PART-II: FEASIBILITY STUDY FOR LAKHANDEI AND BABAI RIVER BASINS

CHAPTER 6 ADDITIONAL INVESTIGATIONS AND STUDIES

6.1 General

Two river basins, the Lakhandei and Babai river basins, were selected for the Feasibility Study. Supplemental and detailed data necessary for the Feasibility Study were collected for these two rivers.

The Study Team members visited the site of these river basins from time to time, to inspect conditions of the rainy season rivers and basins, to collect verbal information from the residents, and to discuss with the local government officials concerned on the flood mitigation plan.

Workshops were held on July 20 and 21, 1998 for the Babai river in Bardiya district and on August 18 and 19, 1998 for the Lakhandei river in Sarlahi district. The workshops aimed to seek inputs from district level line agencies, local authorities and communities on the flood mitigation problems; possible roles in effective project implementation; and ways for maximizing of participation.

6.2 Topographic Mapping and River Survey

Topographic Mapping: Topographic maps of scale 1/10,000 with the contour intervals at 2.5 meters were prepared for the riverine inundated area along the Lakhandei and Babai rivers based on 1/25,000 topographic maps supplementing with additional field survey data. The mapping area measures approximately 160 km^2 for the Lakhandei river, 145 km^2 for the Babai river, and 205 km^2 in total.

River Survey: River survey was carried out for the Lakhandei and Babai rivers selected for the Feasibility Study. The survey includes longitudinal, cross-sectional and flood-mark surveying along the rivers. Cross sections were surveyed approximately at one-km intervals, and the river length for the survey is about 100 km in total.

The river surveys were conducted, before the peak period of rainy season, from May to June in 1998 by the Nepalese surveying firms, TAEC Consult P. Ltd. for the Lakhandei river and by TECHDA (Technical Development Associates) (P) Ltd. for the Babai river.

6.3 Flood Flow Investigation

Objective: Flood flow investigation of the Lakhandei and Babai river basins aims to:

1) Collect information on flood flow conditions, by site inspection and interviews with VDC and the village people;
2) Delineate places and extent of flooding, sediment cover and bank erosion, by site inspection and interviews with VDC and the village people; and
3) Prepare flood and sediment hazard map based on the above results, upgrading the hazard map prepared in the master plan stage.

Field Investigation: Site inspection and interviews with VDC and the village people were performed at more than 50 sites for each river along the entire length of right and left riverbanks, to collect data and information relevant to the flood and sediment disasters:

Flood and Sediment Hazard Map: As a result of investigation, flood and sediment hazard maps were prepared as shown in Fig. 6.1 for the Lakhandei river and in Fig. 6.2 for the Babai river, based on the field investigation results, upgrading the hazard map prepared in the Master Plan stage. The hazard map indicates active bank erosion sites, sediment suffering lands and the maximum inundated areas.

6.4 Environmental Study

Introduction: Part-I Report (Master Plan Study) has outlined the environmental rules that are pertinent, if and when a project proposal is formulated as a result of the flood mitigation Master Plan (FMMP). An environmental screening has been done for all the eight rivers in the FMMP, and impacts were listed, both positive and negative, according to the social and natural environment and the possible pollution effects caused by the interventions. The overall conclusion of this screening is that the environmental impacts will be very positive.

Environmental Study: The study was put out for tender and the Contract was awarded to GEOCE Consultants (P) Ltd., Consulting Engineers, of Kathmandu. In accordance with the study program prepared by the Study Team, the environmental study was carried out as follows:

1) **General Environmental Inventory:** Because the various proposed

interventions may affect the people and their land along the banks of the two rivers, it was decided to undertake an inventory along these banks. The inventory documented land use, land ownership, houses (by type), other buildings and infrastructure in a belt up to 500-m wide on either side of the Lakhandei and Babai rivers in the Terai.

2) **Environmental Study (Babai River):** In order to test the Environmental Conservation Rules (ECR) of 1997, it was decided to undertake a study at specific sites on the Babai river where either an IEE or an EIA will be required, once a project is proposed and funds are allocated.
3) **Environmental Study (Lakhandei River):** When a watershed plan is proposed, an IEE is required. Thus, regarding the proposed watershed study, it was again decided to test the ECR by undertaking an environmental assessment in two of the sub-watershed areas of the Lakhandei river.

Results of Studies: The study report prepared as a result describes conditions along the river and the anticipated effects of flood mitigation measures at specific sites on the Babai river and in sub-catchment of the Lakhandei watershed. These findings are summarized in Table 6.1.

6.5 Watershed of Lakhandei River

The Lakhandei river was selected for an investigation of a comprehensive flood mitigation plan which includes the erosion control and soil conservation measures in the watershed area in addition to the flood mitigation measures in the Terai plain. In this regard, studies were made further for the Lakhandei watershed on the geological and topographic characteristics related to watershed management.

There is no mass movement such as debris flow and landslide in the Lakhandei watershed. Formation of the Lakhandei watershed is the middle Siwalik mainly composed of sandstone and mud stone. These are soft rocks that are easily weathered and transported to the Terai plain not as mass movement. The sediment problems in the watershed of the Lakhandei river are summarized below.

1) There are two major sources of sediment brought into the Terai plain. One is from the southern slope of Siwalik hills facing to the Terai plain and the other is from the side erosion of the main Lakhandei river in the middle watershed.
2) The southern slopes of Siwalik hills are steep with high relief. Sediment from

the southern slopes, of which basin areas range from 2 to 5 km^2, are finally transported by two tributaries, the Chapani and Baune rivers.

3) The middle watershed of the main Lakhandei river is relatively flat and low in elevation with river terraces along the river. The main Lakhandei river erodes these terraces and transports the sediments into the Terai plain.
4) In addition to the above, clearing of natural forests for cultivation and other domestic use may aggravate the sediment problems coupled with inherent poor geological situation.

6.6 Additional Findings on Channel Characteristics

(1) River Course Shifting of Lakhandei River

River course actively shifts in the lower reaches. Near the Padariya village, the Lakhandei river took route toward west since the 1997-flood season. This year (1998) floodwater of the Lakhandei river directly attacked Belhi village. The floodwater took several courses between Padariya and Belhi villages as shown in Fig. 6.3.

At about 400 m downstream of Phulparasi bridge of Hulaki Sadak road, flood water of the Lakhandei river often overflowed toward Inaruwa village. Before the this rainy season (1989), the VDC constructed an earth dike on right bank with sand bag spurs. At about 1.5 km downstream from the bridge, a new channel was formed on the left bank at the end of July 1989. Almost all the floodwater of the Lakhandei river flows through this new channel toward Bhadsar and Matahitol villages as shown in Fig. 6.4.

In order to look into the past shifting of river course over a longer period, topographic maps prepared in 1953/54 (scale: 1/50,000) and those in 1992 (scale: 1/25,00) were superimposed and shown in Fig. 6.5. According to the figure, the river course seems to remain within the meandering belt over the past 38 years, in spite of the active instantaneous river course shifting mentioned above.

(2) Channel Characteristics of Lakhandei River

The longitudinal profile of the Lakhandei river is shown in Fig. 6.6 based on the results of river survey conducted in May/June, 1998 by the Study Team. The Figure includes the profiles of the lowest riverbed, right and left riverbanks, mean riverbed and flood water levels of 1997-flood according to the new survey result and information obtained from residents.

Figure 6.7 and Table 6.2 show the principal characteristics of the Lakhandei river such as the overall channel profile, hydraulic mean depth, channel width, flow area, bank-full capacity and profile of the riverbed materials. From these data the Lakhandei river was divided into several river stretches. Average channel features of respective river stretches are summarized below.

(Average Channel Features: Lakhandei River)

River stretch	Bed slope (I)	River width (m)	Mean depth (m)	Flow area (m^2)	Bank-full capacity (m^3/s)
Segment 2-2:					
No.0-No.21	1/1,531~862	62	0.59	36	26
Segment 2-1:					
No.21-No.32	1/569	411	0.81	324	354
No.32-No.40	1/376	598	0.89	533	745
Segment 1:					
No.40-No.52	1/253~150	498	1.97	848	2,793

(3) Channel Characteristics of Babai River

The longitudinal profile of the Babai river is shown in Fig. 6.8 based on the results of river survey conducted in May/June, 1998 by the Study Team. The Figure includes the profiles of the lowest riverbed, right and left riverbanks, mean riverbed and flood water levels of 1995-flood according to the new survey result and information obtained from resident peoples.

Figure 6.9 and Table 6.3 show the principal characteristics of the Babai river such as the overall channel profile, hydraulic mean depth, channel width, flow area, bank-full capacity and profile of the riverbed materials. From these data the Babai river was divided into three river stretches. Average channel sizes of respective river stretches are summarized below.

(Average Channel Features: Babai River)

River stretch	Bed Slope (I)	River width (m)	Mean depth (m)	Flow area (m^2)	Bank-full capacity (m^3/sec)
Segment 2-2:					
No.0-No.13	1/3,716	407	3.21	1,264	1,511
No.13-No.30	1/1,820	471	2.42	1,094	1,600
Segment 2-1:					
No.30-No.37	1/1,000	623	2.53	1,534	2,610
Segment 1:					
No.37-No.46	1/436~383	804	2.38	1,796	3,932

6.7 Runoff and Flood Flow Analyses

6.7.1 Runoff Analysis

(1) Sub-basin Area

The Lakhandei river has a total area of 300 km^2 of which the main Lakhandei river shares 107 km^2 (36 % of the total basin area) before the confluence of the Chapani river. On the other hand the basin area of the Babai river is 3,425 km^2 in total. The watershed area upstream from the Babai barrage covers 3,002 km^2 (88% of the total basin area).

The plain basin is further divided into several sub-basins at the confluence of major tributaries and major structure sites for flood flow analysis. The sub-basin areas are shown in Tables 6.4 and 6.5 respectively for the Lakhandei and Babai rivers.

(2) Probable Peak discharge

The probable peak discharges estimated for the Master Plan study were adopted. The probable discharges of 2-year return periods at specific points are shown in Tables 6.4 and 6.5 respectively for the Lakhandei and Babai rivers.

(3) Base-flow Discharge

Base-flow discharge was studied based on the runoff records for 20 years at Babai river station (No.290). The base-flow is an assumed constant flow before and during the flood runoff due to rainfall. According to the study:

1) Average of annual maximum monthly discharges is 388 m^3/s, and
2) Average of monthly discharges of the months the annual maximum discharge occurred is 382 m^3/s.

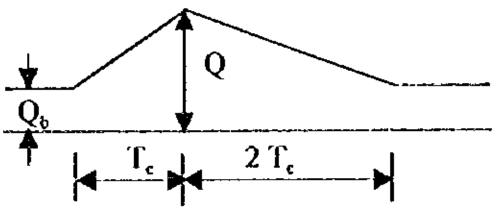
Based on the above, the base-flow at the Babai river station was assumed to be 390 m^3/sec. Base-flow discharges (Q_b) were assumed at the respective river sections of interest in the Babai and Lakhandei rivers, applying the same specific base-flow discharge (q_b) assumed at the Babai river station as follows:

q_b = 390 m^3/s / 3,002 km^2 = 0.13 $m^3/s/km^2$

Q_b = 0.13 $m^3/s/km^2$ x A, where A is a basin area in km^2.

(4) Discharge Hydrograph

Since the recorded runoff hydrograph was not available, the triangular discharge hydrograph was assumed as shown below for the present study.



Q : Peak discharge
Q_b: Base-flow discharge
T_c : Time of concentration

Recession period of flood is assumed to be twice of the time of concentration (T_c). The time of concentration (T_c) was estimated at the Chapani river junction for the Lakhandei river and at Babai barrage for the Babai river, using Kraven's empirical formula for natural mountainous basins as follows:

(Items)	(Lakhandei R.)	(Babai R.)
River length	20 km	154 km
Propagation velocity	3.5 m/s	3.5 m/s
Time of concentration (T_c)	2 hr	12 hr

Hourly discharges were estimated as shown in Tables 6.4 and 6.5 respectively for the Lakhandei and Babai rivers. Runoff from the residual basin is estimated as a balance of discharges at adjacent river sections for runoff calculation.

6.7.2 Flood Flow Analysis

(1) Methodology

Flood flow analysis was made using an unsteady flow simulation model. The model mainly consists of channel and flood plain models.

Channel Model:

1) Fundamental equations:

$$\frac{\eta}{g}\frac{\partial v}{\partial t}+\frac{a}{2g}\frac{\partial v^2}{\partial x}+\frac{\partial H}{\partial x}+\frac{n^2}{R^{4/3}}v|v|=0$$

$$\frac{\partial A}{\partial t}+\frac{\partial Q}{\partial x}=-q$$

2) Boundary conditions:

- Upper end: Discharge hydrograph
- Lower end: Water level hydrograph or stage-discharge curve

3) Channel data: Channel sections surveyed

Flood Plain Model:

1) Fundamental equations:

$$\frac{1}{g}\frac{\partial v_p}{\partial t}+\frac{\partial H_I}{\partial l}+f_p v_p\left|v_p\right|=0$$

$$F\frac{dH_p}{dt}=Q_{in}-Q_{out}$$

2) Boundary conditions: Various types of boundary conditions such culvert, canal, embankment, etc. can be incorporated at the boundary of the plain block.
3) Flood plain data: Plain areas at various elevations for each plain block.

Notations of Above Equations:

t	: Time
x	: Distance along river
Q and v	: Channel discharge and velocity
H, A and R	: Water level, flow area and hydraulic mean depth
n	: Manning's coefficient of roughness
g	: Acceleration of gravity
η , α	: Coefficients depending on velocity distribution
v_p	: Velocity at the joint of plain blocks
f_p	: Energy loss at the joint of plain blocks
$\delta H_I / \delta l$	: Surface slope in plain block
F, H_p	: Surface area and water level of in plain block
Q_{in} and Q_{out}	: Inflow and outflow of the plain block

(2) Results of Simulation

The model was first adjusted for each basin condition using the latest flood data, i.e., 1997-flood for the Lakhandei river and 1995-flood for the Babai river. Then the model was run under the following cases for 1.05, 2, 5, 10, 20, 50 and 100 year probable floods:

1) Flood flow under the present channel conditions
2) Flood flow confined within the present river area.

The results of calculations are shown in Fig. 6.10 and Table 6.6 for the Lakhandei river and Fig. 6.11 and Table 6.7 for the Babai river.

(Further in-depth descriptions on the investigations and studies of this chapter are compiled in SUPPORTING REPORT-A (A3: LAKHANDEI RIVER and A7: BABAI RIVER): FLOOD MITIGATION PLAN)

PRELIMINARY ENVIRONMENTAL STUDY
for
the Lakhandei and Babai Rivers

People and property close to the rivers in the Terai are most under threat from flooding and flood damage during the monsoons. Therefore, a Survey was undertaken in September of this year (1998) along the narrow strip of land on either side of the Lakhandei and Babai rivers. The purpose of the survey was to determine the number of people, buildings, the land use and the land ownership in this narrow belt. Estimates were made of the damage to property, riverbanks and land. A preliminary assessment of the economic and environmental cost has been made and is presented in the following tables.

Population and Buildings in the Area.

	Lakhandei	Babai
Length of river in the Terai (m)	50960	49840
Average width of strip surveyed (m)	345	409
Number of houses in the area	7748	1908
Number of other buildings	188	29
Number of people	39590	9820
Population density, (people per hectare)	11.3	2.4

The riverbank area is densely populated along the banks of the Lakhandei and at present there is a fairly low population density along the Babai.

Land Use pattern (Units: hectares)

	Lakhandei	%	Babai	%
Cultivated land	3025	85.9	1635	40.1
Barren land	154	4.4	455	11.1
Forest land	254	7.2	1960	48.1
Building area	79	2.2	21	0.5
Road/canal area	11	0.3	8	0.2
Total area	3523	100.0	4079	100.0

Cultivated land, practically all private, accounts for 86% of land use in the Lakhandei, whereas along the Babai river, forest land at 48% is the largest form of land use. Over 40% of the forest land are communal in the Babai, but it is less than 1% in the Lakhandei.

Estimated Damage.

	Lakhandei	%	Babai	%
Houses destroyed or moved in 1998	75	1.0	50	2.6
Houses in danger from flood damage	65	0.8	66	3.5
Length of river bank erosion (m)	11500	11.3	5295	5.3
Length of road damage (m)	1800	4.6	0	0.0

Estimated Area Damaged (hectares).

	Lakhandei	Babai
Riverside land eroded and lost (average depth 10 m)	12	5
Land inundated with coarse material	165	120
Land flooded	1200	520

Estimated Loss of Crops and Land in Weight and Value Terms.

	Lakhandei		Babai	
	t.	$	t.	$
Land permanently lost ($ 4800 per ha)		57600		24000
Permanent crop loss (2.8 t/ha – 2 crops/yr)	67	13400	28	5600
Land inundated with coarse material. Cost of reclamation ($ 1600 per ha)		264000		192000
Temporary loss of crops (5.6 t/ha)	924	184800	672	134400
Flooded land rehabilitation ($ 50 per ha)		60000		26000
Loss of 1 crop (2.8t/ha)	3360	672000	1456	291000
Total	4351	1251000	2156	673200

Note: the loss of crops is given in rice equivalent terms, valued at $ 200/t. ex-farm.

Estimated Loss of Animals.

	Lakhandei		Babai	
	number	$	number	$
Cattle ($ 50 each)	120	6500	55	2750
Goats/sheep ($ 10 each)	260	2600	115	1150
Poultry ($ 1 each)	950	950	410	410
Total	1330	10050	580	4310

Estimated Infrastructure Repair Costs.

	Lakhandei		Babai	
	number	$	number	$
Houses destroyed/removed ($ 1000/house)	75	75000	50	50000
Houses to be reinforced ($ 100 per house)	65	6500	66	6600
Road repair ($ 50/m)	1800 m	90000	0	0
Total		171500		56600

Estimated Total Cost of Flood Damage.

	Lakhandei	Babai
Total Damage in 1998 ($)	1,433,350	734,110

The physical environmental costs include the loss of habitat, pollution of water and land. The social environmental costs include destruction and damage to property and the infrastructure and an increase in the incidence of diseases. Much of the above damage could have been prevented with adequate flood prevention measures. Unless this is done, land will be eroded continually and lost and several houses will be destroyed each year. When a project is proposed, an IEE is required to assess the impact on endangered houses and other buildings.

ENVIRONMENTAL STUDY FOR LAKHANDEI WATERSHED AREA

An environmental study was undertaken in September 1998 in two sub-catchment areas of the Lakhandei water catchment area. The study area covered two streams in the far west of the water catchment, namely the Chapani khola and the Kothi khola. Their total area is about 1,400 hectares and the land use pattern is given in the following table.

Land Use Pattern in the Study Area.

	Chapani khola		Kothi khola		Total	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Forest land	410	54	350	53	760	54
Agricultural land	310	40	280	43	590	41
River bed	40	5	20	3	60	4
Infrastructure	5	1	5	1	10	1
Total	**765**	**100**	**655**	**100**	**1,420**	**100**
Length of stream (m)	4,600 m		4,200 m		8,800 m	

Even though this is a watershed area, and farming is not supposed to occur, about 40% of the land are farmed, much of which are not terrace. An estimated 3,226 people live in these two areas in 539 houses. Practically all these people do not have title to the land they farm. Most of the people (about 80%) are farmers, but some are labourers, shop keepers or have cottage industries.

Forest land.
On the 760 hectares of forest land, the average stocking of trees above 20 cm. diameter is about 800 per hectare and there are about 3,900 small trees or bushes per hectare. Thus the total stocking density is 4,700 trees per hectare. This is a high density. To encourage deep rooting and strong growth of the trees, the stocking density could initially be reduced by half. The estimated standing volume of trees above 20 cm. diameter is about 590 cubic metres per hectare, (including branch wood); this is a well-stocked forest.

Agricultural land.
The estimated annual production of cereals is 450 t. with a net yield of about 0.6t. ha. On average, about 60 t. of cereals are lost each year due to flood damage. This is a low per hectare yield, due to poor soil, lack of fertilizers and inappropriate land management practices – much of the land is not terraced or protected against erosion. The production from cash crops such as potatoes and pulses is about 240 tonnes, with a yield of 0.7 t/ha (potatoes 3.5 t/ha). There are about 8,000 livestock in the area, 40% are large animals, 33% goats and 27% poultry.

Environmental damage.
Several landslides occurred last year in the forest. There was bank erosion along the streams and gully erosion, especially on the farm land. The monsoon floods damaged about 150 hectares or 25% of the farm land. The estimated value of crops lost last year was $ 22,400. The rural road built in Kothi khola in 1997 was severely damaged during the monsoons. Some sections were washed out and it is now impassible for vehicles or even animal carts. Some parts were turned into a stream. No environmental assessment was undertaken before construction. This should have been done according to the Environmental Conservation Rules. The alignment is too steep and unless it is realigned with gentle slopes, it will be washed away.

Watershed Plan.
In order to reduce the amount of sediment being washed out from this watershed area, protection has to be undertaken in three areas.

First and foremost agricultural practices have to be improved through terracing, incorporating bioengineering practices in the agricultural system (grass and trees – especially nitrogen fixing trees) and prohibiting farming within about 20 to 50 metres of the streams. This strip of land should be planted with grass and fodder trees etc. Most animals are stall-fed, but more could be stall-fed, this could prevent some erosion in forest areas. These measures will not only curtail soil erosion, but also improve crop yields and animal production.

Secondly, there should be bank protection with gabions etc. and plants. Existing gullies should be plugged and measures taken to protect existing roads and paths, through realignment and soil stabilization along these routes.

Thirdly, the forest should be managed to try and minimize erosion. It would be most appropriate if the forests were managed on a community basis. The trees could be thinned out annually, thus allowing the remaining trees to grow more rapidly and have a stronger root system. By following this prescription, there should be a much larger sustainable yield of forest products from the area. This will increase the income for the people living in the area and ensure that the forest will be fully protected, rather than being mismanaged and encroached upon.

All these measures should ensure that the sediment flow from the area to the Terai is reduced and that the environmental (economic and social) conditions in the sub-watershed areas are improved.

ENVIRONMENTAL STUDY ALONG BABAI RIVER

The Flood Mitigation master Plan has recommended that protection work be undertaken along the Babai river in the Terai. According to the Environmental Protection Rules, some of these interventions will have to have an environmental assessment undertaken on them, if and when the plan is acted upon and a project is undertaken. In anticipation of a project proposal, four sites along the Babai river, which will require an assessment at the project proposal stage, were studied for possible environmental impacts as a result of the proposed initiatives.

At three sites, bank strengthening over a stretch of more that one-kilometer is proposed, whereas at the other site, it is proposed to straighten the river channel by eliminating two large bends. An alternative to river strengthening at one site is to realign the river from a sharp bend to gradual smooth bend.

The purpose of these various initiatives is to protect irrigation canal intakes, to prevent irrigated land from being damaged, to reduce bank erosion, to stop the river from taking its old course and to reclaim some land.

Environmental Costs and Benefits.

The study found that at all sites the environmental benefits far outweigh the costs. At the first site about 900 hectares of irrigated land will be protected and riverbank erosion will be minimized. There are no environmental costs at this site.

At the second site, the erosion caused a village of about 20 houses to be washed away. These people are living in temporary shelters in a forest plantation. Some farmland was also washed away and other areas covered with coarse sand and gravel. About 5 old protected sal trees, which are stabilizing the southern bank of the river were washed away. This bank is very close to a main gravel road that is in danger of being eroded along this stretch of the river. In addition about 25 trees on the northern bank are being destroyed because of bank erosion.

The river takes a sharp bend at this point. As an alternative, it is proposed to redirect the river and form a gradual bend at this point. About 9 hectares of government forest will have to be cut down in order to form the new channel. This will regulate the flow of the river at this point and protect houses, agricultural land and the road. More than 9 hectares of land could be reclaimed. Thus again the environmental benefits far outweigh costs.

At the third site, bank protection is needed to prevent the river from taking its old course. If it did it would seriously damage the main town in the area, - Gulariya – as well as much farmland and the "Black Buck" conservation area. No environmental costs are envisaged at this site.

The fourth site is near Gulariya town. At this point the river meanders considerably and both banks are affected by erosion. It is proposed to straighten the river and protect the new banks. About 50 hectares of agricultural land and 2 hectares of forest would be lost. On the other hand about 200 hectares of land would be reclaimed. Thus again the benefits far outweigh the costs.

This environmental study has generated very useful information about population, land use, animal and plant vegetation, river water quality and likely impacts of initiatives proposed in the Flood Mitigation Master Plan. Most of the environmental benefits are positive and are significantly greater than the environmental costs.

PRINCIPAL CHANNEL CHARACTERISICS OF LAKHANDEI RIVER

Sect. No	Distance from border X (km)	River width B (m)	Section area A (m2)	Mean depth R (m)	Bank height Hm (El.m)	Channel slope I	Manning's roughness n	Channel capacity Qch (m3/s)	River segment No
NO.0	0	15.4	9.5	0.604	75.176	1/1,531	0.030	6	2-2
NO.1	0.92	23.4	18.0	0.755	75.845	1/1,531	0.030	13	2-2
NO.2	1.69	38.6	25.3	0.643	76.607	1/1,531	0.030	16	2-2
NO.3	2.71	38.8	35.0	0.893	76.867	1/1,531	0.030	28	2-2
NO.4	3.32	59.7	22.8	0.379	77.661	1/1,531	0.030	10	2-2
NO.5	3.93	21.8	6.4	0.289	78.001	1/1,531	0.030	2	2-2
NO.6	4.85	20.4	6.4	0.311	78.559	1/1,531	0.030	3	2-2
NO.7	5.83	8.9	1.7	0.192	79.418	1/1,531	0.030	0	2-2
NO.8	6.83	16.6	7.7	0.457	79.823	1/1,531	0.030	4	2-2
NO.9	7.58	42.0	18.3	0.432	80.788	1/1,531	0.030	9	2-2
NO.10	8.55	42.7	30.9	0.720	80.990	1/1,531	0.030	21	2-2
NO.11	9.58	62.9	53.5	0.845	81.875	1/1,531	0.030	41	2-2
NO.12	10.58	47.1	42.7	0.897	82.213	1/1,531	0.030	34	2-2
NO.13	11.58	66.5	56.1	0.838	82.512	1/1,531	0.030	42	2-2
NO.14	12.60	51.4	56.9	1.099	83.391	1/1,531	0.030	52	2-2
NO.15	13.62	46.4	39.7	0.840	84.070	1/862	0.030	40	2-2
NO.16	14.75	63.2	30.9	0.487	85.493	1/862	0.030	22	2-2
NO.17	15.99	91.1	33.4	0.366	86.794	1/862	0.030	19	2-2
NO.18	16.80	82.7	22.3	0.269	87.981	1/862	0.030	11	2-2
NO.19	17.52	77.0	59.0	0.765	88.475	1/862	0.030	56	2-2
NO.20	18.60	134.6	72.8	0.541	89.849	1/862	0.030	55	2-2
NO.21	20.12	322.9	133.0	0.412	91.398	1/862	0.030	84	2-2
NO.22	21.12	408.6	328.4	0.803	92.767	1/569	0.035	340	2-1
NO.23	22.27	560.4	373.1	0.665	94.455	1/569	0.035	341	2-1
NO.24	23.29	327.5	313.7	0.957	96.163	1/569	0.035	365	2-1
NO.25	24.16	338.3	280.3	0.828	97.672	1/569	0.035	296	2-1
NO.26	25.18	204.4	159.3	0.779	99.001	1/569	0.035	162	2-1
NO.27	26.12	442.5	423.5	0.957	100.584	1/569	0.035	493	2-1
NO.28	27.36	336.0	234.8	0.698	102.772	1/569	0.035	221	2-1
NO.29	28.30	699.3	367.8	0.526	104.764	1/569	0.035	287	2-1
NO.30	29.13	351.0	191.5	0.545	106.255	1/569	0.035	153	2-1
NO.31	30.13	407.5	633.2	1.550	108.070	1/569	0.035	1,016	2-1
NO.32	31.36	443.9	260.6	0.587	110.413	1/569	0.035	219	2-1
NO.33	32.28	345.6	403.0	1.164	112.396	1/376	0.035	657	2-1
NO.34	33.29	652.2	765.9	1.172	114.738	1/376	0.035	1,254	2-1
NO.35	34.34	731.3	551.1	0.753	117.367	1/376	0.035	672	2-1
NO.36	35.42	452.6	395.1	0.872	119.838	1/376	0.035	531	2-1
NO.37	36.32	677.2	698.0	1.029	122.251	1/376	0.035	1,048	2-1
NO.38	37.43	566.8	540.1	0.952	124.988	1/376	0.035	770	2-1
NO.39	38.42	554.7	306.6	0.553	127.657	1/376	0.035	304	2-1
NO.40	39.44	736.9	676.4	0.917	130.453	1/376	0.035	941	2-1
NO.41	40.44	582.8	387.8	0.665	134.095	1/253	0.040	464	1
NO.42	41.48	339.2	633.4	1.864	138.056	1/253	0.040	1,507	1
NO.43	42.53	351.9	312.4	0.885	142.365	1/253	0.040	452	1
NO.44	43.47	251.5	201.3	0.800	146.050	1/197	0.040	309	1
NO.45	44.39	781.8	1501.2	1.919	150.861	1/197	0.040	4,126	1
NO.46	45.41	502.8	1126.5	2.235	155.845	1/197	0.040	3,428	1
NO.47	46.42	709.4	1059.5	1.487	160.863	1/197	0.040	2,457	1
NO.48	47.34	867.1	771.4	0.890	165.671	1/150	0.040	1,458	1
NO.49	48.27	775.1	1433.1	1.847	171.173	1/150	0.040	4,409	1
NO.50	49.44	630.1	1025.9	1.628	177.712	1/150	0.040	2,901	1
NO.51	50.46	291.6	536.4	1.838	184.092	1/150	0.040	1,645	1
NO.52	50.96	205.1	1618.7	7.735	189.855	1/150	0.040	12,937	1

PRINCIPAL CHANNEL CHARACTERISICS OF BABAI RIVER

Sect. No	Distance from border X (km)	River width B (m)	Section area A (m2)	Mean depth R (m)	Bank height Hm (El.m)	Channel slope I	Manning's roughness n	Channel capacity Qch (m3/s)	River segment No
NO.1	0	240.2	998.8	4.125	136.685	1/3,716	0.030	1,405	2-2
NO.2	0.77	404.7	1228.3	3.007	138.044	1/3,716	0.030	1,399	2-2
NO.3	1.60	219.1	852.3	3.804	136.726	1/3,716	0.030	1,136	2-2
NO.4	3.24	518.1	1621.4	3.113	137.097	1/3,716	0.030	1,890	2-2
NO.5	4.08	472.0	1195.4	2.519	138.531	1/3,716	0.030	1,210	2-2
NO.6	4.80	627.7	1533.3	2.427	138.573	1/3,716	0.030	1,514	2-2
NO.7	5.57	633.7	2247.7	3.529	137.401	1/3,716	0.030	2,849	2-2
NO.8	6.90	459.4	969.3	2.098	138.852	1/3,716	0.030	869	2-2
NO.9	8.03	249.5	883.8	3.482	137.928	1/3,716	0.030	1,110	2-2
NO.10	9.39	447.7	1823.4	4.034	138.046	1/3,716	0.030	2,527	2-2
NO.11	10.00	410.3	760.1	1.845	139.305	1/3,716	0.030	625	2-2
NO.12	10.87	230.3	1034.5	4.465	138.355	1/3,716	0.030	1,534	2-2
NO.13	12.01	382.6	1286.4	3.340	140.030	1/3,716	0.030	1,572	2-2
NO.14	12.78	533.9	786.6	1.466	140.124	1/1,820	0.030	793	2-2
NO.15	14.06	656.6	1089.1	1.654	140.456	1/1,820	0.030	1,190	2-2
NO.16	14.98	761.7	2515.2	3.292	140.708	1/1,820	0.030	4,348	2-2
NO.17	16.08	877.7	1008.0	1.146	141.884	1/1,820	0.030	862	2-2
NO.18	17.42	207.8	415.8	1.998	141.602	1/1,820	0.030	515	2-2
NO.19	18.57	404.1	950.8	2.322	142.468	1/1,820	0.030	1,303	2-2
NO.20	20.11	576.4	946.7	1.637	144.103	1/1,820	0.030	1,027	2-2
NO.21	21.10	326.9	488.6	1.493	143.808	1/1,820	0.030	499	2-2
NO.22	21.94	474.9	893.1	1.880	144.690	1/1,820	0.030	1,063	2-2
NO.23	22.36	390.6	1110.5	2.822	144.278	1/1,820	0.030	1,733	2-2
NO.24	24.30	674.1	2067.6	3.055	145.575	1/1,820	0.030	3,401	2-2
NO.25	25.45	271.9	1011.7	3.696	145.724	1/1,820	0.030	1,890	2-2
NO.26	27.39	500.6	1214.0	2.415	147.635	1/1,820	0.030	1,707	2-2
NO.27	28.52	323.6	1031.4	3.155	147.245	1/1,820	0.030	1,733	2-2
NO.28	29.51	386.4	765.3	1.970	147.950	1/1,820	0.030	940	2-2
NO.29	30.35	309.9	1159.2	3.723	148.197	1/1,820	0.030	2,176	2-2
NO.30	30.96	328.9	1135.9	3.437	148.923	1/1,820	0.030	2,021	2-2
NO.31	32.29	951.5	1866.9	1.958	150.842	1/1,000	0.035	2,640	2-1
NO.32	33.48	382.8	1371.4	3.578	151.672	1/1,000	0.035	2,899	2-1
NO.33	34.50	635.0	2062.3	3.230	153.240	1/1,000	0.035	4,071	2-1
NO.34	36.01	515.9	1111.1	2.139	154.451	1/1,000	0.035	1,667	2-1
NO.35	37.42	583.1	954.2	1.634	157.636	1/1,000	0.035	1,196	2-1
NO.36	38.42	646.8	1522.5	2.349	158.621	1/1,000	0.035	2,430	2-1
NO.37	39.80	647.1	1851.5	2.852	160.638	1/1,000	0.035	3,364	2-1
NO.38	40.81	832.1	1342.0	1.608	162.782	1/436	0.040	2,204	1
NO.39	42.04	1401.8	3558.4	2.533	166.417	1/436	0.040	7,915	1
NO.40	43.44	626.4	1401.2	2.226	169.114	1/436	0.040	2,859	1
NO.41	44.59	793.5	2193.2	2.720	171.770	1/436	0.040	5,115	1
NO.42	45.50	1075.3	1936.8	1.789	173.531	1/383	0.040	3,646	1
NO.43	46.45	1287.3	2539.1	1.972	176.528	1/383	0.040	5,101	1
NO.44	47.71	500.4	740.0	1.473	179.117	1/383	0.040	1,224	1
NO.45	48.90	415.3	1113.0	2.677	182.573	1/383	0.040	2,742	1
NO.46	49.84	304.8	1338.4	4.383	184.867	1/383	0.040	4,580	1

Table 6.4

BASIN AREA AND RUNOFF HYDROGRAPHS: LAKHANDEI RIVER

Creager's C = 6.0 for 2~years flood

Section	#1	#2	#3	#4	#5	#6
Location	No.44	No.40	No.37	No.29	No.12	No.4
	+950m	+200m	+600m	+250m	+700m	+300m
$dA(km^2)$	107	48	19	34	81	11
$A(km^2)$	107	155	174	208	289	300
C	6.0	6.0	6.0	6.0	6.0	6.0
$Q(m^3/s)$	242	302	323	357	428	437
$Q_b(m^3/s)$	14	20	23	27	38	39

DISCHARGE HYDROGRAPHS:

Time (hr)	Q#1 (m^3/s)	dQ (m^3/s)	Q#2 (m^3/s)	dQ (m^3/s)	Q#3 (m^3/s)	dQ (m^3/s)	Q#4 (m^3/s)	dQ (m^3/s)	Q#5 (m^3/s)	dQ (m^3/s)	Q#6 (m^3/s)
0	14	6	20	2	23	4	27	11	38	1	39
1	128	33	161	12	173	19	192	41	233	5	238
2	242	60	302	21	323	34	357	71	428	9	437
3	185	46	232	16	248	27	275	56	331	7	338
4	128	33	161	12	173	19	192	41	233	5	238
5	71	20	91	7	98	12	110	26	135	3	139
6	14	6	20	2	23	4	27	11	38	1	39

Table 6.5

BASIN AREA AND RUNOFF HYDROGRAPHS: BABAI RIVER

Creager's C = 11.1 for 2-year flood

Section	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
Location	No.46 +150m	No.44 +850m	No.36 +700m	No.28 +0m	No.25 +800m	No.23 +900m	No.18 +700m	No.15 +1050m	No.8 +400m	No.3 +400m
$dA(km^2)$	3002	6	12	36	15	38	83	132	92	9
$A(km^2)$	3002	3008	3020	3056	3071	3109	3192	3324	3416	3425
C	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1	11.1
$Q(m^3/s)$	2374	2376	2380	2391	2396	2408	2433	2473	2499	2502
$Q_b(m^3/s)$	390	391	392	397	399	404	415	432	444	445

DISCHARGE HYDROGRAPHS

Time (hr)	Q#1 (m^3/s)	dQ (m^3/s)	Q#2 (m^3/s)	dQ (m^3/s)	Q#3 (m^3/s)	dQ (m^3/s)	Q#4 (m^3/s)	dQ (m^3/s)	Q#5 (m^3/s)	dQ (m^3/s)	Q#6 (m^3/s)	dQ (m^3/s)	Q#7 (m^3/s)	dQ (m^3/s)	Q#8 (m^3/s)	dQ (m^3/s)	Q#9 (m^3/s)	dQ (m^3/s)	Q#10 (m^3/s)
0	390	1	391	2	392	5	397	2	399	5	404	11	415	17	432	12	444	1	445
1	555	1	556	2	558	5	563	2	565	6	571	12	583	19	602	13	615	1	616
2	721	1	722	2	724	6	729	2	732	6	738	13	751	21	772	14	786	1	788
3	886	1	887	2	889	6	896	3	898	7	905	14	919	23	942	16	958	2	959
4	1051	1	1052	2	1055	7	1062	3	1065	7	1072	16	1087	25	1112	17	1129	2	1131
5	1217	1	1218	2	1220	7	1228	3	1231	8	1239	17	1256	26	1282	18	1300	2	1302
6	1382	1	1383	3	1386	8	1394	3	1397	8	1406	18	1424	28	1452	19	1472	2	1473
7	1547	1	1549	3	1552	9	1560	4	1564	9	1573	19	1592	30	1622	21	1643	2	1645
8	1713	2	1714	3	1717	9	1726	4	1730	10	1740	21	1760	32	1792	22	1814	2	1816
9	1878	2	1880	3	1883	10	1893	4	1897	10	1907	22	1928	34	1962	23	1985	2	1988
10	2043	2	2045	3	2048	10	2059	4	2063	11	2074	23	2097	36	2132	24	2157	2	2159
11	2209	2	2210	4	2214	11	2225	4	2229	11	2241	24	2265	38	2302	26	2328	2	2331
12	2374	2	2376	4	2380	11	2391	5	2396	12	2408	25	2433	40	2473	27	2499	3	2502
13	2291	2	2293	4	2297	11	2308	5	2313	12	2324	25	2349	39	2387	26	2414	3	2416
14	2209	2	2210	4	2214	11	2225	4	2229	11	2241	24	2265	38	2302	26	2328	2	2331
15	2126	2	2128	4	2131	11	2142	4	2146	11	2157	24	2181	37	2217	25	2242	2	2245
16	2043	2	2045	3	2048	10	2059	4	2063	11	2074	23	2097	36	2132	24	2157	2	2159
17	1961	2	1962	3	1966	10	1976	4	1980	10	1990	22	2013	35	2047	24	2071	2	2073
18	1878	2	1880	3	1883	10	1893	4	1897	10	1907	22	1928	34	1962	23	1985	2	1988
19	1795	2	1797	3	1800	9	1809	4	1813	10	1823	21	1844	33	1877	23	1900	2	1902
20	1713	2	1714	3	1717	9	1726	4	1730	10	1740	21	1760	32	1792	22	1814	2	1816
21	1630	1	1631	3	1634	9	1643	4	1647	9	1656	20	1676	31	1707	21	1729	2	1731
22	1547	1	1549	3	1552	9	1560	4	1564	9	1573	19	1592	30	1622	21	1643	2	1645
23	1465	1	1466	3	1469	8	1477	3	1481	9	1489	19	1508	29	1537	20	1557	2	1559
24	1382	1	1383	3	1386	8	1394	3	1397	8	1406	18	1424	28	1452	19	1472	2	1473
25	1299	1	1301	3	1303	8	1311	3	1314	8	1322	18	1340	27	1367	19	1386	2	1388
26	1217	1	1218	2	1220	7	1228	3	1231	8	1239	17	1256	26	1282	18	1300	2	1302
27	1134	1	1135	2	1138	7	1145	3	1148	8	1155	16	1172	26	1197	18	1215	2	1216
28	1051	1	1052	2	1055	7	1062	3	1065	7	1072	16	1087	25	1112	17	1129	2	1131
29	969	1	970	2	972	7	979	3	981	7	988	15	1003	24	1027	16	1043	2	1045
30	886	1	887	2	889	6	896	3	898	7	905	14	919	23	942	16	958	2	959
31	803	1	804	2	806	6	812	3	815	6	821	14	835	22	857	15	872	1	874
32	721	1	722	2	724	6	729	2	732	6	738	13	751	21	772	14	786	1	788
33	638	1	639	2	641	6	646	2	649	6	654	13	667	20	687	14	701	1	702
34	555	1	556	2	558	5	563	2	565	6	571	12	583	19	602	13	615	1	616
35	473	1	473	2	475	5	480	2	482	5	487	11	499	18	517	13	529	1	531
36	390	1	391	2	392	5	397	2	399	5	404	11	415	17	432	12	444	1	445

RESULT OF FLOOD FLOW ANALYSIS (LAKHANDEI RIVER WITHOUT PROJECT)

No.	Section	Distance (m)	2 - year H (m, MSL)	2 - year Q (m³/s)	5 - year H (m, MSL)	5 - year Q (m³/s)	10 - year H (m, MSL)	10 - year Q (m³/s)	20 - year H (m, MSL)	20 - year Q (m³/s)	50 - year H (m, MSL)	50 - year Q (m³/s)	100 - year H (m, MSL)	100 - year Q (m³/s)
1	NO.0	0	75.949	45	75.949	31	75.949	33	75.949	32	75.870	151	75.870	109
2	NO.1	900	76.715	49	76.715	92	76.715	107	76.715	103	76.748	115	76.748	138
3	NO.2	1,600	77.798	53	77.800	108	77.803	126	77.804	125	77.825	145	77.838	171
4	NO.3	2,500	78.520	111	78.524	177	78.525	185	78.526	202	78.263	226	78.296	258
5	NO.6	4,550	80.412	31	80.536	63	80.561	83	80.580	109	80.628	139	80.669	164
6	NO.7	5,500	80.586	96	80.586	119	80.619	135	80.661	175	80.730	208	80.789	230
7	NO.8	6,500	80.638	83	80.653	108	80.722	117	80.773	147	80.849	170	80.909	173
8	NO.9	7,250	81.416	71	81.416	85	81.416	92	81.416	111	81.457	128	81.456	133
9	+360m	7,600	81.882	110	81.882	110	81.882	110	81.883	116	81.938	131	81.968	142
10	NO.10	8,200	82.944	143	82.944	143	82.956	143	83.047	143	83.180	159	83.284	159
11	NO.11	9,200	83.635	151	83.635	151	83.635	151	83.635	151	83.742	173	83.742	173
12	NO.12	10,100	84.172	152	84.172	166	84.172	191	84.172	208	84.276	233	84.276	259
13	NO.13	11,100	84.635	196	85.077	196	85.242	196	85.374	196	85.535	220	35.721	220
14	NO.14	11,950	85.021	106	85.271	106	85.385	106	85.491	107	85.626	119	85.796	119
15	NO.15	12,900	85.911	125	85.907	125	86.007	125	86.061	125	86.145	144	86.250	144
16	NO.16	13,950	86.784	108	86.784	108	86.784	108	86.903	108	86.894	122	86.885	122
17	NO.17	15,150	88.131	117	88.290	117	88.243	117	88.221	128	88.272	136	88.269	137
18	NO.18	15,950	89.002	124	89.064	148	89.098	159	89.117	166	89.154	173	89.267	187
19	NO.19	16,650	89.918	183	90.040	215	90.082	253	90.193	273	90.126	290	90.197	286
20	NO.20	17,700	91.355	208	91.174	264	91.276	303	91.339	312	91.416	348	91.536	354
21	NO.21	19,200	92.233	286	92.344	406	92.412	480	92.430	504	92.459	537	92.501	594
22	NO.22	20,100	93.621	286	93.802	407	93.894	481	93.921	505	93.992	538	94.101	606
23	NO.23	21,200	95.233	288	95.436	412	95.560	485	95.628	493	95.649	516	95.686	600
24	NO.24	22,200	96.998	289	97.312	416	97.415	486	97.406	480	97.455	513	97.580	587
25	NO.25	23,000	98.545	289	98.722	347	98.822	400	98.817	398	98.864	424	98.946	481
26	NO.26	24,000	100.234	292	100.344	404	100.447	462	100.442	458	100.486	482	100.614	528
27	NO.27	24,900	101.420	293	101.665	394	101.773	449	101.763	446	101.809	467	101.897	539
28	NO.28	26,150	103.605	298	103.760	453	103.828	575	103.827	573	103.861	573	103.961	589
29	NO.29	27,050	105.312	299	105.522	494	105.674	620	105.686	688	105.682	736	105.684	785
30	NO.30	27,850	107.017	295	107.273	472	107.395	579	107.473	661	107.527	729	107.570	790
31	NO.31	28,850	108.850	296	109.104	474	109.238	580	109.335	663	109.417	724	109.484	781
32	NO.32	30,050	111.121	297	111.382	476	111.519	584	111.617	666	111.683	820	111.739	916
33	NO.33	30,950	113.250	297	113.501	477	113.634	585	113.729	668	113.891	831	113.986	941
34	NO.34	31,900	115.239	299	115.506	479	115.645	587	115.744	671	115.926	835	116.040	945
35	NO.35	32,900	117.773	300	118.018	481	118.149	591	118.241	675	118.413	842	118.520	953
36	NO.36	33,950	120.424	301	120.680	483	120.812	595	120.905	678	121.080	848	121.190	957
37	NO.37	34,850	122.615	302	122.887	485	123.032	597	123.133	681	123.324	853	123.439	966
38	+480m	35,400	124.266	303	124.587	486	124.746	599	124.854	683	125.060	857	125.184	969
39	NO.38	35,930	125.536	288	125.837	459	126.001	566	126.114	646	126.361	743	126.501	836
40	NO.39	36,930	128.181	291	128.371	474	128.479	591	128.550	704	128.639	848	128.708	949
41	NO.40	37,930	130.925	293	131.125	477	131.235	595	131.333	708	131.449	852	131.527	957
42	NO.41	38,930	134.549	239	134.732	390	134.833	486	134.921	579	135.024	701	135.094	793
43	+870m	39,830	138.623	242	138.932	393	139.092	490	139.233	584	139.403	708	139.520	800

Table 6.6 (1/2)

RESULT OF FLOOD FLOW ANALYSIS (LAKHANDEI RIVER WITH PROJECT)

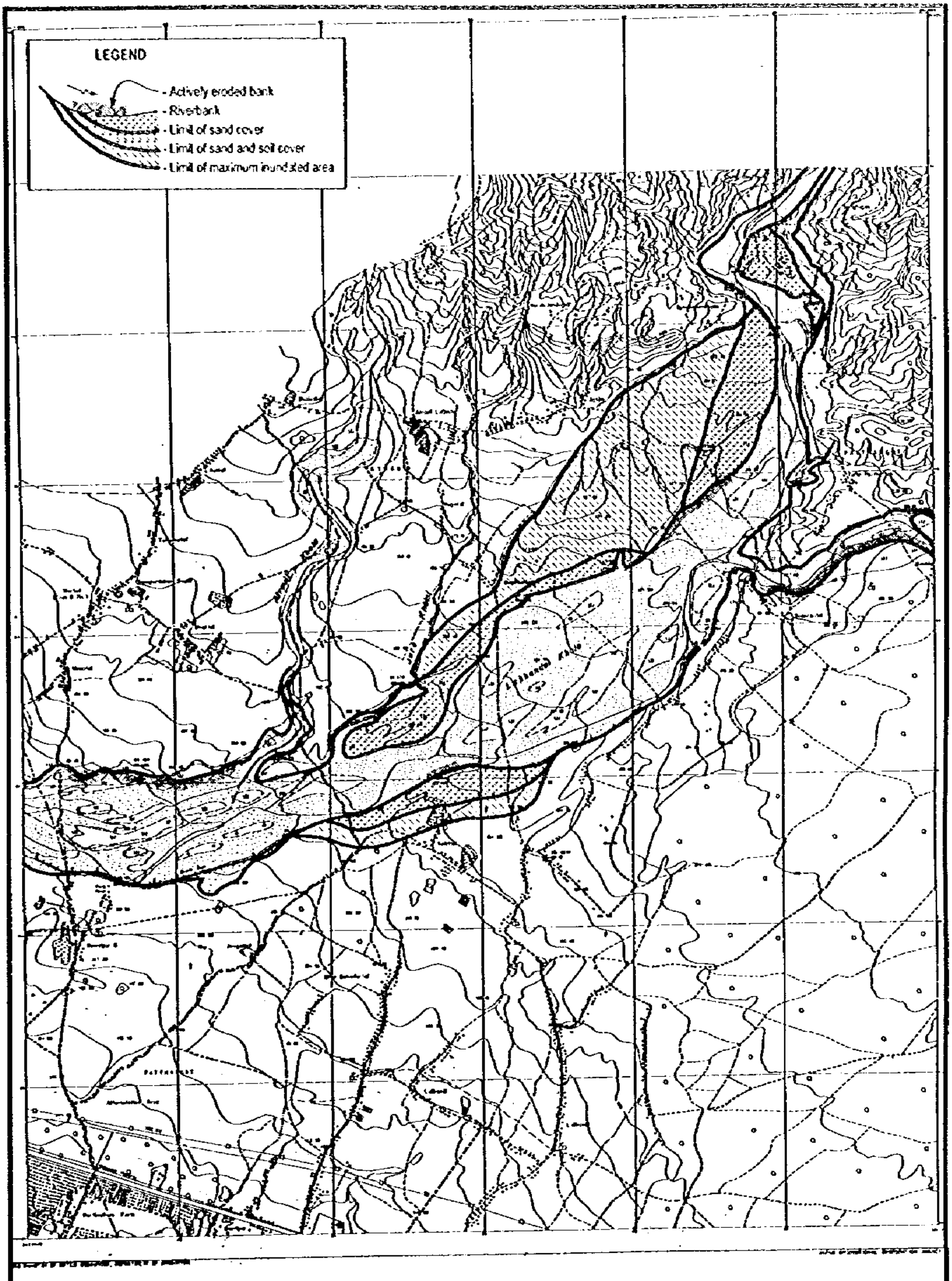
No.	Section	Distance (m)	2 - year H (m, MSL)	2 - year Q (m^3/s)	5 - year H (m, MSL)	5 - year Q (m^3/s)	10 - year H (m, MSL)	10 - year Q (m^3/s)	20 - year H (m, MSL)	20 - year Q (m^3/s)	50 - year H (m, MSL)	50 - year Q (m^3/s)	100 - year H (m, MSL)	100 - year Q (m^3/s)
1	NO.0	0	75.955	168	75.959	117	75.958	121	75.962	122	75.959	124.65	75.961	125
2	NO.1	900	76.784	175	76.848	241	76.858	249	76.865	253	76.868	257.00	76.871	259
3	NO.2	1,600	77.926	181	77.993	242	78.003	250	78.011	254	78.015	257.32	78.018	259
4	NO.3	2,500	78.338	189	78.423	250	78.436	261	78.446	269	78.451	272.42	78.456	276
5	NO.6	4,550	80.574	198	80.651	249	80.666	260	80.678	270	80.684	274.20	80.689	273
6	NO.7	5,500	80.795	200	80.900	254	80.921	260	80.940	259	80.951	279.48	80.958	306
7	NO.8	6,500	80.883	202	81.003	254	81.033	294	81.069	341	81.092	315.47	81.102	220
8	NO.9	7,250	81.501	200	81.592	261	81.712	222	81.863	149	81.957	408.51	81.992	425
9	+360m	7,600	82.130	205	82.235	262	82.402	288	82.575	333	82.673	365.24	82.707	377
10	NO.10	8,200	83.790	143	84.195	143	84.313	143	84.438	143	84.575	159.42	84.631	159
11	NO.11	9,200	83.737	151	84.112	151	84.224	151	84.320	151	84.403	173.22	84.451	173
12	NO.12	10,100	84.172	136	84.256	166	84.383	174	84.494	175	84.565	178.50	84.616	190
13	NO.13	11,100	84.748	196	85.075	196	85.132	196	85.203	196	85.275	220.18	85.358	220
14	NO.14	11,950	85.077	106	85.350	113	85.393	121	85.439	124	85.501	127.71	85.570	129
15	NO.15	12,900	85.843	94	86.075	99	86.155	111	86.191	117	86.219	120.46	86.232	122
16	NO.16	13,950	86.784	99	86.917	103	87.022	117	87.063	125	87.093	131.58	87.104	134
17	NO.17	15,150	87.935	103	88.529	175	88.535	176	88.549	177	88.603	174.24	88.639	181
18	NO.18	15,950	89.073	160	89.792	258	89.784	257	89.764	254	89.791	258.39	89.797	271
19	NO.19	16,650	90.091	266	90.224	293	90.189	331	90.262	354	90.277	375.77	90.297	385
20	NO.20	17,700	91.331	199	91.406	311	91.520	370	91.587	410	91.650	451.06	91.674	467
21	NO.21	19,200	92.234	286	92.422	434	92.523	519	92.596	589	92.658	641.44	92.684	658
22	NO.22	20,100	93.622	287	93.837	435	93.940	522	94.100	606	94.156	657.97	94.175	684
23	NO.23	21,200	95.233	288	95.563	445	95.638	543	95.678	606	95.744	670.68	95.769	701
24	NO.24	22,200	96.998	289	97.353	448	97.477	531	97.579	594	97.614	634.85	97.628	661
25	NO.25	23,000	98.545	289	98.771	372	98.898	447	98.956	486	99.032	533.64	99.070	558
26	NO.26	24,000	100.234	292	100.396	433	100.524	497	100.623	529	100.700	566.01	100.740	591
27	NO.27	24,900	101.420	293	101.721	420	101.835	482	101.891	531	101.955	560.60	101.998	581
28	NO.28	26,150	103.605	298	103.808	453	103.887	520	103.942	596	103.990	676.51	104.013	721
29	NO.29	27,050	105.312	299	105.521	493	105.603	606	105.689	696	105.775	767.27	105.818	809
30	NO.30	27,850	107.017	295	107.271	471	107.399	585	107.489	689	107.551	773.76	107.580	818
31	NO.31	28,850	108.850	296	109.102	472	109.246	587	109.367	691	109.487	773.92	109.514	817
32	NO.32	30,050	111.121	297	111.380	476	111.527	591	111.650	695	111.738	818.00	111.786	876
33	NO.33	30,950	113.250	297	113.501	477	113.643	593	113.762	700	113.890	829.17	113.947	893
34	NO.34	31,900	115.239	299	115.506	479	115.655	596	115.780	702	115.923	831.69	115.990	898
35	NO.35	32,900	117.773	300	118.018	481	118.158	600	118.276	707	118.409	836.31	118.473	902
36	NO.36	33,950	120.424	301	120.680	483	120.822	604	120.941	712	121.073	839.66	121.139	904
37	NO.37	34,850	122.615	302	122.887	485	123.043	607	123.172	715	123.314	842.31	123.384	909
38	+480m	35,400	124.266	303	124.587	486	124.758	608	124.897	717	125.046	843.34	125.121	911
39	NO.38	35,930	125.536	288	125.837	459	126.016	576	126.163	683	126.325	803.91	126.405	867
40	NO.39	36,930	128.181	291	128.371	474	128.490	591	128.587	704	128.689	849.47	128.733	954
41	NO.40	37,930	130.925	293	131.125	477	131.235	595	131.333	708	131.450	853.70	131.530	960
42	NO.41	38,930	134.549	239	134.732	390	134.833	486	134.921	579	135.026	701.39	135.097	793
43	+870m	39,830	138.623	242	138.932	393	139.092	490	139.233	584	139.403	708.00	139.520	800

RESULT OF FLOOD FLOW ANALYSIS (BABAI RIVER WITHOUT PROJECT)

No.	Section	Distance	2 - year		5 - year		10 - year		20 - year		50 - year		100 - year	
		(m)	H (m, MSL)	Q (m^3/s)	H (m, MSL)	Q (m^3/s)	H (m, MSL)	Q (m^3/s)	H (m, MSL)	Q (m^3/s)	H (m, MSL)	Q (m^3/s)	H (m, MSL)	Q (m^3/s)
1	NO.1	0	141.266	1681	141.814	2028	142.042	2175	142.221	2292	142.414	2417	142.531	2493
2	NO.2	690	141.496	1740	142.029	2342	142.244	2663	142.410	2945	142.585	3274	142.690	3489
3	NO.3	1,461	141.655	2059	142.130	3203	142.301	3822	142.415	4390	142.522	5020	142.574	5440
4	Bnd	1,891	141.835	2059	142.464	3203	142.737	3822	142.961	4390	143.205	5020	143.360	5440
5	NO.4	3,001	142.166	1576	143.030	2517	143.433	3300	143.777	4124	144.147	5165	144.384	5924
6	NO.6	4,548	142.247	1629	143.144	2288	143.587	2822	143.973	3367	144.397	4032	144.673	4504
7	NO.8	6,688	142.477	2041	143.354	2956	143.819	3415	144.229	3958	144.681	4597	144.977	5053
8	NO.9	7,708	142.755	1969	143.613	2630	144.083	2941	144.503	3244	144.970	3524	145.277	3700
9	NO.12	10,204	143.518	2076	144.415	2739	144.882	2876	145.284	3184	145.701	3573	145.971	3869
10	NO.13	11,344	143.942	2078	144.774	3264	145.209	3654	145.596	4258	146.009	4989	146.282	5519
11	NO.14	11,924	144.111	2081	144.994	3397	145.423	3963	145.826	4690	146.257	5559	146.542	6193
12	NO.15	12,836	144.254	2085	145.192	3302	145.627	3945	146.048	4729	146.503	5597	146.806	6224
13	NO.16	13,577	144.364	2043	145.336	3317	145.787	4064	146.232	4923	146.710	5862	147.029	6559
14	NO.17	14,457	144.474	1722	145.460	2789	145.917	3629	146.369	4642	146.852	5655	147.176	6418
15	NO.18	15,729	145.027	1730	145.879	2743	146.355	3289	146.847	3788	147.321	4399	147.653	4866
16	NO.19	16,809	145.749	2069	146.630	3177	147.027	3636	147.405	4290	147.846	5027	148.146	5581
17	NO.20	18,147	146.513	1817	147.375	3154	147.743	3734	148.156	4199	148.620	4768	148.942	5174
18	NO.21	19,059	146.950	1822	147.917	2715	148.308	3147	148.689	3392	149.119	3697	149.421	4003
19	NO.22	19,871	147.450	2034	148.338	3459	148.668	4196	148.986	4685	149.376	5465	149.651	6061
20	NO.23	20,291	147.683	2084	148.600	3505	148.946	4184	149.254	4716	149.657	5320	149.944	5779
21	NO.24	22,043	148.417	2076	149.500	3492	149.927	4189	150.242	4817	150.646	5467	150.936	5880
22	NO.25	23,043	148.845	2078	149.902	3503	150.356	4014	150.722	4408	151.116	4920	151.354	5392
23	NO.27	25,913	150.953	1862	152.350	2469	152.799	2860	153.125	3262	153.540	3577	153.880	3877
24	NO.28	26,865	151.293	2314	152.529	3390	152.961	4041	153.284	4666	153.667	5356	153.986	5928
25	NO.29	27,665	151.712	2303	152.869	3516	153.302	4276	153.635	5020	154.068	6001	154.398	6609
26	NO.30	28,225	152.141	2304	153.260	3520	153.724	4338	154.101	5144	154.487	6177	154.795	6884
27	NO.31	29,443	153.082	2333	154.098	3885	154.625	4828	155.085	5647	155.605	6533	155.971	7045
28	NO.32	30,593	154.393	2338	155.293	3896	155.763	4860	156.141	5783	156.531	6882	156.766	7619
29	NO.33	31,525	155.668	2339	156.652	3799	157.183	4693	157.641	5549	158.135	6676	158.439	7516
30	NO.34	32,695	157.018	2342	157.878	3949	158.355	4826	158.787	5577	159.299	6526	159.643	7213
31	NO.35	33,907	159.265	2343	160.236	3910	160.617	4712	160.936	5281	161.339	5907	161.625	6334
32	NO.36	34,759	160.824	2345	161.724	3976	162.096	4949	162.353	5712	162.635	6631	162.843	7124
33	NO.37	35,939	162.574	2349	163.427	3991	163.858	5010	164.156	5939	164.496	6978	164.664	7698
34	NO.38	36,819	164.448	2343	165.196	4003	165.608	5080	165.946	6060	166.287	7285	166.504	8197
35	NO.39	38,003	167.458	2341	168.089	3968	168.442	4988	168.744	5938	169.101	7060	169.358	7892
36	NO.40	39,267	170.889	2340	171.614	3967	171.973	4982	172.278	5950	172.604	7058	172.842	7786
37	NO.41	40,337	173.335	2332	174.168	3958	174.556	4976	174.897	6031	175.258	7267	175.480	8185
38	NO.42	40,962	174.901	2382	175.537	3927	175.881	4975	176.217	6142	176.554	7300	176.804	8252
39	NO.43	41,762	177.618	2299	178.165	3879	178.472	4917	178.904	6082	179.108	7087	179.351	7887
40	NO.44	42,791	181.925	2368	182.838	4075	183.194	5212	183.452	6302	183.682	7706	183.764	8615
41	NO.45	43,890	185.167	2370	186.278	4077	186.915	5215	187.477	6305	188.156	7728	188.567	8774
42	NO.46	44,790	187.661	2374	188.700	4083	189.263	5223	189.756	6315	190.353	7739	190.757	8784

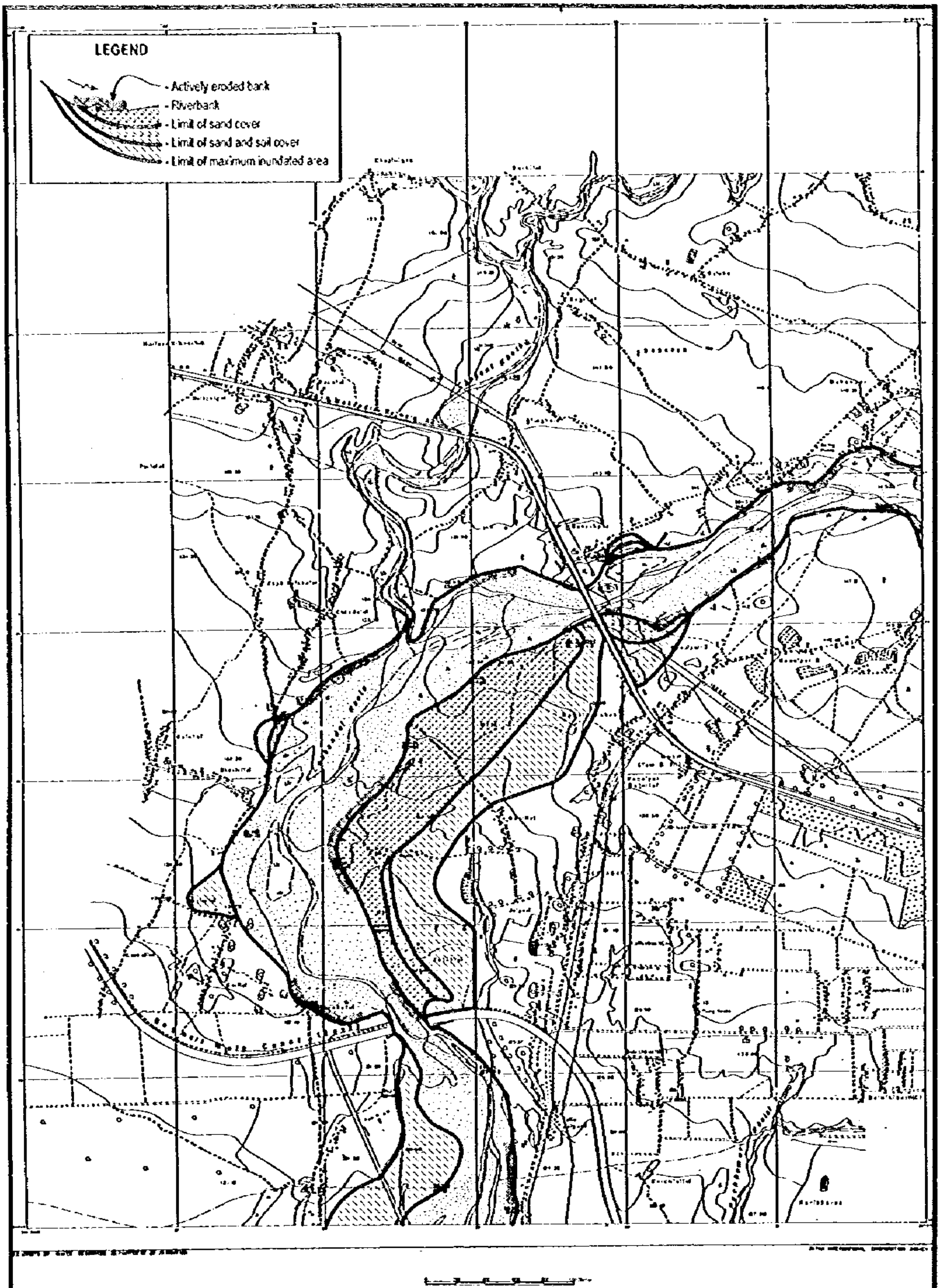
RESULT OF FLOOD FLOW ANALYSIS (BABAI RIVER WITH PROJECT)

No.	Section	Distance (m)	2 - year H (m, MSL)	2 - year Q (m^3/s)	5 - year H (m, MSL)	5 - year Q (m^3/s)	10 - year H (m, MSL)	10 - year Q (m^3/s)	20 - year H (m, MSL)	20 - year Q (m^3/s)	50 - year H (m, MSL)	50 - year Q (m^3/s)	100 - year H (m, MSL)	100 - year Q (m^3/s)
1	NO.1	0	141.297	1699	141.790	2012	141.991	2143	142.184	2267	142.403	2410	142.540	2499
2	NO.2	690	141.527	1766	142.006	2309	142.197	2589	142.375	2883	142.575	3256	142.698	3506
3	NO.3	1,461	141.682	2108	142.110	3141	142.265	3679	142.391	4270	142.517	4982	142.582	5458
4	Brid	1,891	141.869	2108	142.434	3141	142.676	3679	142.914	4270	143.191	4982	143.370	5458
5	NO.4	3,001	142.201	2107	142.979	3007	143.335	3527	143.701	4132	144.126	5070	144.399	5823
6	NO.6	4,548	142.342	2111	143.141	2938	143.513	3333	143.896	3818	144.357	4460	144.663	4973
7	NO.8	6,688	142.705	2051	143.503	2939	143.870	3349	144.258	3852	144.730	4450	145.053	4883
8	NO.9	7,708	142.935	1968	143.744	2665	144.110	2948	144.499	3281	144.972	3622	145.299	3817
9	NO.12	10,204	143.623	2107	144.510	2845	144.889	3064	145.290	3385	145.727	3767	146.013	4045
10	NO.13	11,344	144.033	2109	144.913	3307	145.267	3759	145.648	4413	146.065	5195	146.344	5743
11	NO.14	11,924	144.195	2112	145.131	3357	145.491	3940	145.892	4723	146.332	5614	146.623	6261
12	NO.15	12,836	144.332	2118	145.310	3284	145.685	3937	146.109	4784	146.572	5677	146.880	6329
13	NO.16	13,577	144.438	2123	145.445	3292	145.843	3944	146.296	4853	146.782	5805	147.107	6514
14	NO.17	14,457	144.543	2098	145.548	3267	145.955	3821	146.420	4734	146.913	5688	147.244	6428
15	NO.18	15,729	145.234	2106	146.048	3258	146.398	3681	146.881	4121	147.354	4632	147.689	5049
16	NO.19	16,809	146.097	2086	146.907	3403	147.176	4032	147.513	4673	147.904	5371	148.193	5872
17	NO.20	18,147	146.687	1802	147.631	3016	147.980	3675	148.350	4161	148.756	4831	149.053	5236
18	NO.21	19,059	147.047	1802	148.038	2649	148.418	3155	148.798	3549	149.216	3944	149.500	4182
19	NO.22	19,871	147.497	2041	148.410	3310	148.796	4062	149.126	4706	149.511	5430	149.771	5898
20	NO.23	20,291	147.718	2107	148.625	3476	149.027	4165	149.347	4813	149.729	5576	149.994	5971
21	NO.24	22,043	148.446	2099	149.492	3533	149.954	4257	150.332	4964	150.756	5728	150.997	6132
22	NO.25	23,043	148.871	2101	149.896	3568	150.352	4227	150.741	4932	151.145	5549	151.363	5922
23	NO.27	25,913	150.980	1869	152.410	2401	152.965	2730	153.443	3045	153.967	3357	154.234	3617
24	NO.28	26,865	151.315	2329	152.569	3317	153.091	3937	153.545	4509	154.040	5132	154.288	5685
25	NO.29	27,665	151.733	2317	152.879	3485	153.379	4204	153.804	4908	154.286	5683	154.548	6341
26	NO.30	28,225	152.152	2317	153.260	3488	153.759	4298	154.185	5104	154.650	6052	154.929	6804
27	NO.31	29,443	153.094	2348	154.092	3819	154.625	4789	155.110	5676	155.652	6507	156.015	7015
28	NO.32	30,593	154.403	2353	155.267	3823	155.750	4821	156.148	5785	156.542	6866	156.781	7600
29	NO.33	31,525	155.679	2354	156.612	3785	157.164	4645	157.647	5500	158.139	6560	158.445	7369
30	NO.34	32,695	157.028	2357	157.861	3938	158.328	4856	158.763	5702	159.252	6682	159.586	7426
31	NO.35	33,907	159.278	2359	160.230	3899	160.631	4691	160.992	5276	161.401	5884	161.702	6344
32	NO.36	34,759	160.835	2360	161.719	3964	162.092	4927	162.361	5724	162.645	6609	162.873	7131
33	NO.37	35,939	162.582	2363	163.421	3976	163.849	4979	164.161	5964	164.486	7003	164.673	7769
34	NO.38	36,819	164.454	2360	165.191	4016	165.597	5034	165.960	6057	166.298	7253	166.529	8156
35	NO.39	38,003	167.459	2362	168.094	4011	168.425	4991	168.738	5905	169.093	7063	169.346	7902
36	NO.40	39,267	170.903	2363	171.634	4021	171.973	4983	172.268	5917	172.607	7045	172.846	7781
37	NO.41	40,337	173.334	2364	174.201	4019	174.560	4979	174.886	6001	175.256	7210	175.481	8111
38	NO.42	40,962	174.837	2367	175.588	4093	175.892	5008	176.188	6058	176.538	7276	176.791	8151
39	NO.43	41,762	177.645	2368	178.201	3995	178.543	4969	178.893	6065	179.098	7125	179.322	7882
40	NO.44	42,791	181.997	2388	182.937	4113	183.259	5257	183.480	6358	183.748	7781	183.816	8698
41	NO.45	43,890	185.167	2370	186.279	4077	186.915	5215	187.479	6307	188.159	7736	188.571	8781
42	NO.46	44,790	187.661	2374	188.700	4083	189.263	5223	189.756	6315	190.353	7739	190.757	8784



HAZARD MAP
Lakhandei River 1997 Flood (1/6)

His Majesty's Government of Nepal Department of Irrigation, Ministry of Water Resources
THE STUDY ON FLOOD MITIGATION PLAN FOR SELECTED RIVERS IN THE TERAI PLAIN IN THE KINGDOM OF NEPAL
JAPAN INTERNATIONAL COOPERATION AGENCY

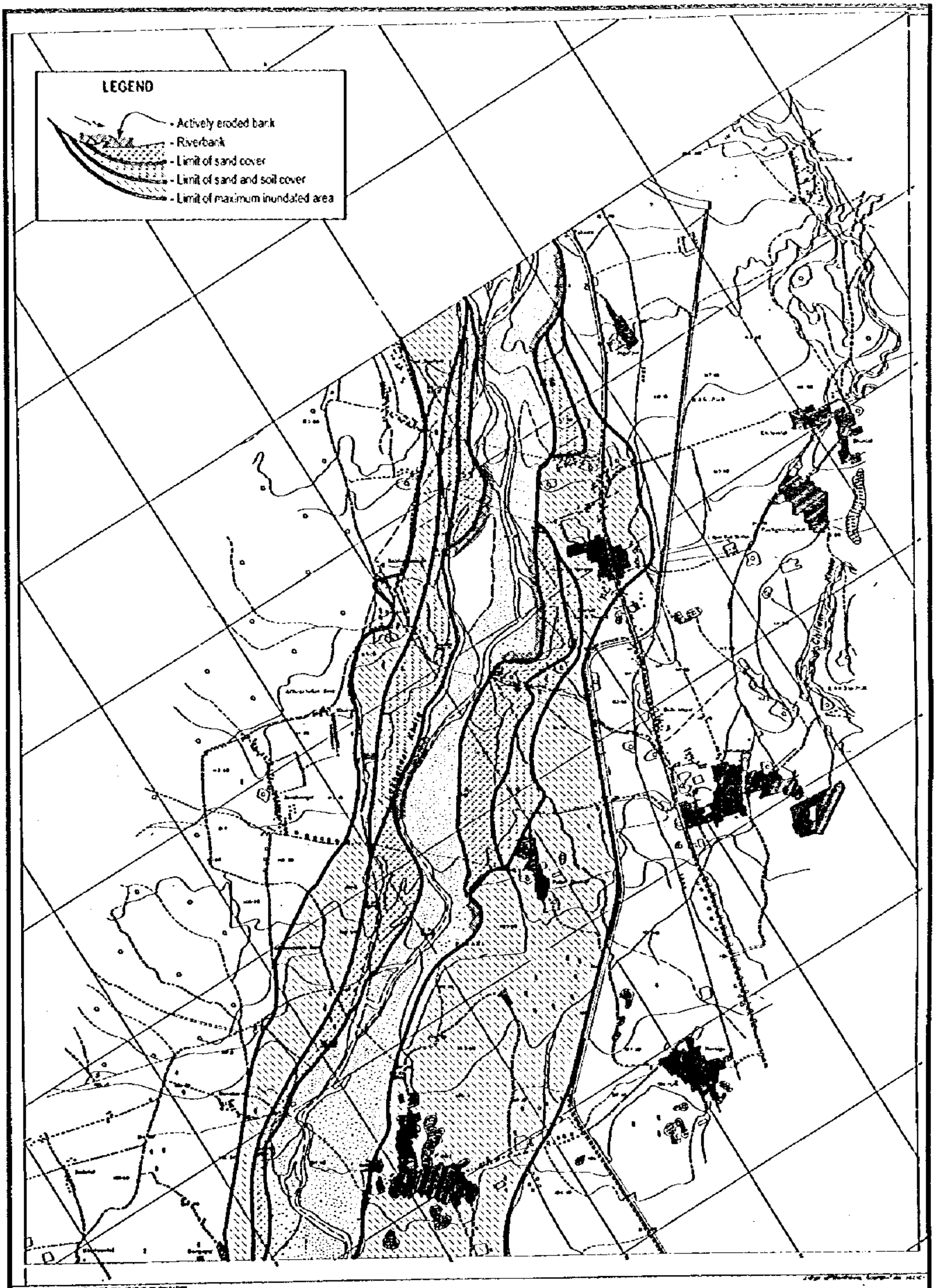


HAZARD MAP
Lakhandei River 1997 Flood (2/6)

His Majesty's Government of Nepal
Department of Irrigation, Ministry of Water Resources

THE STUDY ON FLOOD MITIGATION PLAN FOR SELECTED RIVERS IN THE TERAI PLAIN IN THE KINGDOM OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY

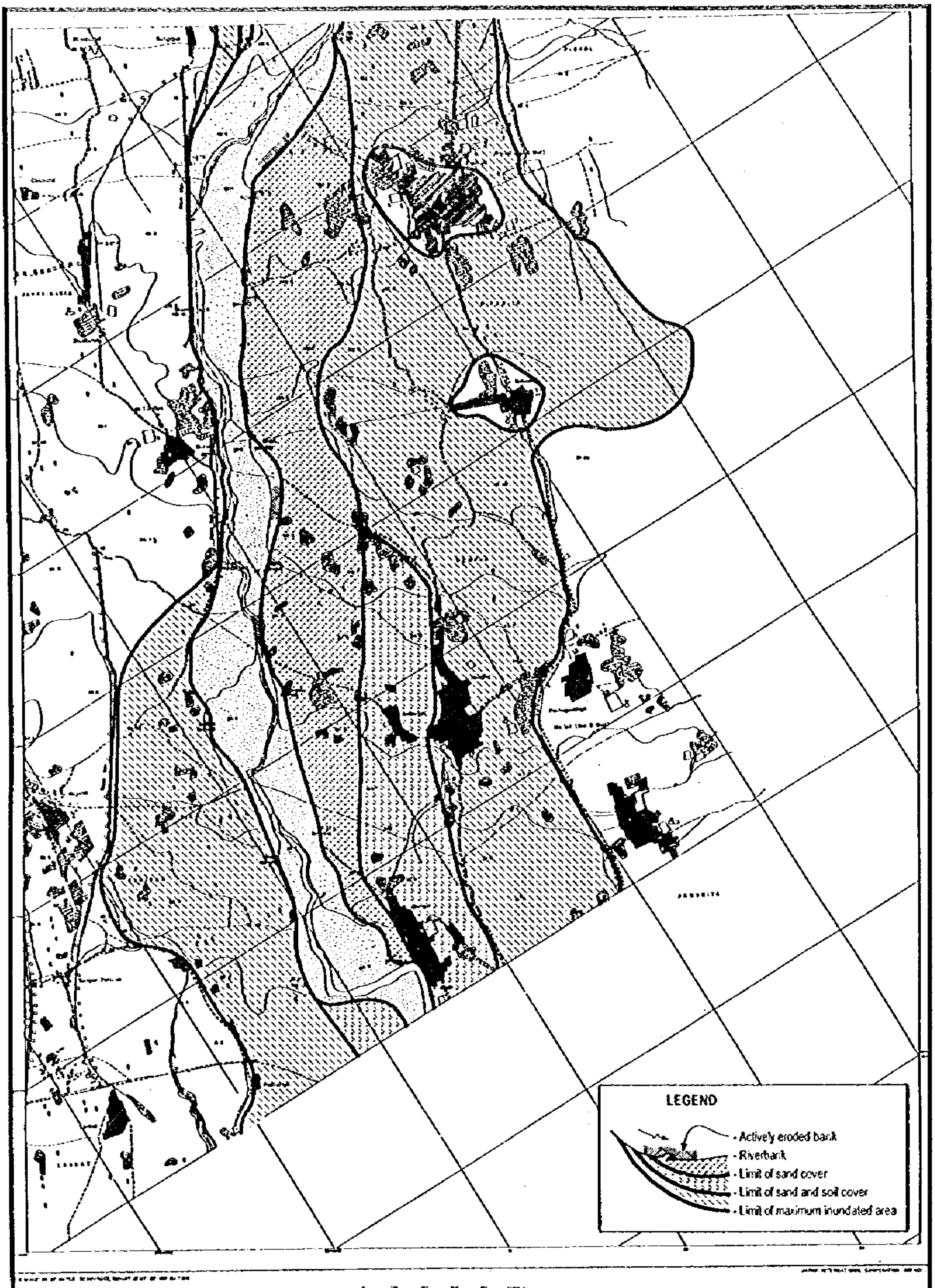


HAZARD MAP
Lakhandei River 1997 Flood (3/6)

His Majesty's Government of Nepal
Department of Irrigation, Ministry of Water Resources

THE STUDY ON FLOOD MITIGATION PLAN FOR SELECTED RIVERS IN THE TERAI PLAIN IN THE KINGDOM OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY



HAZARD MAP
Lakhandei River 1997 Flood (4/6)

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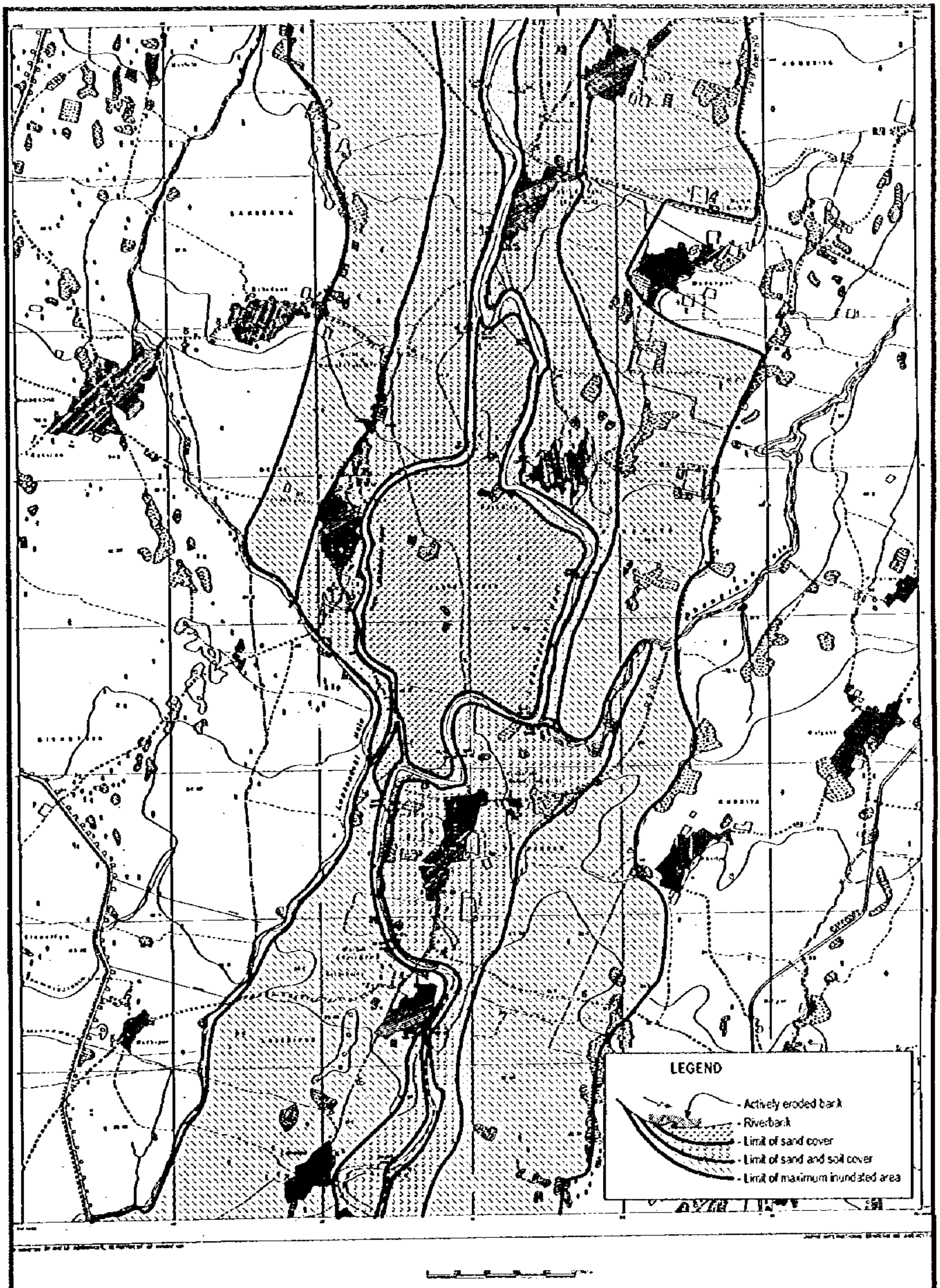

HAZARD MAP
Lakhandei River 1997 Flood (5/6)

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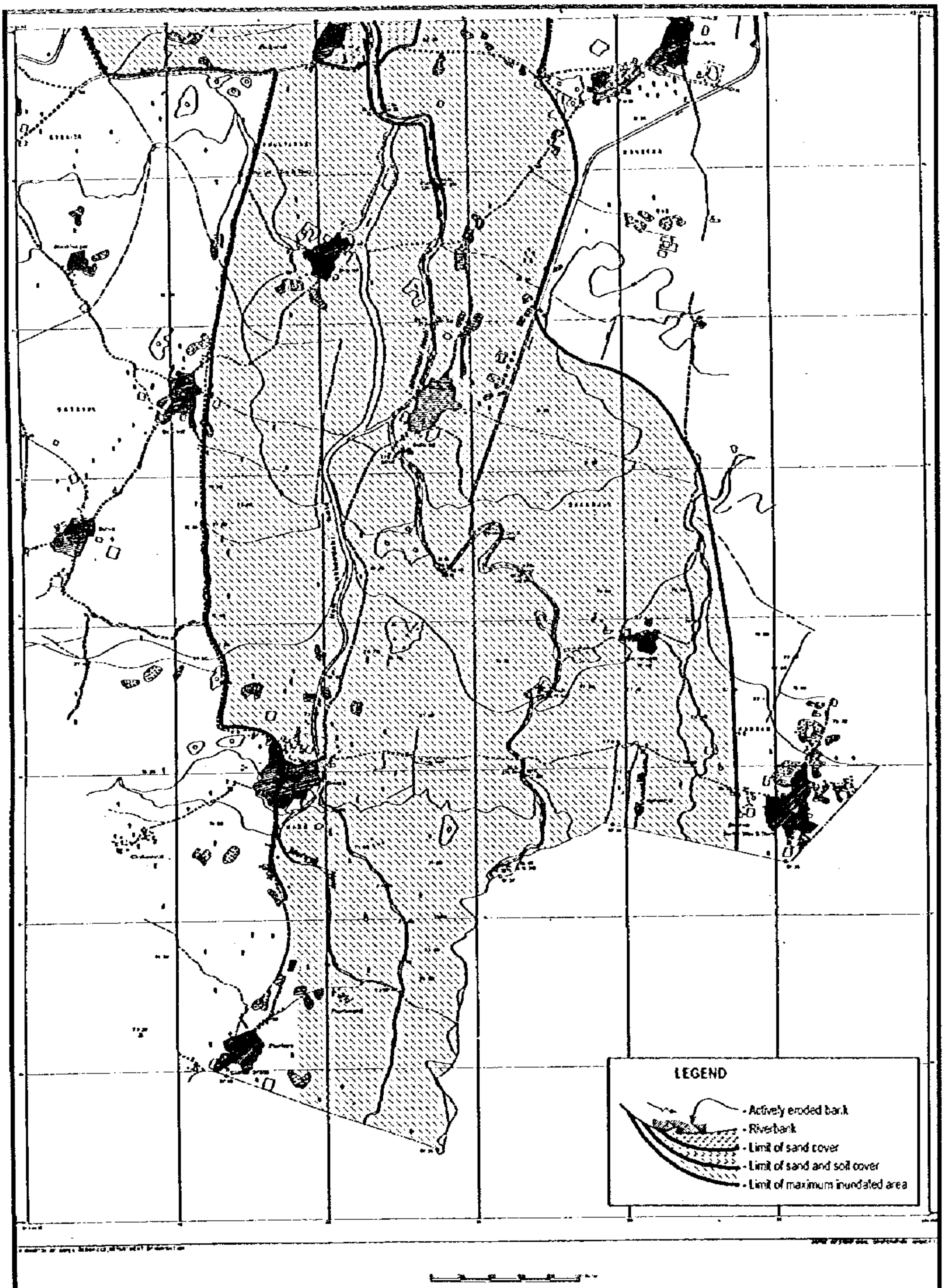

HAZARD MAP
Lakhandei River 1997 Flood (6/6)

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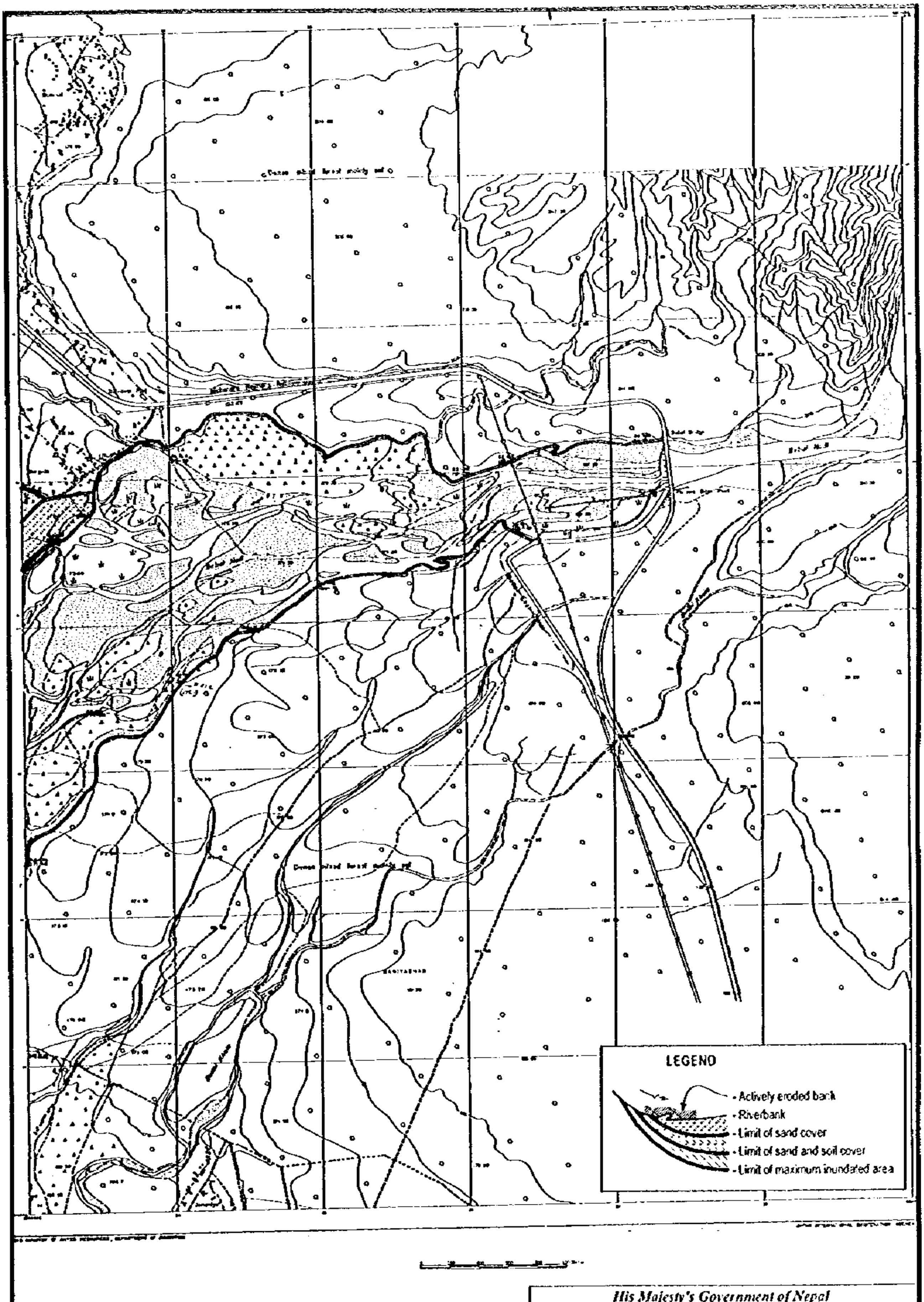

HAZARD MAP
Babai River 1995 Flood (1/7)

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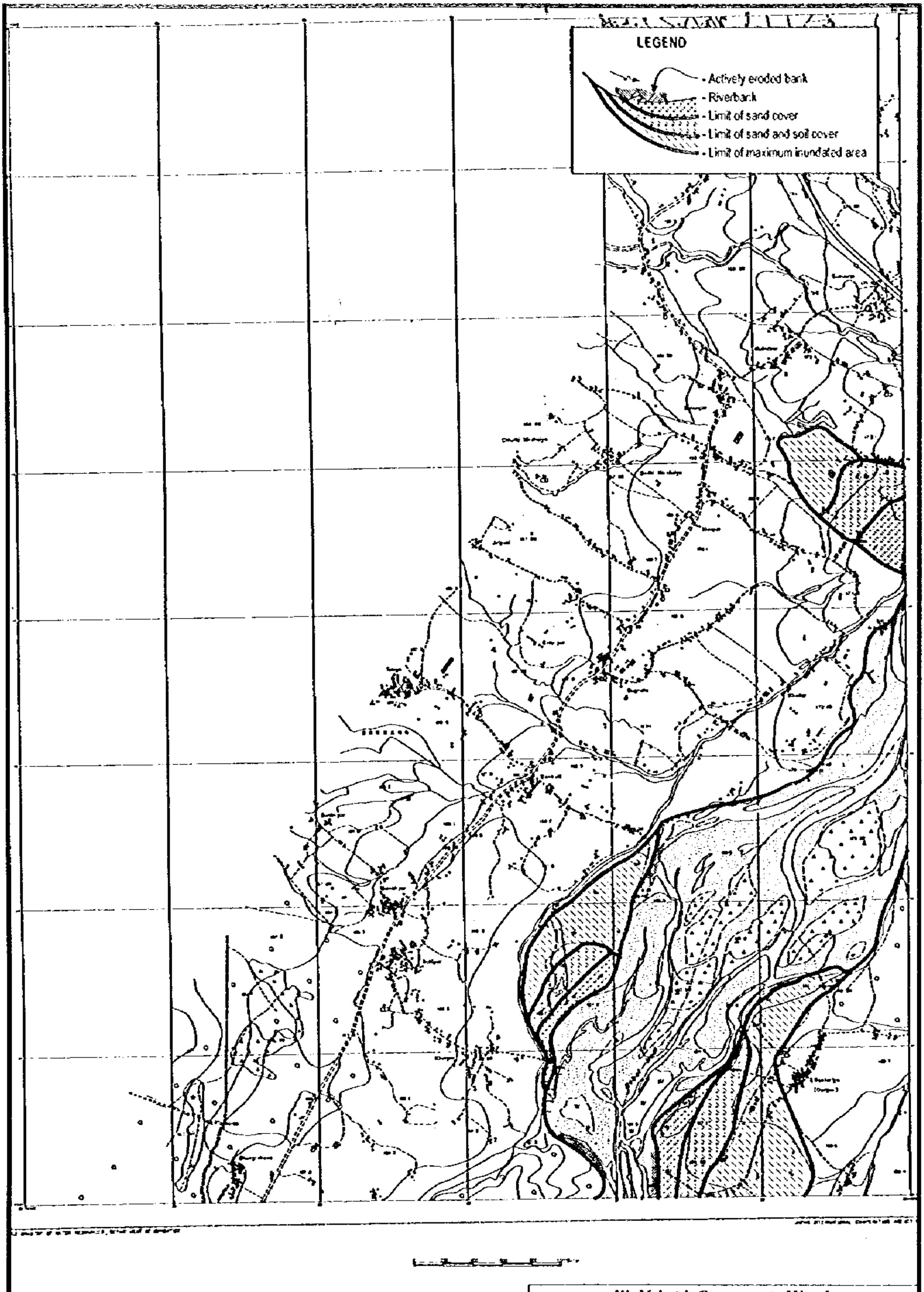

HAZARD MAP
Babai River 1995 Flood (2/7)

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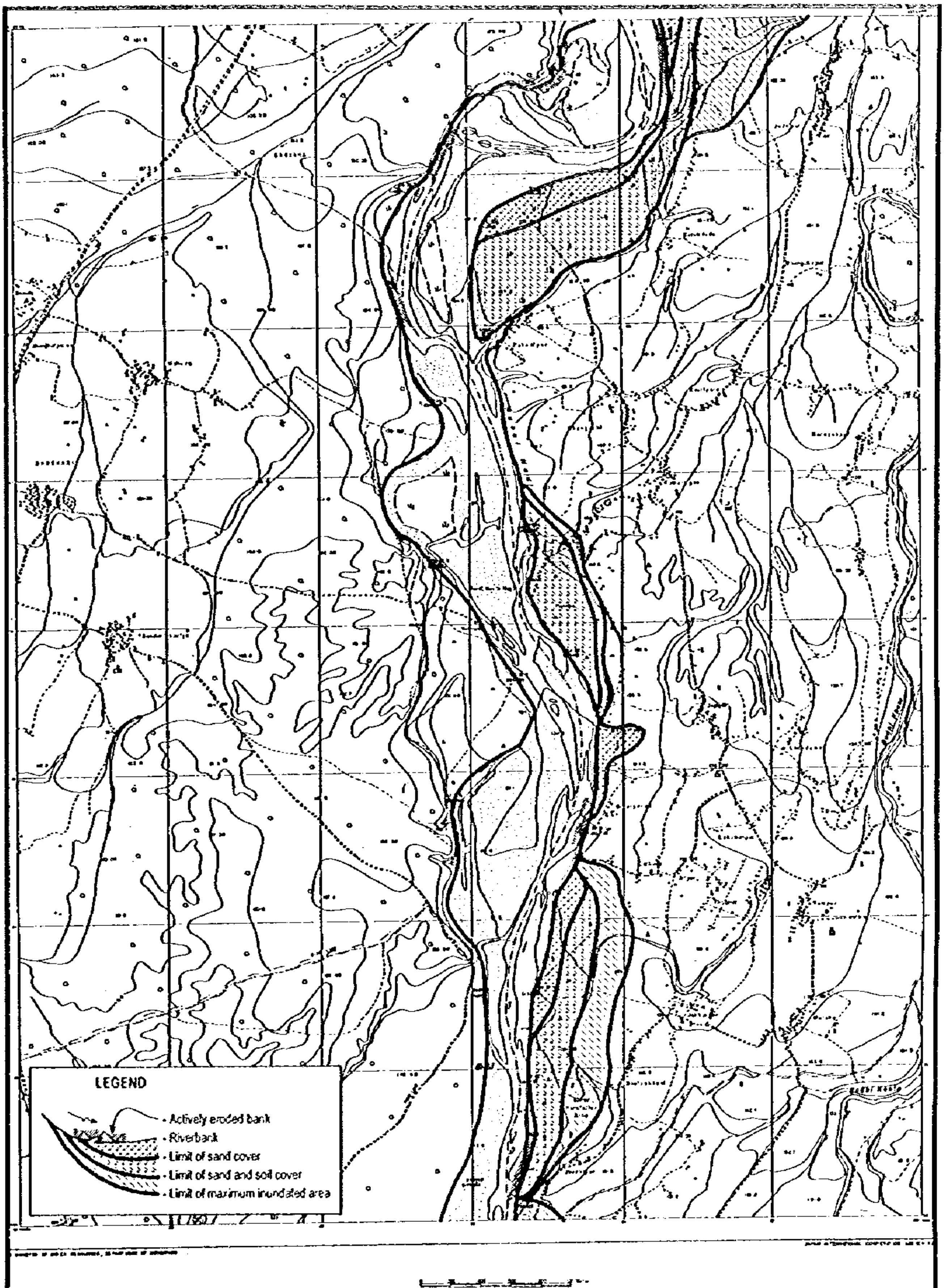

HAZARD MAP
Babai River 1995 Flood (3/7)

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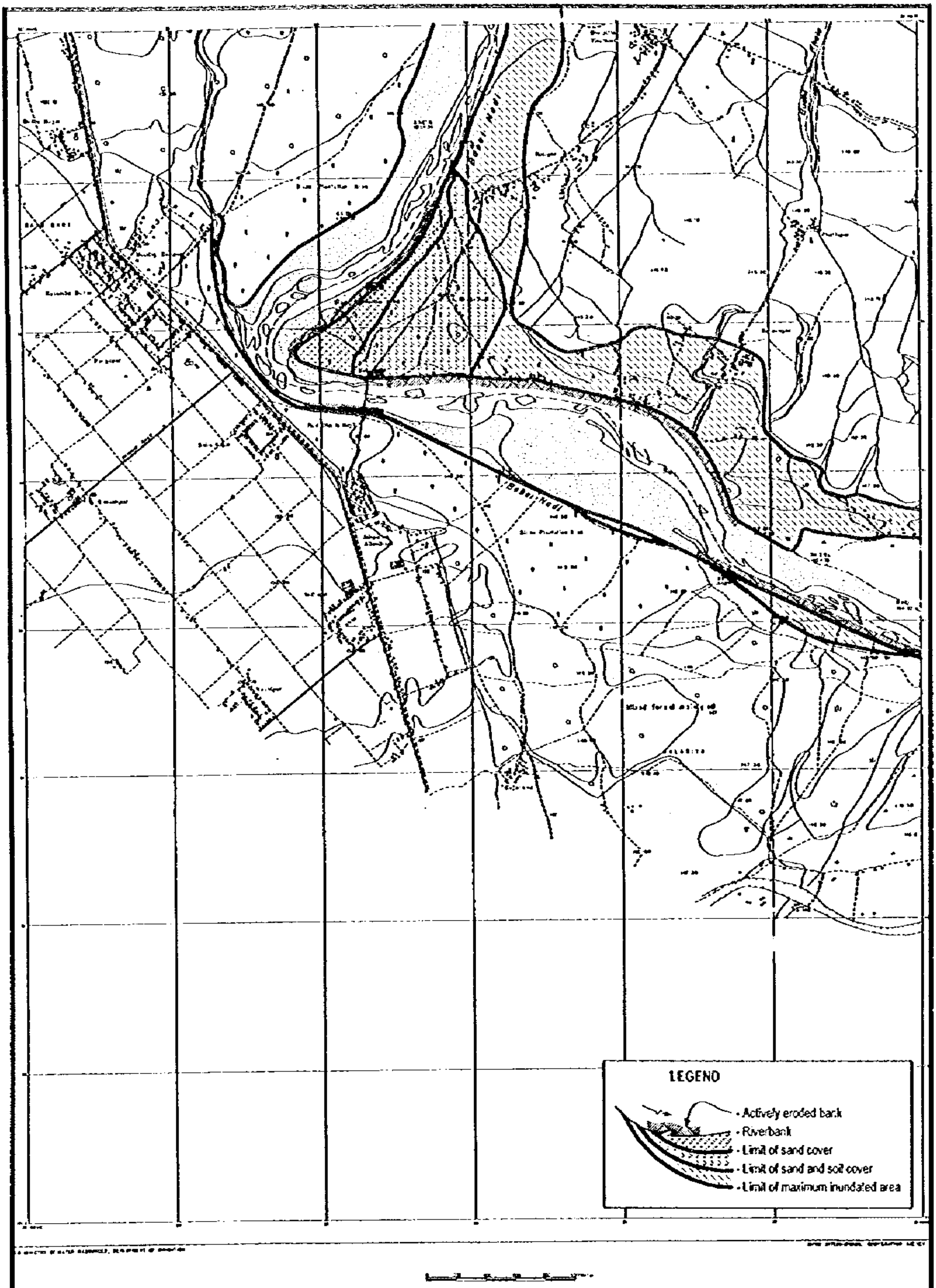
Fig. 6.2 (4/7)



HAZARD MAP
Babai River 1995 Flood (4/7)

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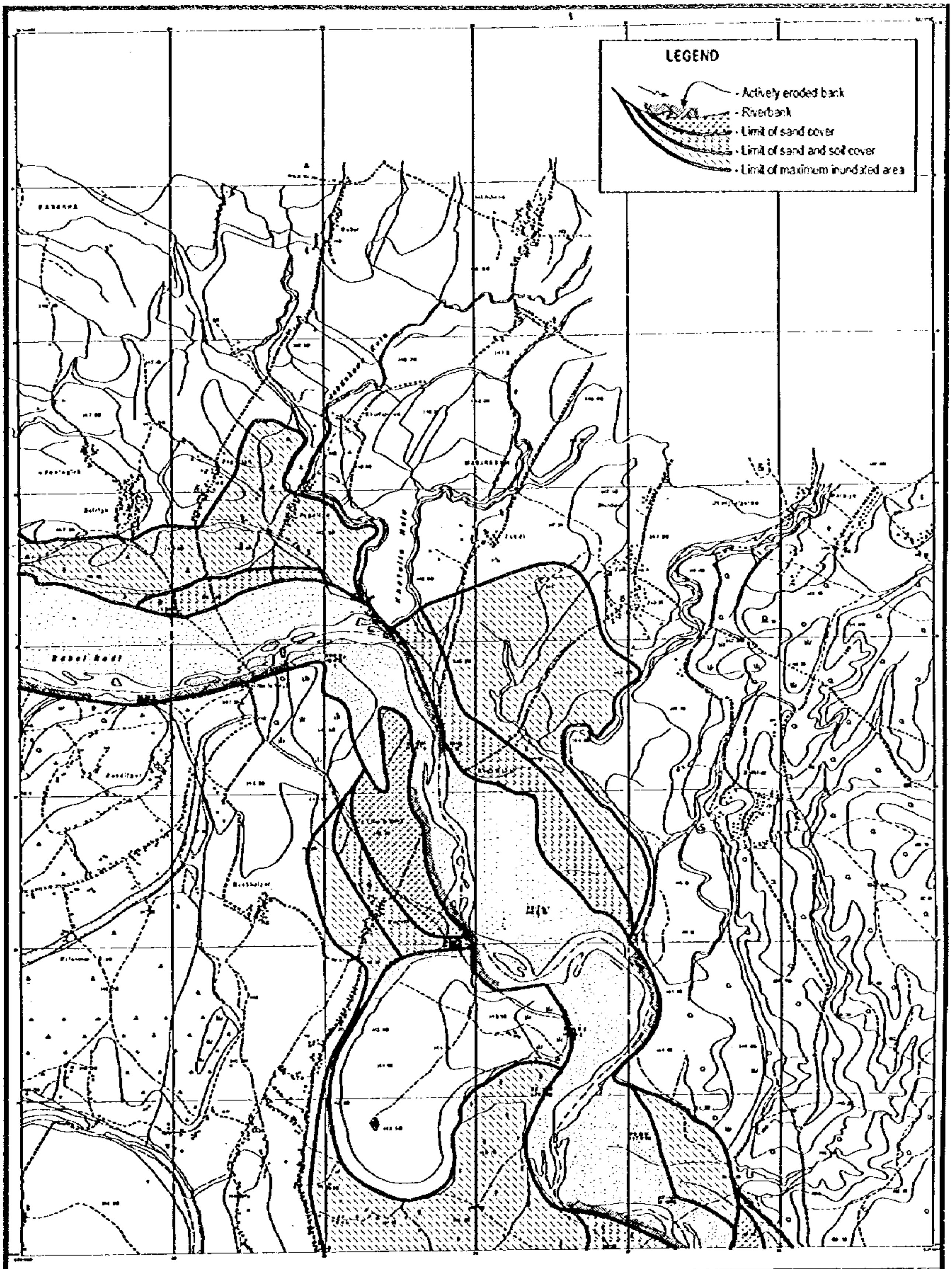
Fig. 6.2 (5/7)



HAZARD MAP
Babai River 1995 Flood (5/7)

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THE STUDY ON FLOOD MITIGATION PLAN FOR SELECTED RIVERS IN THE TERAI PLAIN IN THE KINGDOM OF NEPAL

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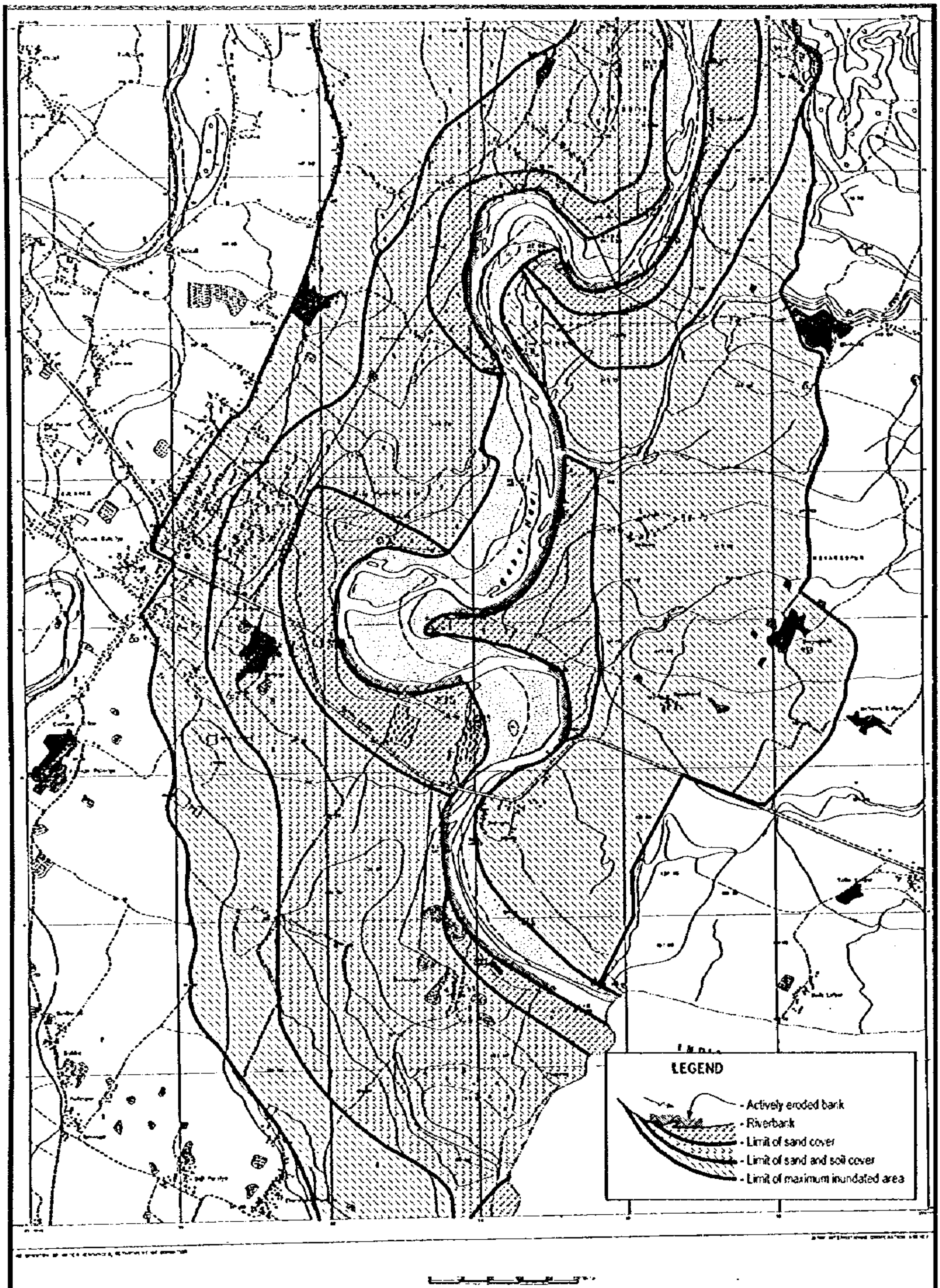

HAZARD MAP
Babai River 1995 Flood (6/7)

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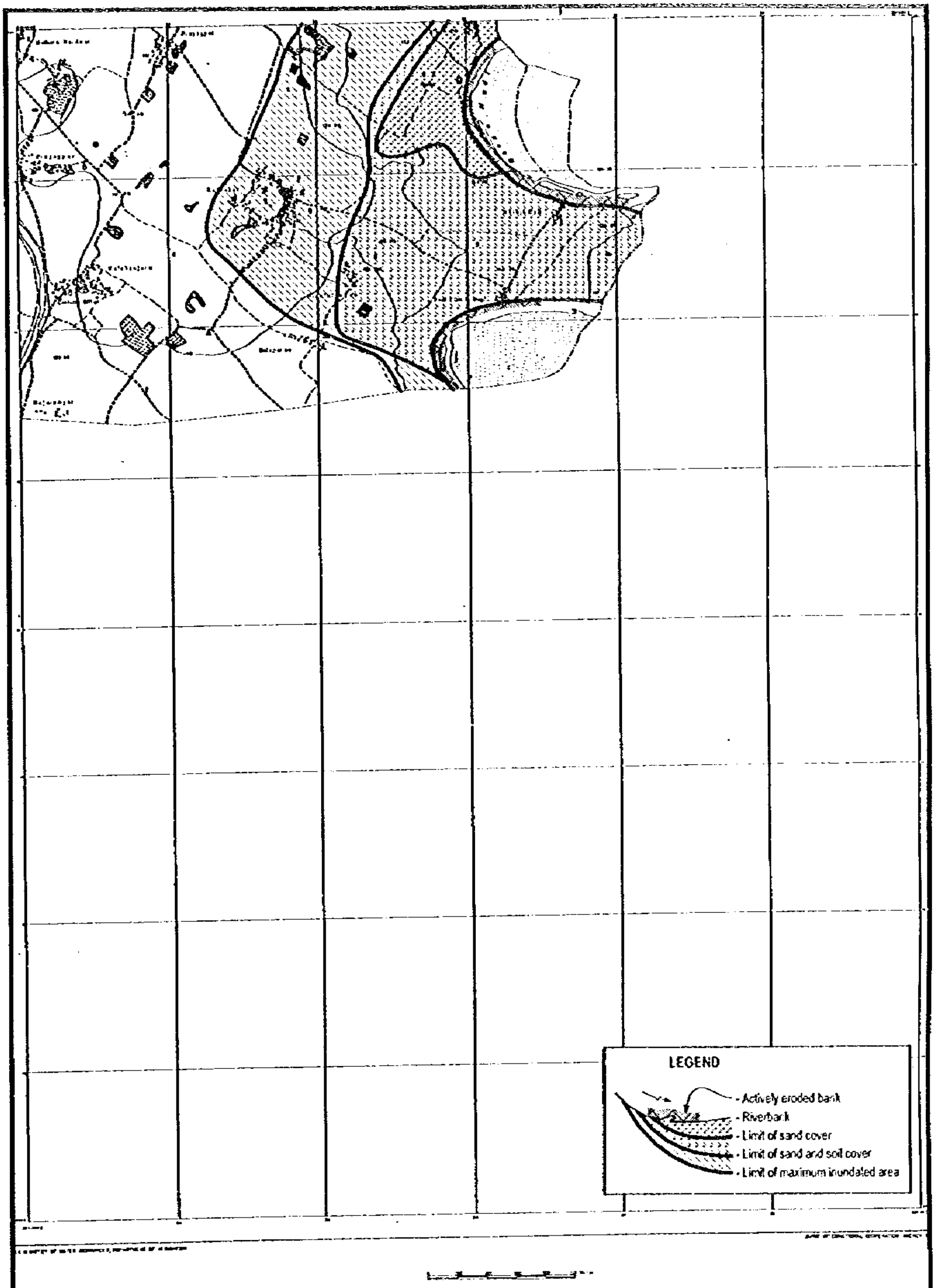

HAZARD MAP
Babai River 1995 Flood (7/7)

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THE STUDY ON FLOOD MITIGATION PLAN FOR SELECTED RIVERS IN THE TERAI PLAIN IN THE KINGDOM OF NEPAL

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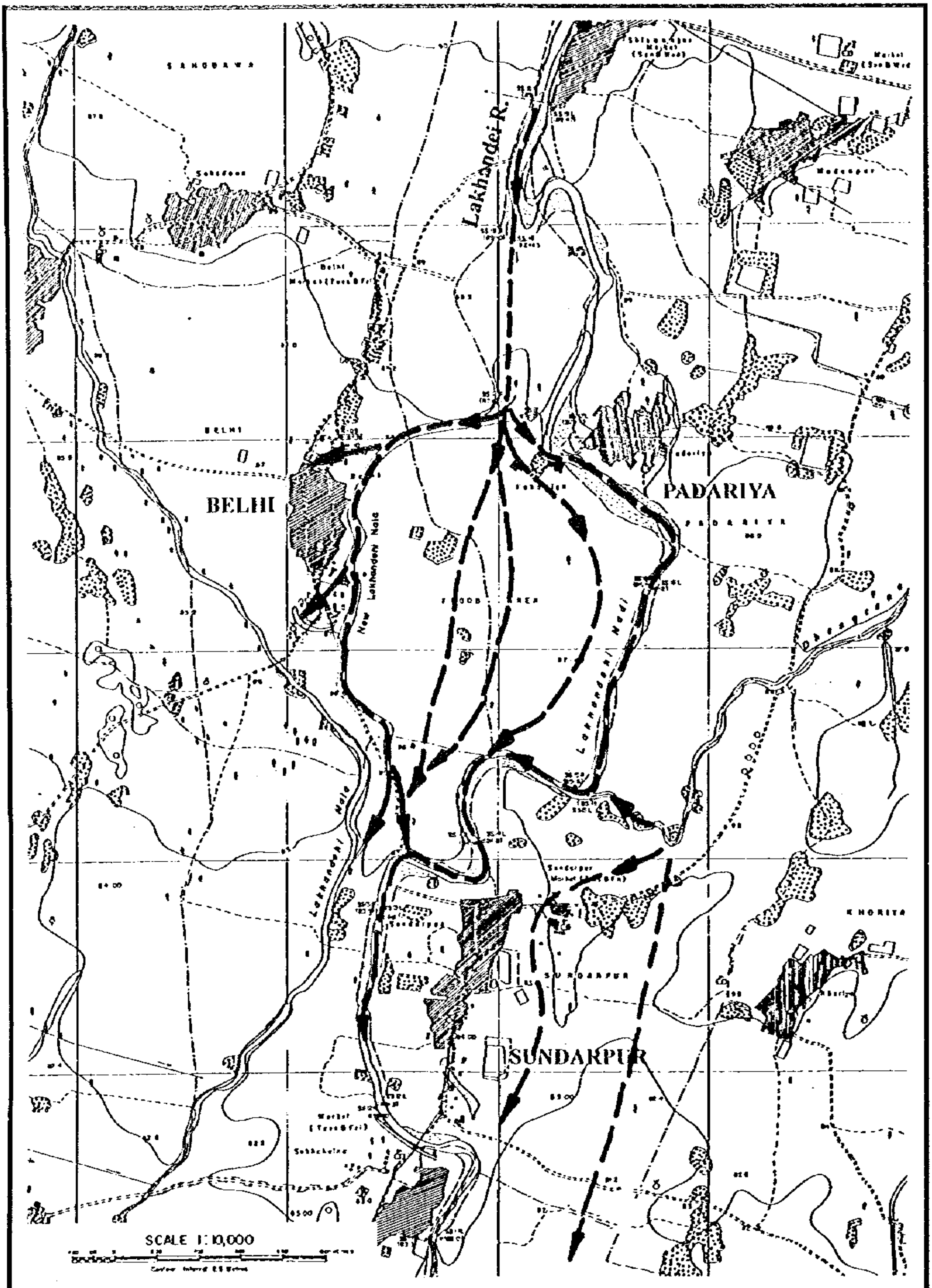

RIVER COURSE NEAR BELHI VILLAGE AFTER 1998-FLOOD

His Majesty's Government of Nepal
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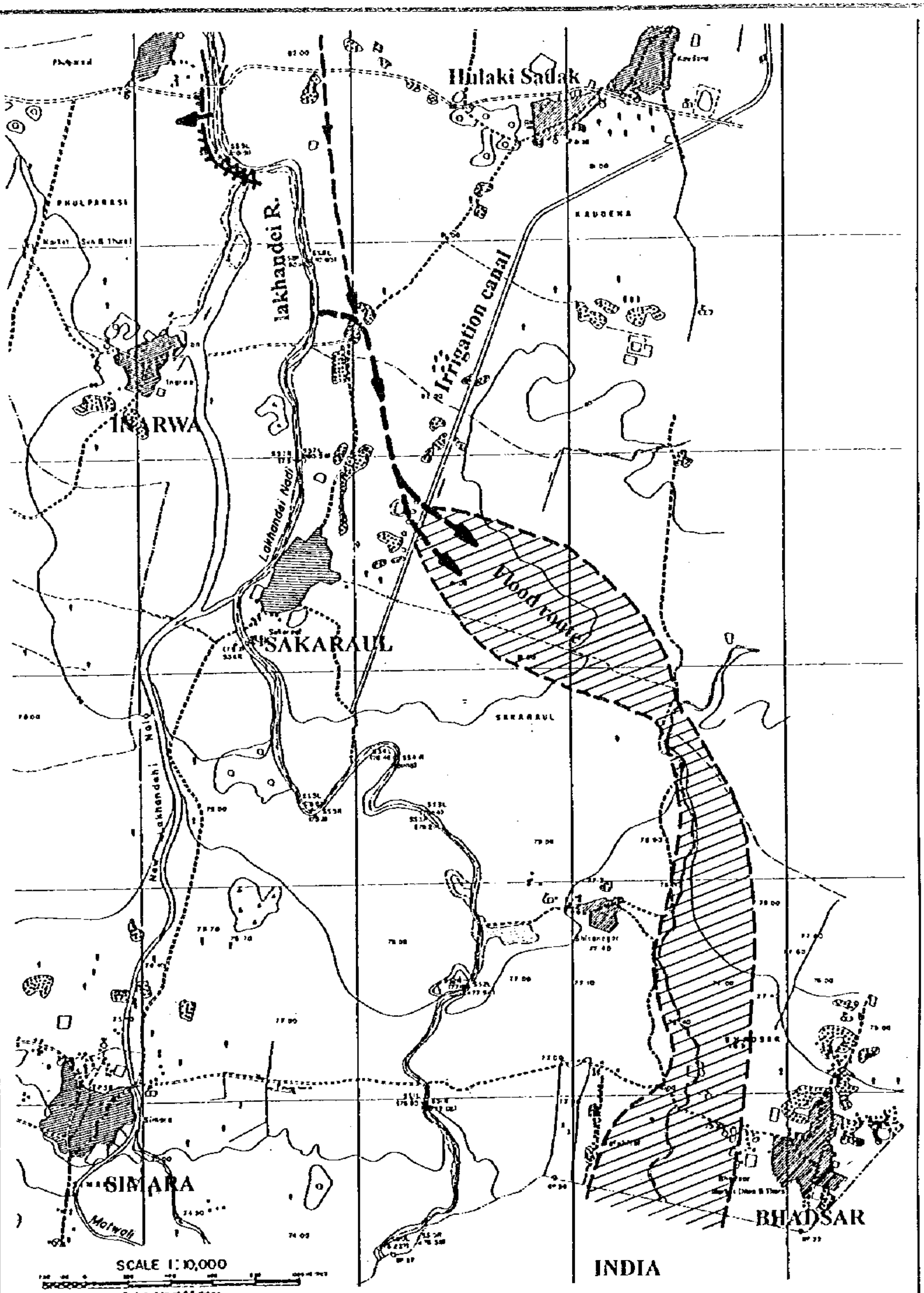
THE STUDY ON FLOOD MITIGATION PLAN FOR SELECTED RIVERS IN THE TERAI PLAIN IN THE KINGDOM OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY



RIVER COURSE NEAR SAKARAUL VILLAGE AFTER 1998-FLOOD

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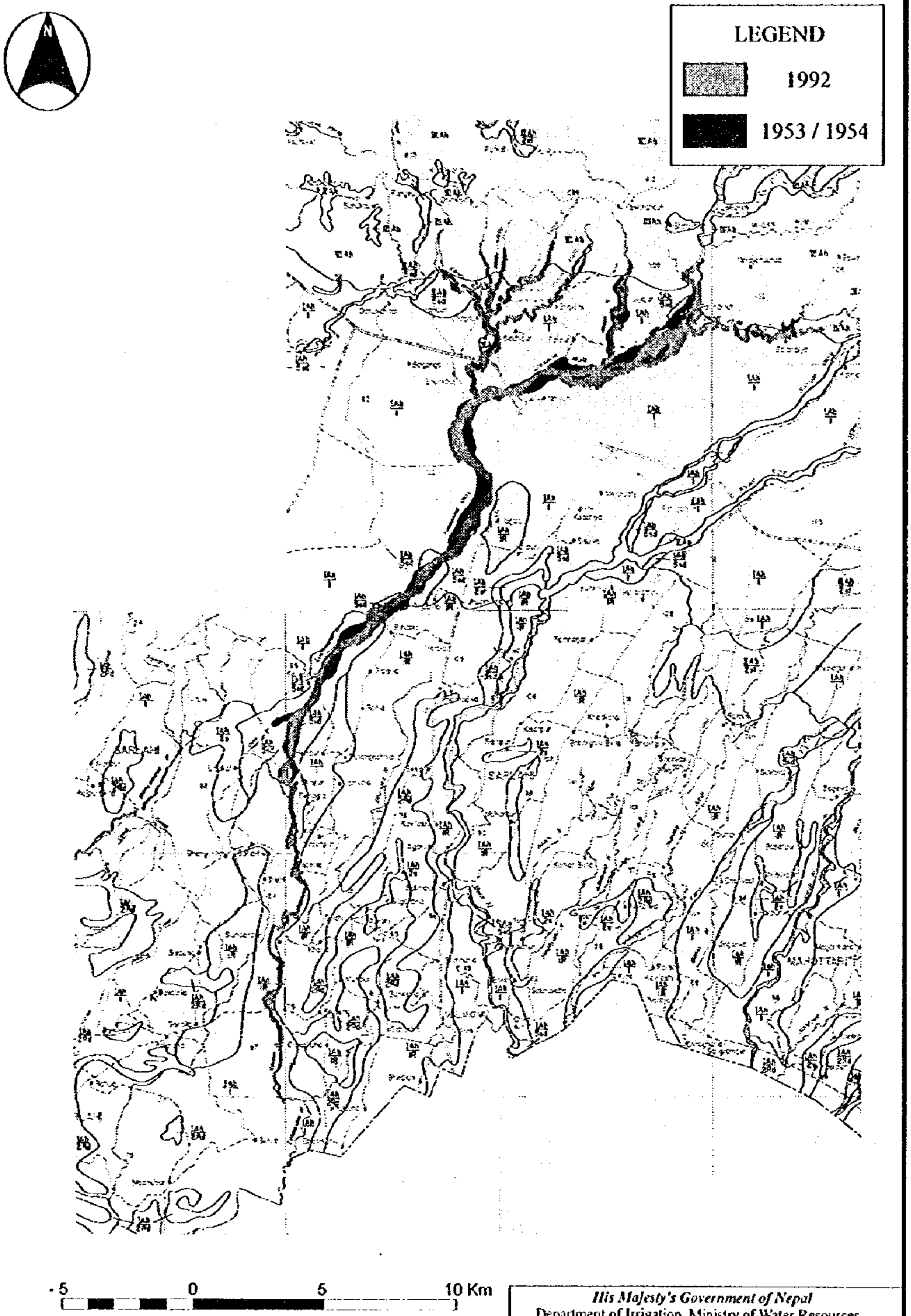
JAPAN INTERNATIONAL COOPERATION AGENCY



CHANGE OF LAKHANDEI RIVER COURSE

His Majesty's Government of Nepal
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THE STUDY ON FLOOD MITIGATION PLAN FOR SELECTED RIVERS IN THE TERAI PLAIN IN THE KINGDOM OF NEPAL

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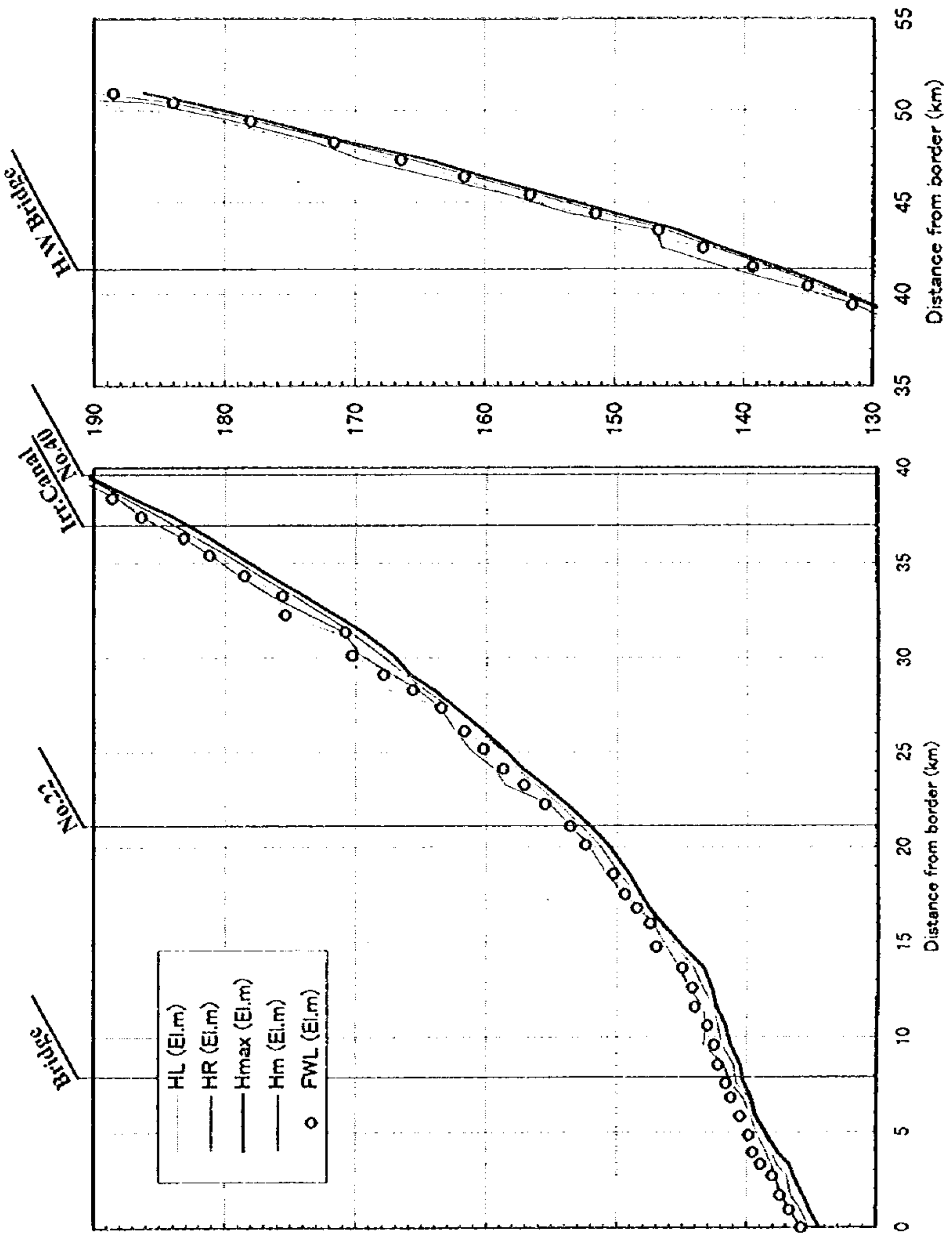
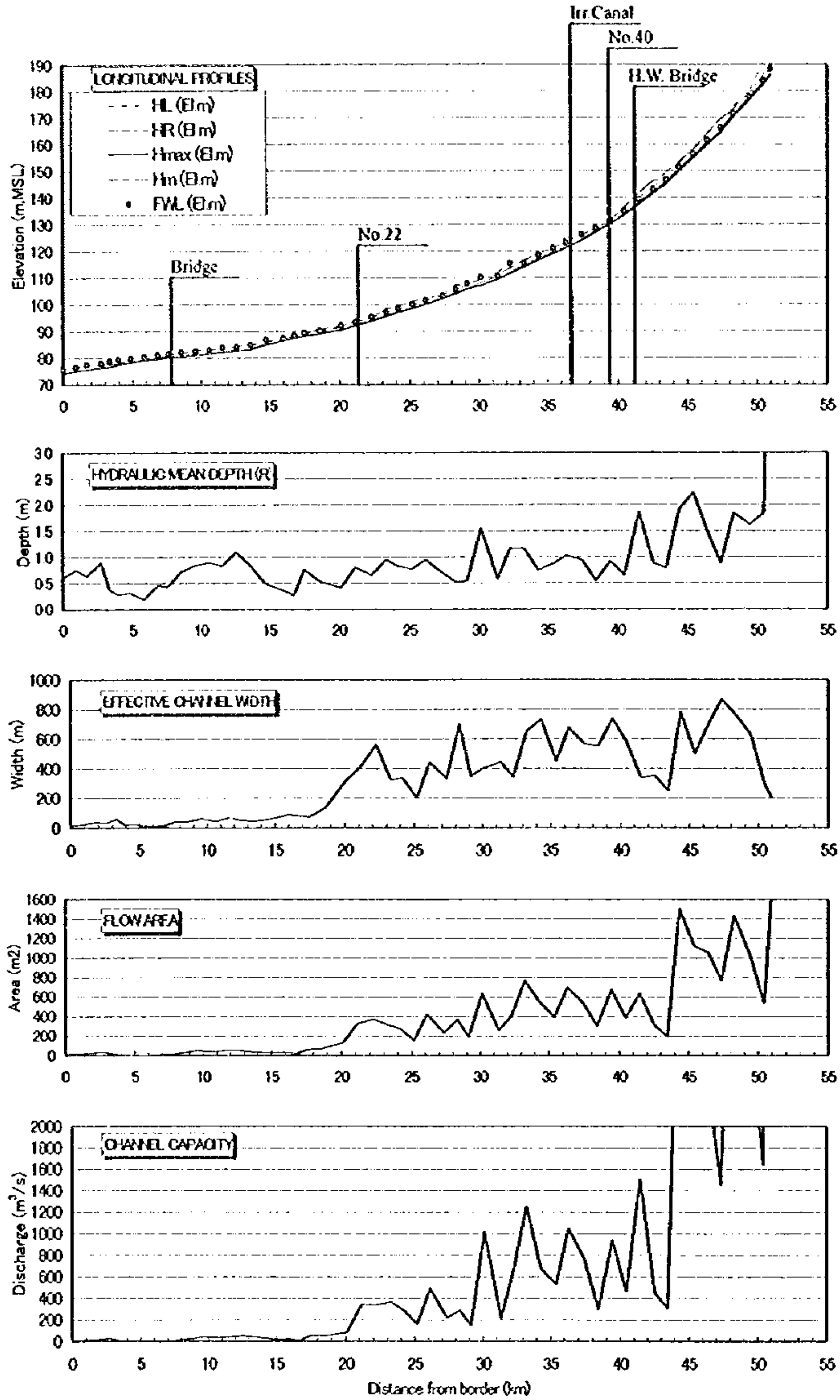
Fig. 6.6



LONGITUDINAL PROFILE OF LAKHANDEI RIVER

His Majesty's Government of Nepal Department of Irrigation, Ministry of Water Resources
THE STUDY ON FLOOD MITIGATION PLAN FOR SELECTED RIVERS IN THE TERAI PLAIN IN THE KINGDOM OF NEPAL
JAPAN INTERNATIONAL COOPERATION AGENCY



PRINCIPAL CHANNEL CHARACTERISTICS OF LAKHANDEI RIVER

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THE STUDY ON FLOOD MITIGATION PLAN FOR SELECTED RIVERS IN THE TERAI PLAIN IN THE KINGDOM OF NEPAL

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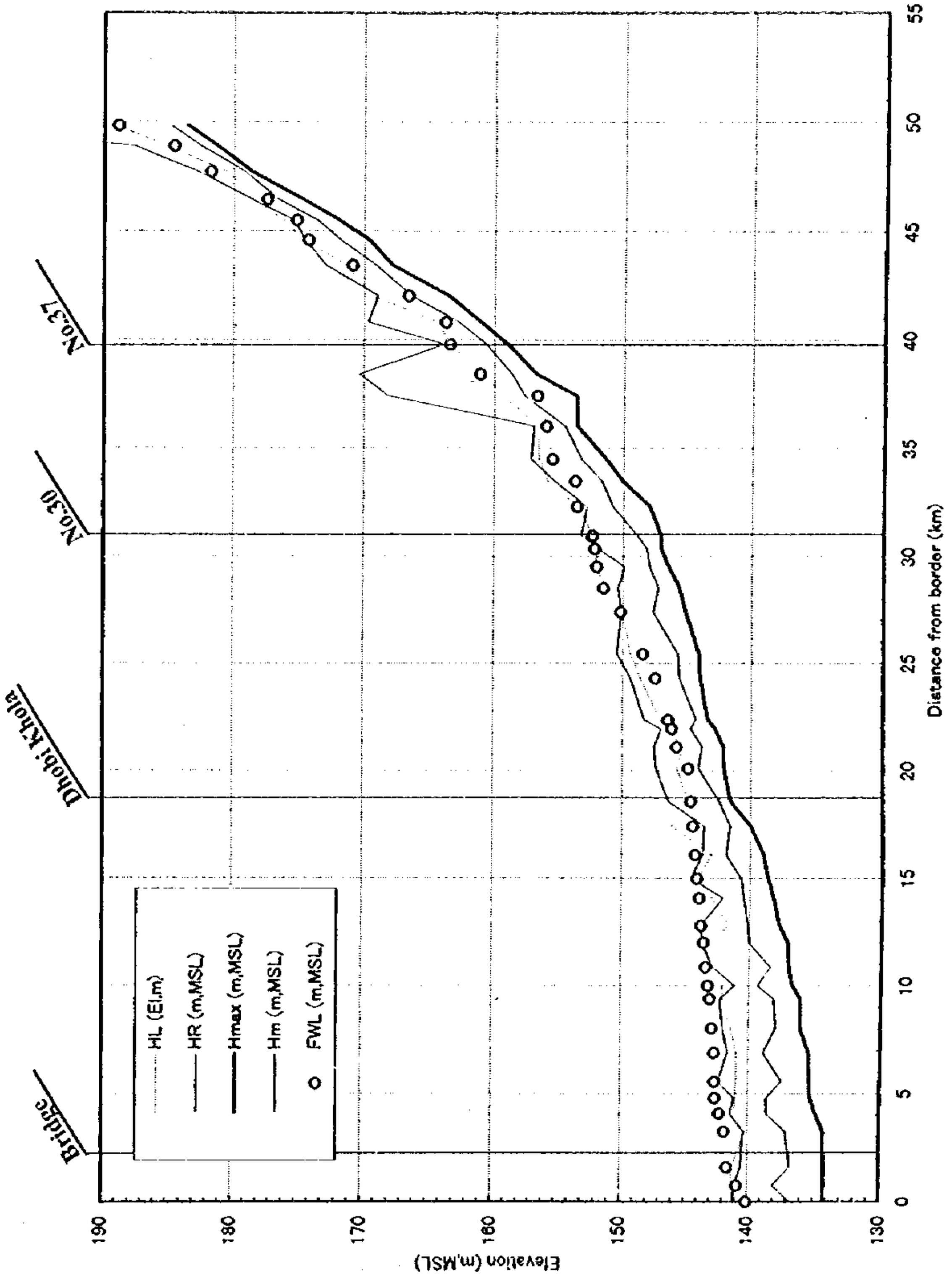

LONGITUDINAL PROFILE OF BABAI RIVER

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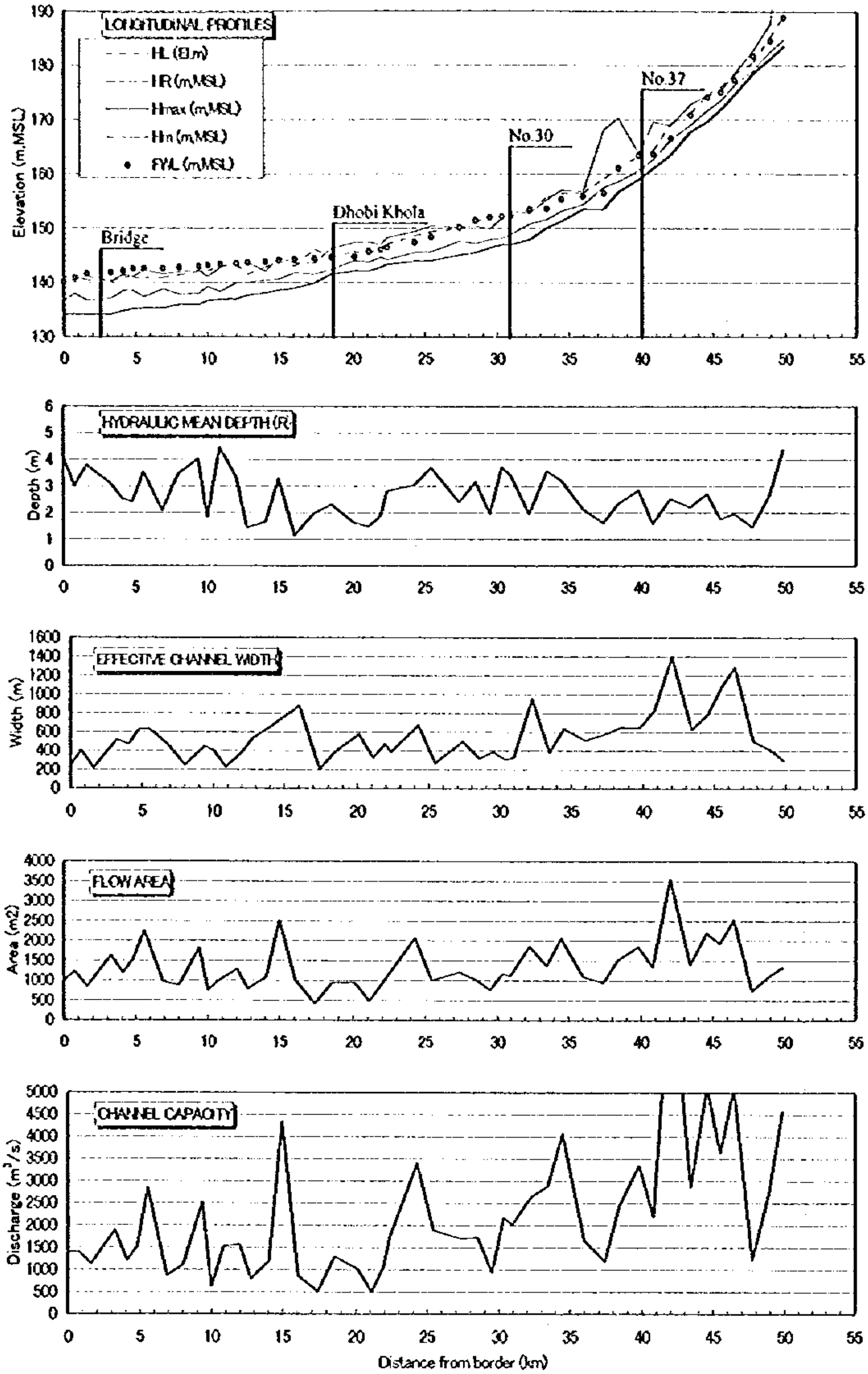
THE STUDY ON FLOOD MITIGATION PLAN FOR SELECTED RIVERS IN THE TERAI PLAIN IN THE KINGDOM OF NEPAL
JAPAN INTERNATIONAL COOPERATION AGENCY



PRINCIPAL CHANNEL CHARACTERISTICS OF BABAI RIVER

His Majesty's Government of Nepal
Department of Irrigation, Ministry of Water Resources
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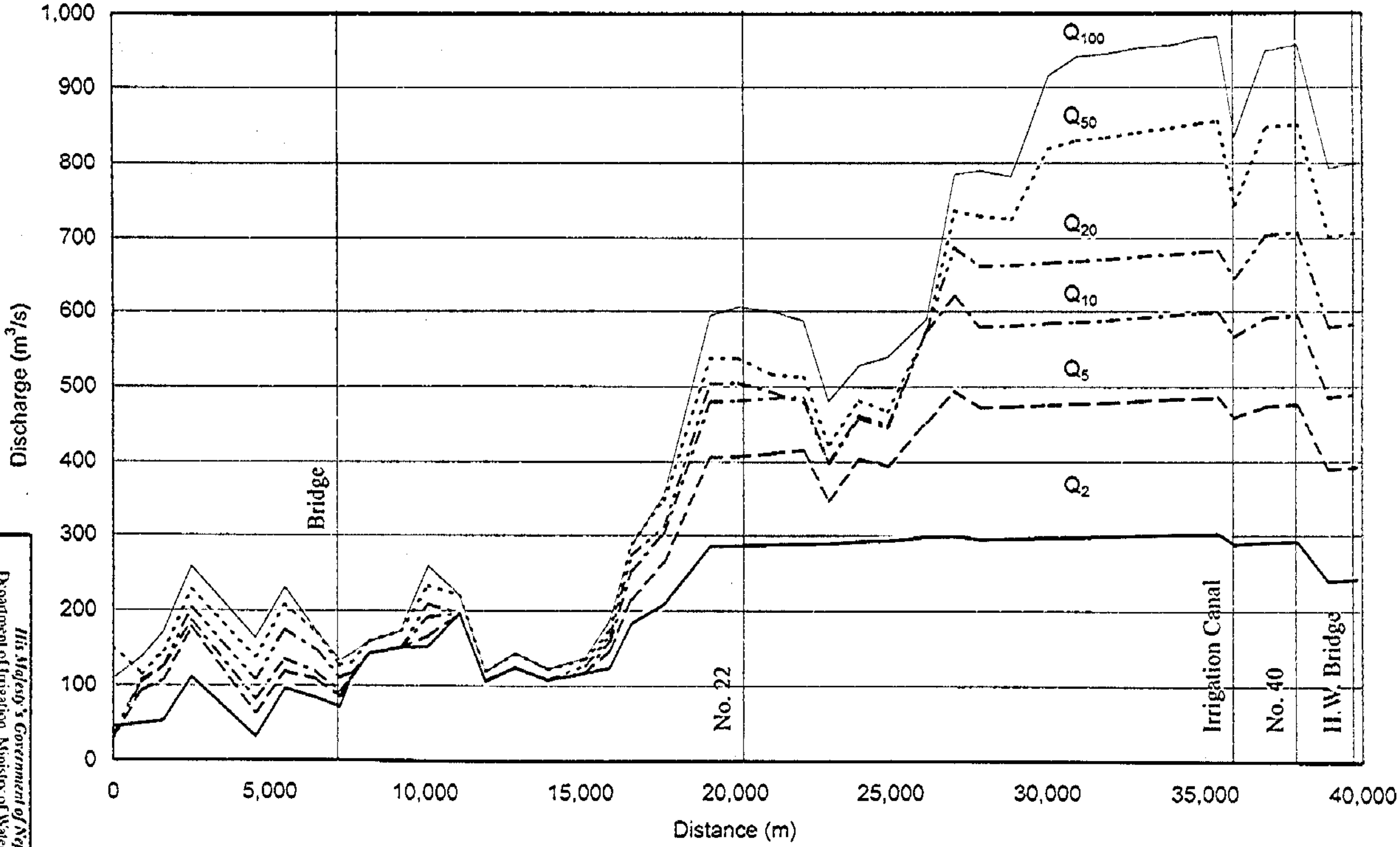
JAPAN INTERNATIONAL COOPERATION AGENCY



RESULT OF FLOOD FLOW ANALYSIS (LAKHANDEI RIVER WITHOUT PROJECT)

His Majesty's Government of Nepal
Department of Irrigation, Ministry of Water Resources
THE STUDY ON FLOOD MITIGATION PLAN FOR SELECTED RIVERS IN THE TERAI PLAIN IN THE KINGDOM OF NEPAL
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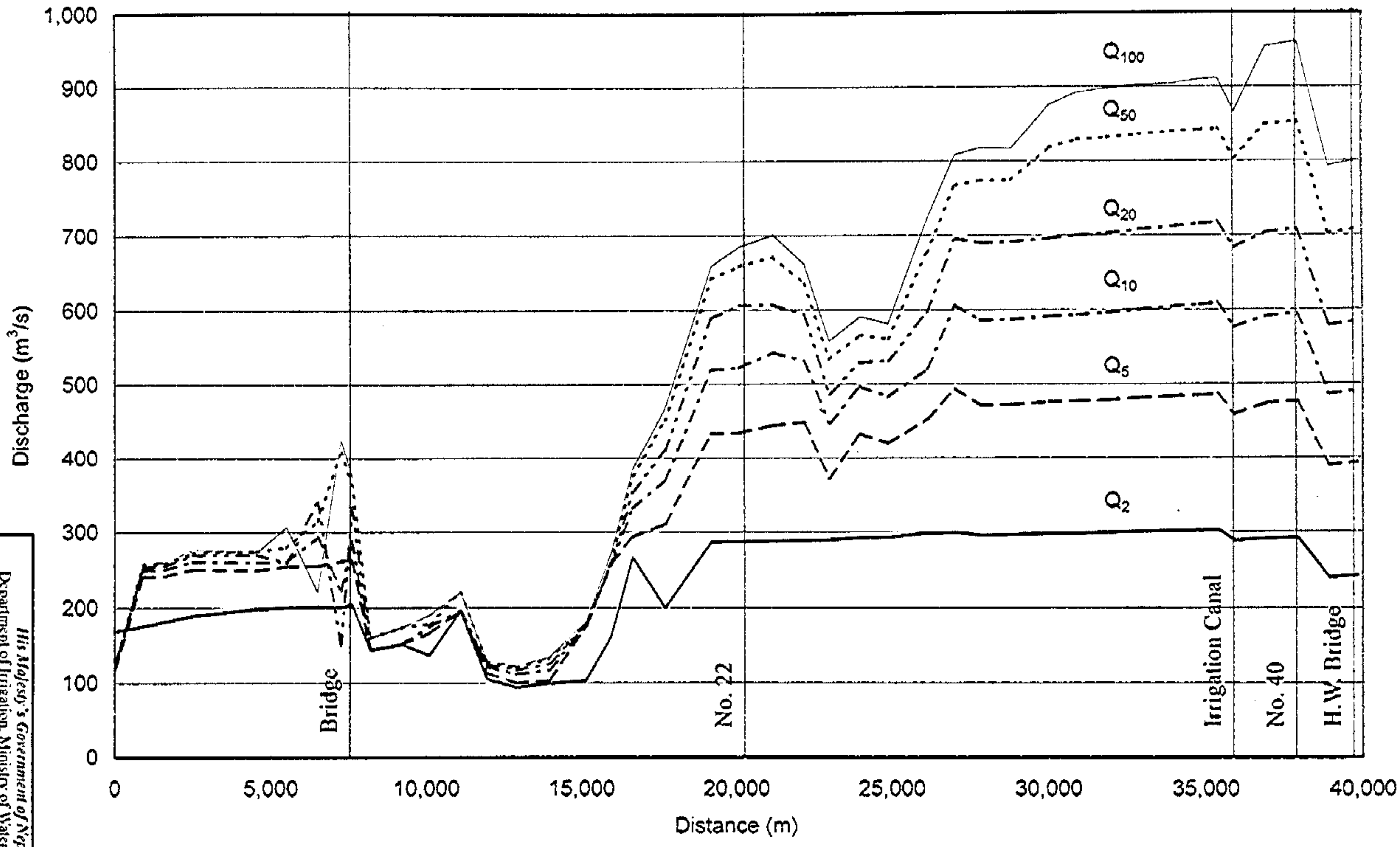
Fig. 6.10(2/2)



RESULT OF FLOOD FLOW ANALYSIS (LAKHANDEI RIVER WITH PROJECT)

His Majesty's Government of Nepal
Department of Irrigation, Ministry of Water Resources

THE STUDY ON FLOOD MITIGATION PLAN FOR SELECTED RIVERS IN THE TERAI PLAIN IN THE KINGDOM OF NEPAL

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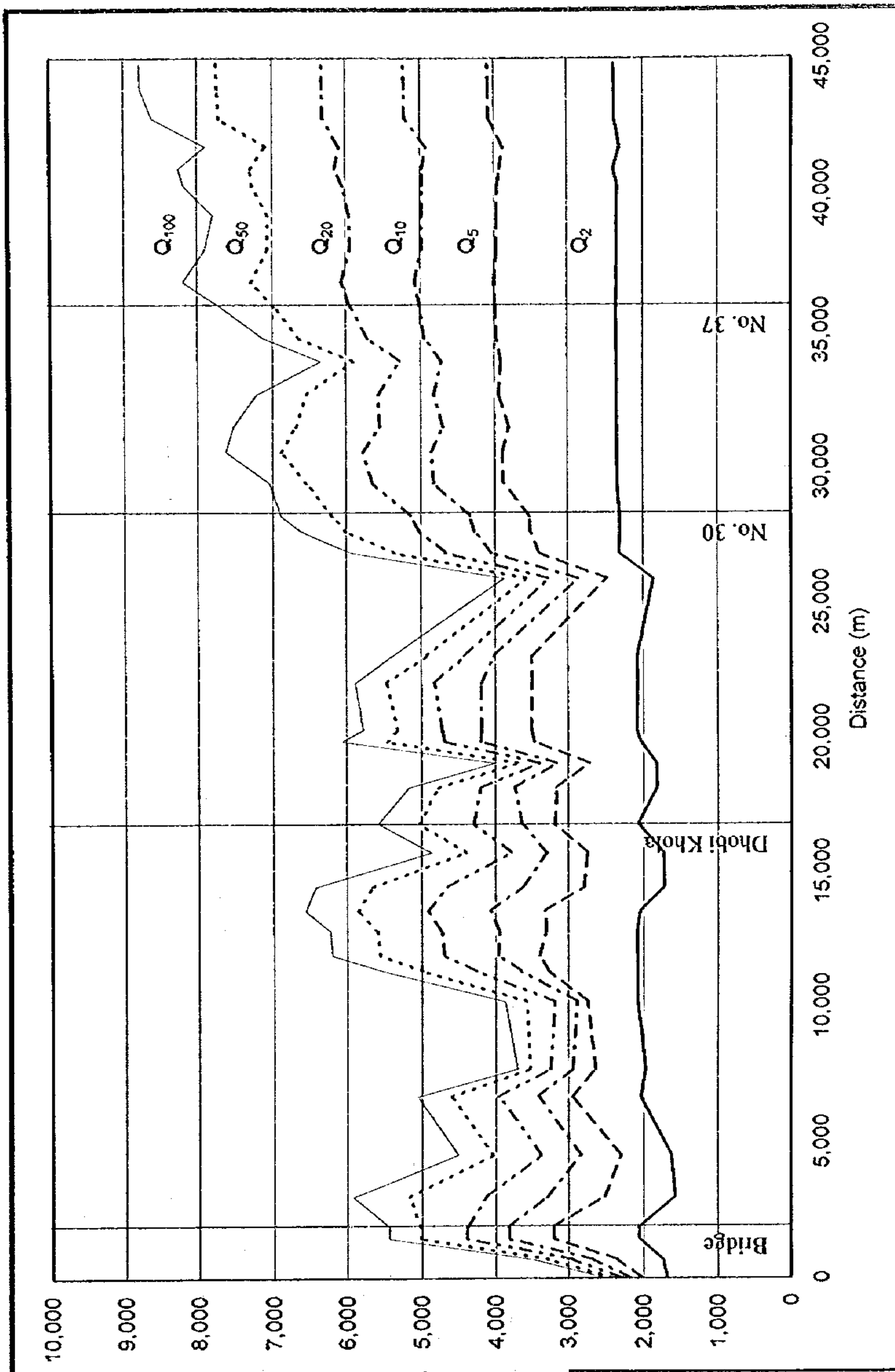
Fig. 6.11(1/2)



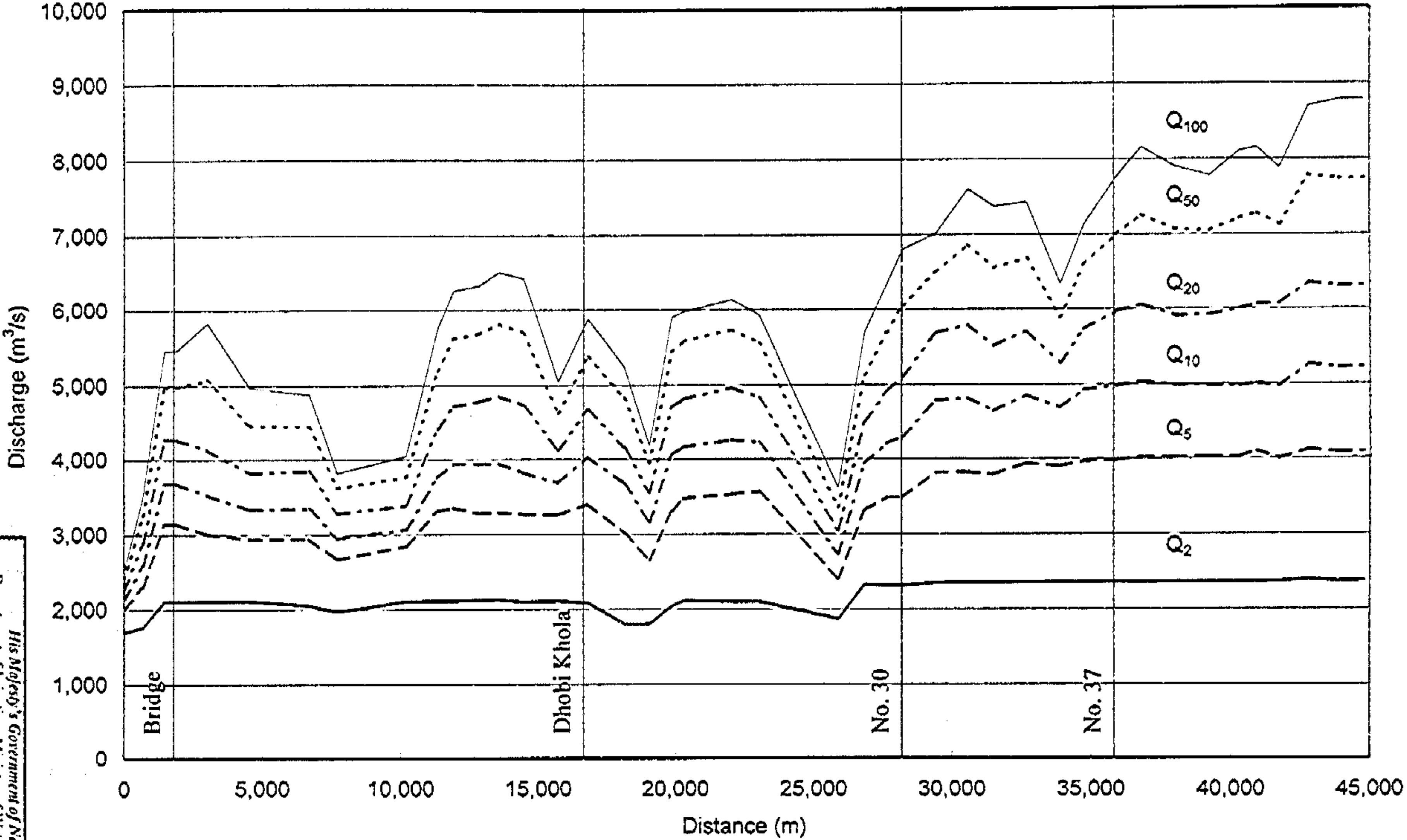
RESULT OF FLOOD FLOW ANALYSIS (BABAI RIVER WITHOUT PROJECT)

His Majesty's Government of Nepal
Department of Irrigation, Ministry of Water Resources

THE STUDY ON FLOOD MITIGATION PLAN FOR SELECTED RIVERS IN THE TERAI PLAIN IN THE KINGDOM OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY

Fig. 6.11(2/2)



RESULT OF FLOOD FLOW ANALYSIS (BABAI RIVER WITH PROJECT)

His Majesty's Government of Nepal Department of Irrigation, Ministry of Water Resources
THE STUDY ON FLOOD MITIGATION PLAN FOR SELECTED RIVERS IN THE TERAI PLAIN IN THE KINGDOM OF NEPAL
JAPAN INTERNATIONAL COOPERATION AGENCY

CHAPTER 7 PROJECT PLANNING

7.1 Principles for Planning

Within the frame of the Master Plan set forth in Chapter 4, the priority project selected for the Feasibility Study shall be planned here further in detail, based on the results of additional surveys and investigations. The principles established for the Master Plan shall be observed in this phase, too.

Objective of Project: The flood mitigation project aims to support people's livelihood and the development of agriculture in the Terai plain, reducing damages due to flood and sediment, reclaiming some of the sterile land, and enabling intensified cropping.

Safety Level: It is intended to form a river channel of about 2-year return period by bioengineering measures. In addition, every efforts will be made to mitigate substantial damages in the flood prone areas.

Project Area: The project covers plain and watershed areas of the Lakhandei river and plain area of the Babai river.

Objects to be Protected: The major causes of damages in the Terai plain are (1) bank erosion, (2) sedimentation in the riverine areas, and (3) flooding and inundation. The following objects in the flood prone area have to be protected from these:

1) Human being
2) Settlements
3) Public facilities
4) Farmland and livestock

Project Component: In order to carry out the project in practical and sustainable manners, it is crucial to adopt all the possible structural and non-structural measures in combination with community development activities. Therefore, the project is composed of three components, i.e., (1) watershed management, (2) river control, and (3) community development components.

Target Year and Implementation of Pilot Project: Although the target year for the Master Plan has been set in the year 2017, the implementation schedule of the priority project for the Lakhandei and Babai rivers should be rearranged, so that the project could be completed by the year 2007 (by the end of 10th national plan).

More than sixty rivers flow through the Nepal Terai plain, and all of these rivers are causing flood and sedimentation. Eight of these rivers were first selected throughout the Terai plain for flood mitigation Master Plan, representing river basins of a similar nature. Two river basins, the Lakhandei and Babai rivers, were then selected as a priority project for Feasibility Study. These two rivers bear an important role as a model and/or pilot project of the flood mitigation. The priority project for the Lakhandei and Babai rivers should be, therefore, implemented intensively in advance to other river basins. The experience and technical know-how obtained through the priority project could be applied to more than sixty rivers in the Terai plain as well.

Flood Mitigation Budget and Project Size: Budgetary situation of HMG/N is summarized below on the expenditure basis:

(Budgetary Situation on Expenditure Basis: in million Rs.)

Descriptions	(1996/97)	(1997/98)
National total expenditure	50,724	69,693
DOI total expenditure	2,577.9	3,040.8
Local-level river training program	44.9	120.0
District-wise river training budget		
- Sarlahi District	0.8	1.4
- Bardiya District	0.8	4.4

The above figures clearly show the severe financial constraints of HMG/N. Given the overall financial constraints, the budgetary allocation per district is small in size. The budget assigned to one river is even more limited, since each district has to distribute the funds among several rivers. For example, the 1996/97 funding for local river training was Rs.0.3 million for Lohandra river, Rs.0.4 million for Tinau River, and Rs.0.5 million for Babai. The existing river training budget is too small to implement basin-wide flood mitigation project and should be considered as a part of maintenance cost.

An idea on the project size can be drawn from the ongoing national-level river training works. As of March 1998, DOI operates six national-level undertakings for river training (see Table 2.11). Cost of these projects ranges from 28.5 to 370 million Rupees.

7.2 Watershed Management Component

In order to control and manage sediment in the watershed area, (1) construction of erosion control facilities, (2) encouragement of afforestation/reforestation and proper land use in the watershed are recommended as primary measures. Furthermore, (3) publicity activities are also essential to mobilize local communities and governmental and non-governmental organizations. These measures and activities should be put into practice in each watershed from those that are ready for implementation.

(1) Erosion Control Facilities for Lakhandei Watershed

Sediment Source and Coping Measures: The major sources of sediment in the Lakhandei watershed are due to (1) hill-side erosion on the southern slope of Siwalik hills (through tributaries), and (2) river-side erosion of the main Lakhandei river and major tributaries in the middle and upper watershed. Two kinds of measures are necessary to cope with these problems as follows:

1) Measures for hill-side erosion in the southern slope of Siwalik hills:
   - Gully erosion control
   - Hill-side works
2) Measures for river-side erosion along the river:
   - Consolidation of riverbed
   - Protection of riverbank from scoring
   - Planting permanent crops along the riverbanks.

Erosion Control Works: Various works applicable to these measures are shown in Fig. 7.1. In the Figure, a combination of structural works and bioengineering is also presented. The effects of these works largely depend on the geology and mechanism of erosion. These are not investigated as yet intensively in any part of the Siwalik hills. It is therefore proposed to conduct an experimental work, selecting test sites in the southern slope of the Siwalik and the river reaches along the main Lakhandei river.

Experimental Work on Hill-side Erosion: Experimental work on hill-side erosion aims to analyze the flood and sediment runoff of two small catchment basins with and without experimental works in the southern slopes of the Siwalik hills, and to evaluate their effects in relation to rainfall intensity, flood and sediment runoff, etc., using the records obtained at the test sites.

1) **Test sites:** Two basins (Basin-A and Basin-B of about 5 km^2 each) in the Chapani river basin.
   - Basin-A: With experimental works for gully erosion control, hillside works, bioengineering, etc.
   - Basin-B: Without work and leave as it is for comparison.
2) **Observations:**
   - Rainfall: One set of recording rain gauge to be used commonly for two test basins and an ordinary rain gauge for each basin.
   - Discharge: By a recording water-level gauge at check dams to be constructed at the lower end of each test basin.
   - Sediment: By water sampling for suspended and wash loads. Bed load will be estimated analytically based on the observed flow records.
3) **Monitoring:** Cross-sectional river survey and bed material sampling in the upstream and downstream reaches of the check dam at the fixed monitoring sections, twice a year in April (before rainy season) and in October (after rainy season). For this purpose a survey benchmark should be installed at the check dam.

Experimental Work for River-side Erosion: Experimental work for river-side erosion in Lakhandei river is also proposed, which aims to analyze the flood and sediment runoff of the main Lakhandei river basin, and to evaluate the effects of coping measures in relation with rainfall and flood runoff, using the records obtained at the test sites.

1) **Test sites:** A river stretch along the main Lakhandei river for riverbed consolidation and riverbank protection works.
2) **Observation:**
   - Rainfall: One set of recording rain gauge and three common rain gauges set in the lower, middle and upper watershed.
   - Discharge: By a recording water-level gauge to be installed at a section.
   - Sediment: By water sampling for suspended and wash loads. Bed load will be estimated analytically using the observed flow records.
3) **Monitoring:** Cross-sectional river survey and bed material sampling on the test stretch at fixed monitoring sections, twice a year in April (before rainy season) and in October (after rainy season). For this purpose a survey benchmark should be installed near the test stretch.

(2) Afforestation and Land Use Regulations

The following activities for afforestation/reforestation and land use regulation should be encouraged:

1) Management of forests including planting trees and natural regeneration. Community forest management should be encouraged.
2) Designation of steep slopes for planting permanent crops. Multi-year crops are also encouraged in the watershed areas.
3) Encouragement of planting commercial vegetation such as fruit trees, medicinal herbs, aromatic plant and dye plants with appropriate care for erosion control. The root crops should not be chosen.
4) Fodder grasses and trees to be planted along the contour and on terraces. Livestock should be restricted within a permissible limit for the sustainable use of pasture and forest.
5) Wild medical herbs to be protected from over-collecting by practicing sustained yield management.
6) In wood deficit areas, use of firewood to be decreased through improved cooking devices.
7) Training of local people on community forest management and the appropriate management of pasture and farmland in watershed areas.

(3) Publicity Activities

In order for communities, NGOs, and local/central governments to benefit from the efforts made in other watershed, and to be familiar with watershed management, any possible activities for publicity should be undertaken.

7.3 River Control Component

There are some design criteria for river and drainage structures in Nepal. Deliberating over the collected criteria and standards, and through discussions with related organizations, the following criteria were applied for designing structures:

1) Design Manual for River Training Works in Nepal, prepared by Ministry of Water Resources, Nepal.
2) Technical Standard for River and Sabo Facilities, prepared by the Ministry of Construction, Japan.

7.3.1 Preliminary Facility Design

Spur (or Groin): Spurs are classified into two types, permeable and impermeable ones. Generally speaking, the permeable spurs are used for river channels with gentle bed slope, while the impermeable spurs are adopted for river channels with steep slope. The length, height and spacing of spurs depend on local conditions, expected function, materials to be used, etc.

A pile spur was proposed for the present study as the permeable type and a gabion spur as the impermeable type. The pile spur consists of four (4) lines of reinforced concrete (RC) piles and Type-Pa as shown in Fig. 7.2 was designed for the Lakhandei river and Type-Pb for the Babai river. The gabion spur consists of gabion mattress with boulders. The gabion spur is shown in Fig. 7.3. Types Ia and Ib were adopted to the Lakhandei river, and Types Ic and Id to the Babai river. The major dimensions of spurs are as follows:

(Major Design Dimensions of Spurs)

River Name	Section (km)	Spur Type	Length(m)	Height(m)	Span(m)
Lakhandei	0.0 ~ 25.2	Permeable	20.0	1.0	40.0
	25.2 ~ 39.4	Impermeable	20.0	1.5	60.0
	39.4 ~ 51.0	Impermeable	20.0	3.0	80.0
Babai	0.0 ~ 28.5	Permeable	40.0	2.0	80.0
	28.5 ~ 39.8	Impermeable	40.0	2.5	120.0
	39.8 ~ 49.8	Impermeable	40.0	3.0	160.0

Revetment: Revetment works were designed on dike slopes which might suffer from scouring and seepage. Type Ra, consisting of boulder pitching and backfill gravel as shown in Fig. 7.4, was proposed for the Lakhandei river. Types Ra, Rb and Rc were proposed for the Babai river depending on the respective site conditions.

Forest and Grass Belts: Forest and grass belts were proposed along the river course to temper flood flow over the land and to trap the sediment. In principle, these belts are aligned on the river boundary line (RBL). Figure 7.5 shows schematically the layout of forest/grass belt and the RBL. The forest belt consists of trees to protect the belt from floating logs and other course materials and grass to trap the sediment. The forest belt can replace the grass belt.

Earth Dike: Ring dike, dike road and closing dike were proposed as earth dike structures. Typical sections of each dike are shown in Fig. 7.6. Dimensions of dikes such as freeboard, crown width and side slope gradient were designed depending on the magnitude of design discharge and proposed functions of each dike. The dike crown metalled with gravel of 4.0-m width can be used as a maintenance road and as rural road as well for the local people.

Sluice: Sluices were provided for ring dikes to drain interior rainwater through the earth dike. Typical section of the sluice is shown in Fig. 7.7.

7.3.2 Studies on Alternative Schemes

(1) Route of Lakhandei River between Laksmipur and Belhi Villages

Problems: In the stretch between Laksmipur and Belhi villages, the Lakhandei river changes its route frequently and the channel system is complicated. Many villages are located close to the river in this stretch. They are Laksmipur, Sundarpur, Belhi, Padariya and Sivanagar villages. All of these villages have suffered repeatedly from flood and sediment disasters.

Alternative Schemes: The stabilization of the river course is the primary concern in this stretch. Considering the existing river course and the distribution of villages and houses, the following alternative routes were considered (Fig. 7.8).

1) Alternative-1: Existing route
2) Alternative-2: Eastern route
3) Alternative-3: Western route

These alternative schemes were compared from various aspects and evaluated as shown in Table 7.1, to select the optimum scheme. In conclusion, alternative-2 (Eastern route), which takes the smoothest alignment and requires the least cost (see Table 7.4), was selected.

(2) Route of Lakhandei River Downstream from Phulparasi Bridge

Problems: The Lakhandei river bifurcates in the downstream from the Phulparasi bridge of Hulaki road near Inaruwa village, and in the upstream and downstream sections near Sakaraul village. In order to promote flood mitigation measures in these reaches, it is necessary (1) to select a route for the main river channel and (2) to stabilize the river course.

Alternative Routes: There are several conceivable routes as the main Lakhandei river, i.e., (1) Existing route passing by Sakaraul village, (2) Inaruwa route (right branch) passing by Inaruwa village, and (3) left route (new left branch) newly branched this year. Out of these, existing route is proposed mainly for the following reasons:

1) Although the Inaruwa route has the smoothest alignment, this route is not recommended, because it passes by the villages of Inaruwa, Simara and Phenhara and other village houses scatter along the riverbanks. This route may lead to flooding in this populated area. In addition, the VDC closed this branch with an earth dike this year.
2) The new left route has not yet form a channel, and this new route will have difficulty in reaching a consensual agreement from the affected people.
3) According to the topographic map of about 40 years ago, the main channel of the Lakhandei river took the existing route. Thus, in all probability, this route has been the main channel for more than 40 years. Hence, the existing route is most reasonable as main course. Except for Sakaraul village, no houses are found along the river course.

Measures to Stabilize River Course: Major cause of river course shifting is the silting the riverbed due to the spilling floodwater over the banks. It is necessary to confine floodwater and sediment within the river channel with enough sediment transport capacity. For this purpose, a grass belt is proposed along the river channel, so as to promote formation of natural levees on both banks.

Excavation of Pilot Channel: The existing channel capacity of the Lakhandei river is extremely low in the downstream reaches of the Phulparasi bridge (from Sections No.0 to No.9). The existing bank-full capacity in this stretch is only 9 m^3/s on average ranging from 0 to 28 m^3/s. In order to ensure the stabilization of the river course, it is necessary to excavate a pilot channel. The pilot channel section was designed under the following conditions:

1) The design discharge is 38 m^3/s, taking the average channel capacity in the adjacent upstream river reaches from No.10 to No.14.
2) The channel depth is designed at 1.0 m so that the shear velocity (U_*) of the

new channel is almost same as those of adjacent channel sections.

3) The pilot channel of a total length of about 7.6 km is designed with 50 m of top width.

(3) Severe Meandering of Babai River at Indrapur Bridge

Problem: The Babai river meanders severely in just upstream reaches from the Indrapur bridge of the Hulaki road. Owing to this meandering, farmland on both riverbanks is being eroded. In addition the approach roads on both sides of the bridge are exposed to the menace of scouring. During large floods, the approach roads are submerged.

Alternative Measures: Two alternative measures are considered to cope with the problems (Fig. 7.9).

1) Alternative-1: Intensive bank protection of the existing river channel
2) Alternative-2: Cut-off channel

These schemes were compared from various aspects as shown in Table 7.2, and evaluated to select an optimum scheme. In conclusion, alternative-2 (Cut-off channel) was selected mainly due to the lower net-cost taking into consideration the value of the reclaimed land (see Table 7.4).

(4) Sharp Bend of Babai River near Kusumba Bazar

Problems: Active bank erosion at the sharp bend of the Babai river near Kusumba Bazar is threatening the Hulaki road and Shivanagar village on the right bank and settlements located on the left bank in the downstream.

Alternative Measures: Two alternative schemes are considered to mitigate these problems (Fig. 7.10).

1) Alternative-1: Intensive bank protection of existing river channel
2) Alternative-2: Cut-off channel

These alternative schemes were compared from various aspects as shown in Table 7.3, and evaluated to select an optimum scheme.

In conclusion, alternative-1 (Intensive bank protection of existing channel) was selected mainly due to the advantage of cost (see Table 7.4). Since the cutoff channel takes route on the old riverbed and may submerge during large flood, it would be difficult to maintain the channel on the designated cut-off route.

7.3.3 Construction Plan

The construction plan was worked out considering the quantity of works, hydrological/meteorological site conditions, topographic/geological conditions, and other factors related to the implementation of the project.

Daily Working Hours and Workable Days: All construction works were assumed under a single shift of 8-hour a day. The number of workable days was estimated based on rainfall data recorded in the study area. Saturdays, national holidays and religious events were also considered as non-workable days. The estimated workable days for respective rivers and type of works are as follows:

(Annual Workable Days)

Work Items	Workable Days	
	Lakhandei R.	Babai R.
Concrete Works	230	240
Embankment Works	210	220

Construction Method: The work plan must be prepared considering safety and costs, bearing in mind the scale of the work and site conditions. The standard construction methods for the major work items are described as follows.

1) Excavation for on-land works will be basically carried out by a combination of manpower and hauling machines.
2) Embankment works will be carried out basically by a combination of manpower and suitable compaction machines.
3) Other construction works such as gabion work, concrete work, masonry work, afforestation work, etc. generally will be performed by conventional methods.

Construction Materials: The major construction materials for flood mitigation structures are as follows.

1) **Embankment Materials:** The earth materials along the length of the Lakhandei and Babai rivers are mostly usable as embankment material when constructing earth dikes. The excavated soil from the construction of other flood mitigation structures can also be utilized as embankment material.
2) **Boulder:** A large quantity of boulders will be required for gabion and masonry

works. According to the result of bed material investigation, procurement of boulder is possible at the upper reach of the Lakhandei river. As to the Babai river, although it is possible to get boulder at upper reach in Babai river, the hauling distance is considerably long. Therefore, quarry site in the Karnali river located next to the Babai river is recommended for the project.

3) **Coarse and Fine Aggregate:** Specified gravel sizes are required as the coarse and fine aggregate for concrete works. From the result of bed material investigation, it is judged sufficient quantity of coarse and fine aggregates is available from the Lakhandei and Babai rivers.
4) **Other Construction Materials:** Other materials required for the construction of flood mitigation structures, such as cement, reinforcing bars, gabion wire, etc. have to be procured at local markets or from neighboring districts.

7.4 Community Development Component

This section demonstrates how the basic framework of the community development component described in Chapter 4 will be tailored to the location-specific situations along the Lakhandei and Babai rivers.

7.4.1 Community Mobilization (Lakhandei River)

Workshops for Local Government Institutions (LGIs): One major limitation of the present VDC leaderships is that most of the Chairmen are only concerned with keeping the river as far away from their villages as possible. Accordingly, the Workshops for LGIs along Lakhandei will include one additional subject on "Cost-Benefit of Flood Mitigation Master Plan". This is intended to enable the VDCs to see the totality of the Plan, so that they will be ready to compromise with one another to collectively gain the benefits.

Formation of Community Organizations (COs): There is hardly any tradition of self-organized activities that can be tapped for Lakhandei flood mitigation, as shown in Table 7.5. Moreover, there is not much external support in forming community organizations. More time will be required in dialoguing with local communities along the Lakhandei river, before getting them organized for flood mitigation activities. At the same time, there are, of course, exceptions. Some areas have practiced organized approaches to flood mitigation (e.g., Patharkot VDC, Janaki Nagar VDC, Pidari VDC, Padariya VDC). Local communities will be assisted in revisiting such precedents, to follow similar participatory approaches.

Promotion of Public Awareness, Knowledge and Skills:

1) **Technicalities of Flood Control Measures:** The people generally attribute the major cause of flooding to the run-off and erosion from the upper watersheds. The CO training along Lakhandei will inform the people that the forest/grass belts have been designed in such a manner to temper the flood flow and trap the sediment. A majority of the localities hopes for continuous dikes that are not proposed in the Plan. The training will deal with the reasons why continuous dikes are not opted (refer to Section 4.2, (4)).
2) **Skills in Masonry and Gabion-netting:** One third of the affected VDCs (Patharkot VDC, Gurkauli VDC, Janaki Nagar VDC, Laksmipur VDC, Sakaraul VDC) have people with capabilities in masonry and gabion netting, but only in small numbers in each village. Representatives from each CO will therefore be given training, who will then be hired for the construction of flood control works, and will also take the lead in regularly maintaining the structures at later stages.
3) **Community Participation in Flood Mitigation:** As mentioned already, although the local communities will revisit some examples of locally initiated flood mitigation to draw lessons how to be involved in flood mitigation, this does not mean the people should blindly follow the precedents. Since most of these localities hire a limited number of beneficiaries as laborers only, the people will instead learn to initiate the equity principle (i.e., the larger benefits, the larger contributions), as already practiced by some model localities (e.g., Patharkot VDC, Janaki Nagar VDC, Pidari VDC, Belhi VDC).

Generation of Financial Resources by COs: Some VDCs have been assisted in forming women's groups with group saving schemes (see Table 7.5). Such schemes may potentially be evolved into group savings for flood mitigation purposes. Moreover, vegetable farming and livestock raising are important sources of cash income for women throughout Sarlahi district. The program will tap into the women's incomes. It is to be noted, however, where there has been no external support, it will require substantial efforts to draw them into such public activities.

7.4.2 Local Coping Measures (Lakhandei River)

Flood Proofing: Where agricultural land is often covered by infertile sand, a list of such catch crops will potentially be adopted in different localities along Lakhandei

(Table 7.6) as have already been taken in some areas (e.g., Netragunj VDC, Sakaraul VDC). Farmers who potentially face shortage of paddy seedlings, after their land is covered by alluvial soil, will produce a reserve of extra seedlings (e.g., Pidari VDC, Shripur VDC, Sundarpur VDC, Padariya VDC, Simara VDC, Bhadsar VDC). Localities with felt needs for more durable housing structures (e.g., Netragunj VDC, Gurkauli VDC, Janaki Nagar VDC, Sundarpur VDC. Laksimipur VDC) will be assisted in the plantation of the species that produce quality timber. The program will also assist in improve on, and disseminate other flood proofing practices, e.g., the artificial mounds for the houses (e.g., Belhi VDC), bamboo-stand to store grain (e.g., Shripur VDC).

Forecasting, Warning and Evacuation: Because of small basin size and flash flood runoff, telemetering system would not be applicable for flood forecasting and warning. However, there is ample scope to promote organized warning and evacuation, following some localities (e.g., an organized evacuation in Haripur VDC, collective river watching in Janaki Nagar VDC). In addition, warning can be enhanced by using the existing facilities, e.g., public call office (P.C.O.) and mosque speakers available in most of the affected VDCs. To facilitate evacuation, road improvements will be undertaken, through installing culverts and constructing bridges, etc. (e.g., Pidari VDC, Shripur VDC, Padariya VDC, Sakraul VDC, Bhadsar VDC). This will also assist the people to meet other daily lives during the dry season as well.

Flood Fighting: There exist locally-initiated flood fighting (e.g., bamboo piles in Shripur VDC, Phul Parasi VDC, Padariya VDC, Laksmipur VDC, a permeable type of log spurs in Phul Parasi, Gurkauli VDC). In those places, the communities will be assisted to augment their locally initiated structures, by making available materials that are not available locally (e.g., boulders to be placed between the bamboo piles, or). Other localities which cannot implement flood fighting, due to the lack of materials (e.g., Gurkauli VDC), the local communities will plant such types of trees and shrubs that can be used for their flood fighting.

7.4.3 Community-based Sustainable Measures (Lakhandei River)

Forest and Grass Belts as Dike Works: Along the Lakhandei river, there exist a range of local trees and grass that can be used as fuel, fodder, timber, roofing, etc (Table 7.7). Moreover, since different localities exhibit unique variations, the selection of the species should be tailored to a particular situation surrounding each community (Table 7.8).

Especially some of the local communities will plant trees that produce durable housing materials, to cope better with inundation, thus linking the forest/grass belts with flood proofing. Finally, since Sarlahi district in which Lakhandei flows, is among the target districts under the government's sericulture policy. The plantation of mulberries, which silkworms feed on, will also be promoted, which is also good for soil erosion control.

Preventive Bank Protection Works: Communities plant a type of shrub (i.e., Behiya) as stand-alone protection work (e.g., Netragunji VDC). Where relevant support will be extended to combine shrubs, with other simple measures, e.g., spurs made of bamboo nets and sandbags, and where feasible, to change the switch to higher-value species, such as Amlisso (fodder and broom-making, etc.) and Khar (roofing, paper-making etc.). Also, such practice of bioengineering will be disseminated to other villages where river control works are proposed under the river control component, for example, planting shrubs/grasses at the backside of the revetments/spurs, and/or at the sand deposit areas of the spurs.

Access Improvements Using Flood Control Facilities: Dikes proposed for the two sites (i.e., one inside Padariya VDC, and the other linking Sundarpur VDC and Phul Parasi VDC) are designed as rural roads. Where the accessibility between the settlement and the dike is no good, short-distance roads will also be provided, so that the dikes can be used as part of the road networks. In other places where closing dike works are proposed (e.g., Patharkot VDC, Laksimipur VDC, Janaki Nagar VDC, Belhi VDC, Sakaraul VDC, Simara VDC), the closing dikes will be linked with other roads.

Bed Material Collection as Channel Excavation Works: Along the Lakhandei river, quality bed materials can be collected only in a few villages near the East-West Highway (e.g., Patharkot VDC, Gurkauli VDC). Still, there is scope to assist in clarifying whether the bed material collection comes under the jurisdiction of DDC or VDC (both of which are at present inactive). Another constraint is the lack of access roads, which can be overcome by graveling about 2 to 3 km of dirt roads to be linked with the East-West Highway. At the same time, guidelines should be developed and enforced to enable the authorities to monitor and regulate extraction activities, in order to exercise tighter control over contractors and local communities who tend to limit their extractions to accessible locations (near riverbanks or bridges).

Operation and Maintenance (O&M) of Flood Control Structures: For the dikes and