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RIVER SURVEY PROJECT

Special Report No.3

Bathymetric surveys

October 1996

2

Special Report 3

Bathymetric Surveys

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Acronyms and abbreviations

AWLR	:	Automatic water level recorder
BIWTA	:	Bangladesh Inland Water Transport Authority
BM	:	Bench mark
BTM	:	Bangladesh Transverse Mercator (a geodetic grid)
BWDB	:	Bangladesh Water Development Board
DGPS	:	Differential Global Positioning System
DHA	:	Survey vessel A (mother ship)
DHC	:	Survey vessel C (catamaran type)
E	:	Easting (east coordinate in the BTM grid)
EGIS	:	Environmental and Geographic Information System Support Project for Water Sector Planning (formerly FAP19)
FAP	:	Flood Action Plan
FMBM	:	FINMAP bench mark
FPCO	:	Flood Plan Coordination Organization (today merged with WARPO)
GPS	:	Global Positioning System
HYDRO	:	Brand name of a hydrographic software package
N	:	Northing (north coordinate in the BTM grid)
PA	:	Project Adviser
PC	:	Personal computer
PWD	:	Public Works Department (and name of a datum)
SLW	:	Standard Low Water (a reference level)
SoB	:	Survey of Bangladesh
TBM	:	Temporary bench mark
UTM	:	Universal Transverse Mercator (a geodetic grid)
VHF	:	Very high frequency
WARPO	:	Water Resources Planning Organization (of the Ministry of Water Resources)
WGS84	:	World Geodetic System 1984

Glossary

Terms or explanations marked with an asterix (*) relate specifically to the RSP.
Cross-references are printed in *italics*.

Accuracy (of a survey instrument): The compliance between a *true* and a measured value, expressed in the physical unit of the value, and often expressed as the (estimated) standard deviation. For a given instrument, the accuracy is normally related both to the instrument itself and to the actual procedure for its application, notably including the applied *calibration* procedure

Analysis (of river data): Processing, involving a sometimes comprehensive transformation, in order to arrive at the intended information that was the objective of the measurements. Data analysis is often carried out stage-wise and in different contexts. In general, data analysis involves both hidden and explicit assumptions about the relation between primary data and final results

* Bankline: A line illustrating the location of the river bank. It can be defined as the *water line* at a given *stage*, usually a characteristic high stage. In practice, the bankline is relatively well-defined at eroding and stable banks, but is less well-defined at accreting banks with a small gradient

Bathymetric survey: Mapping of river bed or sea bed elevations (normally by water depth measurements by echo sounding)

Bedforms (of a river): Morphological features of the river bed, for example sand dunes

BTM (Bangladesh Transverse Mercator) grid: A geodetic projection of the Mercator type, which features a true projection of angles and a slightly distorted projection of distances. The grid is aligned with the 90° east meridian. The scale distortion is small, and the grid coordinates, *eastings* and *northings*, are approximately orthogonal. They are given in m or km from a defined point of origin located southwest of Bangladesh (whereby all coordinates within Bangladesh become positive)

Calibration (of a survey instrument): Measurement of a set of values that are, at the same time, also measured by other, more accurate means, in order to determine a systematic *error* of the instrument (for subsequent compensation)

Datum: A defined vertical reference level (for water levels, bed levels, or land elevations), for example *SLW* or *PWD*

Depth reduction (of bathymetric soundings): Conversion of depth measurements to the applied *datum*.
* RSP measured depths by echo sounding relative to the survey vessel (or relative to the surface of the river). The *depth reduction* (to *SLW datum)* was made by gauging of the water level at a place where *SLW* was defined, specifying the actual water level *slope* during the measurements and assuming that this slope represented the slope of the *SLW* between the water level gauge and the survey vessel

* Easting: East coordinate in the BTM grid, given in m (6 digits) or km (3 digits). Easting = 500 km + the distance (positive towards east) from the 90° east meridian. Hence, per definition, the 90° east meridian has an easting of 500. For example, the easting of Gulshan (at the SoB primary bench mark) is 542

Error (of a survey instrument, a survey procedure, or a calculation method): The difference between a *true* and a measured value, or between a desired and an actual value. Errors are inversely related to *accuracy* and *validity*. They can be random (stochastic) or systematic

* Feature mapping: Mapping of land surface characteristics (embankments, structures, vegetation, etc.), for example for interpretation of satellite imagery

Frequency (of an echo sounder): The frequency of the transmitted and reflected sound wave. A higher frequency gives a better resolution but a reduced penetration. * RSP used 30 kHz and 30/210 kHz echo sounders

Gauge: A device for measuring water level (or pressure)

* Geodetic survey: Mapping of geodetic coordinates (of bench marks, reference stations, etc.)

Hydrograph: A time series of water levels at a fixed location (either measured or calculated by a model)

Morphology (of a river): (1) its shape, (2) the study of states, processes and effects related to the shape of a river

* Northing: North coordinate in the BTM grid, given in m (6 digits) or km (3 digits). The northing = the distance to equator minus 2000 km. For example, the northing of Gulshan (at the SoB primary bench mark) is 631

Off-line processing (or post-processing) (of survey data): Data processing carried out after completion of the field work

On-line processing (of survey data): Real-time data processing onboard the survey vessel, one objective being to monitor the data *quality* and data coverage, so that measurements can be repeated immediately, if needed. * RSP applied on-line processing of position, current, flow and depth data

Procedure (for a river survey): The combination of instruments, software and practices applied for arriving from one point in the data flow to a subsequent point

PWD = Public Works Department datum: A horizontal datum applied by PWD, BWDB and others. It is defined by a network of SoB and BWDB benchmarks with a specified elevation above PWD. Its zero level is located somewhat below Mean Sea Level (0.46 m, according to a definition from 1909)

Quality: The compliance between a desired and an actual property (or set of properties)

* Raw data: Primary survey data, as produced in the field, such as onboard the survey vessel, in the state in which they are received by the RSP data processing office in Dhaka upon completion of the field work. Some raw data have been organised, edited and converted by *on-line processing* onboard the vessel

Runline: A well-defined line along which measurements are carried out. It is good practice to retain runlines for successive surveys, in order to improve the *validity* of comparisons between the results

SLW = Standard Low Water datum: A datum representing the water level that is exceeded in 95 percent of the time. Hereby, the slope of the datum (approximately) follows the dry season *slope* of the river surface, inclining downwards towards the sea. The present SLW was defined at a number of gauge locations by BIWTA in 1990

Spheroid (for geodetic mapping): An assumed, simplified, but geometrically well-defined shape of the earth. An example is 'Everest 1830', which is applied by Survey of Bangladesh. Several variants of this spheroid exist and have been applied on different occasions

Stage: Water level at a given location

Surface slope: The (local or general) inclination of the river surface, relative to a horizontal plane, and positive in the downstream direction. For a given cross-section (with a given roughness and a given hydraulic radius), the slope is related to the flow in a well-defined way. * Typical average slopes of the rivers of the RSP survey area are between 2 cm/km (Upper Meghna) and 8 cm/km (Jamuna)

* Survey: A specific programme of (related or unrelated) field measurements

Topographic survey: Mapping of land elevations

Transparency (of a survey or data analysis procedure): The insight conveyed to the data user about how the data were produced, for example for assessing the *validity* of the data for a given, possibly unforeseen, purpose. An acceptable transparency is obtained by documentation and can be supported by using standard methods

True value (of a physical characteristic within river hydraulics): An ideally correct value, determined without any errors whatsoever. A true value can be instantaneous or averaged over a certain period of time, and it can relate to an infinitesimal point or be averaged over a certain length, area or volume

Validity (of survey data): The compliance between a desired value and an actual value. Even if both are *accurate*, the validity can be low, for example due to time and space variations (such as measuring current for determination of flow in a few points and over a few seconds only)

Water line: The intersection between the water surface and the bank

1 Introduction

As part of the Consultancy Contract of 22 May 1992 for the River Survey Project (RSP, or FAP24), ALA/90/04, bathymetric surveys should be undertaken in Phase 2 of the project at 7 sites just before and just after the flood season, i.e. in April and December.

In April/May 1993 it was decided, in agreement with the RSPMU, to advance the start of the bathymetric work and to carry out bathymetric pilot surveys in the left main channel of the Jamuna River at Bahadurabad over the flood season, when the morphological changes are expected to be most distinct. The pilot surveys of 1993 (June, August/September and November) are described in *RSP Survey Report 9: 'Bathymetric pilot surveys on Jamuna River at Bahadurabad in 1993'*. From the results it was concluded that execution of bathymetric surveys in particular areas over the flood season indeed is important for the evaluation of morphological development patterns in the main rivers of Bangladesh.

A summary of all bathymetric surveys carried out during the River Survey Project is given in Table 1.1. A key plan of the survey areas is shown as Figure 1.1.

The present *RSP Special Report 3* provides background information about the surveys, while the maps are submitted separately. Surveys with a line spacing of 200 m are plotted on maps at a scale of 1:20,000, and those with a survey line spacing of 100 m are plotted at a scale of 1:10,000.

A draft version of the report was submitted as *RSP Survey Report 11* in April, 1996. During the review, several open questions were pointed out by the RSPMU, as summarised in the 14th PA Mission Report, April 1996. Part of these comments have been incorporated in the present edition, whereas others, particularly some more general ones, are addressed in *RSP Final Report Annex 1: 'Surveys'* and *Annex 2: 'Sustainable survey techniques'*. Hereby, the present report mainly describes what was actually done by the RSP.

Survey No.	Location	Type of survey	From	To	Line Spacing	Average Water Level	Water Level Slope	Location of SLW	SLW	Average W.L reduction	Scale	No. of sheets Contour	Chart	Area
					m	m+PWD	cm/km		m+PWD	m				sq.km
During 1993														
8001	Bahadurabad	Bathymetry	08 Jun	03 Jul	100	18.51	8.4	Bahadurabad	12.03	-6.48	1:10,000	6	6	73.5
8002	Bahadurabad	Bathymetry	23 Aug	09 Sep	100	19.15	8.5	Bahadurabad	12.03	-7.12	1:10,000	4	4	81.6
8003	Aricha Confluence	Bathymetry	15 Oct	31 Oct	200	7.02	5.8	Aricha/Teota	2.31	-4.71	1:20,000	6	6	149.5
8004	Bahadurabad	Bathymetry	10 Nov	18 Nov	100	15.48	7.0	Bahadurabad	12.03	-3.45	1:10,000	4	4	55.9
8005	Hurasagar	Bathymetry	23 Nov	30 Nov	100	4.88	3.5	Mathura	2.50	-2.38	1:10,000	4	4	21.1
During 1994														
8006	Arial Khan Offtake	Bathymetry	01 Jan	10 Jan	200	1.71	1.7	Chowdhury Hat	0.85	-0.86	1:20,000	3	3	79.1
8007	Aricha Confluence	Bathymetry	19 Apr	05 May	200	4.06	4.2	Aricha/Teota	2.31	-1.75	1:20,000	6	6	106.7
8008	Kamarjani	Bathymetry	03 Sep	25 Sep	200	18.99	8.7	Kamarjani	13.87	-5.12	1:20,000	2	2	160.1
8009	Gorai offtake	Bathymetry	13 Oct	23 Oct	200	9.51	4.0	Talbaria	4.11	-5.40	1:20,000	4	4	92.0
8010	Bahadurabad	Bathymetry	01 Nov	10 Nov	100	15.18	6.5	Bahadurabad	12.03	-3.15	1:10,000	4	4	48.3
8011	Dhaleswari Offtake	Bathymetry	24 Nov	11 Dec	200	7.64	7.4	Bhuyanpur	6.03	-1.61	1:20,000	3	3	85.4
9038	Kamarjani	Bathymetry	10 Nov	20 Nov	100	15.97	8.4	Kamarjani	13.87	-2.10	1:10,000	7	7	50.3
8012	Aricha Confluence	Bathymetry	13 Dec	25 Dec	200	3.18	4.0	Aricha/Teota	2.31	-0.87	1:20,000	6	6	80.4
8013	Hurasagar	Bathymetry	25 Dec	29 Dec	200	3.41	3.5	Mathura	2.50	-0.91	1:20,000	2	2	15.4
During 1995														
8014	Gorai Offtake	Bathymetry	06 Jan	20 Jan	200	5.53	3.0	Talbaria	4.11	-1.42	1:20,000	4	4	39.1
9044	Gorai Offtake	Land survey	15 Jan	14 Feb	100						1:10,000	1	1	8.0
		Land survey & contour plot done in m+PWD												
8015	Arial Khan Offtake	Bathymetry	04 Feb	13 Feb	200	1.13	1.2	Chowdhury Hat	0.85	-0.28	1:20,000	3	3	88.0
8016	Bahadurabad	Bathymetry	24 Feb	27 Feb	100	13.03	5.0	Bahadurabad	12.03	-1.00	1:10,000	4	4	29.3
8017	Kamarjani	Bathymetry	07 Mar	13 Mar	100	14.18	8.0	Kamarjani	13.87	-0.31	1:10,000	5	5	33.4
8018	Dhaleswari Offtake	Bathymetry	29 Mar	04 Apr	200	6.82	7.5	Bhuyanpur	6.03	-0.79	1:20,000	3	3	60.3
8019	Aricha Confluence	Bathymetry	08 Apr	15 Apr	200	2.94	3.6	Aricha/Teota	2.31	-0.63	1:20,000	5	5	73.4
8020	Hurasagar	Bathymetry	18 Apr	20 Apr	200	3.55	3.5	Mathura	2.50	-1.05	1:20,000	2	2	20.0
8021	Arial Khan Offtake	Bathymetry	27 Apr	07 May	200	2.22	2.0	Chowdhury Hat	0.85	-1.37	1:20,000	4	4	98.6
8022	Gorai Offtake	Bathymetry	28 May	12 Jun	200	7.24	3.5	Talbaria	4.11	-3.13	1:20,000	4	4	52.8
8023	Gorai Offtake	Bathymetry	24 Jun	25 Jun	200	9.35	4.0	Talbaria	4.11	-5.24	1:10,000	1	1	2.0
8024	Bahadurabad	Bathymetry	04 Jul	25 Jul	100	19.65	9.0	Bahadurabad	12.03	-7.62	1:10,000	6	6	90.8
9071	Bahadurabad	Float Tracking	26 Jul	31 Jul										
8025	Gorai Offtake	Bathymetry	10 Aug	13 Aug	200	12.09	5.0	Talbaria	4.11	-7.98	1:10,000	1	1	3.8
8026	Kamarjani	Bathymetry	01 Aug	19 Aug	200	20.32	9.0	Kamarjani	13.87	-6.45	1:20,000	3	3	92.7
8027	Gorai Offtake	Bathymetry	08 Sep	24 Sep	200	12.53	5.0	Talbaria	4.11	-8.42	1:20,000	5	5	106.5
9080	Gorai Offtake	Float Tracking	11 Oct	17 Oct										
8028	Gorai Offtake	Bathymetry	18 Oct	20 Oct	200	10.04	4.5	Talbaria	4.11	-5.93	1:20,000	1	1	9.9
8029	Bahadurabad	Bathymetry	11 Nov	24 Nov	100	15.52	6.8	Bahadurabad	12.03	-3.49	1:10,000	5	5	54.1
8032	Bahadurabad	Land survey	25 Nov	06 Jan 96										35.0
9094	Bahadurabad	Float Tracking	18 Nov	23 Nov										

Table 1.1.a: Summary of bathymetric surveys

Survey No.	Location	Type of survey	From	To	Line Spacing	Average Water Level	Water Level Slope	Location of SLW	SLW	Average W.L reduction	Scale	No. of sheets Contour	Chart	Area
					m	m+PWD	cm/km		m+PWD	m				sq.km
During 1995														
8030	Kamarjani	Bathymetry	24 Nov	14 Dec	100	15.28	8.2	Kamarjani	13.87	-1.41	1:10,000	7	7	59.5
8034	Kamarjani	Land survey	07 Jan 96	16 Jan 96										72.0
			15 Mar 96	18 Mar 96										
9095	Kamarjani	Float Tracking	05 Dec	19 Dec										
During 1996														
8031	Dhaleswari Offtake	Bathymetry	26 Dec	09 Jan	200	7.34	7.4	Bhuyanpur	6.03	-1.31	1:20,000	3	3	66.6
8033	Aricha Confluence	Bathymetry	14 Jan	31 Jan	200	3.41	4.0	Aricha/Teota	2.31	-1.10	1:20,000	4	4	80.9
8037	Aricha Confluence	Land survey	22 Mar	31 Mar										13.0
9096	Aricha Confluence	Float Tracking	25 Jan	04 Feb										
8035	Arial Khan Offtake	Bathymetry	03 Feb	14 Feb	200	1.38	1.5	Chowdhury Hat	0.85	-0.53	1:20,000	5	5	116.0
8036	Hurasagar	Bathymetry	03 Mar	04 Mar	200	2.81	3.0	Mathura	2.50	-0.31	1:20,000	2	2	16.4
8038	Gorai Offtake	Bathymetry	02 Apr	07 Apr	200	4.57	2.7	Talbaria	4.11	-0.46	1:20,000	2	2	30.0
8039	Bahadurabad	Bathymetry	07 Mar	13 Mar	100	13.5	5.3	Bahadurabad	12.03	-1.47	1:10,000	4	4	32.3

Table 1.1.b: Summary of bathymetric surveys

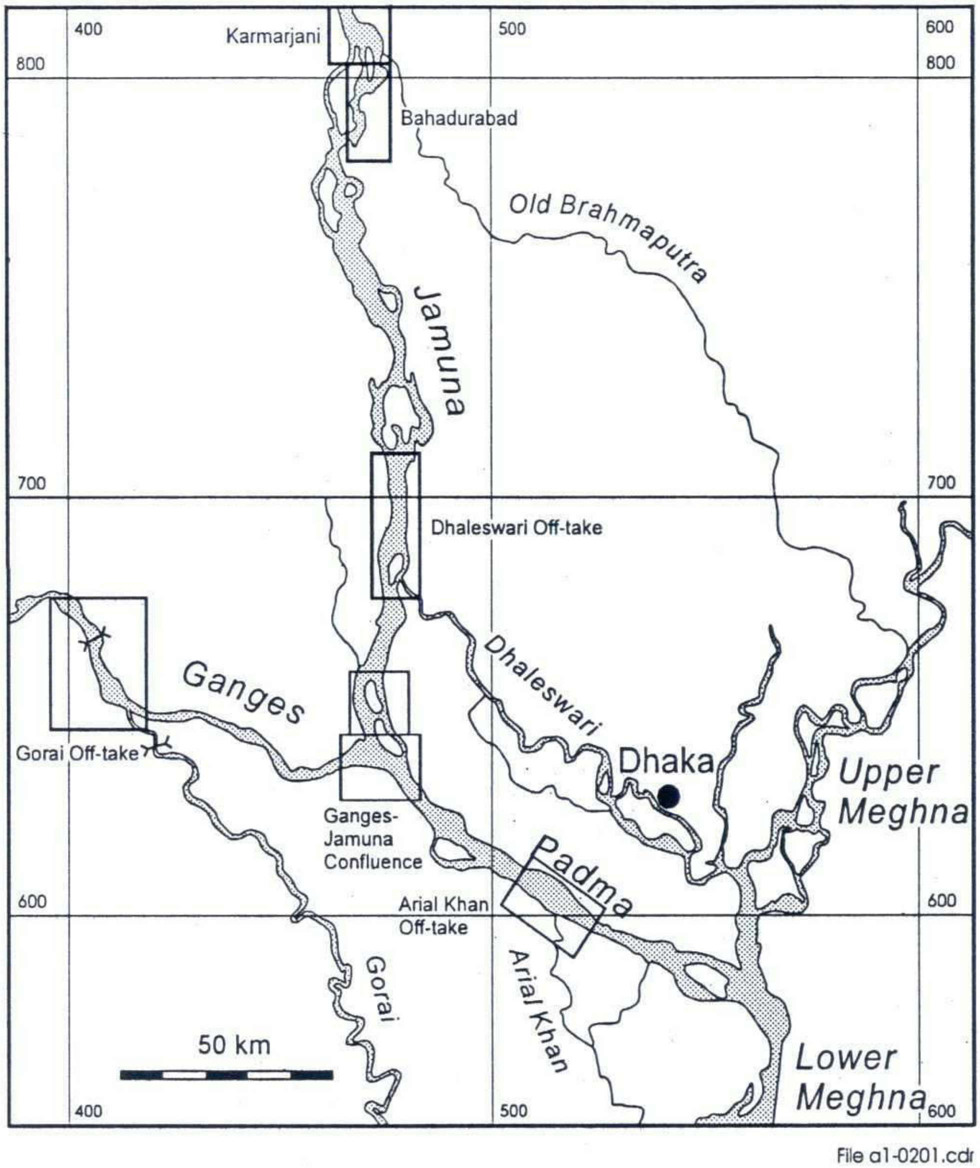

Figure 1.1: Key plan of bathymetric survey areas

2 Extent and methods of survey

The bathymetric surveys cover the navigable water level sections of the river areas, as depicted in Figures 2.1 to 2.6. Due to a variation in water levels between the flood and dry seasons and also over the flood season, the areas covered during the individual surveys will be different.

The coverage of the respective survey areas can be summarized as follows :

- The surveys were carried out along runlines oriented north-south or east-west, depending on the orientation of the river channel. Line spacing was applied as summarized in Table 1.1.
- Water depths have been recorded for approximately every 2 m along the survey lines.
- Banklines have been determined by direct measurements or by estimation of the distance to shore from the last bathymetric measuring point in the respective lines.

For reduction of depth measurements, water levels recorded at the following stations have been used:

River	Gauging station	Figure
Jamuna (left bank)	Bahadurabad	2.1
Jamuna (right bank)	Kamarjani	2.2
Jamuna (Dhaleswari Off-take)	Bhuyanpur	2.3
Jamuna/Ganges Confluence	Aricha (Teota)	2.4
Jamuna (Hurasagar)	Mathura	2.4
Ganges (Gorai Off-take)	Talbaria	2.5
Padma (Arial Khan Off-take)	Chowdhury Hat	2.6

Table 2.1: Water level stations applied for depth reduction

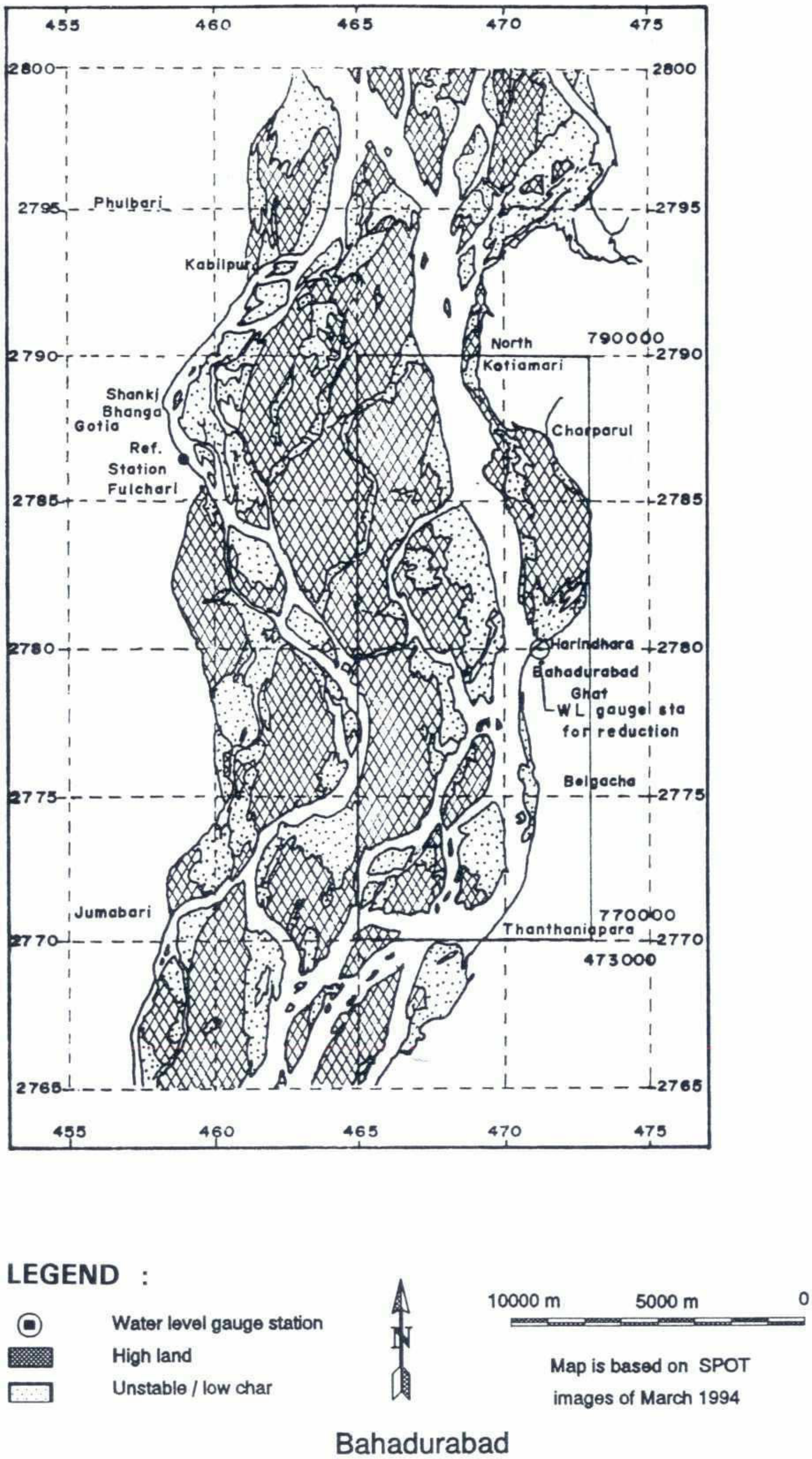

Figure 2.1 : Bathymetric survey area, Jamuna River at Bahadurabad

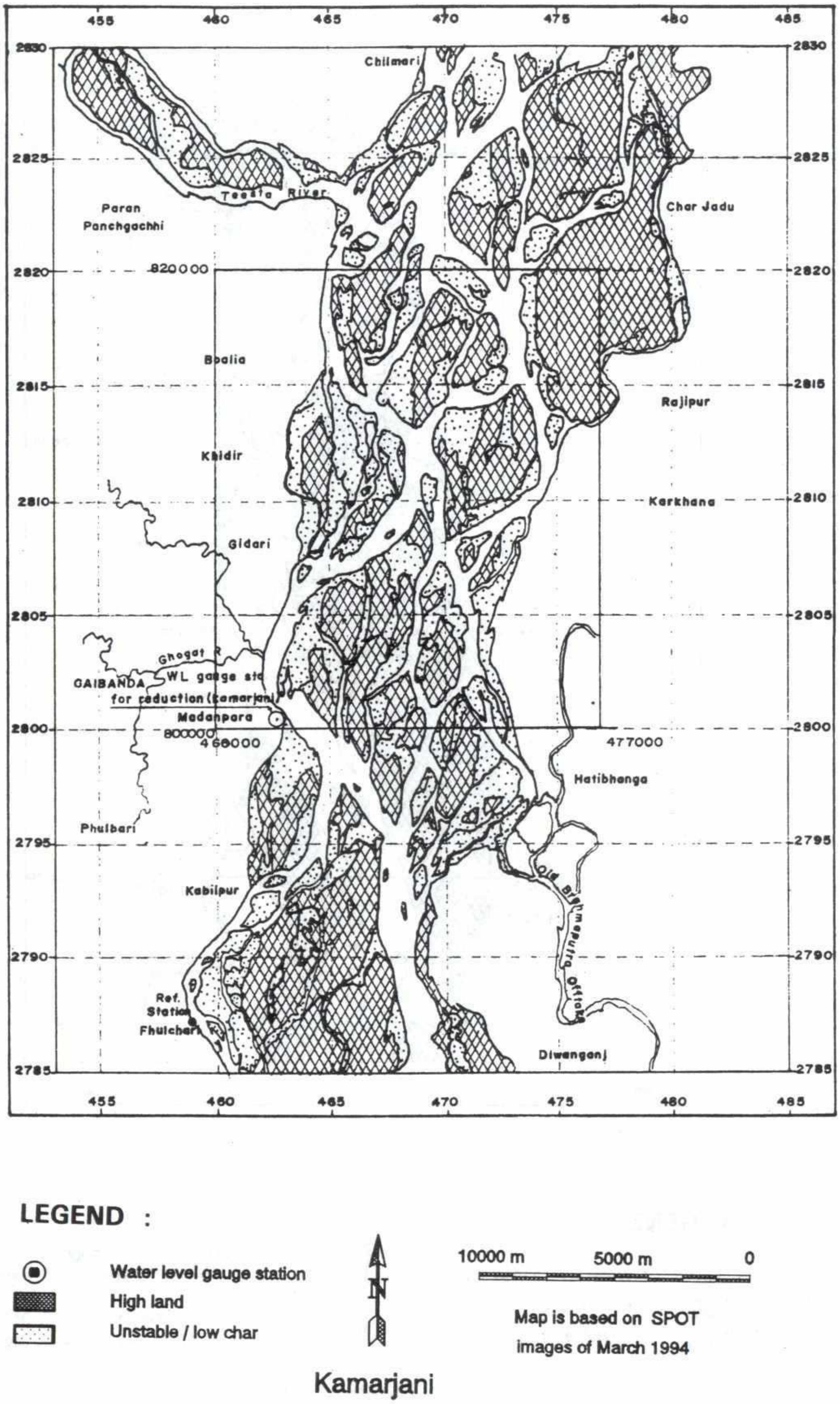

Figure 2.2: Bathymetric survey area, Jamuna River at Kamarjani

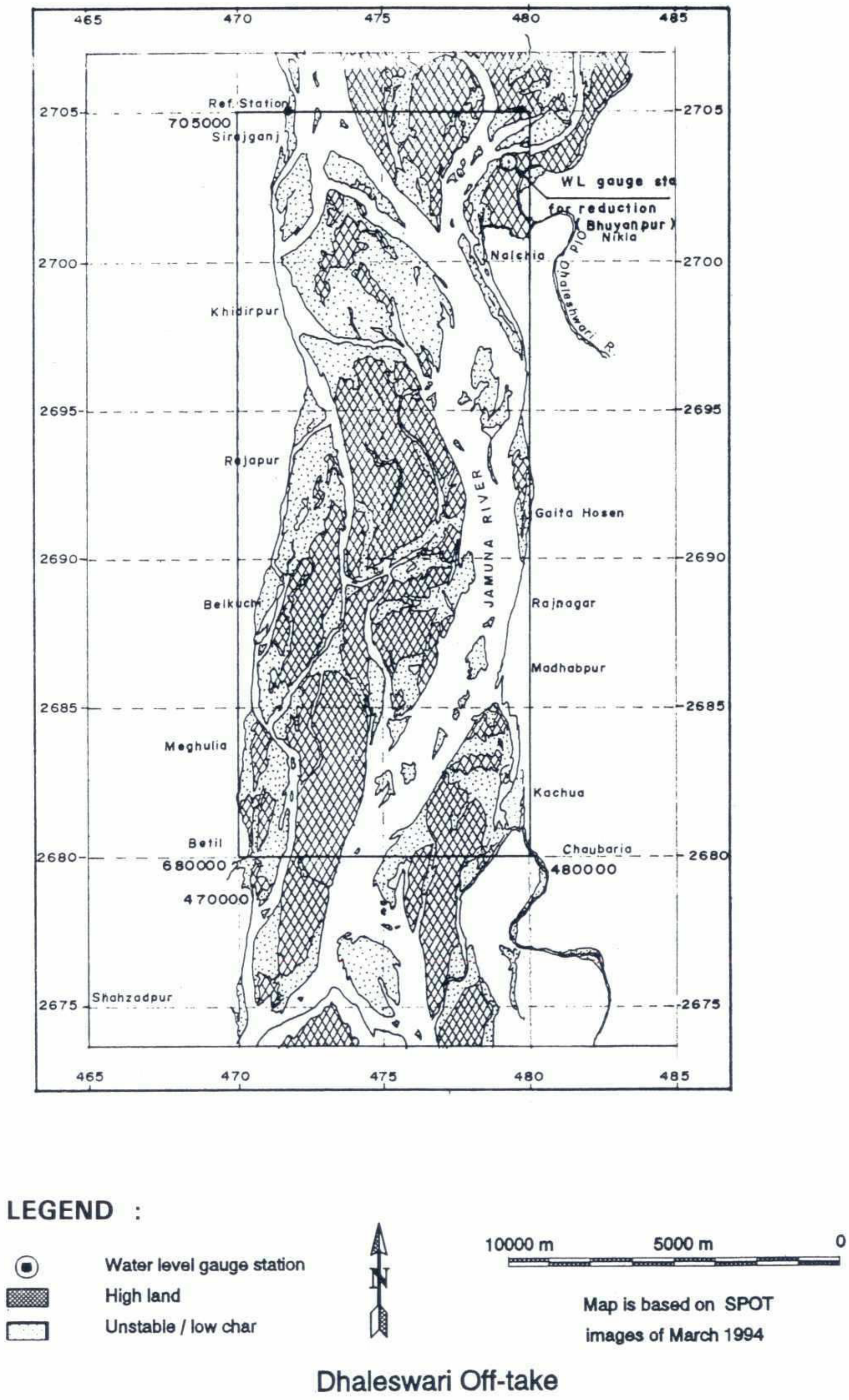

Figure 2.3: Bathymetric survey area, Jamuna River at Dhaleswari Off-take

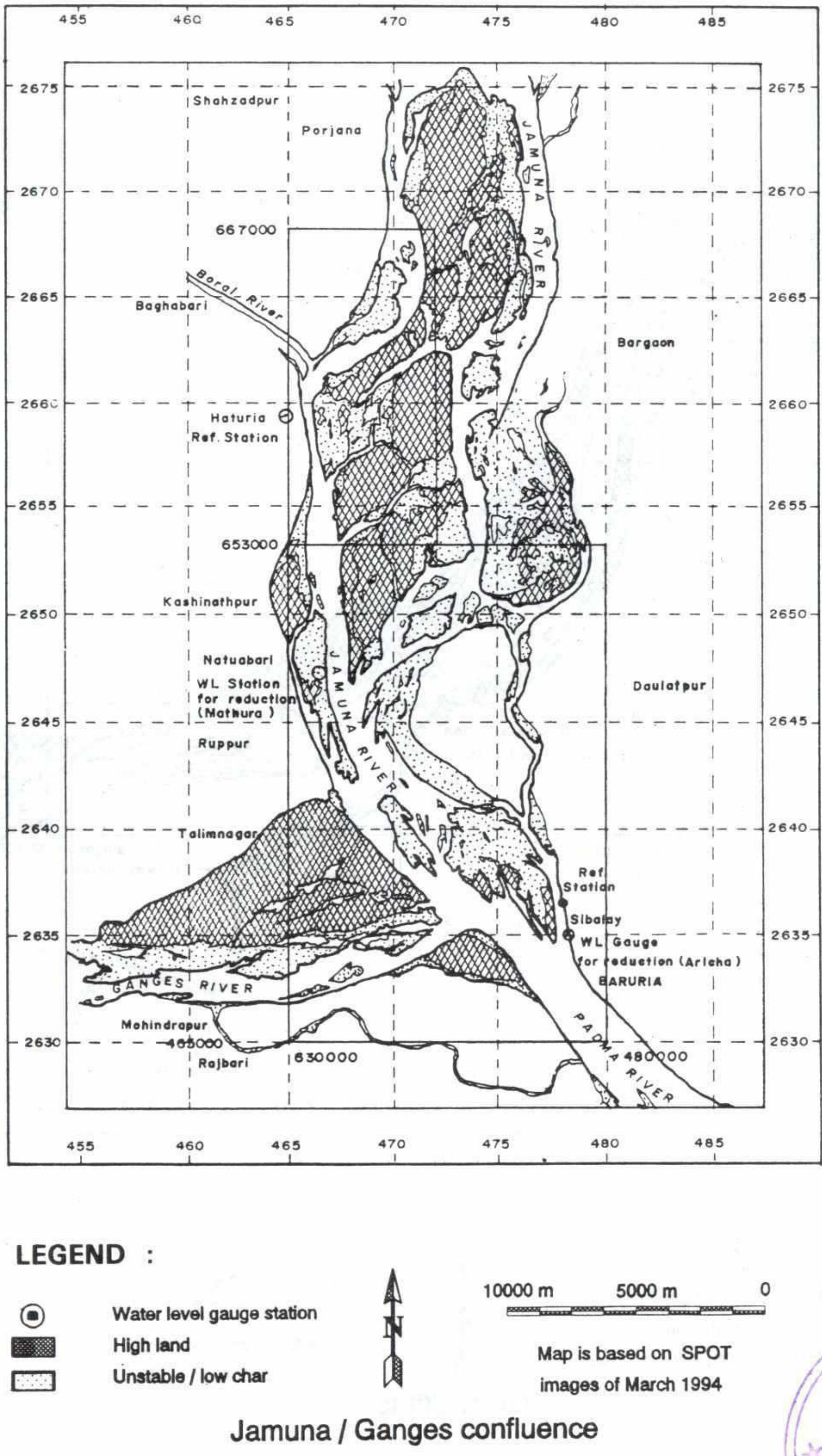

Figure 2.4: Bathymetric survey area, Jamuna/Ganges Confluence and Hurasagar

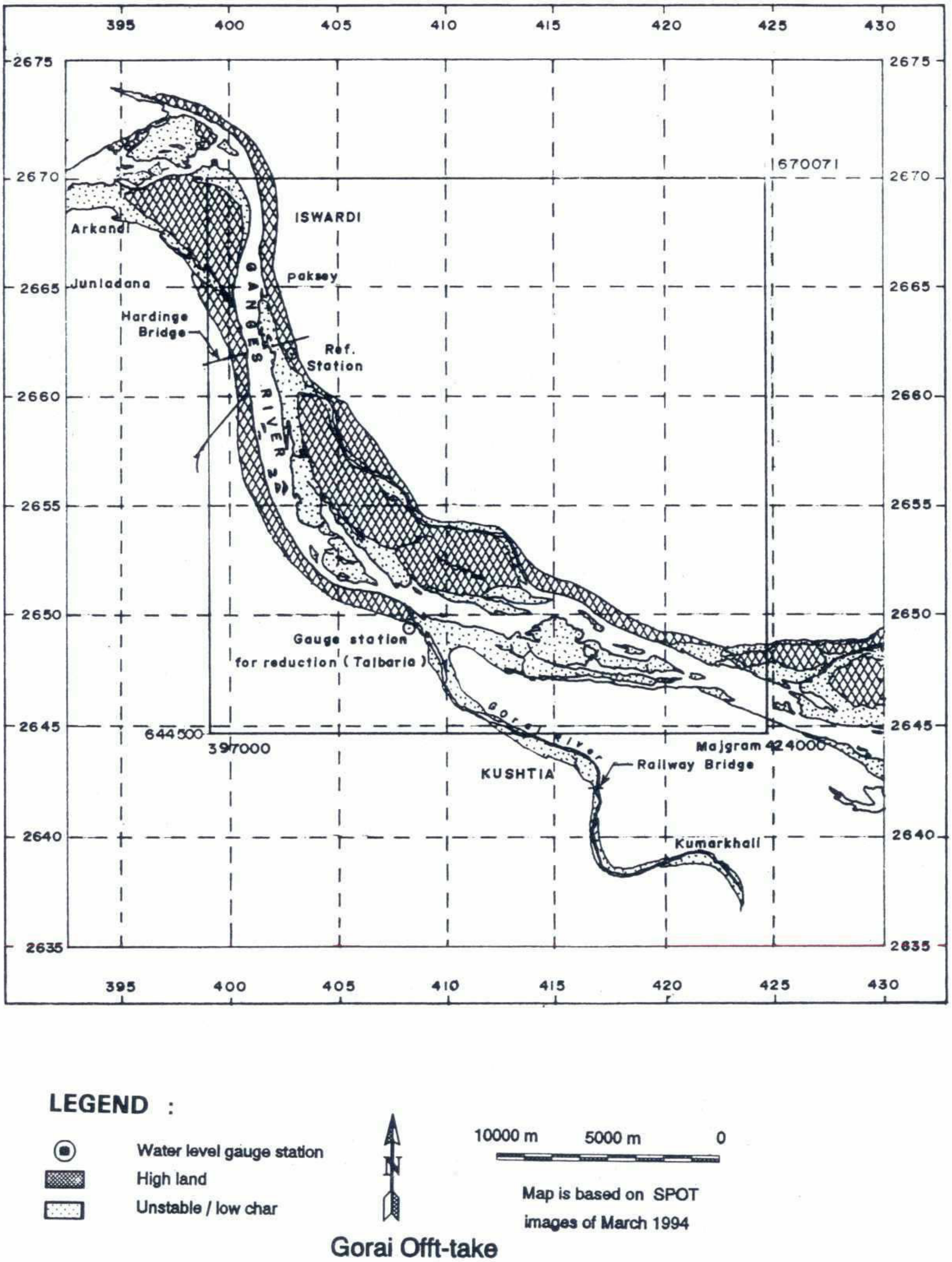

Figure 2.5: Bathymetric survey area, Ganges at Gorai Off-take

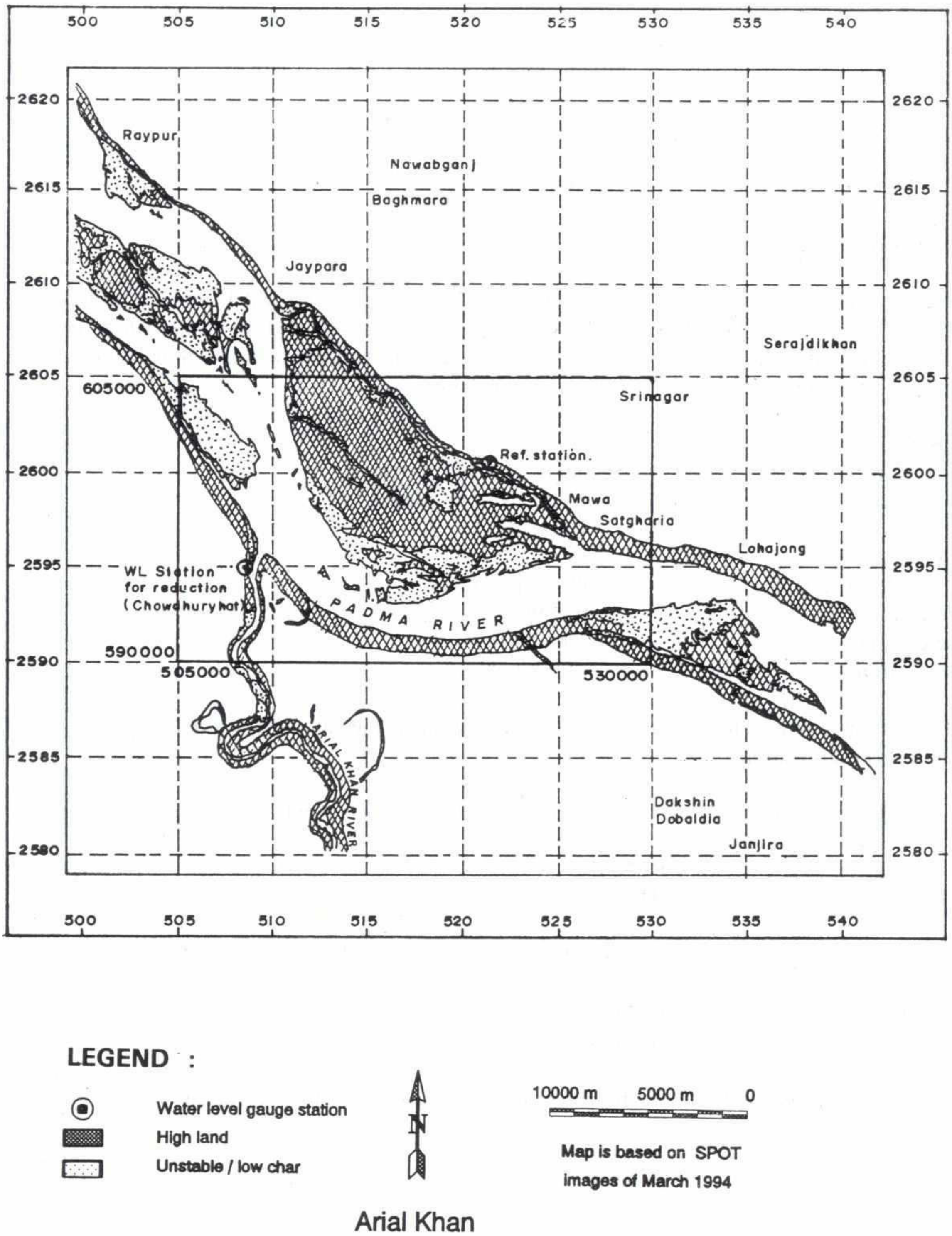

Figure 2.6: Bathymetric survey area, Padma River at Arial Khan Off-take

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3 Measurement equipment and procedures

3.1 General

All the survey equipment and vessels operated by the River Survey Project as well as the related general procedures for bathymetric surveying have been described in Chapter 5 of *RSP Survey Report 3: 'Test Gauging Report'*, and in *RSP Survey Report 5: 'Bathymetric pilot surveys on Jamuna River at Bahadurabad in 1993'*. A summary is provided in the following.

3.2 General survey control and datums

Planimetric control

The surveys were conducted in the World Geodetic System 1984 (WGS84) and in the Bangladesh Transverse Mercator BTM, which is a UTM-like zone system based on the so-called *Modified Everest Modified* ellipsoid. For the rationale behind this choice, please refer to *RSP Final Report Annex 1: 'Surveys'*. The applied grid had the following parameters:

Ellipsoid		
Major axis	:	6,377,298.524 metres
Minor axis	:	6,356,097.518 metres
Flattening	:	1/300.8017
Projection		
Central Meridian (CM)	:	90.0° Longitude
Scale factor	:	0.9996
False easting	:	500,000
False northing	:	-2,000,000

DGPS reference stations for positioning of the vessels during the bathymetric surveying were installed in the following locations:

- For Jamuna River at Bahadurabad and Kamarjani, at the T&T relay station in Fulchari ghat (Figures 2.1 and 2.2):
  Coordinates : BTM E 459,018.03
  BTM N 785,996.21

- For Jamuna River at Dhaleswari Off-take, on B.L. High School north of Sirajganj Launch and Ferry Ghat (Figure 2.3) :
  Coordinates : BTM E 471,864.93
  BTM N 705,012.25

- For the Jamuna/Ganges Confluence, on the roof of the BIWTA building in Aricha (Figure 2.4):
  Coordinates : BTM E 478,255.77
  BTM N 635,845.82

- For Hurasagar River sections of Jamuna, on the Union Council Office at Nakalia (Figure 2.4):
  Coordinates : BTM E 465,071.51
  BTM N 658,405.31

- For Ganges River at Gorai Off-take, on the RSP Pakshey Guest House (Figure 2.5) :
  Coordinates : BTM E 402,685.90
  BTM N 661,608.50

- For Padma River at Arial Khan Off-take on the BWDB staff quarter at Bhagyakul (Figure 2.6):
  Coordinates : BTM E 522,839.19
  BTM N 600,153.51

All the original preparations of fixed points including determination of coordinates were undertaken as a part of the general mobilization for the routine gauging programme.

Vertical control

All the depth data have been reduced to Standard Low Water (SLW) at the respective recording stations. SLW represents a sloping reference level (as compared with the PWD, which is a horizontal reference level). However, the reduction of measured depths relates to the actual water surface in the survey area at the time of the survey. The actual slope of the water surface during the measurements has been estimated and presented on the contour maps, as discussed in Section 3.4 and included in Table 1.1.

The relationship between the two reference levels is given in the report on *'Determination of standard low water and standard high water levels in Bangladesh'*, issued by BIWTA (December 1990) and prepared by Norwegian Interconsult A/S.

For the BWDB water level gauging stations, the following figures have been obtained from this report:

River	Station	SLW (m+PWD)
Jamuna	Kamarjani	13.87
Jamuna	Bahadurabad	12.03
Jamuna	Bhuyanpur	6.03
Jamuna	Hurasagar (Mathura)	2.50
Confluence	Jamuna/Ganges, Aricha	2.31
Padma	Chowdhury Hat	0.85
Ganges	Gorai off-take (Talbaria)	4.11

Table 3.1: Location of SLW datum relative to PWD datum

The datum of the water level gauging station was determined/verified by geometric levelling from the bench marks shown in Table 3.2.

Area	Location	Bench-mark code	Bench-mark level (in m+PWD)
Jamuna	Kamarjani	FMBM 7602	21.910
Jamuna	Bahadurabad	BWDB TBM	21.785
Jamuna	Bhuyanpur	BWDB BM	10.466
Confluence	Teota	FMBM 8122	10.203
Hurasagar	Mathura	BWDB BM	12.757
Arial Khan off-take	Chowdhury Hat	BIWTA BM	8.002
Gorai off-take	Talbaria	BWDB BM	14.136

Table 3.2: Applied reference bench marks

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In this way, water levels during the surveys become available in m+PWD, see further in Section 4.2. The details involved in the horizontal as well as the vertical control work have been provided in *RSP Survey Report 7: 'Transfer of bench-mark levels across Jamuna River at Bahadurabad'*

Details about the installation of water level recorders have been provided in *RSP Special Report 2: 'Water level gauging'*.

3.3 Bank-line survey

Identification of the bank line during the surveys took place by direct measurements, where possible, or by positioning relative to the vessel by estimating the distance from the vessel to the river bank at each end of each survey line.

3.4 Water level slopes

The instantaneous water level slope is a measure of the water level difference between the water level gauge and the survey vessel. The dry season water level slope illustrates the slope of the SLW reference level, because SLW, while being defined at a number of bench marks along the river, was established on the basis of a calculated (95 % exceedence) water level at these stations. (Literally, SLW is not *defined* as the water level exceeded in 95 % of the time; even if data were abundant, such definition would be time-dependent). At a given location, the slope is largely determined by the flow, but also the wind can play a role.

The RSP surveys were made as follows:

- Depths were reduced to SLW at the nearest gauge location where SLW is defined;
- the water level difference between the vessel and the gauge location was controlled by the actual slope at the time of the survey;
- this slope was indicated as a map reference (and is listed in Table 1.1).

The procedure is illustrated in Figure 3.1.

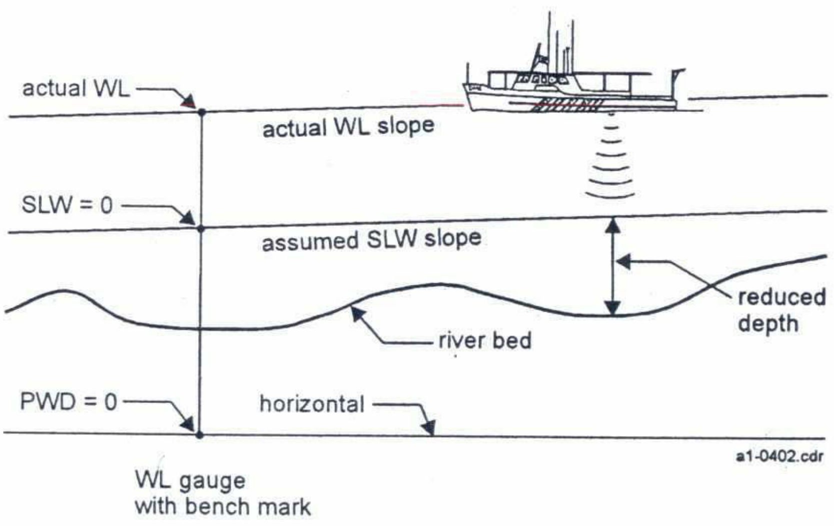

Figure 3.1: Depth reduction of echo soundings

During Phase I, RSP studied the water level profiles at low, average and high flow conditions for the Jamuna, Ganges and Padma Rivers. The study revealed that the average overall water surface slope varies from 7.5 to 8.5×10^{-5} for the upper reach of the Jamuna and 5.5 to 7.5×10^{-5} for its lower reach. Average slopes ranging from 4 to 5.5×10^{-5} and 3 to 4×10^{-5} were found for the Ganges and Padma Rivers, respectively.

Bathymetric surveys were carried out at seven locations in different rivers during different seasons. Water surface slopes for those sites were computed using BWDB and RSP stations. The prevailing water surface slopes are presented for each reach in the following sections.

Bahadurabad

The Bahadurabad area was surveyed several times in 1993, 1994 and 1995. In 1993, RSP had water level stations just at the upstream and downstream ends of the survey area, i.e the stations North-Khatiamari and Thanthunipara. To find the average slope, the water levels at Bahadurabad are plotted against computed slopes, see Figure 3.2. The average water level slope varied from 6 to 9 cm/km for the range of water levels 15 m+PWD to 20 m+PWD, see Figure 3.2.

Kamarjani

There were no water level stations at the two ends of the survey area during the survey periods. The BWDB stations Chilmari at the upstream end of the survey area and Bahadurabad at the downstream end were used for calculating slopes, which are plotted against the water level at Kamarjani, see Figure 3.3.

Dhaleswari Offtake

Slopes were calculated using the water level stations at Sirajganj and Mathura and were related to the water level at Bhuyanpur. Figure 3.4 presents this relation. The backwater effects at Mathura during high flows are evident and a slope of 7 to 7.5 cm/km at Sirajganj is likely.

Aricha Confluence

Mathura and Baruria water level stations were used for estimating the slopes, which were related with the water level at Aricha, see Figure 3.5.

Hurasagar

Calculated water level slopes between Mathura and Aricha were related to the water level at Mathura, see Figure 3.6. Backwater effects are obvious and an average slope of 3.5 cm/km has been adopted.

Gorai Offtake

Hardinge Bridge and Sengram water level stations were used to calculate water level slopes for the survey area, see Figure 3.7.

Arial Khan Offtake

Slopes between Baruria and Mawa were related to the water level at Chowdhury Hat, see Figure 3.8.

The enclosed graphs were used to estimate the water surface slopes for each individual bathymetric survey. These slopes are included in Table 1.1 and are also presented on the contour maps.

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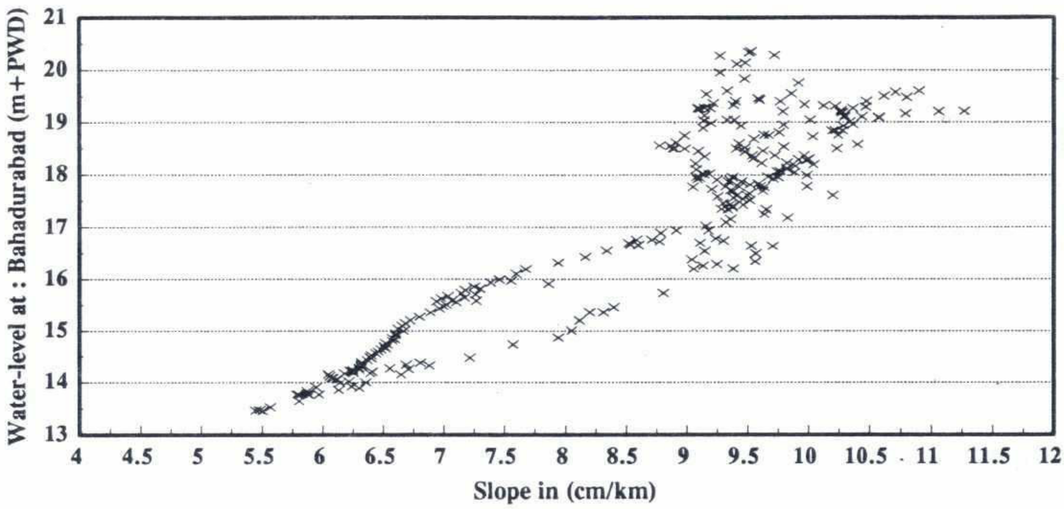

Figure 3.2 : Water surface slope between Khatiamari and Belgacha, 1995. Lower sector is rising stage, upper sector is falling stage

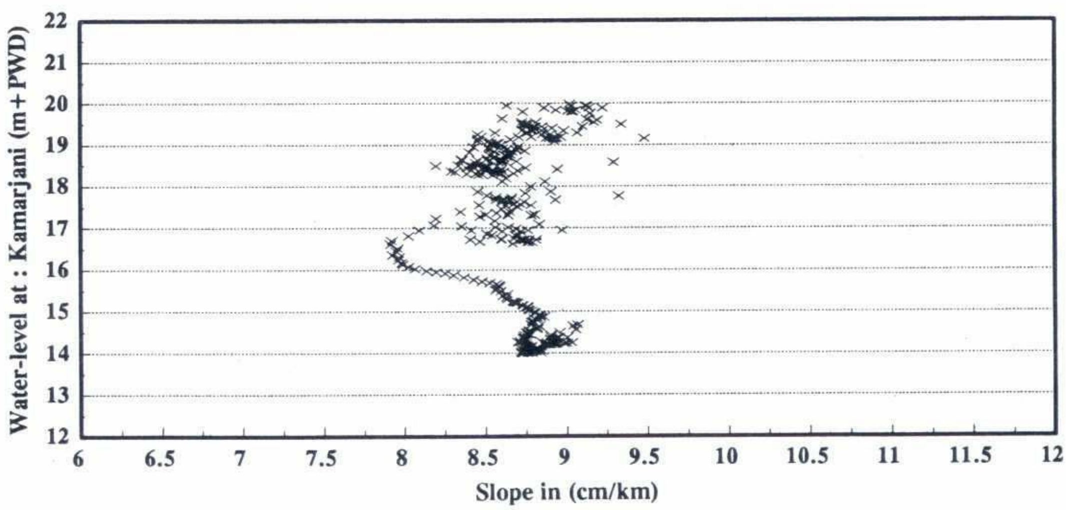

Figure 3.3.a: Water surface slope between Chilmari and Bahadurabad, 1994

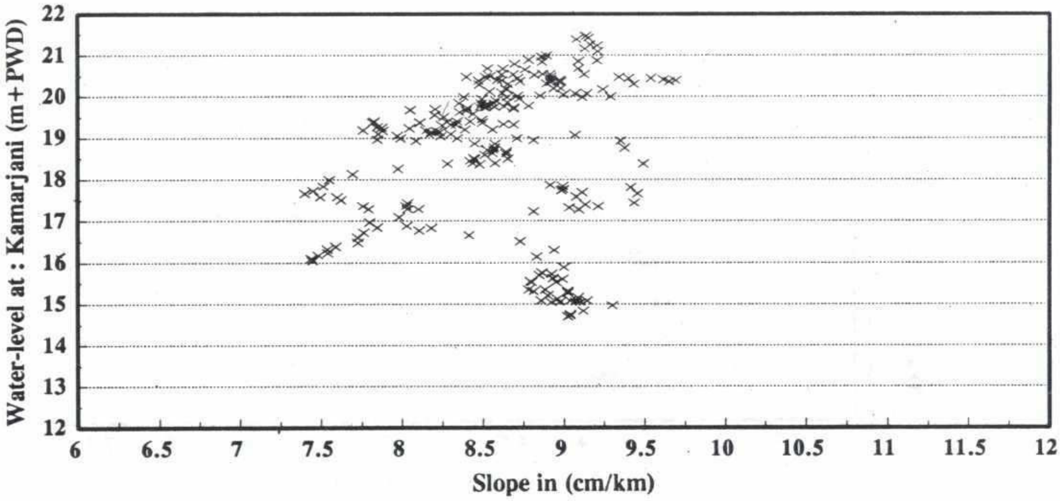

Figure 3.3.b: Water surface slope between Chilmari and Bahadurabad, 1995

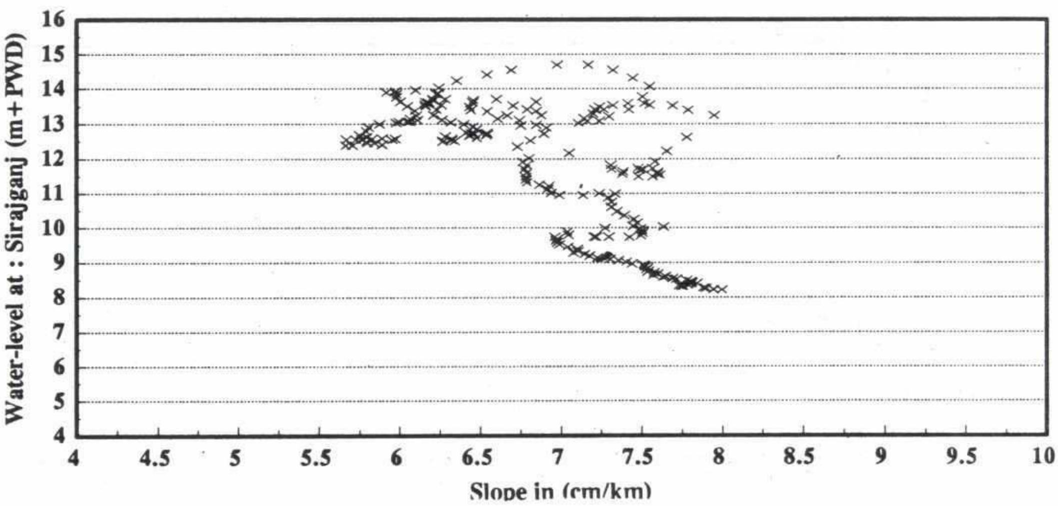

Figure 3.4 : Water surface slope between Sirajganj and Mathura, 1995

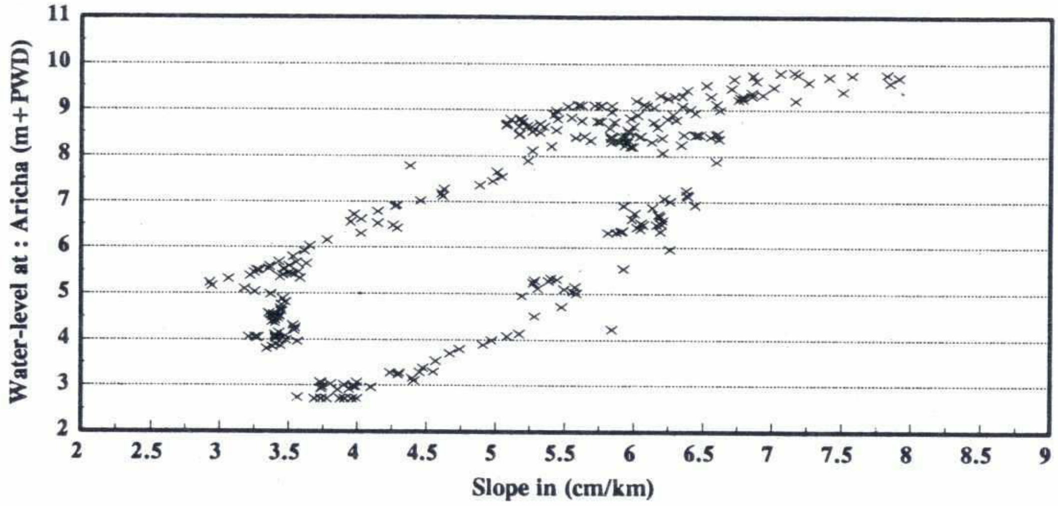

Figure 3.5 : Water surface slope between Mathura and Baruria, 1995. Lower sector is rising stage, upper sector is falling stage

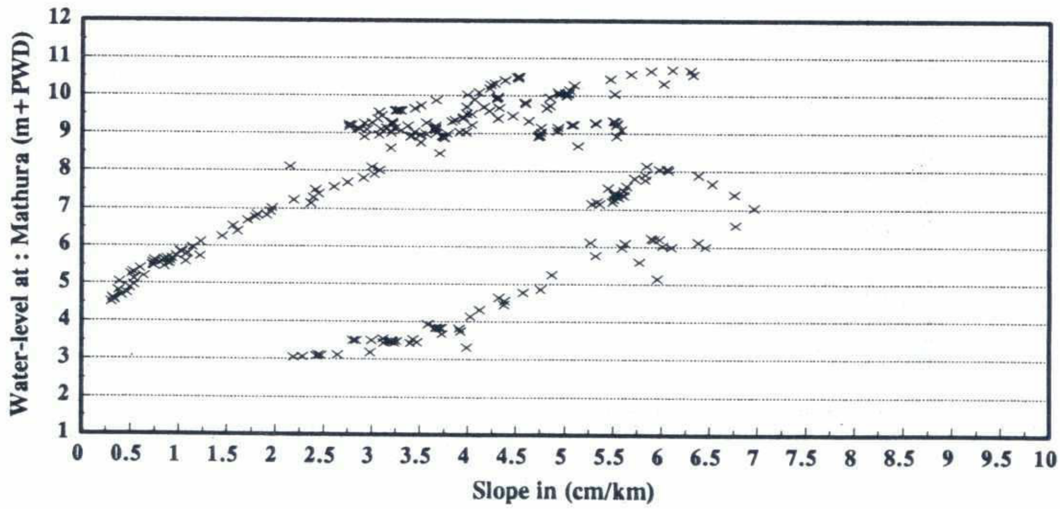

Figure 3.6 : Water surface slope between Mathura and Aricha, 1995. Lower sector is rising stage, upper sector is falling stage

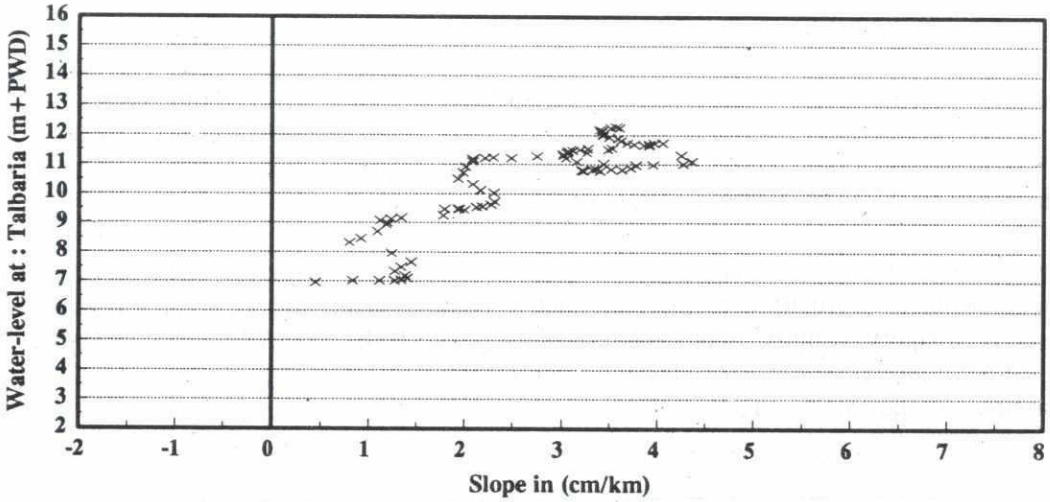

Figure 3.7 : Water surface slope between Hardinge Bridge and Sengram, 1995

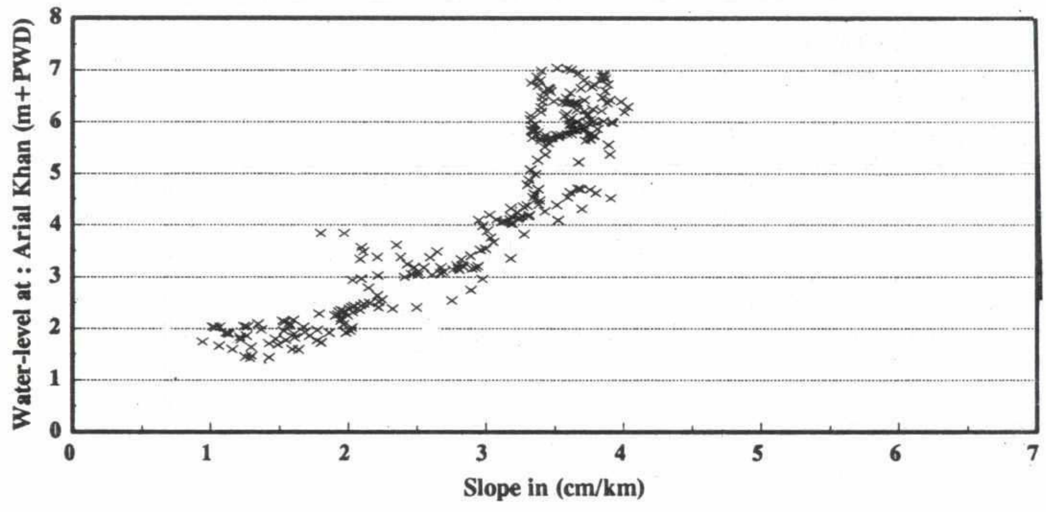

Figure 3.8 : Water surface slope between Baruria and Mawa, 1995

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3.5 Topographic surveys of chars

Topographic surveys were carried out by RSP as indicated in Table 3.3. The surveys determined spot elevations along survey lines that were aligned with the bathymetric survey runlines, in the direction across the river. The line spacing was 500 m. The point increment along the line was 100-200 m for regular surfaces and less in case of irregularities. The survey lines extended from the river bank (or banks), and the water level was determined as well as the ground elevation. The location of the lines, and the two first points of each line were established by DGPS. From this basis, the horizontal and vertical coordinates of the points along the line were determined by a Topcon total station. With the procedures applied in the field, the accuracy is estimated at 3 m (horizontally) and 2-3 cm (vertically). The range of the total station was around 1200 m.

The surveys included a mapping of topographic features, with the twin objective of providing supplementary information to the bathymetric contour maps and as a support to interpretation of satellite imagery (jointly undertaken by EGIS and RSP, see *RSP Special Report 17: 'Spatial representation and analysis of hydraulic and morphological data')*. For this purpose, features were classified as indicated in Table 3.4.

Location	Period	Survey no.
Gorai Off-take x):	15/1-14/2 95	9044
Bahadurabad	25/11-20/12 95	8032
Bahadurabad	25/12 95 - 6/1 96	8032
Bahadurabad	9-14/3 96	8032
Kamarjani	7-16/1 96	8034
Kamarjani	15-18/3 96	8034
Ganges/Jamuna Confluence	22-31/3 96	8037

x): Feature mapping was not included in this survey

Table 3.3: Topographic surveys

- Crop type: Paddy (species), wheat, jute, sugar cane, firewood (species), tobacco, spices (species), pulse, mustard, others
- Crop height (cm) and area
- Soil type: Silt or sand, dry or moist
- Structures: Buildings, roads, dikes, ditches, embankments, etc.
- Scour holes

Table 3.4: Feature classification

3.6 Determination of flow lines

On request of RSPMU float tracking has been implemented in conjunction with bathymetric surveys as from July, 1995, as listed in Table 3.5. The drogues had a depth of 2 m. Generally, shallow-draft vessels are employed, equipped with DGPS for positioning and Hydro software for the logging of positions. The following method was adopted :

1. Two drogues were tracked by each boat simultaneously

2. Separation between drogues at the time of dropping along a cross section was about 400 to 500 m in the larger rivers. When the cross-river distance between flow lines would become too large or too small, the drogues were re-positioned

3. Fixing of the positions of drogues was done at an interdistance of about half the width of the river or earlier, depending on how fast the alternate drogues could be reached by the vessel

4. In case of excessive separation of the drogues, due to one moving slower than the other, the fastest drogue was picked up

5. Availability of an on-line plotting facility was found to be essential to ensure a good coverage of the total survey area

It was experienced that it was possible to track two drogues by a single boat, but, except when both drogues are in the thalweg, the speed of the work is limited by the speed of the slower one. When there is a considerable difference in speed between the drogues, the risk of loosing one (or both) is evident.

Processing of the field date consisted of plotting the flow lines on the basis of consecutive DGPS positions of the drogues, at the same scale as the corresponding contour maps (1:10,000 or 20,000). Flow velocities were calculated and plotted on the basis of positions and time between two consecutive fixes.

Area	Period	Survey no.
Bahadurabad	26-31/7 95	9071
Gorai Off-take	11-14/8 95	9077
Gorai/Kushtia	11-15/10 95	9080
Bahadurabad	18-23/11 95	9094
Kamarjani	5-19/12 95	9095
Ganges-Jamuna Confluence	25/1-4/2 96	9096

Table 3.5: Drogue measurements

3.7 Navigation system

All the bathymetric survey work was performed with Differential Global Positioning System (DGPS). Trimble 4000 and Trimble Navtrack units were used. A VHF telemetry link was established for transmission of differential corrections between the reference stations and the respective receivers aboard the survey vessels.

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The DGPS gives immediate positions in the World Geodetic System WGS 84. These values are transformed into BTM coordinates by a PC based on-line Hydro software package, which also controls the actual navigation.

The positioning system has been verified by comparing the BTM coordinates of a bench-mark with 'known' coordinates (GPS 764) to the coordinates measured by the DGPS positioning system. According to the below positions, the deviation (= the difference between the 'true' value and the recorded value) was within the 2 m horizontal accuracy of the DGPS system operated in stationary mode.

A Robertson SKR 82 gyro compass interfaced to the on-line navigation computer was used to provide heading control for the A-vessel.

3.8 Echo sounding

Dual and single frequency echo sounders were used to record analogue and digital depths. The resolution of the instruments was better than 1 cm. The beam widths were as follows:

Transducer		**beam width**
Elac:	30 kHz	24°
	200 kHz	10°
Simrad:	200 kHz	7°

The sound velocity through the water column was determined to be 1500 m/s (corresponding to fresh water at a temperature of 30 °C). For the sake of transparency, this value was maintained throughout the survey. The water column was regarded as homogenous. Sound velocity deviations (due to temperature fluctuations) amount at around 0.1 % per °C.

The draught of the transducers was regularly measured in calm conditions. Regular checking of the draught of the survey vessels was also made, as well as occasional bar checks. Only small differences of a few cm were recorded. On this basis, the accuracy of the depth registration itself was estimated at ± 5 cm + 1 % of the water depth. Deviations related to the positioning accuracy (of ± 3-5 m) depend on the slope of the river bed and may typically contribute by around 10 cm in shallow areas, but less than that at depths larger than around 10 m, due to smoothing caused by the beam width. It is noted that the use of DGPS has effectively reduced this potential error contribution as compared with any alternative positioning method.

Assuming (1) an (absolute) accuracy of the water level registration of ± 5 cm (considering wind set-up and Coriolis effects), and (2) surface slope irregularities of ± 2 cm/km, the estimated general absolute accuracy of each individual sounding becomes around ± 0.1 m + 1 % of the water depth + 0.002 % of the distance between the vessel and the water level gauge.

It is noted that the relative accuracy is several times better than the absolute accuracy, one reason being that part of the error is systematic, and another reason being the averaging effect of the data conversion into a finite (50 m by 50 m) grid, whereby the random part of the error is highly reduced. An impression of the relative accuracy of the surveys is obtained when comparing successive surveys from the same area, for example in order to identify erosion and accretion rates and impact areas in connection with the morphological studies. Such comparisons were made repeatedly during the Project. They indicated a high consistency, with relative accuracies better than 0.1 - 0.2 m.

The echo sounders were interfaced to the navigation computers and fix marks were sent from the computers with fix number, date, time, line file no. and positions.

3.9 Line spacing

In general, the spacing between the survey lines is a practical compromise between data quality (resolution of the bed elevation variation) and area coverage. In the Contract, a line spacing of 200 m has been assumed as a reference, with a provision for a finer line spacing if agreed upon in the course of the project.

At the initiative of the PA, a suitable line spacing was evaluated on the basis of the August-September 1993 survey at Bahadurabad. A comparison was made of line spacings of 100-200-300-500 m (see Figure 3.9). It was concluded that a line spacing of between 100 m and 200 m provided an acceptable description of the river bed and was suited for the different data applications.

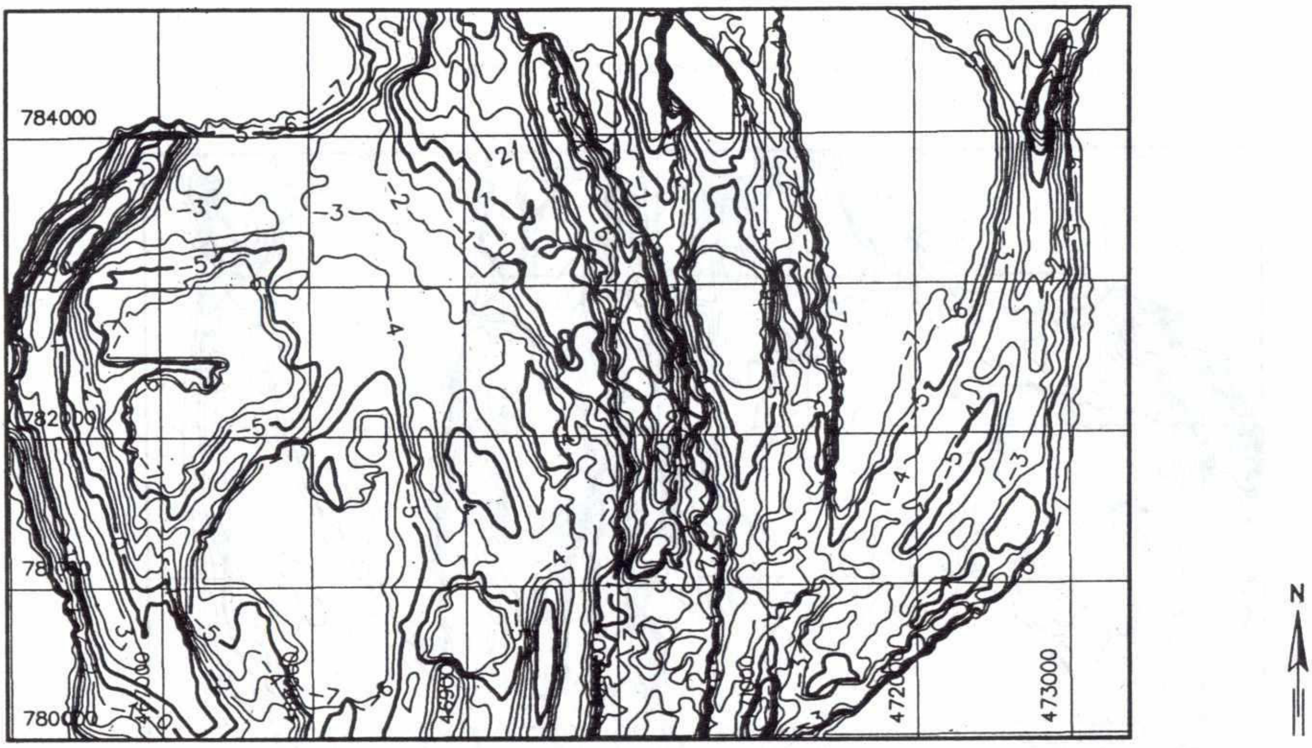

Figure 3.9.a: Depth contours, line spacing 100 m (Bahadurabad, August-September 1993)

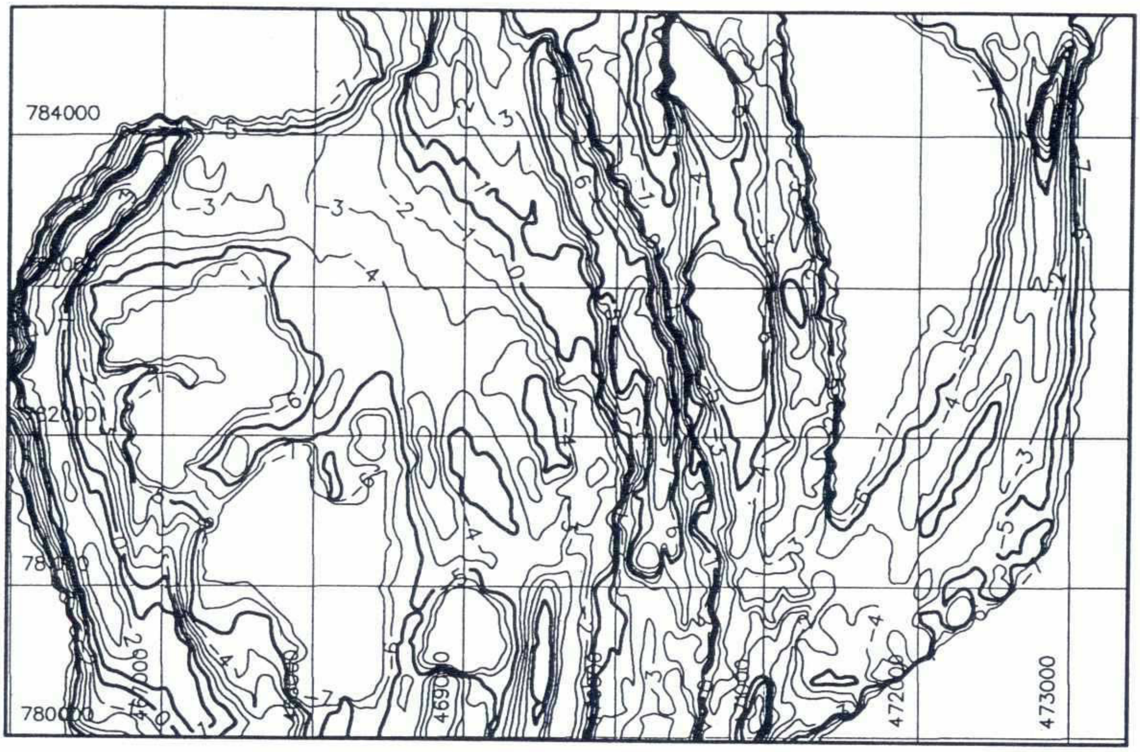

Figure 3.9.b: Depth contours, line spacing 200 m (Bahadurabad, August-September 1993)

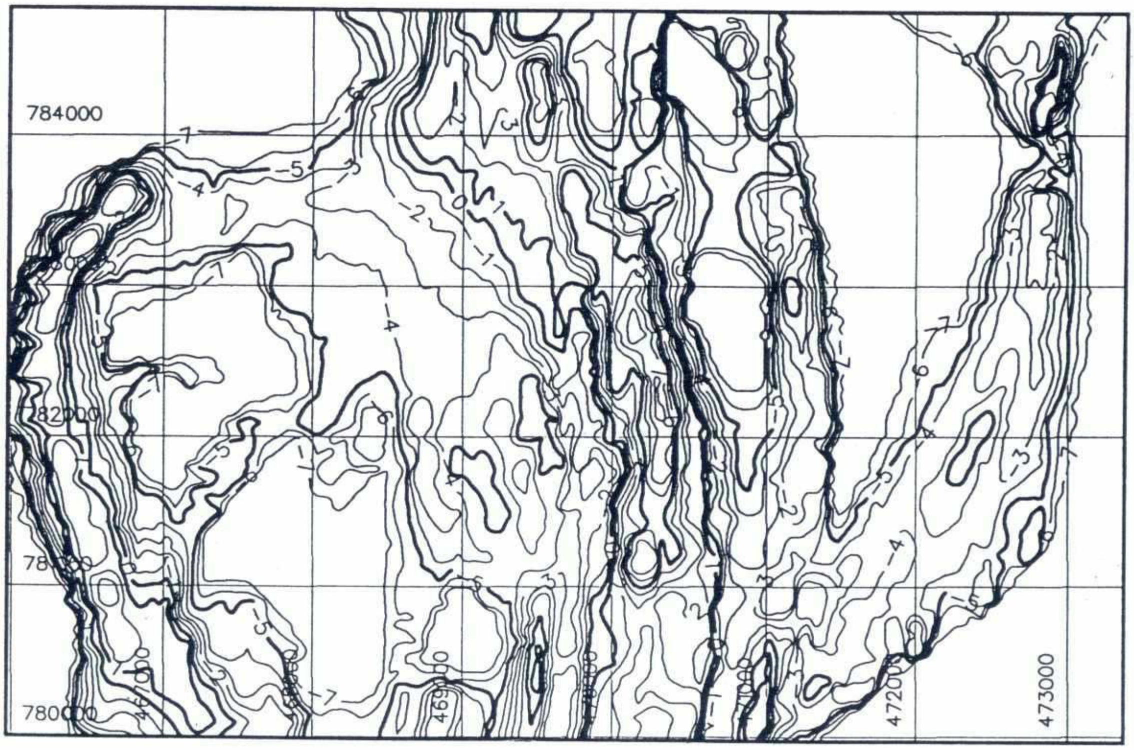

Figure 3.9.c: Depth contours, line spacing 300 m (Bahadurabad, August-September 1993)

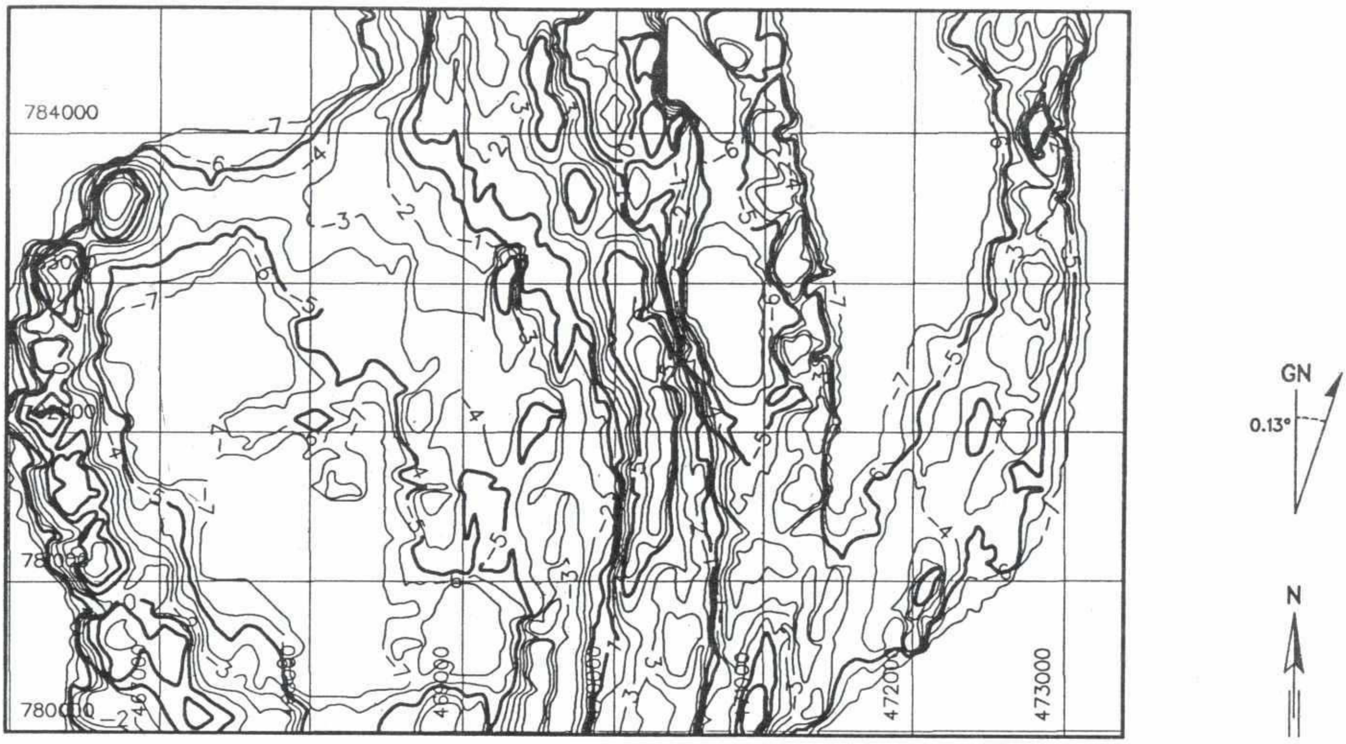

Figure 3.9.d: Depth contours, line spacing 500 m (Bahadurabad, August-September 1993)

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4 Data processing and reporting

4.1 Navigation and datalogging

Navigation and datalogging is controlled by a special software package, type Datacom Hydro, developed by Trimble Datacom in New Zealand and operated on a conventional PC. The HYDRO package has been designed especially for bathymetric surveying and conducts all necessary navigation controls such as positioning, time reference, and navigation outputs. At the same time, it constitutes the operation centre for the surveyor in charge.

The HYDRO package basically logs time and position together with relevant sensor inputs, such as water depths and water levels. The package also includes facilities for on-board quality check of the recorded data.

The programme created survey lines, produced pre-plotted track charts and at the same time controlled the helmsman's display showing all the necessary information for steering the vessels in the respective survey lines.

The on-line computer cycle was set to its optimum of 1 second. Thus the depth data were recorded every second corresponding to 2 m horizontal distance at a navigation speed of 4 knots, which was the normal survey speed.

The fixing interval was also 1 second. Every fix was sent to the printer for hard copy. An A3 track plotter was used to record the vessel's progress on paper charts in scale 1:10.000 with the survey lines pre-plotted.

4.2 Temporary data storage and transfer

When the data had been collected and pre-checked, they were stored in the file formats of the HYDRO package for later transfer to the data processing unit in Dhaka. The actual data administration on-board was done on a file by file basis for the individual survey lines with manual tracking of the recorded data. In addition, each file contained a header with key information on measurement location and period. As often as practically possible, data were transferred to the project office for further processing. The tapes used for this transfer are considered to constitute the raw data of the project and will be the ultimate backup and data reference source.

4.3 Raw data storage

When tapes from the field were received in the project office, the contents were copied immediately to disk storage for further processing. Library information in the tape contents (data type, area, time period etc) were entered into the RSP file catalogue system and registered as external files residing on tape. The tapes were then moved to their final storage. For security reasons the raw data tapes were stored in a building separate from the project office.

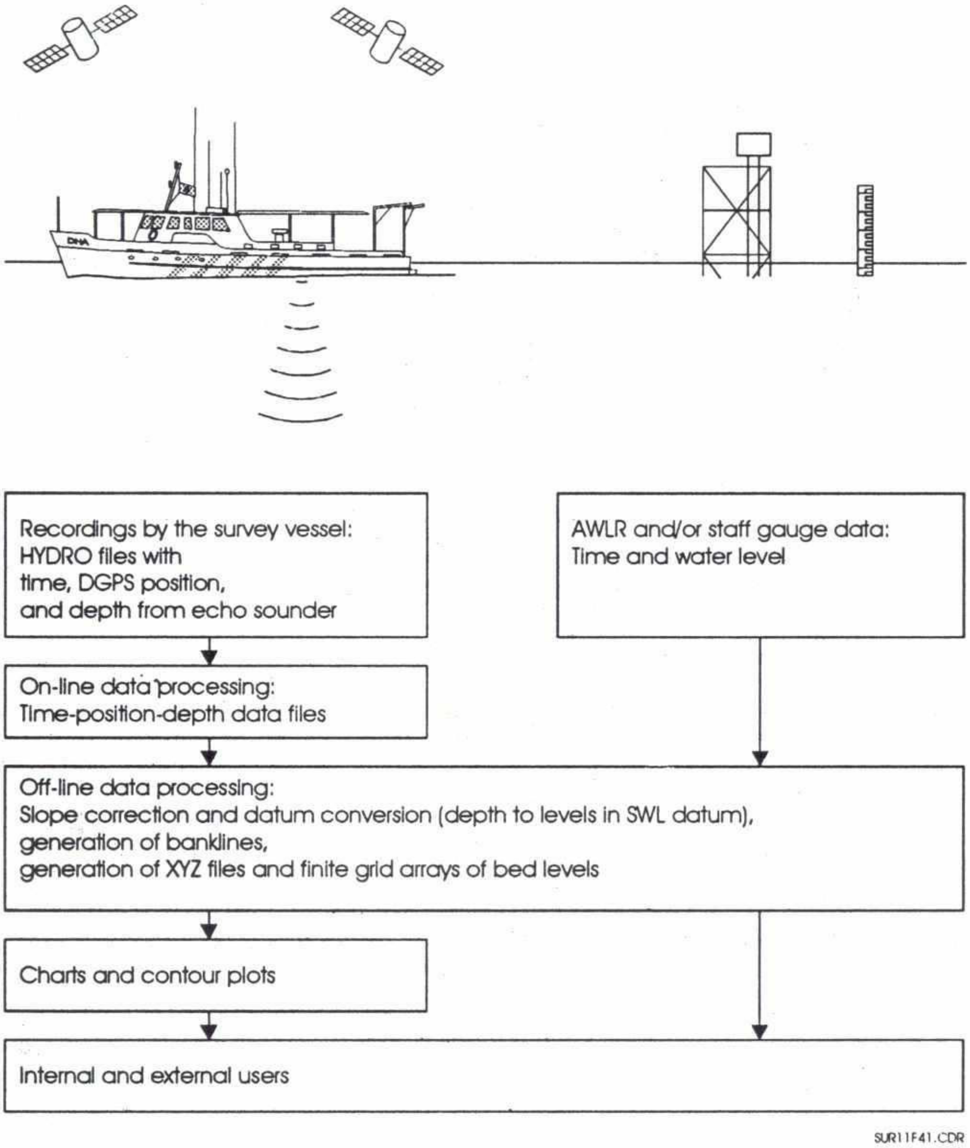

Figure 4.1: Data flow

4.4 Quality control and data editing

During the off-line data processing in the RSP Project Office in Dhaka, every data file has been subject to the following processing steps:

- Manual/semi-automatic check for spikes, errors etc.
- Correction of errors as appropriate, by deletion, interpolation and/or filtering
- Reduction of data sets to include only useful information, so superfluous and insignificant measurements were deleted
- Offset corrections relating to the entire data set. Based on the water level data, the data were reduced to SLW

This process produced files with only sound and valid data, allowing for subsequent application of standard processing programs.

4.5 Storage of edited data

The edited and quality assured data being the main data source for the further processing and analysis were stored on-line on magnetic disks for immediate access.

These data files are large, up to 30 Mb of raw data per km^2 of survey. Therefore, during the planning of the project (in 1992), is was evaluated that their processing required a UNIX environment. (Today, it would be possible to do it on a high-end PC). Hence, the files are stored on a UNIX server, from where they can be accessed within the UNIX system of the project.

4.6 Mapping

The data are presented in the following ways:

- Index maps of each survey
- Bathymetry charts, scale 1:10,000 or 1:20,000
- Contour plots, scale 1:10,000 or 1:20,000 and 1:50,000

The data are stored in two ways for special or more detailed analyses:

- Files of edited sets of all recordings of position, depth, and time along the survey lines (so-called xyz-files)
- Files of averaged and interpolated depths and bank contours in a fixed (50 m by 50 m) grid covering the entire survey area (called DT2 and CT2 files)

5 Summary of results

5.1 Water levels

The water levels recorded at the respective stations and during the surveys are shown in Enclosure A. Reductions are computed as the difference between daily mean water levels and SLW. The reduction is used to transfer the measured water depth into depth below SLW, thus transferring all level indications on the charts and contour plots into depth below SLW. (Hereby, levels above SLW become negative).

5.2 Index maps

Index maps for all surveys are attached as Enclosure B. The maps show a track plot of the survey lines as sailed.

5.3 Bathymetry charts

The survey results from the respective sites have been presented in a series of bathymetry charts (scale 1:10,000 or 1:20,000), which have been submitted separately to WARPO.

The bathymetry charts have been produced by plotting the edited data with the horizontal positions in the BTM system. The charts show as many actual soundings as practical for the scale selected for the charts.

5.4 Contour plots

Contour curves have been generated on the basis of the depths in a fixed grid, produced by a bilinear interpolation. The grid spacing is 50 m by 50 m. The produced mesh has the orientation true north and covers the whole survey area. Based on these grid data the contour plots are produced.

The isoline distance of the contour plots has been selected at 1 m, as compared to the 0.5 m distance stated in the Technical Specifications for lean season surveys. This is done to make the contour plots better readable. A comparison between 0.5 m and 1 m isoline distance is shown on Figure 5.1.

Contour plots at a scale 1:10,000 or 1:20,000 have been submitted separately to WARPO. Contour plots at a scale of 1:50,000 are also available.

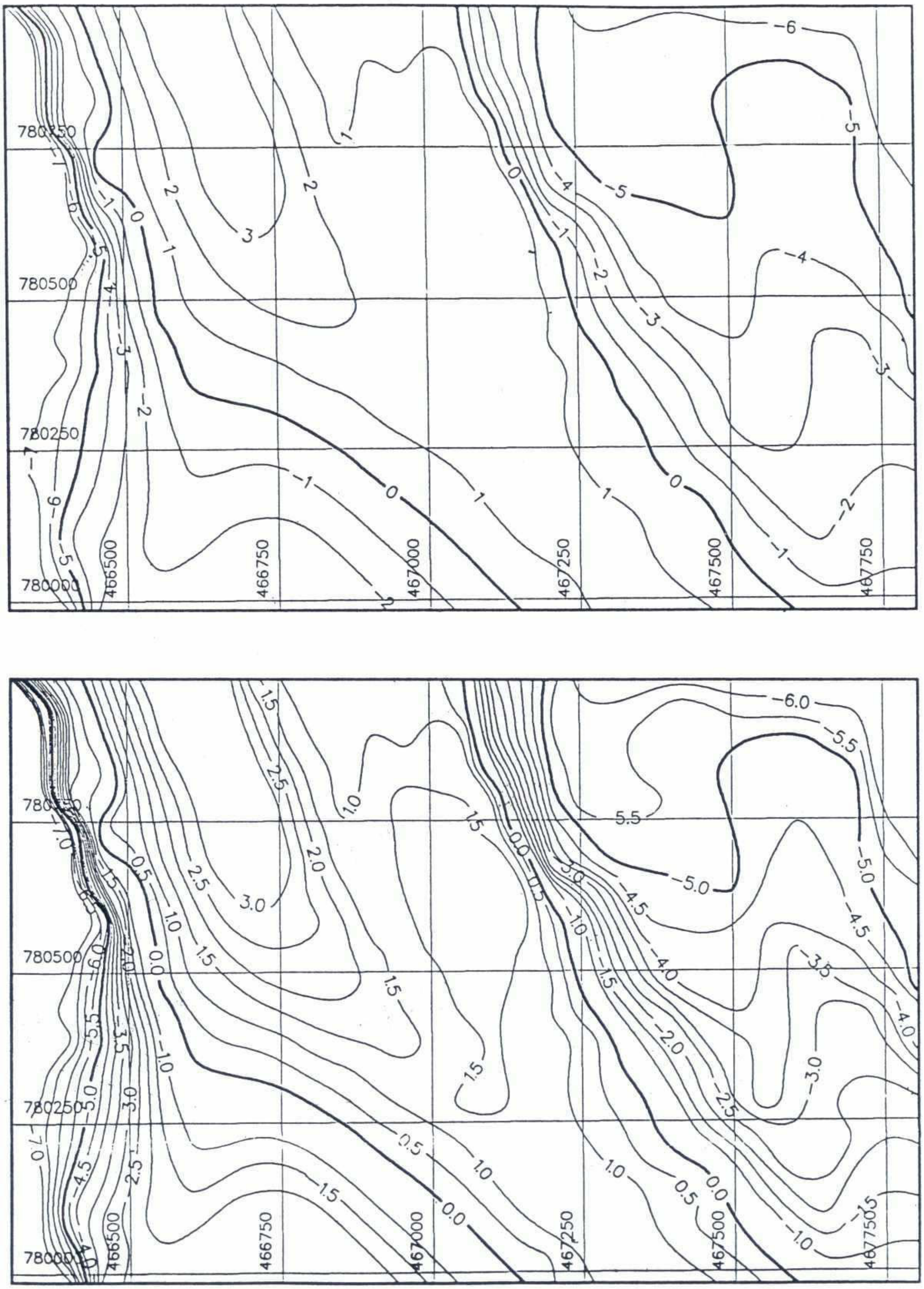

Figure 5.1: Sample contour plots with 0.5 m and 1 m isoline distance (scale 1:10,000)

Enclosure A

Water levels during the surveys

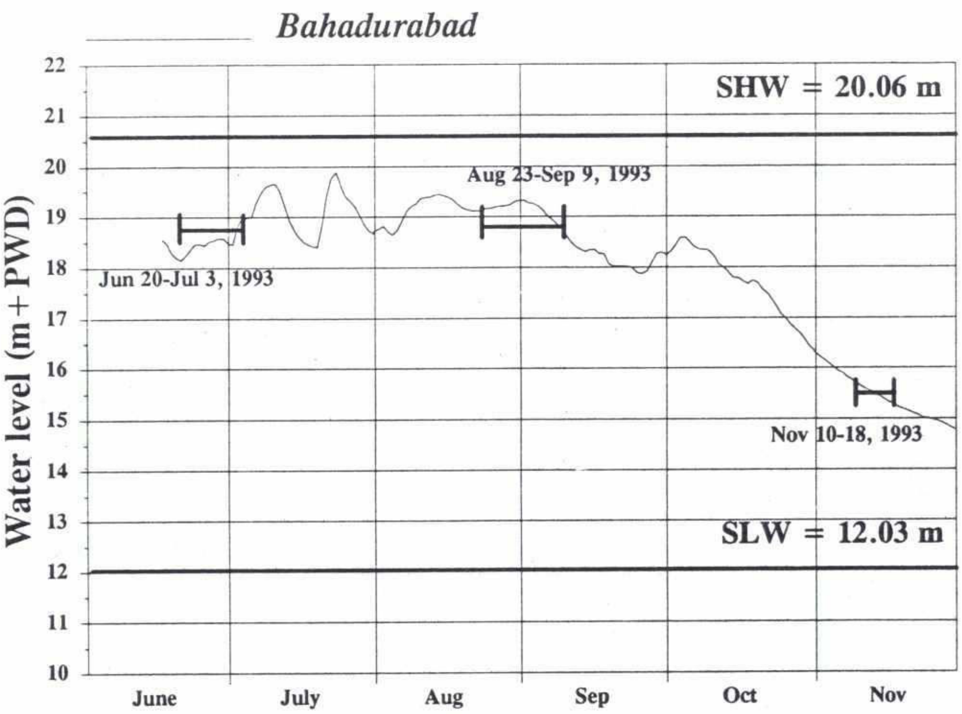

Figure A.1.a: Water levels at Bahadurabad, June - November 1993

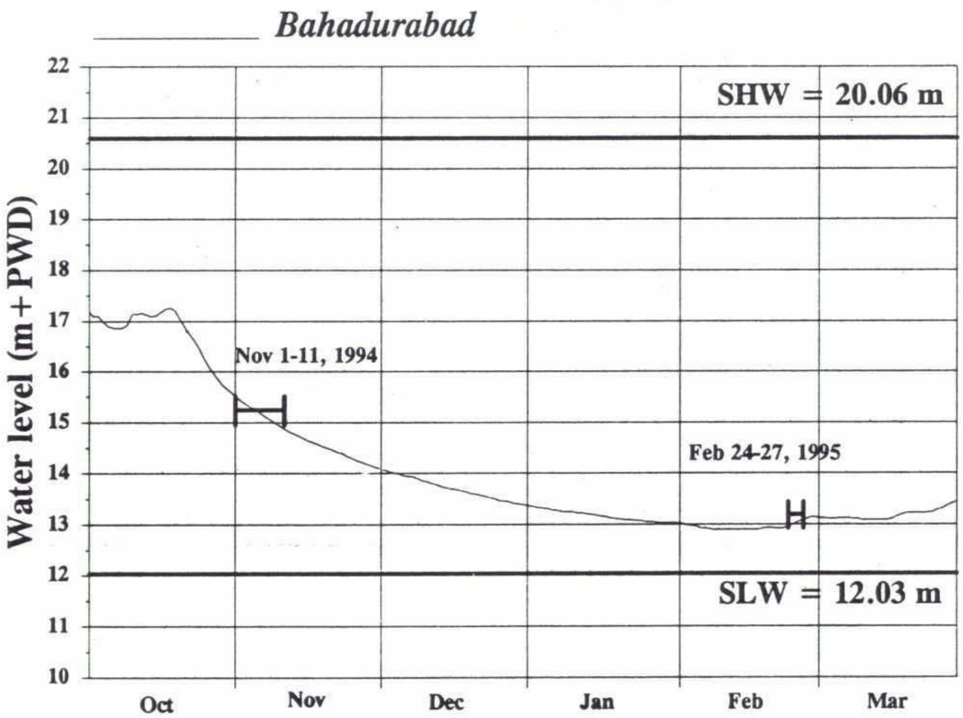

Figure A.1.b: Water levels at Bahadurabad, October 1994 - March 1995

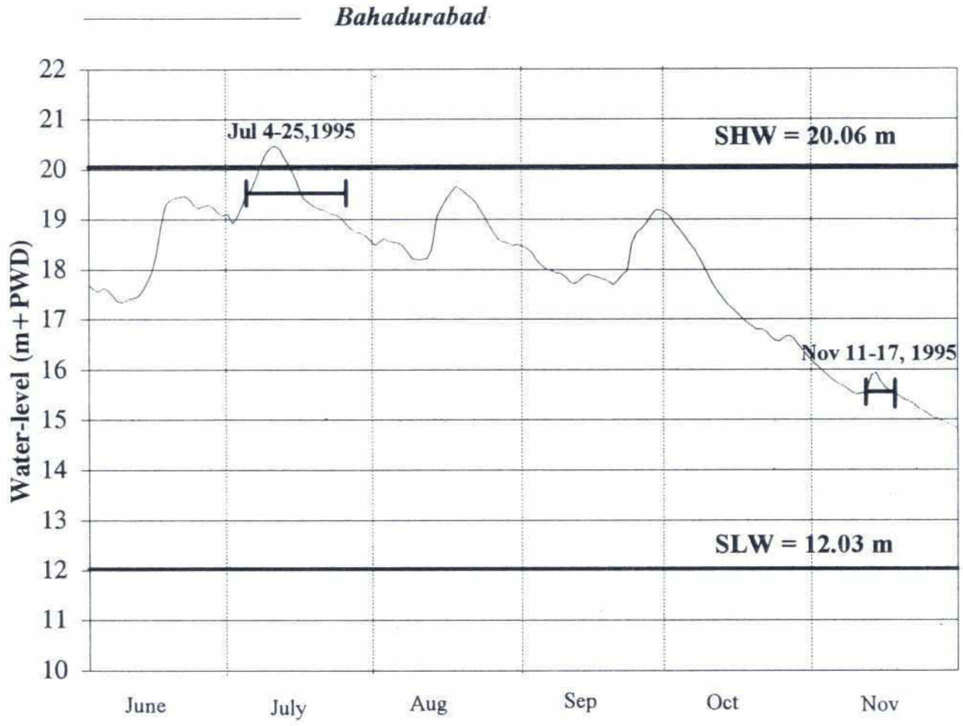

Figure A.1.c: Water levels at Bahadurabad, June - November 1995

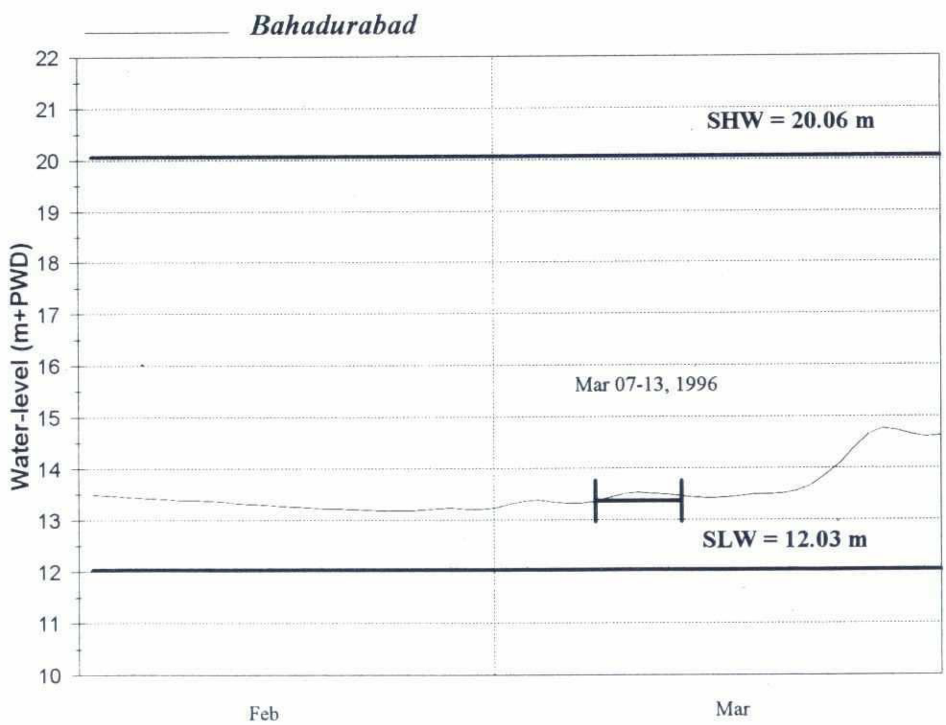

Figure A.1.d: Water levels at Bahadurabad, February - March 1996

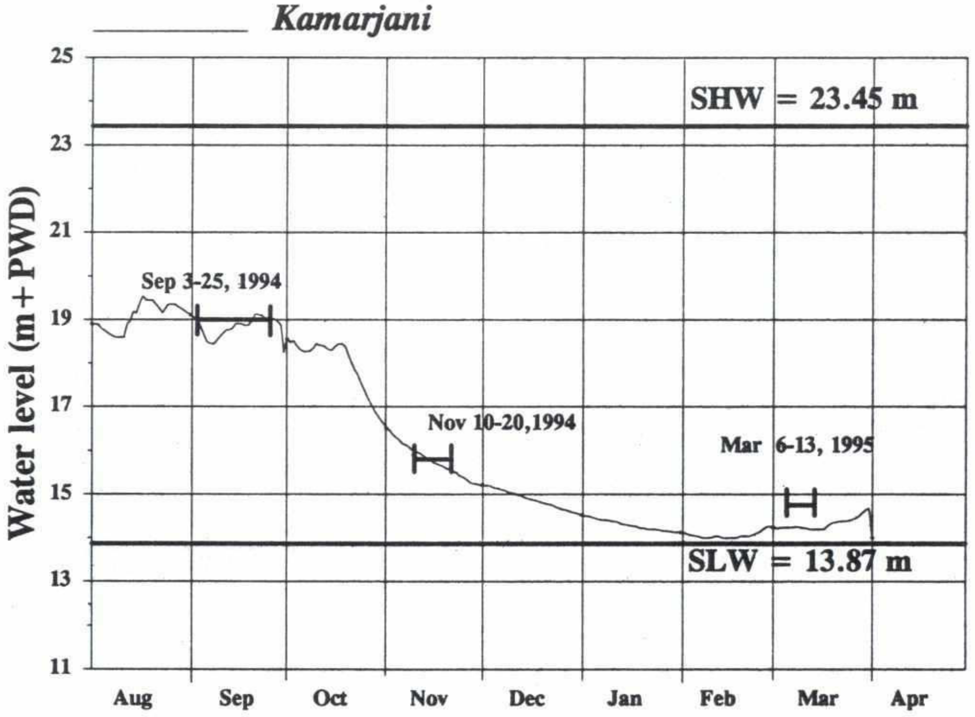

Figure A.2.a: Water levels at Kamarjani, August 1994 - April 1995

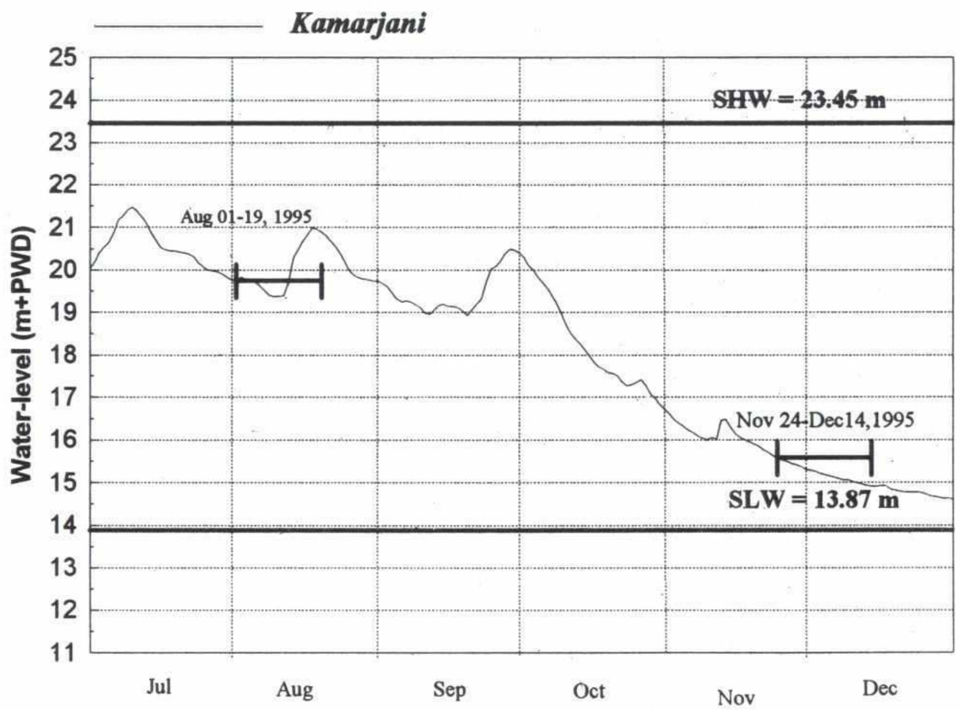

Figure A.2.b: Water levels at Kamarjani, July - December 1995

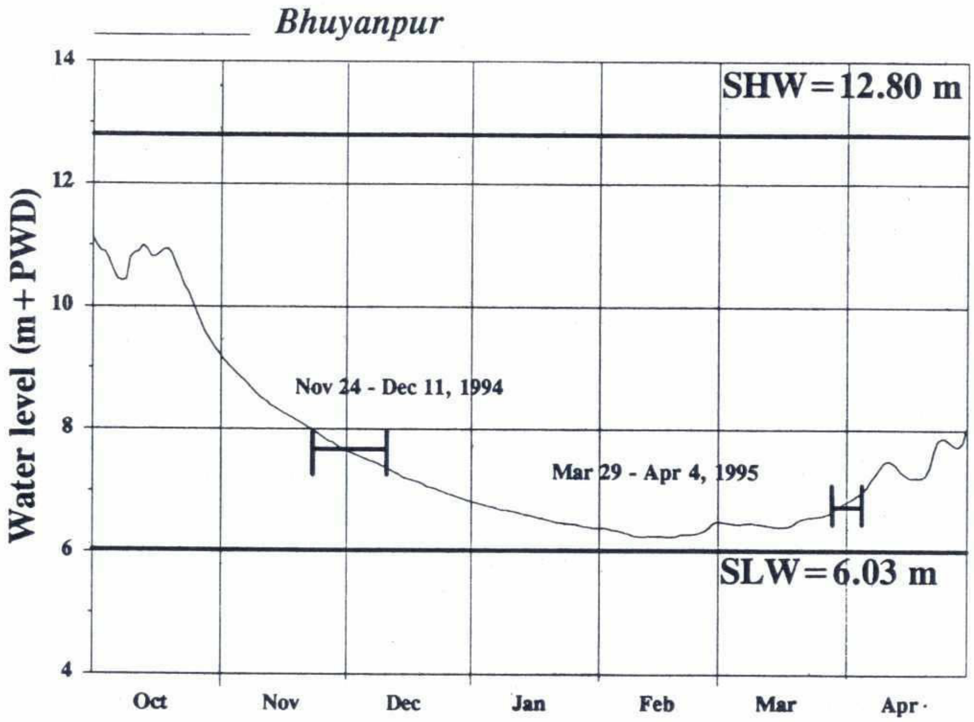

Figure A.3.a: Water levels at Bhuyanpur, October 1994 - April 1995

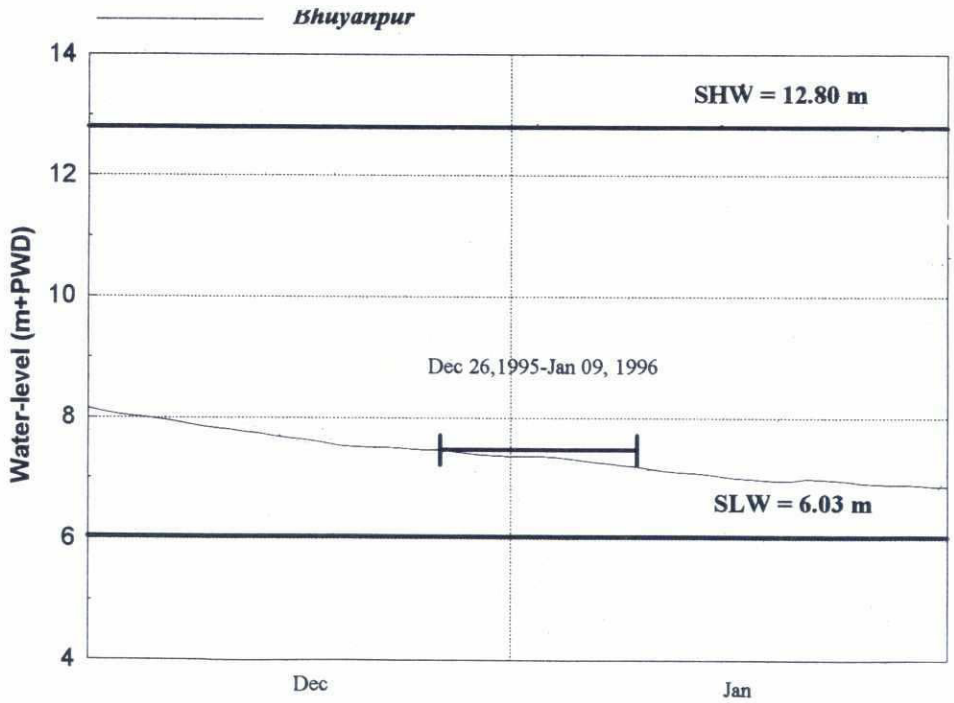

Figure A.3.b: Water levels at Bhuyanpur, December 1995 - January 1996

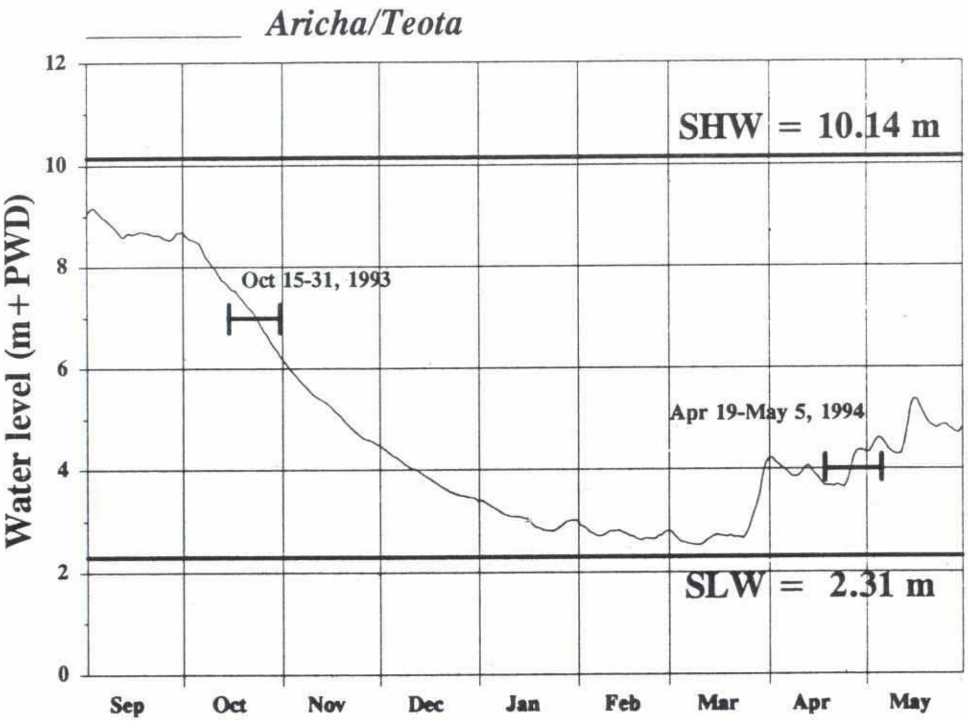

Figure A.4.a: Water levels at Aricha (Teota), September 1993 - May 1994

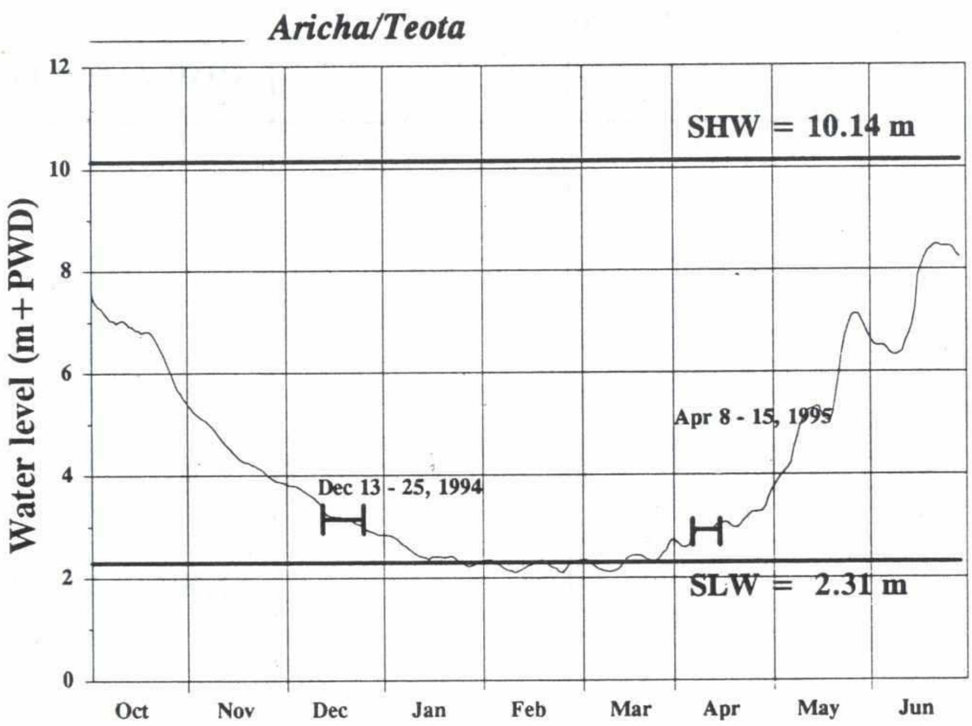

Figure A.4.b: Water levels at Aricha (Teota), October 1994 - June 1995

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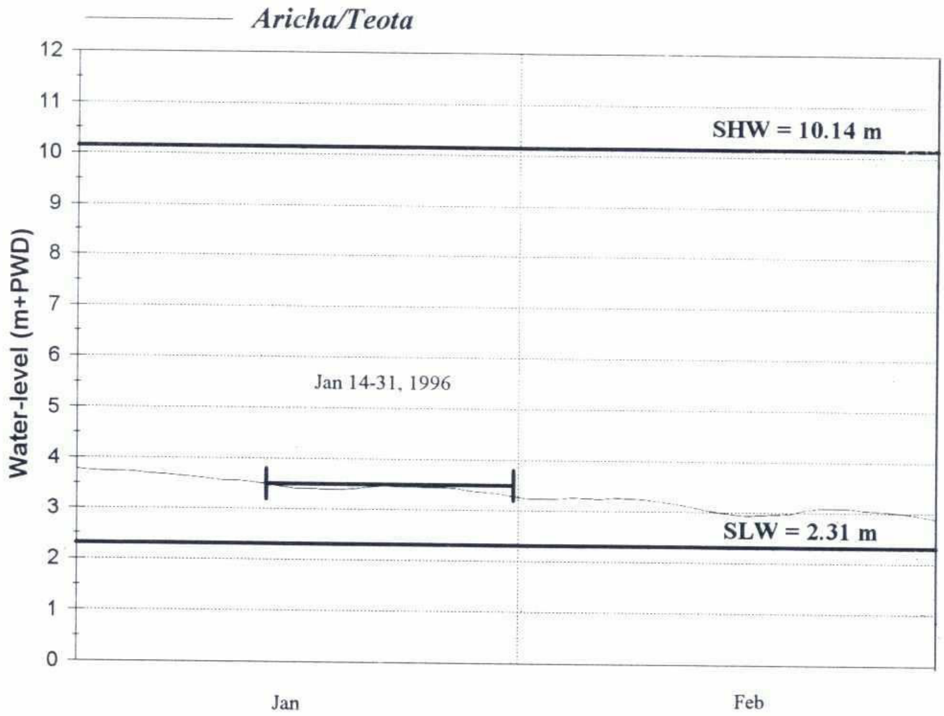

Figure A.4.c: Water levels at Aricha (Teota), January - February 1996

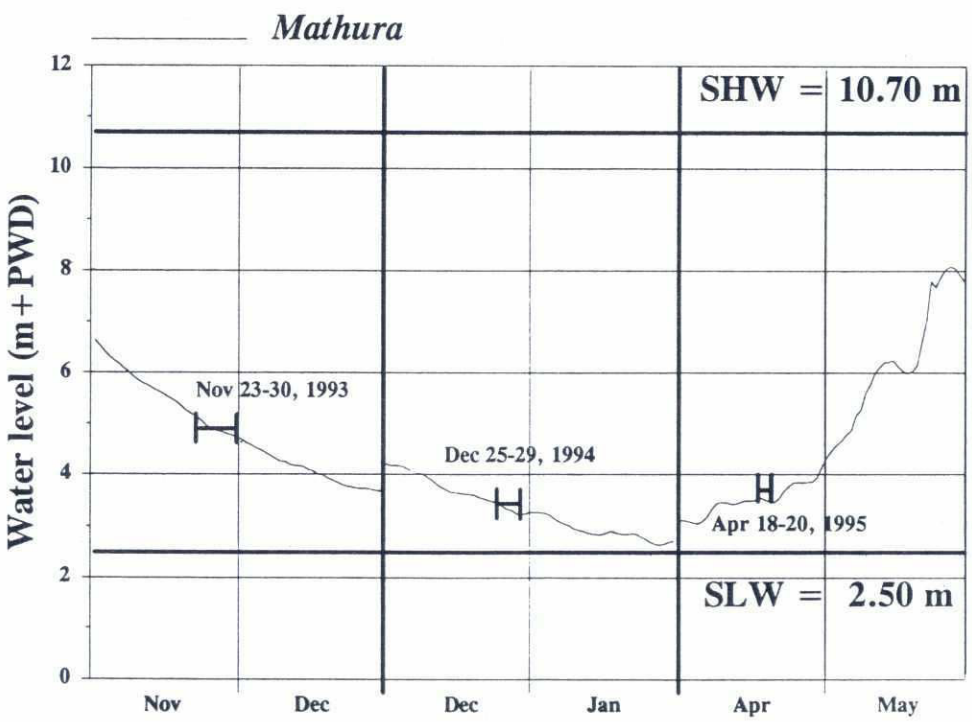

Figure A.5: Water levels at Mathura (Hurasagar), November 1993 - May 1995

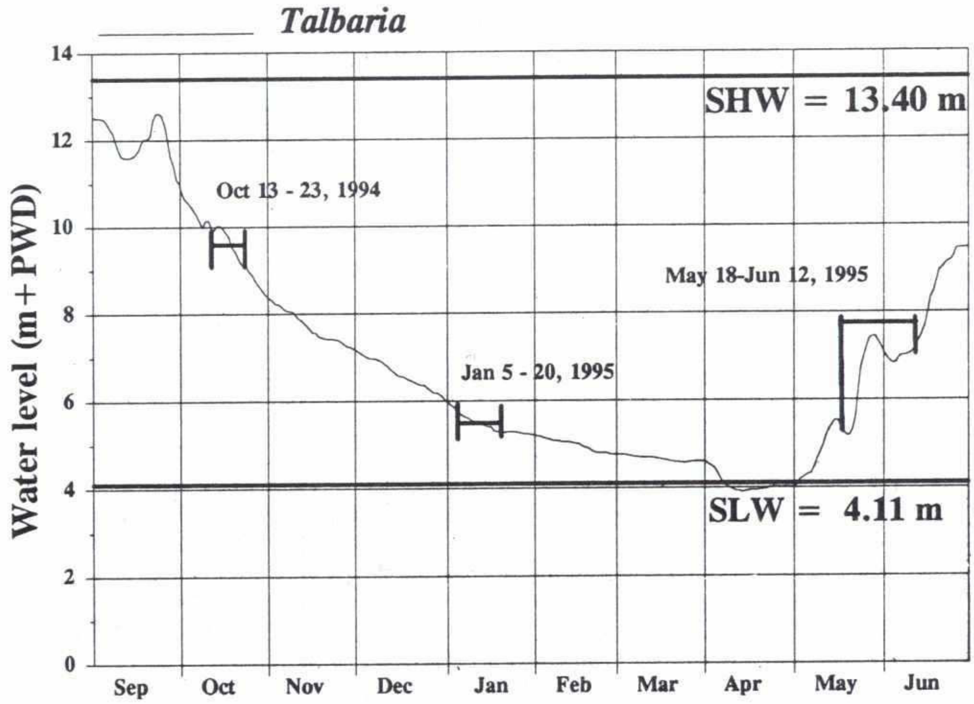

Figure A.6.a: Water levels at Gorai Off-take (Talbaria), September 1994 - June 1995

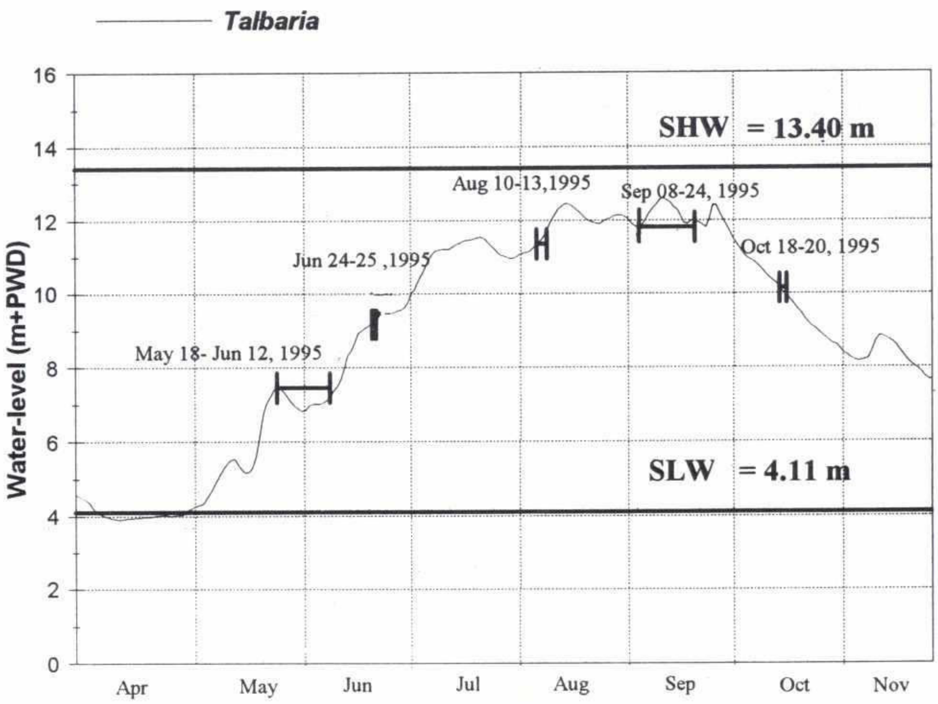

Figure A.6.b: Water levels at Gorai Off-take (Talbaria)

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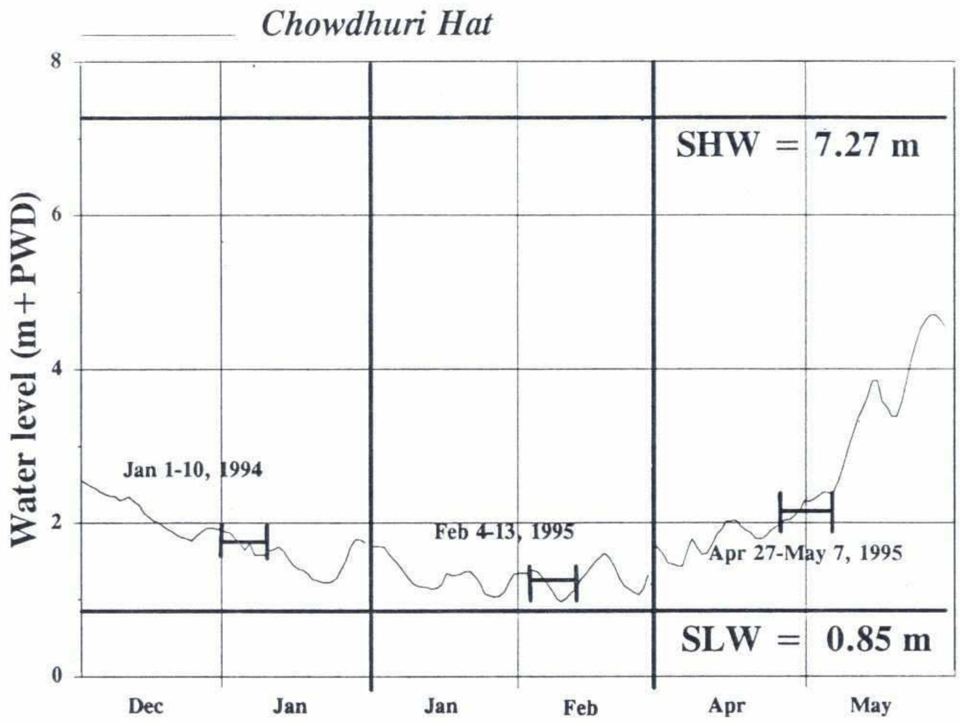

Figure A.7.a: Water levels at Arial Khan Off-take (Chowdhury Hat), December 1994 - May 1995

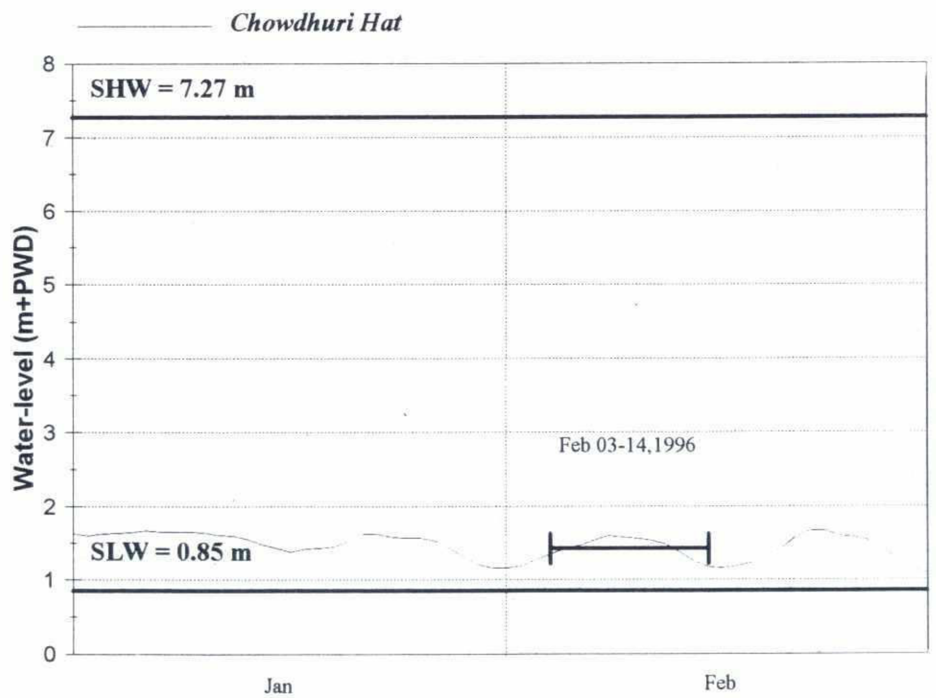

Figure A.7.b: Water levels at Arial Khan Off-take (Chowdhury Hat), January - February 1996

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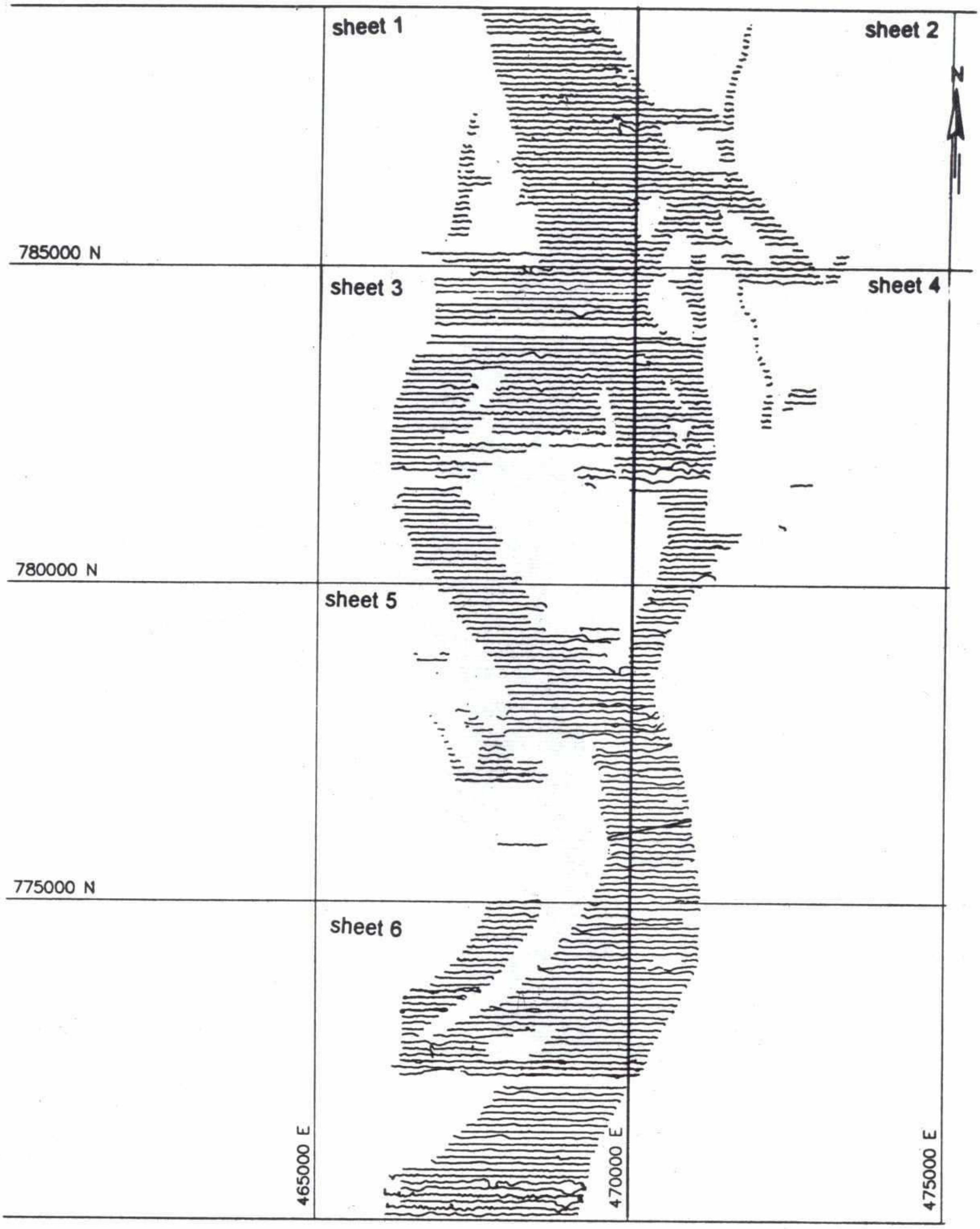

Figure B.1: Bahadurabad, June-July 1993

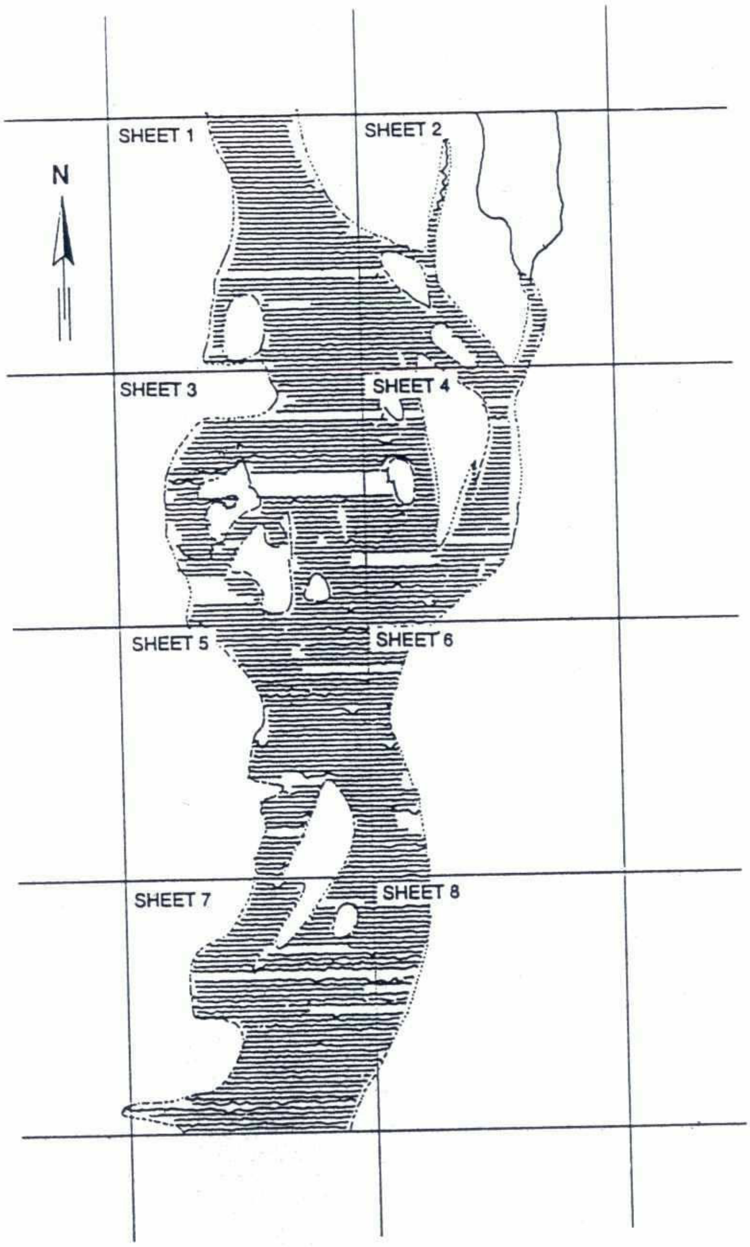

Figure B.2: Bahadurabad, August - September 1993

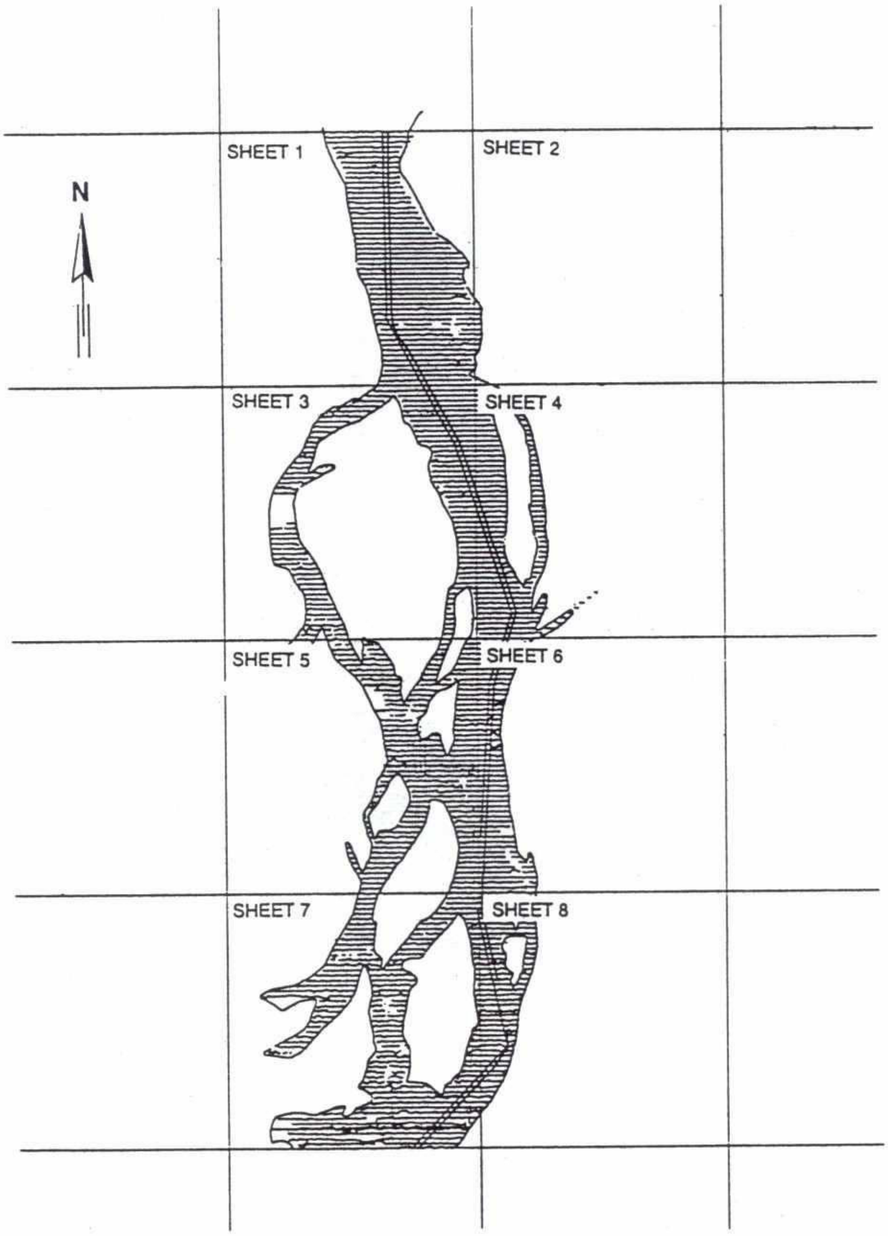

Figure B.3: Bahadurabad, November 1993

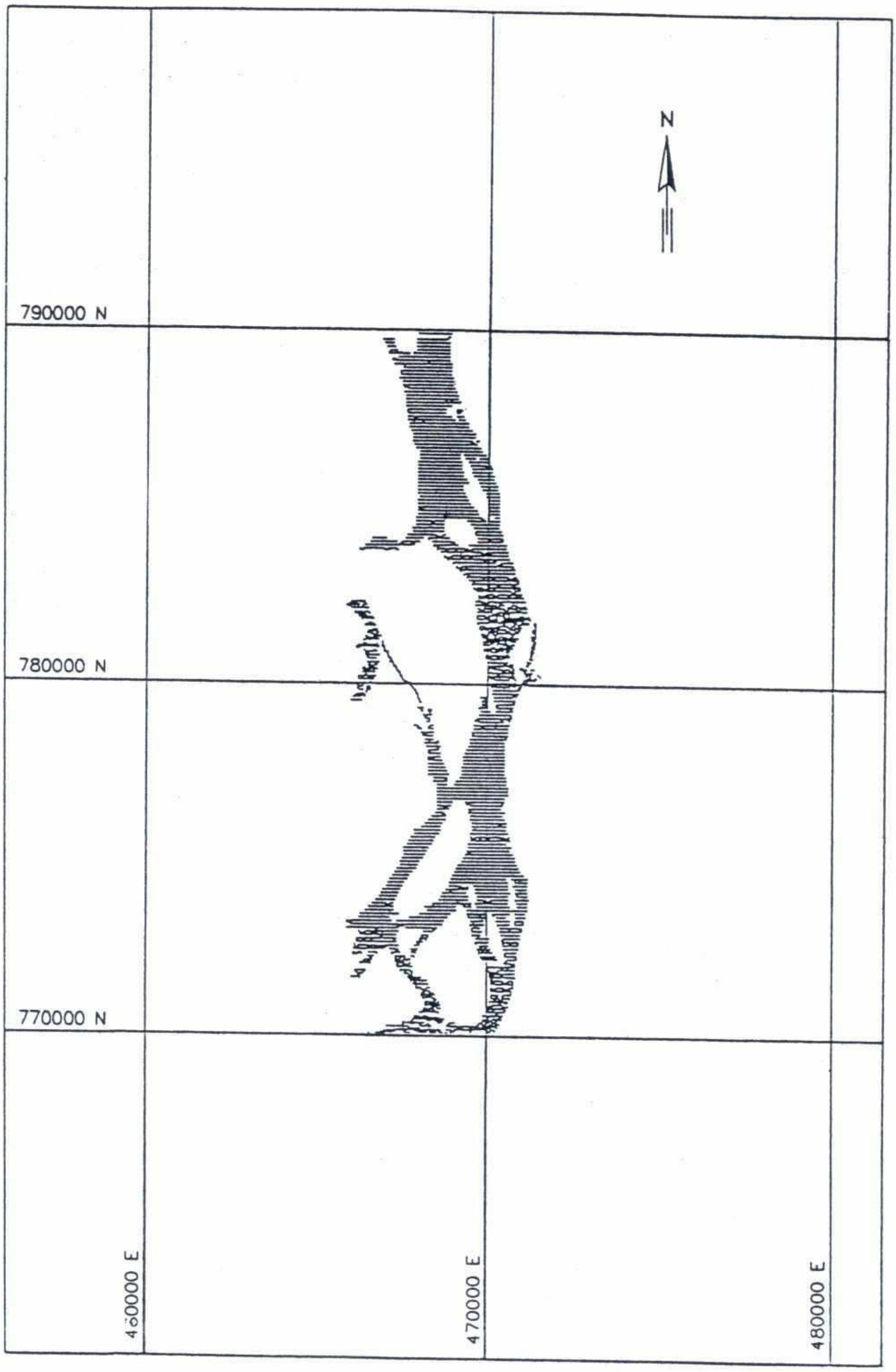

Figure B.4: Bahadurabad, November 1994

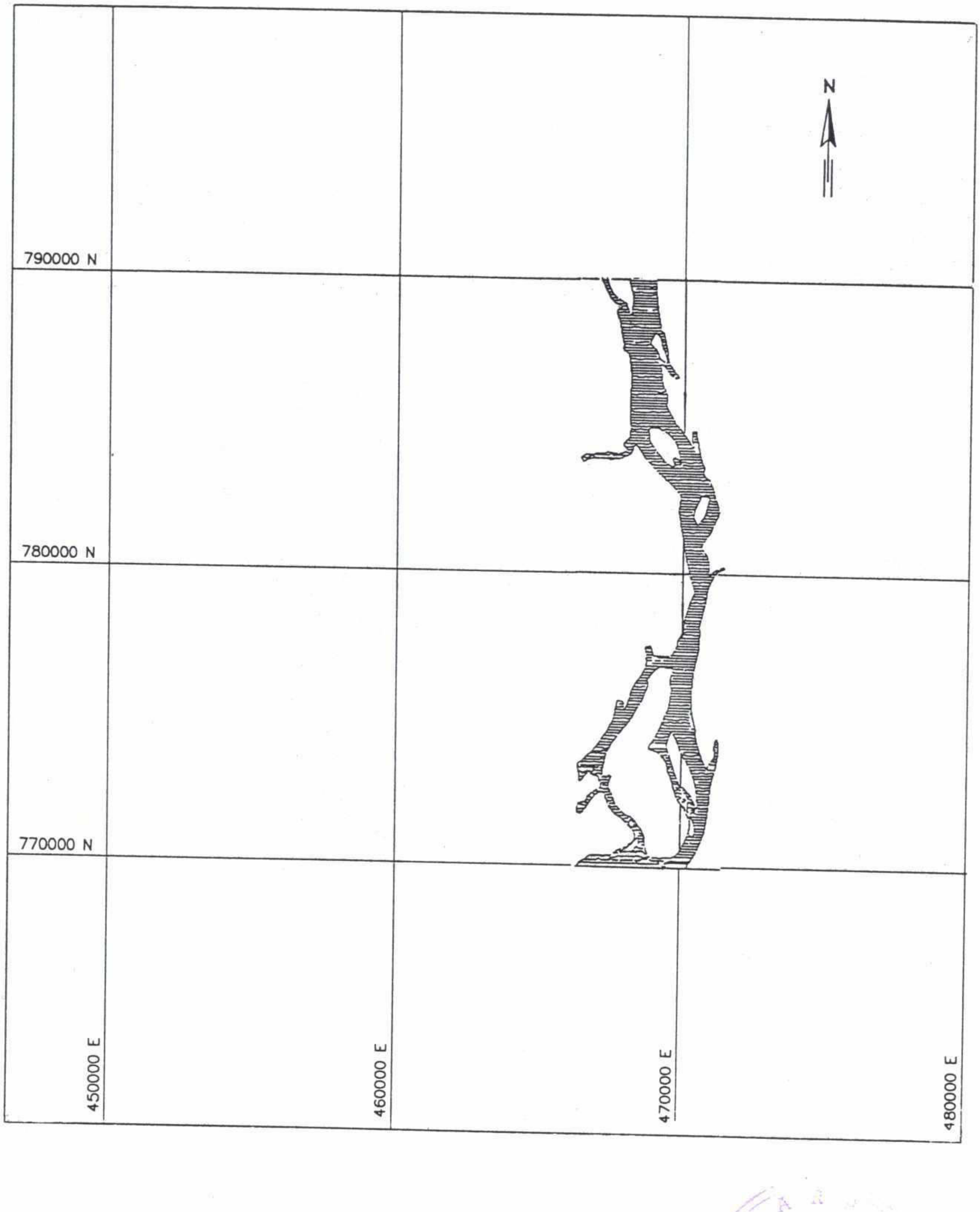

Figure B.5: Bahadurabad, February 1995

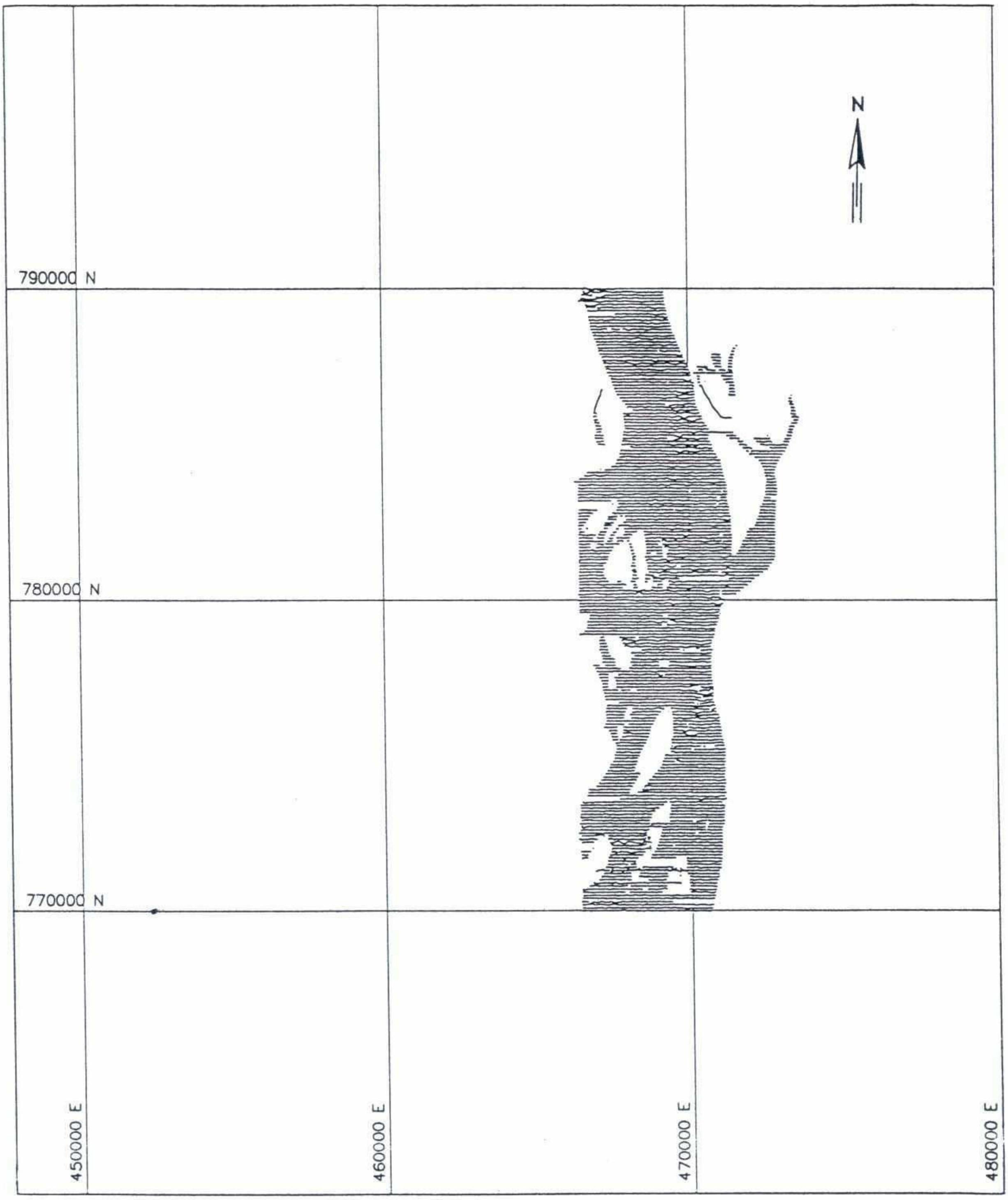

Figure B.6: Bahadurabad, July 1995

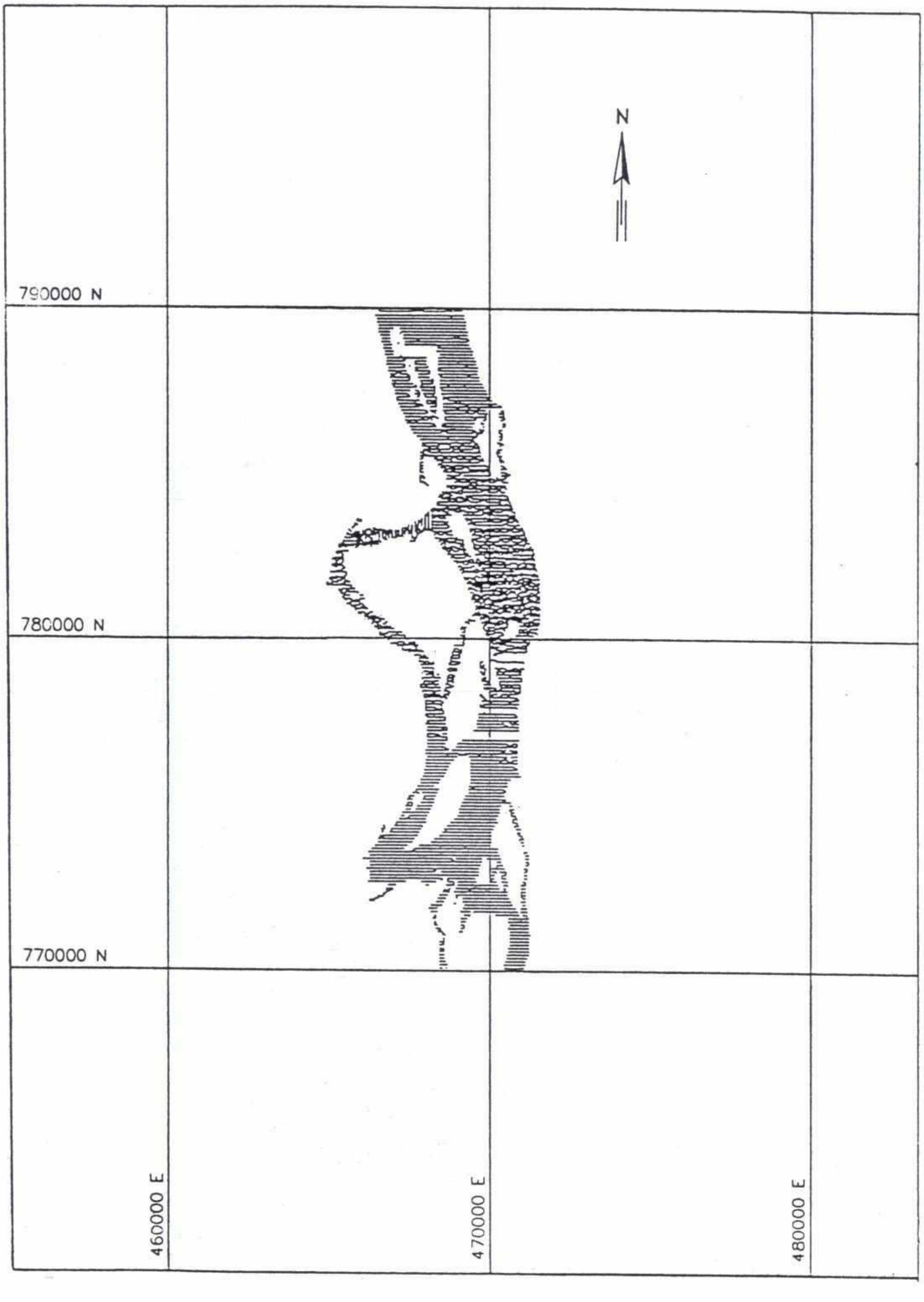

Figure B.7: Bahadurabad, November 1995

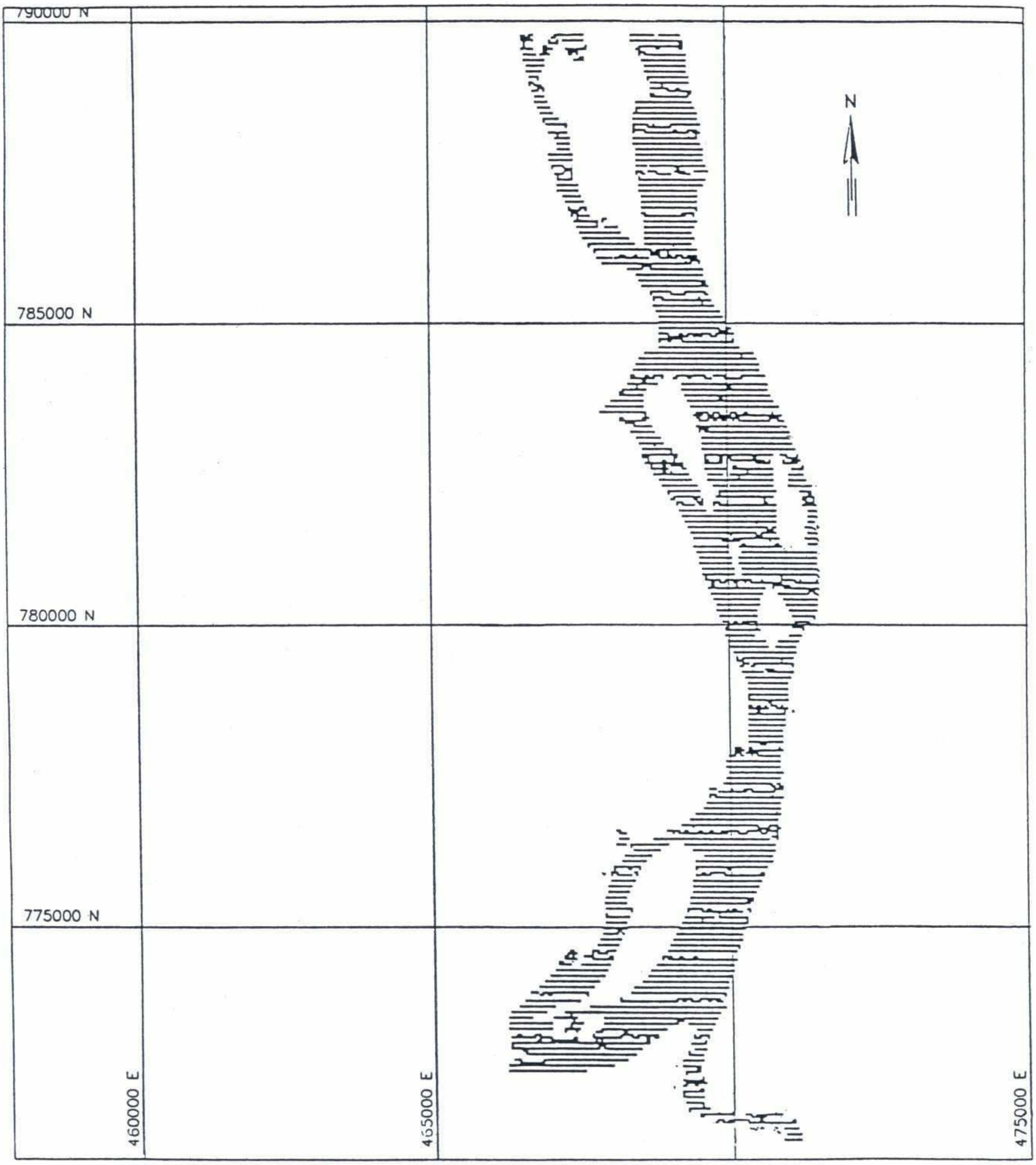

Figure B.8: Bahadurabad, March 1996

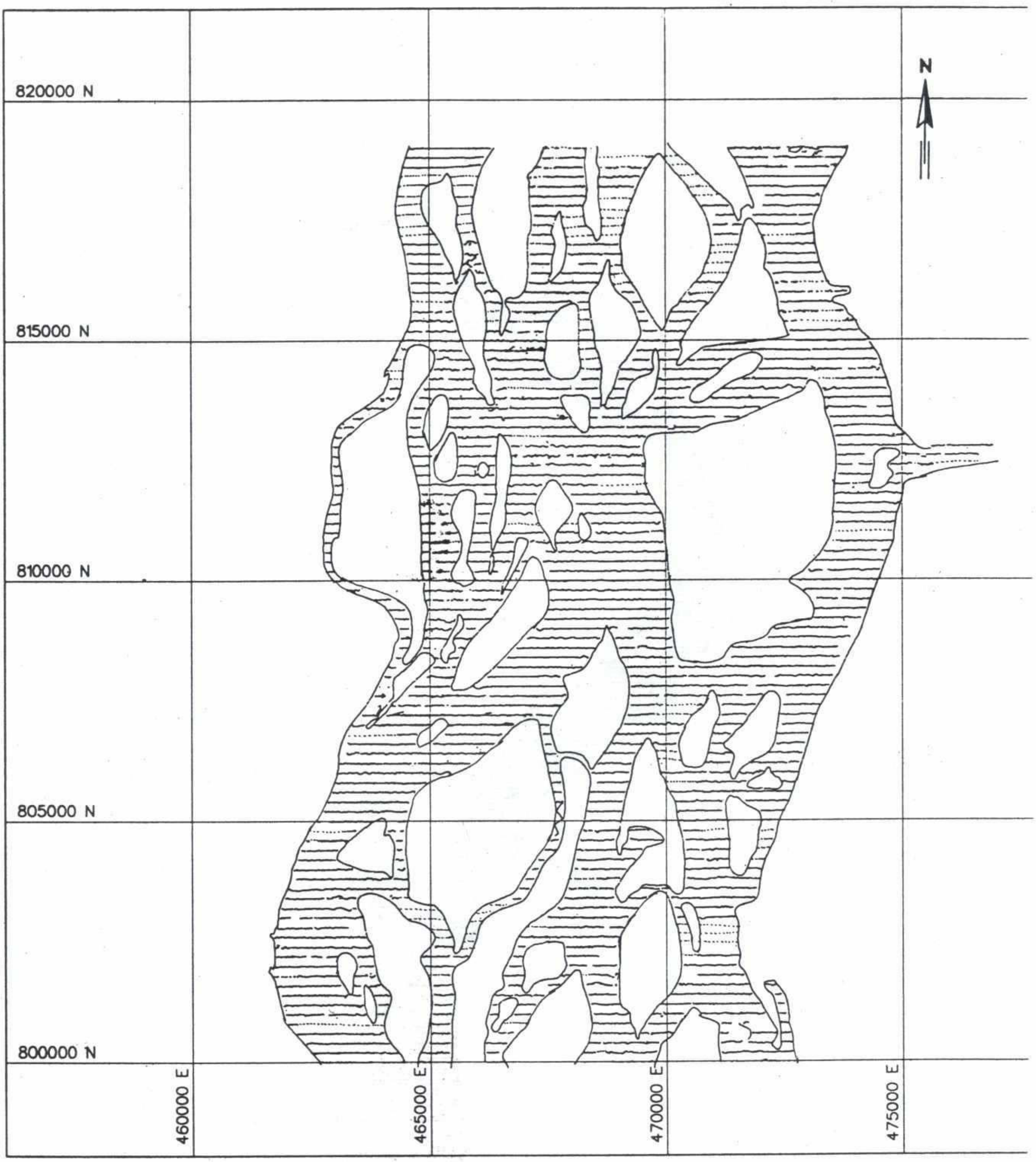

Figure B.9: Kamarjani, September 1994

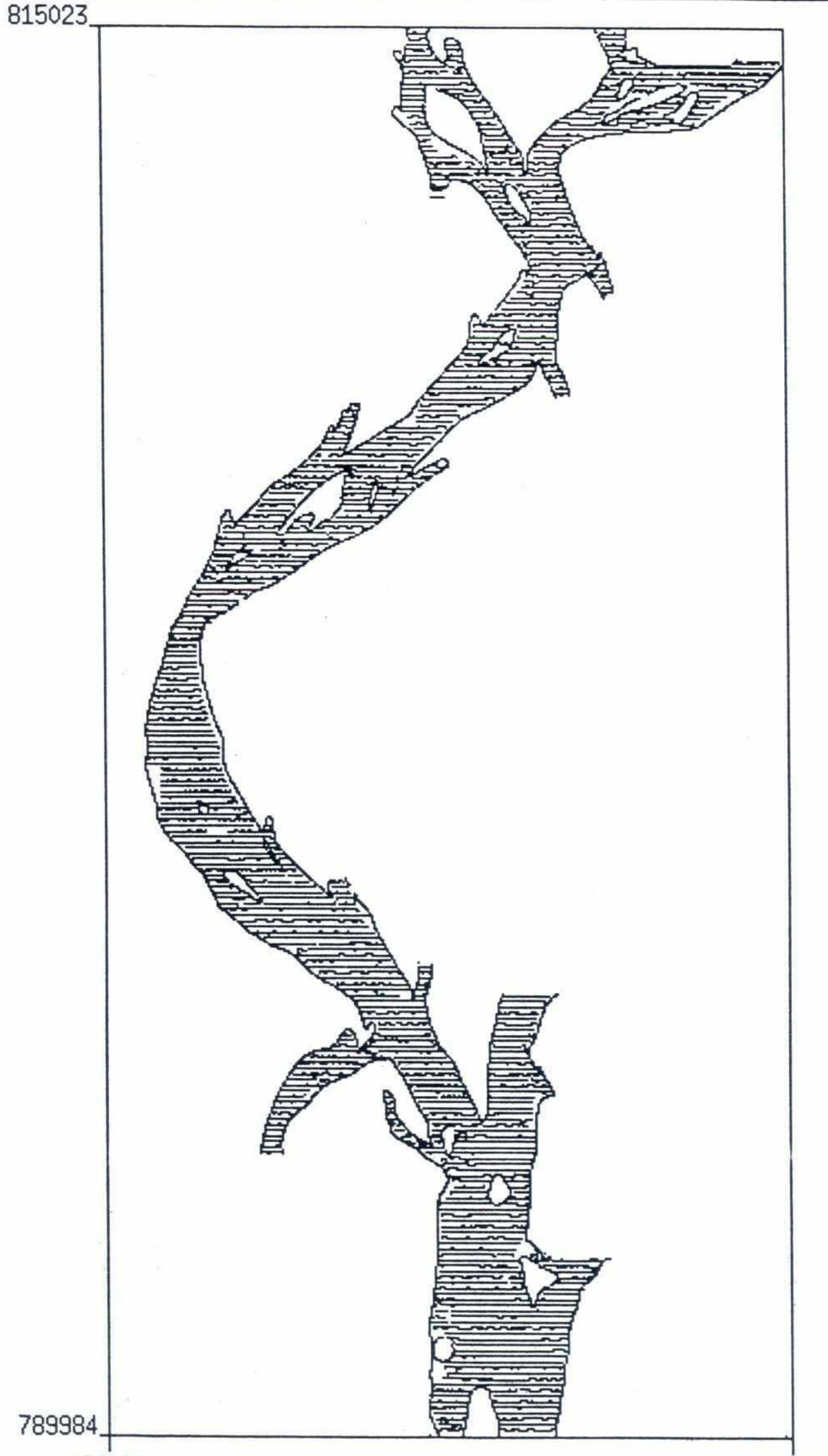

Figure B.10: Kamarjani, November 1994

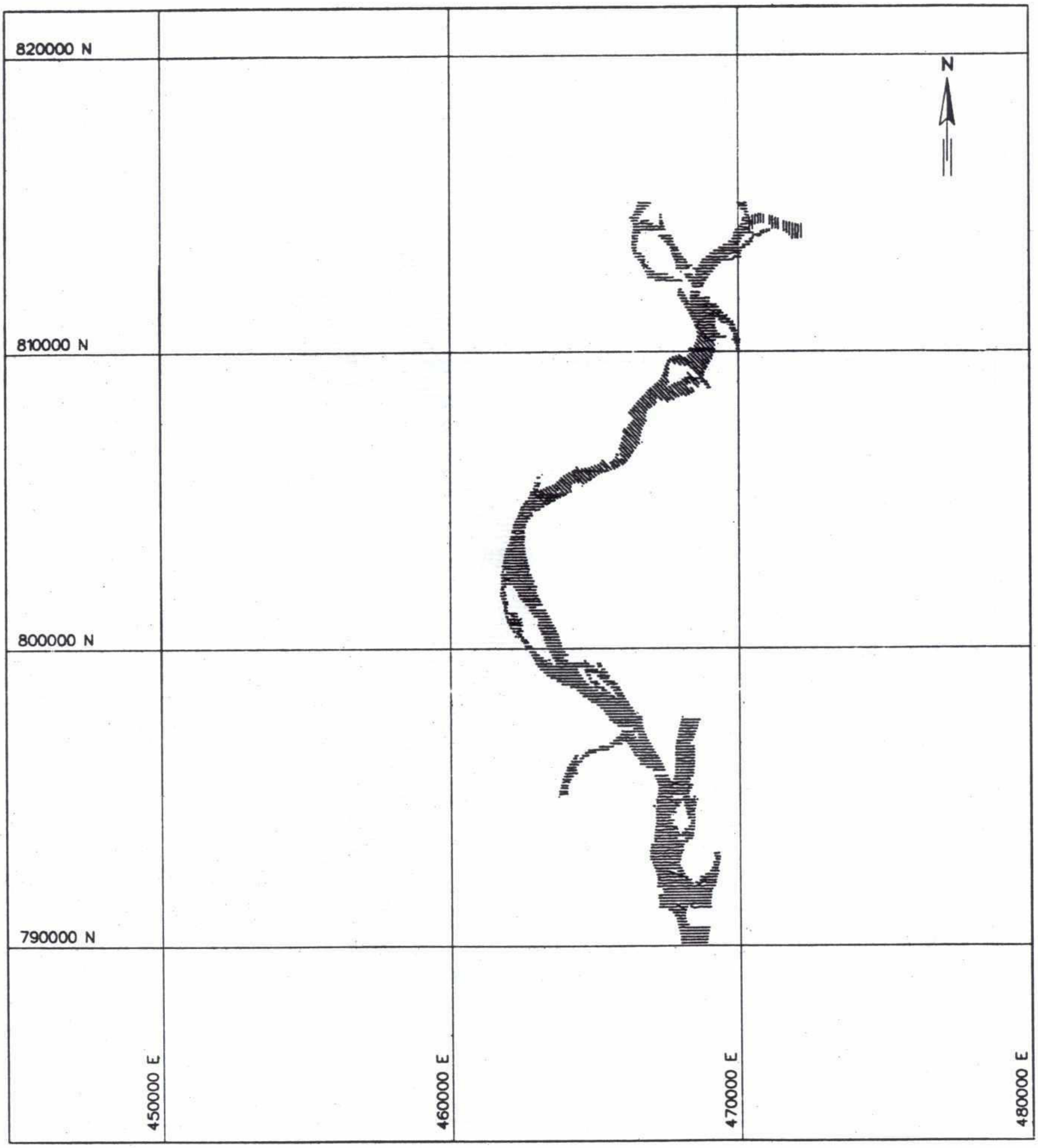

Figure B.11: Kamarjani, March 1995

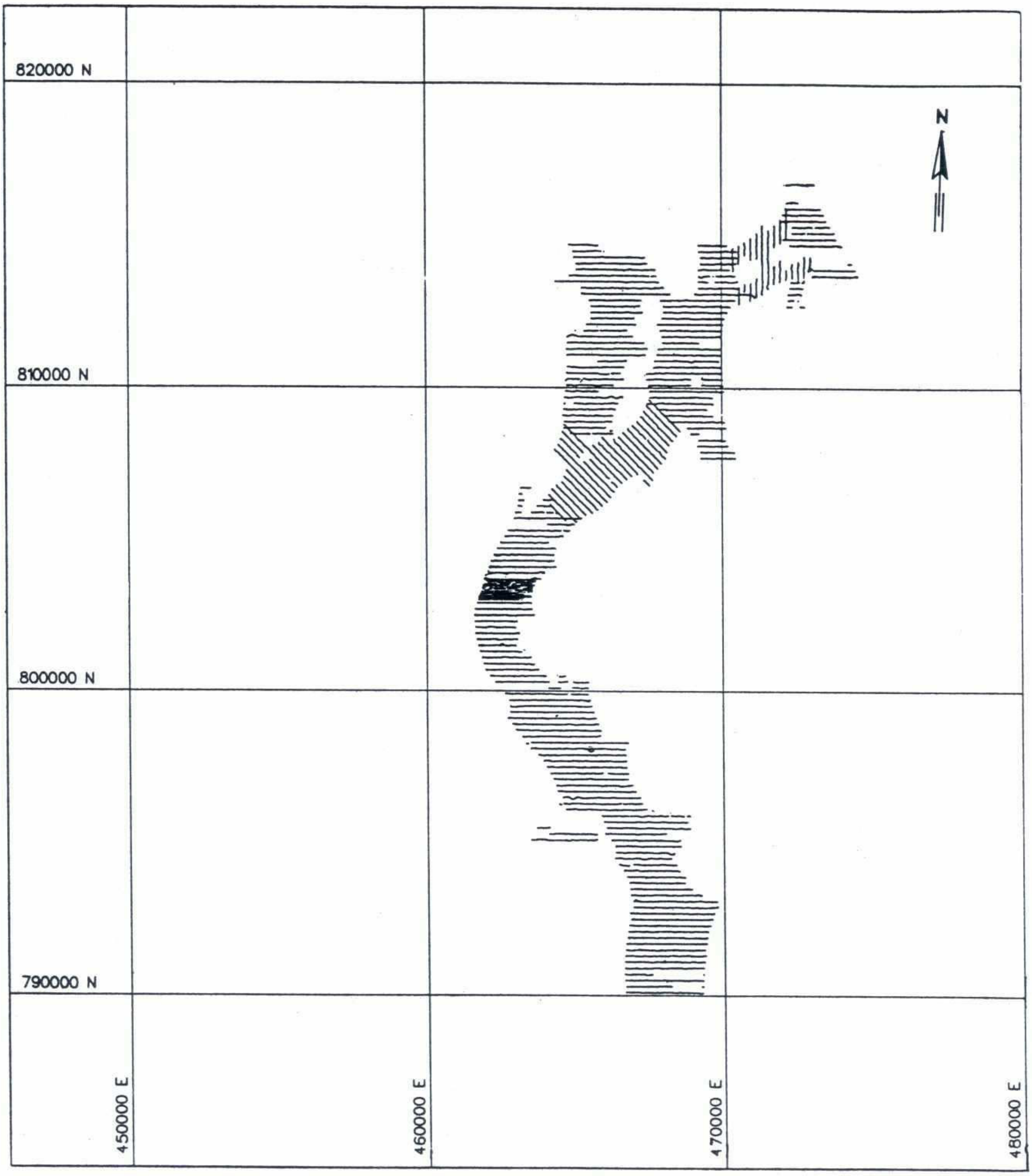

Figure B.12: Kamarjani, August 1995

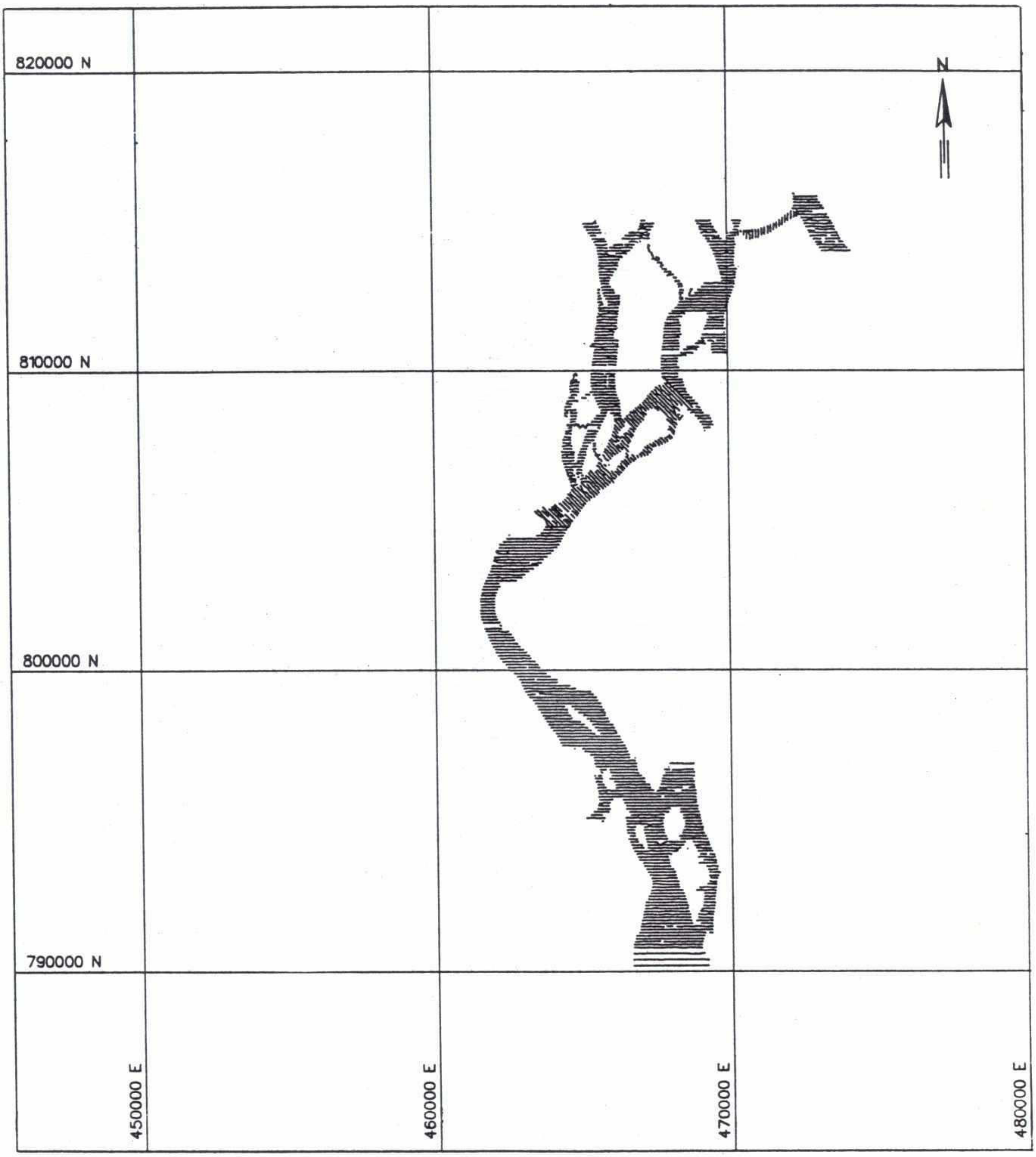

Figure B.13: Kamarjani, November-December 1995

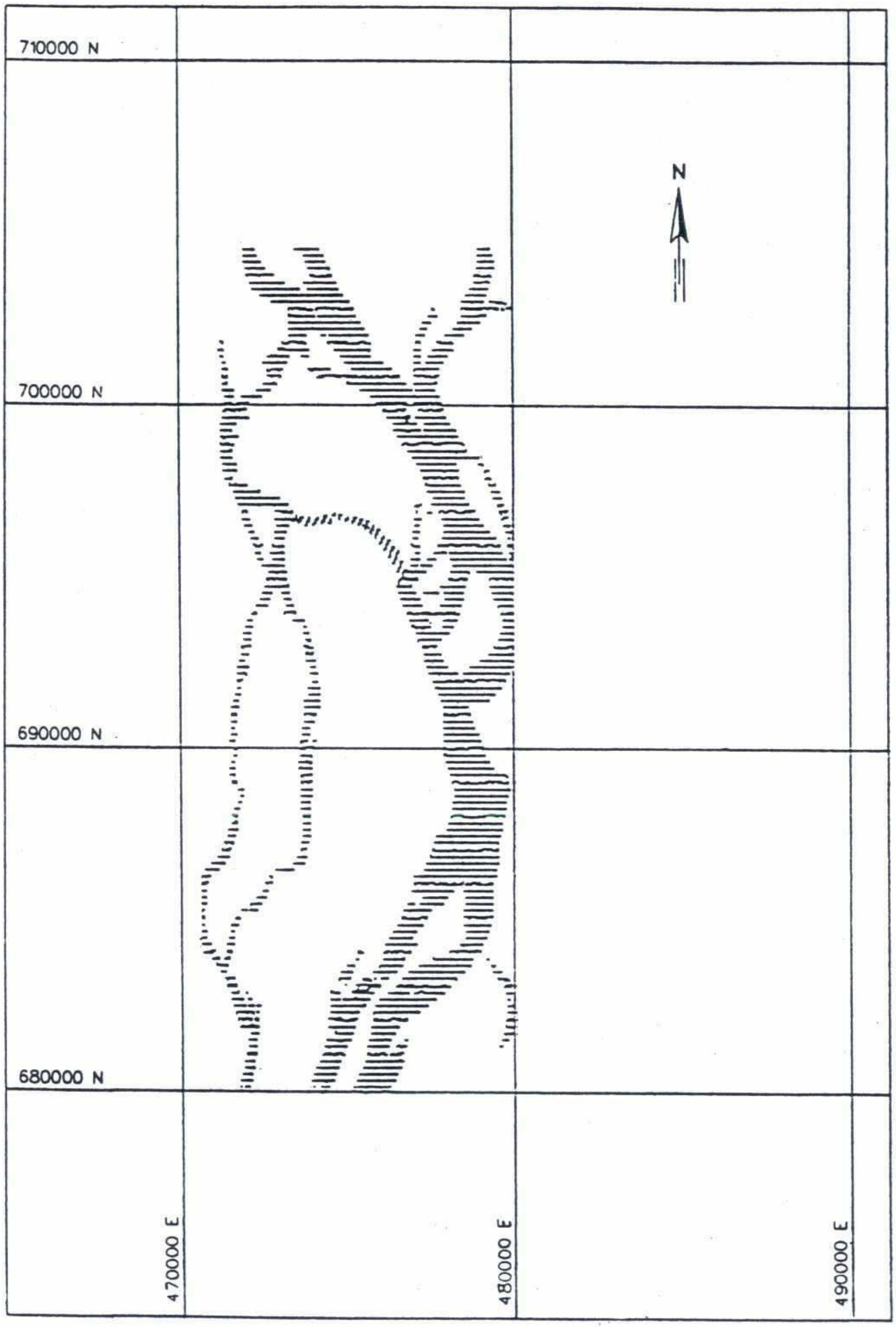

Figure B.14: Dhaleswhari Off-Take, November - December 1994

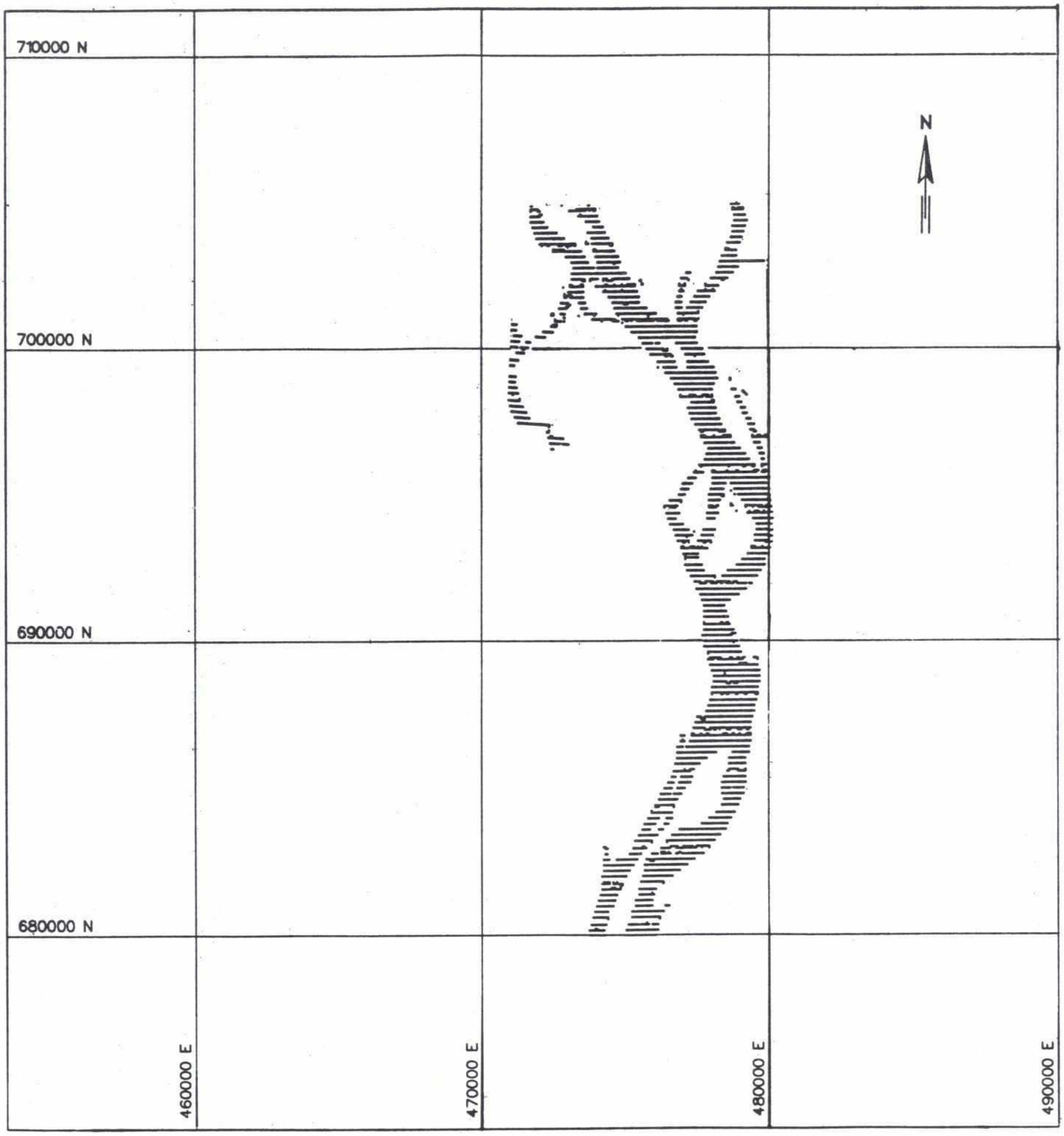

Figure B.15: Dhaleswhari Off-Take, March-April 1995

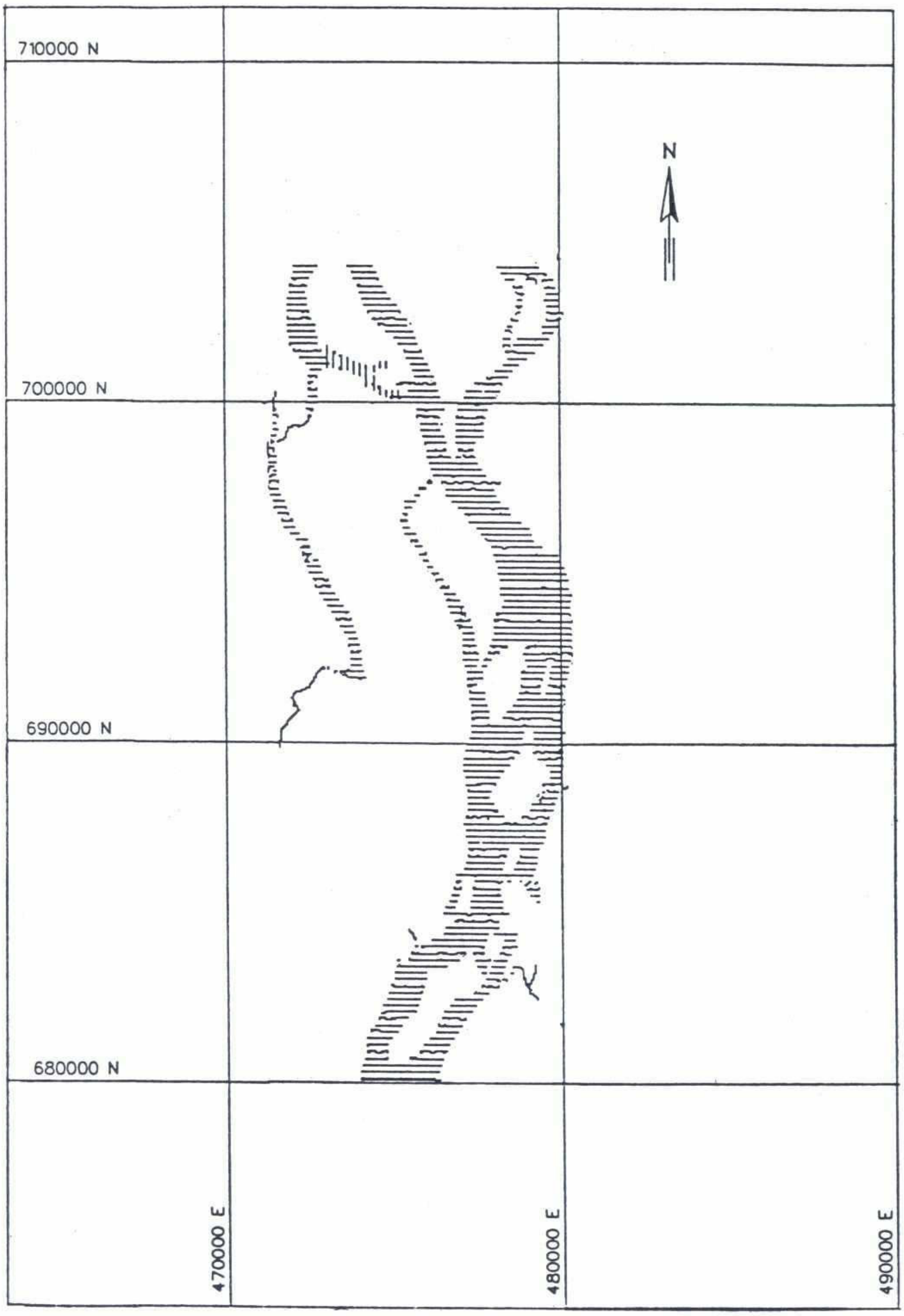

Figure B.16: Dhaleswhari Off-Take, December 1995 - January 1996

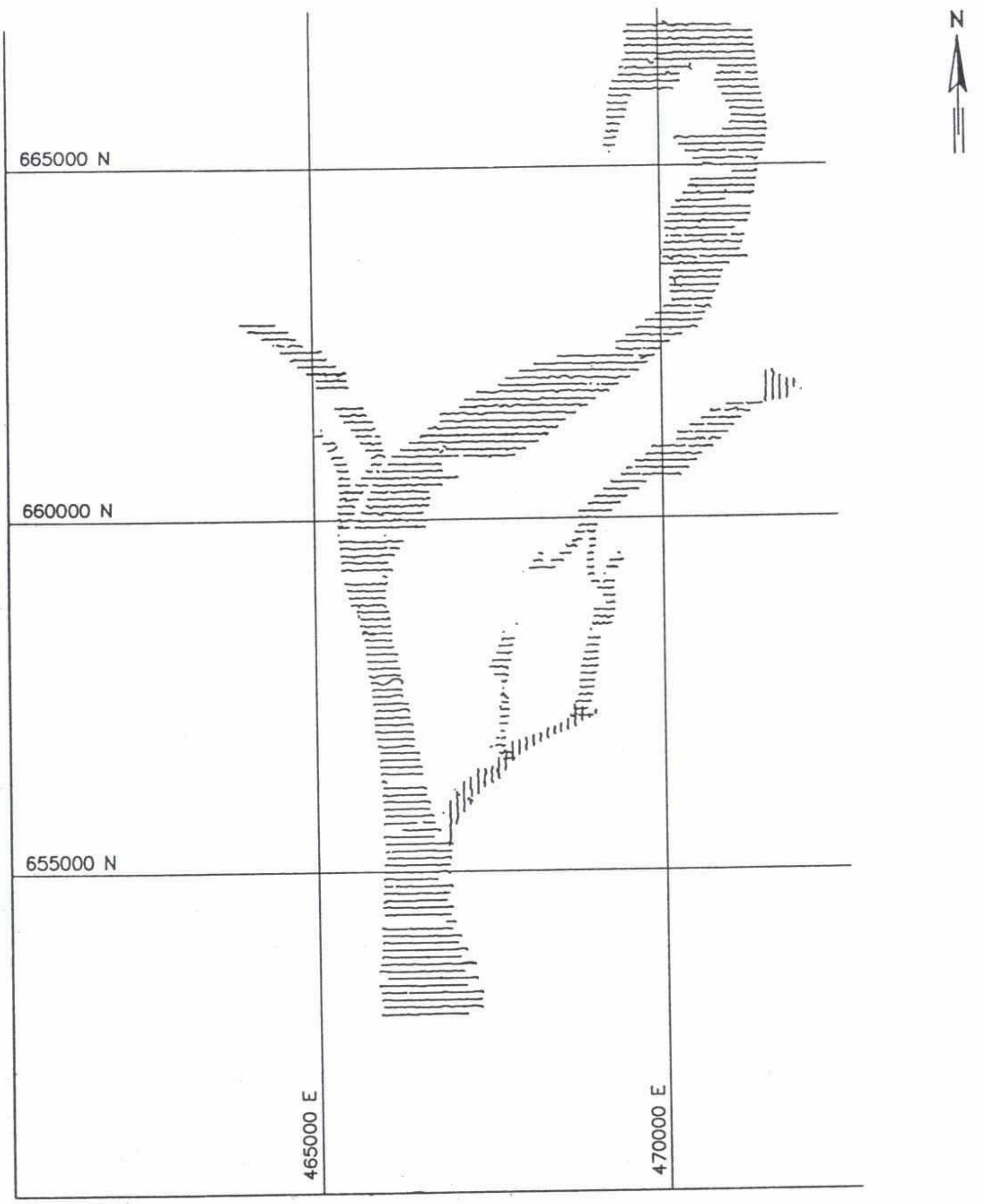

Figure B.17: Hurasagar, November 1993

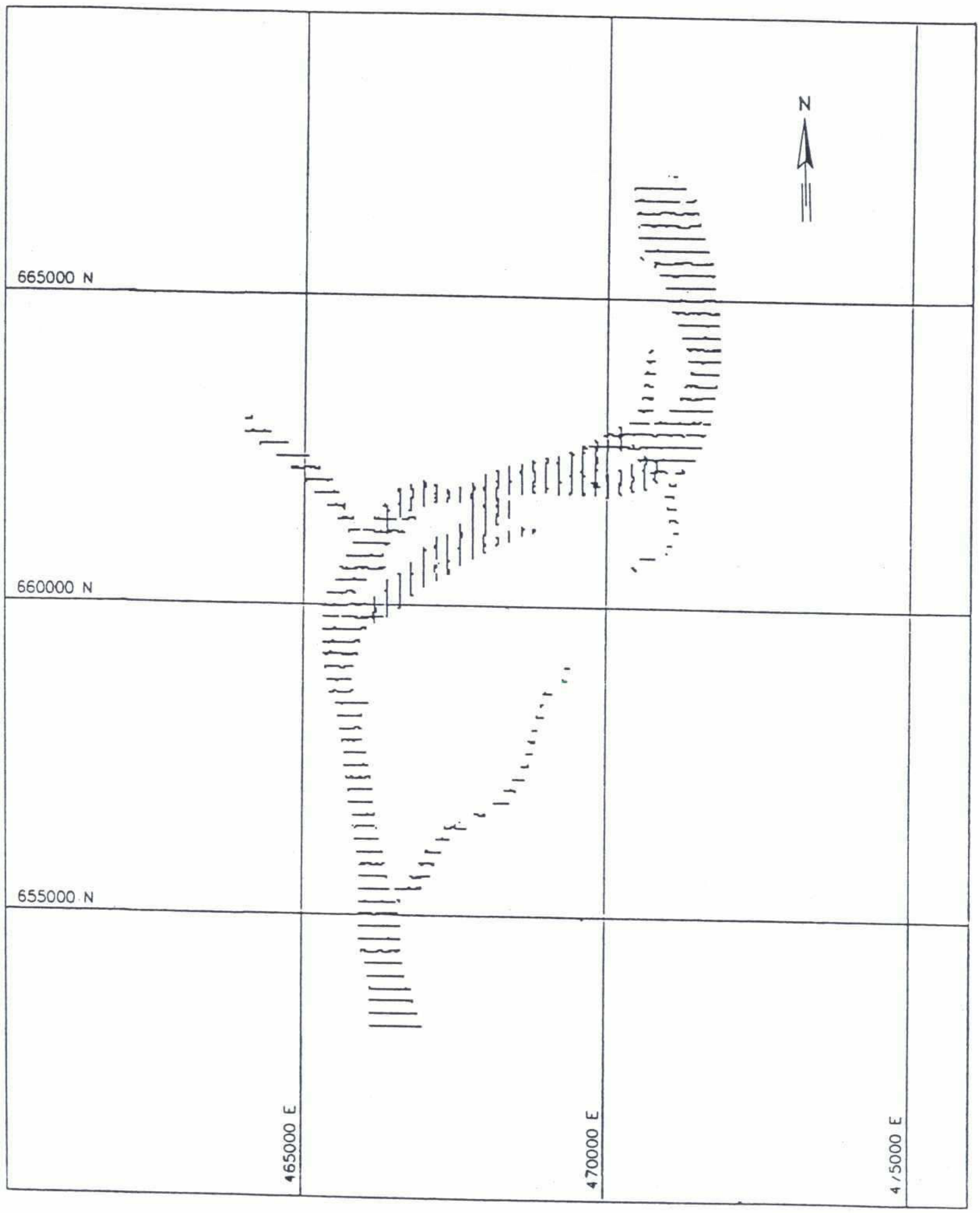

Figure B.18: Hurasagar, December 1994

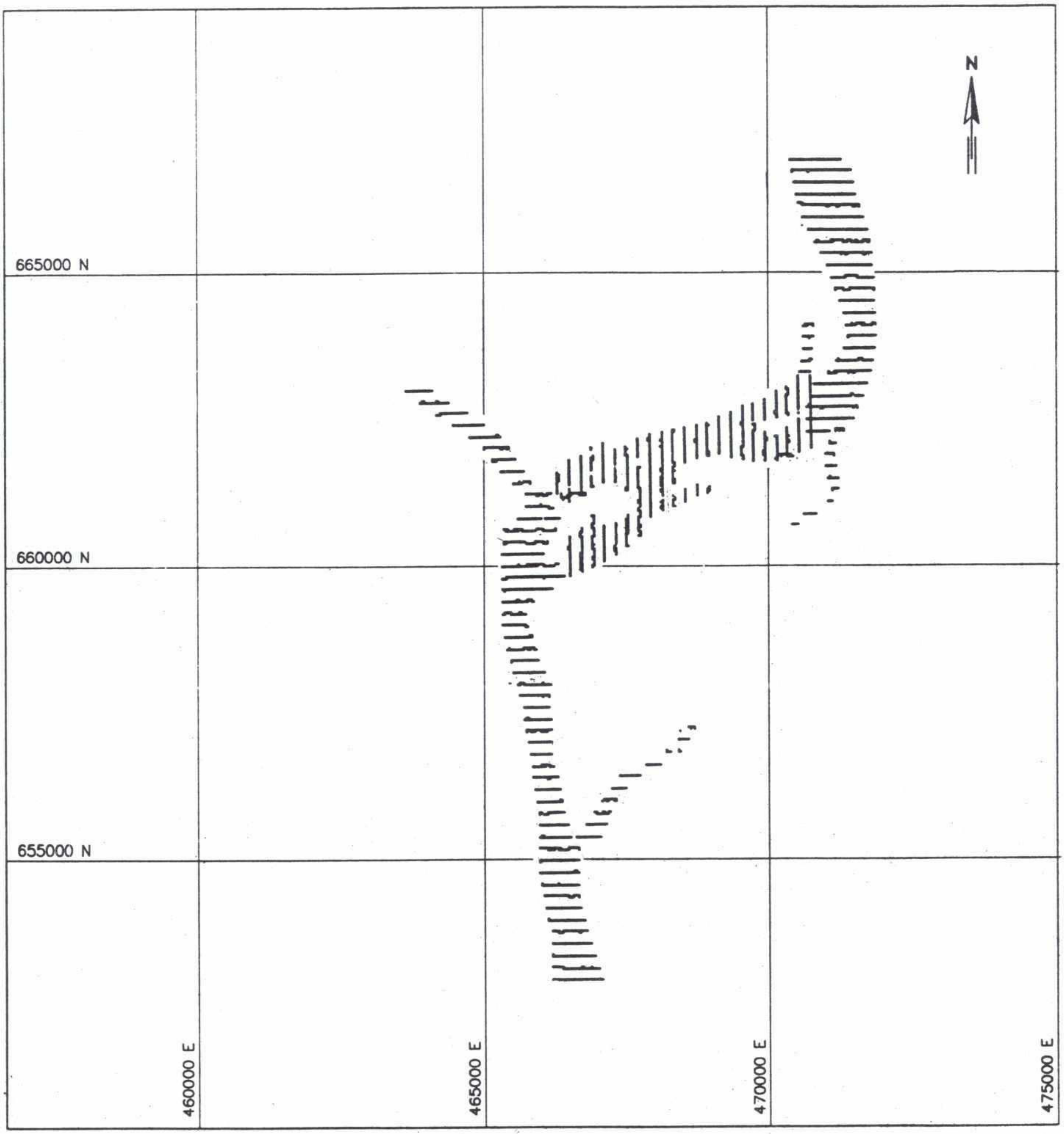

Figure B.19: Hurasagar, April 1995

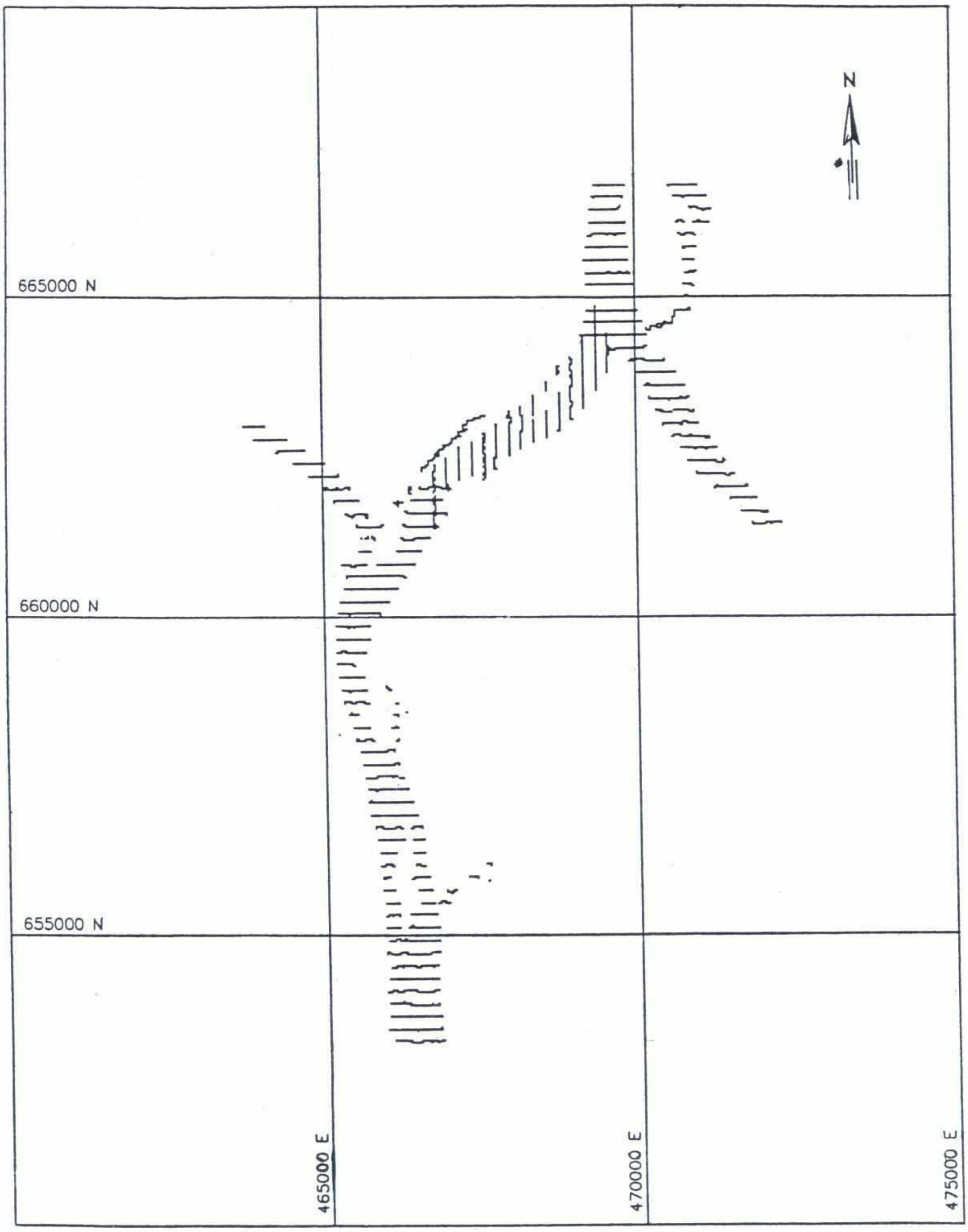

Figure B.20: Hurasagar, March 1996

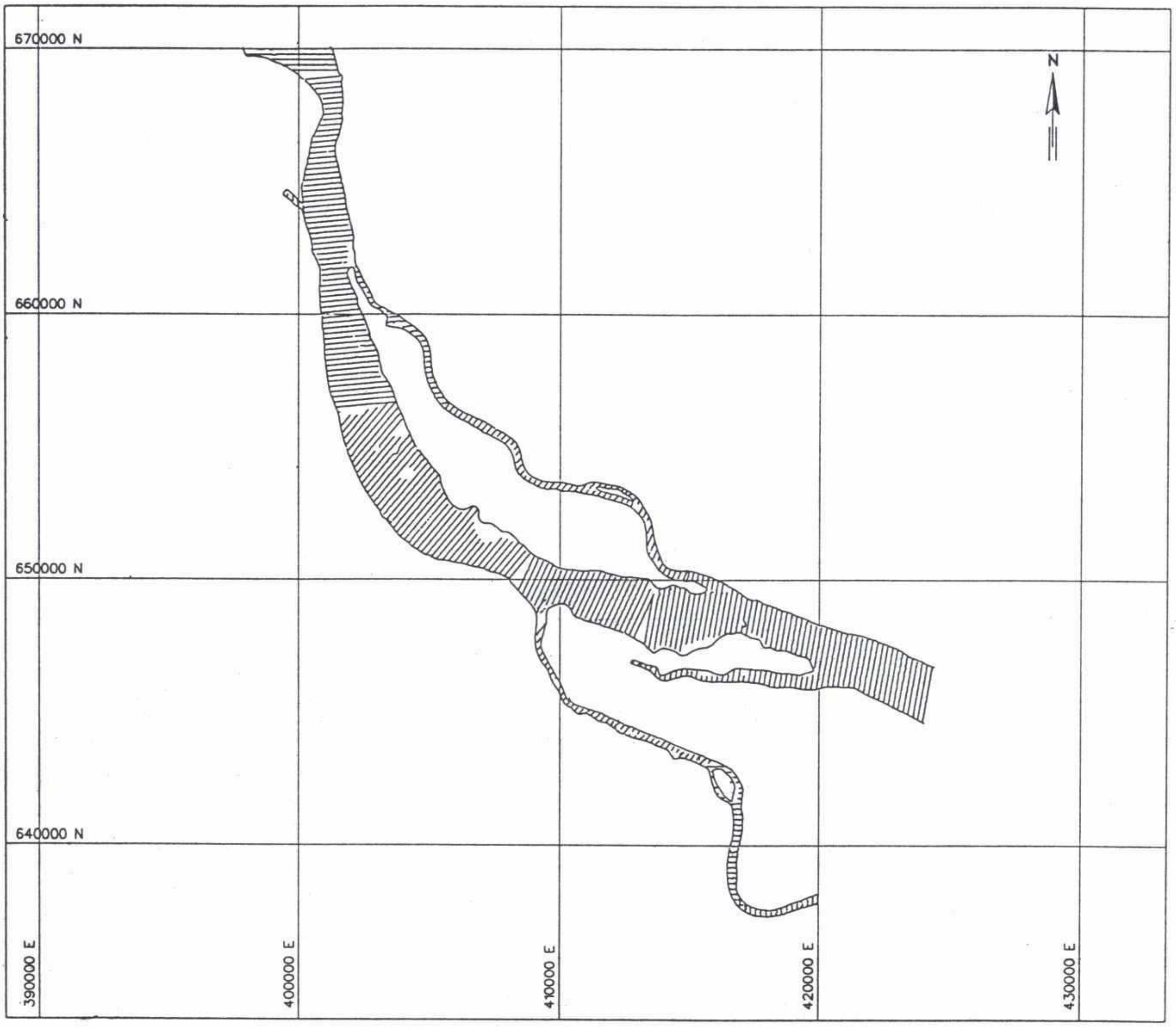

Figure B.21: Gorai Off-Take, October 1994

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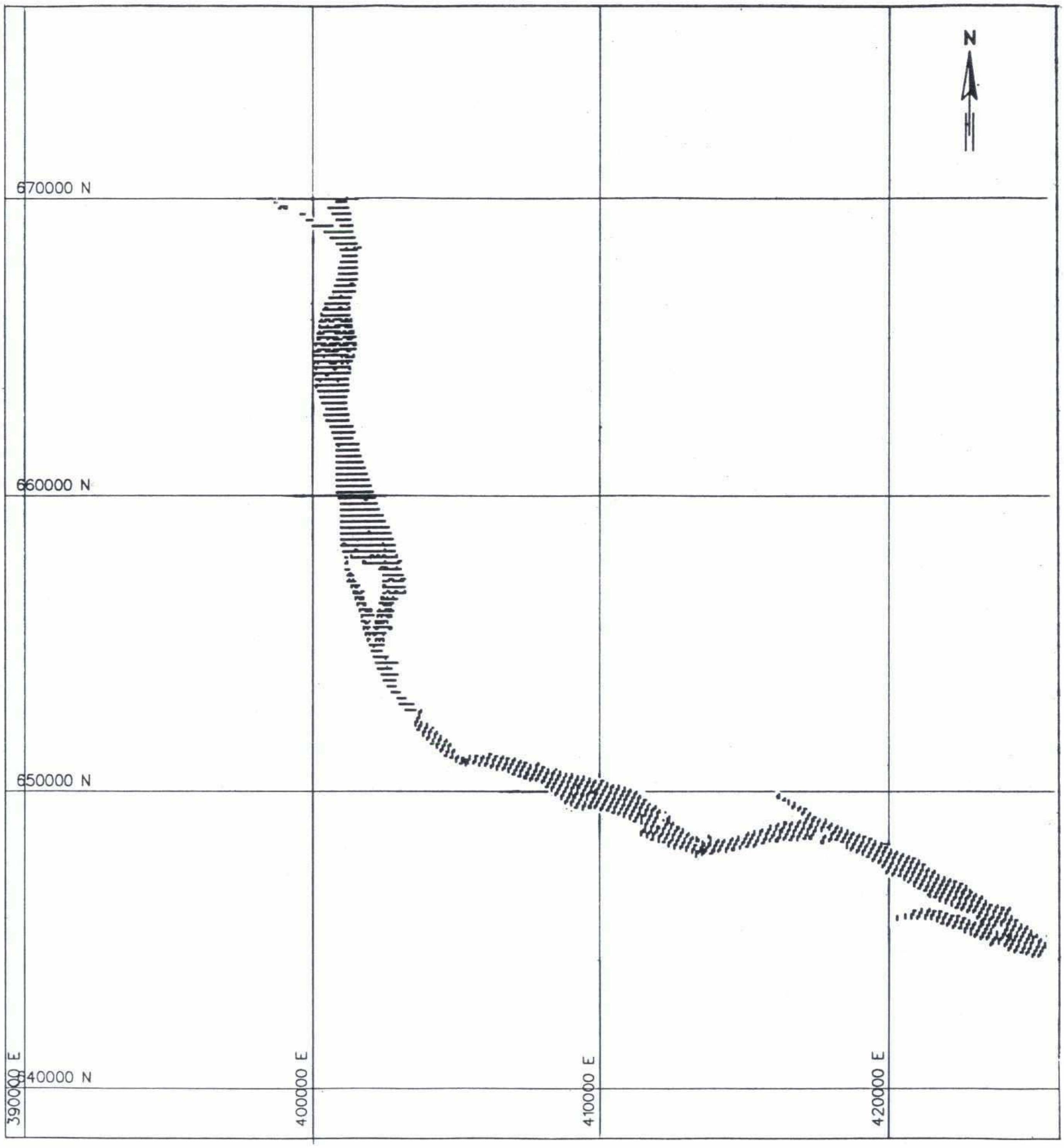

Figure B.22: Gorai Off-Take, January 1995

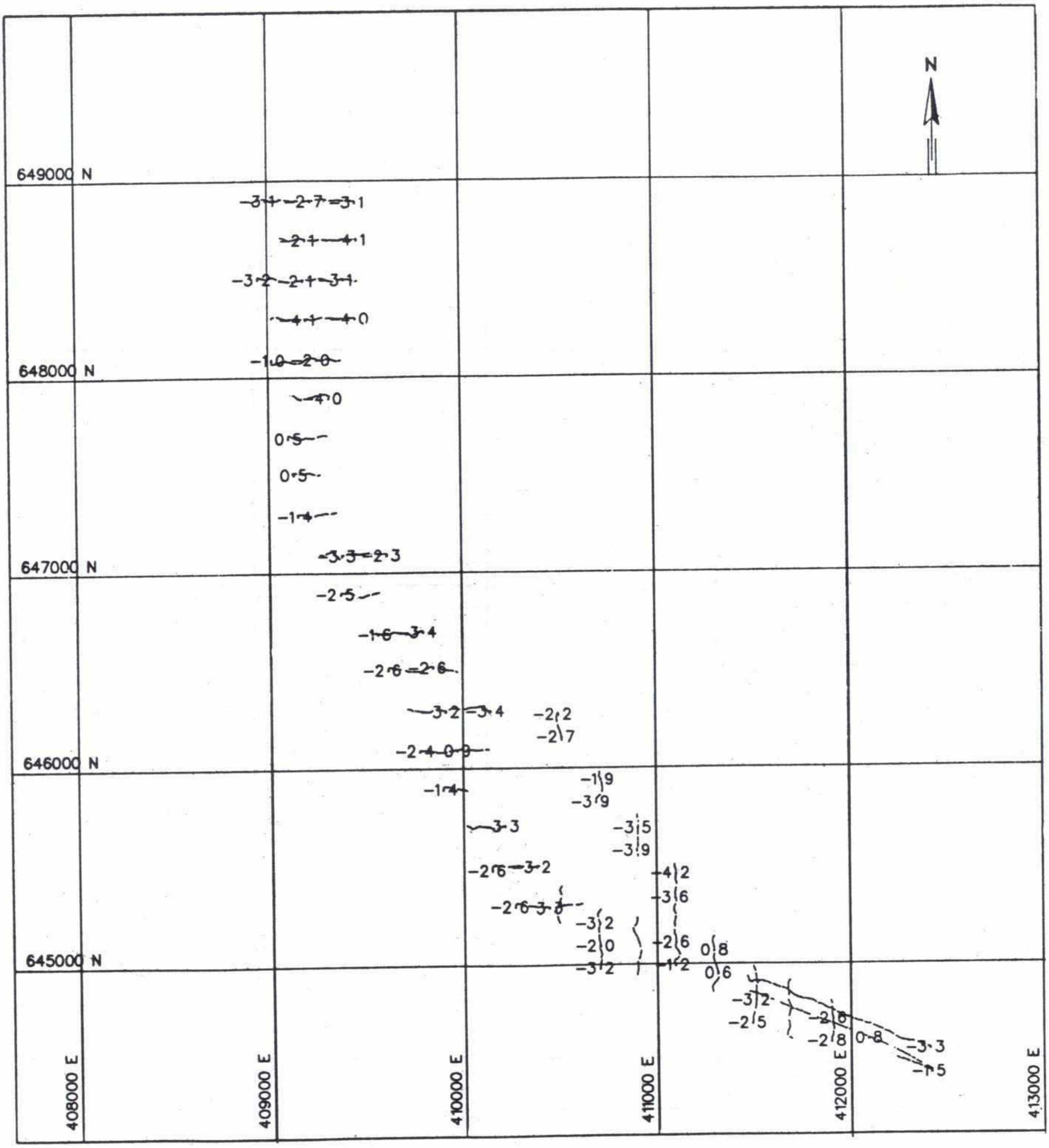

Figure B.23: Gorai Off-Take, May-June 1995

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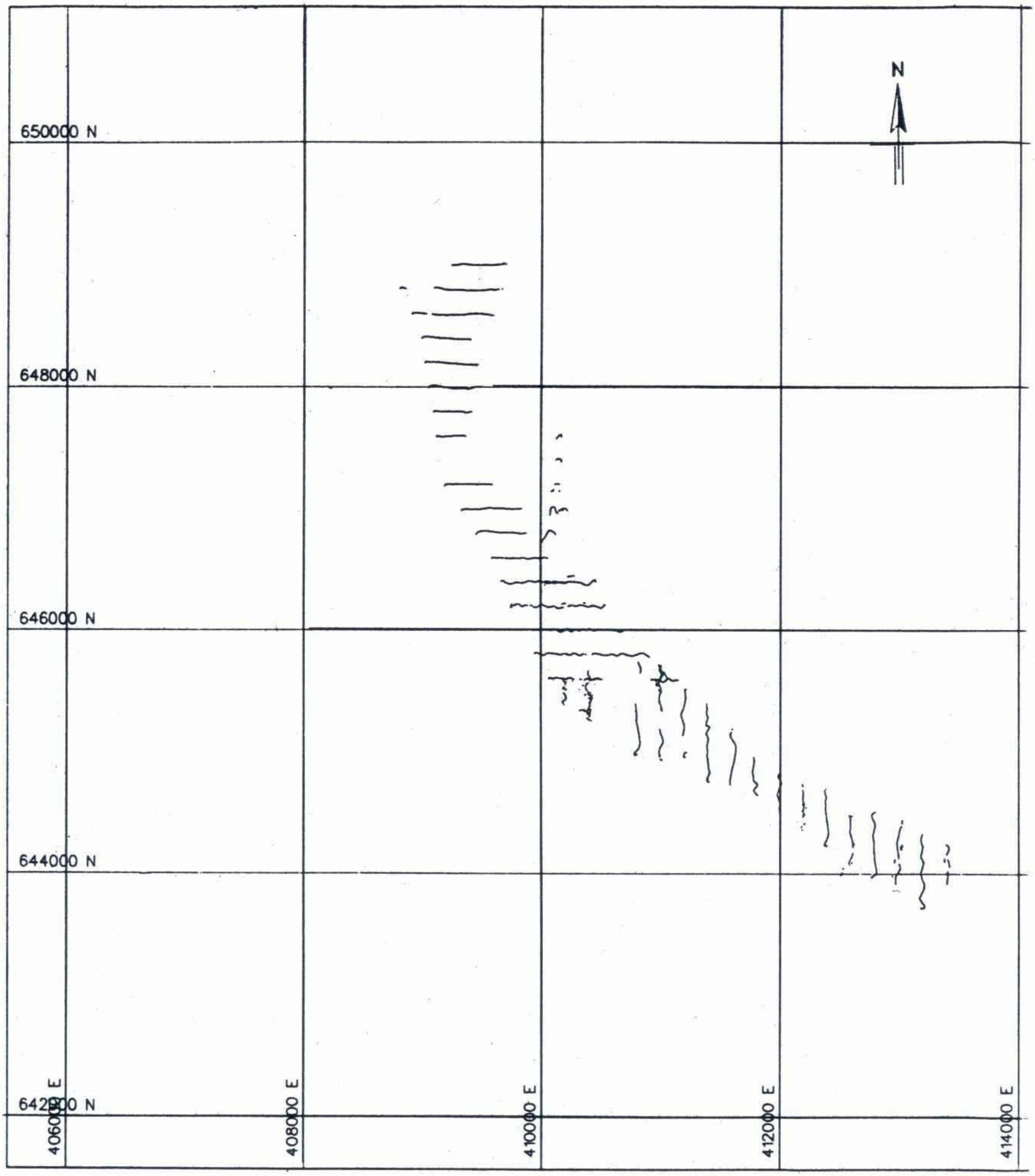

Figure B.24: Gorai Off-Take, August 1995

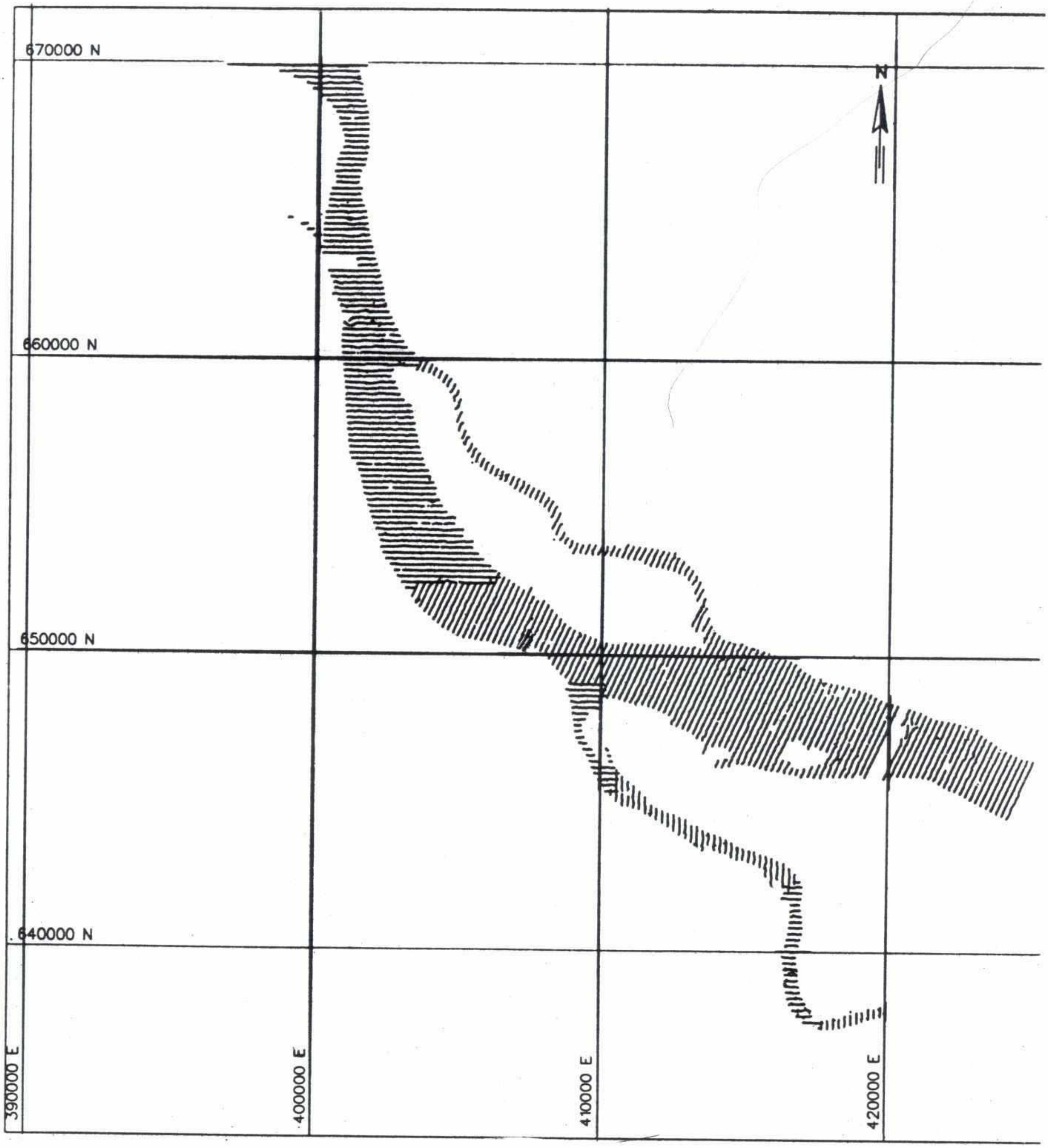

Figure B.25: Gorai Off-Take, September 1995

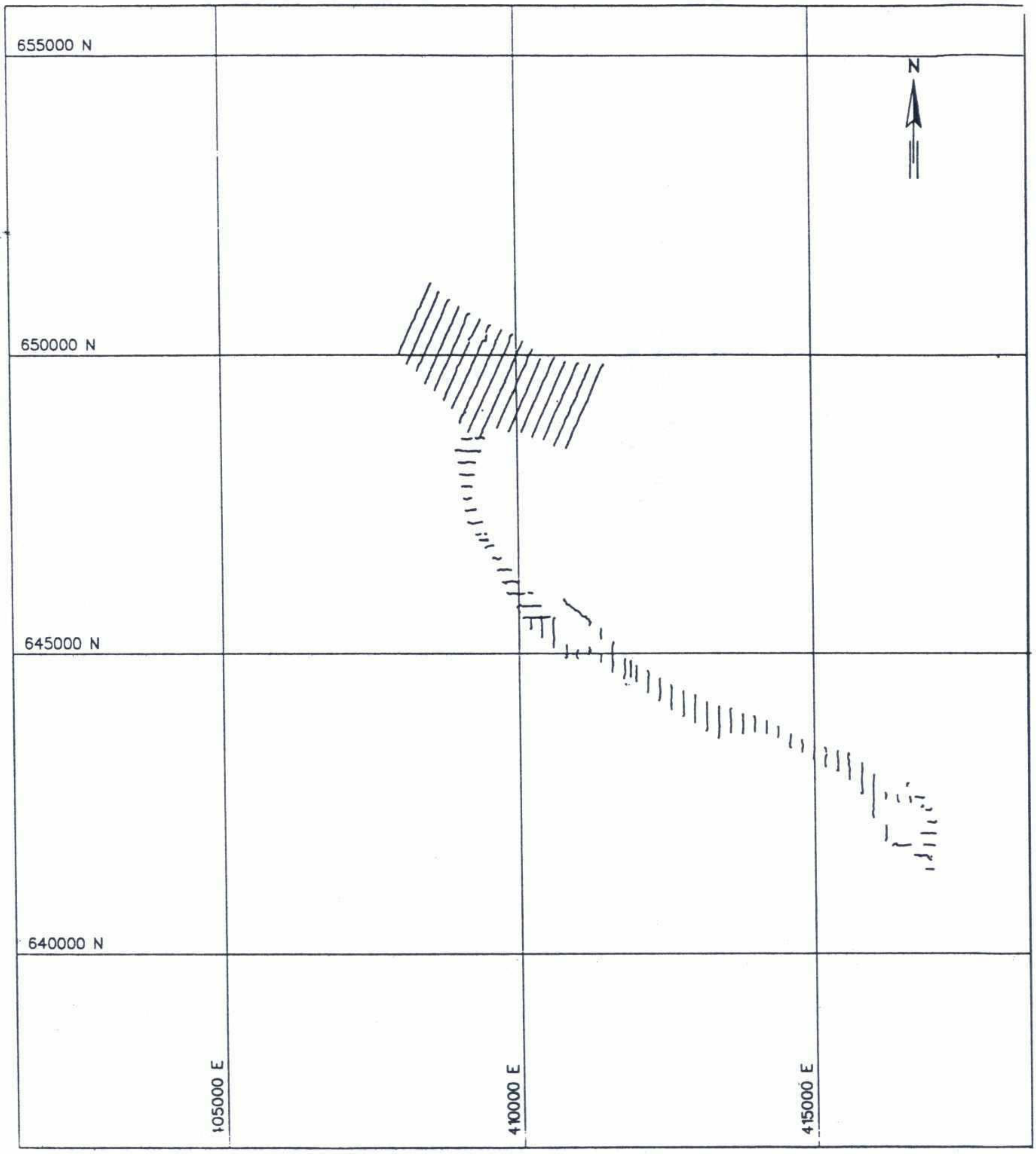

Figure B.26: Gorai Off-Take, October 1995

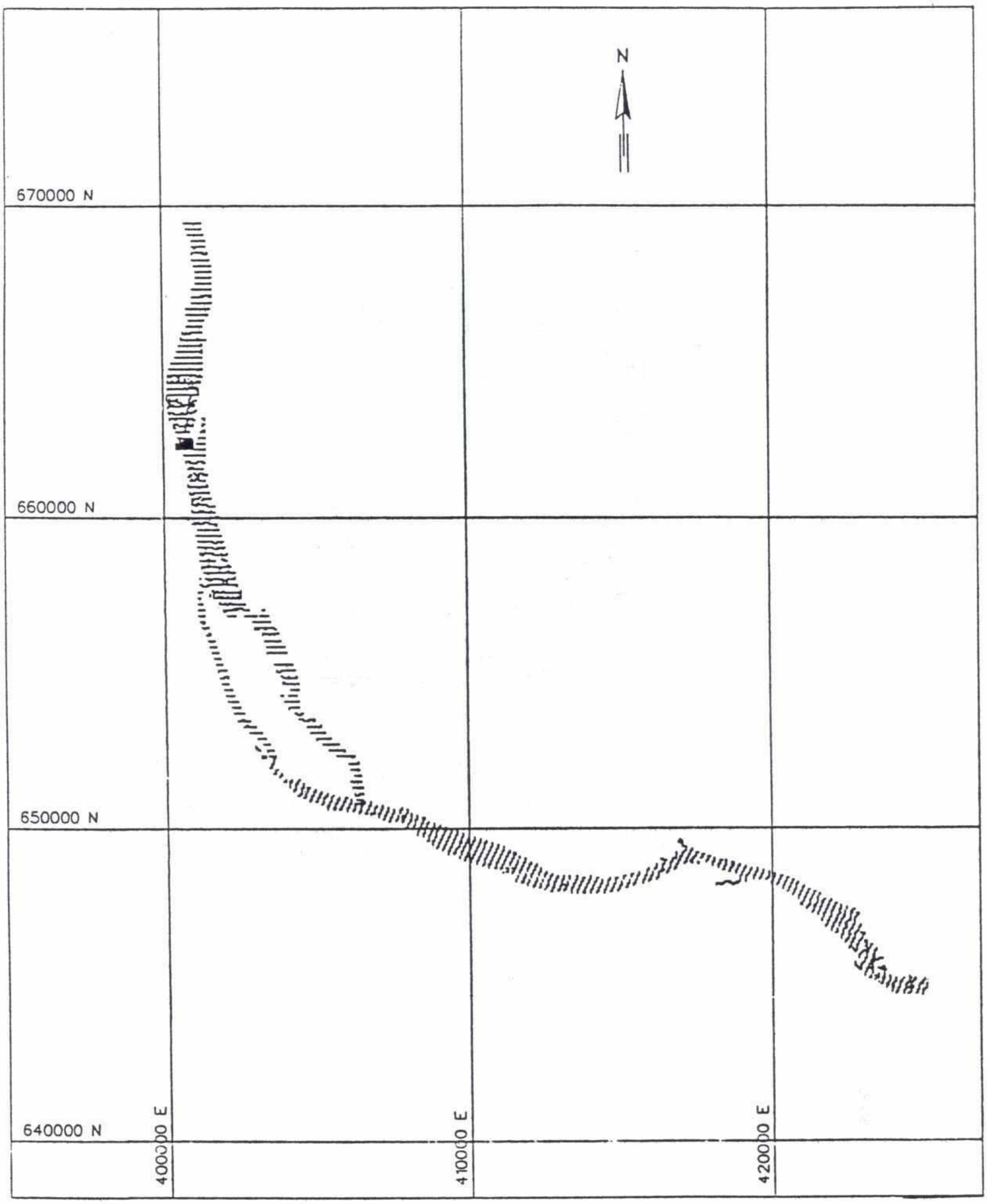

Figure B.27: Gorai Off-Take, April 1996

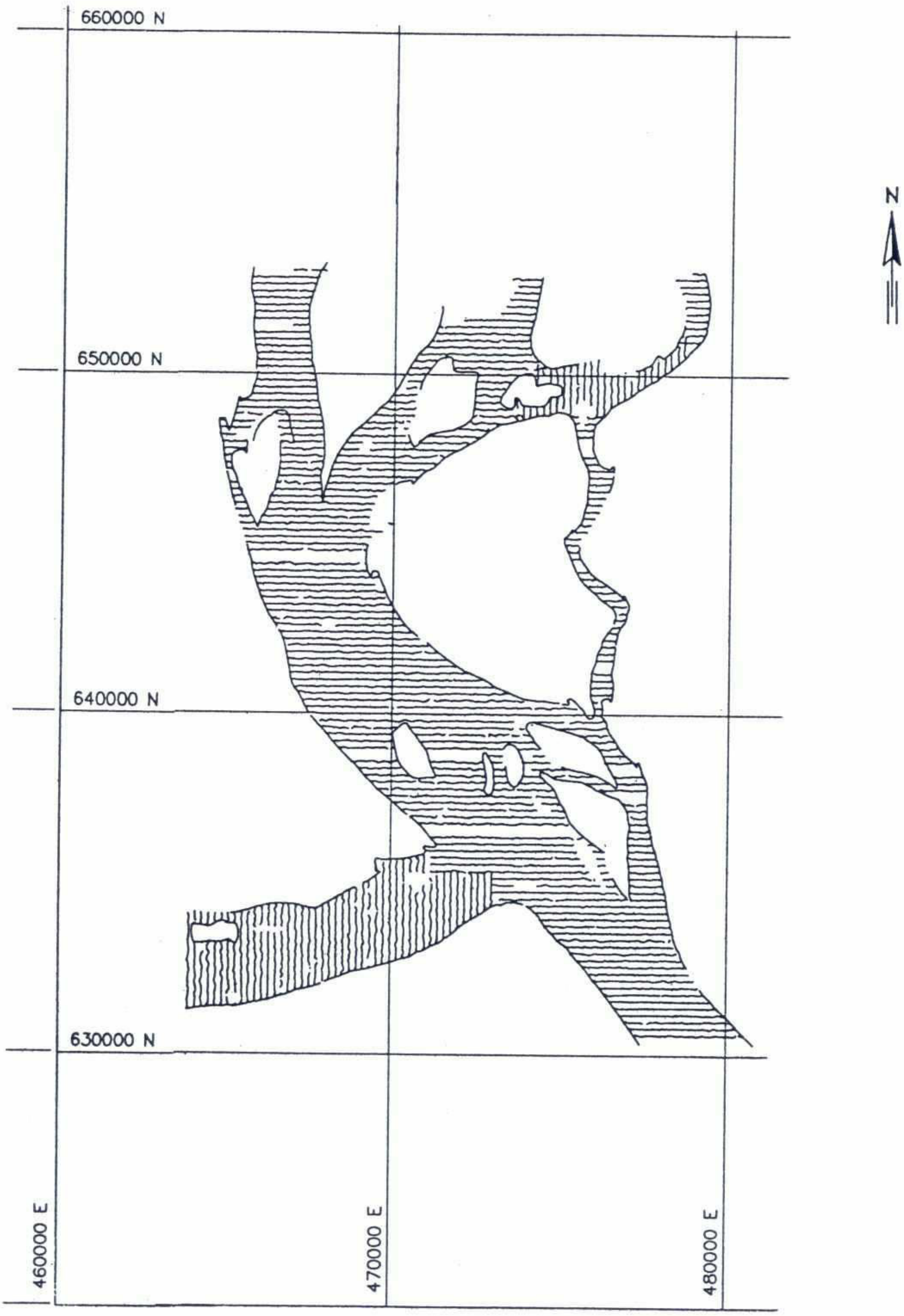

Figure B.28: Ganges-Jamuna Confluence, October 1993

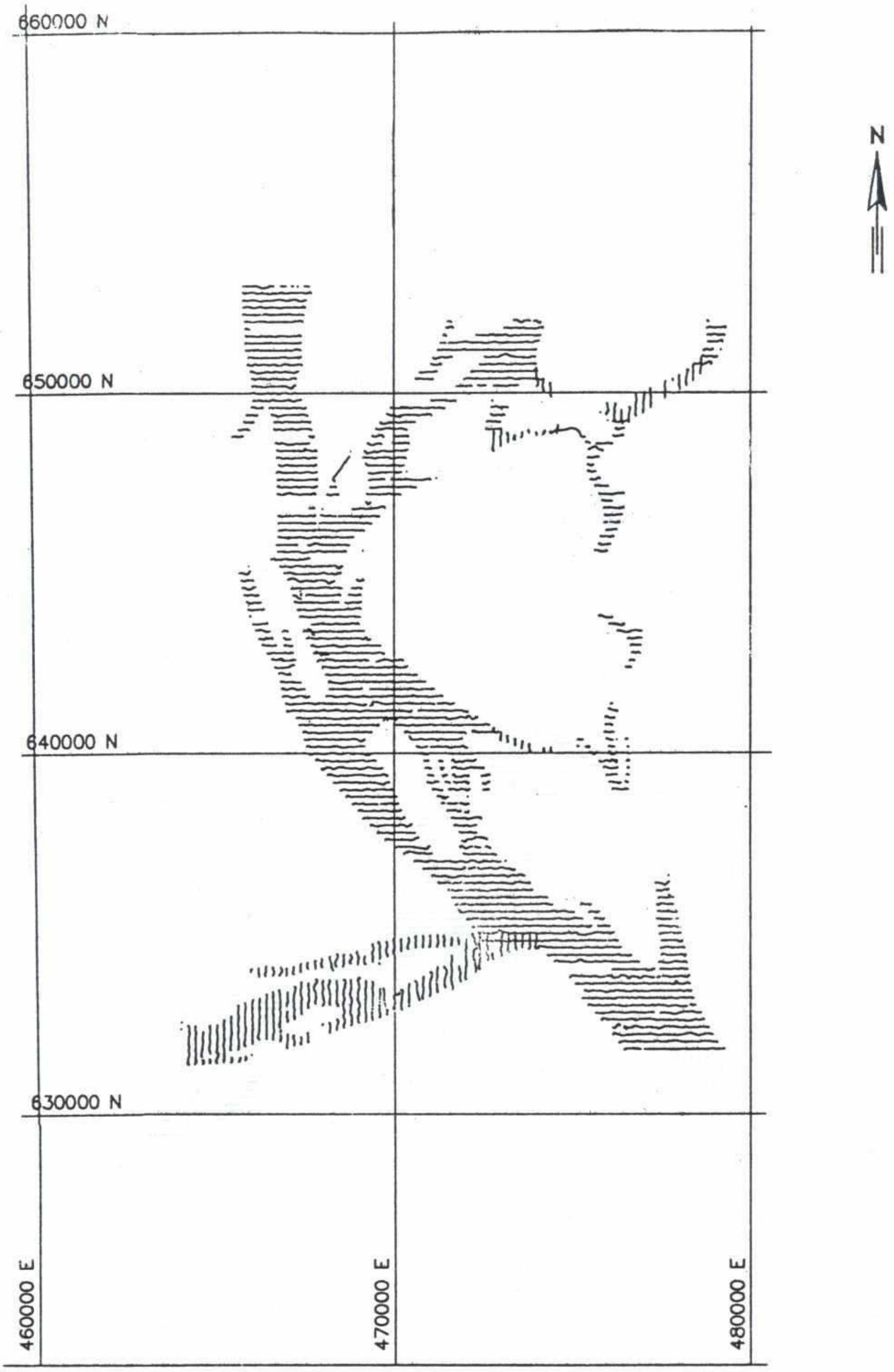

Figure B.29: Ganges-Jamuna Confluence, April - May 1994

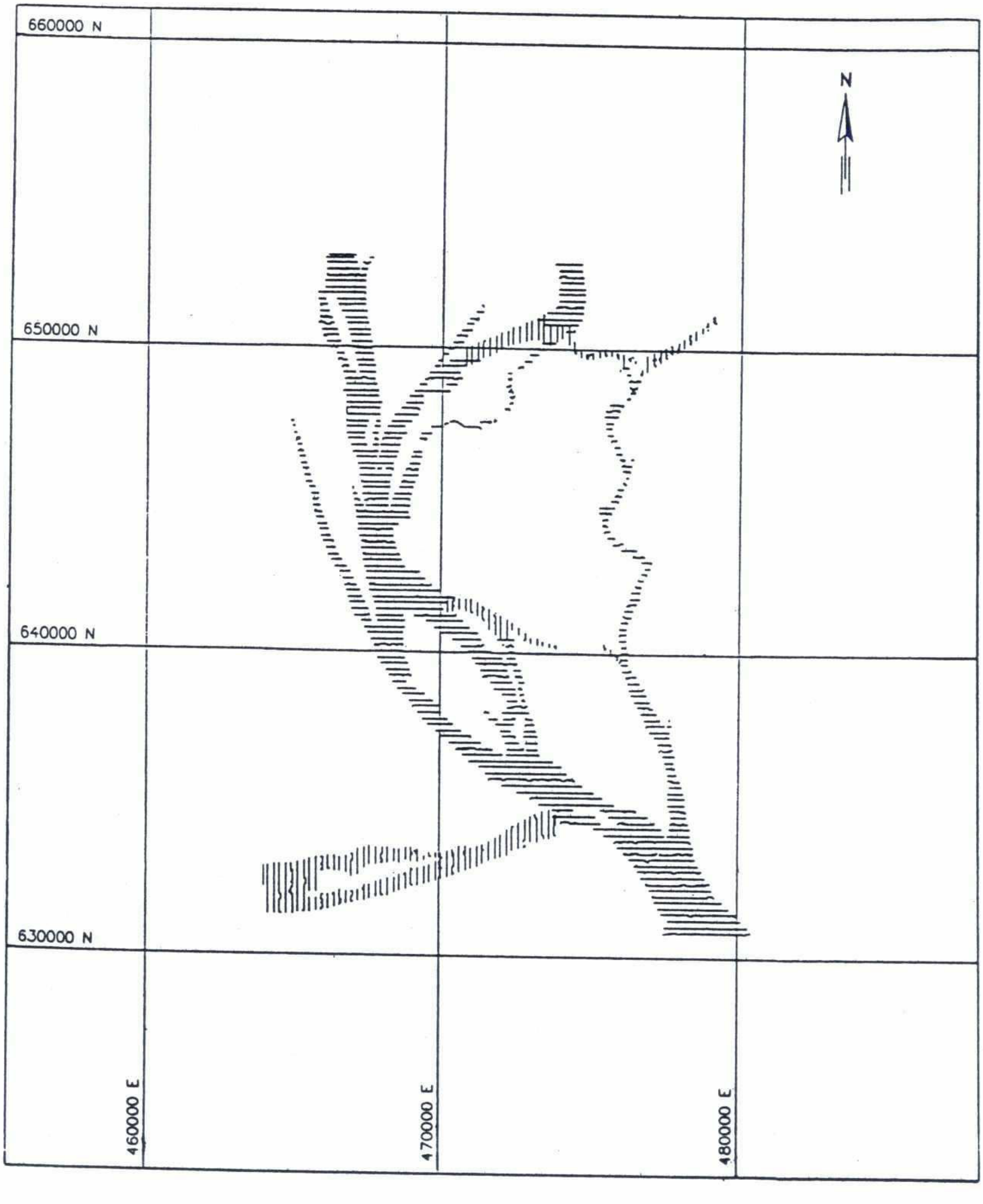

Figure B.30: Ganges-Jamuna Confluence. December 1994

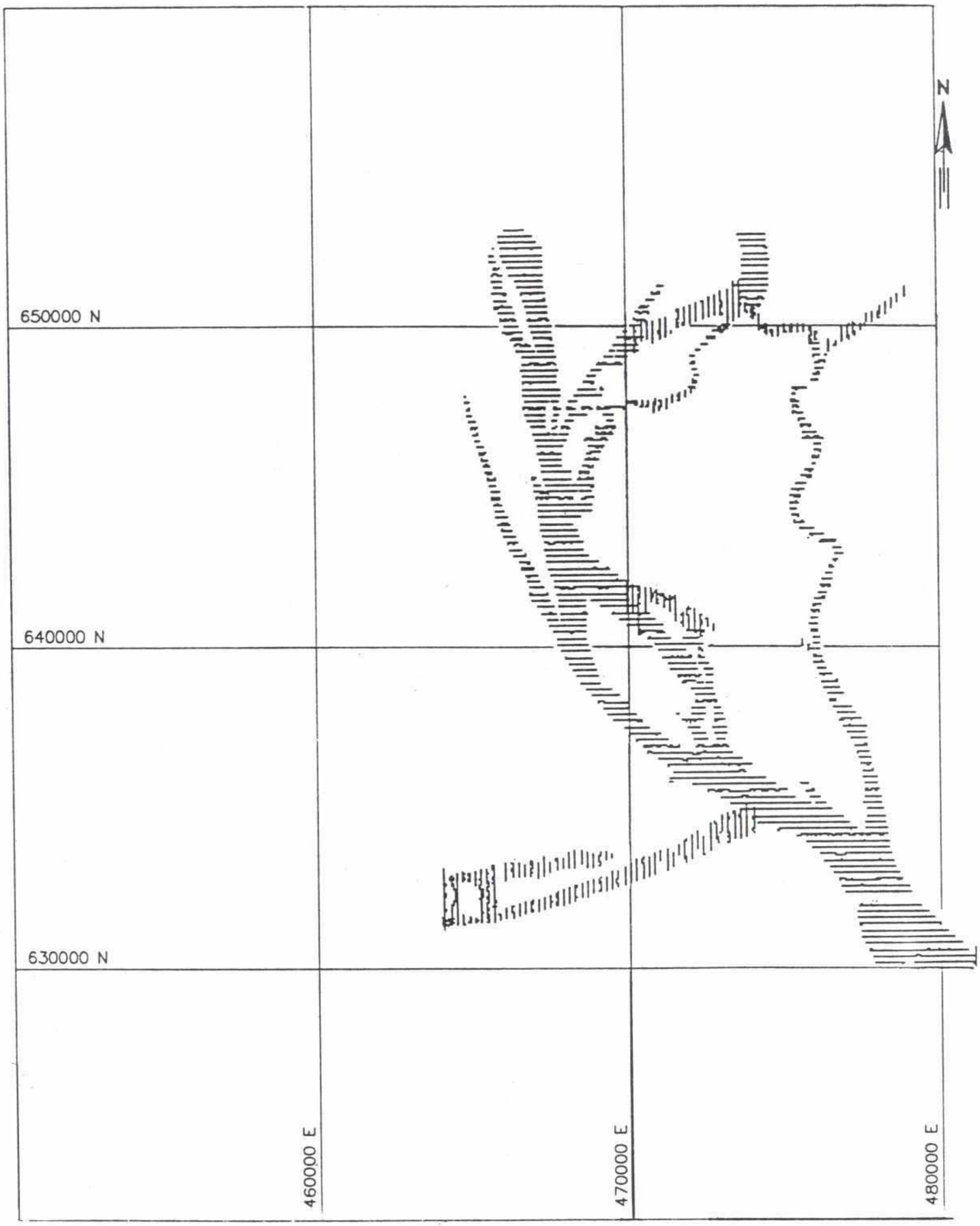

Figure B.31: Ganges-Jamuna Confluence, April 1995

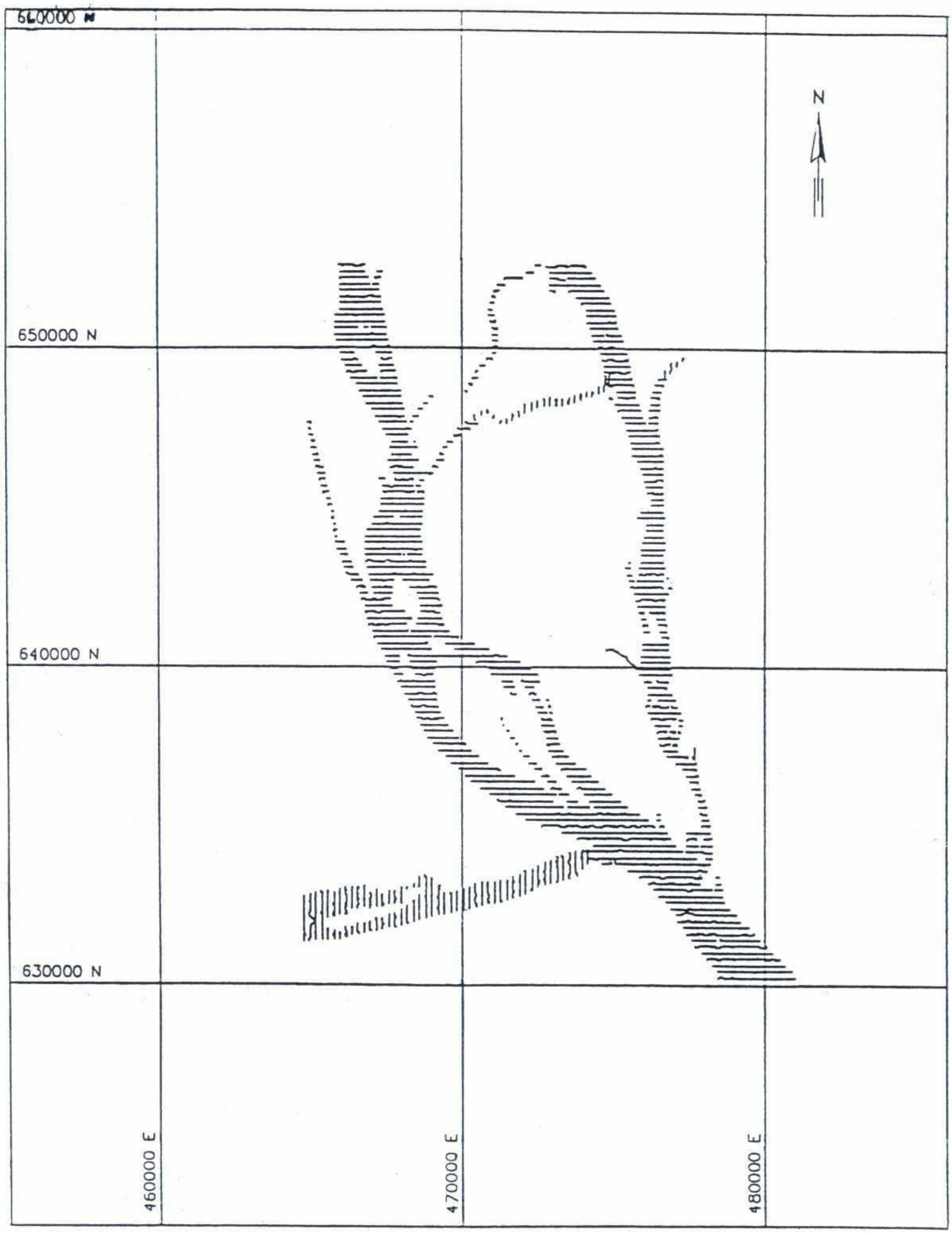

Figure B.32: Ganges-Jamuna Confluence, January 1996

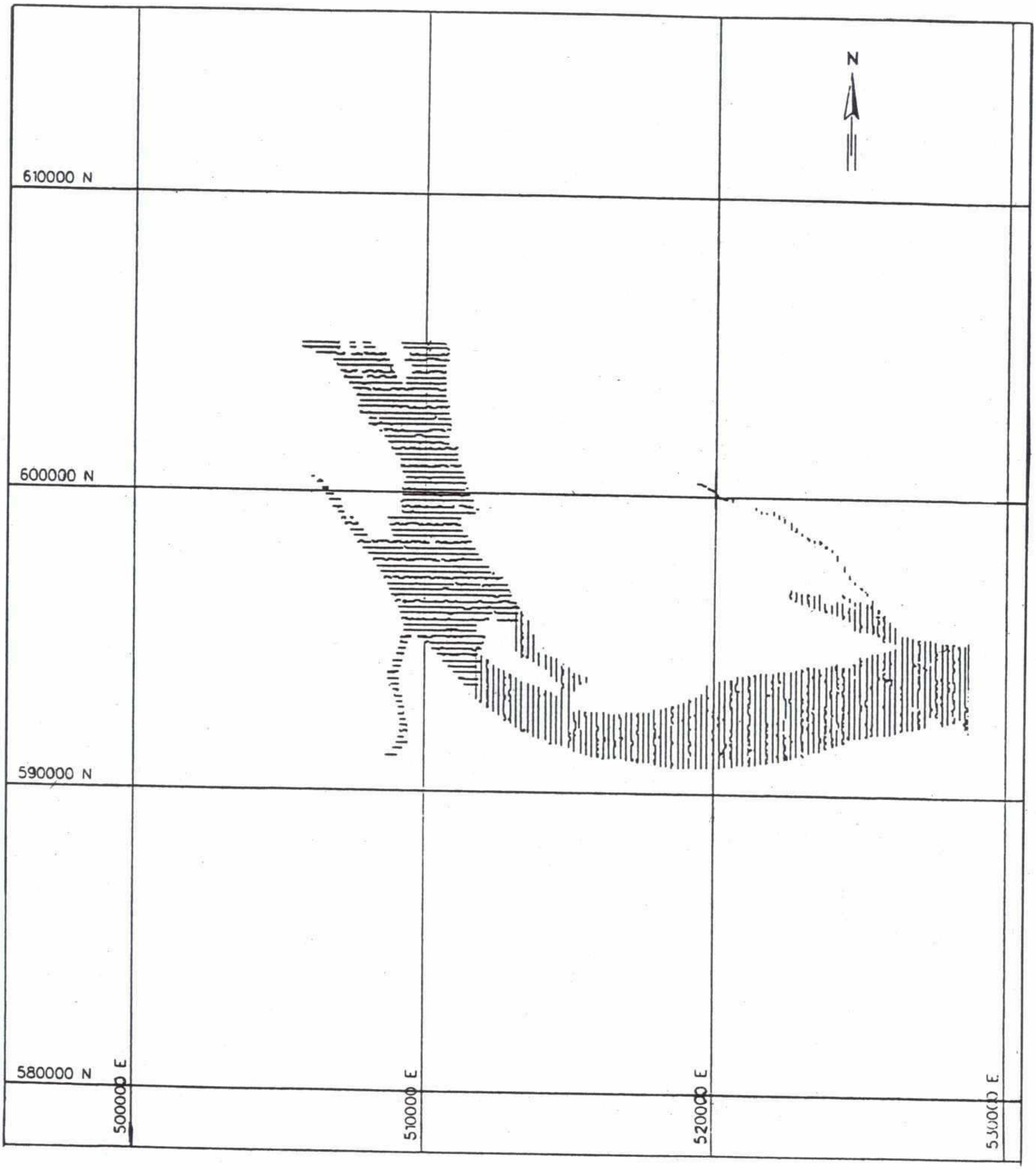

Figure B.33: Arial Khan Off-take, January 1994

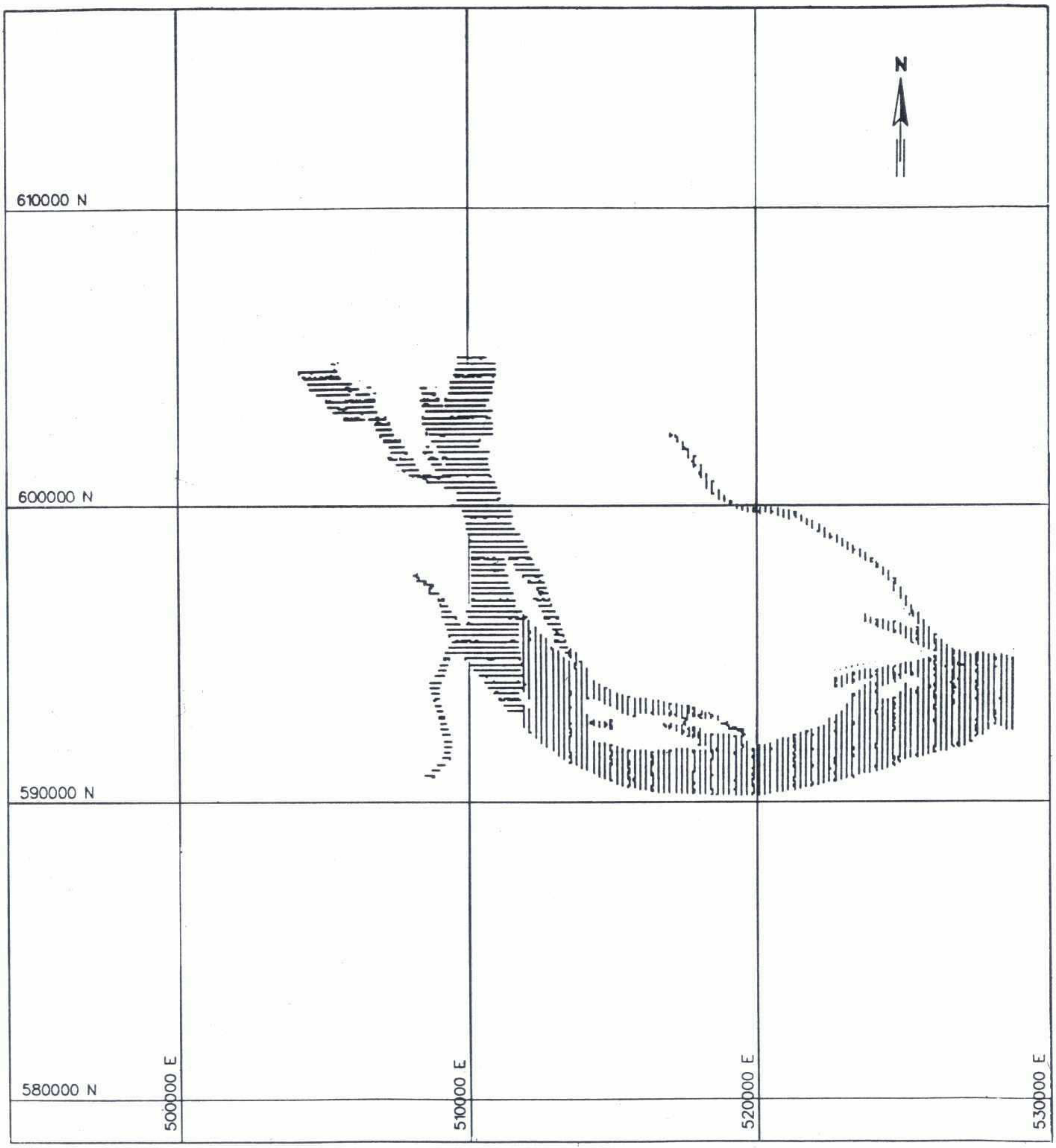

Figure B.34: Arial Khan Off-Take, February 1995

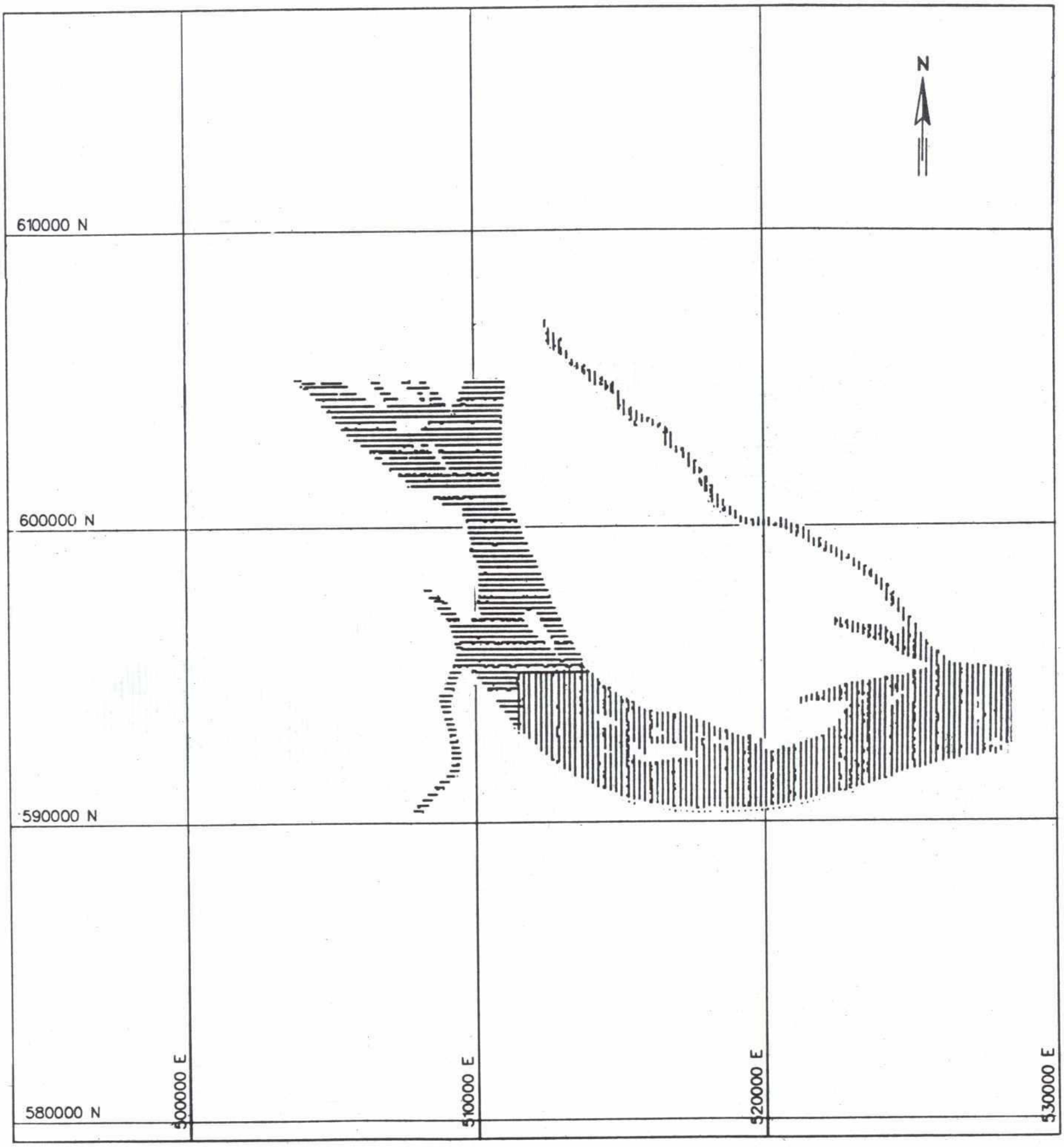

Figure B.35: Arial Khan Off-Take, April-May 1995

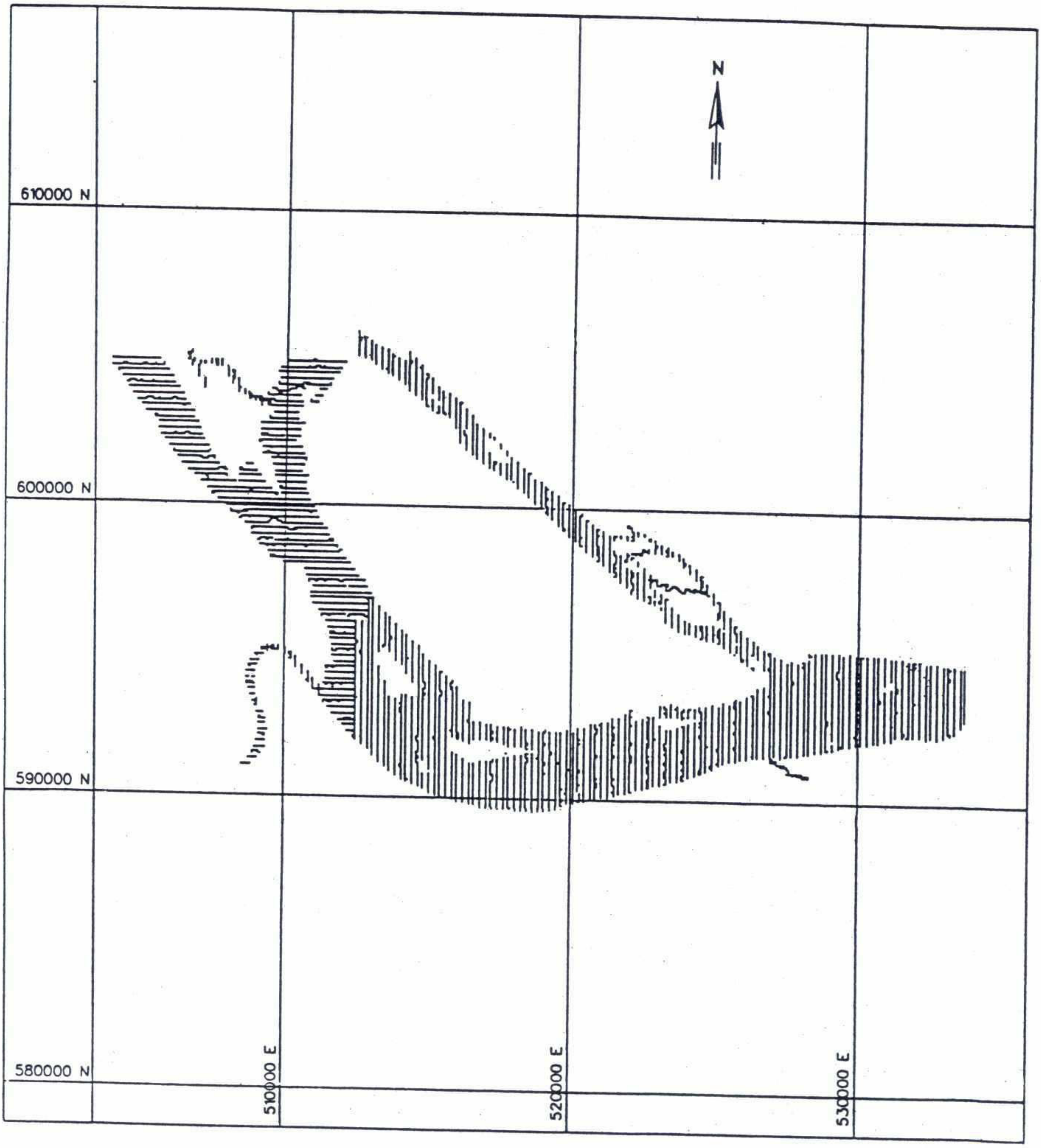

Figure B.36: Arial Khan Off-Take, February 1996