.10: Erosion and deposition at Kamarjani from November 1994 to March 1995 (processed by EGIS)

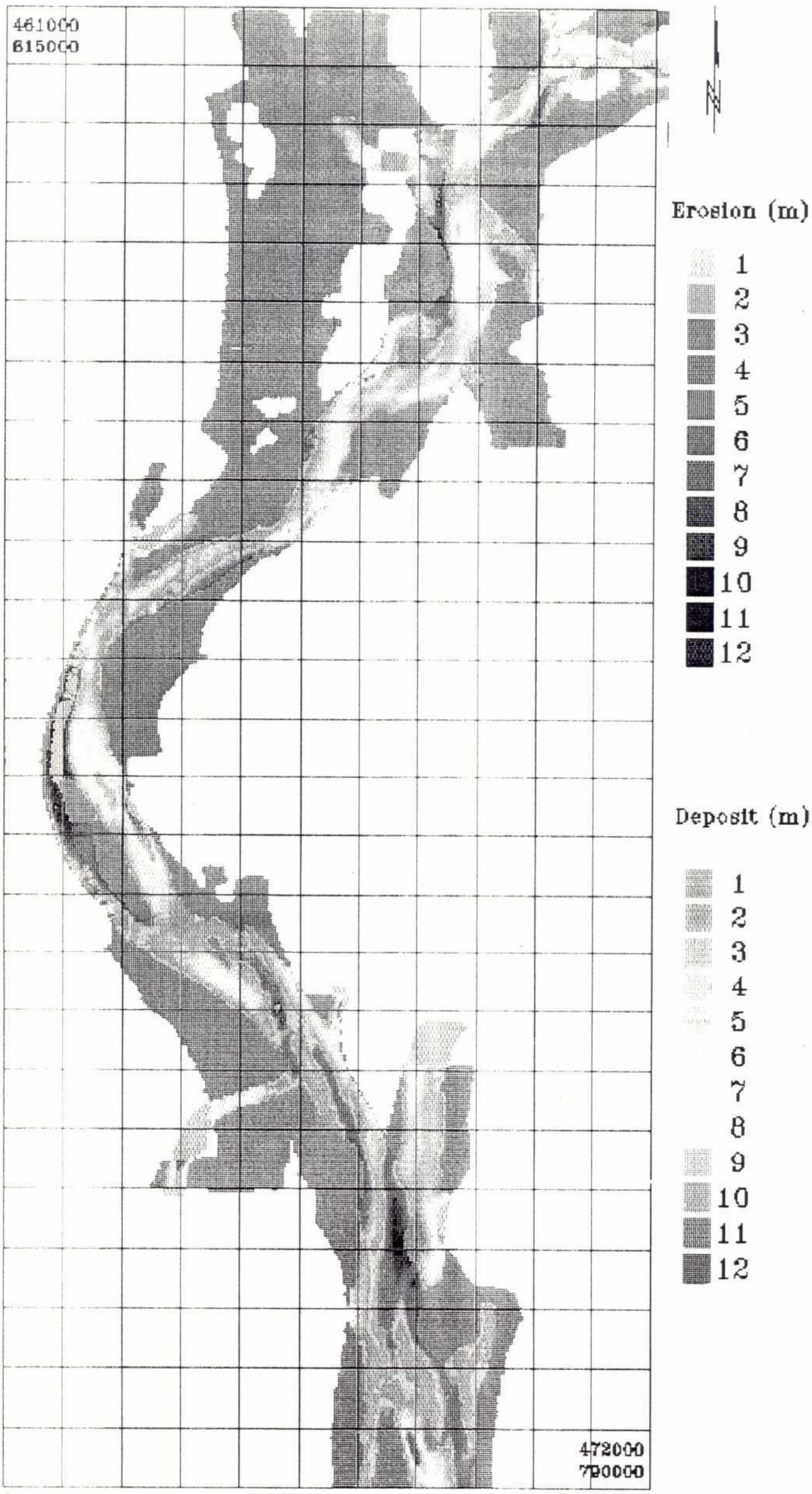

Fig. 2.11: Erosion and deposition at Kamarjani from March 1995 to August 1995 (processed by EGIS)

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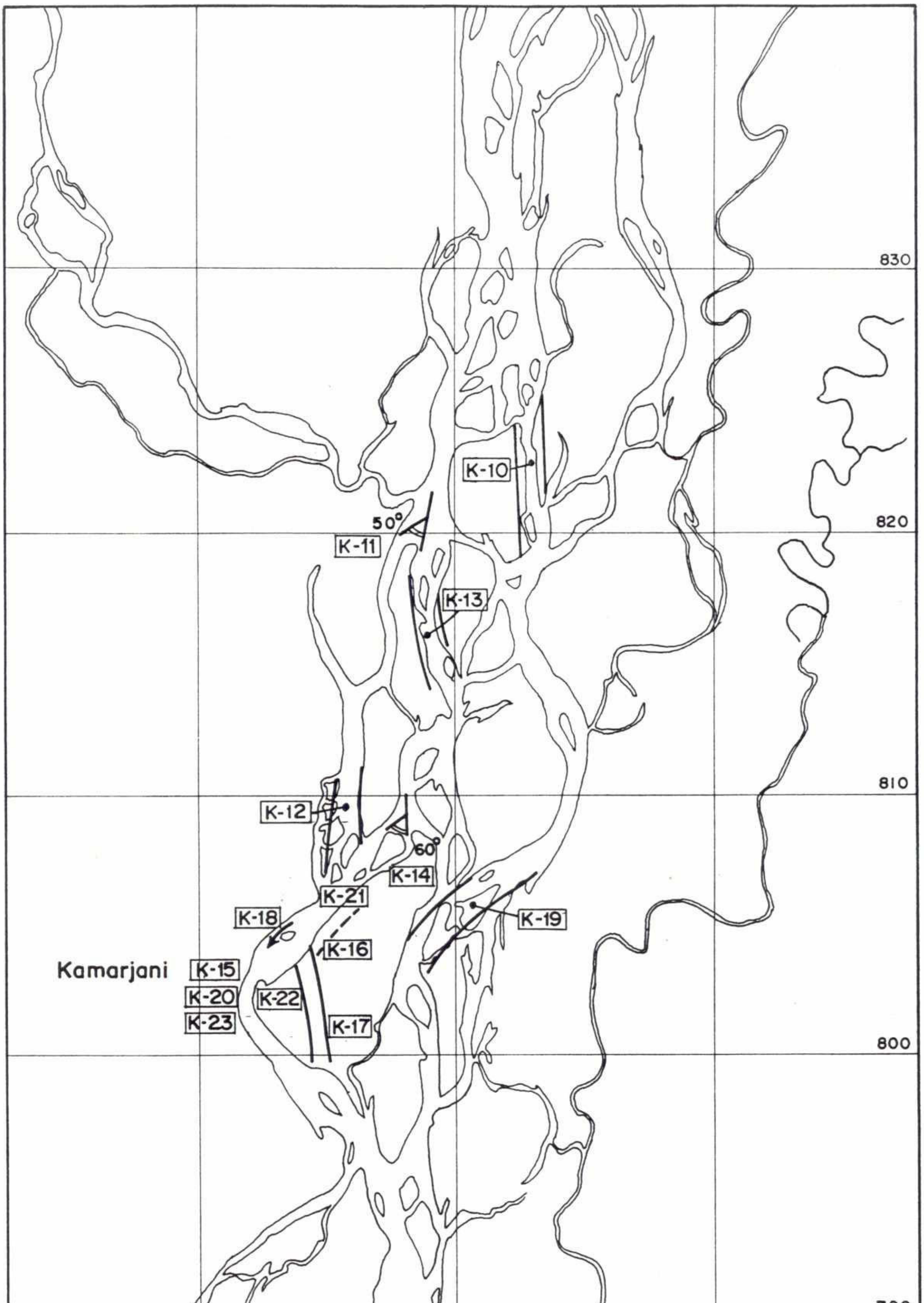

Fig. 2.12: Area of Kamarjani with ongoing and predicted morphological developments (January 1996 bank lines)

3 BAHADURABAD

3.1 Purposes

The morphological analysis of the area of Bahadurabad has the following purpose:

- To verify that Bahadurabad is still suitable for the revetments of Test Site II.

3.2 Evaluation of Predictions made in September 1995

Morphological predictions made in 1992 (Consulting Consortium FAP 21/22, 1993) resulted in selecting the area of Bahadurabad-Belgachha for Test Site II. An upstream bend cut-off, however, changed the bank attack in the area and resulted even in accretion along the bank at Bahadurabad-Belgachha. Reviews of the suitability of the area of Bahadurabad after the 1993, 1994 and 1995 floods by Consulting Consortium FAP 21/22 (1994a, 1994b, 1995a, 1995b) led to the conclusion that actually there was no site in the area with a high certainty of continued attack. Nonetheless, continued erosion of Bahadurabad Ghat and Kulkandi was still considered to be likely in the immediate future and this location was therefore retained as a possible suitable area for Test Site II.

The predictions made by Consulting Consortium FAP 21/22 (1995b) are evaluated in Table 3.1. These predictions are indicated in Figure 3.2 and had been based on Figures 3.1 and 3.5 to 3.8. The evaluation is carried out by comparing the predicted development with the actual development which is shown in Figures 3.3, 3.4 and 3.9.

Two predicted developments turn out to have been wrong: the development of a course towards the western anabranch (B-2) and the decline of the aggressively eroding bend 8 km downstream of Bahadurabad Ghat (B-7). A comparison of the Landsat TM images of January 1995 (Fig. 3.1) and January 1996 (Fig. 3.3) shows that the complex area 8 km downstream of Bahadurabad Ghat changed completely.

3.3 Analysis in March 1996

Ongoing and predicted morphological developments are presented in Table 3.2 and Figure 3.13. They indicate that continued attack of Test Site II in 1996 has a high probability, estimated to be 90%. Attack in 1997 and 1998 is less certain because the absence of a clear bend makes that capricious planform changes easily occur.

Morphological development identified and predicted in September 1995	Information used in September 1995	Evaluation in March 1996
B-1: Possible re-activation of course through embayment north of Bahadurabad Ghat	Landsat TM image of January 1995, report Halcrow (1993)	No: though part of embayment was eroded by eastward migration of main approach channel (Development B-3). Comparison of bathymetries of August 1993 (Fig. 3.5) and July 1995 (Fig. 3.8) shows that substantial deposition occurred in the embayment, so that the probability of re-activation decreases. It should be noted that this development was only identified as a possibility, without explicit quantification of the probability
B-2: Course towards western anabranch gains importance	Bathymetry of July 1995	No: the channel returns to the eastern anabranch, e.g. comparison of Landsat TM images of January 1995 (Fig. 3.1) and January 1996 (Fig. 3.3)
B-3: Eastward migration of thalweg of main approach channel	Bathymetries of February 1995 and July 1995	Yes: e.g. comparison of bathymetries of July 1995 (Fig. 3.8) and November 1995 (Fig. 3.9)
B-4: Growth of mid-channel bar at 4 km upstream of Bahadurabad Ghat	Bathymetries of February 1995 and July 1995	Yes: on downstream side, e.g. comparison of Landsat TM images of January 1995 (Fig. 3.1) and January 1996 (Fig. 3.3)
B-5: Western channel near Bahadurabad Ghat gains importance	Landsat TM image of January 1995	Partly: only the downstream part which has been captured by another channel, e.g. comparison of Landsat TM images of January 1995 (Fig. 3.1) and January 1996 (Fig. 3.3)
B-6: Continuation of bank erosion at Bahadurabad and Kulkandi	Landsat TM image of January 1995, bathymetry of July 1995	Yes: e.g. comparison of Landsat TM images of January 1995 (Fig. 3.1) and January 1996 (Fig. 3.3)
B-7: Decline of aggressively eroding bend 8 km downstream of Bahadurabad Ghat, while being by-passed by developing chute cut-offs	Landsat TM image of January 1995	No: e.g. comparison of Landsat TM images of January 1995 (Fig. 3.1) and January 1996 (Fig. 3.3)

Table 3.1: Evaluation of September 1995 predictions for Bahadurabad

Morphological development identified and predicted in March 1996	Information used in March 1996	Substantiation in March 1996
B-8: Eastern Bahadurabad Branch remains dominant over western Fulchari Branch	Landsat TM image of January 1996	Bifurcation angle of Bahadurabad Branch is negligible, whereas bifurcation angle of Fulchari Branch is 60°
B-9: Two channels impinge on the bank at Bahadurabad-Kukandi: western approach channel (B-10) and eastern approach channel (B-11)	Bathymetry of November 1995	Present situation is that main approach channel divides around a bar at Northing 785 000. This situation is expected to persist during the flood of 1996
B-10: Western approach channel is dominant but might decline	Bathymetry of November 1995	Increase of bifurcation angle
B-11: Eastern approach channel excavates its bed until it meets western approach channel in front of bank at Bahadurabad-Kulkandi	Bathymetry of November 1995	Extrapolation of ongoing growth
B-12: Confluence scour hole in front of bank around Northing 779 000 or 780 000	Development B-11	Confluence of western and eastern approach channels
B-13: High probability (say 90%) that bank erosion at Bahadurabad and Kulkandi continues in 1996	Developments B-8 to B-12	Growing eastern approach channel (B-11) and formation of confluence scour hole (B-12). If eastern approach channel would be abandoned, then western approach channel could still be expected to erode the bank

Table 3.2: March 1996 predictions for Bahadurabad

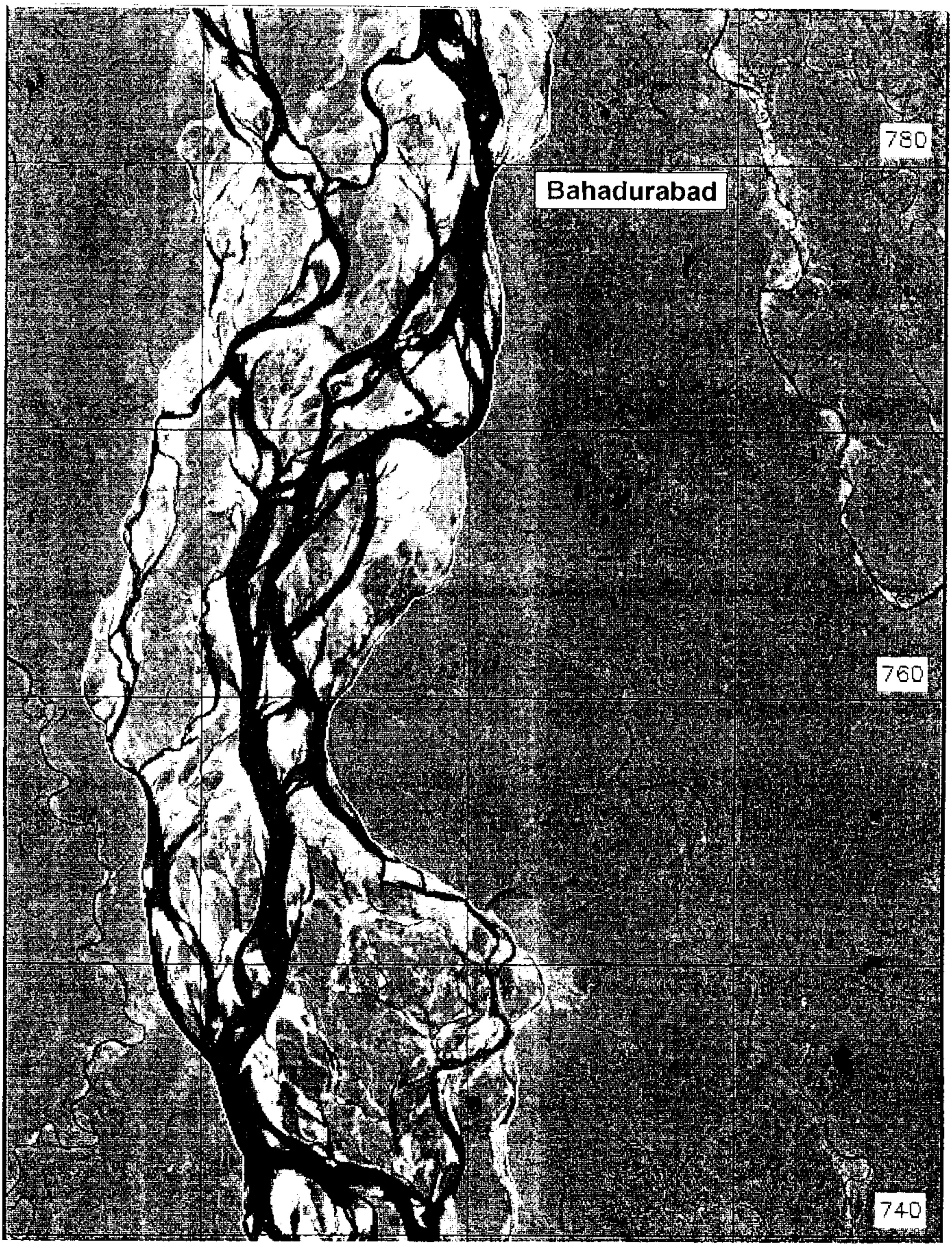

Fig. 3.1: Area of Bahadurabad on Landsat TM image of January 1995

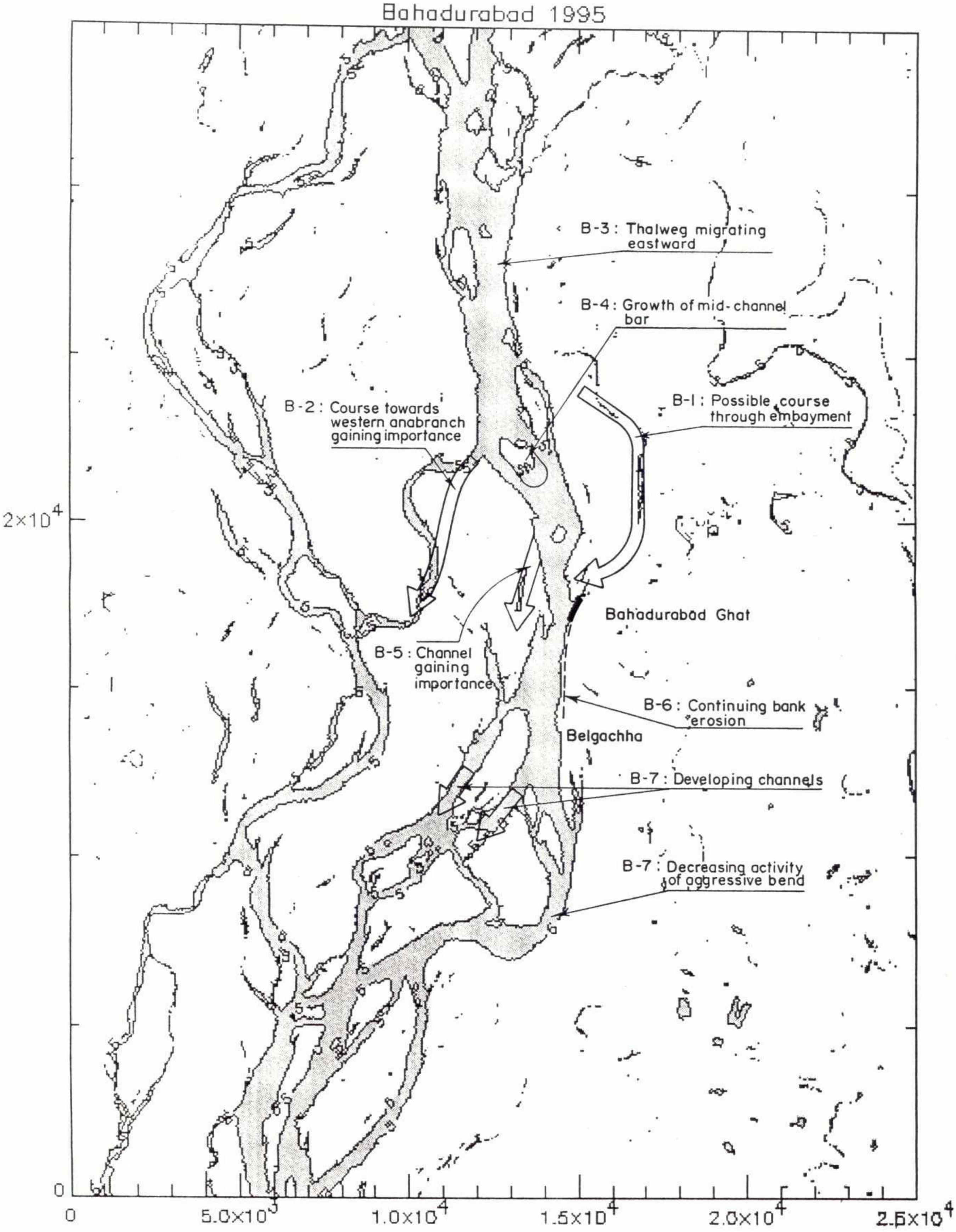

Fig. 3.2: Area of Bahadurabad in January 1995 with morphological developments identified and predicted in September 1995

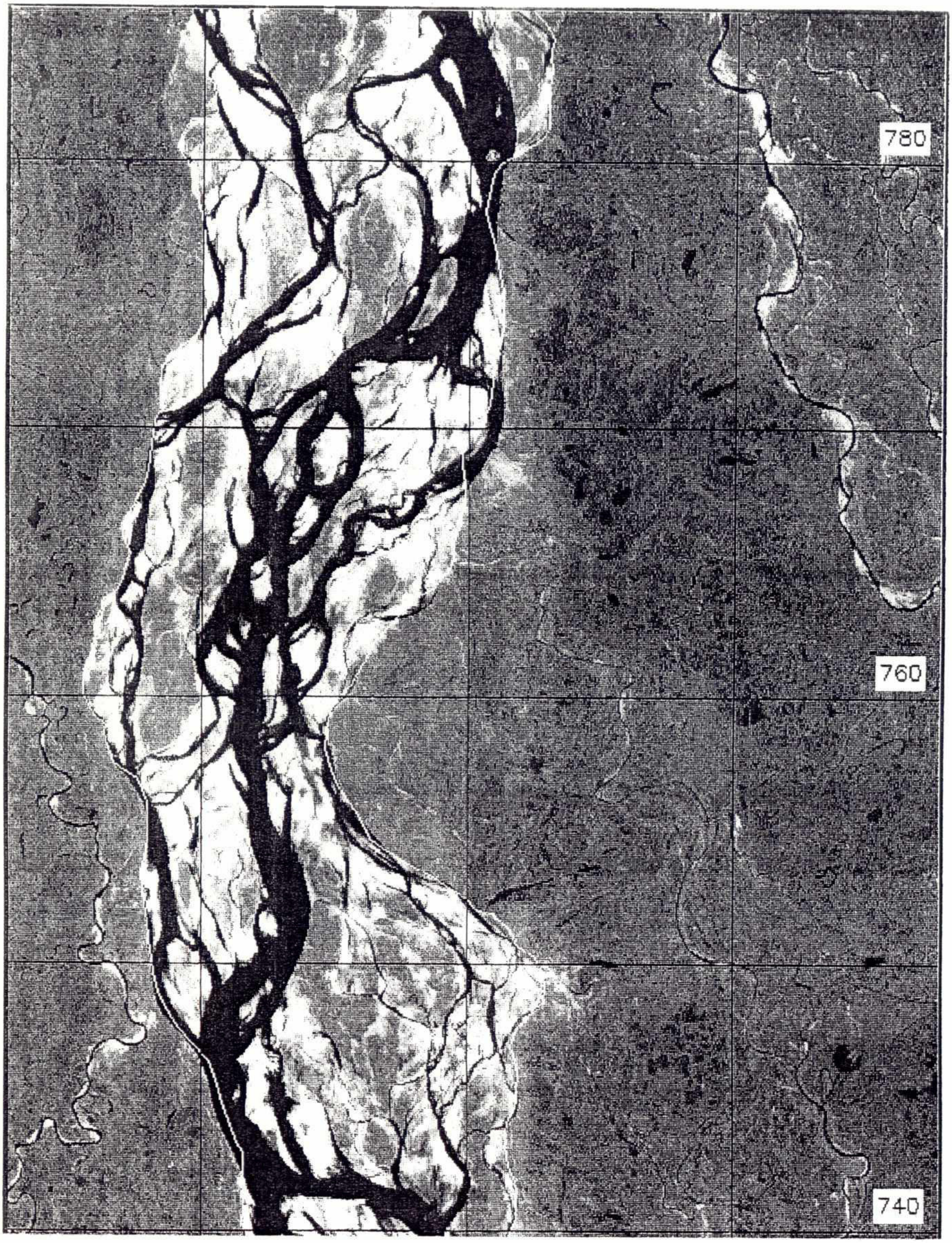

Fig. 3.3: Area of Bahadurabad on Landsat TM image of January 1996

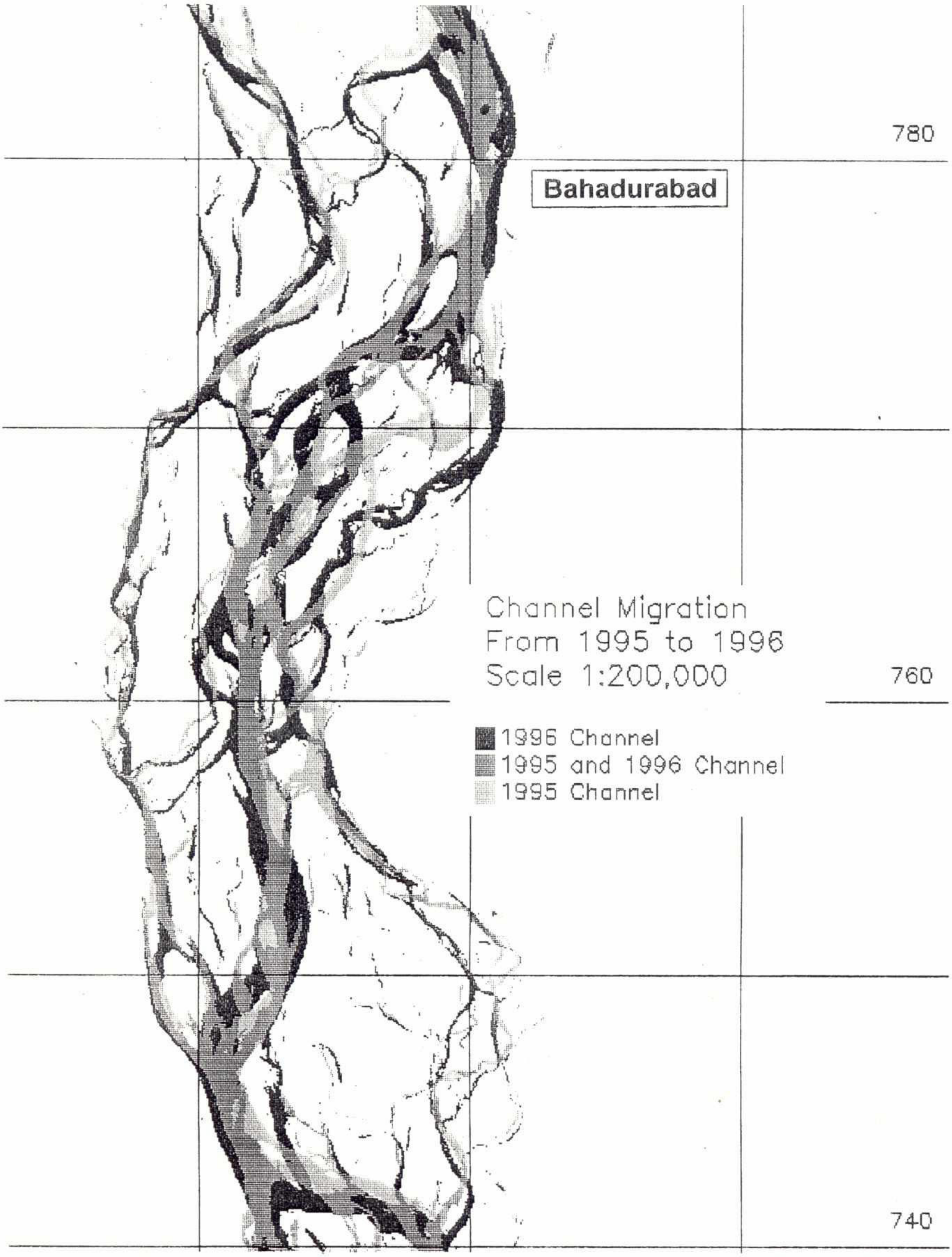

Fig. 3.4: Planform changes at Bahadurabad from January 1995 to January 1996 (processed by EGIS)

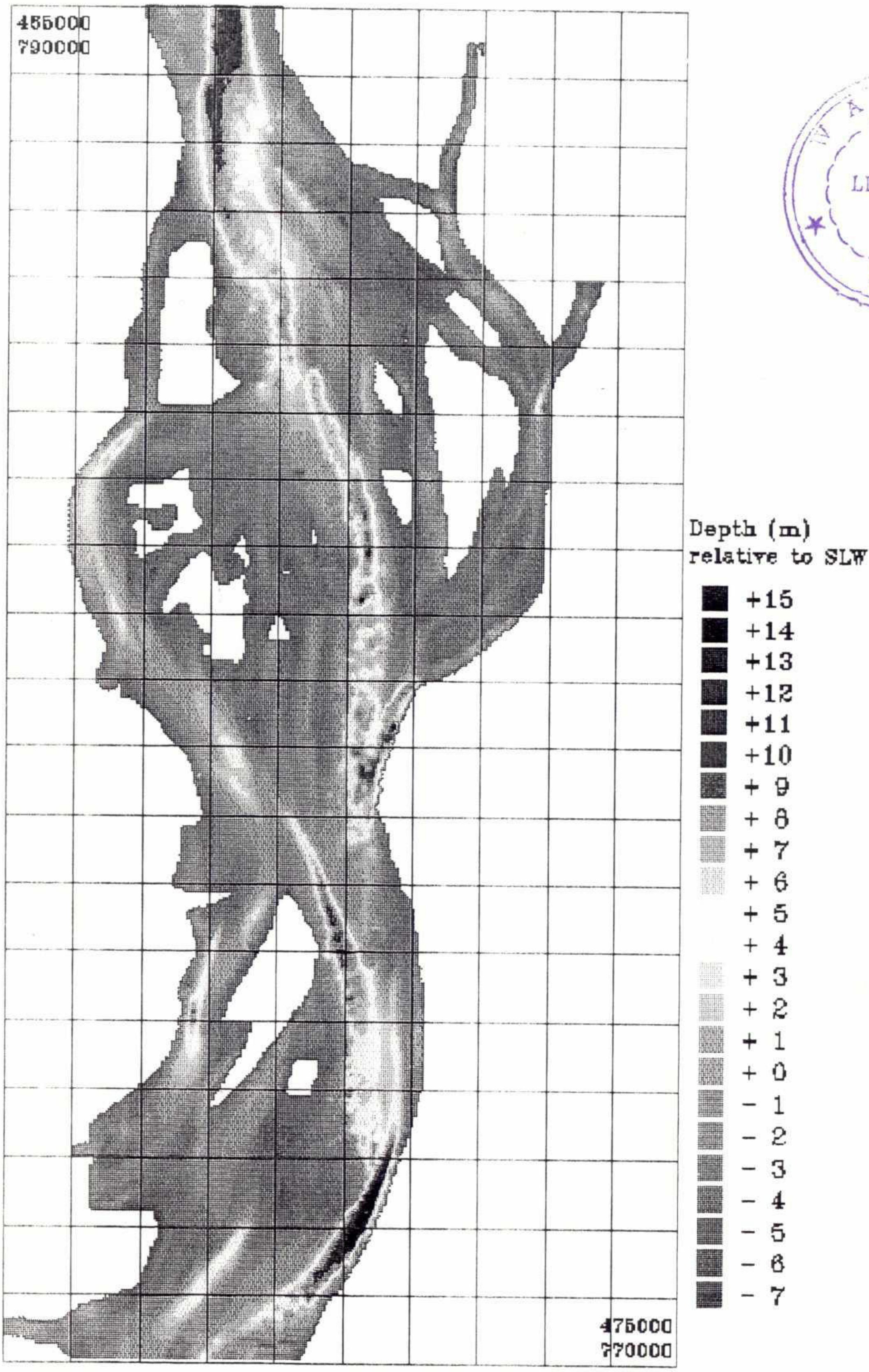

Fig. 3.5: Bathymetry at Bahadurabad in August 1993 (surveyed by FAP 24 and processed by EGIS)

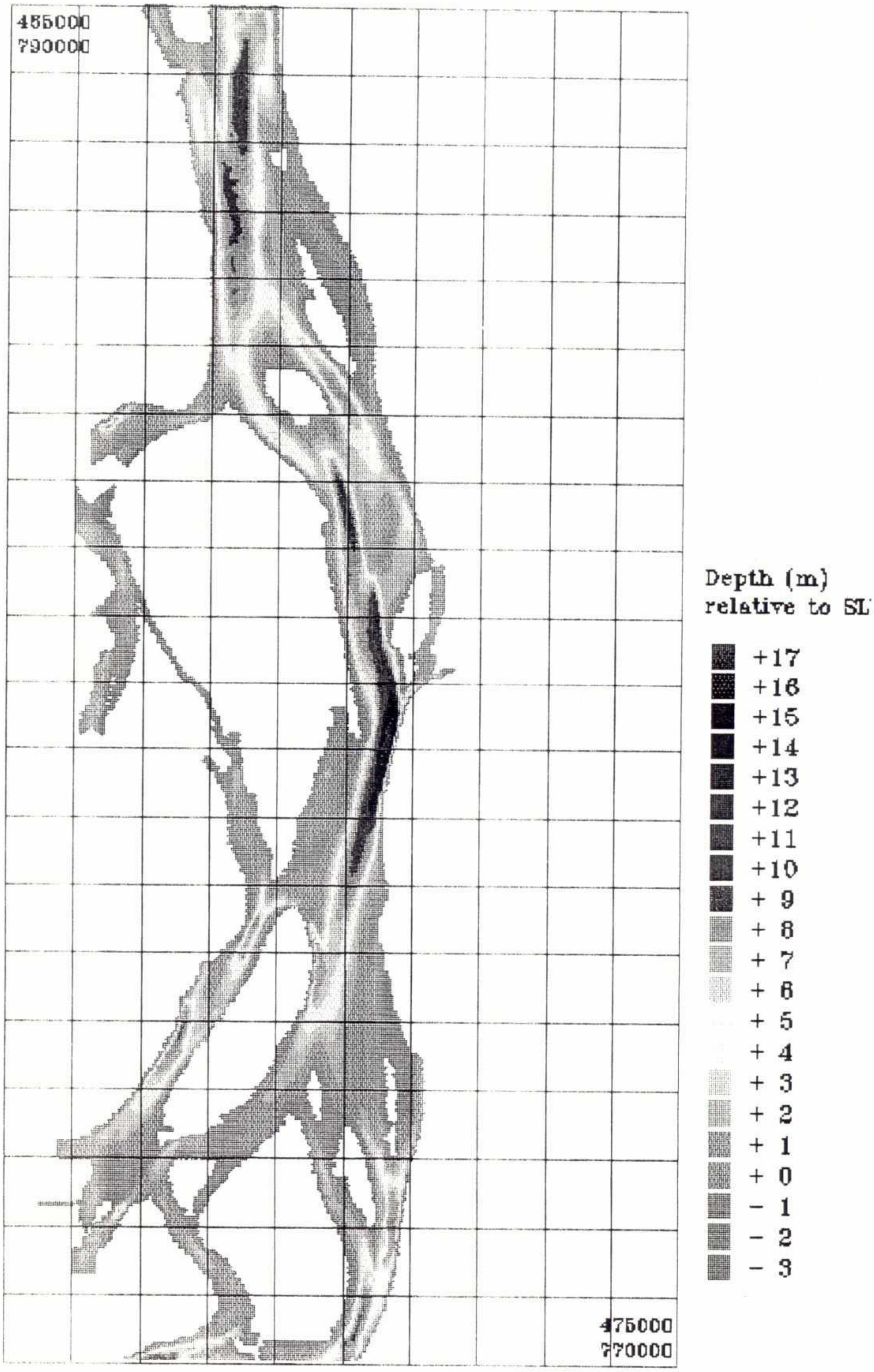

Fig. 3.6: Bathymetry at Bahadurabad in November 1994 (surveyed by FAP 24 and processed by EGIS)

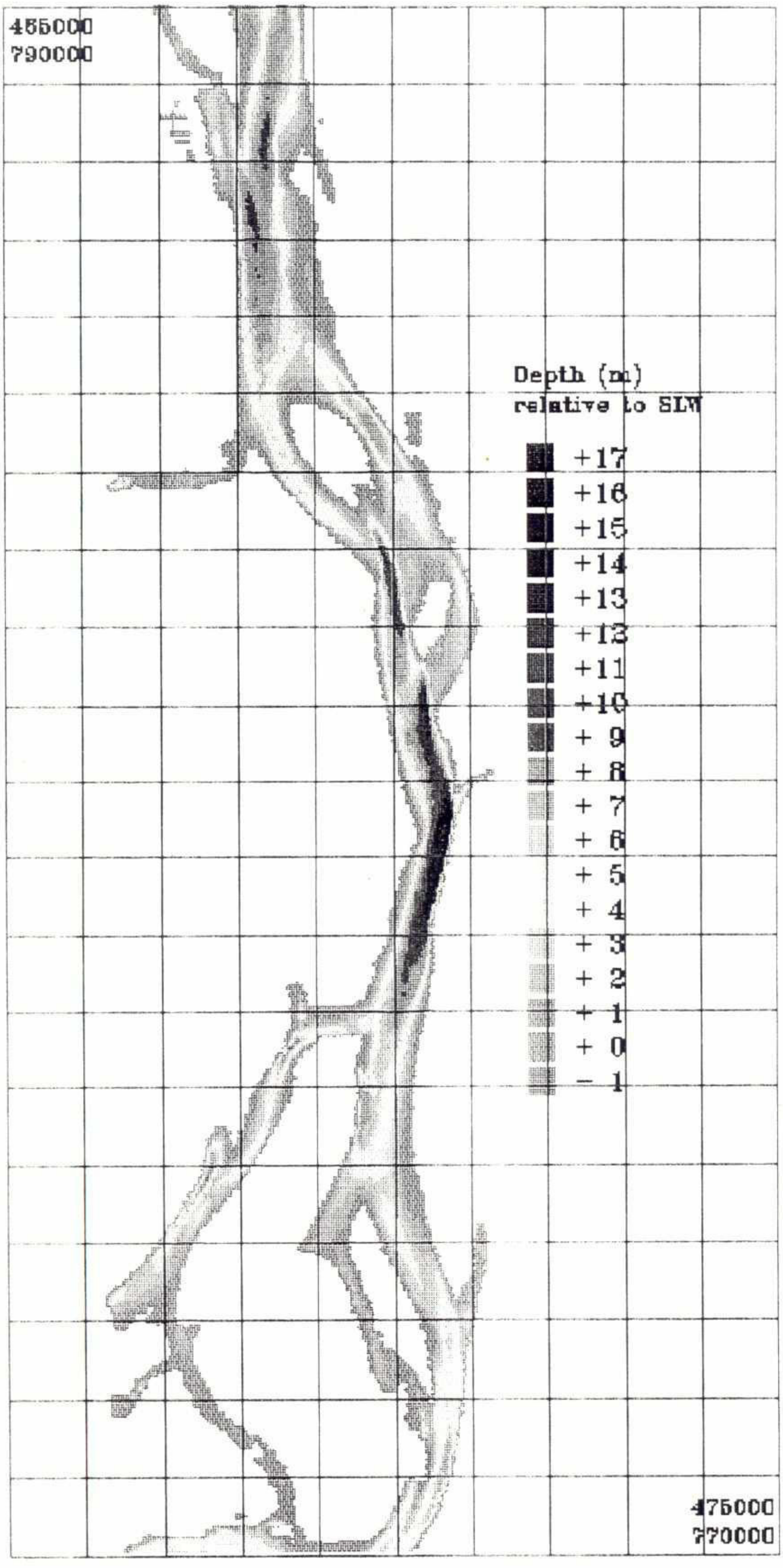

Fig. 3.7: Bathymetry at Bahadurabad in February 1995 (surveyed by FAP 24 and processed by EGIS)

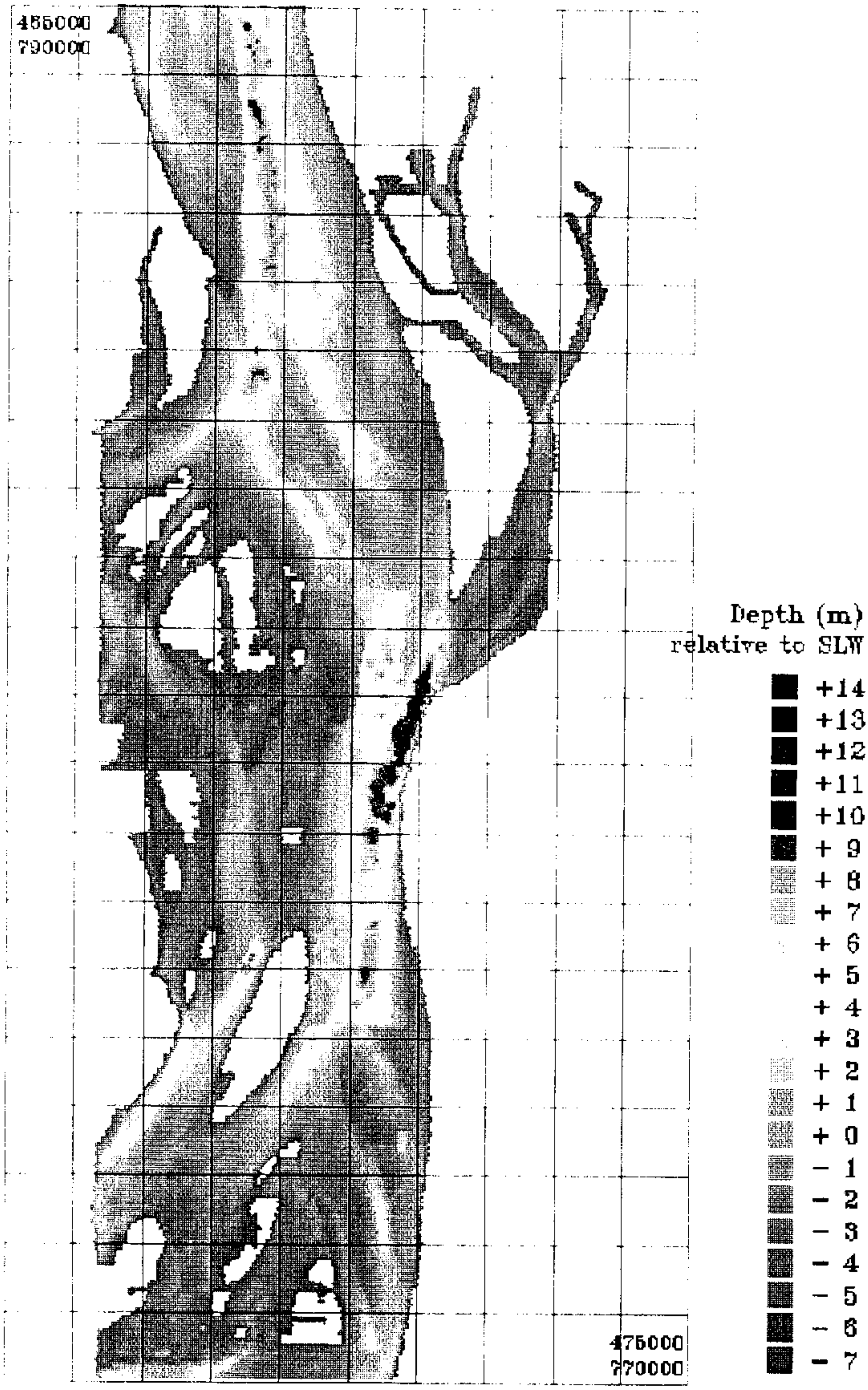

Fig. 3.8: Bathymetry at Bahadurabad in July 1995
(surveyed by FAP 24 and processed by EGIS)

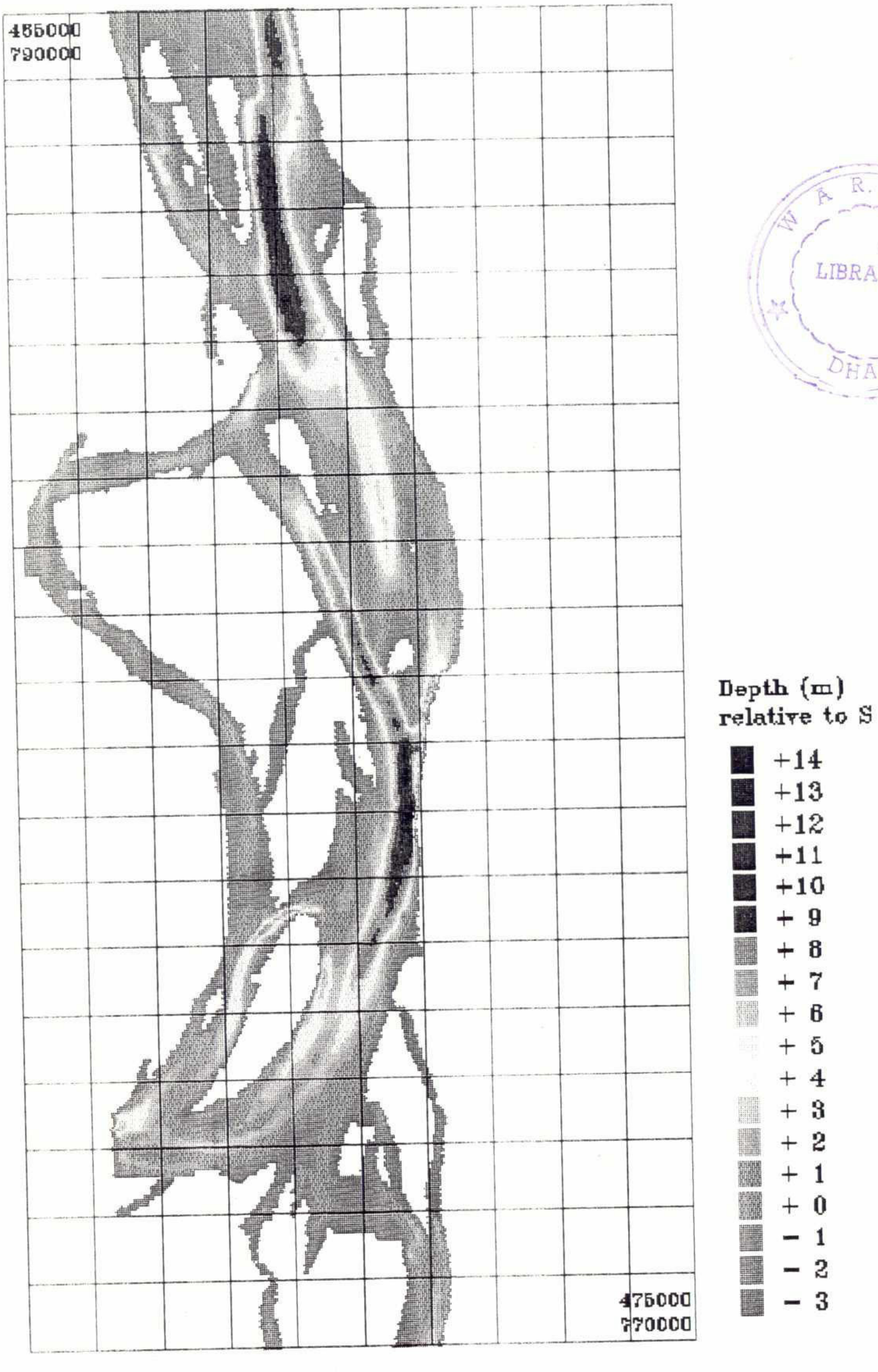

Fig. 3.9: Bathymetry at Bahadurabad in November 1995
(surveyed by FAP 24 and processed by EGIS)

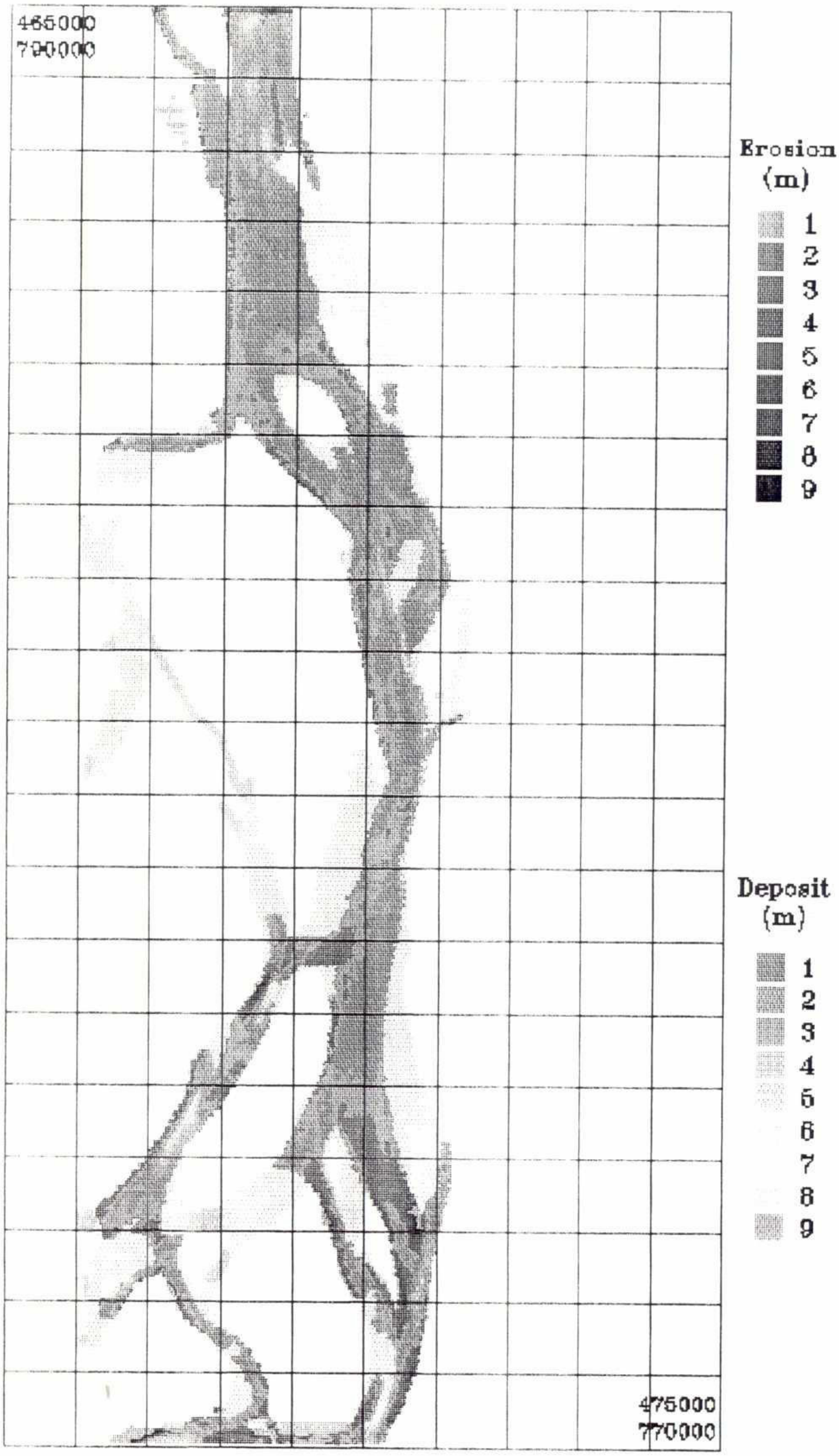

Fig. 3.10: Erosion and deposition at Bahadurabad from November 1994 to February 1995 (processed by EGIS)

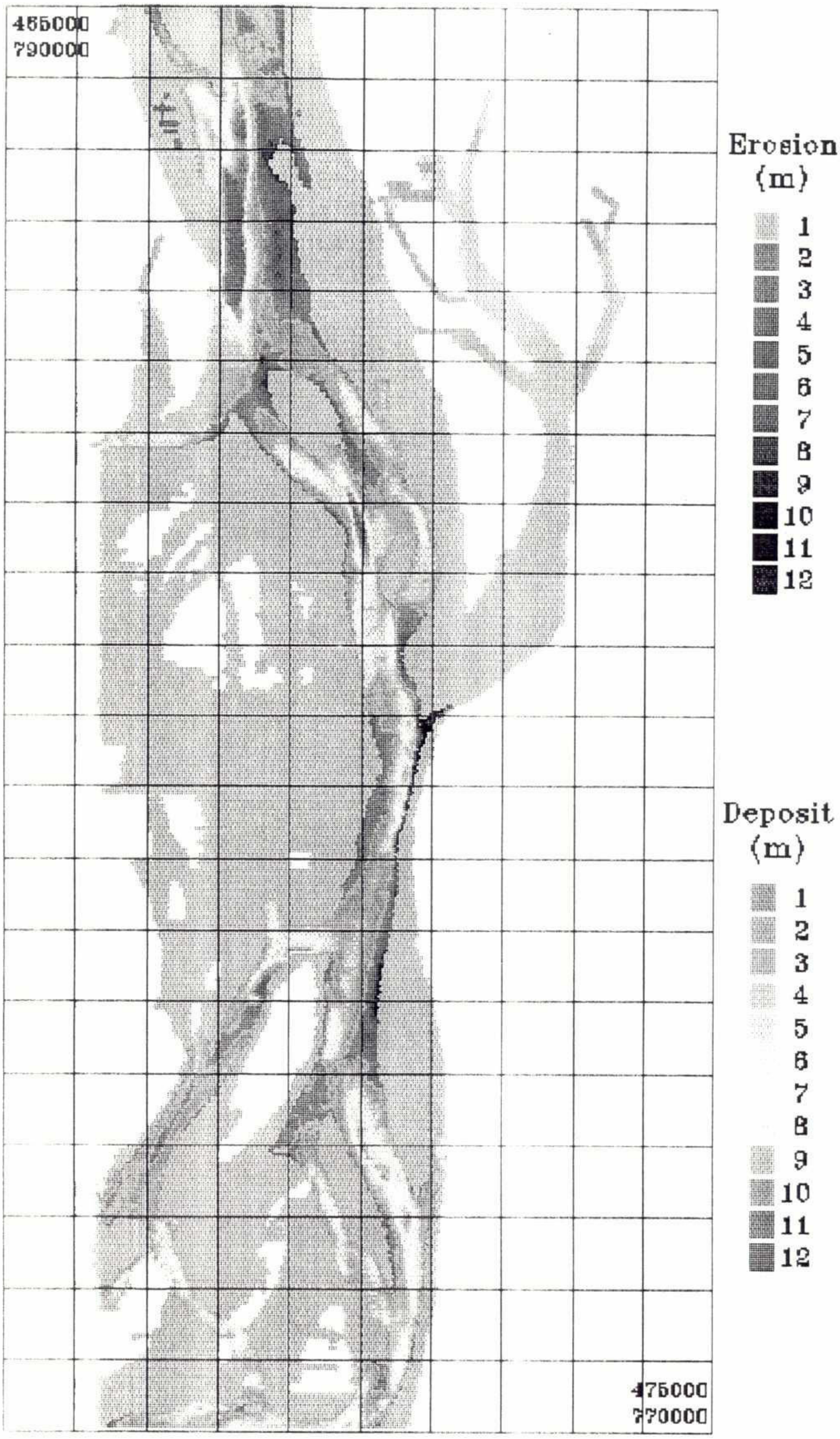

Fig. 3.11: Erosion and deposition at Bahadurabad from February 1995 to July 1995 (processed by EGIS)

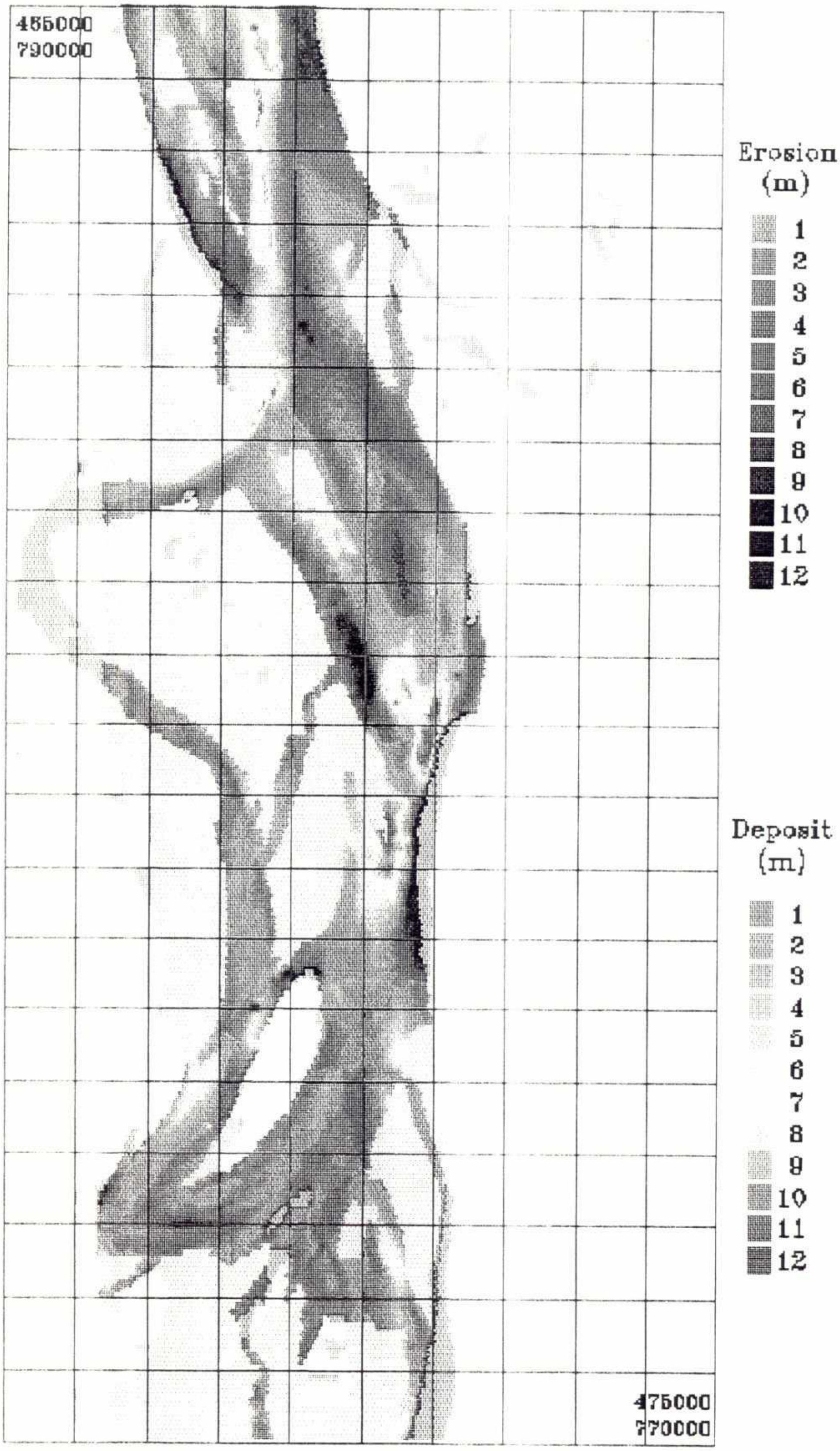

Fig. 3.12: Erosion and deposition at Bahadurabad from July 1995 to November 1995 (processed by EGIS)

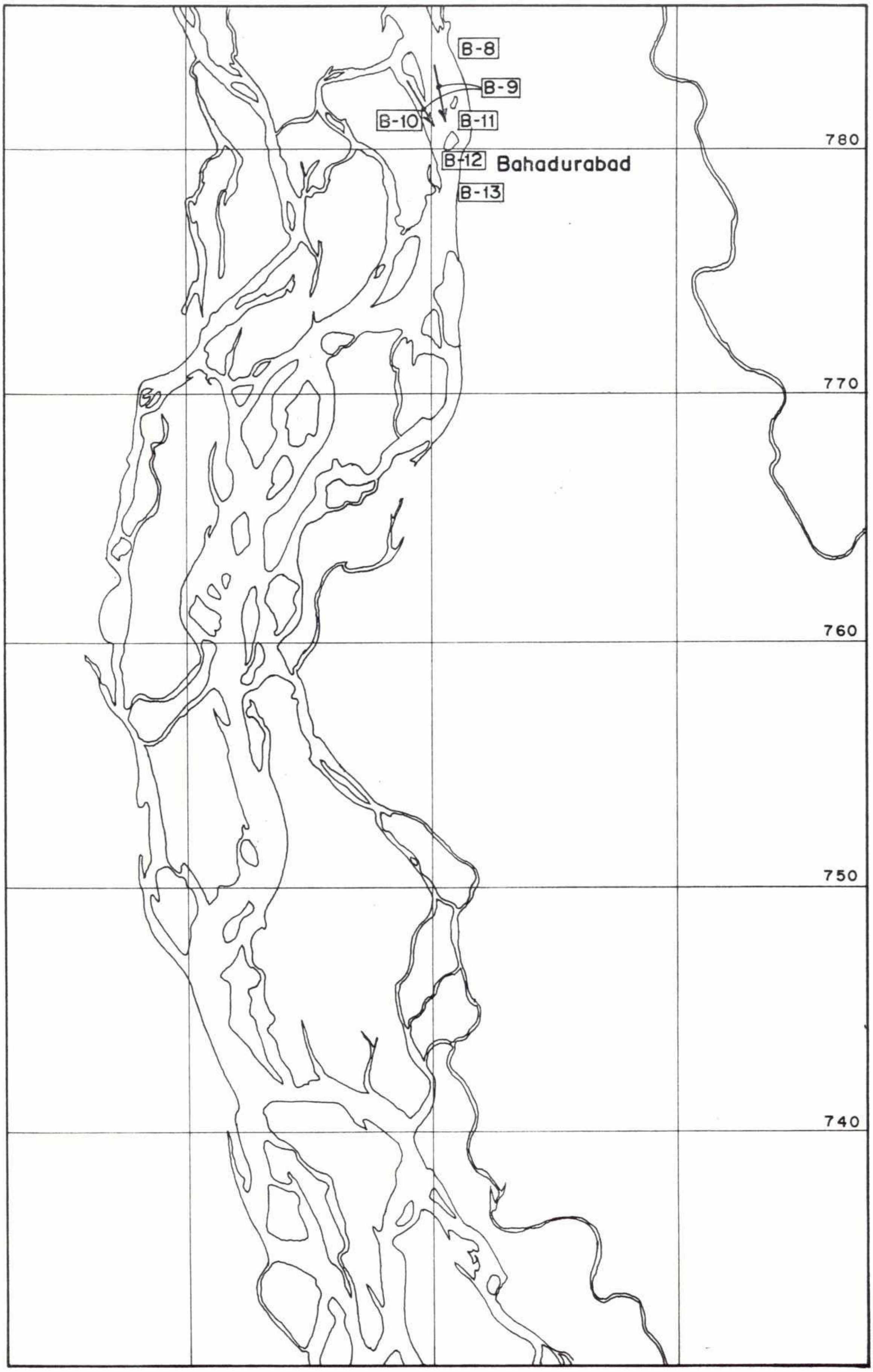

Fig. 3.13: Area of Bahadurabad with ongoing and predicted morphological developments (January 1996 bank lines)

4 DATA REQUIREMENTS FOR MORPHOLOGICAL PREDICTIONS IN SEPTEMBER 1996

The next mission for morphological analyses is scheduled to be carried out in September 1996. The purposes of these analyses are:

- To assess the effect of the groynes at Kamarjani-Dhutichara on bank retreat in 1996;
- To predict whether attack of the groynes at Kamarjani-Dhutichara will continue;
- To assess the risk that the present FAP 21 camp at Kamarjani-Dakatia will be washed away during the flood of 1997 (provided that this is still relevant);
- To verify that Bahadurabad Ghat is still suitable for Test Site II.

The following new information is needed for this and should be available at the start of the mission:

- Satellite images: none, because the Landsat TM image of January 1996 is already available;
- All results from bathymetrical surveys carried out by FAP 21/22 and FAP 24 in the areas of Kamarjani and Bahadurabad during the flood of 1996.

All images and maps should have a BTM coordinate grid.

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APPENDIX A: FIELD VISIT

On Thursday 29 February 1996 Messrs. E. Mosselman (FAP 21/22) and H.R.A. Jagers (University of Twente) left Dhaka by Tista Express train. They arrived at Bahadurabad around 15:00, crossed the river by boat and arrived at Kamarjani around 17:00, to spend the night in the FAP 21 camp.

The following morning, Friday 1 March 1996, they visited the groynes of Test Site I and an upstream char. The following observations were made:

- The flow impinges on the char upstream of the groynes, causing erosion of the char bank. This might be an indication that the channel north of the shoal immediately upstream of the test site is gaining importance;
- The bank of the mainland showed a few exposed semi-lunar slip surfaces;
- In the immediate vicinity of each groyne, bank erosion has been strongest on the downstream side. Mr. G. Hourseau stressed the importance of return currents for this erosion.

After crossing the river, Messrs. Mosselman and Jagers visited the construction site at Bahadurabad. They returned to Dhaka by Tista Express Train in the evening.

APPENDIX B: OUTLINE OF MANUAL FOR MORPHOLOGICAL PREDICTIONS

A manual for predictions of the morphological development of the Brahmaputra-Jamuna River is being prepared. It aims at an integration of the methods developed by FAP 21/22, FAP 24, FAP 1 and EGIS (formerly FAP 19) and is meant to become a part of the future bank protection and river training standards most appropriate for the prevailing conditions at the Brahmaputra-Jamuna River and other rivers of Bangladesh. Special attention will be paid to the criteria to select one method or another.

The manual will have the following contents:

1 Introduction

1.1 Objective and scope

- Integration of methods developed by FAP 21/22, FAP 24, FAP 1 and EGIS (formerly FAP 19)
- Tools: surveys, remote sensing, GIS and image processing, expert judgement, graphical procedures and calculations by hand, physical models, numerical models
- Manual will require yearly updates, with good illustrations, based on further experiences (*learning by doing*)

1.2 Dependence of prediction method on prediction span

- Short-term (weeks and months, up to one year)
- Medium-term (years)
- Long-term (decades)
- Need of probabilistic approach

1.3 Certainty of attack and probability of attack

- Relation between probability of attack and certainty of attack
- Settings with a high certainty of attack

2 Short-term predictions

2.1 Model concept

- Processes (traditional: 3-D flow, sediment transport, sediment balance, with reference to findings of FAP 24)
- Secondary flow (FAP 24 & University of Nottingham Joint Study)
- Mathematical equations

2.2 Recognition of sedimentary structures

- Certain specific sedimentary structures provide clues to ongoing morphological developments (also visible on satellite images in dry season, when ongoing developments are temporarily frozen and the sedimentary structures are exposed):

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- bends
- wider sections with bars
- major scour holes (van der Wal)
- spits or sand arrows (Peters)
- mid-channel bar wings (University of Leeds, relation with de Vriend)
- confluence bar nibs and sediment plumes (Peters)
- finger channels (FAP 21/22)

2.3 Data analysis using overlays

- Extrapolation based on difference maps
- Relaxation model (Peters, currently tested by FAP 24 and EGIS): carried out with GIS or by hand
- Velocity-gradient model (Exner, currently tested by EGIS): carried out with GIS (by hand is not feasible)

2.4 Local assessment in the field

- Subtle changes in water surface slope indicate ongoing development (Peters)

2.5 Physical modelling

- Experience braid patterns Jamuna Bridge (Klaassen), bank erosion Mississippi (Friedkin), topographic steering of shallow areas (Peters), interaction with river training structures (RRI, FAP 21/22)

2.6 Numerical modelling

- Experience Jamuna Bridge

3 Medium-term predictions

- Model concept (FAP 21/22)
- Procedure for manual evaluation (FAP 21/22)

4 Long-term predictions

- Statistical analysis of trends
- GIS as tool (FAP 1, FAP 19)

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