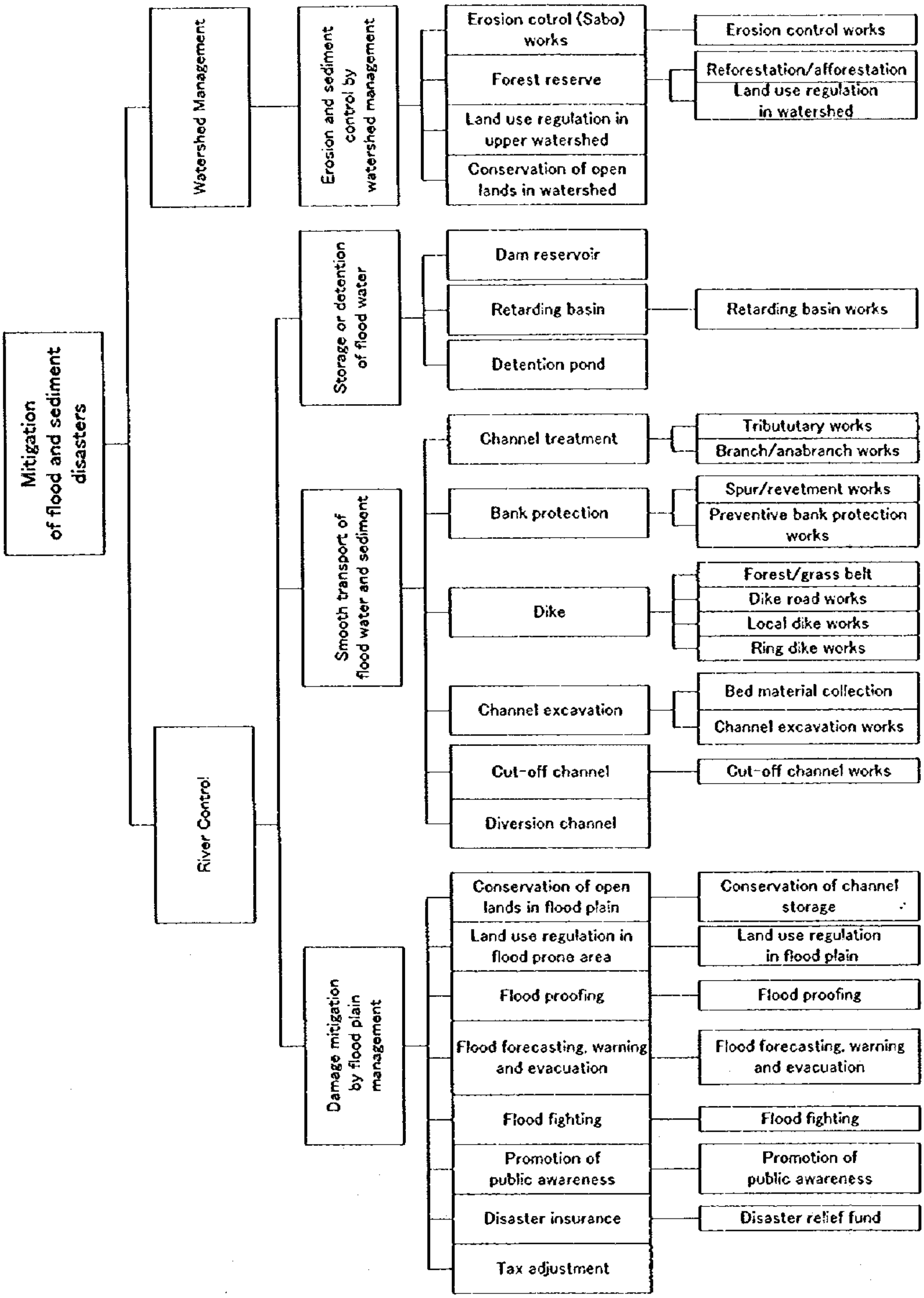
Fig. A2.1



FLOOD MITIGATION MEASURES

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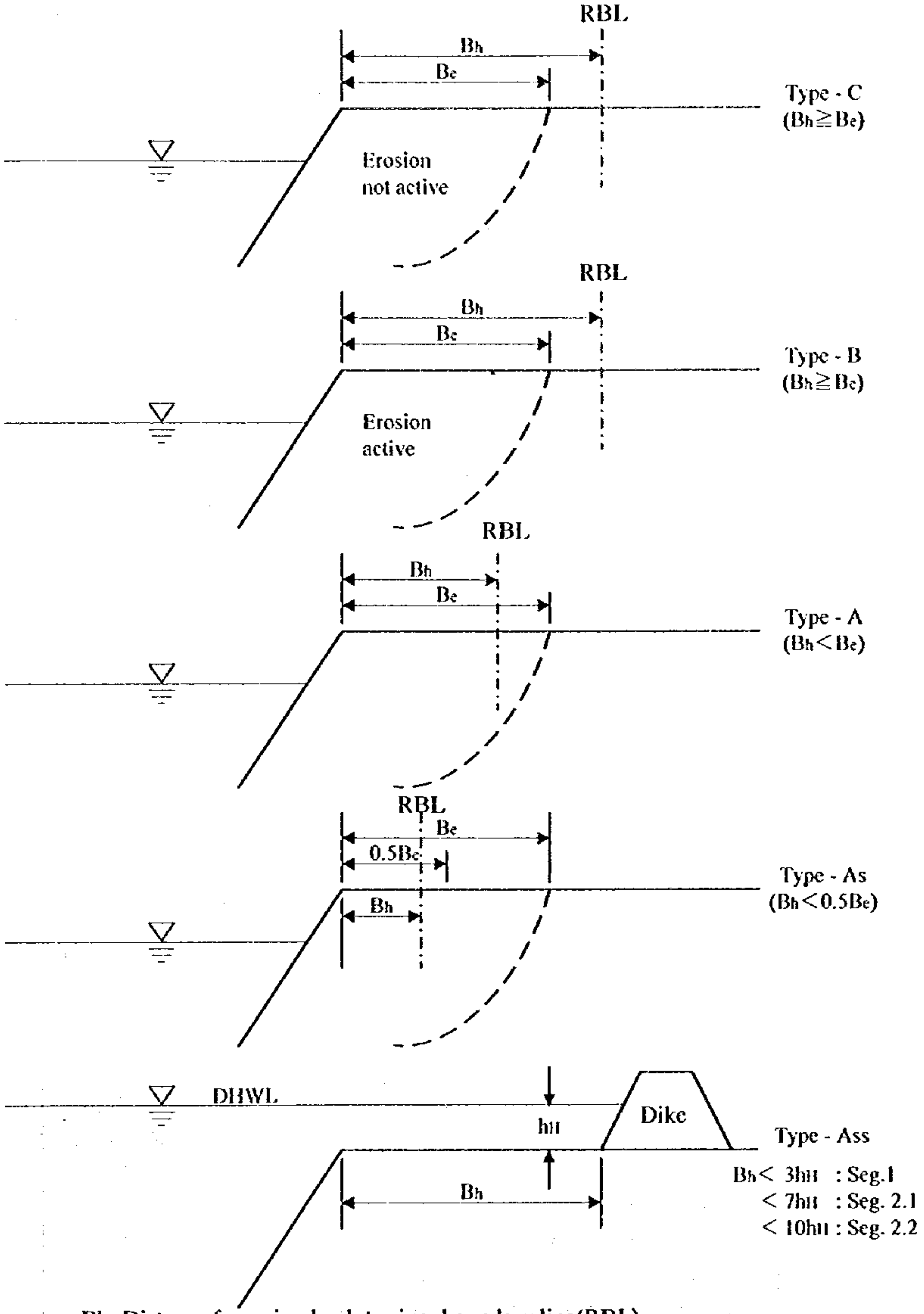
JAPAN INTERNATIONAL COOPERATION AGENCY



Bh: Distance from riverbank to river boundary line(RBL)

Be: Design erosion width (Assumed maximum annual erosion width)

CLASSIFICATION OF TYPES OF RIVER BANK

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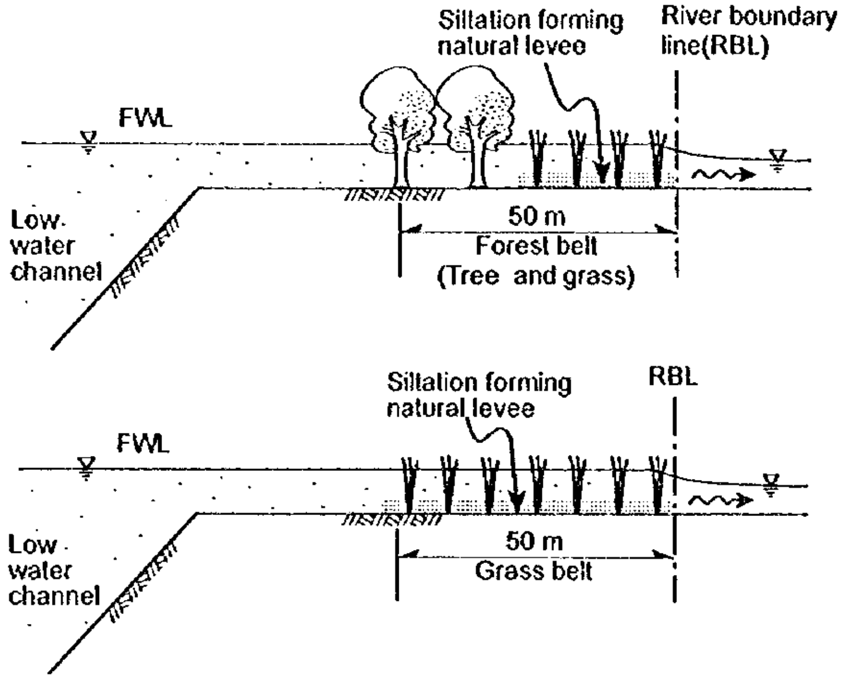
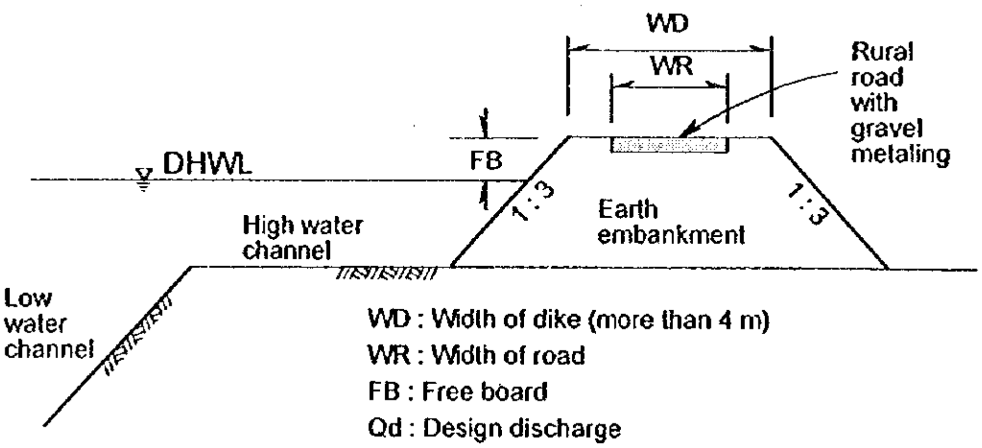
Forest and Grass Belt



Earth Dike / Road



WD : Width of dike (more than 4 m)
WR : Width of road
FB : Free board
Qd : Design discharge

Qd (m^3/s)	FB (m) (Not less than)	WD (m, Not less than)	
		Dike only	Dike road
Less than 200	0.6	3	5
200 to 500	0.8	3	5
500 to 2,000	1.0	4	5
2,000 to 5,000	1.2	5	5
5,000 to 10,000	1.5	6	6
More than 10,000	2.0	7	7

DIKE WORKS

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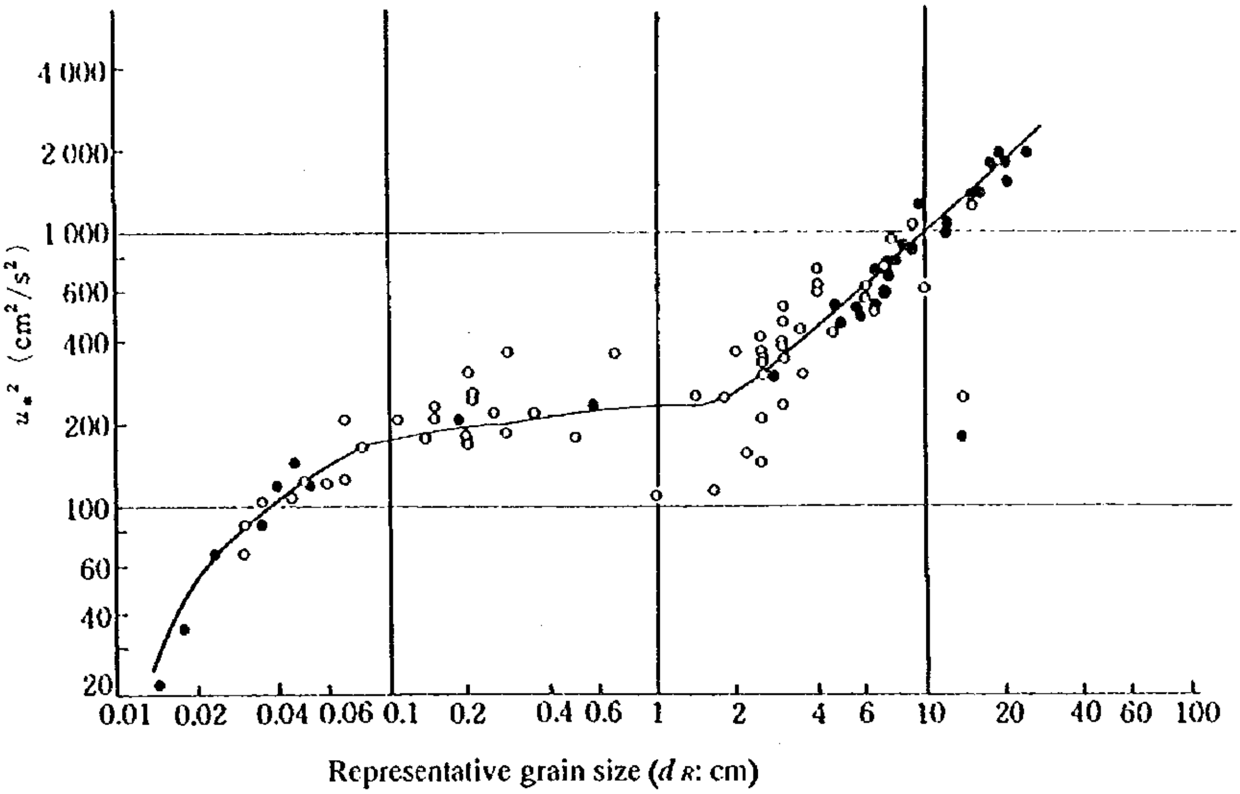

$$Q_2 = A \cdot V = \frac{B \cdot h_L^{5/3} \cdot I^{1/2}}{n} \Rightarrow h_L = \left\{ \frac{Q_2 \cdot n}{B \cdot I^{1/2}} \right\}^{3/5}$$

$$u_*^2 = g \cdot h_L \cdot I \Rightarrow I = \frac{u_*^2}{g \cdot h_L}$$

$$B = \frac{n \cdot Q_2}{h_L^{5/3} \cdot I^{1/2}} = \frac{n \cdot g^{1/2} \cdot Q_2}{u_* \cdot h_L^{7/6}} \qquad (m, \text{sec})$$

n : Manning's coefficient of roughness

g : Acceleration of gravity (m/sec²)

Q_2 : Two-year probable discharge (m3/s)

u_* : u_*-value obtained from d_R-u_* diagram for a given representative grain size (d_R) (m/s)

h_L : Mean depth of low water channel (m)

B : Low water channel width

RELATIONSHIP BETWEEN BED MATERIAL SIZE AND FRICTION VELOCITY

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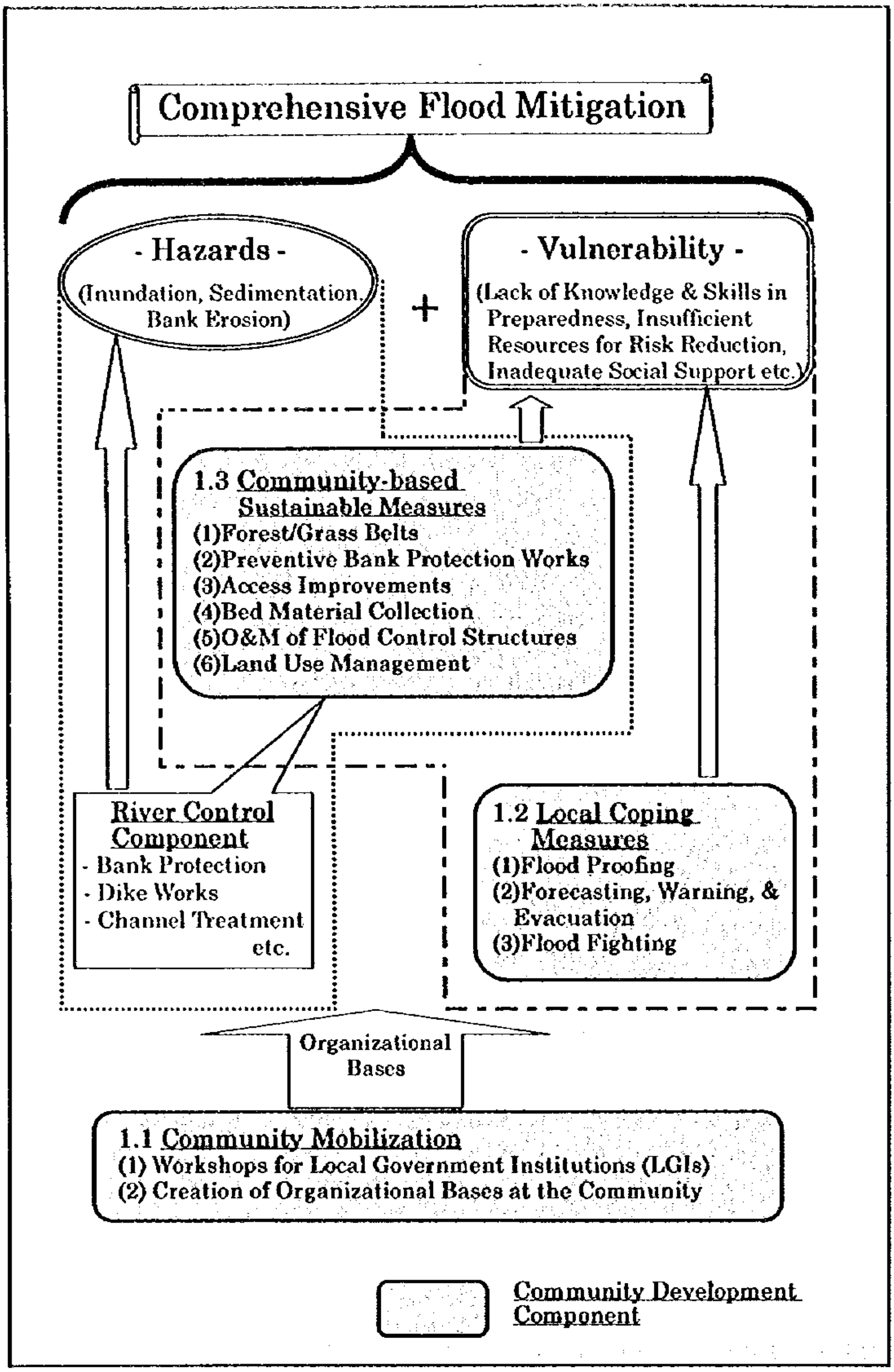

COMPREHENSIVE FLOOD MITIGATION

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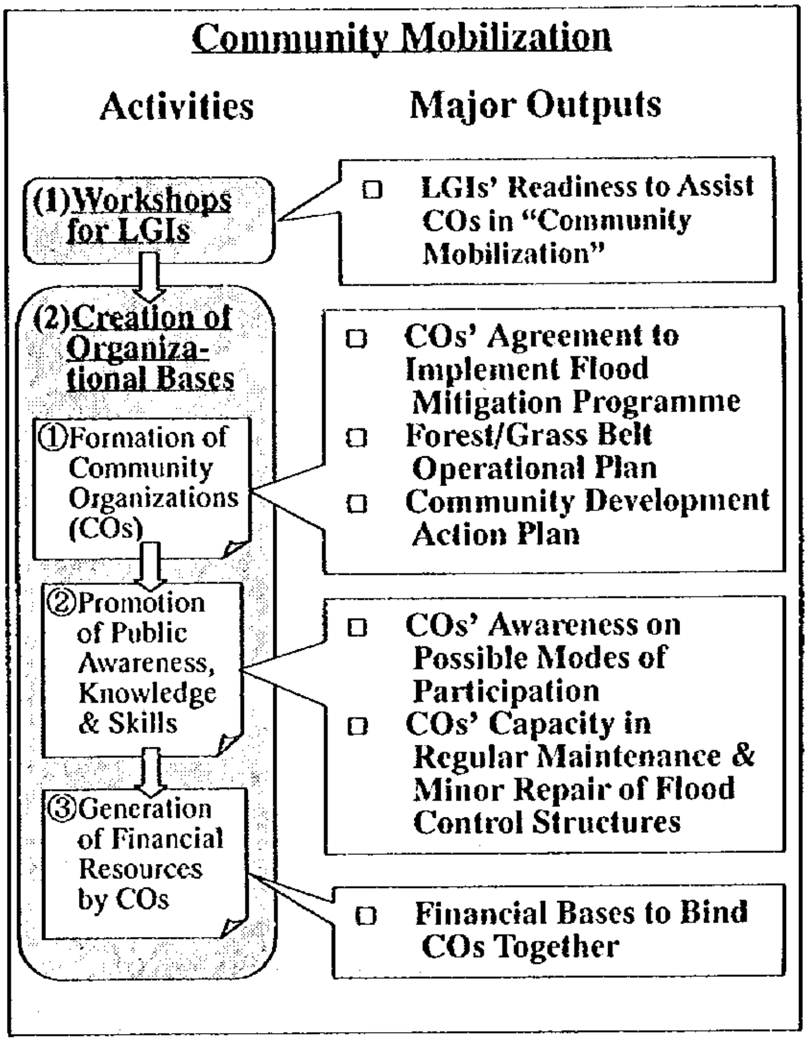

COMMUNITY MOBILIZATION

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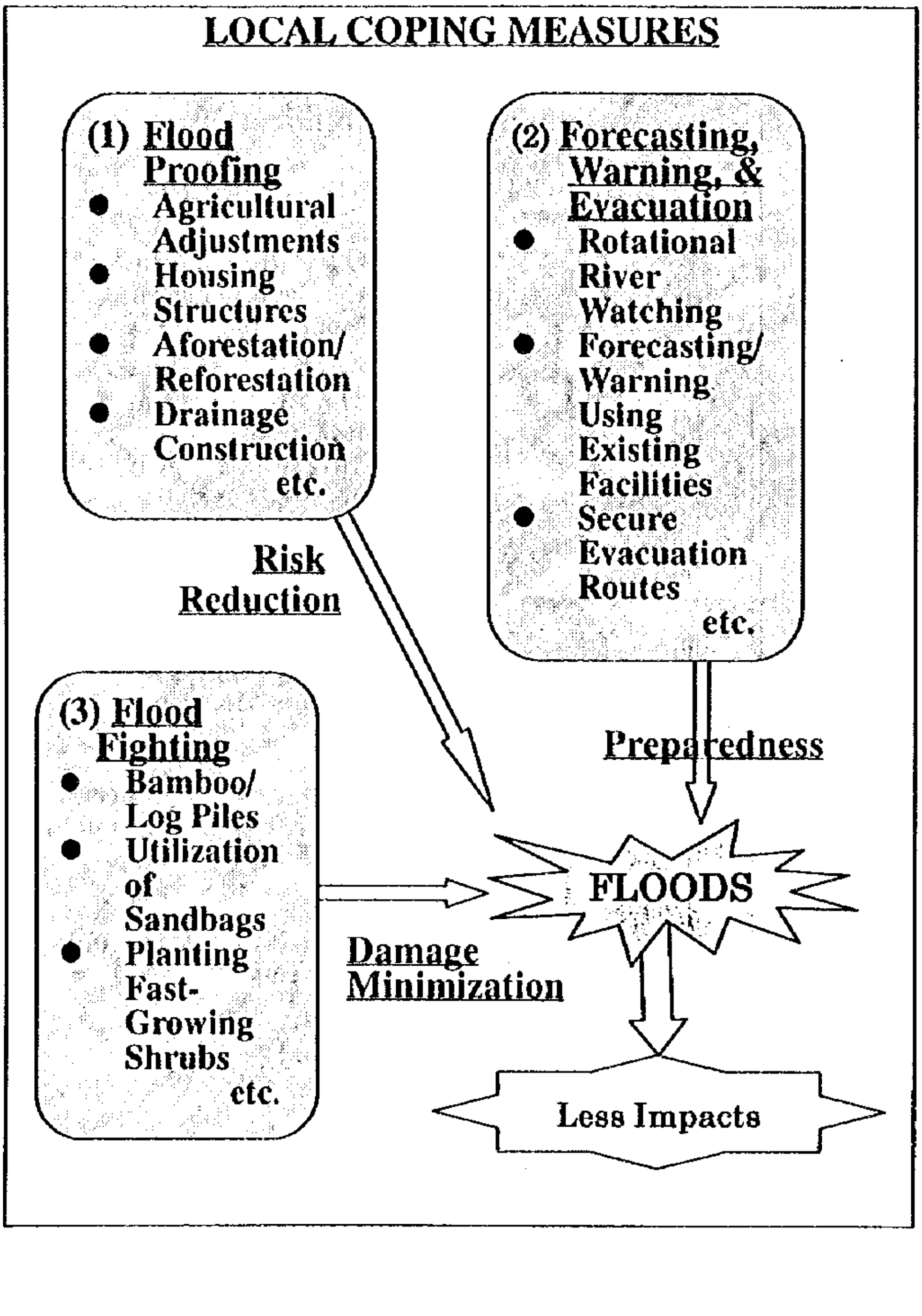

LOCAL COPING MEASURES

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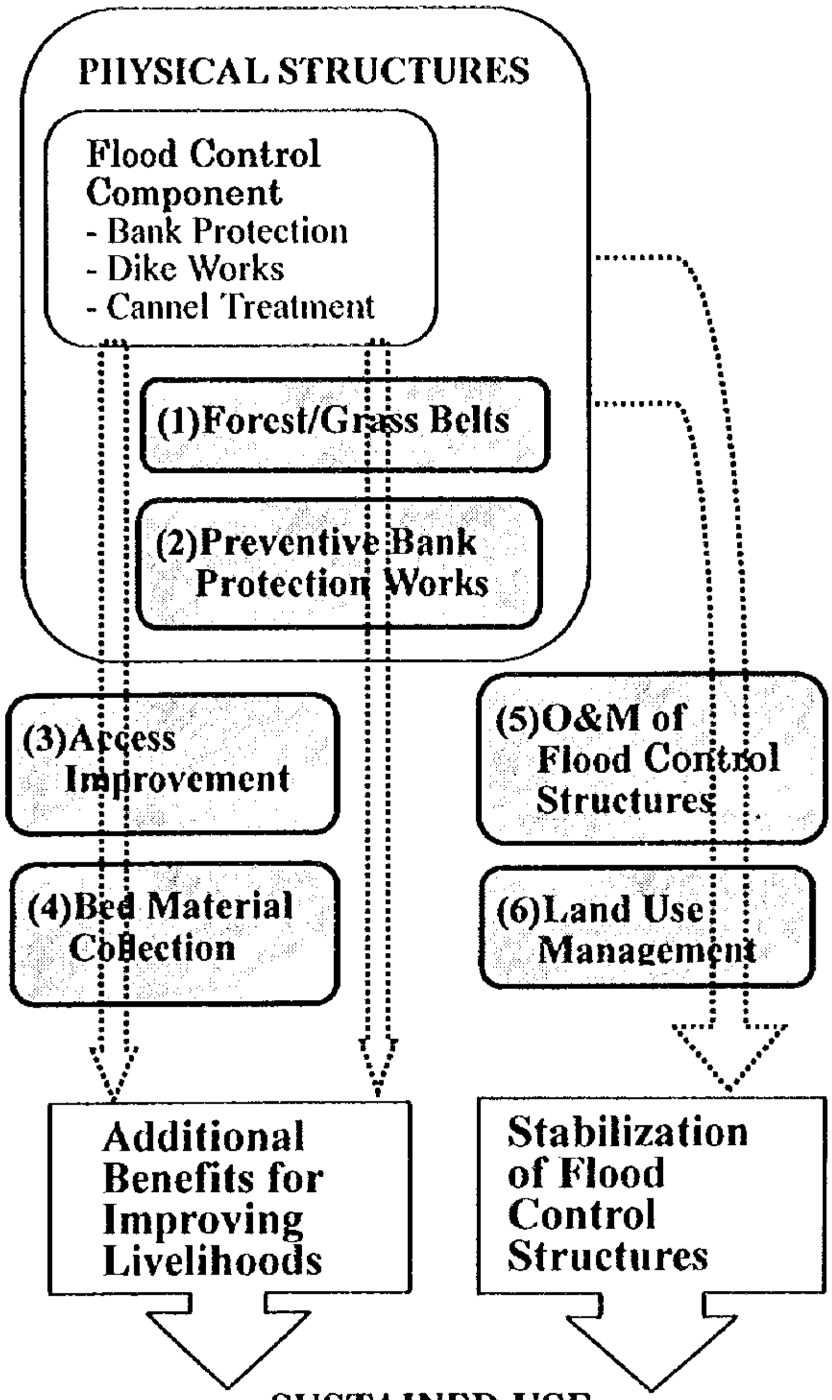
Community-based Sustainable Measures



SUSTAINED USE OF FLOOD CONTROL STRUCTURES

COMMUNITY-BASED SUSTAINABLE MEASURES

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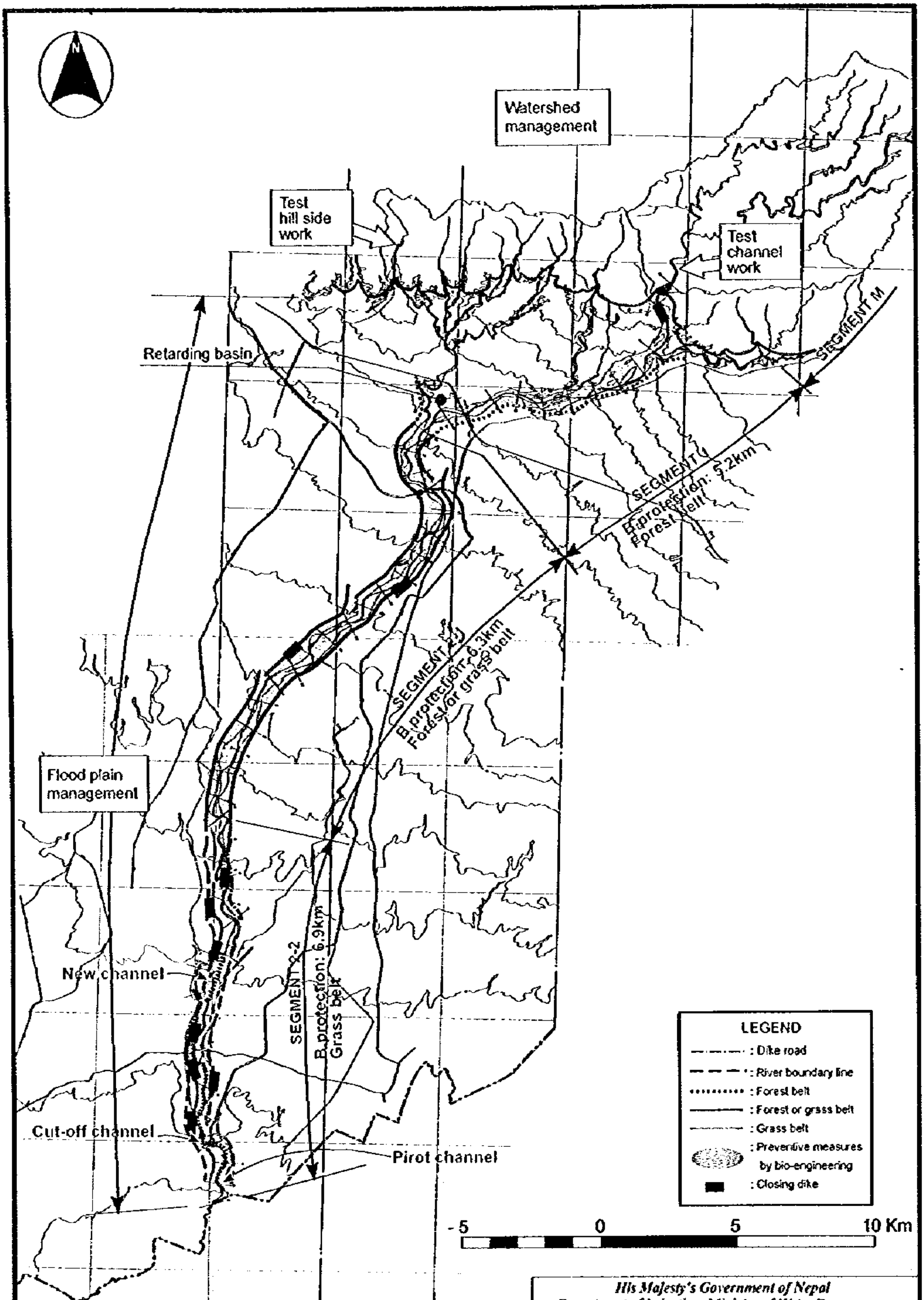

LAYOUT PLAN FOR FLOOD MITIGATION (LAKHANDEI RIVER)

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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

3. ACTION PROGRAM TOWARD TARGET YEAR

3.1 Sequence of Works

The Master Plan is proposed for the implementation by the target year of 2017. The project works must be carried out effectively in orderly manner toward the target year. It is also important to realize the flood mitigation effects, in the course of implementation, corresponding to the progress of work. In view of the above, consideration was given to the sequence of work as presented below.

(1) Preparatory Works

1) **Feasibility Study:** A Feasibility Study will be conducted immediately, mainly covering the following:
   (a) **River Survey:** To obtain topographic maps along the river with smaller contour intervals, longitudinal river profiles and cross sections.
   (b) **Restudy of Master Plan:** Based on the river survey result, the Master Plan proposed at the present stage should be subject to in-depth study.
   (c) **Feasibility Study:** The study will cover discrete environmental studies as well, in order to obtain approval for project implementation from MOPE.
2) **Fund Arrangement:** The project cost estimated in the Feasibility Study is allocated between the central and local governments, and local communities, taking into consideration the nature of work and the capability of funding.
3) **Definite Plan/Detail Design:** A definite plan of the flood mitigation works, including the river boundary line (RBL), will be drawn up after getting consent of the central and local government agencies and local communities concerned. A detailed design will be prepared of the project facilities.
4) **Preservation of Lands:** Population in the Terai is growing rapidly. Because of this, more and more people live in the flood prone areas close to the rivers. Therefore, it is essential to preserve the lands for flood mitigation facilities, and this should start immediately after the preparation of definite flood mitigation plan. Appropriate land use should also be encouraged as outlined in the definite plan and detail design.
5) **Research and Investigation:** In parallel with implementation of the specific flood mitigation projects, research and investigation activities are needed to support the projects. Among these following are included, but not limited to:
   (a) **Hydrological Study for Class-III Rivers:** Flood runoff and sediment yield to be studied and analyzed especially for class III rivers originating

at Siwalik hills. Observations on a designated model basin would serve this purpose.

(b) **Investigation of Bank Erosion Characteristics:** Characteristics of bank erosion in the Terai have yet to be investigated. Mechanisms of bank erosion, erosion speed/width, etc. should be investigated in relation with the river segment, riverbed and bank materials, river flow condition, etc.

(c) **Development of Bank Protection Works:** Various types of bank protection works should be introduced in each of the river segment, hared on effectiveness, materials available and cost-performance. Recommended bank protection work for rivers in the Terai should be made through hydraulic model tests in the laboratory and prototype models in field.

(d) **Research on Application of Bio-engineering Technology:** In order to introduce bio-engineering technology as a component of flood mitigation, research works and accumulation of experience are necessary, mainly for the selection of plant species, type and function of work applicable, cultivation techniques, and contribution to income generation.

(2) Coordination For Flood Mitigation

Coordination to mobilize watershed management and flood plain management should be taken as soon as possible in combination with the community development activities.

(3) River Works

1) **Channel Treatment Works:**

(a) **Tributary Works:** Tributary work to stop inflow/outflow from/to adjacent river basins will be implemented soon after the preparation of the definite plan.

(b) **Branch/Anabranch Work:** Closing works of branches and anabranches, with diversion structure if necessary, will be carried out soon after the preparation of definite plan.

(c) **Channel Connection Works:** Unification and normalization by connecting tributaries and drainage can be executed at any time before dike work commences.

2) **Bank Protection Works:**

(a) **Spur/Revetment Work:** Riverbank classified as Type-As bank needs protection works immediately and works are desirable for Type-A bank as well. The bank protection works will be executed continuously, primarily for Type-As banks identified by the periodic monitoring after every flood seasons.

(b) **Preventive Bank Protection Measures:** Preventive bank erosion measures by bioengineering is required immediately for Type-A bank and are desirable for all the river bank between river course and boundary line of river zone.

3) **Dike Works:**

(a) **Forest and Grass Belts:** Forest belt will be formed inside of the river boundary line (RBL) in Segment 1 (alluvial fan) and grass belt in Segments 2-1 and 2-2 (natural levee zone). The work can be carried out at any time and any place, but for the purpose of marking the RBL it is best to do it quickly.

(b) **Local Dike and Dike Road:** The local dike and the dike road will be constructed inside along the RBL to protect the land locally and serves as rural road as well. These works should be started soon from the places where possible so as to realize the flood mitigation.

(c) **Ring Dike:** Ring dike work will be executed at the critical site.

(d) **Retarding Basin:** It is important to preserve the lands for the retarding basin, confining by forest belt, grass belt or earth dike.

4) **Channel Excavation and COC Works:**

(a) **Channel Excavation:** Channel excavation will be executed for channel normalization in extremely narrow sections.

(b) **Bed Material Collection:** Bed materials can be collected for construction materials soon after the preparation of definite plan according to a regulation to be prepared for bed material exploitation.

3.2 Action Plan

Implementation of the Master Plan project is programmed, in principle, by the phases of the national development plan from the ninth through twelfth plans as follows:

1) **1st Phase (Ninth plan: 1997-2002):**

(a) Preparatory works such as feasibility study, fund arrangement, definite plan/detail design, preservation of lands will be performed.

(b) Research and investigation, and coordination for watershed management and flood plain management will be started in combination with community development activities.

(c) Bank protection and ring dike works will be executed at the critical sites.

(d) Preventive bank protection works by bioengineering, and bed material collection are also started in this phase.

2) 2nd Phase (Tenth plan: 2002-2007):

(a) Channel treatment works which are the key to stabilize the river system will be executed.

(b) Forest belt will start for its work in field. Grass belt will be completed for Segment 2-1 and 2-2.

(c) Local dikes and dike roads will be constructed where they are required.

3) 3rd Phase (Eleventh and twelfth plan: 2007-2017):

(a) All the works and activities targeted for the Master Plan will be completed.

General Action plan for the implementation of the Master Plan project is shown in Fig. A3.1.

ACTION PROGRAM TOWARD TARGET YEAR

River: **LAKHANDEI RIVER**

Activities	Phasing			
Master Plan	1st.	2nd.	3rd.	
National Plan	9th	10th	11th	12th
(year)	(1997-2002)	(2002-2007)	(2007-2012)	(2012-2017)
(1) Preparatory Works				
1) Feasibility study:				
•River survey	▬ (1st half)			
•Restudy of master plan	▬ (1st half)			
•Feasibility study	▬ (1st half)			
•Environmental study	▬ (1st half)			
2) Fund arrangement	▬ (2nd half)			
3) Definite plan/ detail design	▬ (2nd half)			
4) Preservation of lands	▬ (2nd half)			
5) Rsearch/ investigation	▬ (2nd half)	▬▬	▬▬	▬▬
(2) Coordination for Flood Mitigation				
1) Community development	▬▬	▬▬	▬▬	▬▬
2) Watershed management	▬▬	▬▬	▬▬	▬▬
3) Flood Plain Management	▬▬	▬▬	▬▬	▬▬
(3) River Works in Segment-1				
Channel treatment works:				
•Tributary works				
•Branch/ anabranch works				
Bank protection works:				
• Spur/ rvetment	▬ (2nd half)	▬▬	▬▬	▬▬
• Preventive bank protection measurs (by bio-engineering)	▬ (2nd half)	▬▬	▬▬	▬▬
Dike works:				
• Forest belt		▬▬	▬▬	▬▬
• Ring dike	▬ (2nd half)	▬▬	▬▬	▬▬
Channel excavation works:				
• Bed material exploitation	▬ (2nd half)	▬▬	▬▬	▬▬
Retarding basin		▬▬	▬▬	▬▬
(4) River Works in Segment-2				
Channel treatment works:				
•Tributary works				
•Branch/ anabranch works		▬▬		
Bank protection works:				
• Spur/ revetment	▬ (2nd half)	▬▬	▬▬	▬▬
• Preventive bank protection measurs (by bio-engineering)	▬ (2nd half)	▬▬	▬▬	▬▬
Dike works:				
• Grass belt		▬▬		
• Low dike road w/ drainage sluice		▬▬		
• Continuous dike w/ drainage sluice			▬▬	▬▬
• Ring dike	▬ (2nd half)	▬▬	▬▬	▬▬
Channel excavation works:				
• Bed material exploitation				
• Widening channel		▬▬	▬▬	▬▬
Cut-off channel works			▬▬	▬▬
Retarding basin				

4. ECONOMIC EVALUATION FOR MASTER PLAN PROJECT

4.1 Basin Overview

The Lakhandei's plain areas lie on 19,400 hectares of land, nearly 80% of which is under agriculture. Paddy is grown on the largest portion of the agricultural land (with the estimated 1996/97 production of 12,300 metric tons), followed by wheat (4,000 metric tons) and pulses (2,100 metric tons). In 1996/97 the retail value of paddy production was Rs.52 million, and pulses it was about Rs.84 million.

The Lakhandei river runs through Sarlahi district which is famous for its production of such cash crops as tomatoes, tobacco, and sugarcane. Particularly in Sarlahi district, the Master Plan has an important role in protecting these cash crops, as well as the grains. In addition, the second largest number (15) of manufacturing establishments exist in the flood-risk villages along the Lakhandei (9-cigarette, 4-brick, 1-sugar, 1-beer).

4.2 Effects of Flood Mitigation

Implementation of the flood mitigation Master Plan will primarily safeguard the land and properties in the flood prone areas and also bring about other favorable effects to the Study Area. The potential benefits and effects expected to accrue from the Master Plan, including tangible and intangible ones, are listed below.

1) **Reduction of damage due to flood and sediment:** Inundation and sedimentation will be alleviated and reduce damages of village houses, crop production, public facilities, etc.
2) **Protection of riverbank from erosion:** Loss of lands due to riverbank erosion are averted, and villages and farmlands will be protected.
3) **Indirect effects:** Owing to the reduction in damages in flood prone area, social and economic activities in the surrounding areas will not be interfered.
4) **Land enhancement:** Flood mitigation project ensures the social and economic activities in the flood prone area which enable further investments for the development of the flood prone area and the surrounding areas.
5) **Land reclamation:** Existing low-lying barren lands along the river turn to arable ones. Channel excavation and normalization at severely meandering section may create lands for agriculture and settlement.
6) **Flood-free embankment:** The earth embankment constructed as local dike and ring dike can be used as rural roads and flood-free areas in the flood prone

area. The area will also serve for evacuation and flood fighting activities.

7) **Income generation:** The forest belt and grass belt for flood mitigation will generate community's income. The trees from the forest belt could be used for flood mitigation as well.
8) **Stabilization of residents' livelihood:** Flood free land is the basis of the residents' livelihood in the flood prone areas. Only under such conditions, residents are encouraged to accumulate their immovable and other properties, and accordingly can stabilize their livelihood.
9) **Community development:** The Master Plan places emphasis on flood mitigation through community development. The community-based approaches will forge links among the resident people and may enable other community development activities.

4.3 Preliminary Economic Evaluation

Economic viability of the flood mitigation Master Plan was examined preliminarily. Out of the various effects listed in the previous section, (a) flood damage reduction benefit, (b) bank protection benefit, and (c) indirect benefit were considered as tangible benefit for the evaluation.

Flood Damage Reduction Benefit: Flood damage study by hydraulic analysis is difficult at this stage, since the river section data are not available and available topographic and hydrological data are limited. The flood damage reduction benefit was estimated preliminarily based on the damage data of recent large flood.

Bank Protection Benefit: Benefit accruing from bank protection works was estimated as a product of the land area to be protected from erosion and the amount of property on the unit land area to be protected.

Conditions for Economic Evaluation: Evaluation was made for the existing basin conditions and future basin conditions in target year (2017). The benefit in the target year was assumed in proportional to the population projected. Cash flows of the project cost, maintenance cost and benefit are shown in Table A4.1. With these cash flows, the economic internal rate of return (EIRR), cost-benefit ratio (B/C) and net present value (NPV, or B-C) were worked out.

The results are summarized below, though these should be restudied based on river survey data.

River	Existing basin			Future basin		
	EIRR (%)	B/C	NPV (10^6Rs)	EIRR (%)	B/C	NPV (10^6Rs)
Lakhandei	3.6	0.47	-135.7	10.2	1.02	4.6

(Note) B/C and NPV were calculated under the discount rate of 10%.

Methodology and procedures of economic evaluation of the project are compiled in SUPPORTING REPORT-C.

COST BENEFIT FLOW FOR MASTER PLAN
(Existing Basin)

River: Lakhandei (Unit: NRs. 1,000)

Year		Economic cost/benefit				Discounted (10%)	
		Project cost	Maintenance cost	Total cost	Benefit	(C) Cost	(B) Benefit
1	1999	8,630	0	8,630	0	8,630	0
2	2000	8,630	0	8,630	0	7,845	0
3	2001	16,442	0	16,442	0	13,588	0
4	2002	41,509	0	41,509	0	31,186	0
5	2003	41,509	221	41,730	2,384	28,502	1,628
6	2004	41,509	443	41,952	4,767	26,049	2,960
7	2005	29,788	664	30,452	7,151	17,190	4,036
8	2006	29,788	823	30,611	8,861	15,708	4,547
9	2007	29,788	982	30,770	10,572	14,354	4,932
10	2008	29,788	1,141	30,929	12,282	13,117	5,209
11	2009	29,788	1,300	31,088	13,993	11,986	5,395
12	2010	29,788	1,459	31,247	15,703	10,952	5,504
13	2011	29,788	1,618	31,406	17,414	10,007	5,549
14	2012	29,788	1,777	31,565	19,124	9,143	5,540
15	2013	29,788	1,935	31,723	20,835	8,354	5,486
16	2014	29,788	2,094	31,882	22,545	7,632	5,397
17	2015	29,788	2,253	32,041	24,256	6,973	5,279
18	2016	29,788	2,412	32,200	25,967	6,371	5,137
19	2017	21,976	2,571	24,547	27,677	4,415	4,978
20	2018		2,688	2,688	28,939	440	4,732
21	2019		2,688	2,688	28,939	400	4,302
22	2020		2,688	2,688	28,939	363	3,911
23	2021		2,688	2,688	28,939	330	3,555
24	2022		2,688	2,688	28,939	300	3,232
25	2023		2,688	2,688	28,939	273	2,938
26	2024		2,688	2,688	28,939	248	2,671
27	2025		2,688	2,688	28,939	226	2,428
28	2026		2,688	2,688	28,939	205	2,207
29	2027		2,688	2,688	28,939	186	2,007
30	2028		2,688	2,688	28,939	169	1,824
31	2029		2,688	2,688	28,939	154	1,658
32	2030		2,688	2,688	28,939	140	1,508
33	2031		2,688	2,688	28,939	127	1,371
34	2032		2,688	2,688	28,939	116	1,246
35	2033		2,688	2,688	28,939	105	1,133
36	2034		2,688	2,688	28,939	96	1,030
37	2035		2,688	2,688	28,939	87	936
38	2036		2,688	2,688	28,939	79	851
39	2037		2,688	2,688	28,939	72	774
40	2038		2,688	2,688	28,939	65	703
41	2039		2,688	2,688	28,939	59	639
42	2040		2,688	2,688	28,939	54	581
43	2041		2,688	2,688	28,939	49	528
44	2042		2,688	2,688	28,939	45	480
45	2043		2,688	2,688	28,939	41	437
46	2044		2,688	2,688	28,939	37	397
47	2045		2,688	2,688	28,939	34	361
48	2046		2,688	2,688	28,939	30	328
49	2047		2,688	2,688	28,939	28	298
50	2048		2,688	2,688	28,939	25	271
Total		537,661	105,031	642,692	1,130,640	256,586	120,915

EIRR: 3.6%
B/C: 0.47
NPV(B-C): -135,672 (NRs.1,000)

COST BENEFIT FLOW FOR MASTER PLAN

(Future Basin)

River: Lakhandei (Unit: NRs. 1,000)

Year		Economic cost/benefit				Discounted (10%)	
		Project cost	Maintenance cost	Total cost	Benefit	(C) Cost	(B) Benefit
1	1999	8,630	0	8,630	0	8,630	0
2	2000	8,630	0	8,630	0	7,845	0
3	2001	16,412	0	16,412	0	13,588	0
4	2002	41,509	0	41,509	0	31,186	0
5	2003	41,509	221	41,730	5,148	28,502	3,516
6	2004	41,509	443	41,952	10,297	26,049	6,394
7	2005	29,788	664	30,452	15,445	17,190	8,719
8	2006	29,788	823	30,611	19,140	15,708	9,822
9	2007	29,788	982	30,770	22,835	14,354	10,653
10	2008	29,788	1,141	30,929	26,530	13,117	11,251
11	2009	29,788	1,300	31,088	30,224	11,986	11,653
12	2010	29,788	1,459	31,247	33,919	10,952	11,888
13	2011	29,788	1,618	31,406	37,614	10,007	11,985
14	2012	29,788	1,777	31,565	41,309	9,143	11,966
15	2013	29,788	1,935	31,723	45,003	8,354	11,851
16	2014	29,788	2,094	31,882	48,698	7,632	11,658
17	2015	29,788	2,253	32,041	52,393	6,973	11,402
18	2016	29,788	2,412	32,200	56,088	6,371	11,097
19	2017	21,976	2,571	24,547	59,782	4,415	10,752
20	2018		2,688	2,688	62,508	440	10,221
21	2019		2,688	2,688	62,508	400	9,291
22	2020		2,688	2,688	62,508	363	8,447
23	2021		2,688	2,688	62,508	330	7,679
24	2022		2,688	2,688	62,508	300	6,981
25	2023		2,688	2,688	62,508	273	6,346
26	2024		2,688	2,688	62,508	248	5,769
27	2025		2,688	2,688	62,508	226	5,245
28	2026		2,688	2,688	62,508	205	4,768
29	2027		2,688	2,688	62,508	186	4,335
30	2028		2,688	2,688	62,508	169	3,940
31	2029		2,688	2,688	62,508	154	3,582
32	2030		2,688	2,688	62,508	140	3,257
33	2031		2,688	2,688	62,508	127	2,961
34	2032		2,688	2,688	62,508	116	2,691
35	2033		2,688	2,688	62,508	105	2,447
36	2034		2,688	2,688	62,508	96	2,224
37	2035		2,688	2,688	62,508	87	2,022
38	2036		2,688	2,688	62,508	79	1,838
39	2037		2,688	2,688	62,508	72	1,671
40	2038		2,688	2,688	62,508	65	1,519
41	2039		2,688	2,688	62,508	59	1,381
42	2040		2,688	2,688	62,508	54	1,256
43	2041		2,688	2,688	62,508	49	1,141
44	2042		2,688	2,688	62,508	45	1,038
45	2043		2,688	2,688	62,508	41	943
46	2044		2,688	2,688	62,508	37	858
47	2045		2,688	2,688	62,508	34	780
48	2046		2,688	2,688	62,508	30	709
49	2047		2,688	2,688	62,508	28	644
50	2048		2,688	2,688	62,508	25	586
Total		537,661	105,031	612,692	2,442,183	256,586	261,176

EIRR: 10.2%
B/C: 1.02
NPV(B-C): 4,589 (NRs.1,000)

PART-II: FEASIBILITY STUDY

5. ADDITIONAL INVESTIGATIONS AND STUDIES

5.1 General

The Lakhandei river basin was selected for the Feasibility Study. Supplemental and detailed data necessary for the Feasibility Study were collected for the Lakhandei river.

Members of the Study Team visited the site from time to time, mainly from the middle of July to the end of August in 1998. During the site visits, they inspected rainy season conditions of the rivers and basins, collected verbal information from the residents, and discussed with the local government officials concerned on the flood mitigation plan. In order to inspect the flood conditions, sites were also inspected by helicopter on August 25 and October 18, 1998 for the Lakhandei river.

Workshops were held on August 18-19, 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.

5.2 Topographic Mapping and River Survey

(1) 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 river. The mapping area measures approximately 160 km^2.

The mapping work was carried out by the following procedures:

1) Reproduction of preliminary maps at the scale of 1/10,000 from the existing topographical maps at the scale of 1/25,000 or 1/50,000 using a precise photomechanical process.
2) Ground survey for the following items:
   - Measurement of spot height by leveling or GPS survey
   - Field verification for such as road width, channel width, riverbanks, and annotation
3) Editing with contour interpolation at every 2.5 m interval
4) Tracing by inking, or another technical procedures

(2) River Survey

River survey was carried out for the Feasibility Study on flood mitigation. The surveys included longitudinal surveying, cross sectional surveying and flood mark surveying along the rivers. Cross sections were surveyed at approximately one (1) kilometer intervals, and the river length of the survey is about 50 km.

The river survey was conducted from May to June in 1998 by the Nepalese Surveying firms, TAEC Consult P. Ltd.

Major work items and quantities for the river surveys are as follows:

1) Installation of section stakes on both river banks: 50 sections
2) Marking of past flood water levels near every section stakes: 50 places
3) Longitudinal leveling: 50 km
4) Cross sectional leveling: 50 sections
5) Drawing and Report: 3 copies and original

5.3 Flood Flow Investigation

Objective: Flood flow investigation of the Lakhandei river basin aims:

1) To collect information on flood flow conditions, by site inspection and interviews with VDC and the village people;
2) To clarify the places and extent of flooding, sediment cover and bank erosion, by site inspection and interviews with VDC and the village people; and
3) To 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 along the entire length of right and left riverbanks, to collect the following data and information relevant to the flood and sediment disasters:

1) Flood Flow Conditions: Time of concentration of flood runoff, places where the floodwater spills/overflows frequently, and photos taken during floods.
2) Inundated Area Survey: Extent of the maximum inundated area, extent of

frequently inundated area, extent of inundated area during recent big flood (1997-flood), source of inundated water, and photos of typical inundated areas.

3) Sedimentation Survey: Extent of sediment cover, sedimentation damages, period required for recovery, effects to next year crops, and photos of typical sediment covered farm land and settlement areas.
4) Bank Erosion Survey: Severely eroded riverbank in recent years, riverbank eroded last rainy season, bank erosion damages, river course shifting, and photos of severe bank erosion sites.

Flood and Sediment Hazard Map: Flood and sediment hazard maps were prepared as shown in Fig. A5.1, 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.

5.4 Environmental Study

(1) 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 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.

(2) Environmental Study

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. Such an inventory would help the engineers and social scientists, as well as indicate to the environmentalist the type of survey required if houses have to be relocated as a result of the proposed interventions. The inventory documented land use, land ownership, houses (by type), other buildings and infrastructure in a belt up to 500 meters wide on either side of the Lakhandei river in the Terai.

Environmental Study (Lakhandei R.): 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. The present land use was determined and the state of the streams that feed the Lakhandei in these two areas was assessed. A survey was carried out of the present population including their economic and social activities. The likely environmental impact on these people was recorded and a monitoring system was suggested to examine the effect of various interventions.

Implementation of 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, fieldwork for the general environmental study and in the sub-watershed areas of the Lakhandei took place from August to October of 1998.

(3) Results of Studies

The study report prepared as a study result describe the conditions along the river and the anticipated effects of watershed mitigation measures in sub-catchment areas of the Lakhandei watershed area. These findings are summarized in Table A5.1.

5.5 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 taken in the Terai plain. In this regard, studies are made for the Lakhandei watershed in order to disclose the geological and topographic characteristics related to the watershed management measures.

(1) Geology of Siwalik Hills

The geology of watershed of the Lakhandei river is characterized by the Siwalik hills formed in the Mid-Miocene and the Pleistocene periods (Fig. A5.2).

The Siwalik hills extend over 3,000 km at the foot of the Himalayas. The thickness of this group is 5,000 to 6,000 meters mainly consisting of continental clastic rocks. Its stratification exhibits a coarsening upward sequence, reflecting the rising Himalayas. Based on lithostratigraphy, the group is divided into three formations, i.e., the lower, middle and upper Siwalik formations. The lower Siwalik formation is composed mainly of red purple sandstone and mudstone. The middle Siwalik formation is composed mainly of bedded sandstone with blue gray mudstone, and the upper Siwalik formation is composed mainly of conglomerates beds. The causes of these changes, from lower to upper Siwalik formations, are thought to be that the sedimentation system changed from that of a meandering river with wide flood plain to that of a braided river sedimentation or an alluvial fan sedimentation. The maturity of the sandstone becomes less toward in the upper layers in the Siwalik group.

Determination of geochronologic division of Siwalik hills had been difficult, since the group is deficient in fossils because of continental sediment and it lacks the key beds for the geologic correlation of wide areas. Recently, however, the findings of volcanic ashes in Pakistan and the establishment of paleomagnetic stratigraphy in the Nepal Siwalik have enabled the determination of geochronologic time. According to the findings, the bases of the lower, middle and upper Siwalik formations of the Arung river in Midwestern Nepal are formed respectively about 16 Ma (million of years before the present), 10 Ma and 3 Ma.

The lower Siwalik formation covers a small area at the south-end and the middle Siwalik formation covers most of the Lakhandei watershed. The upper Siwalik formation is found in very small parts at the northern end of the watershed. The lower and middle Siwalik formations are made of consolidated or semi-consolidated sandstone and mudstone. And the conglomerate in the upper Siwalik formation is unconsolidated. Therefore, effects of erosion are more severe to the upper Siwalik formation than in the other formations. Investigation of an accurate distribution of the upper Siwalik formation is important, particularly for planning erosion control in the Siwalik hills.

Two types of rocks form the conglomerate in the upper Siwalik formation. One is white and hard quarzite pebbles transported and accumulated from the Midland about 2.5Ma to 1Ma, and the other is a dark brown colored soft boulder of sandstone and mudstone transported and accumulated from the Siwalik group about 1Ma to 0Ma.

These two types of rocks were transported from upper Siwalik hills, and formed river terraces along river course in the Siwalik hills and in the Bhabhar on the south of Siwalik hills. Boulders of the sandstone and mudstone of the Siwalik group are easily weathered, and are found only at or in the river terraces and riverbeds close to the Siwalik hills. On the other hand, Quartzite pebble transported from the Midland are hard and not easily weathered and form a thick gravel layer in the river terraces. The river terraces with quartzite pebble layers develop especially in Dun valley (Kimura, Kazuo 1994, 1995).

The quartzite pebbles in the river terraces are further transported to the East-West Highway, forming bars on the present riverbed.

The river terraces in Bhabhar and Terai are classified into three; high, middle and low, according to the height and sediment materials of the terrace. The characteristics of these types of terraces are discussed in the ensuing sections.

(2) River terraces at Bardibas (Shinduli Highway)

Two step river terraces are observed along the Shinduli Highway going to the north from the Bardibas in the Terai Plain (Fig. A5.3a). The elevation of the Badibas Guesthouse located at the north of the Bardibas Town ranges from 260 to 280 m above mean sea level (MSL) which is 40 to 50 meters higher than that of the Terai Plain. This is a part of middle river terrace. From the light yellow cliff of the river terrace on the southern side of the guesthouse, large quantity of terrace gravels have disintegrated and deposited forming a small scale alluvial cone. The diameter of the terrace gravels of quartzite is about 10 cm, and the slope of the alluvial cone is about 10 degrees. The geologic time of the middle terraces is considered to be 18ka (thousand of years before the present) to 33ka. The surface of the middle terraces is used as farmland.

At about 2.5 km north from Badibas along the Shinduli Highway, there are rolling dissected hills with red soil at elevations ranging from 280 to 330 m,MSL and the relative height is 40 meters from the middle terrace. This dissected terrace is a part of the high terraces. It suffers from severe gully erosion. Numerous dried gullies are developed densely on the dissected terrace and red colored cliffs with deep cuts are seen. The terraces are mainly composed of unconsolidated sand and mud strata, interbedded with large amounts of quartzite gravel strata. Dried riverbeds are filled with quartzite gravel washouts. The geologic time of these terraces is considered to be the Middle Pleistocene. Sal forests cover the high terrace surfaces. Large trees were already cut down and young trees are rejuvenating.

(3) Terraces in Lakhandei Watershed and Bhabhar

The Lakhandei watershed has low terrace group with two to three steps in the Siwalik hills and Bhabhar (Fig. A5.3b). The height of the low terrace group is about 5 m at maximum from the riverbed. The lower terraces are composed mainly of brown colored unconsolidated sand and mud strata inter-bedded with quartzite gravel strata. The geologic time of the low terraces is considered to be 3ka to 10ka.

The river terraces at Bhabhar contain white quartzite gravels and large amounts of brown colored Siwalik boulders of sandstone and mudstone with a diameter ranging from 10 cm to 1 m. Large quantities of boulders of sandstone and mudstone with a diameter of about 1 m have accumulated at the riverbed next to the southern side of the Siwalik hills. These boulders may have been washed out when the lower terraces were eroded, since a mass movement from other locations is hard to imagine. The exact locations of the source of such large boulders are unidentified, but probably they were produced in nearby steep slopes and transported during a period of heavy rain.

On the hillside of the low terrace group adjacent to the Siwalik hills, talus cone slopes are seen. These are accumulation of sandstone/mudstone breccia produced and transported from the Siwalik hills.

The river terraces in Bhabhar are eroded easily and suffering from erosion at many locations. Sand and mud are washed down to the Terai plain. However, quartzite pebbles washed out from the river terrace do not move much in a short time period.

In the Lakhandei watershed, two major tributaries, the Narayan and Dayani rivers, flow from northeast to southeast along with the main Lakhandei river. Along these rivers, river terraces are formed with two to three steps (Fig. A5.4). These river terraces seem to be the low terrace group as seen in Bhabhar. It is estimated that large quantities of gravels have accumulated in these river terraces more than in Bhabhar. Further, the mixture of Siwalik sandstone/mudstone is much more. It is also estimated that a large quantity of quartzite pebbles from Midland and boulder breccia from the Shiwalik hills have accumulated in the riverbed.

(4) Topography of Lakhandei Watershed

The topography of the Lakhandei watershed was analyzed based on the maps and figures. These showed elevation, relief, topographic profiles, slope and relative heights. They were all prepared for the present study.

Elevation and topographic profiles: The lowest elevation is about 200 m,MSL in the south end of the Lakhandei watershed, while the highest point is 706 m,MSL in the southern part of the watershed. The watershed higher than 500 m,MSL traverses from east to west in the southern part of the watershed adjacent to the Terai plain (the southern mountains) and the northern end of watershed. In the central part, the elevations of the watershed are lower than 400 meters (Fig. A5.5). This distribution of elevation in the Lakhandei watershed is unique unlike a typical mountain topography. The southern mountains (lower watershed) are higher than the central watershed.

Relief map and slope: The relief map (Fig. A5.6 top) clearly shows the unique formation of higher mountains in the southern mountains and terraces in the upstream. The topographic structure is consistent with the geological structure that has an east-west directional pattern.

According to the study by watershed blocks of 1 km square, the relative heights more than 250 m are seen only in the southern mountains. The maximum relative height in the Lakhandei watershed is 366 meters and the minimum is 40 meters. In the upper watershed areas, the relative heights are mostly smaller than 100 meters. .

The southern mountains are composed of the lower strata of the middle Siwalik formation (Ms_1), and the central watershed are composed of the upper strata of the middle Siwalik formation (Ms_2). The northern end of watershed is composed of the upper Siwalik formation.

Slope map: Slopes of the watershed are classified into three major categories with seven detailed subdivisions in total as shown below (Fig. A5.6 bottom).

Slope Classification	Stretch of River
$\theta \leqq 3°$	Sedimentation stretch of debris flow and sediment flow.
$3° < \theta \leqq 10°$	Sedimentation stretch of debris flow .
$10° < \theta \leqq 15°$	Transport and sedimentation stretch of debris flow. Transport stretch of sediment flow.
$15° < \theta \leqq 20°$	Occurrence and transport stretch of debris flow.
$20° < \theta \leqq 30°$	Occurrence and transport stretch of debris flow (Steep slope 1)
$30° < \theta \leqq 45°$	Occurrence and transport stretch of debris flow (Steep slope 2)
$45° < \theta$	Occurrence and transport stretch of debris flow (Very steep slope)

Debris flow occurrence is possible on slopes with gradients of more than 20 degrees.

Most of the steep slopes are distributed in the southern mountains. These areas are the important sediment sources of the Terai plain.

The slope map shows an average slope gradient with a relative height of more than 20 meters. Therefore, cliffs of bare rocks with a relative height lower than 20 m are not included, though many such cliff of sandstone and mudstone are found in the southern mountains. A study on the distribution of cliffs of sandstone and mudstone is important for forest protection and disaster prevention due to debris flow.

(5) Erosion Control in Lakhandei Watershed

There is no mass movement such as debris flow and landslide recognized in the Lakhandei watershed. The formation of the watershed is the middle Siwalik composed mainly of sandstone and mudstone. These are soft rocks that are easily weathered and transported to the Terai Plain without causing mass movement in the watershed.

Finally, 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 due to hillside erosion in the southern slope of the southern mountains (southern slope of Siwalik hills facing to the Terai plain) and the other is due to 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 transported mainly 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 due to tree felling for cultivation and other domestic use may aggravate the sediment problems coupled with inherent poor geological situation.

5.6 Additional Findings on Channel Characteristics

(1) River Course Shifting

River course actively shifts in the lower reaches of the Lakhandei river. Near the

Padariya village, the Lakhandei river has taken a new route toward west since the 1997-flood season. This year (1998) the Lakhandei river basin suffered from large flood disasters and the floodwater directly attacked Belhi village. The floodwater formed several river courses between Padariya and Belhi villages as is shown in Fig. A5.7.

At about 400 m downstream of Phulparasi bridge of Hulaki Sadak road, flood water of the Lakhandei river often overflowed toward Inaruwa village. This year before the rainy season, the VDC constructed a right earth dike with sandbag spurs.

At about 1.5 km downstream from the bridge, a new channel was formed on the left bank at the end of July. Almost all the floodwater of the Lakhandei river flows through this new channel toward Bhadsar and Matahitol villages as shown in Fig. A5.8.

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. A1.9. 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 shiftings mentioned above.

Aerial photos taken in 1987 and 1990 were also checked, but unfortunately photos downstream from the Phulparasi bridge were not available.

(2) Channel Characteristics

The longitudinal profile of the Lakhandei river is shown in Fig. A5.9 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 information obtained from residents.

Figure A5.10 and Table A5.2 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 three river segments, as follows:

1) Segment 2-2: Sec. No. 0 – No.21
2) Segment 2-1: Sec. No.21 – No.40

3) Segment 1: Sec. No.40 – No.52

Average channel sizes of respective river stretches are summarized below.

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

5.7 Runoff and Flood Flow Analyses

5.7.1 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.

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 Table A5.3.

(2) Probable Peak discharge

The probable peak discharges estimated for the Master Plan study were adopted.

$$Q_n = (Q_n / Q_2) \cdot q_2 \cdot A$$
$$q_2 = C \cdot A^{(A^{-0.05} - 1)}$$

The probable discharges of 2-year return period at specific points are shown in Tables A5.3.

(3) Base-flow Discharge

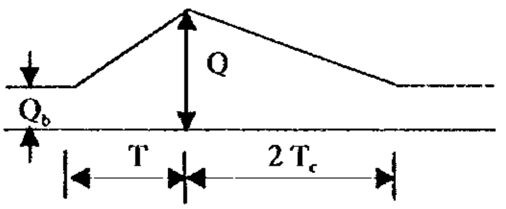
Base-flow is an assumed constant flow before and during the flood runoff due to rainfall.

Base-flow discharges (Q_b) at the sections of interest on the Lakhandei river were assumed, applying the specific base-flow discharge (q_b) estimated based on the Babai river data as follows:

$q_b = 390\ m^3/s\ /\ 3{,}002\ km^2 = 0.13\ m^3/s\ /km^2$
$Q_b \quad = 0.13\ m^3/s/\ km^2 \times A$, where A is a basin area in km^2.

(4) Discharge Hydrograph

Since the actual 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 time the concentration (T_c). The time of concentration (T_c) was estimated at the Chapani river junction for the Lakhandei river, using Kraven's empirical formula for natural mountainous basins as follows:

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

Hourly discharges were estimated as shown in Tables A5.3. Runoffs from the residual basins are estimated as a balance of discharges at adjacent river sections for runoff calculation.

5.7.2 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:

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

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

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:

$$\frac{1}{g}\frac{\partial v_P}{\partial t}+\frac{\partial H_T}{\partial l}+f_P v_P|v_P|=0$$

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

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

$\delta H_T / \delta l$: 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 1997-flood data. 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. A5.11 and Table A5.4.

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 (2.3 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.

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.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

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 +950m	No.40 +200m	No.37 +600m	No.29 +250m	No.12 +700m	No.4 +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

RESULT OF FLOOD FLOW ANALYSIS (LAKHANDEI RIVER WITHOUT PROJECT)

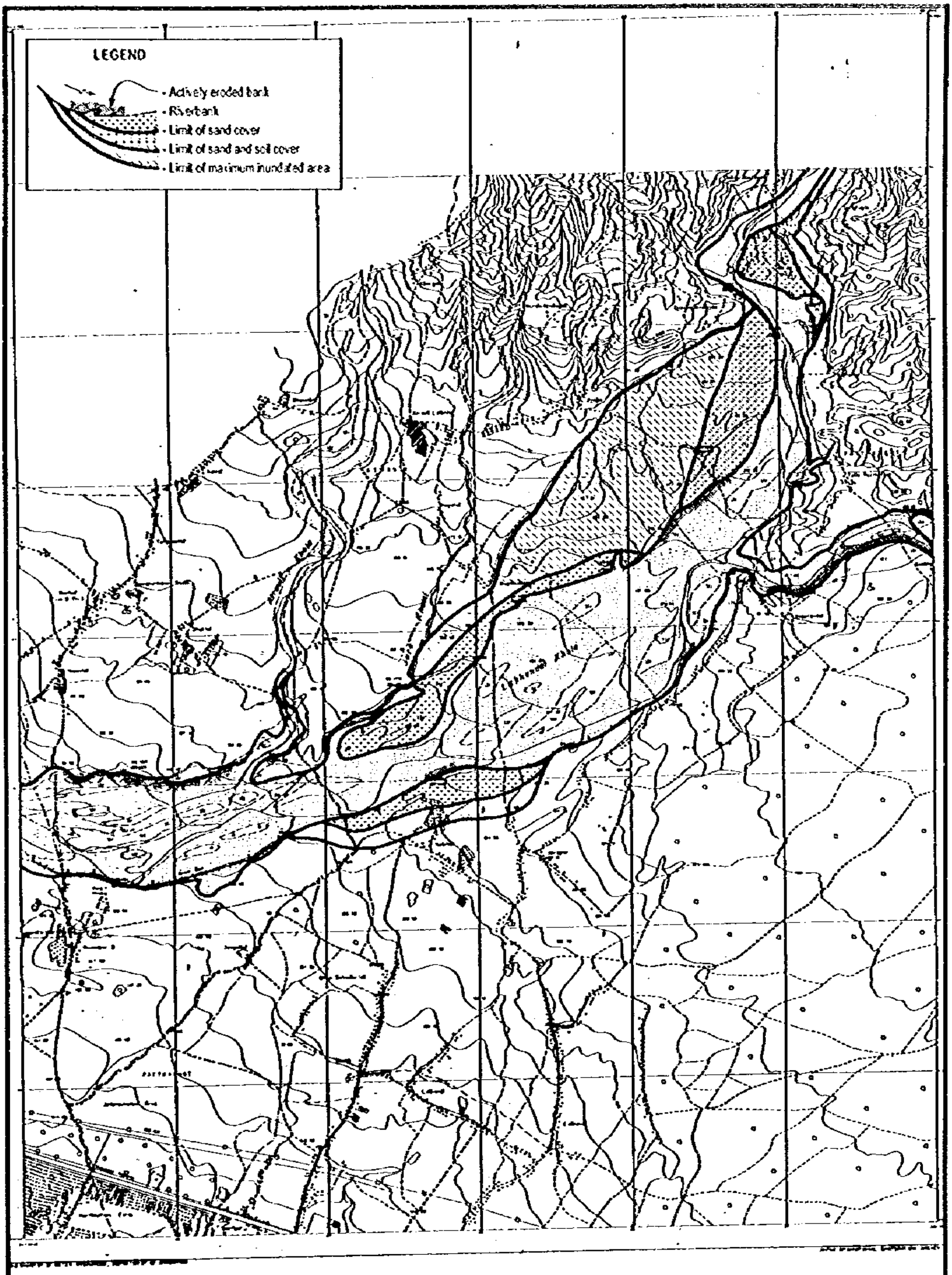
No.	Section	Distance	2 - year		5 - year		10 - year		20 - year		50 - year		100 - year	
		(m)	H (m, MSL)	Q (m^3/s)	H (m, MSL)	Q (m^3/s)	H (m, MSL)	Q (m^3/s)	H (m, MSL)	Q (m^3/s)	H (m, MSL)	Q (m^3/s)	H (m, MSL)	Q (m^3/s)
1	NO.0	0	75.949	45	75.949	31	75.949	33	75.949	32	75.870	151	75.870	109
2	NO.1	900	76.715	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	85.721	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 A5.4 (2/2)

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	634
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

Fig. A5.1(1/6)

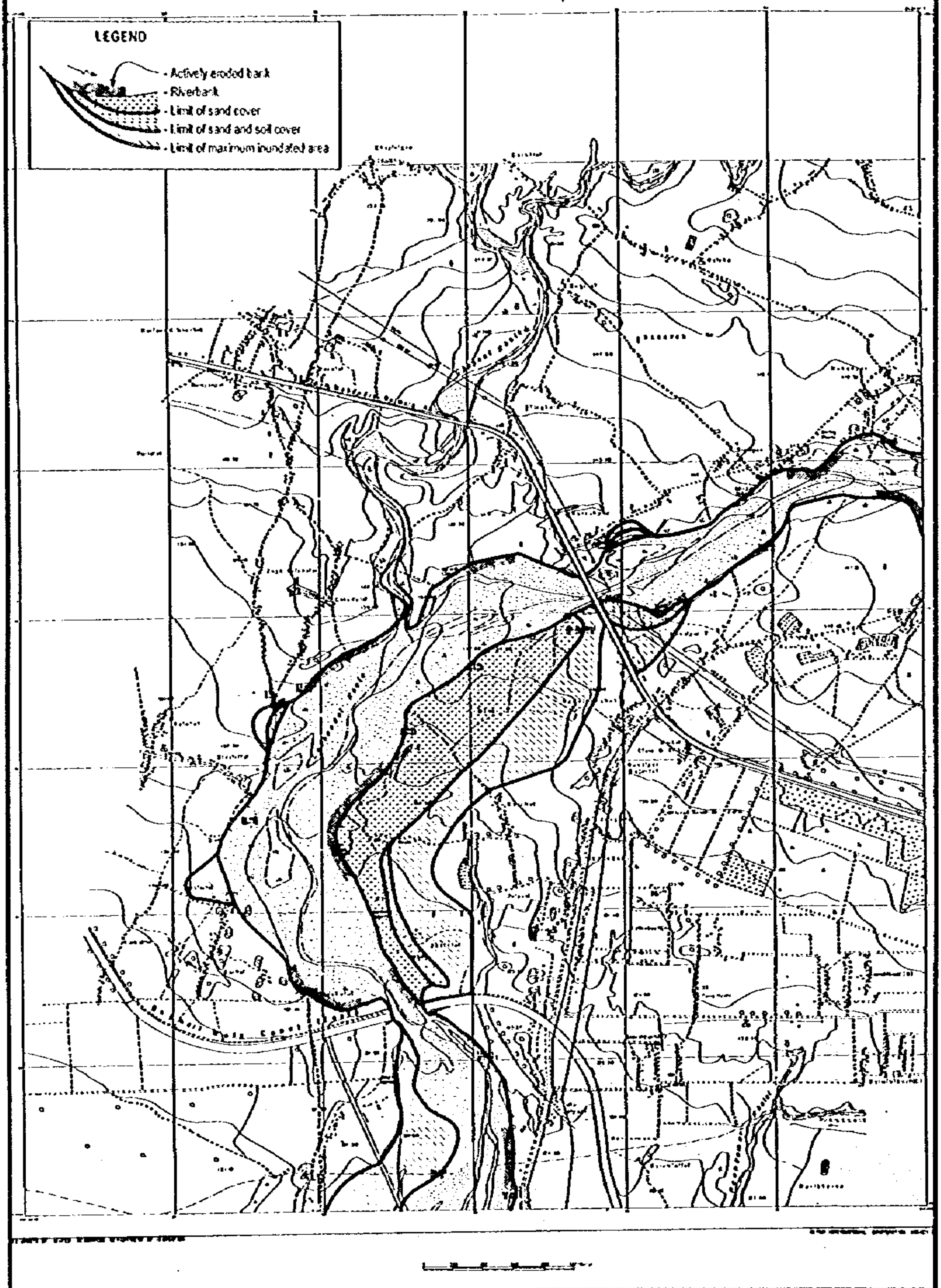


HAZARD MAP
Lakhandei River 1997 Flood (1/6)

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
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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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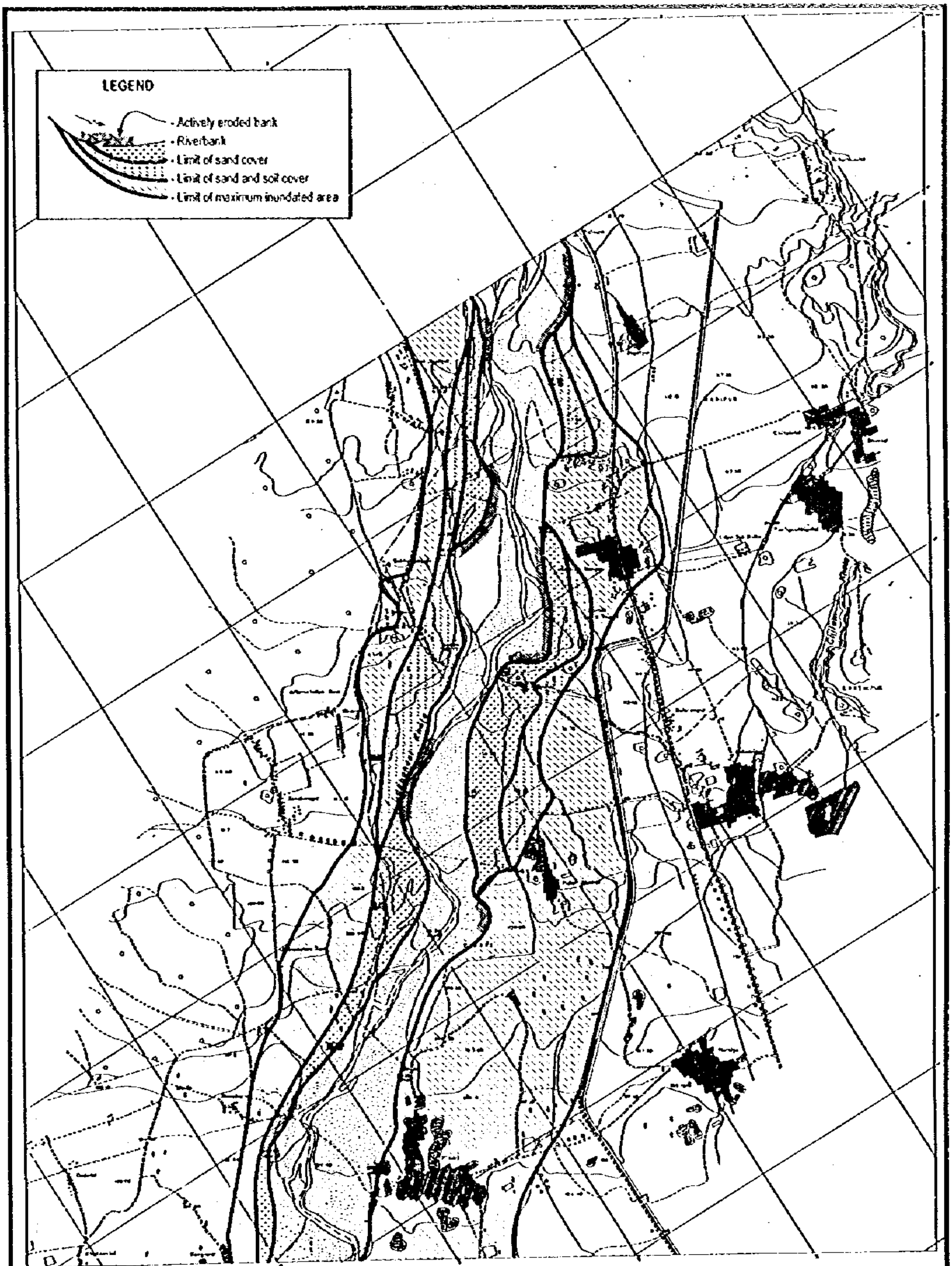
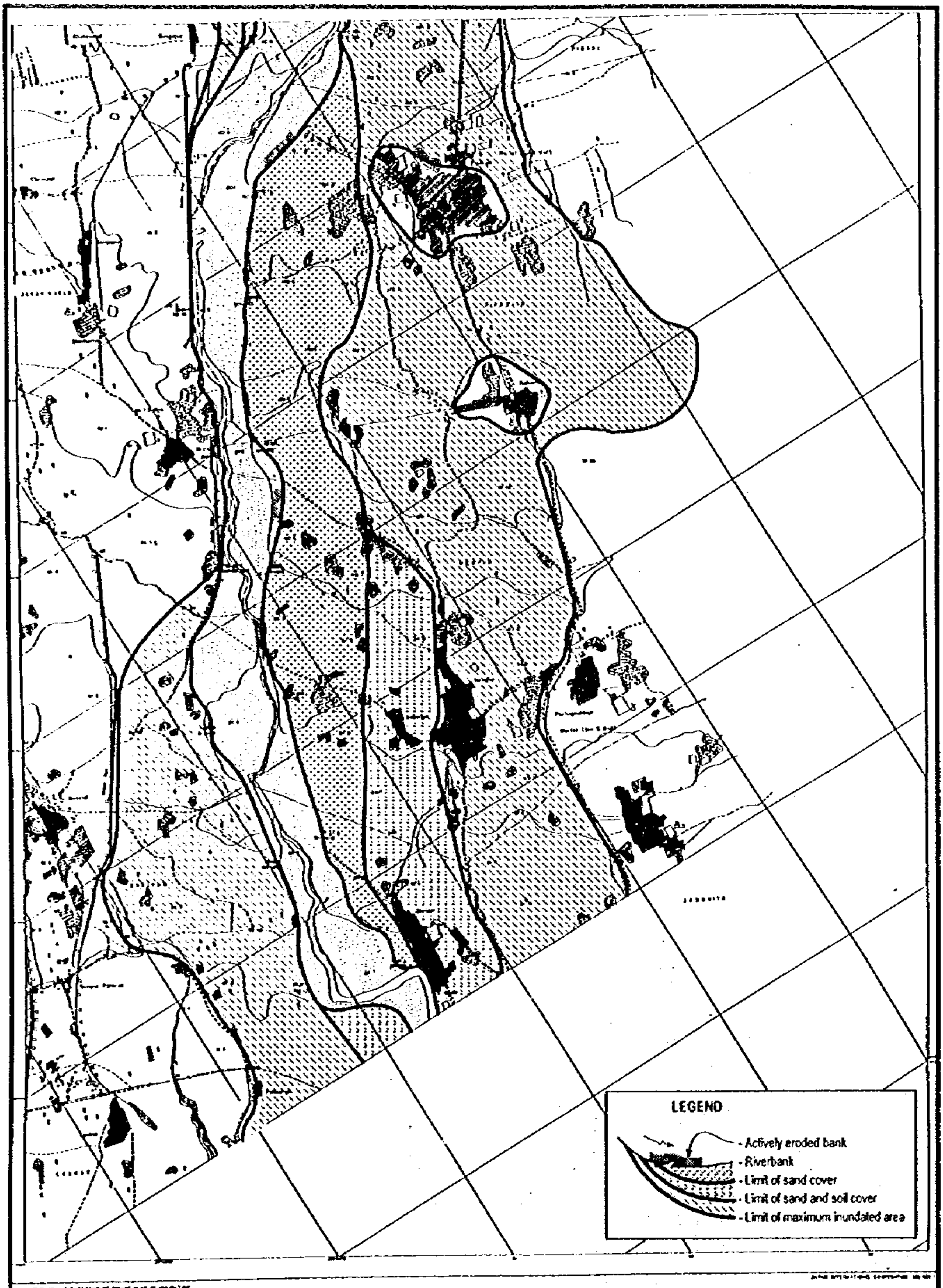


HAZARD MAP
Lakhandei River 1997 Flood (3/6)

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

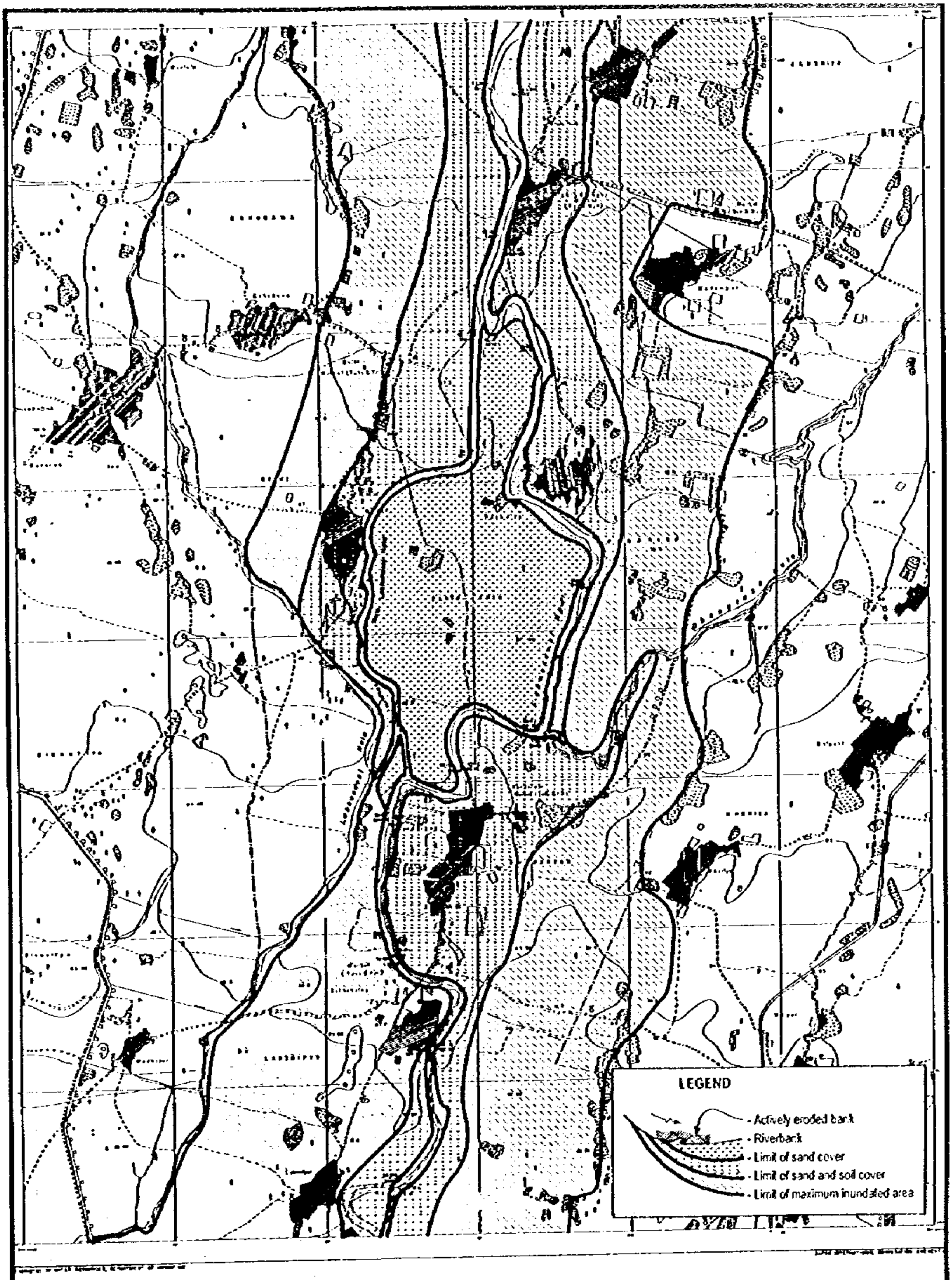


HAZARD MAP
Lakhandei River 1997 Flood (4/6)

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 (5/6)

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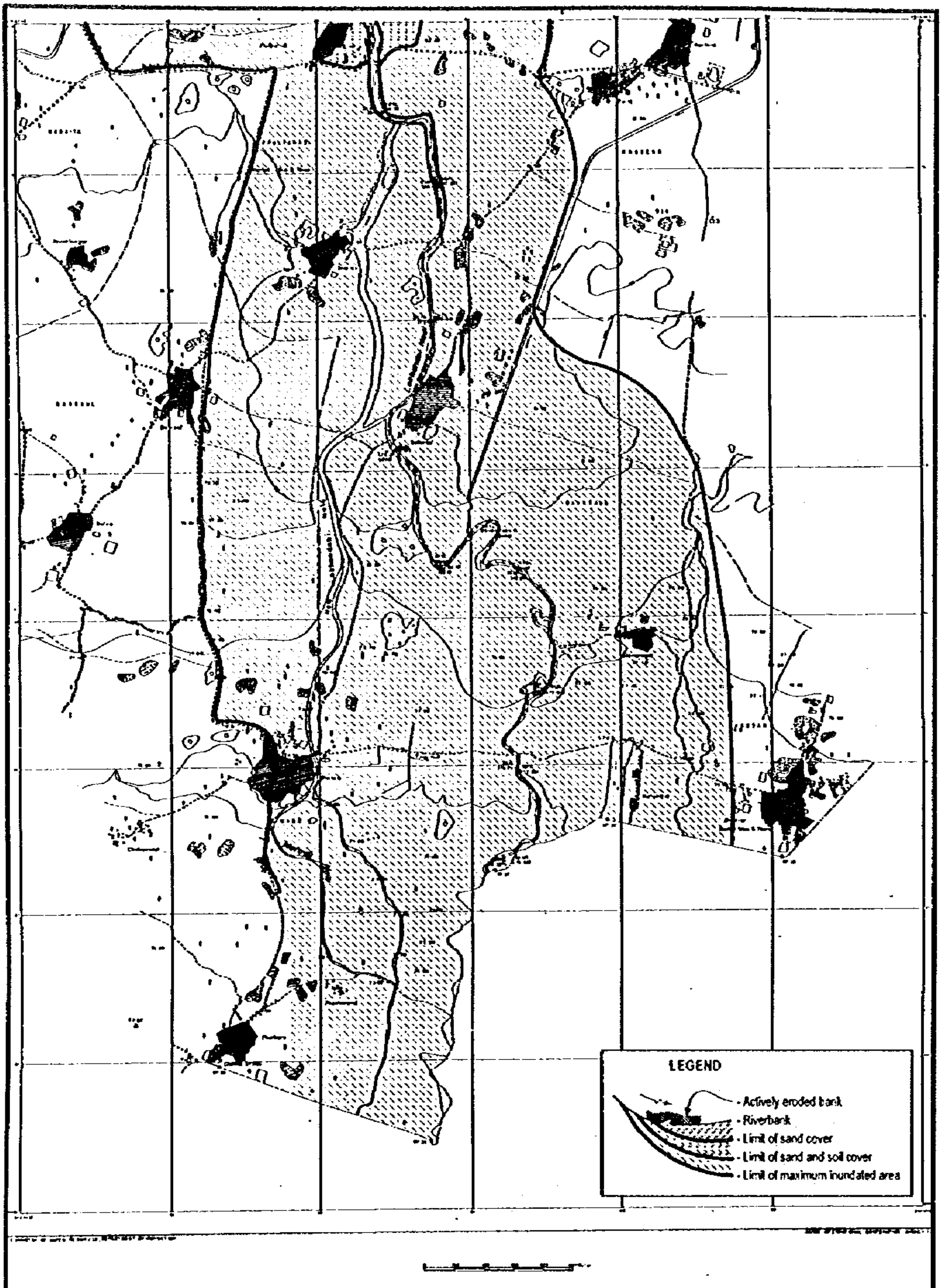
THE STUDY ON FLOOD MITIGATION PLAN FOR SELECTED RIVERS IN THE TERAI PLAIN IN THE KINGDOM OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY



HAZARD MAP
Lakhandei River 1997 Flood (6/6)

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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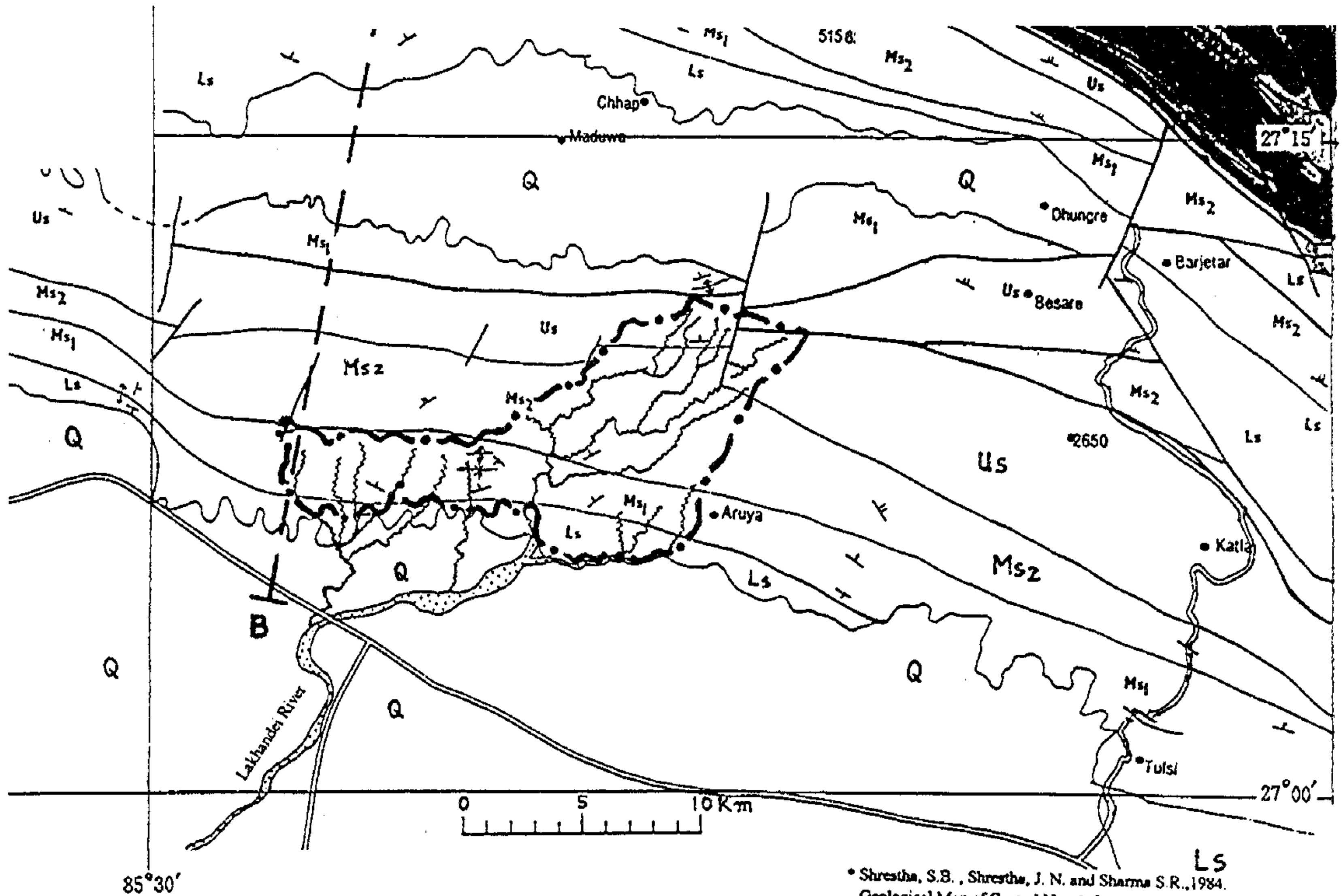


* Shrestha, S.B. , Shrestha, J. N. and Sharma S.R.,1984.
Geological Map of Central Nepal, Scale 1:250,000,
Department of Mines and Geology, Lainchour, Khathmandu

LEGEND

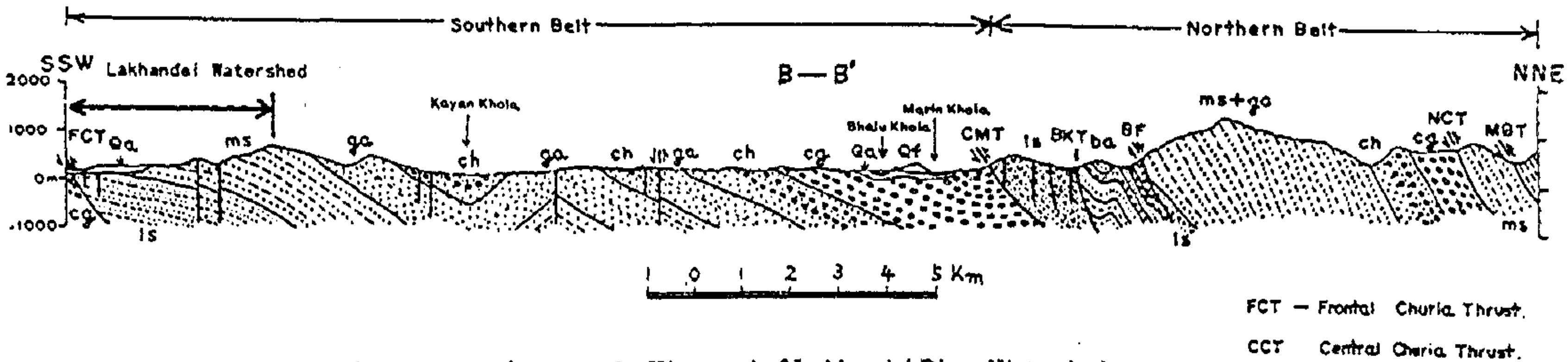
Q	Quaternary	Alluvium boulders, gravels, sands and clays.
	SIWALIK GROUP (Mid-Miocene,- Pleistocene)	
Us	Upper Siwalik	Coase boulders, Conglomerates with irregular beds and lenses of sandstones and thin intercalations of yellow, brown, grey sandy clays.
Ms_2	Middle Siwalik	Medium to coarse grained, arkosic, pebbly sandstones with rare grey to dark grey clays and occasionally silty sandstones and conglomerates.
Ms_1	Middle Siwalik	Fine to medium grained friable arkosic sandstones and hard, compact massive sandstones intercalated with green to greenish grey clays, thin bands of pseudo-conglomerates and mudstones. Plant and animal fossils are present in clays.
Ls	Lower Siwalik	Fine grained, hard grey sandstones interbedded with purple and chocolate coloured shales, nodular maroon clays and pseudo comglomerates.

* Shrestha, S.B. , Shrestha, J. N. and Sharma S.R.,1984.
Geological Map of Central Nepal, Scale 1:250,000
Department of Mines and Geology, Lainchour, Khathmandu

LEGEND of GIOLOGIC CROSS-SECTION

Quaternary	Qf	Flood Plain Deposits
	Qa	River terrass & Debris Flow Deposits
Upper Pleistocene?	dg	Dun Gravels
CHURE (SIWALIK) GROUP		
Lower to Upper Pleistocene	Ck	Bhainse Khola Formation
	Ch	Chiruwa Khola Formation
	ga	Gadhan Khola Formation
Middle Pliocene Lower Pliocene	ms	Middle Siwalik
Upper-Miocene	ls	Lower Siwalik
BAGMATI (PRE-SIWALIK) GROUP		
Middle Eocene?	ba	
	xxxx	Basic Rocks
NAWAKOT GROUP		
Pre-Cambrian?	bs	Benighat Slates
SHIMPHEDI GROUP		
Pre-Cambrian	bd	Bhainsedobhan Morble
	ra	Raduwa Formation

Adhikary, T. P. andRimal, L. N. 1996,
Journal of Geological Society, Vol. 13, pp. 37-50
Stratigraphy and structural framework of the Sub-Himalaya,
Bagmati River region, Central Nepal



FCT — Frontal Churia Thrust.
CCT Central Churia Thrust.
BKT — Bason Khola Thrust.
BF — Baseri Fault.

Geological cross-section along B-B' across the West- end of Lakhandei River Watershed

GEOLOGICAL MAP OF LAKHANDEI RIVER

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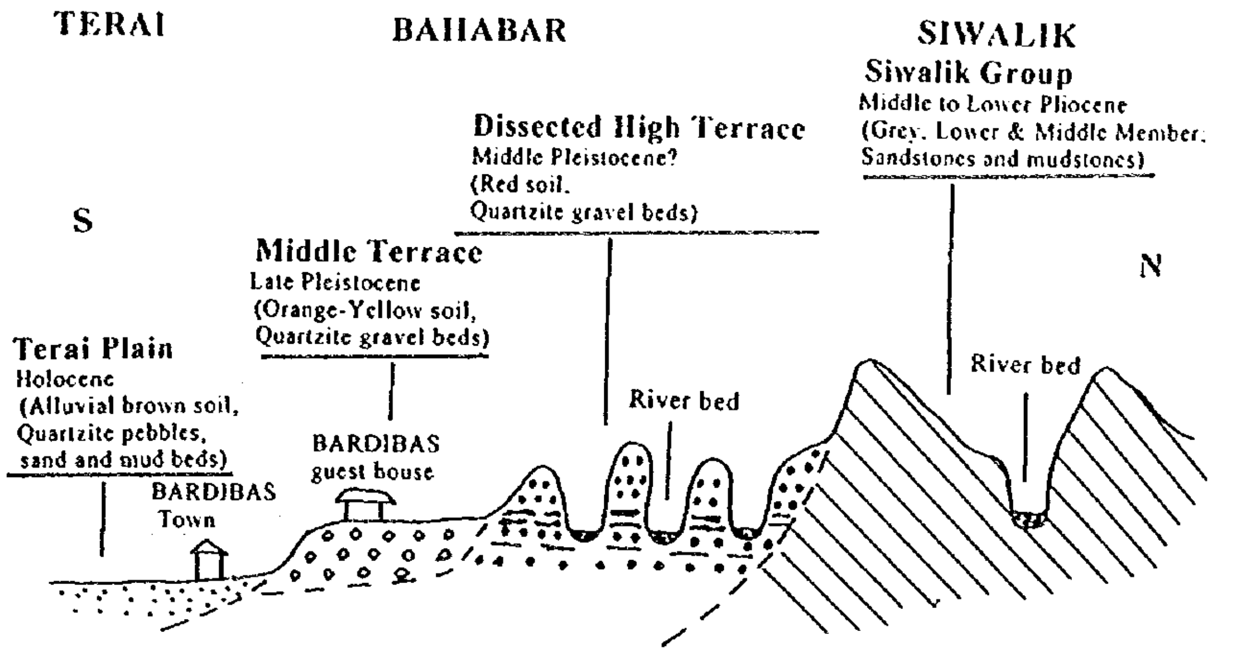
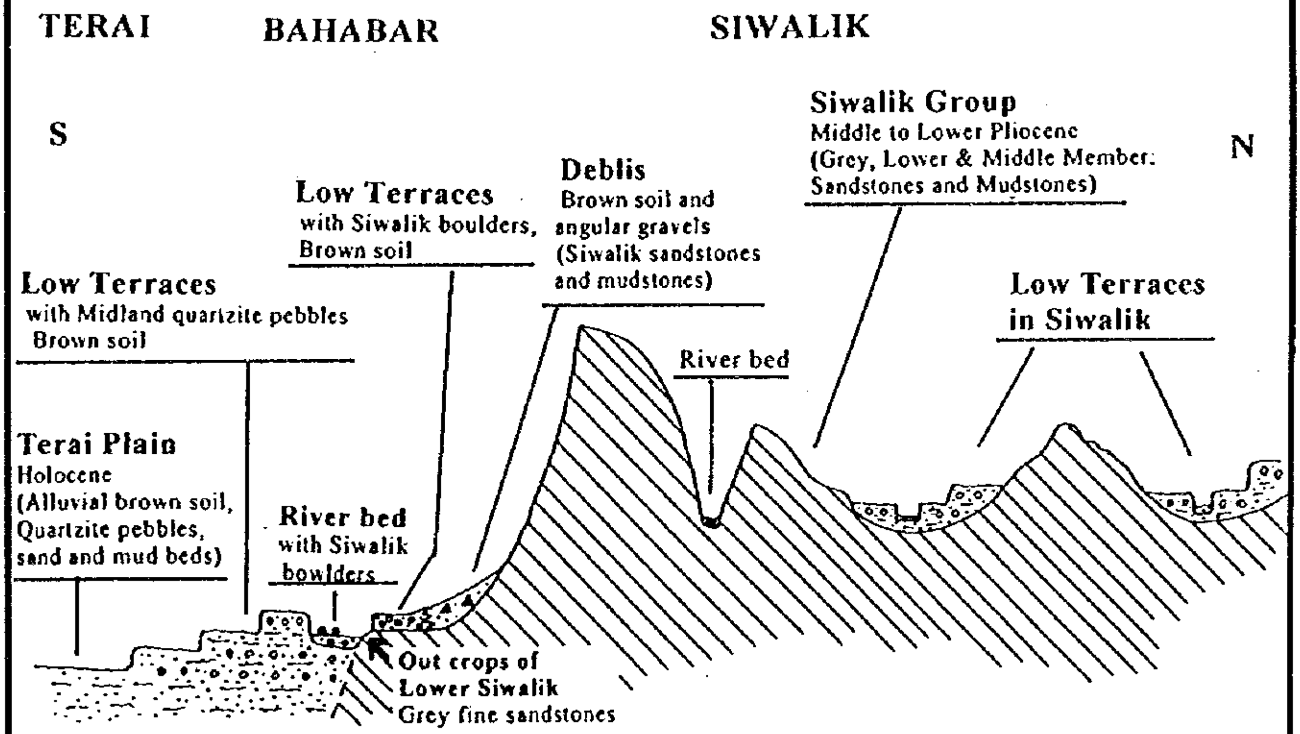
THE STUDY ON FLOOD MITIGATION PLAN FOR SELECTED RIVERS IN THE TERAI PLAIN IN THE KINGDOM OF NEPAL
JAPAN INTERNATIONAL COOPERATION AGENCY



(a) Geologic schematic profile of the Bardibas along the Sinduli Highway



(b) Geologic schematic profile of the Lakandei River

SCHEMATIC GEOLOGIC PROFILE
OF LAKHANDEI WATERSHED

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FOR SELECTED RIVERS IN THE TERAI PLAIN
IN THE KINGDOM OF NEPAL

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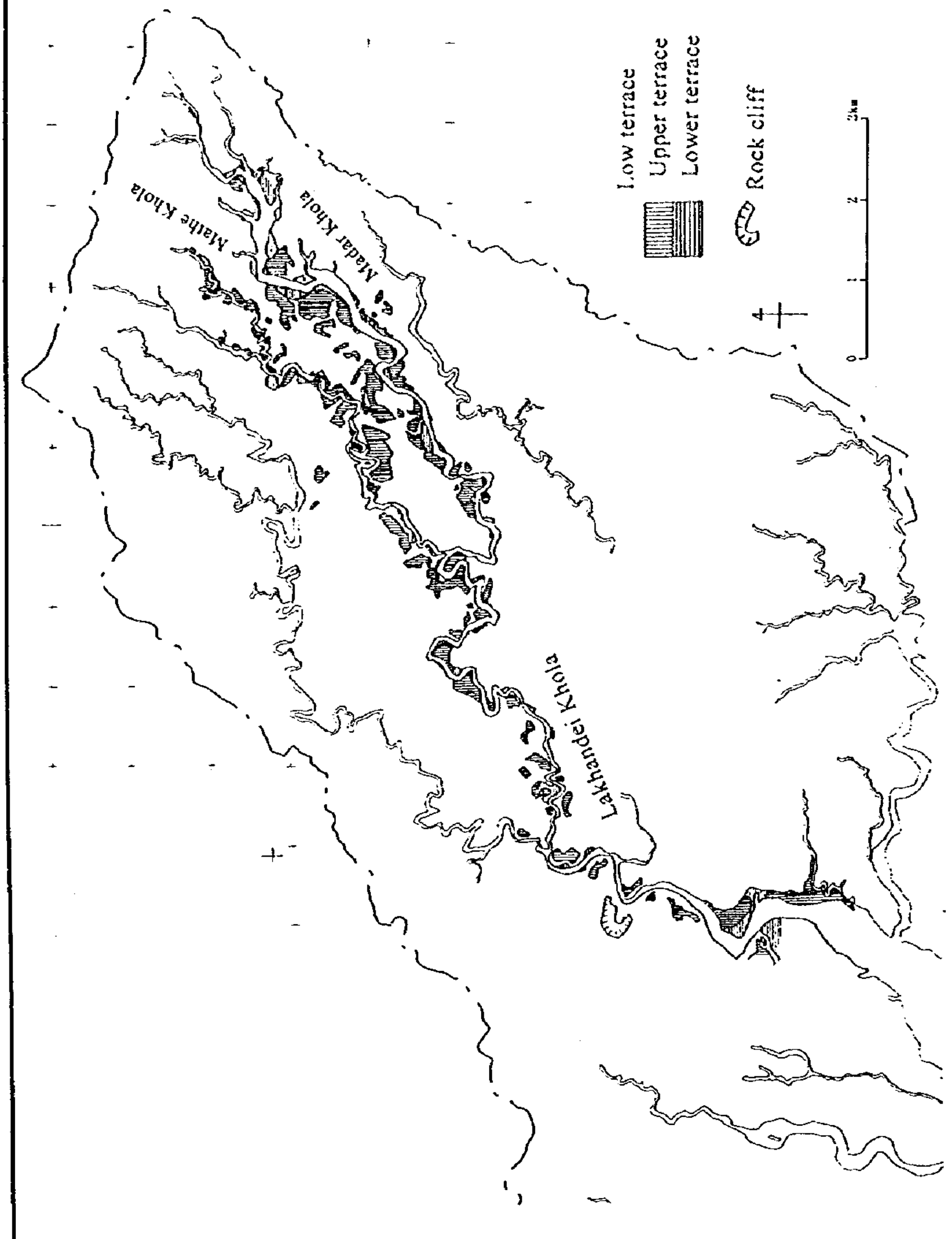

River Terraces in Siwalik Hill along the Main Lakhandei River, Sarlahi District

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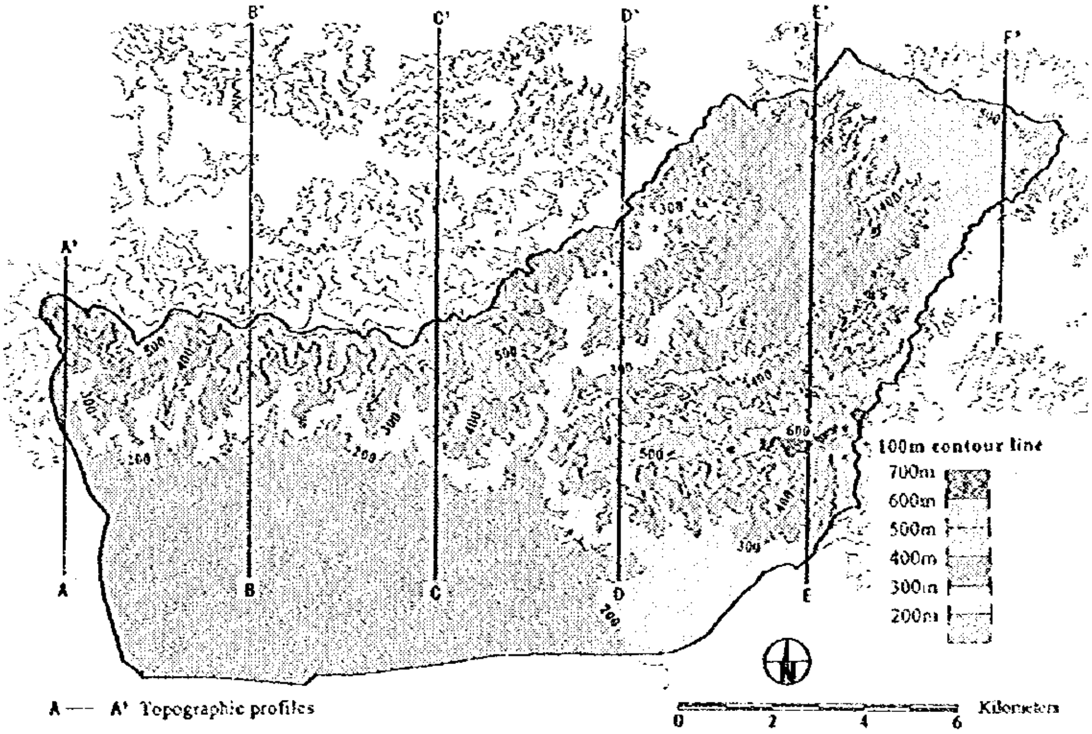
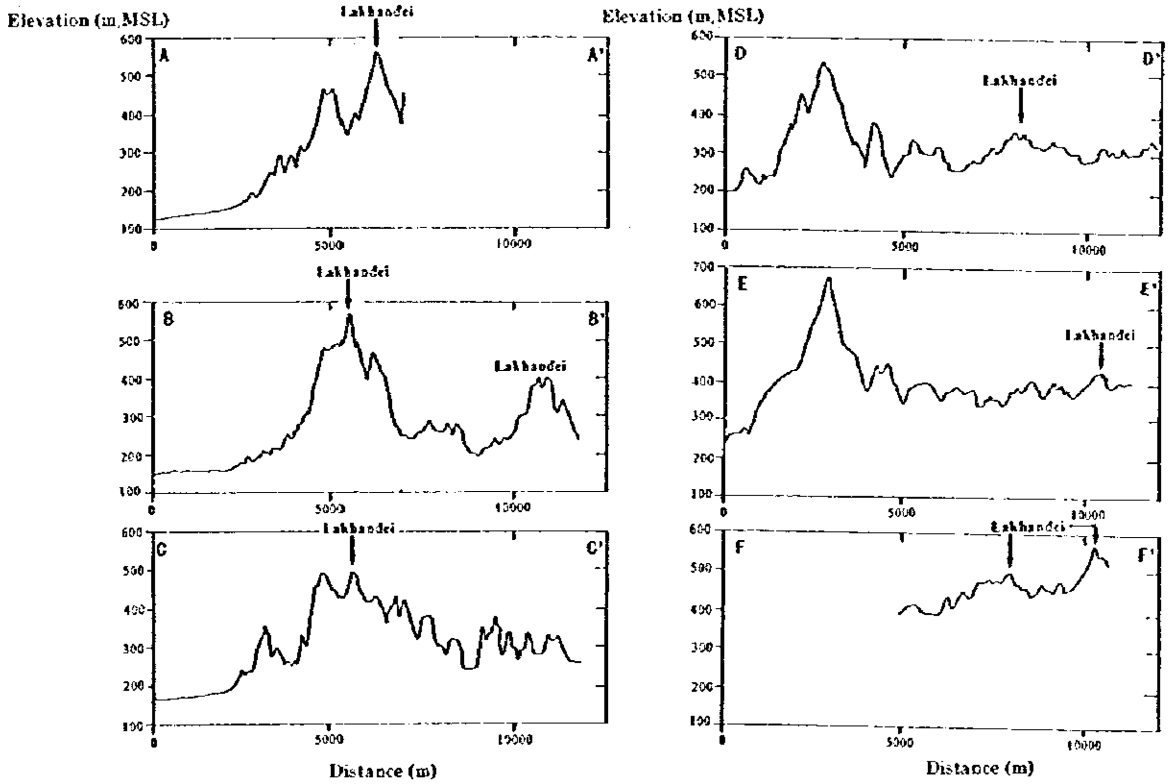


Contour Map of Lakhandei Watershed



Topographic profiles of Lakhandei Watershed

TOPOGRAPHY OF LAKHANDEI WATERSHED

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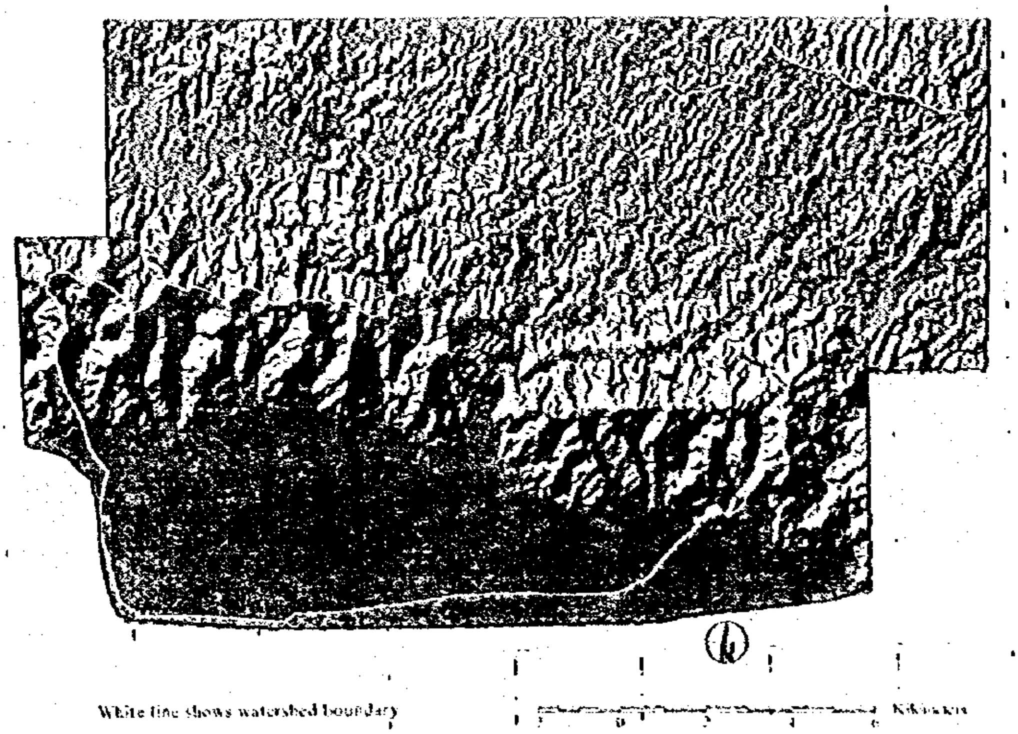
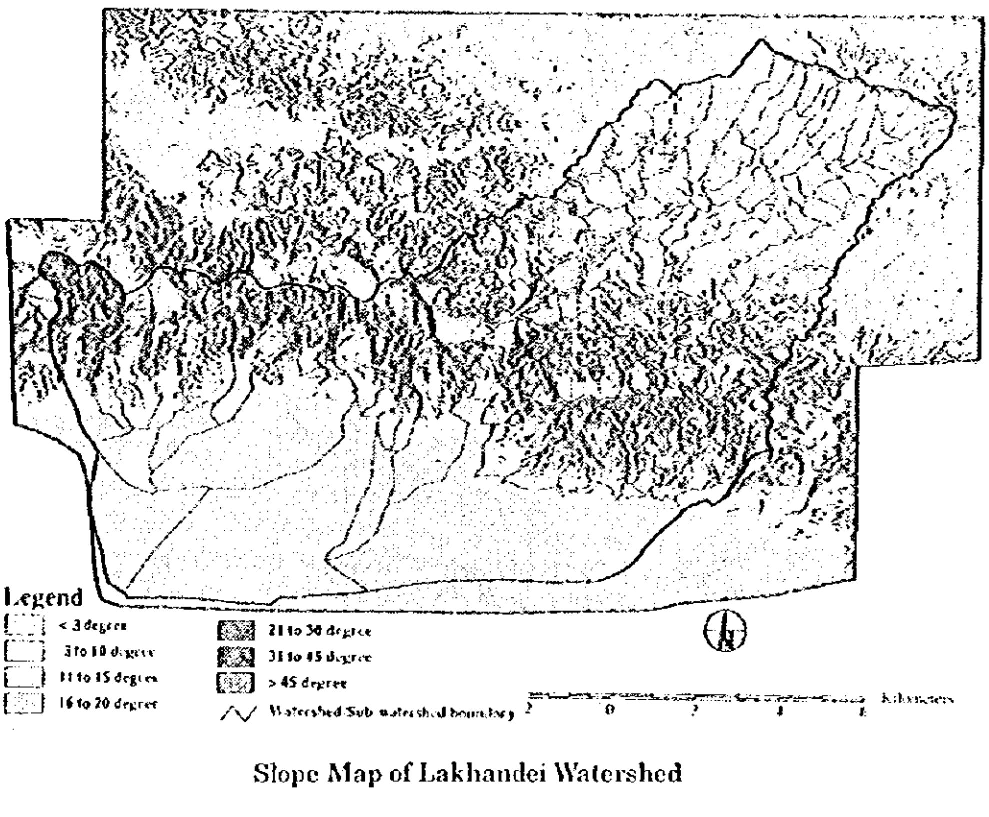
THE STUDY ON FLOOD MITIGATION PLAN FOR SELECTED RIVERS IN THE TERAI PLAIN IN THE KINGDOM OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY



Relief Map of Lakhandei Watershed



Slope Map of Lakhandei Watershed

RELIEF AND SLOPE OF LAKHANDEI WATERSHED

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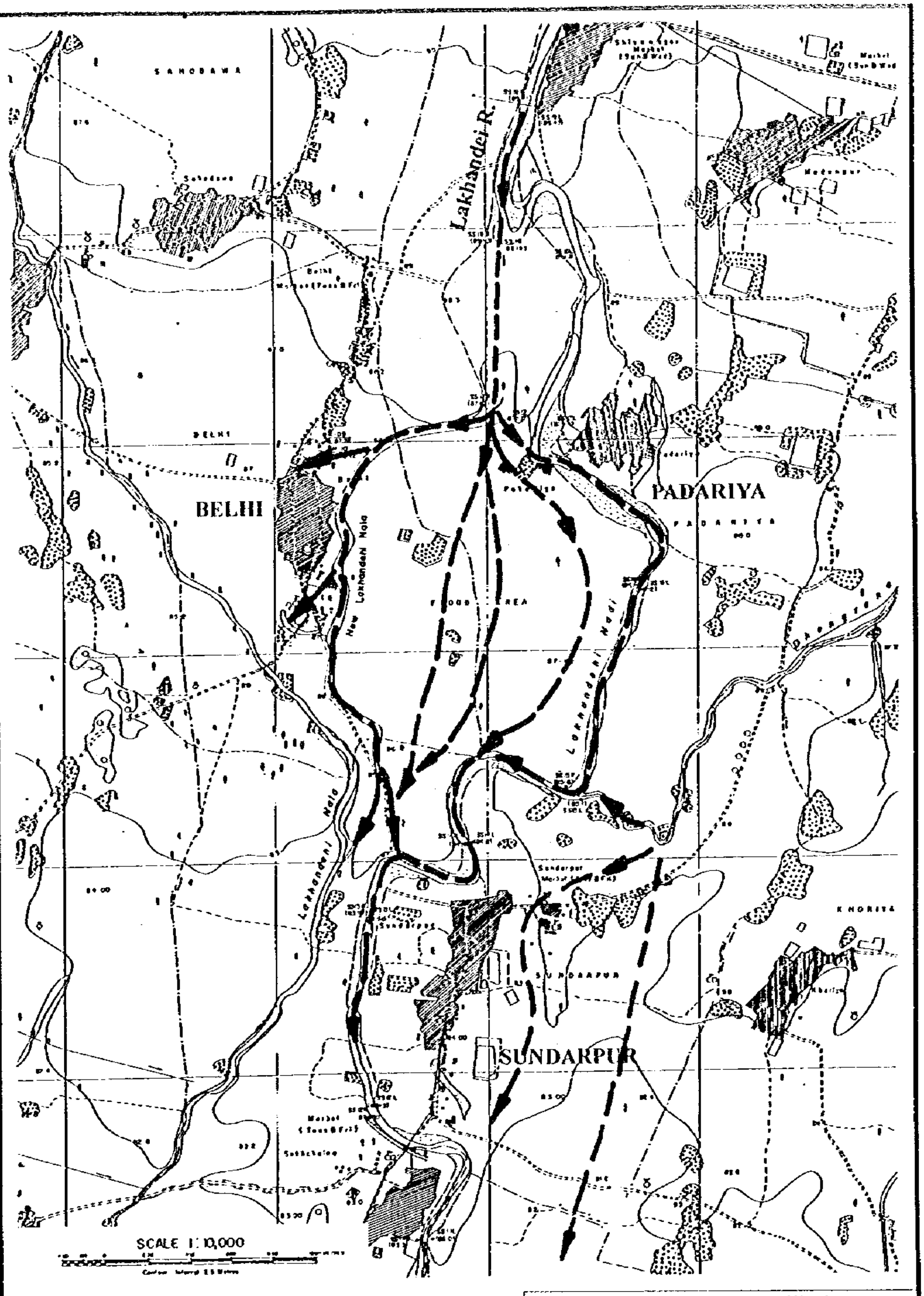

RIVER COURSE NEAR BELHI VILLAGE AFTER 1998-FLOOD

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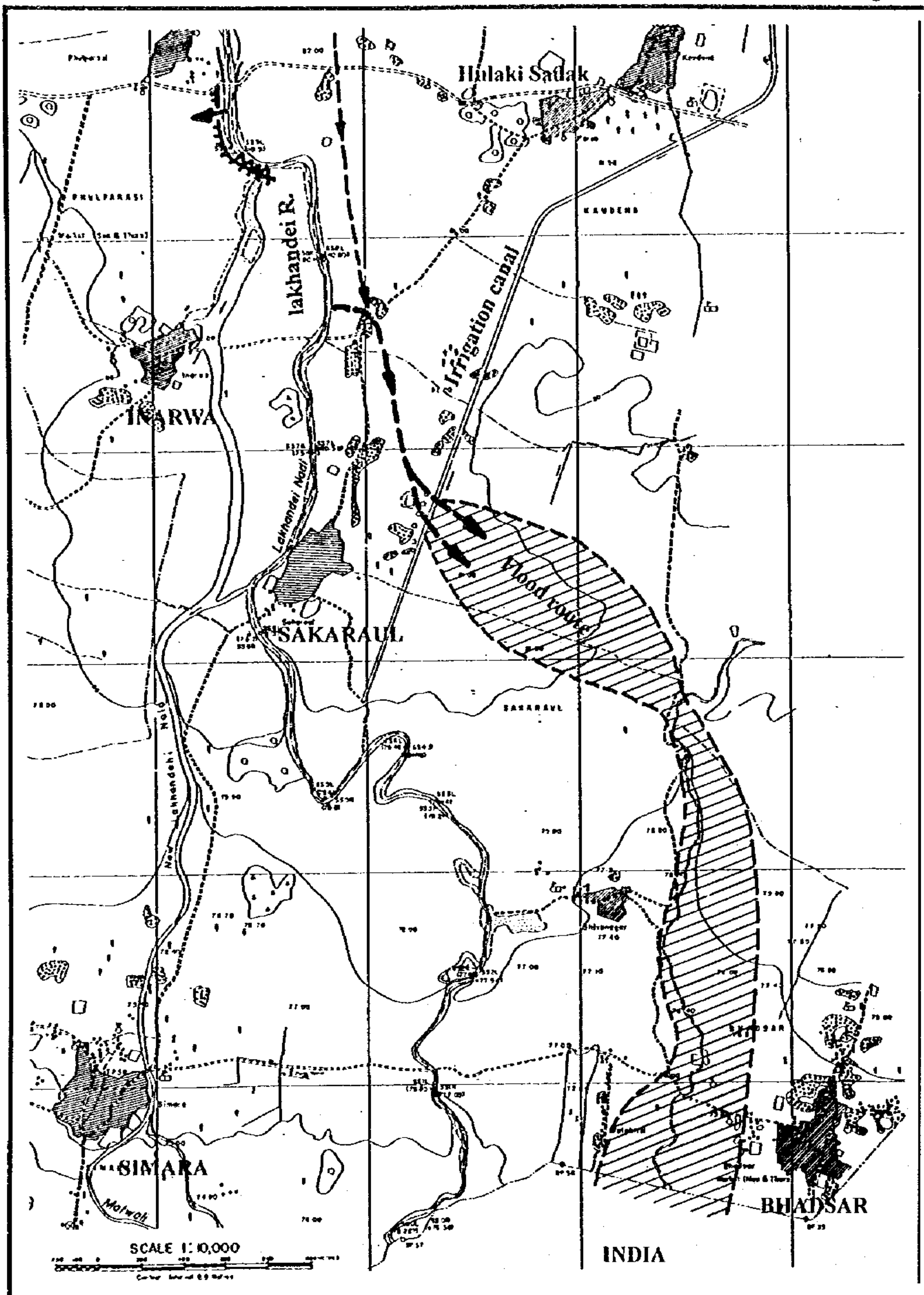
Fig. A5.8



RIVER COURSE NEAR SAKARAUL VILLAGE AFTER 1998-FLOOD

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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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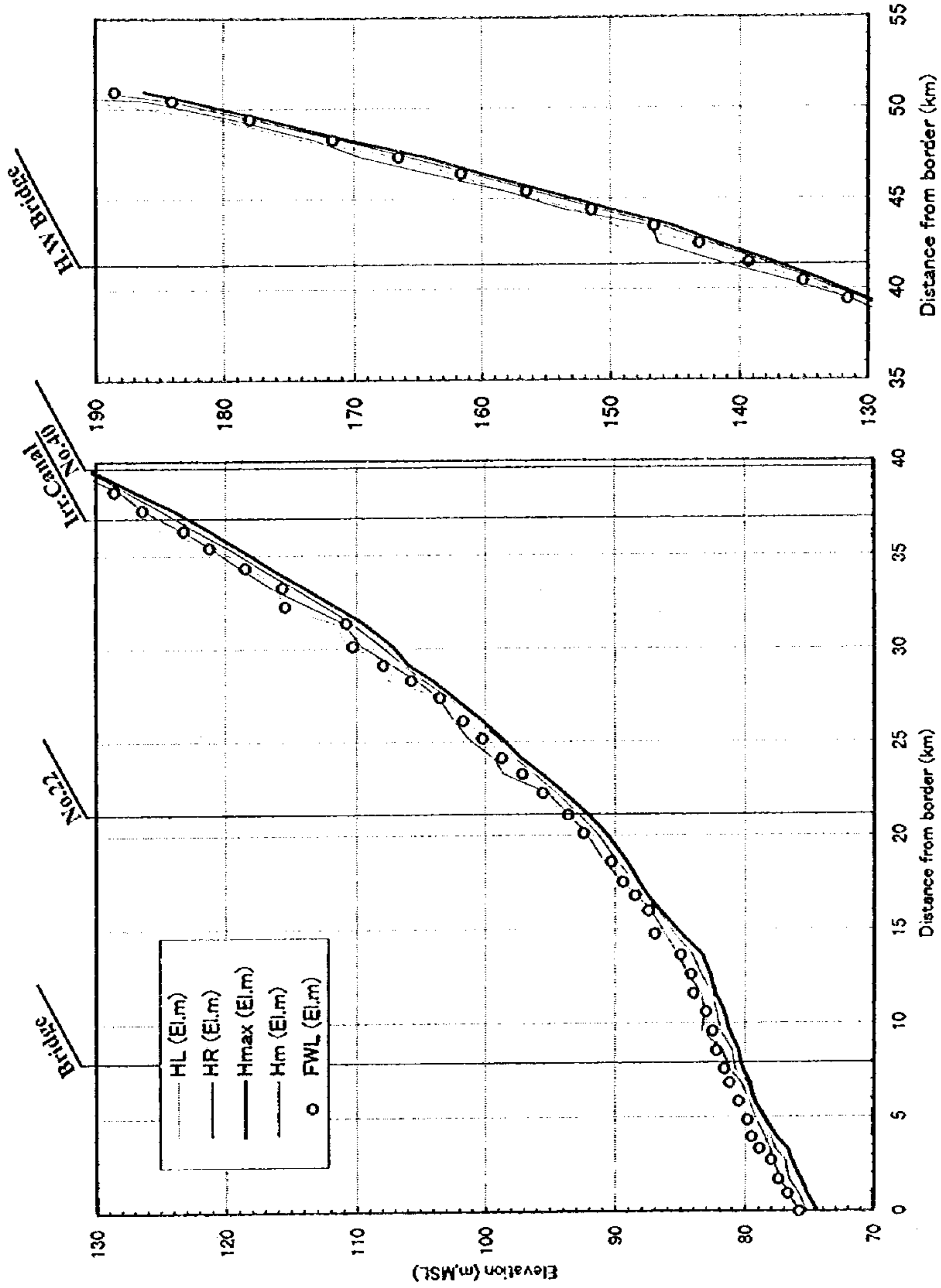
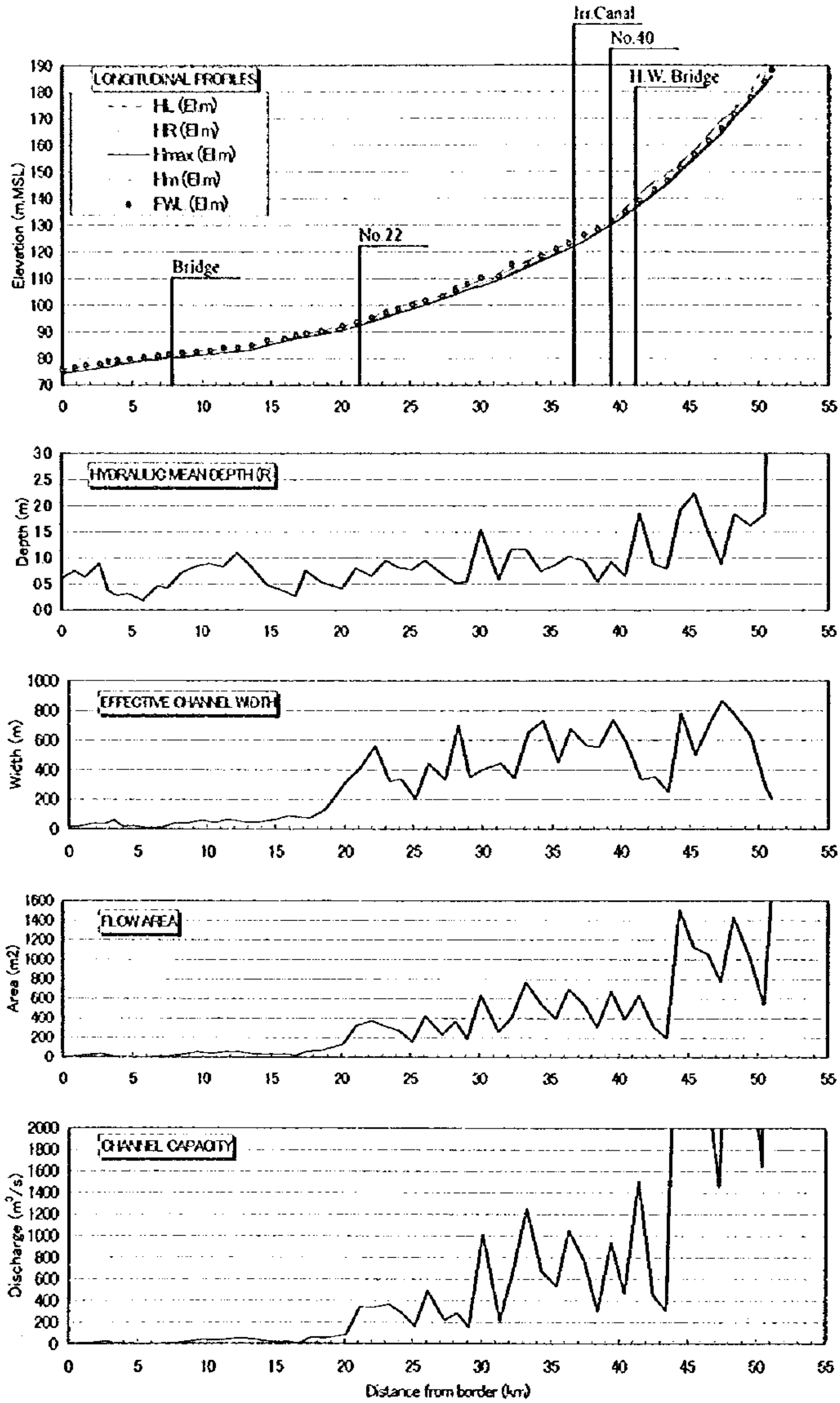


LONGITUDINAL PROFILE OF LAKHANDEI RIVER

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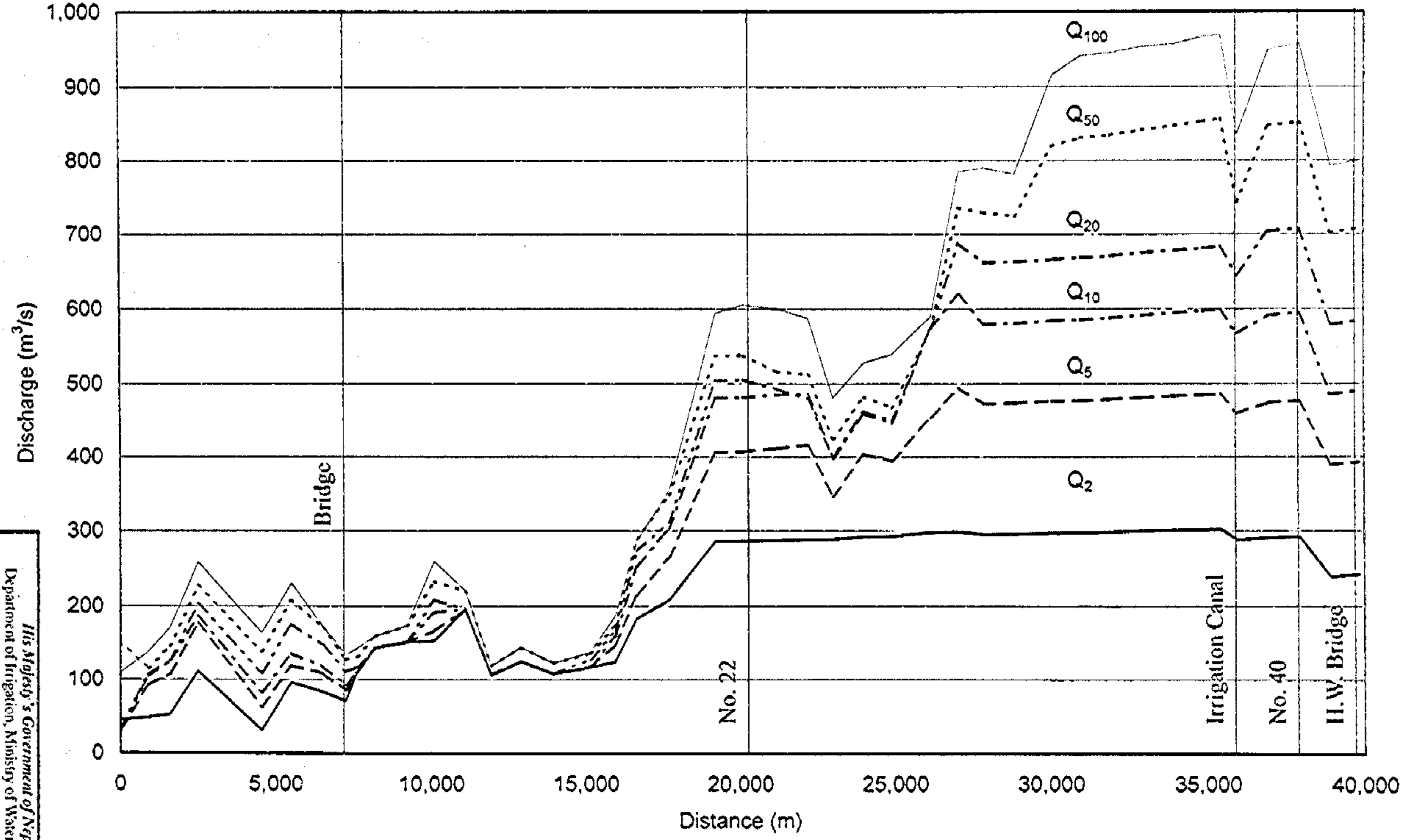
THE STUDY ON FLOOD MITIGATION PLAN FOR SELECTED RIVERS IN THE TERAI PLAIN IN THE KINGDOM OF NEPAL

JAPAN INTERNATIONAL COOPERATION AGENCY

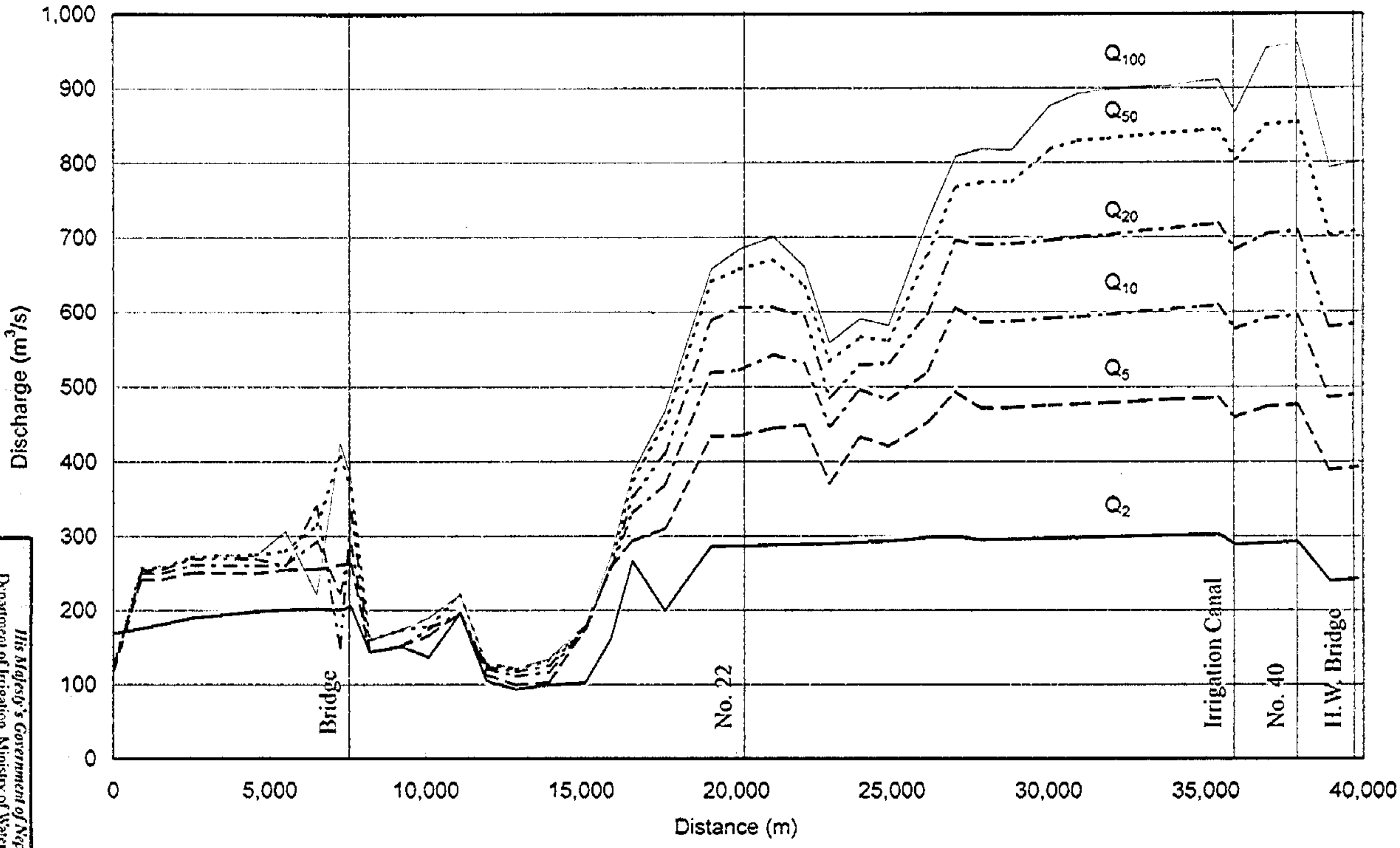


RESULT OF FLOOD FLOW ANALYSIS (LAKHANDEI RIVER WITHOUT PROJECT)

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

JAPAN INTERNATIONAL COOPERATION AGENCY



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

JAPAN INTERNATIONAL COOPERATION AGENCY